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Current Research 1997-A CORDILLERA AND PACIFIC MARGIN

**Recherches en cours 1997-A
CORDILLÈRE ET MARGE DU PACIFIQUE**

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ERRATA

“Contents” – Current Research 1996-E **Table des matières – Recherches en cours 1996-E**

The titles of two reports were omitted and two reports were listed in the incorrect section.
Substitute this page for last page of Contents.

Les titres de deux articles ont été oubliés et ceux de deux autres ont été placés dans la mauvaise section.
Veuillez remplacer la dernière feuille de la table des matières par celle-ci.

Electrical characteristics of rock samples from the La Ronge Domain of the
Trans-Hudson Orogen, northern Saskatchewan
T.J. Katsube, A.G. Jones, N. Scromeda, and P. Schwann 159

Petrophysical characteristics of diatreme-facies kimberlites from Kirkland Lake, Ontario
T.J. Katsube, M.B. McClenaghan, and N. Scromeda 171

EASTERN CANADA AND NATIONAL AND GENERAL PROGRAMS EST DU CANADA ET PROGRAMMES NATIONAUX ET GÉNÉRAUX

Groundwater prospects in the Oak Ridges Moraine area, southern Ontario:
application of regional geological models
**D.R. Sharpe, L.D. Dyke, M.J. Hinton, S.E. Pullan, H.A.J. Russell,
T.A. Brennand, P.J. Barnett, and A. Pugin 181**

Regional geoscience database for the Oak Ridges Moraine project (southern Ontario)
**H.A.J. Russell, C. Logan, T.A. Brennand, M.J. Hinton,
and D.R. Sharpe 191**

Digital Elevation Models in environmental geoscience, Oak Ridges Moraine,
southern Ontario
F.M. Kenny, H.A.J. Russell, M.J. Hinton, and T.A. Brennand 201

Digital Elevation Models for hydrological applications in Oak Ridges Moraine,
southern Ontario: the necessity for structured drainage networks
J. Paquette 209

Le glissement de terrain d'avril 1996 à Saint- Boniface-de-Shawinigan, Québec :
observations et données préliminaires
**C. Bégin, S.G. Evans, M. Parent, D. Demers, G. Grondin,
D.E. Lawrence, J.M. Aylsworth, Y. Michaud, G.R. Brooks,
et R. Couture 215**

Detailed gravity studies in support of the EXTECH II Program, Bathurst mining camp, New Brunswick M.D. Thomas, D. Jobin, M. Daniels, C. Chamberlain, D.B. Hearty, G. Zhang, and J.F. Halpenny	233
Chemical and stable isotopic composition of ground and surface waters from the Restigouche Zn-Pb massive sulphide deposit, Bathurst mining camp, northern New Brunswick – EXTECH II M.I. Leybourne, W.D. Goodfellow, and D.R. Boyle	243
Spatially linked relational database management of petrology and geochemistry using Fieldlog v3.0: a worked example from the Bathurst mining camp, New Brunswick N. Rogers and B. Brodaric	255
Differential subsidence and tectonic control of sedimentation in the Stellarton Basin, Pictou Coalfield, Nova Scotia J.W.F. Waldron	261
The Dorset showings: mesothermal vein-type gold occurrences associated with post-Ordovician deformation along the Baie Verte-Brompton Line, Baie Verte Peninsula, Newfoundland M. Bélanger, B. Dubé, and M. Malo	269
<i>Reprint Explorer</i> , a paleontological reprint database for Microsoft Windows D.C.A. Stanley and J.W. Haggart	281
Author Index	285

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Cover illustration

Gneissic mafic intrusive complex, east of Mount Tournay, Anyox pendant, Nass River area, British Columbia. See paper by Evenchick and Holm, this volume. Photograph by C. Evenchick. GSC 1996-165

Complexe intrusif de roches mafiques gneissifié, à l'est du mont Tournay, pendentif d'Anyox, région de la rivière Nass, Colombie-Britannique. Cette photographie se rapporte à l'étude d'Evenchick et Holm dans le présent volume. Photo : C. Evenchick. GSC 1996-15

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CONTENTS

CORDILLERA AND PACIFIC MARGIN CORDILLÈRE ET MARGE DU PACIFIQUE

Styles of intrusion-related gold mineralization in the Dawson-Mayo area, Yukon Territory K.H. Poulsen, J.K. Mortensen, and D.C. Murphy	1
Bedrock geology of the Anyox pendant and surrounding areas, Observatory Inlet (103P/5) and parts of Hastings Arm (103P/12) and 103O/9 map areas, British Columbia C.A. Evenchick and K. Holm	11
Status of research in the Nass River multidisciplinary geoscience project, British Columbia C.A. Evenchick, D.J. Alldrick, L.D. Currie, J.W. Haggart, S. McCuaig, V. McNicoll, and G.J. Woodsworth	21
U-Pb ages from the northeastern quadrant of Terrace map area, west-central British Columbia S.A. Gareau, R.M. Friedman, G.J. Woodsworth, and F. Childe	31
Foraminifera from the Longarm Formation, Queen Charlotte Islands, British Columbia J.W. Haggart, R.T. Patterson, and A.P. Dalby	41
Regional geology of the northeastern quadrant of Terrace map area, west-central British Columbia S.A. Gareau, G.J. Woodsworth, and M. Rickli	47
Nechako Plateau NATMAP Project overview, central British Columbia, year two L.C. Struik and D.G. MacIntyre	57
General geology of southeast Fort Fraser map area, central British Columbia L.C. Struik, J.B. Whalen, J.M. Letwin, and R. L'Heureux	65
Plutonic rocks of southeast Fort Fraser map area, central British Columbia J.B. Whalen and L.C. Struik	77

Field properties of Pennsylvanian-Lower Permian limestones of Cache Creek Group, northwest of Fort St. James, central British Columbia H. Sano and L.C. Struik	85
Conodont biostratigraphy and correlation, Cache Creek Group, Fort St. James, central British Columbia M.J. Orchard, L.C. Struik, and H. Taylor	95
Geology of Shass Mountain, central British Columbia J.M. Letwin and L.C. Struik	103
Geology of the Hallett Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous, and Eocene? plutonic rocks R.G. Anderson, R. L'Heureux, S. Wetherup, and J.M. Letwin	107
Early Cretaceous plutonic rocks and molybdenite showings in the Nithi Mountain area, central British Columbia R. L'Heureux and R.G. Anderson	117
Geology of the Nulki Hills and surrounding area, central British Columbia S. Wetherup	125
Ice flow and late glacial lakes of the Fraser Glaciation, central British Columbia A. Plouffe	133
Anatomy of the Neoproterozoic-Palaeozoic continental margin, Vernon map area, British Columbia R.I. Thompson and K.L. Daughtry	145
Revised stratigraphy of the Pasayten Group, Manning Park, British Columbia M.A. Kiessling and J.B. Mahoney	151
Borehole measurements of shear wave velocity discontinuities in Quaternary sediments, Fraser River delta, British Columbia J.A. Hunter, S.R. Dallimore, and H.A. Christian	159
East Kootenay multiparameter geophysical survey, southeastern British Columbia: regional synthesis C. Lowe, D.A. Brown, M. Best, and R. Shives	167

Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 4: investigation of continental and montane advances in the Beaver Mines map area, southwestern Alberta P.J. Holme	177
--	-----

Quaternary geology of the Nass River region, British Columbia S.J. McCuaig	183
--	-----

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

The Blind Fiord Formation and Blaa Mountain Group (Triassic) of northwestern Axel Heiberg Island, Canadian Arctic Archipelago A.F. Embry	193
---	-----

Author Index	199
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Styles of intrusion-related gold mineralization in the Dawson-Mayo area, Yukon Territory

K.H. Poulsen, J.K. Mortensen¹, and D.C. Murphy²

Mineral Resources Division, Ottawa

Poulsen, K.H., Mortensen, J.K., and Murphy, D.C., 1997: Styles of intrusion-related gold mineralization in the Dawson-Mayo area, Yukon Territory; in Current Research 1997-A; Geological Survey of Canada, p. 1-10.

Abstract: Gold deposits and occurrences in miogeoclinal rocks of the Selwyn Basin in the Dawson-Mayo area include diverse styles of mineralization such as sheeted quartz veinlet to stockwork zones, gold skarns, carbonate-hosted disseminated zones, noncarbonate-hosted disseminated, stockwork, and replacement zones as well as quartz-sulphide veins. All styles occur in and adjacent to mainly monzonitic intrusions of the Late Cretaceous Tombstone Suite. In addition to zonal relationships to the intrusions, the gold mineralization is controlled regionally by carbonate-bearing strata of the Neoproterozoic-Paleozoic miogeocline and by east-northeast faults related to an interval of north-south extension in contrast to pre- and post-ore north-south shortening. The geochemical suite As-Sb-Hg occurs both proximal and distal to intrusions whereas Bi is diagnostic of proximal deposits.

Résumé : Les gîtes et indices d'or encaissés dans des roches miogéoclinales du bassin de Selwyn dans la région de Dawson-Mayo présentent divers styles de minéralisation, comme des complexes filoniens/stockwerks de quartz, des skarns aurifères, des zones disséminées dans des roches carbonatées, des zones disséminées, des stockwerks et des zones de remplacement dans des roches non carbonatées et des filons de quartz-sulfures. Tous les styles de minéralisation se rencontrent à l'intérieur ou à proximité d'intrusions principalement monzonitiques de la Suite de Tombstone du Crétacé tardif. Outre ces relations zonales avec les intrusions, la minéralisation aurifère est contrôlée à l'échelle régionale par des strates de roches carbonatées du miogéocline néoproterozoïque-paléozoïque et par des failles est-nord-est associées à un intervalle de distension nord-sud qui contraste avec le raccourcissement nord-sud antérieur et postérieur à la minéralisation. La suite géochimique As-Sb-Hg est présente à la fois en position proximale et distale relativement aux intrusions tandis que Bi est un élément diagnostique des gisements proximaux.

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INTRODUCTION

The Dawson area of the Yukon Territory is world-famous for the rich Klondike placer gold deposits which developed on schists of volcanic and plutonic origin in the exotic Yukon-Tanana Terrane southwest of the Tintina Fault (Mortensen, 1992). Less well known are several gold deposits and occurrences, as well as small placer operations, that occur east and northeast of the Tintina Fault within rocks of the Cordilleran miogeocline, a terrane better known for its Pb-Zn SEDEX deposits, Ag-Pb-Zn veins, and W skarns (Poulsen, 1996). The authors spent a total of five weeks during the summers of 1995 and 1996 examining gold deposits and occurrences in the miogeoclinal rocks of the Dawson-Mayo area to establish the characteristics of mineralization in relation to the structural, stratigraphic, and plutonic history of the area. The fieldwork was conducted collaboratively among the Geological Survey of Canada, the Mineral Deposits Research Unit at University of British Columbia (the magmatic hydrothermal ore deposits project), and the Yukon Geology Program (regional mapping initiatives). The geology of the area of the investigation has previously been mapped at 1:250 000 scale (Green and Roddick, 1962; Bostock, 1964; Green, 1972) and, more recently, at 1:50 000 scale in specific subareas (Thompson et al., 1992; Murphy et al., 1993; Murphy and Héon, 1994; Murphy and Héon, 1995). The authors also relied heavily on assessment work records on file and on first-hand information provided during field visits with personnel from mining and exploration companies active in the region.

STRUCTURE

The study area (Fig. 1) forms part of the Selwyn Basin which is a large region characterized by late Proterozoic to middle Devonian deep water offshelf sedimentary rocks that are transitional eastward and northward into shelf carbonate and clastic shelf sedimentary rocks of the Mackenzie Platform (Gordey and Anderson, 1993). Rocks of the Selwyn Basin in the Dawson-Mayo area occur in three tectonic sheets separated by major faults termed the Dawson, Tombstone, and Robert Service thrusts (Thompson, 1995). The rocks in each sheet are folded into upright to locally inclined, moderate to tight folds. The age of folding is bracketed in a general way between the youngest deformed Jurassic strata and Late Cretaceous granitoid magmatism which postdates the folding. This deformation is generally attributed to northerly directed shortening related to the accretion of exotic terranes to the North American continental margin (Gabrielse and Yorath, 1991). Northeast-trending folds and associated thrusts are characteristic of the Dawson and Tombstone sheets (Templeman-Kluit, 1970) whereas west-northwest and east-southeast folds are most common in the Robert Service sheet (Green and Roddick, 1962). The regionally consistent pattern of folding is disrupted in the Mayo area by an east-northeast-trending arch, the McQuesten Anticline (Fig. 1) and parallel normal faults of the Keno Hill and Haggart Creek areas (Templeman-Kluit, 1964; Lynch, 1989a, b). The youngest deformation in the region is generally

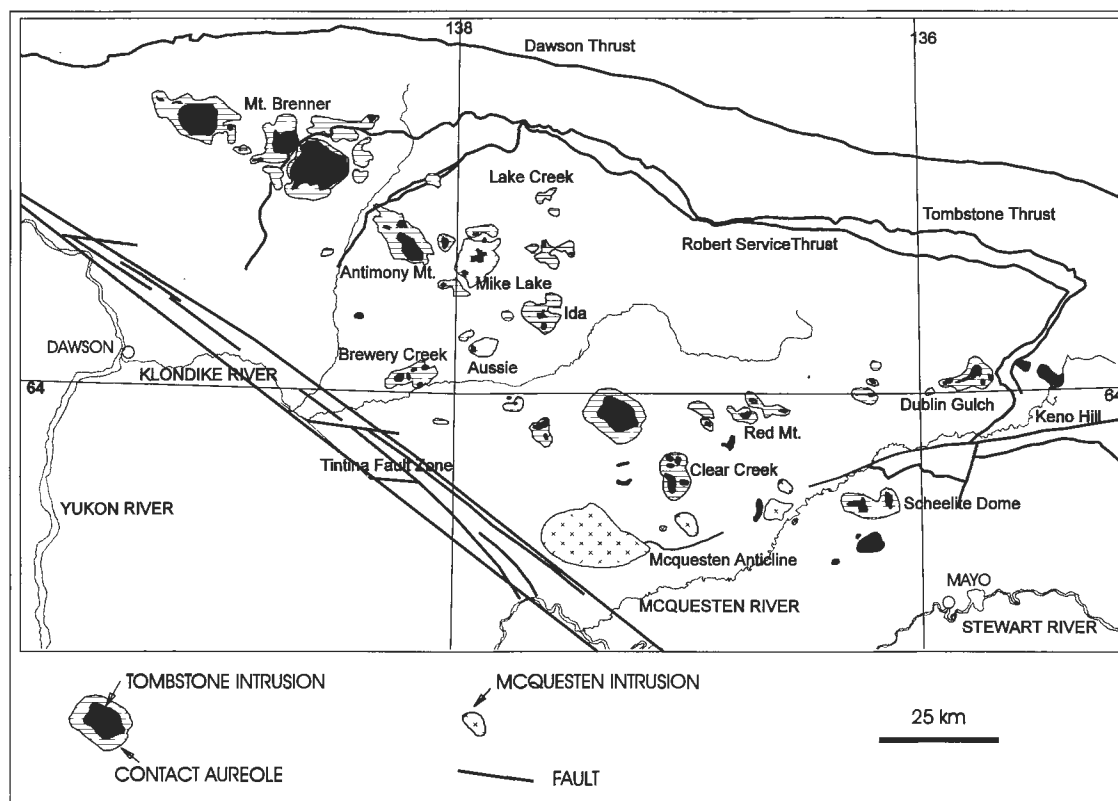


Figure 1. Sketch map of the main geological features in the Dawson-Mayo area, Yukon and of the locations of areas containing gold mineralization.

attributed to Eocene and younger dextral strike slip motion on the Tintina Fault (Mortensen and Van Gaza, 1992) but is mainly localized within and near that major structure.

STRATIGRAPHY

The main lithological units in the Dawson-Mayo area are characteristic of those elsewhere in Selwyn Basin (Table 1) although detailed formal subdivision has only been achieved locally. The Neoproterozoic to Lower Cambrian strata of the Hyland Group are most extensively developed on the southern and eastern margins of the area; Lower Paleozoic rocks are best preserved in a major synclinorium within the Robert Service thrust sheet in the central part of the area; and Carboniferous through Mesozoic strata predominate in the north (Fig. 1).

The sedimentary strata of all ages consist mainly of alternations of coarse to fine siliciclastic rocks (sandstone, siltstone, and minor conglomerate) and argillaceous rocks (mainly red, green, and black shale). Black chert is well developed mainly in black shale of the Ordovician-Silurian Road River Group and bedded barite occurs locally in the Devonian-Mississippian Earn Group. Volcanic rocks, although volumetrically minor, are present in both the Road River and Earn groups. In keeping with the “basinal” setting of most rocks in the area, carbonate strata form but a small portion of the total rock thickness. Nonetheless, limestone and/or

calcareous sandstone and siltstone punctuate the stratigraphic column at four distinct intervals: in the upper part of the Neoproterozoic Yusezyu formation, within Cambro-Ordovician rocks (Rabbitkettle Formation and Gull Lake Formation equivalents), in the upper part of the Road River Group (possibly equivalent to the regionally extensive Silurian Steel Formation), and in the Permian Tahkandit Formation. Although some of these carbonate rocks may have developed as a result of westward marine regression, Gordey and Anderson (1993) regarded these Paleozoic carbonate strata to have formed in relatively deep water. At a regional scale, unconformities are known to exist throughout the stratigraphic column and, in the Dawson-Mayo area, they have been documented at the bases of the Rabbitkettle Formation, the Earn Group, as well as at the bases of the Mount Christie and Jones Lake formations.

PLUTONIC ROCKS

The supracrustal rocks of the Dawson-Mayo area have been intruded by a northwest-trending belt (Fig. 1) of distinctive Cretaceous intrusions which are termed the Tombstone Plutonic Suite. Composed mainly of equigranular to porphyritic biotite-hornblende monzonite and quartz monzonite, these stocks and batholiths range in composition from rare gabbro to syenite and granite. Despite this compositional range, U-Pb zircon dating has demonstrated that the intrusions of the Tombstone Plutonic Suite crystallized in a

Table 1. Stratigraphic units in the Northern Cordilleran Miogeocline, Dawson-Mayo area, Yukon (adapted from Green, 1972; Murphy and Héon, 1994; Thompson et al., 1992; Gordey and Anderson, 1993).

Period	Lithology	Regional correlation	Associated gold deposits
Jurassic	Black slate, conglomerate, and siltstone	“Lower Schist”	
Triassic	shaley limestone	Glen Shale	
	calcareous quartz siltstone	Jones Lake Fm.	
Permian	limestone	Tahkandit Fm.	Marn
	green and red slate	Mount Christie Fm.	
Mississippian	quartzite, minor shale	Keno Hill Quartzite	
Devono-Mississippian	black shale, chert-pebble conglomerate and sandstone, local barite	Earn Group	Brewery Creek, Marn
Ordovician-Silurian	black chert, shale, siltstone, and buff calcareous siltstone	Road River Group (locally divisible into upper Steel Fm. and lower Duo Lake Fm.	Brewery Creek, Ida, Aussie
Cambro-Ordovian	amygdaloidal mafic to intermediate volcanic flows, tuff, and breccia	Menzie Creek Fm. or Marmot Fm.	
	limestone	Rabbitkettle Fm. of Kechika Gp.	
Lower to Middle Cambrian (?)	calcareous siltstone, grey-green phyllite, grey quartzite and mafic volcanic and volcanoclastic rocks	Gull Lake Fm.	Mike Lake, Thor (?)
Upper Proterozoic	maroon and green shale	Narchilla Fm. of Hyland Gp.	
	coarse quartz sandstone (“grit”) and minor limestone and calcareous sandstone	Yusezyu Fm. of Hyland Gp.	Dublin Gulch, Scheelite Dome, Clear Creek, Heidi, AJ

remarkably brief interval between 90 and 95 Ma. They are likely mantle-derived but strongly contaminated with crustal material (Mortensen et al., 1996).

Intrusions of the Tombstone Suite are commonly enveloped by low-pressure contact metamorphic aureoles which can be mapped as zones of hornfels and calc-silicate rocks. In addition, many of the contact aureoles are gossanous; in particular, north of the McQuesten Anticline they contain abundant disseminated pyrrhotite allowing their extents to be estimated, even in poorly exposed or unmapped areas, from aeromagnetic data (Fig. 1). The aureoles commonly envelope two or three small plutons or a large single one (Fig. 2, 3) and cover areas from 50 to 100 km².

Dykes and sills are commonly developed in and adjacent to intrusions of the Tombstone Plutonic Suite. Two compositions are most common, (quartz)-feldspar porphyries and biotite diorite (lamprophyre). U-Pb and K-Ar dating shows

that, despite the fact that they cut the stocks and contact-metamorphosed rocks, the dykes are likely co-genetic with Tombstone magmatism.

Felsic plutons that do not have any apparent relationship to the gold deposits of the region occur locally in the McQuesten Anticline (Fig. 1). They postdate the Tombstone Suite magmatism, having formed at approximately 65 Ma, and have therefore been assigned to a distinctive McQuesten Plutonic Suite (Mortensen et al., 1996).

GOLD DEPOSITS

The gold deposits of the Dawson-Mayo area include diverse styles of mineralization (Table 2) despite the fact that most occur in and adjacent to intrusions of the Tombstone Plutonic Suite (Fig. 1, 2, 3):

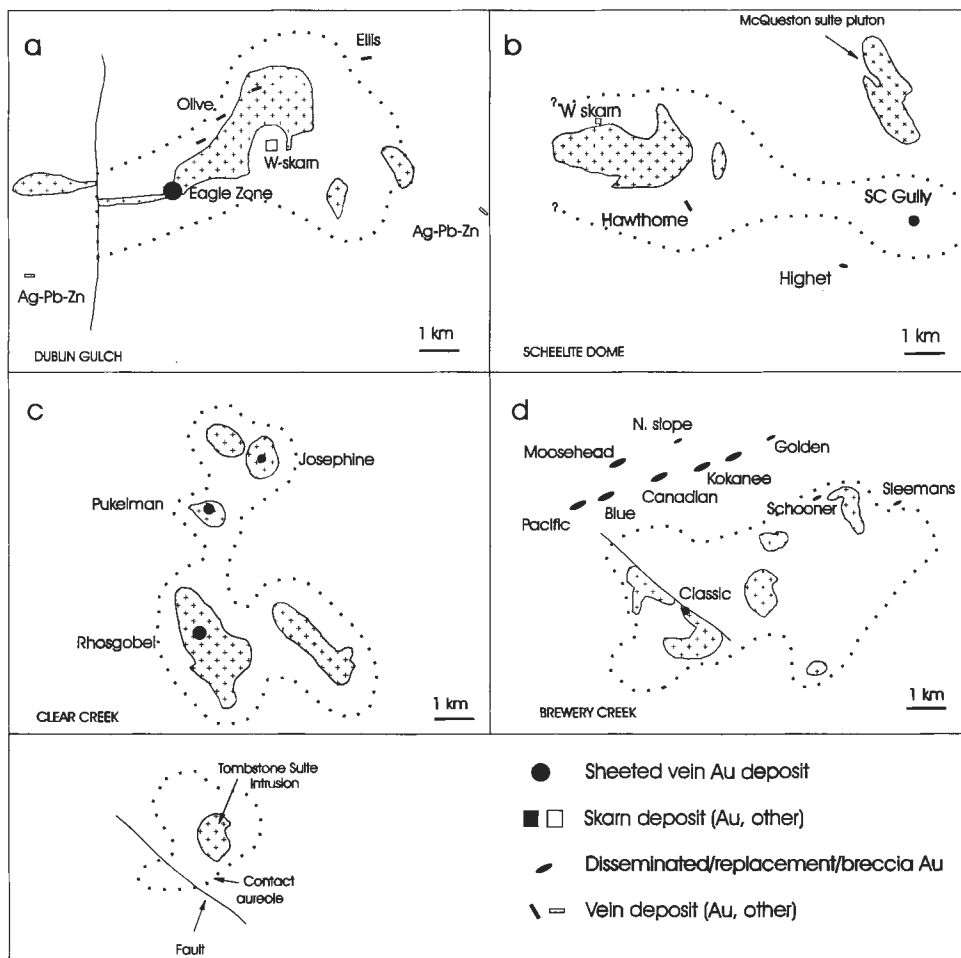


Figure 2. Sketch maps of selected intrusions of the Tombstone Plutonic Suite and related mineral occurrences. The extents of contact metamorphic aureoles are based on direct mapping and by a consideration of aeromagnetic anomalies. **a)** Dublin Gulch (adapted from Hitchins and Orssich, 1995); **b)** Scheelite Dome (after Murphy and Héon, 1995); **c)** Clear Creek (after Murphy et al., 1993); **d)** Brewery Creek (adapted from Diment, 1996).

1. Sheeted quartz veinlet to stockwork zones within stocks of the Tombstone suite form a distinctive style of gold mineralization which is particularly prominent at Dublin Gulch and Clear Creek (Fig. 2a, c) but which was also noted at the Aussie and Mike Lake (Fig. 3b) prospects. This style of mineralization is comparable to that at the Fort Knox deposit (Bakke, 1995) in a similar setting west of the Tintina Fault in Alaska. Native gold occurs with arsenopyrite and bismuthinite as well as minor and variable amounts of pyrite, molybdenite, chalcopyrite, and scheelite in swarms of millimetre- to centimetre-wide subvertical extensional veins which have consistent strikes at the scale of a prospect: 070° to 090° at Dublin Gulch and 090° to 110° at Clear Creek. The veinlet zones locally extend into hornfelsed country rock but appear to be intimately related to the host intrusions by virtue of associated high temperature K-feldspar alteration haloes
2. A notable example of gold skarn mineralization is present at the Marn deposit (Fig. 3d) adjacent to a dioritic to monzonitic apophysis of the Mount Brenner Stock. The prograde scheelite-bearing skarn is iron-rich and hedenbergitic and contains retrograde pyrrhotite plus chalcopyrite as dominant sulphide phases. Gold, along with bismuth, is thought to have been emplaced during a late stage of retrograde alteration (Brown and Nesbitt, 1987). Similar scheelite-bearing skarn is known to occur at Dublin Gulch and Scheelite Dome and tremolite skarn was noted at the Schooner zone at Brewery Creek but, in none of these cases, have significant gold enrichments been documented. Calc-silicate rocks were noted within the hornfels zones of several intrusions. At the Ida

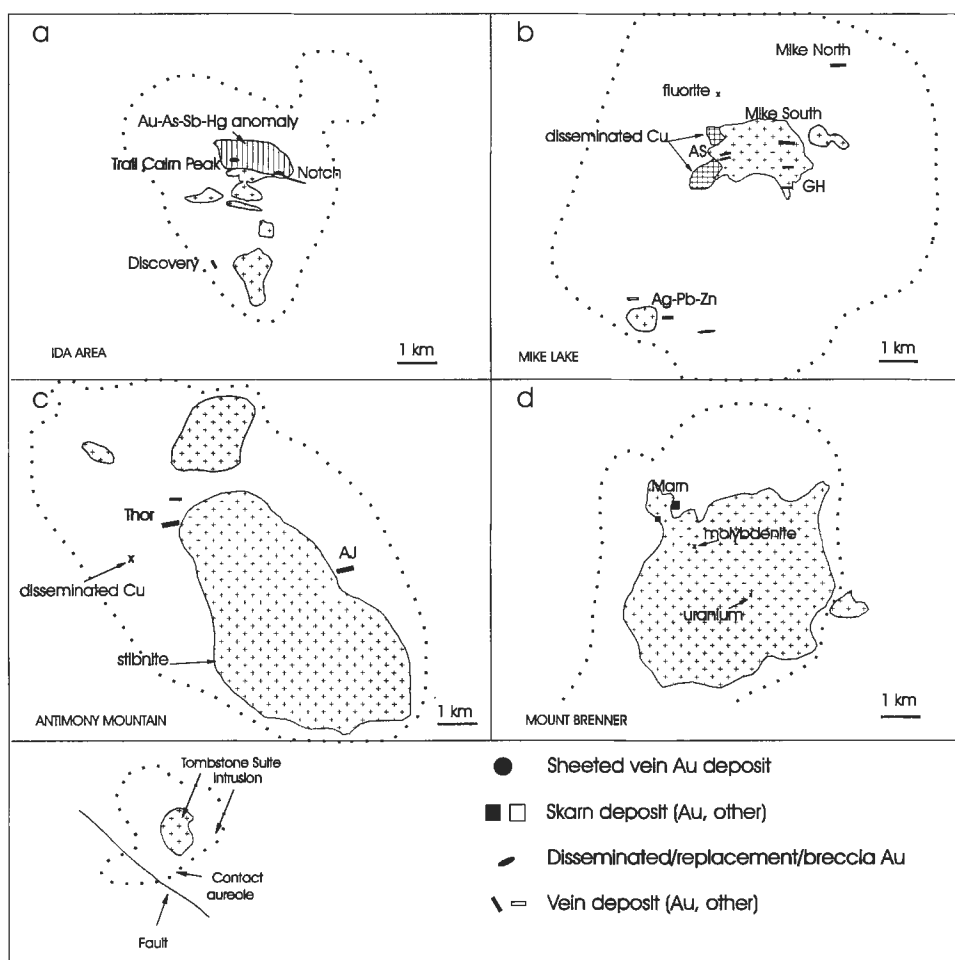


Figure 3. Sketch maps of selected intrusions of the Tombstone Plutonic Suite and related mineral occurrences. The approximate boundaries of metamorphic aureoles are based on direct mapping and on the extents of aeromagnetic anomalies. **a)** Ida (adapted from assessment files, DIAND, Dawson, Yukon); **b)** Mike Lake (adapted from assessment files, DIAND, Dawson, Yukon); **c)** Antimony Mountain (after Thompson et al., 1992); **d)** Mount Brenner (after Thompson et al., 1992).

Table 2. Intrusion-related gold deposits in the Northern Cordilleran Miogeocline, Dawson-Mayo area, Yukon.

Area	Zones	Structural style	Stratigraphic setting	Plutonic Association	Geochemical suite
Dublin Gulch	Eagle	intrusion-hosted E-W sheeted veins, minor stockwork	Yusezyu Fm., Hyland Gp.	mainly intrusion-hosted by Dublin Gulch stock	Au, As, Bi; rare Mo, W; arsenopyrite, bismuthinite common; W-skarn nearby; distal Ag-Pb-Zn veins
	Olive, Catto Creek	sediment-hosted ENE quartz veins	Yusezyu Fm., Hyland Gp.	within hornfels adjacent Dublin gulch Stock	Au, As; arsenopyrite
Keno Hill	Wayne	stratabound sulphide replacement	carbonate member of Yusezyu Fm., Hyland Gp.	Adjacent to quartz-feldspar porphyry dyke	Au, As; abundant arsenopyrite-pyrrhotite; nearby siderite-galena veins in post-porphyry faults
Scheelite Dome	Hawthorne	steep quartz breccia vein strikes 310°	foliated phyllite and gritty sandstone of Yusezyu Fm.; marble and calc-silicate common	within hornfels zone adjacent to biotite-hornblende monzonite of Scheelite Dome Stock	Au, Sb; W-skarn nearby
	SC Gully	sediment-hosted zone of steep veinlets striking 275°	foliated phyllite and gritty sandstone of Yusezyu Fm.	within hornfels zone above inferred stock	Au, As
	Highet	stratabound sulphide replacement	foliated phyllite and gritty sandstone of Yusezyu Fm.; marble and calc-silicate common	adjacent to hornfels zone	Au, As; local massive arsenopyrite
Red Mountain	Hobo Creek	steep quartz breccia vein strikes 310°	Cambrian meta-sandstone	adjacent to Red Mountain biotite-hornblende quartz monzonite	Au, As
Clear Creek	Pukelman, Rhosgobel, Josephine	vertical intrusion-hosted sheeted veinlets strike 90° to 110°	foliated phyllite and gritty sandstone of Yusezyu Fm.; local marble and calc-silicate	in and adjacent to stocks composed of biotite monzonite	Au, Bi, As; local W, Mo
Brewery Creek	Pacific, Blue	sediment-hosted disseminated, veinlet and breccia zones adjacent steep faults	Earn Group argillite and chert-bearing sandstone	external to hornfels zone of biotite monzonite stocks but dikes and sills adjacent	Au, As, Sb, Hg; stibnite common in veinlets and breccias
	Canadian, Fosters, Kokanee, Golden, Lucky, Sleemans, Moosehead	intrusion-hosted disseminated, veinlet and breccia zone in hanging walls of steep faults	at contact between siltstone of Road River Gp. and argillite of Earn Gp.	hosted by feldspar porphyry dykes and sills external to hornfels and calc-silicate zone around biotite monzonite stocks	Au, As, Sb, Hg; stibnite common in veinlets

Table 2 (cont.).

Area	Zones	Structural style	Stratigraphic setting	Plutonic Association	Geochemical suite
Brewery Creek	North Slope	sediment-hosted disseminated and breccia zones	buff, locally calcareous siltstone of Road River Gp.	feldspar porphyry dykes nearby	Au, As, Sb; stibnite present
	Classic, Schooner	disseminated zones and skarn	calcareous meta-siltstone of Road River Gp.	biotite monzonite stocks	Au, As
Aussie Creek	Aussie	intrusion hosted sheeted veins	meta-siltstone, -chert and argillite of Road River Gp.	porphyritic quartz monzonite and biotite monzonite stock	Au, As
Ida	Discovery	sediment-hosted breccia vein in NW fault zone	meta-siltstone, -chert and argillite of Road River Gp.	porphyritic biotite monzonite of Ida Stock	Au, Sb
	Trail Cairn Peak; Notch	E-striking sediment-hosted disseminated and veinlet zones	meta-siltstone, -chert and argillite of Road River Gp.	within zone of intense hornfels, silicification and local calc-silicate adjacent the Ida Stock; quartz-feldspar porphyry dykes adjacent	Au, As, Sb, Hg; minor arsenopyrite and possible local stibnite; tourmaline and axinite nearby
Mike Lake	Mike North	sediment-hosted quartz-sulphide vein strikes 90°	meta-siltstone and limestone of Kechika (?) Gp.	within zone of hornfels and calc-silicate in aureole of Mike Lake Stock	Au, As; locally massive arsenopyrite
	Mike South, AS, GH	intrusion-hosted quartz-sulphide veins in altered fracture zones striking 75° to 110°; sheeted quartz-tourmaline veins	metasiltstone and limestone of Kechika (?) Gp.	porphyritic biotite-hornblende monzonite of Mike Lake Stock	Au, As, Cu; major arsenopyrite; local molybdenite; low grade Cu at intrusion margins; Ag-Pb-Zn at outer limit of aureole
Antimony Mountain	AJ, Thor	steep sediment-hosted quartz-sulphide veins strike 070° to 100°	metasandstone of Yusezyu Fm. of Hyland Gp.	within hornfels zone adjacent to porphyritic hornblende-biotite syenite of Antimony Mountain Stock	Au-As-Cu; major arsenopyrite and local tourmaline; stibnite in dyke elsewhere in intrusion; nearby disseminated chalcopyrite in hornfelsed grit
Lake Creek	Heidi	sediment-hosted stratabound sulphide replacement	limestone and calcareous sandstone of upper Yusezyu Fm. of Hyland Gp.	external to inferred hornfels zone; rare porphyry and lamprophyre dykes nearby	Au, As, Sb; abundant arsenopyrite, jamesonite, and stibnite
Mount Brenner	Marn (Minigrid)	sulphide zones in hedenbergitic skarn	limestone of the Tahkandit Fm. and Earn Gp. (?) argillite-conglomerate	at margin of augite-biotite monzonite of Mount Brenner Stock	Au, Bi, Cu; skarn locally contains scheelite; low grade Mo in veins nearby

prospect (Fig. 3a) the occurrence of calc-silicate rocks coincides with anomalous gold concentrations (0.1 to 0.3 ppm) in broad siliceous, tourmaline-bearing zones within the contact aureole of the Ida stock suggesting weak prograde gold enrichment associated with contact metamorphic effects. At the same prospect, however, higher gold grades (1 to 10 ppm) are much more restricted and likely related to retrogressive structural overprinting of the aureole.

3. There are several occurrences of carbonate-hosted disseminated styles of mineralization in the region. Carbonate replacement types include “manto-like” prospects such as Wayne, Highet Creek, and Lake Creek. They all are localized in limestone and calcareous grit in the upper part of the Yusezyu Formation where disseminated to massive arsenopyrite replaces carbonate minerals and occur well away from stocks of the Tombstone Suite although porphyry dykes are a volumetrically minor, but ubiquitous, feature of such occurrences. A further example of carbonate-hosted mineralization is the North Slope occurrence at Brewery Creek (Fig. 2d). Relatively high concentrations of gold (Table 3) occur along with stibnite in a siliceous breccia within a fault zone cutting calcareous siltstone that likely belongs to the Silurian Steel Formation. This mineralization also occurs adjacent to porphyry dykes and, of all the occurrences examined in the region, is the most “Carlin-like” in its characteristics (Poulsen, 1996).
4. Noncarbonate-hosted disseminated, stockwork, and replacement deposits containing As, Sb, and Hg are the main forms of mineralization at Brewery Creek (Diment, 1996) and similar mineralization has been noted at the Ida prospect. Hosts include both (quartz)-feldspar porphyry dykes and siliciclastic sedimentary rocks, argillite, and sandstone in the case of the Blue and Pacific zones at Brewery Creek (Fig. 2d). Veinlet and breccia zones related to normal faults appear to be the main structural controls for this type of mineralization which commonly is accompanied by stibnite and arsenian pyrite. At Brewery Creek, this style of mineralization is distal to the central stocks and hornfels (Fig. 2d) although hosted in large part by porphyry dykes. At the Ida prospect (Fig. 3a), higher grades of gold are found in narrow stratabound zones well within the hornfels in broader zones of silicification and gold enrichment (>300 ppb).
5. Quartz-sulphide vein deposits are common features in the Dawson-Mayo area and account for many of the early discoveries of gold in the region. On average one metre wide, the veins dip steeply and strike east-northeast (Dublin Gulch, Mike Lake, and Antimony Mountain) or northwest (Scheelite Dome, Red Mountain, Ida Discovery). Quartz content varies from nearly 100% (Scheelite Dome) to nearly zero (massive sulphide veins at Mike Lake). Arsenopyrite and pyrite are the most common sulphide minerals in the veins. Most veins appear to occupy extensional fractures or brittle faults.

Table 3. Geochemical analyses of mineralized specimens* from selected gold deposits in the Dawson-Mayo area, Yukon.

Deposit	Sample description	Au (ppm)	Ag (ppm)	As (ppm)	Sb (ppm)	Hg (ppm)	W (ppm)	Mo (ppm)
Clear Creek	sheeted veinlet in porphyritic monzonite (Pukelman)	0.08	<5	2300	<0.2	<1	<4	<5
	sheeted veinlet in porphyritic monzonite (Pukelman)	0.3	<5	6100	11	<1	2900	74
Dublin Gulch	sheeted veins in porphyritic quartz monzonite (Eagle)	0.08	<5	160	3.6	<1	29	<5
	sheeted veins in porphyritic quartz monzonite (Eagle)	1.5	<5	520	4.4	<1	12	<5
Scheelite Dome	quartz vein (Hawthorne)	1.3	<5	9300	66	<1	22	<8
	arsenopyrite replacement (Highet)	0.8	<5	53000	46	<1	<9	<9
Brewery Creek	sediment-hosted breccia in argillite – Blue Zone	17.4	<5	280	5700	<5	<6	<23
	sediment-hosted breccia in calcareous siltstone	23.7	<5	4300	3200	<4	<7	<15
	oxidized feldspar porphyry – Canadian Zone	4.2	<10	3200	13000	57	<11	<51
	veinlets in porphyry – Bohemian Zone	7.3	<5	5100	3100	<4	<5	<17

* selected samples to illustrate elemental associations – the concentrations are not representative of deposits as a whole
Analyses using INAA by Activation Laboratories Ltd., Ancaster, Ontario.

Mineralized specimens from gold deposits in the Dawson-Mayo area are consistently enriched in arsenic, variably enriched in antimony and mercury, and relatively low in base metal and silver contents irrespective of the style of mineralization (Tables 2 and 3). Arsenopyrite is a common associate mineral in both vein and replacement deposits and pyrite at Brewery Creek is characterized by arsenian rims (Diment, 1996). Stibnite is a relatively common constituent of mineralization that is relatively distant from intrusions. Specific mercury minerals have not been identified in any deposits as yet. Although base metal and silver contents are relatively low, mineralization in the northern part of the area (Marn, Antimony Mountain, and Mike Lake areas) typically includes significant quantities of copper. Bismuth is enriched at the Marn deposit (Brown and Nesbitt, 1987) and the Eagle zone at Dublin Gulch (Hitchins and Orsich, 1995) and is generally correlated with gold in other proximal deposits.

DISCUSSION

All of the styles of mineralization described above for the Dawson-Mayo area conform to the broad class of “intrusion-related” gold deposits as recognized elsewhere in the world (Sillitoe, 1991). There is a clear spatial association between the various styles of mineralization and intrusions of the Tombstone Plutonic Suite (Fig. 2, 3), and it is considered likely that some, if not all, of the styles of mineralization are genetically related to the intrusive rocks. Of clearest direct relationship to magmatic processes are the high temperature sheeted veinlet and skarn bodies which are characterized by the presence of anomalous Bi (Hitchins and Orsich, 1995), a hallmark of deposits of direct magmatic affiliation (Sillitoe, 1991). The carbonate-hosted and noncarbonate-hosted disseminations and replacements are much more difficult to relate genetically to magmatism owing to their late paragenesis and weak links to plutonic rocks. The gold-bearing quartz veins overprint both intrusions and contact aureoles and have a late structural paragenesis relative to other styles of mineralization and in many respects resemble intrusion-related veins in North China (Poulsen et al., 1990; Poulsen and Mortensen, 1993). It is even more difficult, on geological grounds alone, to relate the Ag-Pb-Zn veins of the region, which occupy similar structural sites, to the felsic intrusions even though they occupy the well-known distal position with respect to the Tombstone suite intrusions (Fig. 5 in Poulsen, 1996).

Although an association with intrusions is a dominant feature of the gold deposits of the Dawson-Mayo area, there are specific structural aspects to their genesis. There is a remarkably consistent vertical east-west orientation ($\pm 20^\circ$ of strike and dip) of veins associated with the gold deposits throughout the area irrespective of whether they are millimetre-thick members of a sheeted vein sets or metre-wide quartz-arsenopyrite veins in both intrusions and surrounding sedimentary rocks. Given that most veins are observed to be extensional (lack of offsets parallel to walls), it is significant that the inferred direction of extension is north-south. Additional evidence for this direction of extension during mineralization is the observation of listric normal faults and vertical extensional veins in their hanging walls (both also easterly striking) as controlling structures for

mineralization at Brewery Creek. The inferred north-south extension during mineralization is in sharp contrast to the north-south shortening implied for much of the Mesozoic and Cenozoic history of the area by northerly directed thrusts (Green and McTaggart, 1960; Templeman-Kluit, 1970), east-northeast and west-southwest folds, and the dextral strike-slip displacements on the Tintina Fault. Only in the case of the Ag-Pb-Zn veins in this region has a period of northerly directed extension been inferred (Templeman-Kluit, 1964; Lynch, 1989a, b) providing a possible geometric and structural link between this type of mineralization and the gold deposits. At this point, it is not clear whether the extension in question is local and associated with strike-slip faulting (e.g. Lynch, 1989a, b) or whether it is a manifestation of a relatively short-lived period of regional north-south extension that is broadly equivalent in age to the Tombstone suite magmatism.

A cursory examination of the stratigraphic range of the gold deposits in the Dawson-Mayo area (Table 1, Table 2) suggests that there are also likely lithological controls on their location at a regional scale. A common factor for most deposits is their occurrence at, or near, carbonate members of the stratigraphic succession irrespective of the style of mineralization. These rocks include the calcareous members at the top of the Yusezyu Formation, within the Kechika equivalent rocks, near and within the Road River Group (Steel Formation equivalent) and within the Permian Takhandit Limestone. Skarn and carbonate replacement deposits are, by definition, associated with carbonate strata but, in the Dawson-Mayo area, there is also a good correlation with both sheeted vein, noncarbonate disseminated, and replacement and quartz vein gold deposits: carbonate country rocks, locally with skarn and calc-silicate rocks containing Cu and or W, are present at Dublin Gulch, Scheelite Dome, Brewery Creek, Ida, Mike Lake, and Antimony Mountain. Elsewhere in the world, such stratigraphic controls are ascribed either to a greater degree of reaction between hydrothermal fluids and carbonate rocks (Sillitoe, 1991) or to secular variations in the chemistry of host sedimentary sequences which renders them more favourable sources of gold (Titley, 1991).

In summary, examination of the gold deposits of the Selwyn Basin area leads to the conclusion that there are recurring magmatic, structural, and stratigraphic controls on the siting of gold. Although the deposits are all likely related to magmatic and postmagmatic processes, various styles of mineralization are present and probably represent progressive evolution from essentially magmatic products such as sheeted veins and skarns, to products of retrograde fluids in the cases of discrete veins and replacement styles of mineralization including much of that found within skarns and hornfels zones. Nonetheless all styles of mineralization appear to be products of hydrothermal systems that influenced areas on the order of 100 km². In most cases, intrusions and their immediate environs account for less than 50% of the surface area in these systems but, to date these parts have been most intensively explored owing to the fact that they are the highest, best exposed, and are likely sources of most of the regional geochemical anomalies associated with the intrusions. It is notable, however, that the gold pathfinder suite As-Sb-Hg,

commonly diagnostic of distal deposits in other settings, seems to be equally diagnostic of proximal environments in the Dawson-Mayo district (e.g. Garrett, 1974). As a result the distal parts of these systems (which are also commonly at lower altitude and covered with vegetation) have not received as much exploration even though they represent prospective environments for disseminated, stockwork, and replacement styles of gold mineralization in both carbonate and noncarbonate hosts.

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REFERENCES

- Bakke, A.A.**
1995: The Fort Knox 'porphyry' gold deposit - Structurally controlled stockwork and shear quartz vein, sulphide-poor mineralization, hosted by a Late Cretaceous pluton, east-central Alaska; in *Porphyry Deposits of the Northwestern Cordillera of North America* (ed.) T.G. Schroeter; Canadian Institute of Mining and Metallurgy, Special Volume 46, p. 795-802.
- Bostock, H.S.**
1964: Geology, McQuesten, Yukon Territory; Geological Survey of Canada, Map 1134A, scale 1 inch to 4 miles.
- Brown, I.J. and Nesbitt, B.E.**
1987: Gold-copper-bismuth mineralization in hedenbergitic skarn, Tombstone Mountains, Yukon; *Canadian Journal of Earth Sciences*, v. 24, p. 2362-2372.
- Diment, R.**
1996: Brewery Creek gold deposit; in *Yukon Exploration and Geology, 1995; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, p. 57-66.
- Gabrielse, H. and Yorath, C.J.**
1991: Tectonic synthesis, Chapter 18 in *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, Geology of Canada no.4, p. 677-705 (also Geological Society of America, *The Geology of North America*, v. G-2).
- Garrett, R.G.**
1974: Mercury in some granitoid rocks of the Yukon and its relation to gold-tungsten mineralization; *Journal of Geochemical Exploration*, v. 3, p. 277-289.
- Gordey, S.P. and Anderson, R.G.**
1993: Evolution of the Northern Cordilleran miogeocline, Nahanni map area (1051), Yukon and Northwest Territories; Geological Survey of Canada, Memoir 428, 214 p.
- Green, L.H.**
1972: Geology of the Nash Creek, Larsen Creek and Dawson map-areas, Yukon Territory. Geological Survey of Canada, Memoir 364, 154 p. (accompanied by maps, scale 1:250 000).
- Green, L.H. and McTaggart, K.C.**
1960: Structural studies in the Mayo District, Yukon Territory; *Proceedings of the Geological Association of Canada*, v. 12, p. 119-134.
- Green, L.H. and Roddick, J.A.**
1962: Dawson, Larsen Creek and Nash Creek map-areas, Yukon Territory. Geological Survey of Canada, Paper 62-7, 20 p. (accompanied by preliminary maps, scale 1:250 000).
- Hitchins, A.C. and Orssich, C.N.**
1995: The Eagle zone gold-tungsten sheeted vein porphyry deposit and related mineralization, Dublin Gulch, Yukon Territory; in *Porphyry Deposits of the Northwestern Cordillera of North America* (ed.) T.G. Schroeter; Canadian Institute of Mining and Metallurgy, Special Volume 46, p. 803-810.
- Lynch, J.V.G.**
1989a: Hydrothermal zoning in the Keno Hill Ag-Pb-Zn vein system: a study in structural geology, mineralogy, fluid inclusions and stable isotope geochemistry; Ph.D. thesis, University of Alberta, Edmonton, Alberta, 219 p.
1989b: Large-scale hydrothermal zoning reflected in the tetrahedrite-freibergite solid solution, Keno Hill Ag-Pb-Zn district, Yukon; *Canadian Mineralogist*, v. 27, p. 383-400.
- Mortensen, J.K.**
1992: Pre-mid-Mesozoic tectonic evolution of the Yukon-Tanana Terrane, Yukon and Alaska; *Tectonics*, v. 11, p. 836-853.
- Mortensen, J.K. and Von Giza, P.**
1992: Applications of Landsat TM thermal imagery to structural interpretations of the Tintina Trench in west-central Yukon; in *Yukon Geology, Volume 3; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, p. 214-222.
- Mortensen, J.K., Murphy, D.C., Poulsen, K.H. and Bremner, T.**
1996: Intrusion-related gold and base metal mineralization associated with the Early Cretaceous Tombstone plutonic suite, Yukon and east-central Alaska; in *New Mineral Deposit Models of the Canadian Cordillera; 1996 Cordilleran Roundup Short Course Notes*, section L, 13 p.
- Murphy, D.C. and Héon, D.**
1994: Geology and mineral occurrences of Sprague Creek map area (NTS 115P/15), western Selwyn Basin; in *Yukon Exploration and Geology, 1993; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, p. 29-46 (accompanied by map, scale 1:50 000).
1995: Geology and mineral occurrences of Seattle Creek map area (NTS 115P/16), western Selwyn Basin; in *Yukon Exploration and Geology, 1994; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, p. 59-71 (accompanied by map, scale 1:50 000).
- Murphy, D.C., Héon, D., and Hunt, J.**
1993: Geological overview of Clear Creek map area (NTS 115P/14), western Selwyn Basin; in *Yukon Exploration and Geology, 1992; Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada*, p.61-69 (accompanied by map, scale 1:50 000).
- Poulsen, K.H.**
1996: Carlin-type gold deposits and their potential occurrence in the Canadian Cordillera; in *Current Research 1996-A; Geological Survey of Canada*, p. 1-9.
- Poulsen, K.H. and Mortensen, J.K.**
1993: Observations on the gold deposits of Eastern Hebei Province, China; in *Current Research, Part D; Geological Survey of Canada, Paper 93-1D*, p. 183-190.
- Poulsen, K.H., Taylor, B.E., Robert, F., and Mortensen, J.K.**
1990: Observations on gold deposits in North China Platform; in *Current Research, Part A; Geological Survey of Canada, Paper 90-1A*, p. 33-44.
- Sillitoe, R.H.**
1991: Intrusion-related gold deposits; in *Gold Metallogeny and Exploration* (ed.) R.P. Foster; Blackie and Son, Ltd., Glasgow, p. 165-209.
- Templeman-Kluit, D.J.**
1964: Geology of the Haggart Creek-Dublin Gulch area, Mayo District, Yukon Territory; M.A.Sc. thesis, University of British Columbia, Vancouver, British Columbia, 99 p.
1970: Stratigraphy and structure of the "Keno Hill Quartzite" in Tombstone River, Upper Klondike River map-areas, Yukon Territory (116 B/7, B/8); Geological Survey of Canada, Bulletin 180, 102 p.
- Thompson, R.I.**
1995: Geological compilation (1:250 000) of Dawson map area (116B,C) northeast of Tintina Trench; Geological Survey of Canada, Open File 03223, scale 1:250 000.
- Thompson, R.I., Roots, C.F., and Mustard, P.S.**
1992: Geology of the Dawson map area; Geological Survey of Canada, Open File 2849 (13 map sheets, scale 1:50 000).
- Titley, S.R.**
1991: Phanerozoic ocean cycles and sedimentary-rock-hosted gold ores; *Geology*, v. 19, p. 645-648.

Bedrock geology of the Anyox pendant and surrounding areas, Observatory Inlet (103P/5) and parts of Hastings Arm (103P/12) and 103O/9 map areas, British Columbia

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Abstract: The Anyox pendant underlies a 400 km² region of Paleozoic(?) to Mesozoic volcanic, sedimentary, and plutonic rocks within the Coast Belt. Strata were deformed in an unknown number of events prior to being engulfed by Tertiary granite.

The eastern two-thirds of the pendant consists of Jurassic turbidites of the Bowser Lake Group, underlain by Jurassic or Triassic volcanic rocks. Age, stratigraphic position, and structural history of the western third of the pendant are enigmatic. Units are highly strained and include felsic granitoid, mafic intrusive rocks, ultramafic rock, and metasedimentary and metavolcanic rocks. They are transected and bounded by a network of north-trending cataclastic and mylonitic shear zones.

Tertiary granitoid rocks range from granite to quartz monzodiorite. Pendant rocks and Tertiary granite are intruded by lithologically distinctive dyke swarms which record northeast extension followed by northwest extension. More than 500 m of Tertiary(?) volcanic and sedimentary rock cap one peak.

Résumé : Le pendentif d'Anyox repose sous 400 km² de roches volcaniques, sédimentaires et plutoniques du Paléozoïque(?) au Mésozoïque dans le Domaine côtier. Les strates ont été déformées lors d'un nombre inconnu d'événements avant d'être envahies par un granite du Tertiaire.

Les deux tiers orientaux de l'enclave se composent de turbidites jurassiques du Groupe de Bowser Lake, qui reposent sur des roches volcaniques du Jurassique ou du Trias. L'âge, la position stratigraphique et l'histoire structurale du tiers occidental du pendentif sont problématiques. Les unités sont très déformées et comprennent des granitoïdes felsiques, des roches intrusives mafiques, des roches ultramafiques et des roches métasédimentaires et métavolcaniques. Elles sont recoupées et limitées par un réseau de zones de cisaillement cataclastiques et mylonitiques à direction nord.

Les roches granitoïdes du Tertiaire vont du granite à de la monzodiorite quartzique. Les roches du pendentif et le granite du Tertiaire sont recoupés par des essaims de dykes de lithologie distincte qui témoignent d'une distension vers le nord-est suivie d'une distension vers le nord-ouest. Plus de 500 m de roches volcaniques et sédimentaires du Tertiaire(?) coiffent un sommet

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INTRODUCTION

Bedrock mapping in the Anyox pendant and surrounding areas is part of a multi-year project designed to increase the geoscience database of Nass River area (103P; Fig. 1). Components of the project include bedrock geology and surficial mapping as well as related thematic studies on the stratigraphy, structure, metamorphism, geochronology, neotectonics, and mineral deposits. Quaternary and geophysical studies are also being done. The project began in 1995 with bedrock mapping, stratigraphy, and structural studies, and collections of samples for related studies in the central and north-central parts of Nass River area (103P/6, 10, 15; Evenchick and Mustard, 1996; Evenchick, 1996a, b, c). In 1996 the objective was to map and examine stratigraphic, structural, and metamorphic relationships of the Anyox pendant and surrounding areas, as well as to collect samples for U-Pb, ^{40}Ar - ^{39}Ar , and fission track geochronology. This paper presents the results of bedrock mapping from the 1996 field season; the status of research in other components of the project are presented in Evenchick et al. (1997).

Regional geology and previous work

An overview of the regional geological framework and previous work in Nass River area is presented in Evenchick and Mustard (1996). Most of the bedrock is divided into three broad groupings (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 or Quaternary volcanic rocks, and metamorphic rocks of unknown age.

The Anyox pendant is within the Coast Belt and surrounded by early Tertiary granite. Plutonic rocks were studied in a regional analysis of porphyry Cu and Mo deposits by Carter (1981). Twenty K-Ar age determinations in and around the deposits in Nass River area range from 49 to 55 Ma (Carter, 1981; recalculated using decay constants of Steiger and Jäger, 1977). These include two in the current study area; a third date is younger and assumed to be reset. No pre-Tertiary granites in the study area have been reported.

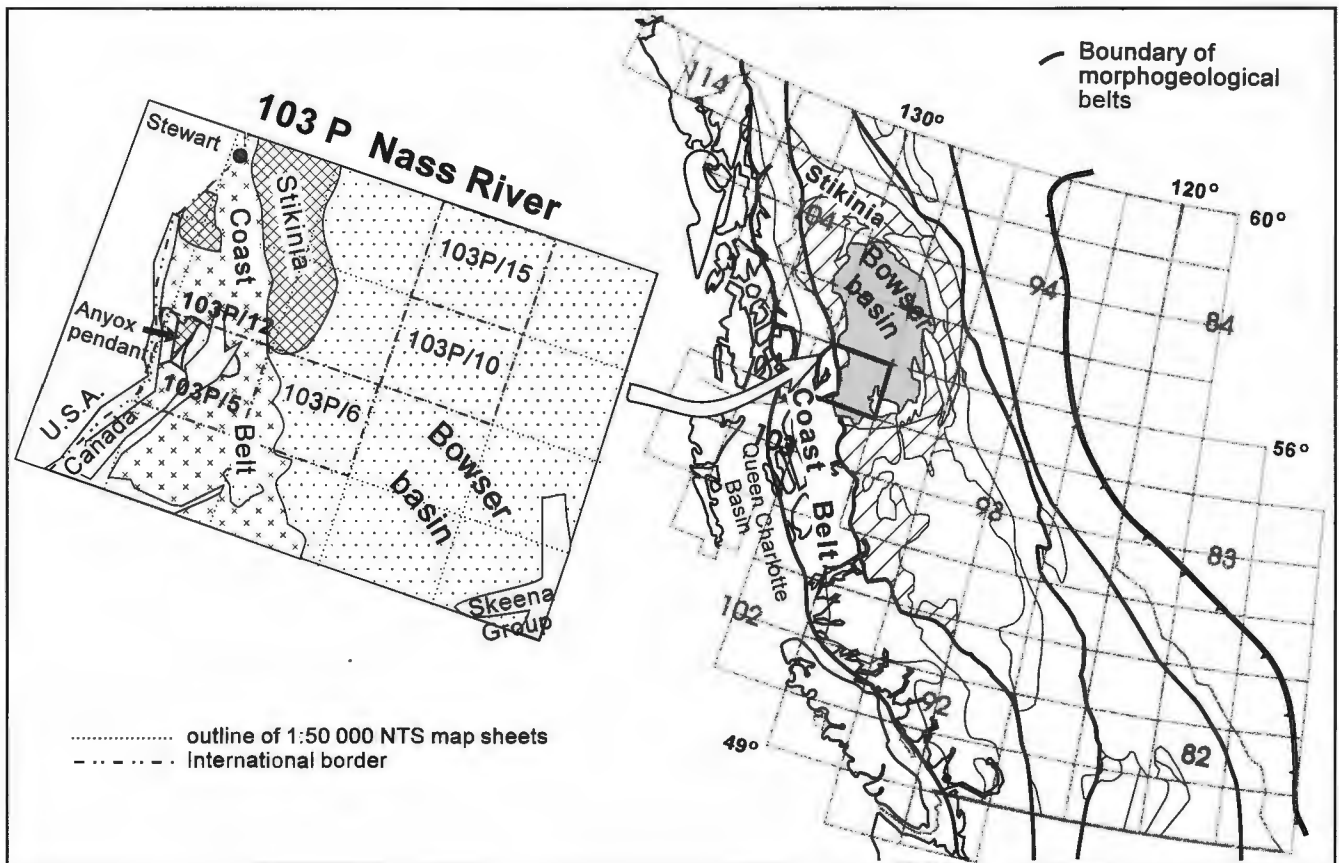


Figure 1. Location of Nass River (103P) map area and its major geological elements. Areas discussed in report are outlined in inset.

Early work within the pendant began with McConnell's (1913) delineation of argillite rocks in the east half of the pendant. Then, as later, the primary focus of research was around the massive sulphide deposits situated at and near the boundary between volcanic and clastic rocks. The first regional map of the pendant and more detailed descriptions of strata were presented by Hanson (1935). The contact between Jurassic clastic and volcanic rocks on that map appears more or less as presently known. The entire western half of the pendant was depicted as Jurassic amphibolite, fragmental amphibolite, and sediments. Carter and Grove (1972) and Grove (1986) also considered rocks in the western half of the pendant as Jurassic, and correlated them with the Hazelton Group. They delineated structures in the clastic rocks, subdivided the Hazelton Group, and noted belts of cataclastic rocks. More recent work has continued to focus on the volcanic/sedimentary contact; the age and correlation of these strata has proven to be an enduring enigma. Sharp (1980) correlated the volcanic rocks with the Triassic Karmutsen Formation (of the Queen Charlotte Islands) based on lithology and chemistry, and the overlying clastic rocks with the Lower and Middle Jurassic Kunga and Yakoun formations based on lithology and position with respect to the volcanics. Alldrick (1986) and Alldrick et al. (1996) also considered the volcanics to be Triassic from Pb isotope ratios. Smith (1993), however, used Sm-Nd and Pb-Pb systematics to argue that the volcanics are Early to Middle Jurassic. The most recent study is a detailed assessment of stratigraphy, mineralization, alteration, and lithogeochemistry of the Hidden Creek deposit (Macdonald, 1995). Lithogeochemistry on volcanic rocks in the Hidden Creek area (Macdonald, 1995) and more regionally in the Anyox pendant (Sharp, 1980; Smith, 1993) is indicative of tholeiitic mid-ocean ridge basalts.

STRATIGRAPHY

Anyox pendant

The Anyox pendant is composed of metamorphosed Paleozoic(?) to Mesozoic plutonic, volcanic, and sedimentary rock (Fig. 2). It can be broadly divided into two parts. An east belt has coherent, moderately well understood stratigraphy, with considerable horizontal shortening expressed as folds and thrust faults. Stratigraphy and structure are enigmatic in the western third of the pendant where stratified rocks are highly strained and intruded by a variety of plutonic rocks, and both are transected by a network of cataclastic and mylonitic shear zones.

Bowser Lake Group

The eastern half of the pendant and eastern Alice Arm are underlain by folded and hornfelsed mudstone, siltstone, and sandstone turbidites. Siltstone and mudstone are dark grey on weathered and fresh surfaces, and are massive or laminated. They commonly contain metamorphic biotite, and less commonly, muscovite, andalusite, and cordierite porphyroblasts.

Sandstone is light to medium grey on weathered and fresh surfaces and is typically medium grained, although gritty beds and fine pebble conglomerate are present. It is composed mainly of quartz, feldspar, chert, and other lithic clasts. More feldspathic varieties have layering defined by randomly oriented biotite. Thick bedded, medium grained sandstone locally has irregular calcareous concretions; beds of calcareous sandstone are rare. The turbidites have many features in common with those to the east in Alice Arm map area (Evenchick and Mustard, 1996). They occur as massive or parallel laminated, medium grained sandstone fining up to siltstone and mudstone in T_{AE}, T_{ABE}, and lesser T_{ABCE} turbidites (Fig. 3). Units of amalgamated sandstone beds up to 15 m thick as well as units of dominantly siltstone and mudstone several tens of metres thick are present (Fig. 4). Common sedimentary structures are graded bedding and flame structures; convoluted bedding, crossbedding, and rip-up clasts are also present.

Clastic rocks are underlain on the west by volcanic rocks, and their character near the base varies along strike. North of Carney Lake, at least 800 m of strata above the contact are entirely thin bedded mudstone, siltstone, or very fine grained sandstone. Those within about 50 m of the contact are more siliceous and rusty weathering. South of Tauw Creek, medium grained sandstone with flame structures and graded bedding occurs within 200 m of the contact. In the three areas examined, rusty weathering siliceous siltstone is at the base of the clastic succession. The lower part of the unit has been described in detail by previous workers, who have reported common thin cherty horizons.

Turbidites are correlated here with the Bowser Lake Group, based on lithology. Well preserved ammonites were found near a locality which previous yielded poorly preserved ammonites and an equivocal age. The new collection indicates a late Middle Jurassic age (Bathonian-Callovian boundary; H.W. Tipper, pers. comm., 1996).

Triassic, Lower Jurassic, or lower Middle Jurassic volcanic rocks

The Bowser Lake Group is conformably underlain by volcanic rocks. The unit is dominantly pillowed and massive volcanic flows, with minor tuff and breccia (Fig. 5). Volcanics are light to dark green weathering, and have aphanitic or fine grained groundmass with feldspar phenocrysts. Tuff occurs as light coloured siliceous lenses up to 100 m or more long, and commonly 3 to 10 m thick. The eastern parts of the unit were described in detail by Sharp (1980) and Macdonald (1995). Rocks in the western half of the unit are similar, but cut by shear zones and intruded by gabbroic or dioritic bodies which have both intrusive and structural contacts with the volcanics. Sharp (1980) considered the intrusive rocks to be subvolcanic feeders to the lava flows. The western boundary of the unit is a fault contact with a sheared granitoid body. On the ridges at the head of Tauw Creek it hosts a ductile shear zone at least 20 m wide at its western contact. Farther north, east of Mount Clashmore, the contact is a fault, but the ductile part of the shear zone is within the sheared granitoid unit.

Correlation of the unit is problematic, although most workers agree that it is either Triassic or Lower Jurassic (see "Regional geology and previous work"). A conformable upper contact with clastic rocks correlated with the Bowser Lake Group offers meagre support for correlation of the volcanics with the Hazelton Group. Pillowed tholeiitic basalt flows are locally common near the top of the Hazelton Group farther north (Eskay Creek facies of the Salmon River Formation) although the geochemical affinities, where known, are different (Souther, 1972; Anderson, 1993).

Cataclastic and mylonitic granitoid

Cataclastic to mylonitic granitoid occupies a 500 m to 2 km wide, north-trending belt at the east side of the highly strained west third of the pendant. It is cream to white weathering, and from a distance of more than a few tens of metres, looks like Tertiary granite. Its structure ranges from cataclasite with random angular fragments millimetres to centimetres across (Fig. 6), to oriented fragments, to strongly foliated and lineated mylonite with sub-millimetre scale foliation and

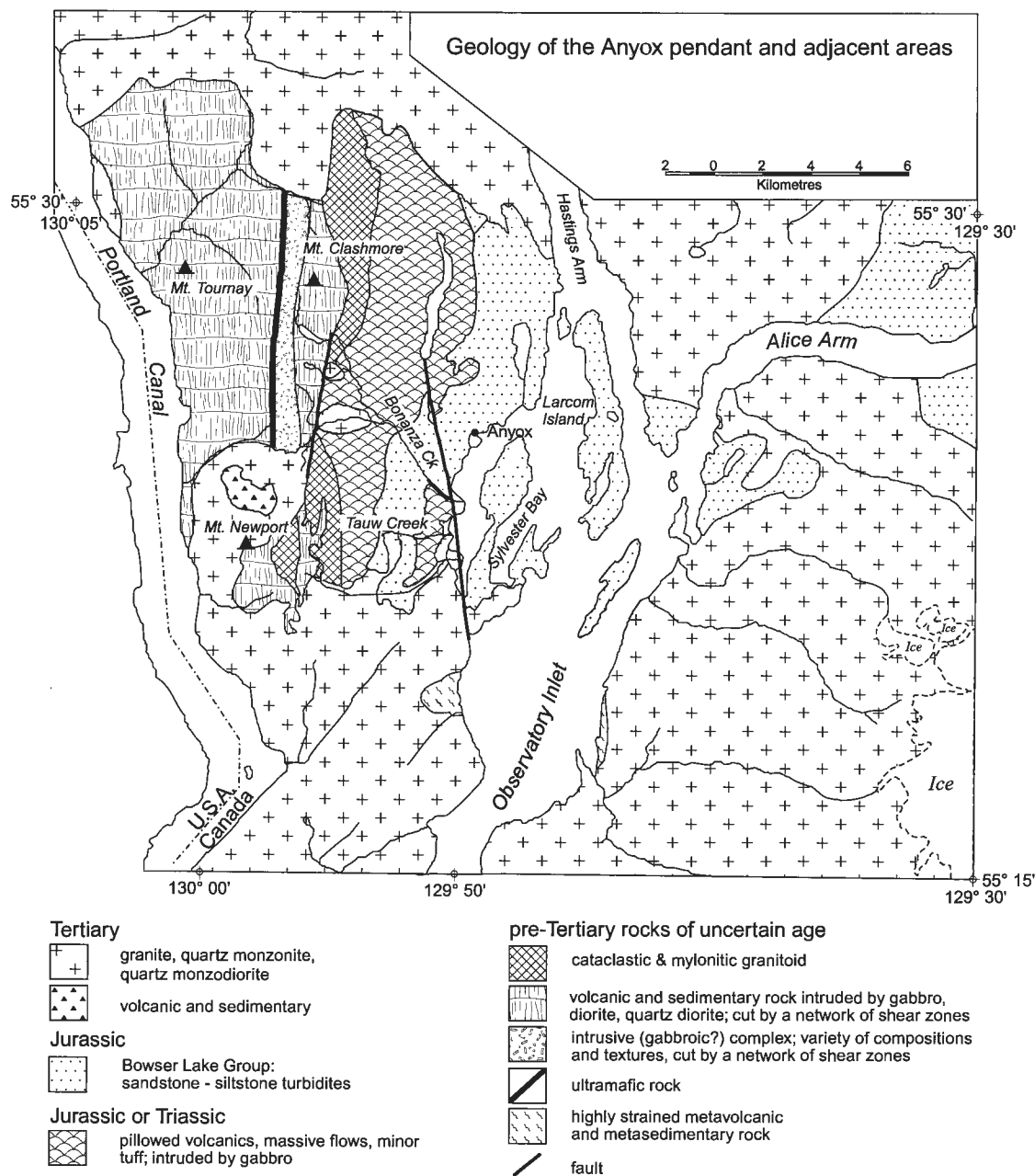


Figure 2. Sketch map of geology in Observatory Inlet (103P/5) and adjacent parts of Hastings Arm (103P/12) and 103O/9 map areas.



Figure 3. Sandstone-siltstone turbidites of the Bowser Lake Group. The light grey rock is medium grained sandstone. It has a sharp base with siltstone at the top of an underlying turbidite unit, and grades up into siltstone. The overlying sandstone has flame structures at the base. South end of Larcom Island.



Figure 4. Fine grained sandstone-siltstone-mudstone turbidites, east side of Larcom Island.

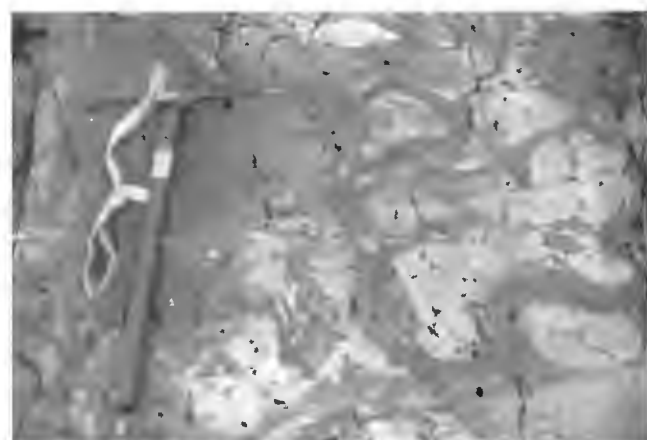


Figure 5. Pillowed volcanics south of Tauw Creek.

quartz ribbons (Fig. 7). Unstrained zones are rare. All textural varieties occur throughout the belt and at its boundaries. For example, at the head of Tauw Creek the eastern boundary is random cataclasite, whereas east of Mount Clashmore it is oriented cataclasite and mylonite. Lenses of gabbro or diorite bounded by shear zones are minor constituents.

The sheared granitoid is cut by Tertiary granite and is therefore older than Tertiary. Lenses of gabbro may have been either intrusive or structurally interleaved, so their age (presently unknown) does not constrain the age of the sheared granitoid. The unit was previously mapped by Carter and Grove (1972) and Grove (1986) as Tertiary granite and Jurassic metamorphic rock; it is probably pre-Tertiary.

Metasedimentary and metavolcanic rocks intruded by gabbro and/or diorite

West of the sheared granitoid is a belt of strained metasedimentary and metavolcanic rocks intruded by large volumes of mafic intrusive rocks. Stratified rock types include



Figure 6. Cataclastic granitoid, head of Tauw Creek.

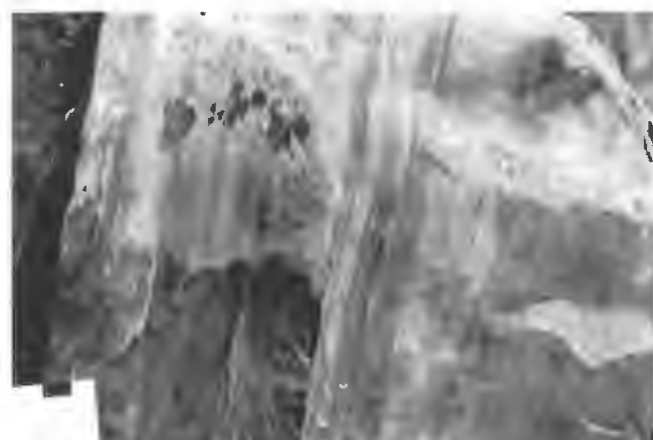


Figure 7. Mylonitic granitoid, head of Tauw Creek.

black phyllite, green chlorite phyllite, metasandstone, minor conglomerate with chert and other lithic clasts, siliceous tuff and/or siltstone, volcanic breccia with chlorite phyllite matrix, pillowed volcanics, and minor marble and calc-silicate rock. They are commonly intensely deformed, and primary contacts rare. In some regions mafic intrusive rocks occupy 85% of the rock volume. They are fine and medium grained, with green mafic phenocrysts and white feldspar phenocrysts. They are typically weakly deformed internally and have foliated margins, but intrusive contacts are also present. Locally they form mappable tectonic lenses.

The grade of metamorphism, high degree of strain, large volumes of intrusive rock and lack of stratigraphic continuity hinder stratigraphic correlation. No fossils have been found in the western part of the pendant. These strata were formerly mapped as Hazelton Group (Carter and Grove, 1972; Grove, 1986), but the range of rock types is also found in the Stuhini Group as well as other Mesozoic units of the Cordillera. Some parts could conceivably be correlative with the Bowser Lake Group, and, in that case, the massive sulphide deposits located at the contact between Bowser Lake Group and underlying volcanics to the east may be repeated in the western part of the pendant. U-Pb geochronology currently in progress may shed some light on the age and correlation of these strata.



Figure 8. *Gneissic mafic intrusive complex, east of Mount Tournay.*

Gabbroic/dioritic intrusive complex

In the central part of the western complex is a belt of gabbroic or dioritic rocks about 800 m wide. It is bound on the west by ultramafic rocks and on the east by the unit described above. It is composed of blocky weathering metamorphosed mafic to intermediate intrusive rocks which weather to a variety of grey and green colours. They are fine to coarse grained and structures include massive, gneissic layering, and penetrative to mylonitic foliation with a moderate lineation (Fig. 8). Discrete, continuous thin shear zones are present within some weakly deformed intrusive rocks. Zircons from a leucocratic variety of this zone yielded a Devonian-Mississippian U-Pb age (364 ± 4 Ma; Alldrick et al., 1996).

Ultramafic rock

Serpentinized ultramafic rock occurs in a north-trending belt 20 to 50 m wide on the west side of the mafic intrusive complex. They are rusty/orange, pink/orange, brown, dun brown, light and dark green weathering, blocky outcrops along a pronounced linear depression. Massive, brecciated, and layered varieties occur at most localities. Layered and massive ultramafic rock form ultramafic fault breccia at most



Figure 9. *View north of ultramafic fault breccia, west of Mount Clashmore.*



Figure 10. View northeast to gabbroic dykes; south of Sylvester Bay.



Figure 12. Volcanic- and granite-cobble conglomerate (Tertiary) on northern Mount Newport.

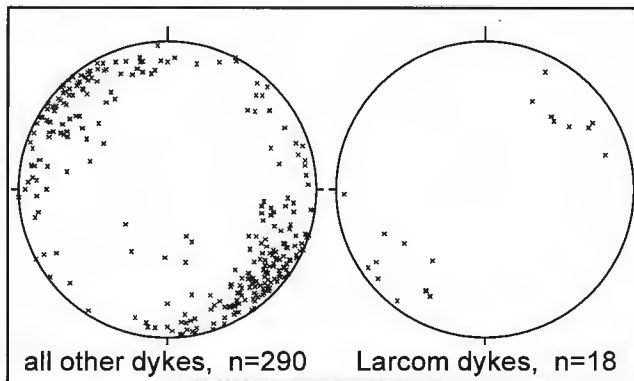


Figure 11. Lower hemisphere projections of poles to dykes for the Larcom dyke swarm, and all other dykes.

localities (Fig. 9). Layering, defined by carbonate, magnetite, and grain size is assumed to be tectonic. It is composed of antigorite, talc, magnetite, and carbonate. Ultramafic rock also occurs locally as tectonic slivers several metres wide in the western part of the mafic intrusive complex.

Tertiary plutonic rock

Tertiary plutonic rocks occupy more than half of the study area, and bound the Anyox pendant on its north, east, and south sides. They include large homogeneous plutonic masses, and dykes which cut most older units.

Hyder pluton

Granitoid 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 to 15% fresh biotite and/or hornblende. Garnet, and locally muscovite, occur in mafic-poor varieties. Texture varies from equigranular to K-feldspar megacrystic, and the structure is

massive except for rare gneissic layering in the south. Zenoliths of more mafic granitoid rocks are uncommon, but in western Alice Arm they form 10 to 20% of the rock. Zenoliths of metamorphic rock are rare.

The granite cuts all map units with the exception of the dykes listed below, and Tertiary stratified rocks. Preliminary U-Pb ages on zircon from granite on the east shore of Observatory Inlet (V. McNicoll, pers. comm., 1996) confirm the Tertiary age reported by Carter (1981) based on the K-Ar method, but indicate a wider range of ages.

Dykes

The predominant dyke rock is gabbro, but granite, lamprophyre, rhyolite and dacite porphyries, and aplitic and pegmatitic dykes are also present. A geographically restricted swarm of distinctive plagioclase porphyritic dykes, called the Larcom dyke swarm, occurs in the northern part of the study area.

Gabbroic dykes

Gabbroic dykes are ubiquitous throughout the area. They are dark grey, green, and brown weathering, aphanitic to coarse grained, equigranular and porphyritic, and massive. They commonly dip steeply to the northwest or southeast (Fig. 10, 11), and are typically 10 cm to several metres wide, although they range to about 10 m wide.

Larcom dyke swarm

Quartz monzodiorite or quartz diorite dykes 50 cm to several metres wide comprise a distinct northwest-trending swarm from the mouth of Alice Arm across northern Larcom Island and to the west side of Observatory Inlet. The swarm is herein informally named the Larcom dyke swarm. They are massive, cream to white weathering, and have a light grey fresh surface. They are composed of zoned plagioclase phenocrysts,

fresh hornblende to 1 cm long, and fresh biotite books to 5 mm across, in a very fine grained groundmass of quartz and feldspar.

Crosscutting relationships indicate that the dykes are Tertiary, and that gabbroic dykes are younger than the Larcom dyke swarm. The Larcom dyke swarm has similar orientation to the Portland Canal dyke swarm farther north, which is 50 Ma (Green et al., 1995).

Tertiary stratified rocks

Dark, blocky weathering, massive volcanic flows, breccia, and cobble conglomerate of granite and volcanic clasts occur on the northern ridge of Mount Newport (Fig. 2, 12). They cap the ridge as a west-dipping unit more than 500 m thick. They were examined briefly in two locations and require further study. Based on the lack of tectonic fabric and

metamorphism they are assumed to be Tertiary. They were formerly mapped as Hazelton Group (Carter and Grove, 1972; Grove, 1986).

STRUCTURE

Bowser Lake Group

Turbidites in the eastern two-thirds of the pendant and in east Alice Arm form megascopic northwest- and northeast-trending, upright to overturned (to the east) and gently plunging folds. Fold hinges are rarely evident on shoreline exposure, which accounts for most of the exposure in the eastern half of the pendant. The abundance of sedimentary structures, however, can be used to determine younging direction, and locate fold hinges. Folds are well exposed on bluffs above Anyox, and in steep creek exposures in Tauw and Bonanza

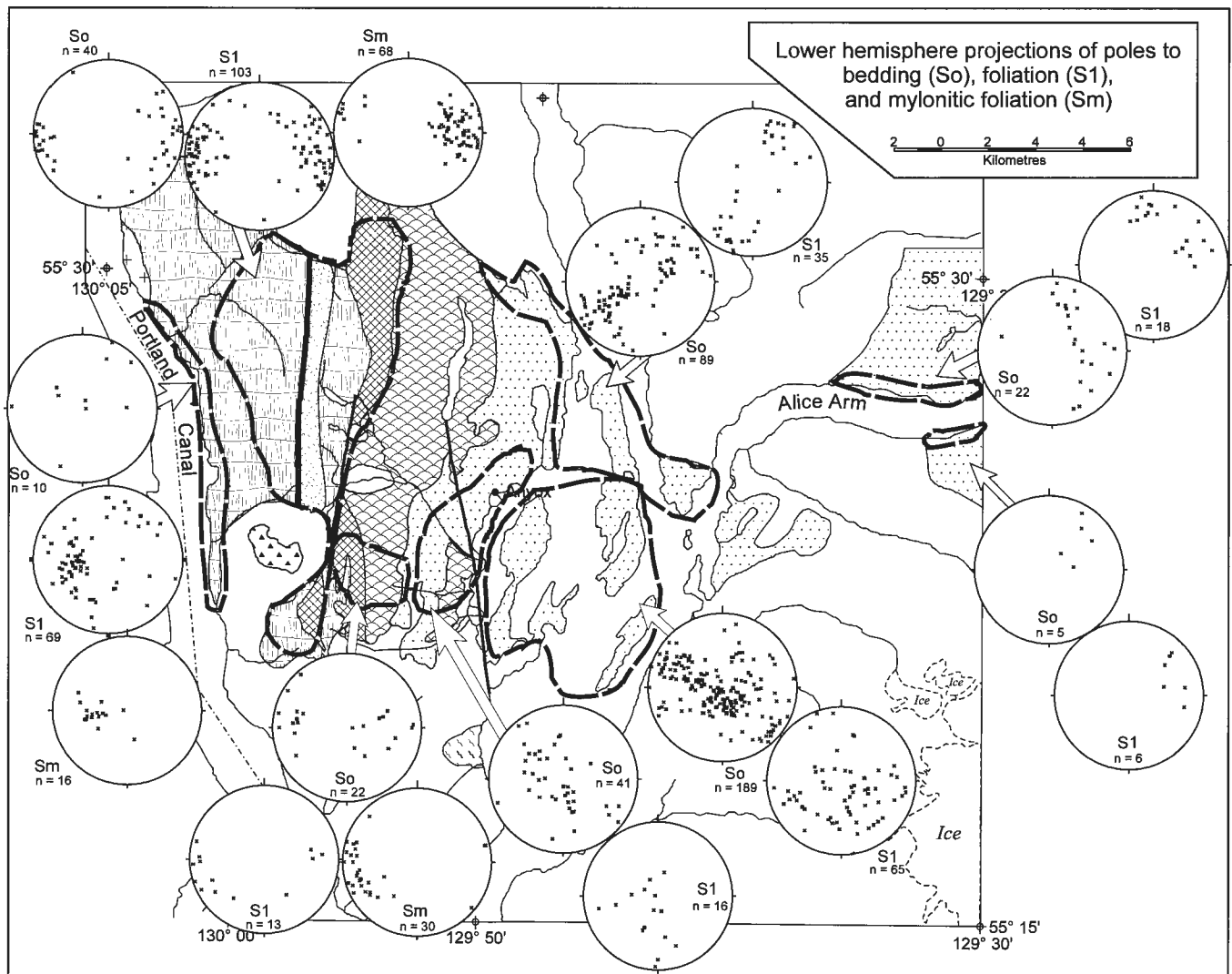


Figure 13. Lower hemisphere projections of lineations, and poles to bedding, foliation, and mylonitic foliation in structural domains of the Anyox pendant.

creeks, where they are commonly overturned to the east. They are generally tens to hundreds of metres in wavelength. The eastern half of the pendant can be divided into domains of broadly similar orientation of folds (Fig. 13). In the north half of the Bowser Lake Group, folds trend northwest and in the south they trend northeast. Fold interference is evident in both domains and is the cause of diffuse great circles of poles to bedding on Figure 13. Folds and foliation are transposed into parallelism with intrusive contacts of Tertiary granite within 100 m of the contact in most places.

Penetrative fabric defined by biotite and locally muscovite is common in pelitic rocks but sporadic in sandstone. It is locally parallel with the axial surface of defined folds, and is also folded. It is overprinted by random biotite, andalusite, and cordierite, and commonly flattened around these porphyroblasts.

Hazelton Group volcanic rocks

There are no stratigraphic marker horizons within the volcanics, and bedding is rarely present, so folds are rarely discernable in outcrop. Large scale structures are only recognized from the map pattern. For example, the region of volcanics near the mouth of Tauw Creek is an anticline with volcanics in the core. Fabrics in the unit range from massive to penetrative. Spectacular shear zones occur in the west, particularly at its western contact at the head of Tauw Creek. Planar fabrics are steeply west or east dipping, and lineations are down-dip (Fig. 13).

Sheared granitoid

The sheared granitoid unit has a range of fabrics from random to strongly foliated and lineated (Fig. 6, 7). Cataclasite with random clasts of feldspar, cataclasite with a preferred orientation of clasts, mylonites with "c-s" structures and shear bands, and ultramylonite occur throughout the width of the belt. The planar fabric is mainly steeply east-dipping on ridges at the head of Tauw Creek, and steeply to moderately west-dipping east of Mount Clashmore (Fig. 13). All lineations are down-dip. Preliminary interpretation of sense of shear indicators observed in the field and in thin section suggest that displacement on the shear zone was west-side-up.

Western complex of metasediments, metavolcanics, intrusive rocks, and Mafic Intrusive Complex

Fabrics in the western third of the pendant range from random to strongly planar and linear. Shear zones from several centimetres to tens of metres wide are present in the mafic intrusive complex. Quartz is sparse, so quartz ribbons which are common in sheared granitoid are absent in these rocks. In the metasedimentary/metavolcanic rocks strain is also localized on discrete high strain zones, leaving parts with well preserved primary textures. The contacts of siliceous siltstone or tuff with gabbroic rocks are strained in most places, but locally intrusive. High strain zones commonly bound and

transect large masses of gabbro. Ultramafic rocks are layered, and fault breccia made of clasts of layered ultramafic is present in most exposures.

In the intrusive complex and eastern part of the metasediment/metavolcanic unit, planar fabrics are steep east or west dipping, and lineations are down-dip. The sense of shear in a 20 m wide shear zone in the intrusive complex northwest of Mount Clashmore is consistent with that in the sheared granitoid. Planar fabrics in the domain on the east side of Portland Canal commonly dip east, in contrast to those around Mount Clashmore.

METAMORPHISM

From field examination, andalusite, biotite, muscovite, and cordierite are common in the more pelitic metasedimentary rocks of the Bowser Lake Group, particularly, but not exclusively, within a few kilometres of the intrusive contact with Tertiary granitoid rocks. Biotite is ubiquitous in pelitic and semipelitic rocks throughout the pendant, but pelitic rocks are rare in the western half of the pendant. Garnet, diopside, and tremolite were noted at two localities in the western pendant, but in general, calc-silicate rocks are rare. Hornblende, actinolite, and chlorite are common in mafic rocks in the western half of the pendant.

The grade of metamorphism in the western part of the pendant is upper greenschist to lower amphibolite facies. The eastern half was probably metamorphosed to greenschist facies prior to intrusion of Tertiary granite. From its random orientation and tendency to be more common closer to contact with Hyder pluton, we consider andalusite to be part of the contact metamorphism related to intrusion of the Hyder Pluton and therefore to be Tertiary in age. This is contrary to Grove's (1986) interpretation that andalusite is a result of pre-Tertiary regional metamorphism.

DISCUSSION AND CONCLUSIONS

Strata in the Anyox pendant include an intriguing range of lithologies. Their petrogenesis and structural history are the subject of ongoing studies. Turbidites in the east are correlated with the Bowser Lake Group. Underlying volcanic rocks are tentatively correlated with the Hazelton Group. Previous workers have determined that the volcanics have geochemical affinities of tholeiitic mid-ocean ridge basalts and infer a back-arc or marginal basin setting (Sharp, 1980; Smith, 1993; Macdonald, 1995). A possibly coeval pillowed volcanic succession farther north is the Eskay Creek facies of the Salmon River Formation, which has island-arc geochemical affinities (Anderson, 1993). The volcanics are in fault contact on the west with a granitoid shear zone. Preliminary interpretation of structures suggests west-side-up displacement. It is possible that the shear zone is a mid-crustal expression of the Skeena Fold Belt to the east (Evenchick, 1991), but the timing of deformation is unknown. All rocks from this zone to the

west include cataclastic and mylonitic high strain zones, and it is unlikely that folds shown by Grove (1986) in the western part of the pendant are accurate depictions of the structural geometry. The region includes a cataclastic zone mapped by Grove (1986), although that zone does not correspond to a specific feature noted in this study. Grove (1986) also mapped a cataclastic zone in the Georgie River pendant, due north and along trend of the highly strained western third of the pendant, which we speculate may be an extension of one of the Anyox pendant shear zones. The high degree of strain, metamorphism, and volume of intrusive rocks in the western third of the pendant make correlation of the metavolcanic and meta-sedimentary rocks challenging.

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REFERENCES

- Alldrick, D.J.**
1986: Stratigraphy and structure in the Anyox area (103P/5); in *Geological Fieldwork 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1, p. 211-216.
- Alldrick, D.J., Mawani, Z.M.S., Mortensen, J.K., and Childe, F.**
1996: Mineral deposit studies in the Stewart District (NTS 103O/P and 104A/B); in *Exploration in British Columbia*; British Columbia Ministry of Energy, Mines and Petroleum Resources, p. 89-109.
- Anderson, R.G.**
1993: A Mesozoic stratigraphic and plutonic framework for northwestern Stikinia (Iskut River area), northwestern British Columbia, Canada; in *Mesozoic Paleogeography of the Western United States-II*, (ed.) G. Dunne and K. McDougall; Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 71, p. 477-494.
- Carter, N.C.**
1981: Porphyry copper and molybdenum deposits of west-central British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 64, 150 p.
- Carter, N.C. and Grove, E.W. (comp.)**
1972: Geological compilation map of the Stewart, Anyox, Alice Arm, and Terrace areas; British Columbia Department of Mines and Petroleum Resources, Preliminary Map No. 8.
- Evenchick, C.A.**
1991: Geometry, evolution, and tectonic framework of the Skeena Fold Belt, north-central British Columbia; *Tectonics*, v. 10, p. 527-546.
1996a: Geology, Cranberry River, British Columbia (103P/10); *Geological Survey of Canada*, Open File 3224, scale 1:50 000.
1996b: Geology, Brown Bear Lake, British Columbia (103P/15); *Geological Survey of Canada*, Open File 3225, scale 1:50 000.
1996c: Geology, Alice Arm, British Columbia (103P/6); *Geological Survey of Canada*, Open File 3272, scale 1:50 000.
- Evenchick, C.A. and Mustard, P.S.**
1996: Bedrock geology of north-central and west-central Nass River map area, British Columbia; in *Current Research 1996-A*; *Geological Survey of Canada*, p. 45-55.
- Evenchick, C.A., Alldrick, D.J., Currie, L.D., Haggart, J.W., McCuaig, S., McNicoll, V., and Woodsworth, G.J.**
1997: Status of research in the Nass River multidisciplinary geoscience project, British Columbia; in *Current Research 1997-A*; *Geological Survey of Canada*.
- Green, D., Greig, C.J., and Friedman, R.M.**
1995: Portland Canal dyke swarm, Stewart area, northwestern British Columbia: geological setting, geochronology, and thermal modelling; in *Current Research 1995-E*; *Geological Survey of Canada*, p. 47-57.
- Grove, E.W.**
1986: Geology and mineral deposits of the Unuk River-Salmon River-Anyox Area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 63.
- Hanson, G.**
1935: Portland Canal area, British Columbia; *Geological Survey of Canada*, Memoir 175.
- Macdonald, R.W.J.**
1995: Geology of the Hidden Creek Deposit, Anyox, West-Central British Columbia; MDRU Annual Technical Report, Year 3, VMS Project, p. 5-1 - 5-58.
- McConnell, R.G.**
1913: Portions of Portland Canal and Skeena Mining Division, Skeena District, British Columbia; *Geological Survey of Canada*, Memoir 32.
- Sharp, R.J.**
1980: The geology, geochemistry, and sulfur isotopes of the Anyox massive sulfide deposits; M.Sc. thesis, University of Alberta, Edmonton, Alberta, 211 p.
- Smith, A.D.**
1993: Geochemistry and tectonic setting of volcanics from the Anyox mining camp, British Columbia; *Canadian Journal of Earth Sciences*, v. 30, p. 48-59.
- Souther, J.G.**
1972: Telegraph Creek map area; *Geological Survey of Canada*, Paper 71-44, 38 p.
- Starkey, J.**
1970: A computer programme to prepare orientation diagrams; in *Experimental and Natural Rock Deformation*, (ed.) P. Paulitsch; Springer, p. 51-74.
1977: The contouring of orientation data represented in spherical projection; *Canadian Journal of Earth Sciences*, v. 14, p. 268-277.
- Steiger, R.H. and Jäger, E.**
1977: Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology; *Earth and Planetary Science Letters*, v. 36, p. 359-362.

Geological Survey of Canada Project 950037

Status of research in the Nass River multidisciplinary geoscience project, British Columbia

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Evenchick, C.A., Alldrick, D.J., Currie, L.D., Haggart, J.W., McCuaig, S., McNicoll, V., and Woodsworth, G.J., 1997: Status of research in the Nass River multidisciplinary geoscience project, British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 21-30.

Abstract: Progress of research in Nass River map area includes completion of bedrock mapping in one quarter of the area and surficial mapping in the west half. Advance on related topics was integrated with bedrock mapping through structural and stratigraphic analysis, radiometric age determination sampling to constrain the timing of events, completion of sampling for a study of Tertiary uplift, and studies of young volcanic rocks.

Résumé : Les progrès accomplis dans la recherche menée dans la région cartographique de la rivière Nass incluent l'achèvement de la cartographie du substratum rocheux dans un quart de la région et la cartographie des dépôts de surface dans la moitié occidentale. Les données recueillies sur des sujets connexes ont été intégrées à la cartographie du substratum rocheux par le biais d'une analyse structurale et stratigraphique, de l'échantillonnage en vue de la datation radiométrique pour établir l'âge des événements, de l'échantillonnage en vue d'une étude du soulèvement au Tertiaire et des études de roches volcaniques récentes.

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INTRODUCTION

The Nass River Project was designed to provide a geoscience database for Nass River map area (Fig. 1). Rationale for the project is the lack of a regional (1:250 000 scale) geological map and corresponding lack of information about the stratigraphy and structure, and their relationships to other elements within the broader framework of Cordilleran geology. The northwest corner of the map area encompasses a region of precious- and base-metal production and exploration, and therefore has been studied at several levels of detail since the early 1900s. The remainder of the area, however, has been mapped little beyond McEvoy's 1893 survey along major waterways (McEvoy, 1894, 1912); consequently the relationship of strata in the northwest to other regions is poorly understood. The northwest corner is also the junction of a seismic experiment (ACCRETE) along the western boundary of Nass River map area with a proposed segment of a Lithoprobe project (SNORCLE) across the northern Canadian Cordillera.

Regional bedrock and surficial mapping surveys are integrated with associated thematic studies, focusing on stratigraphy, sedimentology, structure, geochronology, mineral deposits, geophysics, neotectonics, and environmental factors. An overview of the regional geology and previous work appears in Evenchick and Mustard (1996). This paper is a summary of the status of the components of the program which have begun.

REGIONAL BEDROCK MAPPING/ STRATIGRAPHY/STRUCTURE

The lack of a regional bedrock geology map and corresponding poor understanding of stratigraphy, structure, and metamorphism were the primary impetus for the Nass River Project. The 1:250 000 scale map will be completed by mapping regions at a variety of scales dictated by the geological problems to be resolved. The bulk of stratigraphic, structural, and metamorphic analysis as well as sampling for thematic studies and supporting studies are integral parts of bedrock mapping.

The region can be divided into three geological parts (Fig. 1). Two-thirds of it is underlain by Jurassic clastic rocks of the Bowser basin; they have not been studied prior to the current project. The northwest corner is underlain mainly by Triassic and Jurassic volcanic, plutonic, and sedimentary rocks, some of which have been studied in detail owing to their association with precious and base metal deposits. The clastic and volcanic rocks are intruded by Tertiary granitoid rocks of the Coast Belt, most of which have not been systematically mapped or studied in detail.

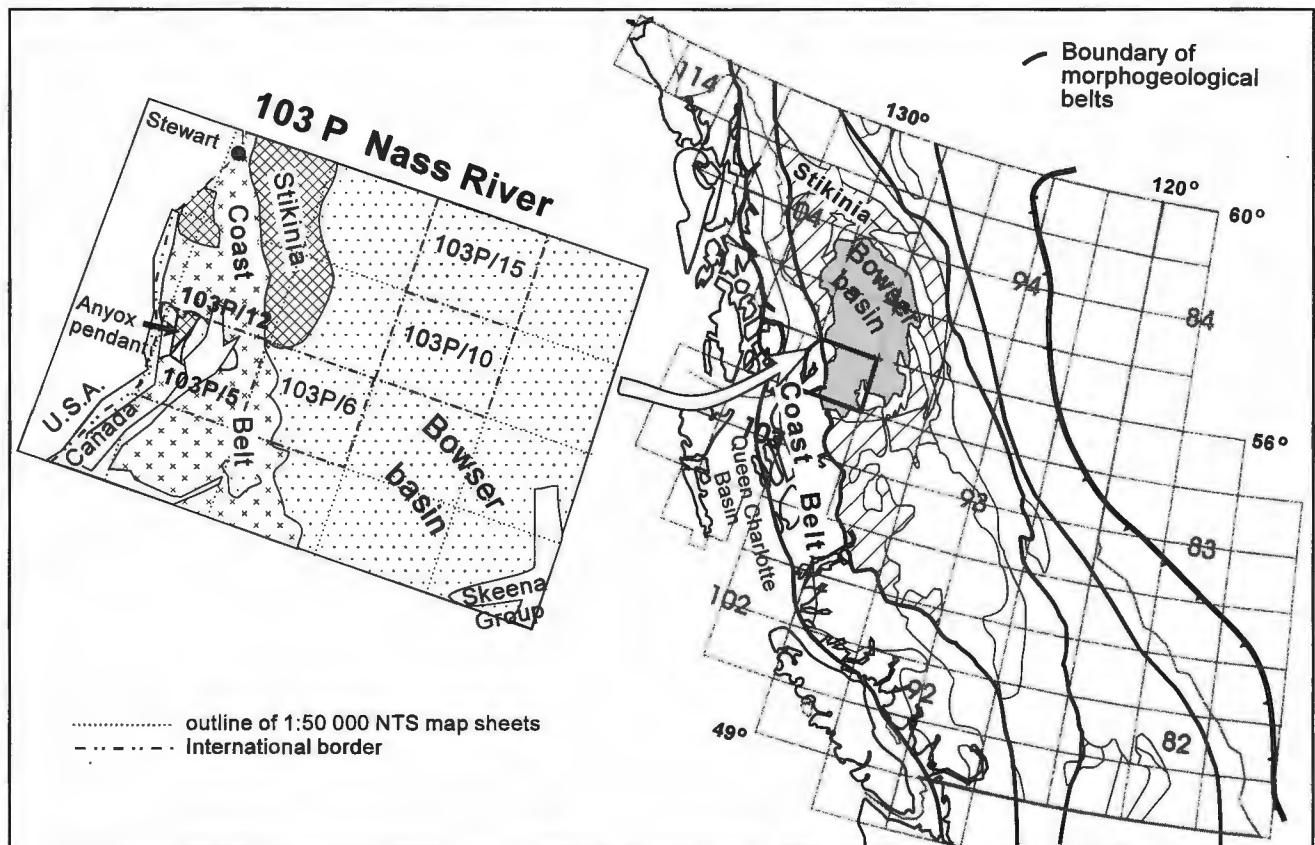


Figure 1. Location of Nass River (103P) map area and its major geological elements. Areas discussed in report are outlined in inset.

Review of 1995 fieldwork

In 1995, the Bowser Lake Group was mapped from the north-central part of the map area west to its contact with Tertiary granite (areas 103P/6, 10, 15; Fig. 1). Turbidites form northwest-trending folds in the north and eastern parts, and northeast-trending folds in the west (Evenchick and Mustard, 1996; Evenchick, 1996a, b, c). Biotite hornfels, some with andalusite, occur within 3 km of an intrusive contact with early Tertiary granite. Late Tertiary or early Quaternary volcanic rock forms erosional remnants hundreds of square metres to several square kilometres in area.

Summary of 1996 fieldwork

Geology of the Anyox pendant and surrounding areas

Mapping was extended west in 1996 to include the Anyox pendant and surrounding areas in Observatory Inlet (103P/5) and southern 103P/12 and 103O/9 map areas (Fig. 1, 2). Details of the geology are reported in Evenchick and Holm (1997). Among the highlights, turbidites in the east half of the pendant are lithologically similar to turbidites of the Bowser Lake Group in Alice Arm area (Evenchick, 1996c). Well preserved ammonites from one locality are Middle Jurassic (Bathonian/Callovian boundary; H.W. Tipper, pers. comm., 1996). Rocks previously mapped as Hazelton Group in the western half of the pendant (Carter and Grove, 1972; Grove, 1986) include three new units not in the Hazelton Group: a granitoid body with cataclastic and mylonitic fabrics, a gabbroic complex with cataclastic and mylonitic fabrics, and a post-tectonic Tertiary(?) volcanic and sedimentary unit which caps one of the highest peaks (Fig. 2). A previously recognized ultramafic occurrence (R.W.J. Macdonald, pers. comm., 1996) is part of a 9 km long belt.

Lithofacies of Hazelton Mountains

Two days of helicopter reconnaissance were spent in the southeast portion of Nass River map area examining the clastic sequences in the Hazelton Mountains (Fig. 3). Three main facies were noted: marine shale, shallow marine, and nonmarine. Rocks in this region are variably metamorphosed but none to more than hornfels grade.

Marine Shale facies

This facies consists predominantly of black to dark grey shale, generally massive and featureless but locally laminated or with thin (1-2 cm) interbeds of siltstone to fine grained sandstone. Locally, discrete sandstone lenses up to several decimetres thick and several tens of metres long contain sparse bivalve debris, including oyster valves up to 6 cm long; these are interpreted as marine channel deposits within the mudstone sequence. Fossils are rare in this facies, although locally fairly abundant: horizontal grazing traces were noted at several localities, and in two places rugose *Buchia* bivalves were collected, many with valves still articulated. Up to several hundred metres of the Marine Shale facies is found at

some localities (Fig. 4). The local presence of marine fauna and substantial thickness of shale found in outcrops of this facies indicate its marine origin.

Shallow Marine facies

Sandstone is the predominant rock type in the Shallow Marine facies. Most outcrops studied consist of light coloured, fine- to coarse-grained, feldspatho-lithic wacke, moderately- to poorly-sorted. The sandstone is typically very thick bedded and planar laminated, but sometimes massive or hummocky cross-stratified (Fig. 5). Locally, thin interbeds of siltstone and mudstone are present. Some sandstone beds show basal scours with pebbles aligned along cross-stratification (Fig. 6). Pebbles appear to be mostly mudstone but several volcanic clasts were noted. Rounded to subangular, elongate, mudstone rip-up clasts up to 15 cm long, were seen here and there. Fine grained intervals locally exhibit water escape features (Fig. 7).

Sandstone sets contain minor shale lenses up to several metres long and several decimetres thick. Narrow (1-2 mm), short (3-4 cm) burrows in the sandstone beds appear randomly distributed; some extend from overlying shale down into the sand layers (Fig. 7), suggesting they are not escape burrows.

Several exposures include thicker mudstone sequences (up to several metres thick), with lenses of fine- to medium-grained sandstone, 1-2 m long and 10-20 cm thick. Some of the sandstone lenses contain shale clasts and several volcanic clasts were noted in float. Locally, gastropod and grazing traces appear on fine grained lamination surfaces.

Other than burrows, no fossils, or wood fragments, were noted in any of the Shallow Marine facies outcrops. The sorting and sedimentary structures in the sandstones, as well as the common grazing traces in the shales, suggest these rocks accumulated in a marine environment, at depths subject to wave activity.

Nonmarine facies

A variety of rock types in association constitutes the Nonmarine facies. Typically, the rocks are massive and featureless, and bedding is vague or indeterminate, although some planar cross-stratification was found in coarser rocks and laminations in finer rocks. Medium- to coarse-grained, angular, poorly sorted, lithic-rich sandstone, locally granular to pebbly, is most common. It is associated in places with abundant plant debris, including fronds, mats, and stem fragments up to 2 cm wide and 10 cm long.

Locally present are mottled argillite and mudstone, containing plant debris, but dominantly delicate leaf and frond material. A few coal seams are present in the fine grained rocks of the Nonmarine facies.

Except for plant material, no fossils were found in the Nonmarine facies. The combination of rock types, lack of marine fauna, abundance of plant fossils, and common occurrence of coaly material indicate a nonmarine depositional environment for this facies.

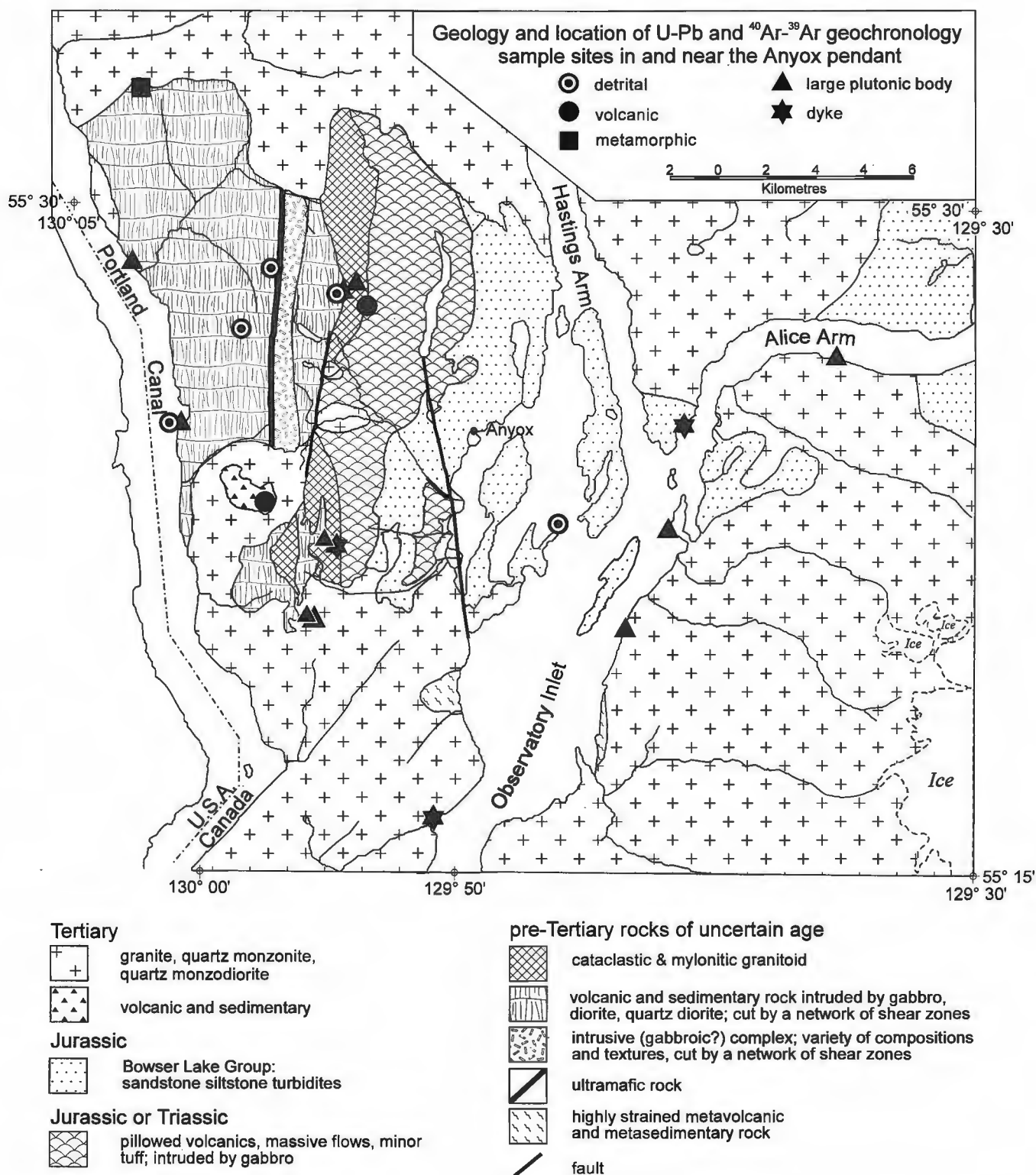


Figure 2. Sketch map of geology in Observatory Inlet (103P/5) and adjacent parts of 103P/12 and 103O/9 map areas, with locations of U-Pb and ^{40}Ar - ^{39}Ar geochronology samples.

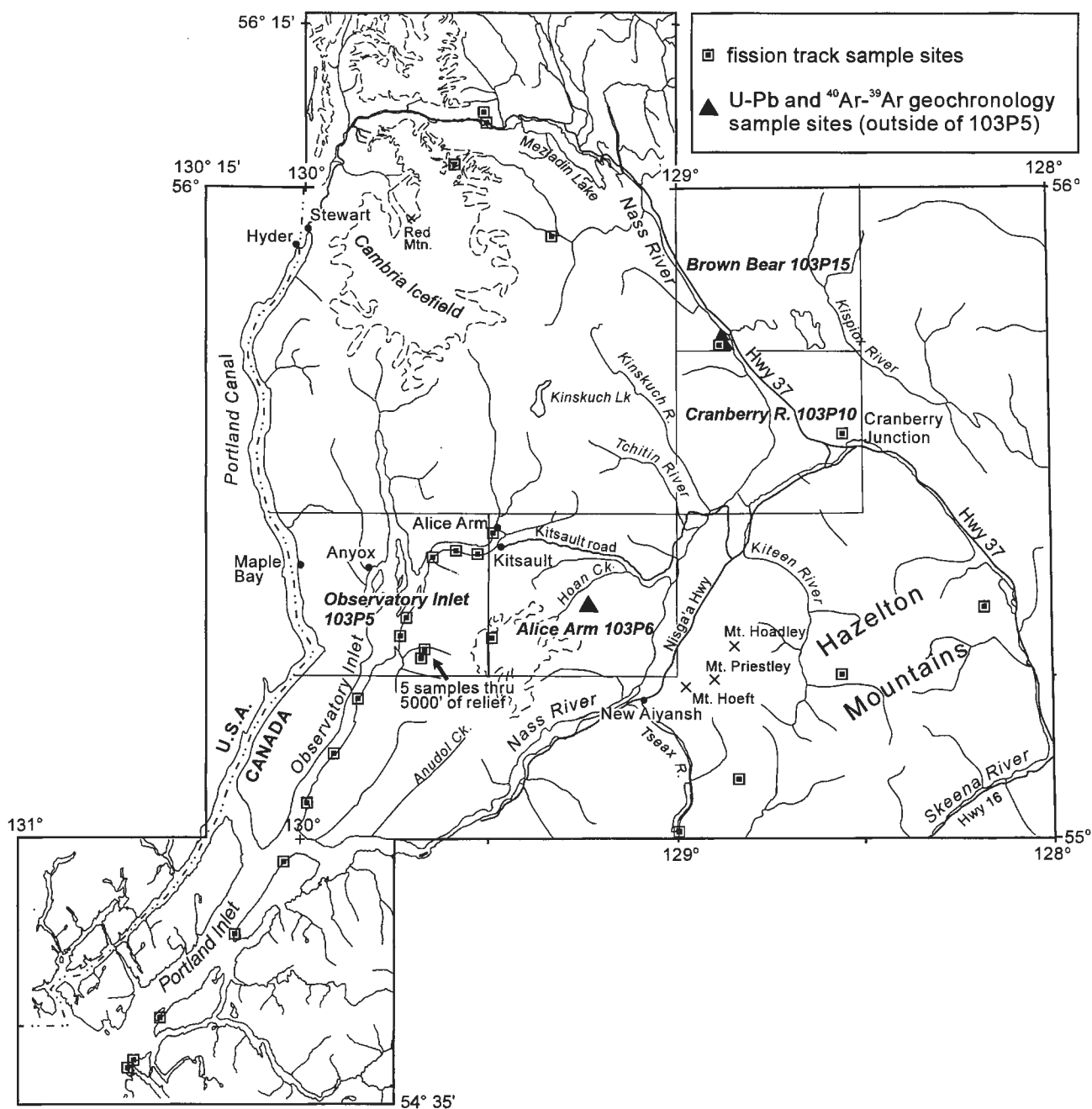


Figure 3. Location of geographic features in Nass River map area and adjacent parts of Prince Rupert and Bowser Lake map areas referred to in text. Location of fission track sample sites are shown by boxes. Location of U-Pb and ^{40}Ar - ^{39}Ar geochronology samples outside of 103P5 are shown by triangles; those within 103P5 are shown on Figure 2.

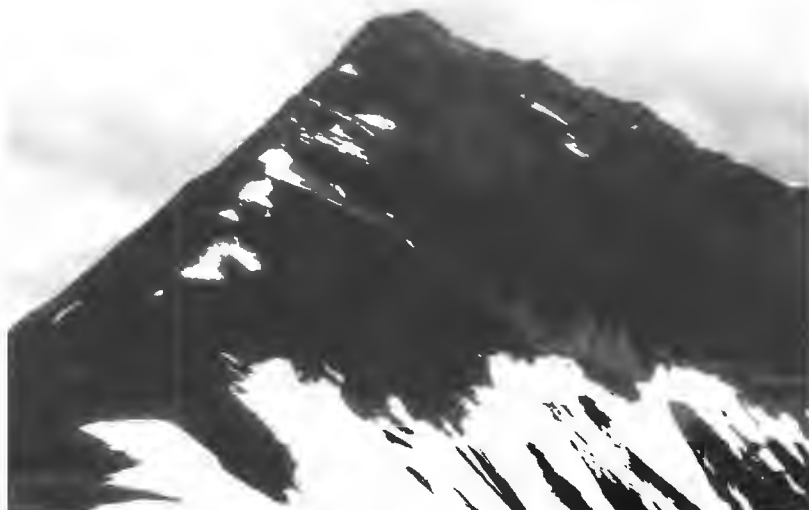


Figure 4.

Thick, ridge top exposure of Marine Shale Facies, looking northwest towards Mount Hoeft. Strata dip away from the camera. Felsic dykes cutting the shale sequence can be seen on the right side of the ridge.

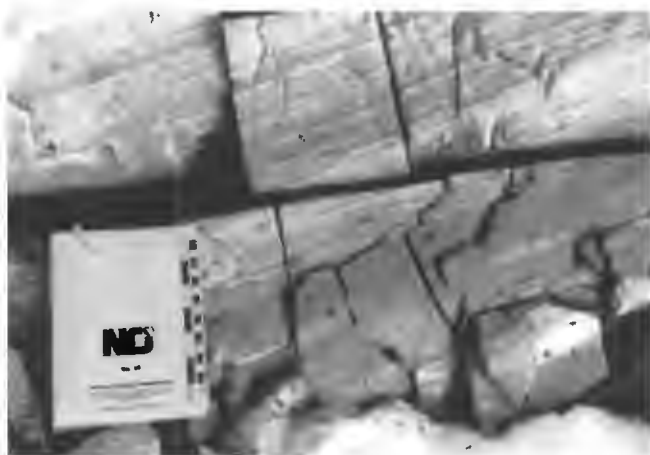


Figure 5. *Planar cross-stratified to hummocky-cross-stratified sandstone of the Shallow Marine Facies, east of Cedar River.*

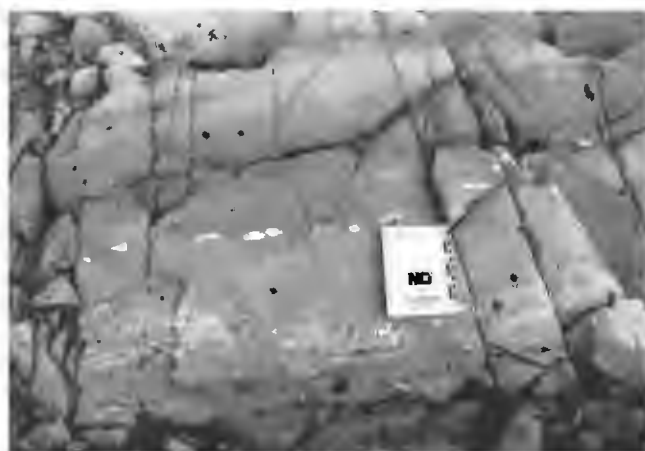


Figure 6. *Massive to planar-stratified sandstone with shale pebbles. Shallow Marine Facies, east of Cedar River.*

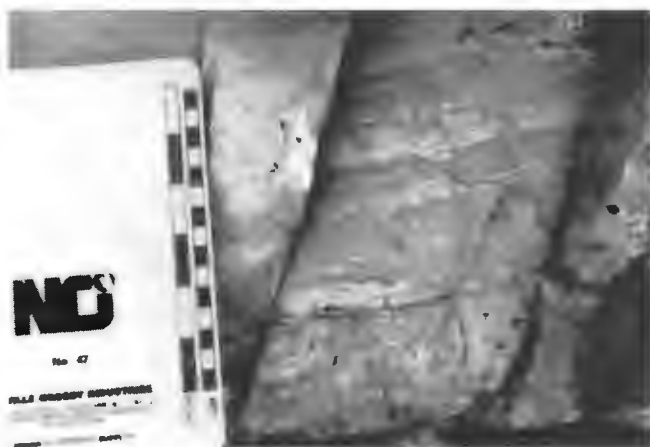


Figure 7. *Alternating beds of fine- to medium-grained sandstone, siltstone and silty shale showing de-watering features and burrow traces. Shallow Marine Facies, east of Cedar River.*

Age of Hazelton Mountains rocks

Most studied exposures appeared barren of marine macrofossils. Oysters and other bivalve debris were noted at one locality northwest of Kitwanga and *Buchia* bivalves were collected from shales of the Marine Shale facies along the ridge southeast of Mount Hoeft. The precise age of these shales is presently indeterminate, although the presence of *Buchia* indicates a general Late Jurassic to Early Cretaceous (Oxfordian to Valanginian) age. These rocks are expected to yield additional fossil collections useful in local correlation of strata.

Discussion

One fossil locality cannot delimit the age of all rocks in the Hazelton Mountains, even though it was found in the middle of the region visited. Rocks of the Marine Shale facies were found in the northwest area visited whereas the Shallow Marine facies was seen in the southern and eastern areas of

the Hazelton Mountains. Outcrops of the Nonmarine Facies are restricted to the eastern and southeastern parts of the study area.

Correlation of strata of the Hazelton Mountains with other regions is problematic due to the present lack of broad fossil control. However, rocks of the Bowser Lake Group described in Cranberry River and Brown Bear map areas to the north (Fig. 3; Evenchick and Mustard, 1996), also contain latest Jurassic and possibly Early Cretaceous *Buchia* bivalves (Haggart, 1996), and are thus correlative in part with localities in the Hazelton Mountains. The turbiditic facies in the more northerly map areas may represent deeper-water basinal equivalents of the nonmarine to shelf deposits present in the Hazelton Mountains. The stratigraphic sequences of the Hazelton Mountains may also provide a key to interpreting the relationship between strata of the Bowser Lake Group and younger Skeena Group, widely exposed south and east of Nass River map area.

METAMORPHISM

A suite of metamorphic rocks from several locations within the Anyox pendant has been collected for petrographic analysis to determine the conditions of metamorphism at various parts of the pendant. They are from metasedimentary rocks of the Bowser Lake Group, and calc-silicate and metavolcanic rocks from the western part of the pendant.

From field examination, andalusite, biotite, muscovite, and probably cordierite are common in the more pelitic metasedimentary rocks of the Bowser Lake Group, particularly, but not exclusively, within a few kilometres of the intrusive contact with Tertiary granitoid rocks. Biotite is ubiquitous in pelitic and semi-pelitic rocks throughout the pendant. Calc-silicate rocks are rare. Garnet, diopside, and tremolite occur at two places in the western pendant. Hornblende, actinolite, and chlorite are common in mafic rocks in the western half of the pendant.

GEOCHRONOLOGY

Samples for U-Pb and ^{40}Ar - ^{39}Ar analyses were collected in 1995 and 1996 to address some of the major geochronology problems. Locations of samples are shown in Figures 2 and 3. The samples which may be dated are listed below with a brief explanation of significance.

Bowser Lake Group

Ages of detrital zircon from sandstone of the Bowser Lake Group are expected to place an upper limit on the age of the sandstone. Radiogenic ages of units in the Bowser Lake Group are necessary to decipher the depositional history of the basin, as fossils are sparse in Nass River area. In addition, zircon ages will bear on the ages of source areas, providing valuable information on regional tectonics.

Volcanic succession below Bowser Lake Group

The age of the volcanic succession west of the Bowser Lake Group is enigmatic (Fig. 2). It has been interpreted as either Triassic, based on lithological and chemical similarity with the Karmutsen Formation (Sharp, 1980) and on Pb isotope ratios (Alldrick, 1986; Alldrick et al., 1996), or as Jurassic, based on lithological correlation with the Hazelton Group (Carter and Grove, 1972; Grove, 1986) and Sm-Nd isotopes and Pb-Pb systematics (Smith, 1993). Felsic tuff from the western part of this belt was sampled in order to constrain the age of this unit.

Stratified rocks in the western complex

Metaclastic rocks were sampled in order to date detrital zircons which will help constrain the age of stratified rocks in the belt and provide information on their tectonic setting during deposition.

Dioritic, quartz dioritic and gabbroic rocks

Rocks with 40 to 80% hornblende and pyroxene(?), minor proportions of quartz, and remainder feldspar occupy a large volume of the western Anyox pendant. In one region they form an entirely gabbroic/dioritic complex (Fig. 2). Elsewhere west of the Bowser Lake Group they form bodies of highly variable size interleaved with all units. Intrusive relationships with volcanic and clastic rocks, including the pillowed succession which is assumed to be Mesozoic, are preserved locally, but most primary features and relationships in the western pendant are obscured by intense deformation; most contacts are structural. A U-Pb date on a felsic rock from the complex yielded a Devonian age (Alldrick et al., 1996). If this interpretation is correct, then there must be more than one age of intrusion of these rocks.

Age of newly recognized plutonic body and timing of deformation and metamorphism

The sheared granitoid, a newly recognized plutonic body, was sampled in order to constrain the age of intrusion as well as the timing of deformation in the highly strained western part of the Anyox pendant. A deformed gabbroic dyke which cuts the sheared granitoid may further constrain the timing of deformation. Samples of amphibolite and calc-silicate gneiss were collected in an attempt to constrain the timing of metamorphism of rocks in the western complex.

Tertiary rocks

Undeformed granite was sampled to further characterize Tertiary plutonism in the region. Preliminary U-Pb data from samples collected in 1995 from the east side of Observatory Inlet confirm the Tertiary age determined by Carter (1981; K-Ar dates), but a greater range in ages is apparent.

Two lithologically distinct dyke swarms differ in orientation (see Evenchick and Holm, 1997). The Larcom dyke swarm is a northwest-trending set of quartz monzonite to quartz diorite dykes which accommodated northeast extension at the south end of Hastings Arm and mouth of Alice Arm. Gabbroic dykes are ubiquitous throughout the Observatory Inlet map area (103P/5). They have a variety of orientations, but northeast strike and steep dip is the most common; they accommodated a minimum of 5-10% northwest extension. Ages of the dyke swarms will help characterize Tertiary plutonism, and because the Larcom dyke swarm is intruded by gabbroic dykes, their ages may date a change in Tertiary tectonics expressed as a change from northeast extension to northwest extension.

Undeformed volcanic and sedimentary rock forms a unit at least 500 m thick which caps the northern peak of Mount Newport, one of the higher peaks in the area. Tertiary volcanic and sedimentary rocks are rare in the Coast Belt, but hold key information on the Tertiary evolution of the northern Cordillera.

Volcanic rock in Hoan Creek in central Alice Arm area (103P/5; Fig. 3) was described briefly by Evenchick and Mustard (1996); its distribution is shown in Evenchick (1996c). It was assumed to be either late Tertiary or Quaternary. It was dated at $175\,000 \pm 50\,000$ years old using the ^{40}Ar - ^{39}Ar method at the Geological Survey of Canada Geochronology Laboratory (V. McNicoll, unpub. data, 1996).

TERTIARY UPLIFT AND DENUDATION – NEOTECTONICS

The role of tectonics in the formation of the spectacular topography of the Coast Mountains in the Nass River map area is only partly understood. On the basis of thermal modelling and fission track ages Parrish (1983) concluded that the Coast Mountains south of the Nass River (between 52°N and 54°45'N) experienced uplift rates of 0.1 to 0.2 km/Ma from 25 to 15 Ma, and slightly faster uplift rates of 0.4 km/Ma in the late Miocene. This interpretation is supported by track length analyses of apatite fission tracks in samples from the Coast Mountains about 350 km southeast of the Nass River map area, which indicate that rapid cooling occurred at about 14 Ma (O'Sullivan and Parrish, 1995). The location of this part of the Coast Mountains, inboard of a transform boundary, makes the cause of rapid Late Miocene cooling enigmatic. Parrish (1983) noted that it is not clear whether thermal expansion due to the passage of the "Anahim hot spot" could induce the observed longitudinal uplift. An alternate explanation for the rapid Middle Miocene cooling, proposed by Rohr and Currie (1996), requires the initiation of an east-dipping, low-angle normal fault rooted beneath the Coast Mountains to generate an increase in uplift and denudation rates, and therefore cooling rates, east of the Queen Charlotte Basin (Fig. 1).

Nass River map area lies about 100 km north of the northernmost samples discussed by Parrish (1983). Samples have been collected from the Nass River map area and farther southwest for apatite, and in some cases zircon, fission track analyses to more closely constrain the cooling, denudation and uplift histories of the Coast Mountains and regions to the east (Fig. 3). Preliminary results from samples from Observatory Inlet suggest that the Coast Mountains near about 55°N also cooled through about 100°C (the closure temperature for the retention of fission tracks in apatite) during Miocene time.

LATE TERTIARY TO RECENT VOLCANIC ROCKS

The youngest strata in the Nass River map area are late Tertiary to Recent volcanic rocks. These may be divided into two broad units based on whether they have been glaciated or not. The sole known postglacial example, the Aiyansh lava flow, is well known, but little attention has been paid to the preglacial flows. Work by Woodsworth will concentrate on characterizing the preglacial volcanic rocks through petrological, geochronological, geochemical, and paleomagnetic studies. Preliminary fieldwork in 1995 concentrated on rocks near Cranberry Junction and Mt. Hoadley (Fig. 3).

Volcanic rocks near Cranberry Junction are basalt or andesite lava flows (for map see Evenchick, 1996a). Commonly the flow rocks are vesicular and have conspicuous columnar jointing. Maximum thickness of the unit is about 50 m; only a single flow appears to be present. These rocks form cliffy outcrops in an area of otherwise poor exposure. They are locally glacially grooved and covered with glacial deposits. The flows appear to be erosional remnants of a much more extensive unit that rests on a paleovalley surface about 150 m above the present level of the Nass River.

Basalt to andesite flows are present as erosional remnants about 3 km southeast of Mt. Hoadley in a large, east-flowing tributary of the Kiteen River. The flows are about 60 m thick, have conspicuous columnar jointing, and are lithologically very similar to the Cranberry Junction flows. The upper surface, locally covered with glacial till, is at an elevation of about 1000 m, between 30 and 250 m above the current valley bottom. The upper surface slopes gently east, suggesting that the source of the flows was farther up the valley and that the valley was extensively deepened after volcanism. Poorly consolidated vent breccia was found as remnants on the valley walls about 3 km northeast of Mt. Priestly, strongly suggesting this area as a source for the flows.

The Mt. Hoadley flows rest on about 30 m of unconsolidated sediments. These consist of a mixture of grey clay containing rounded pebbles to boulders of sedimentary and granitic rock. The sediments show no sorting or stratification and are interpreted as glacial till. If so, then the Mt. Hoadley flows are interglacial and may have acted as a caprock that preserved the earlier till from erosion.

QUATERNARY GEOLOGY

One season of fieldwork is completed for the Quaternary geology component of the Nass River Project. Details are in McCuaig (1997), and highlights are outlined here. Till, clay, and radiocarbon samples have yet to be processed, but some preliminary interpretations can be made from existing data.

Striation evidence clearly shows that ice flowed southwest during the last glacial maximum, overtopping the local mountains. The Coast Mountains were therefore not an ice source area during the last regional (Cordilleran?) glaciation, because the ice divide was northeast of the study area. A compact, blue-grey till deposited during this event commonly underlies glaciofluvial deposits on valley floors, whereas colluvial deposits and bedrock dominate walls and mountain tops. Clay deposits that contain no macrofossils are pervasive in the Nass Valley; their origin is as yet unknown.

Most tills in the region are very compact, blue-grey diamictites that have a clay matrix. Angular clasts of siltstone and sandstone from the Bowser Lake Group make up the major lithological component of till throughout the map area, including regions where the dominant bedrock type is granite. Neoglacial tills skirting modern ice caps are an exception, being dominated by local bedrock types. The lithological evidence confirms the major southwest ice flow trend identified from striation evidence, as the Bowser Lake Group occurs in the east and northeast parts of the study area.

During glaciation, ice thinned and flow became confined to fiords and major valleys. There is no evidence of ice stagnation in the map area, so deglaciation must have proceeded by complex frontal retreat and downwasting. Deglaciation was not complete, however, as ice retreated up fiords and valleys to areas where alpine ice caps remain. Glaciofluvial gravels and sands of varying thickness overlying till and bedrock are the most common deposits representing the deglacial stage. Glaciolacustrine sediments are rare. Extensive clay deposits in the Nass Valley could be either lacustrine or marine, but because they rest on till, are also deglacial phase deposits.

After deglaciation, colluvial and alluvial processes were extremely active and continue today, forming alluvial fans, alluvial plains, colluvial fans, colluvial aprons, and other colluvial deposits. Alpine glaciation is still evident in much of the area, as exemplified by the Cambria Ice Field. Modern glaciers appear to be undergoing rapid retreat, as many ice fronts have retreated from positions held on the 1982 air photographs.

In summary, there is extensive evidence in the Nass River region of one major glaciation with two distinct ice flow histories, one representing the glacial maximum and one representing deglaciation.

MINERAL DEPOSIT STUDIES

The region between the Bowser basin and the Coast Belt (Fig. 1) is a mineral-rich belt of Triassic and Jurassic volcanic rocks. Geological mapping and mineral deposit studies have been completed in the belt northwest of Stewart. The Cambria project was initiated by the British Columbia Geological Survey in 1995 to extend these studies to the remainder of the belt which lies east and south of Stewart. Study and integration of Landsat TM imagery, enhanced aeromagnetic survey data, and regional stream sediment (RGS) sampling results are important components of this program.

The study area covers 2000 km², centred on the Cambria Icefield (Fig. 2). It includes the town of Stewart, British Columbia, the village of Hyder, Alaska, and the sites of the former mining communities of Anyox, Alice Arm, Kitsault, and Maple Bay. The first two producing mines in the Stewart district (Outsider, Red Cliff) lie within the area as well as the former producing mines at Anyox, Dolly Varden, Torbitt, Kitsault, Dunwell, and Georgie River, and important new discoveries at Red Mountain, Willoughby Creek, and Clone. The project area contains 414 documented metallic mineral occurrences (5% of British Columbia's total mineral inventory). Many recent discoveries have yet to be entered into the provincial database, including ten new occurrences reported by Teuton Resources Corporation and Minvita Enterprises Limited and dozens located by Lac Minerals Limited.

Work during a nine-week field program in 1996 focused on camp-scale mapping of three selected areas: the eastern Anyox pendant, the Willoughby Creek area, and the Banded Mountain stock. Deposit examination, sampling and documentation were conducted at six showings within the Anyox pendant and at the Maple Bay, Willoughby Creek, Banded Mountain, Mount Carr, and Clone properties.

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REFERENCES

- Alldrick, D.J.**
1986: Stratigraphy and structure in the Anyox area (103P/5); in *Geological Fieldwork 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1, p. 211-216.
- Alldrick, D.J., Mawani, Z.M.S., Mortensen, J.K., and Childe, F.**
1996: Mineral deposit studies in the Stewart District (NTS 1030/P and 104A/B); in *Exploration in British Columbia*; British Columbia Ministry of Energy, Mines and Petroleum Resources, p. 89-109.
- Carter, N.C.**
1981: Porphyry copper and molybdenum deposits of west-central British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 64, 150 p.

Carter, N.C. and Grove, E.W. (comp.)

- 1972: Geological compilation map of the Stewart, Anyox, Alice Arm, and Terrace areas; British Columbia Department of Mines and Petroleum Resources, Preliminary Map No. 8.

Evenchick, C.A.

- 1996a: Geology, Cranberry River, British Columbia (103P/10); Geological Survey of Canada, Open File 3224, scale 1:50 000.
1996b: Geology, Brown Bear Lake, British Columbia (103P/15); Geological Survey of Canada, Open File 3225, scale 1:50 000.
1996c: Geology, Alice Arm, British Columbia (103P/6); Geological Survey of Canada, Open File 3272, scale 1:50 000.

Evenchick, C.A. and Holm, K.

- 1997: Bedrock geology of the Anyox Pendant and surrounding areas, Observatory Inlet (103P/5) and parts of Hastings Arm (103P/12) and 103O/9 map areas; in *Current Research 1997-A*; Geological Survey of Canada.

Evenchick, C.A. and Mustard, P.S.

- 1996: Bedrock geology of north-central and west-central Nass River map area, British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 45-55.

Grove, E.W.

- 1986: Geology and mineral deposits of the Unuk River-Salmon River-Anyox Area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 63.

Haggart, J.W.

- 1996: Report on Jurassic and ?Cretaceous fossils from Nass River and Bowser Lake map-areas, British Columbia (NTS: 104A and 103P), collected and submitted for identification in 1995 by Carol Evenchick of the Vancouver office of the GSC (22 lots); Geological Survey of Canada, Fossil Report No. JWH-1996-02, 11 p.

McCuaig, S.J.

- 1997: Quaternary geology of the Nass River region, British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.

McEvoy, J.

- 1894: Geological Survey of Canada, Annual Report, v. VI, pt. A, p. 13-16.
1912: Route map of part of Nass River, British Columbia; Geological Survey of Canada, Map 69A.

O'Sullivan, P.B. and Parrish, R.R.

- 1995: The importance of apatite composition and single-grain ages when interpreting fission track data from plutonic rocks: a case study from the Coast Ranges, British Columbia; *Earth and Planetary Science*, v. 132, p. 213-224.

Parrish, R.R.

- 1983: Cenozoic thermal evolution and tectonics of the Coast Mountains of British Columbia 1. Fission track dating, apparent uplift rates, and patterns of uplift; *Tectonics*, v. 2, p. 601-631.

Rohr, K.M.M. and Currie, L.D.

- 1996: The Queen Charlotte Basin and Coast Mountains: a paired belt of subsidence and uplift caused by a low-angle normal fault; Geological Society of America Abstracts with Program, Annual Meeting, Denver, Colorado, v. 28, p. A194

Sharp, R.J.

- 1980: The geology, geochemistry, and sulfur isotopes of the Anyox massive sulfide deposits; M.Sc. thesis, University of Alberta, Edmonton, Alberta, 211 p.

Smith, A.D.

- 1993: Geochemistry and tectonic setting of volcanics from the Anyox mining camp, British Columbia; *Canadian Journal of Earth Sciences*, v. 30, p. 48-59.

Geological Survey of Canada Project 950037

U-Pb ages from the northeastern quadrant of Terrace map area, west-central British Columbia

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Gareau, S.A., Friedman, R.M., Woodsworth, G.J., and Childe, F., 1997: U-Pb ages from the northeastern quadrant of Terrace map area, west-central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 31-40.

Abstract: The study area (103I/9, 10, 15, 16) encompasses the southern tip of Bowser Basin, late Paleozoic to Middle Jurassic Stikine terrane, and the fault-bounded, ductilely deformed and metamorphosed Kitselas-Kitsumkalum block. Volcanic rock from the stratigraphically lowermost unit of Stikine terrane is 285 ± 9 Ma (2 sigma) in age. The Kleanza pluton, which intrudes Stikine terrane, was dated at $200 \pm 13/-3$ Ma.

Kitselas volcanics gave ages of 195.1 ± 2.0 Ma and $193.9 \pm 2.1/-0.6$ Ma. Ductile deformation in Kitselas volcanics postdates, at least in part, an $80.9 \pm 8.4/-0.2$ Ma foliated and lineated dyke cutting the volcanic unit. A $59.6 \pm 0.2/-0.2$ Ma age for the penetratively ductilely deformed North Kitsumkalum pluton which intrudes Kitselas volcanics indicates that deformation, probably related to uplift of the Kitselas-Kitsumkalum block, continued until at least Late Paleocene time. Deformation ceased by $52.6 \pm 1.2/-1.8$ Ma, when the undeformed Carpenter Lake and other plutons of the titanite-bearing suite intruded all units of the map area.

Résumé : La région à l'étude (103I/9, 10, 15, 16) couvre l'extrémité sud du bassin de Bowser, le terrane de Stikine du Paléozoïque tardif-Jurassique moyen et le bloc de Kitselas-Kitsumkalum métamorphisé, limité par des failles et ayant subi une déformation ductile. Les roches volcaniques de l'unité stratigraphiquement la plus basse du terrane de Stikine ont été datées à 285 ± 9 Ma (2 sigma). Le pluton de Kleanza qui recoupe le terrane de Stikine a été daté à $200 \pm 13/-3$ Ma.

Les roches volcaniques de Kitselas ont été datées à $195,1 \pm 2,0$ Ma et à $193,9 \pm 2,1/-0,6$ Ma. La déformation ductile des roches volcaniques de Kitselas est au moins en partie postérieure à un dyke à foliation et à linéations qui recoupe l'unité volcanique. Le pluton de North Kitsumkalum, qui a subi une déformation ductile pénétrative et qui recoupe les roches volcaniques de Kitselas, a été daté à $59,6 \pm 0,2/-0,2$ Ma, ce qui indique que la déformation, probablement liée au soulèvement du bloc de Kitselas-Kitsumkalum, s'est poursuivie au moins jusqu'au Paléocène tardif. La déformation a cessé avant $52,6 \pm 1,2/-1,8$ Ma, lorsque le pluton non déformé de Carpenter Lake et d'autres plutons de la suite titanitifère ont recoupé toutes les unités de la région cartographique.

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INTRODUCTION

The northeastern quadrant of Terrace map area (103I/9, 10, 15, 16) lies immediately east of the boundary between Coast and Intermontane belts (Fig. 1) and encompasses the southern tip of Bowser Basin; late Paleozoic to Middle Jurassic Stikine terrane; and the Kitselas-Kitsumkalum block, an apparently fault-bounded domain composed of rocks which have compositional, metamorphic, and textural characteristics distinct from lithologies of surrounding conventionally defined Stikine terrane and Skeena-Bowser Lake overlap assemblages. Regional mapping in the area was conducted in 1994 and 1996, and geological observations are reported in Gareau et al. (1997). In this paper, we present seven U-Pb ages from samples collected in the area. These data represent only a part of our geochronological study, which is still in progress. The main goal of U-Pb dating is to place age constraints on plutonic suites that were defined in the field based on textural and compositional criteria and to help determine age and affiliation of volcanic suites within the area. An Ar study, only barely begun, will examine cooling patterns across the area, from the boundary between Coast and Intermontane belts, through the Kitselas-Kitsumkalum block into Stikine terrane. This study should improve our understanding of the tectonics of emplacement of the Kitselas-Kitsumkalum block and the nature of the boundary between Coast and Intermontane belts.

GEOLOGICAL SETTING

This section contains a brief description of geological units mapped in the study area and a review of what was known, prior to this study, about the ages of units within the area. The regional geology is discussed in more detail in Gareau et al. (1997). Distribution of units, fossil localities, and locations of U-Pb samples are shown in Figure 1.

Southern Bowser Basin underlies much of the north-western half of the study area and comprises well-bedded sandstone, siltstone, shale, and local chert pebble conglomerate of Early to earliest Late Cretaceous Skeena Group, and three assemblages of Middle Jurassic to mid-Cretaceous Bowser Lake Group: the Ashman Formation, the conglomeratic Trout Creek assemblage, and the upper, marine and nonmarine Thomlinson assemblage (Richards et al., in press). Some lithologies in the northern part of the study area are thought to be transitional between Bowser Lake and Skeena groups (Gareau et al., 1997).

Information on the age of Skeena Group in Terrace east-half is sparse. Bassett (1995) favoured an Early Cenomanian age for the chert pebble conglomerate unit (equivalent to her Rocher Déboulé Formation) based on the stratigraphic position of the unit and on Late Albion to possibly Early Cenomanian pollen assemblages from red siltstones of the type section in the Hazelton map area. Recrystallized belemnoids and compressed belemnoid molds in black shale from the lower part of Skeena Group (Couture Formation of Bassett, 1995) suggest a Hauterivian-Barremian age (J.W. Haggart, unpub. report JWH-1996-01, GSC loc. C-301850).

In Bowser Lake Group, the Thomlinson assemblage is inferred to be Late Oxfordian to at least Early Kimmeridgian in age (Woodsworth et al., 1985, based on unpublished paleontological reports by H.W. Tipper, 1981, GSC loc. C-090693 and J.A. Jeletzky, 1981, GSC loc. C-082679). Marine fossils from the Ashman Formation give Callovian and Early Oxfordian ages (H.W. Tipper, unpub. report, 1981, GSC loc. C-090691 and C-090694; H.W. Tipper, unpub. report, 1985, C-101447 and C-101449; J.W. Haggart, unpub. report JWH-1996-01; and T.P. Poulton, unpub. report J1-TPP-1996, GSC loc. C-301851 and C-301853).

Stikine terrane in the study area comprises Late Triassic to Middle Jurassic Hazelton Group, Late Triassic argillite, Permian limestone, and Late Pennsylvanian or Early Permian volcanic rock. Late Triassic-Early Jurassic plutons of the Kleanza suite intrude Stikine terrane. The Telkwa Formation of Hazelton Group is the most widespread unit of Stikine terrane in the study area. It is exposed on the eastern side of the map area (Fig. 1) and is overlain by the Smithers Formation of inferred Aalenian age (Woodsworth et al., 1985). Fossils from Telkwa Formation are rare in the map area. The Late Sinemurian age estimate for the unit is based on early Late Sinemurian fauna (H.W. Tipper, unpub. report, 1981, GSC loc. C-090695) from material collected near Mount Quinlan (Fig. 1). The presence of blocks of soft-sediment-deformed Late Triassic argillite within the basal member of Telkwa Formation was interpreted as suggesting a Late Triassic (Carnian) age for basal Telkwa Formation (Woodsworth et al., 1985). It is locally underlain by a thin, locally calcareous argillite of Middle to Late Triassic age. In most places, however, Telkwa Formation rests unconformably on Early Permian (Woodsworth et al., 1985 based on an unpublished report by Orchard, 1981) limestone. The lowest exposed unit of Stikine terrane is a heavily altered grey-green volcanic assemblage. No fossils were found in this unit, but U-Pb analysis (Table 1) indicates a Late Pennsylvanian or Early Permian age.

The area between Bowser Basin to the northwest and conventional Stikine terrane to the southeast is underlain by a distinctive tectonic unit, the Kitselas-Kitsumkalum block. The block appears fault-bounded and is differentiated from Bowser Basin and conventional Stikine terrane based on its distinctive combination of lithologies, metamorphic grade, and deformational style. The block comprises three components: the Kitselas volcanics, the North and South Kitsumkalum plutons, and metasedimentary rocks probably correlative with Bowser Lake Group. No fossils were found in the Kitselas volcanics, but U-Pb dating (Table 1) indicates an Early Jurassic age. The predominantly felsic nature of Kitselas volcanics contrasts with mostly intermediate to mafic lithologies of Hazelton Group in the Terrace area. Whereas Bowser Basin and conventional Stikine terrane units have undergone only very low grade regional metamorphism and brittle deformation, Kitselas volcanics are locally metamorphosed to greenschist facies and are strongly ductilely deformed. Intrusive contacts, locally sheared, separate Kitselas volcanics from the Late Paleocene (Table 1) North and South Kitsumkalum plutons (Gareau et al., 1997). Penetrative ductile fabrics in these plutons, which are similar in

nature and orientation to fabrics in the Kitselas volcanics, are interpreted as having formed during or closely following emplacement of the plutons. The North Kitsumkalum pluton is in sharp intrusive contact with a penetratively deformed and metamorphosed assemblage of predominantly sedimentary rocks, probably, but not necessarily, of the Bowser Lake Group. These rocks are interpreted as part of the Kitselas-Kitsumkalum block because fabrics are similar in nature and orientation to fabrics in the rest of the block. The sharp contact between these metasedimentary rocks and cleaved and hornfelsed Bowser Lake lithologies appears to be a fault (Gareau et al., 1997). The cleavage and hornfelsic texture, which gradually disappear away from the Kitselas-Kitsumkalum block, is interpreted as representing a contact aureole to plutonic and associated metamorphic rocks in the block.

Plutons in the Terrace area have been divided into the Kleanza suite, the Kitsumkalum suite, and three suites of undeformed plutons thought to postdate Kitsumkalum plutonism. The Kleanza suite consists of biotite±hornblende quartz diorite to granite and is characteristically altered (orange and green feldspar, chloritization, local sericitization) and fractured, but without planar or linear fabrics. Plutons from this suite intrude conventional Stikine terrane. The suite is interpreted as latest Triassic or earliest Jurassic based on U-Pb data (Table 1) from one pluton from this suite, the Kleanza pluton (Fig. 1). Included in the Kitsumkalum suite are the North and South Kitsumkalum plutons, small bodies which intrude Bowser Lake Group immediately north of the Kitselas-Kitsumkalum block, and plutonic rocks southwest of the Kitsumkalum block which have generally been included in the Coast Plutonic Complex. All these plutonic bodies look similar in the field, but we currently lack age constraints to help us ascertain their magmatic affiliation. Undeformed and discordant Eocene plutons (Table 1) consisting of titanite-bearing biotite±hornblende granodiorite to granite occur throughout the map area and provide a minimum age estimate for metamorphism and ductile deformation in the area. The suite also provides a minimum age for emplacement of units in their current position with respect to each other, because plutons from this suite intrude the components and fabric of the Kitselas-Kitsumkalum block (Hardscrabble pluton, Fig. 1) and intrude the contact between the Kitselas-Kitsumkalum block and surrounding units (Hardscrabble and Carpenter Lake plutons, Fig. 1). Other undeformed and discordant plutons which do not resemble the titanite-bearing suite are divided into two suites: pyroxene-bearing and high level leucocratic. Neither of these suites has been dated, but they are both presumed to be Tertiary in age and younger than the titanite-bearing suite.

U-Pb GEOCHRONOLOGY

New U-Pb geochronological data for seven samples are presented below. This section contains analytical data (Table 1), accompanying concordia plots (Fig. 2) and discussions of U-Pb results including description of physical and geochemical characteristics of zircon populations and strategies used to obtain meaningful results. Complete U-Pb analytical procedures are described in Mortensen et al. (1995).

Paleozoic volcanic rock of Stikine terrane

Collected from a location east of Terrace (Fig. 1), sample GPA-94-118-2 belongs to a suite of volcanic rocks apparently stratigraphically underlying Permian limestone of Stikine terrane. The volcanic suite consists of feldspar-rich intermediate to mafic tuff, breccia, and possibly flows. Ductile fabrics are absent. Chlorite-epidote alteration is widespread. The dated sample is a brown weathering, green and red feldspar porphyry tuff. Despite the mafic look of the sample, quartz and feldspar compose approximately 60% of the sample. Epidote is the most abundant mafic mineral (~25%), chlorite and calcite occur in lesser amounts (each ≤10%). Approximately 3% of the sample consists of anhedral pyrite.

The small quantity of zircon recovered from this sample was clear, colourless, and of good quality, and had shapes which varied from equant multifaceted and stubby prismatic (aspect ratios of 1:2) to elongate prismatic and acicular (aspect ratios >3). Two fractions are concordant at about 291 Ma and 281 Ma, (A and E, respectively) and the third is significantly discordant (C, about 20% discordant), likely due to Pb loss (Fig. 2a). Although fractions A and E are both concordant it is likely that A contains minor inherited zircon and/or E has undergone minor Pb loss. Due to the low U and Pb concentrations in these zircons and the resulting relatively high nonradiogenic to radiogenic Pb ratios of the analyses (Table 1) we cannot unequivocally choose between these options. However, the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of all fractions agree within error, and the weighted mean of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages, 285 ± 9 Ma, is taken as the best estimate for the age of the rock. This age and associated 2σ error envelope overlaps with ellipses of concordant fractions A and E.

A Late Pennsylvanian or Early Permian age fits well with the apparent stratigraphic position of the volcanic unit below Permian limestone within Stikine terrane.

Kleanza pluton

Sample GPA-94-16-4 was collected northeast of Terrace along Highway 16, a few kilometres north of the Zymoetz River (Fig. 1). The sample belongs to Kleanza pluton, a large intrusive body of biotite±hornblende quartz diorite to granite. Planar and linear fabrics are absent. The pluton is heavily fractured and altered (Gareau et al., 1997). East of Terrace, it intrudes Pennsylvanian-Permian volcanic rock, Permian limestone, and Late Triassic to Early Jurassic Telkwa Formation (Fig. 1; Gareau et al., 1997) and is probably in fault contact with Kitselas volcanics. This and other plutons of similar composition, texture, and relationship to Stikine terrane comprise the Kleanza suite. Sample GPA-94-16-4 is composed predominantly of coarse grained (0.5 to 4 mm) quartz (~30%) and feldspar (~60%). Quartz grains are anhedral and show undulose extinction and subgrain formation. Feldspar grains are heavily sericitized and locally broken. Biotite (~5%) and muscovite (trace) are fine grained and generally euhedral. Calcite alteration is also present.

This sample yielded good quality, colourless to pale pink, clear to slightly cloudy zircon. Stubby to moderately elongate (aspect ratio 1.2-2.5) doubly terminated prisms compose most

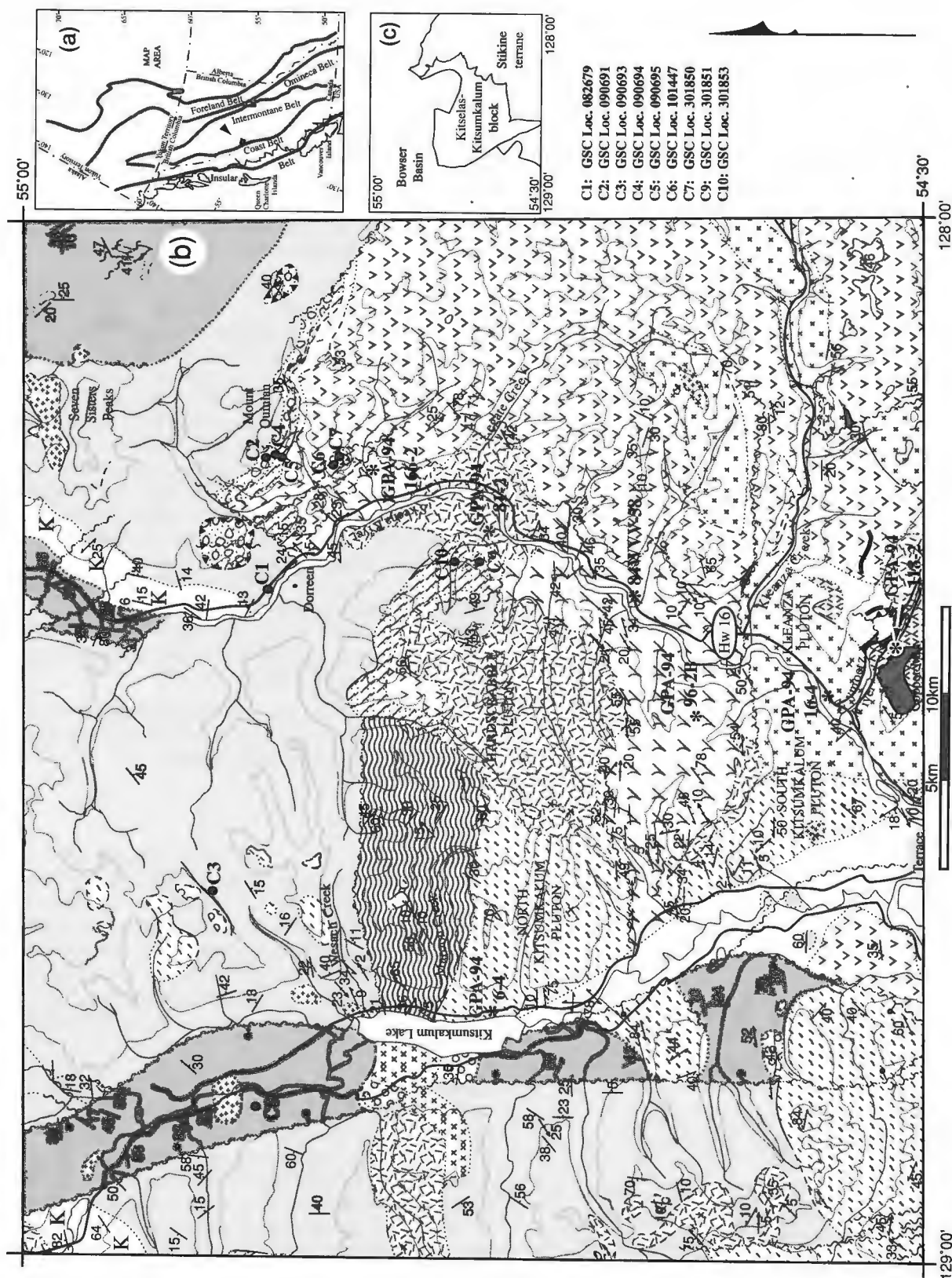


Figure 1. a) Location of map area. **b)** Geological map of the northeastern quadrant (103I/9, 10, 15 and 16) of the Terrace map area. **c)** Approximate extent of the three major tectonic domains in the area.

BOWSER BASIN AND STIKINE TERRANE LOW METAMORPHIC GRADE - NO DUCTILE DEFORMATION EARLY TO EARLIEST LATE CRETACEOUS SKEENA GROUP ALBIAN OR CENOMANIAN (?) Chert pebble conglomerate assemblage HAUTERIVIAN-BARREMIAN (?) Black micaceous shale, siltstone, sandstone	KITSELAS-KITSUMKALUM BLOCK LATE PALEOCENE (59.6 ± 0.5 Ma) Kitsumkalum suite MIDDLE JURASSIC TO MIDDLE CRETACEOUS (?) Kitsumkalum metasedimentary rocks EARLY JURASSIC Kitseles volcanics
 	  
EARLY TO MIDDLE CRETACEOUS (?) SKEENA-BOWSER LAKE TRANSITION ZONE	PLUTONIC ROCKS TERTIARY (POST 52 MA?) high level suite; probably correlative with Alice Arm & Nanika Intrusions
	
MIDDLE JURASSIC TO MIDDLE CRETACEOUS BOWSER LAKE GROUP OXFORDIAN TO AT LEAST EARLY KIMMERIDGIAN Thomson assemblage may include "Trout Creek assemblage" and Ashman Formation	TERTIARY (POST 52 MA?) pyroxene-bearing suite
	
LATE OXFORDIAN Trout Creek assemblage CALLOVIAN TO EARLY OXFORDIAN Ashman Formation	EARLY-MIDDLE EOCENE titanite-bearing suite
 	
LATE TRIASSIC TO MIDDLE JURASSIC HAZELTON GROUP AALENIAN Smithers Formation CARNIAN AND LATE SINEMURIAN Telkwa Formation	EARLY JURASSIC Kleanza suite
 	
MIDDLE TO LATE TRIASSIC SMITHIAN TO CARNIAN Argillite, chert, minor limestone	SYMBOLS
	Contact (mapped, approximate, inferred or assumed and in some cases of unknown nature) Fault; nature unknown (mapped, approximate, inferred or assumed)
EARLY PERMIAN SAKMARIAN TO ARTINSKIAN Limestone, silty limestone, calcareous mudstone, minor tuff	Thrust fault (mapped, approximate, inferred or assumed)
	Normal fault (mapped, approximate, inferred or assumed)
LATE PENNSYLVANIAN OR EARLY PERMIAN Green volcanic tuff, breccia and flow, minor sedimentary interlayers	Bedding (inclined)
	Foliation (inclined, vertical, horizontal, absent)
	Lineation; mineral or elongate clast (inclined)
	Fossil locality
	U-Pb sample locality

of the zircon concentrate, but rare more elongate (aspect ratio 2.5-5; fraction B) and tabular grains (fraction A) were also observed and selected for analysis. Titanite recovered from this rock is pale yellow, clear to slightly cloudy, and is made up largely of broken fragments of larger euhedral to subhedral grains. Three of the four zircon fractions (A, C, and D) cluster to the right of concordia at about 200 Ma (Fig. 2b). Of these, fraction A gives the oldest $^{207}\text{Pb}/^{206}\text{Pb}$ age and is likely to contain minor inherited zircon. Fraction B lies below concordia at about 190 Ma and appears to have undergone Pb loss. Fractions B, C, and D give similar $^{207}\text{Pb}/^{206}\text{Pb}$ ages (ca. 209 Ma). There are two ways to interpret these results: the age of this rock could be approximated at 208.7 ± 4.0 Ma using the weighted mean of $^{207}\text{Pb}/^{206}\text{Pb}$ ages for B, C, and D, or at 200 Ma assuming that fractions A, C, and D contain minor inheritance and have undergone negligible Pb loss. Three titanite fractions lie along concordia between about 200 Ma and 187 Ma with little overlap. The oldest of these, fraction T3 with a $^{206}\text{Pb}/^{238}\text{U}$ age of 199.7 ± 2.4 Ma, provides a minimum age for this rock. Because of the clustering of

zircon and titanite results at around 200 Ma, we favour the younger (~ 200 Ma) age for the sample, but, as an older age cannot be ruled out, we interpret the best age estimate to be $200 \pm 13/-3$ Ma, an estimate which has an appropriately conservative error envelope derived from the union of both age options and of minimum age based on titanite results.

Ages for Kleanza pluton (latest Triassic or earliest Jurassic) and Telkwa Formation (Sinemurian) are roughly coincident, but because Kleanza plutonic bodies clearly intrude Telkwa volcanics, the plutonic suite postdates at least part of Telkwa Formation. A younger rather than older age for Kleanza pluton is favoured based on this geological relationship and on analytical arguments discussed in the previous paragraph. However, because of the analytical uncertainty and uncertainties in calibration of the Jurassic time scale, this date does not contribute to better constraining the age of Telkwa Formation and further geochronological work on the Kleanza suite may be warranted. Overlapping ages for the Kleanza suite and Telkwa Formation could

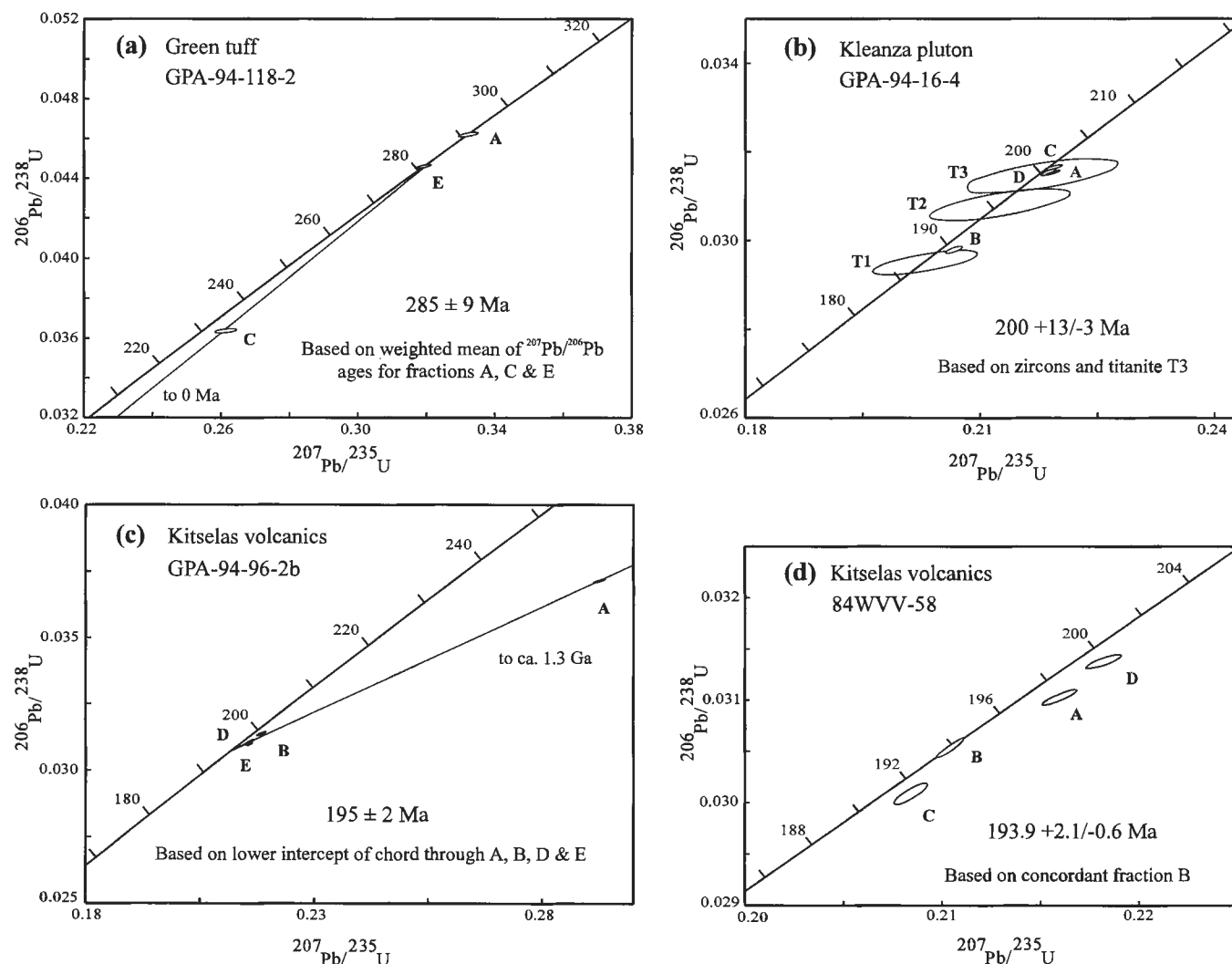


Figure 2. U-Pb concordia plots for samples from the northeastern quadrant of Terrace map area.

indicate that the two are comagmatic. The latest Triassic/earliest Jurassic Kleanza suite intrudes Stikine terrane, and as with all conventionally defined Stikine terrane in the area, it shows no evidence of ductile deformation.

Kitselas volcanics

Two samples, GPA-94-45-4 and GPA-94-96-2b, from Kitselas volcanics were collected for dating. A third sample, 84WVV-58, was collected by P. van der Heyden in 1984. Sample GPA-94-45-4, a siliceous feldspar porphyry yielded no dateable minerals. Sample GPA-94-96-2b was collected from a thick-bedded siliceous sequence. Anhedral feldspar megacrysts compose less than 2% of the rock which consists mostly of fine (<0.1 mm) quartz, feldspar, and white mica aggregated into elongate, rounded shapes, probably relic clasts. The clastic texture is emphasized by variations in size of grains from clast to clast and by concentration of white mica rimming the clasts. The deformed clasts and the white mica are oriented parallel to the foliation. Pyrite occurs in trace amounts and many crystals have small deformational

tails. Sample 84WVV-58 was collected from a nonclastic, weakly banded rhyolitic rock containing small feldspar phenocrysts; the rock was interpreted to be a flow.

Sample GPA-94-96-2b yielded a small quantity of colourless to pale yellow, clear to slightly cloudy, good quality to strongly fractured zircon, commonly characterized by euhedral prismatic morphology. Four analyzed zircon fractions define an array which indicates the presence of minor (fractions B, D, and E) to significant (fraction A) inheritance (Fig. 2c). A chord fit through all of the data yields an Early Jurassic lower intercept age of 195.1 ± 2.0 Ma, which is considered the best estimate for the age of this rock. An upper intercept of 1.3 ± 0.1 Ga gives an indication of the average age of inherited zircons.

Sample 84WVV-58 yielded high quality, clear, colourless, primarily stubby prismatic zircon. Four zircon analyses suggest the presence of inherited zircon in most fractions and subsequent Pb loss for relatively fine fraction C (Fig. 2d). The best age estimate of $193.9 \pm 2.1/-0.6$ Ma is based on the $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ages for concordant fraction B.

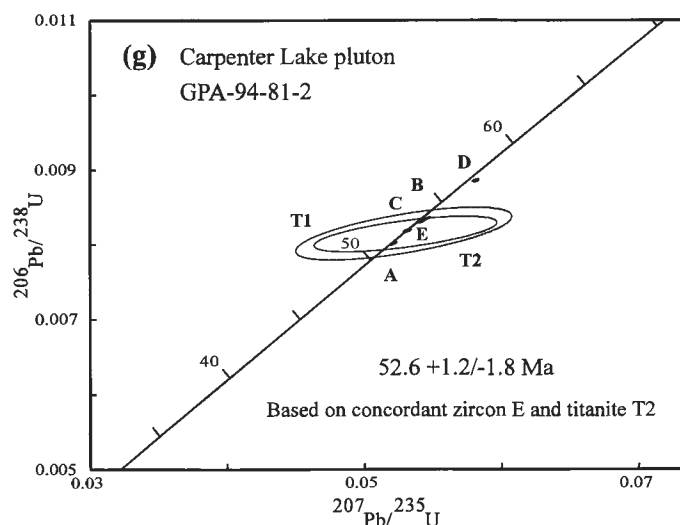
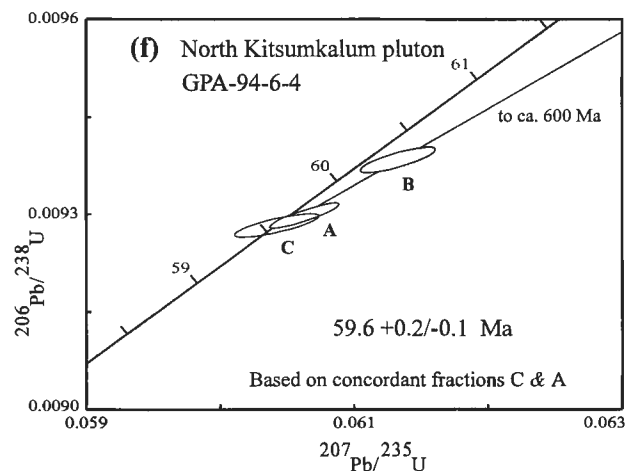
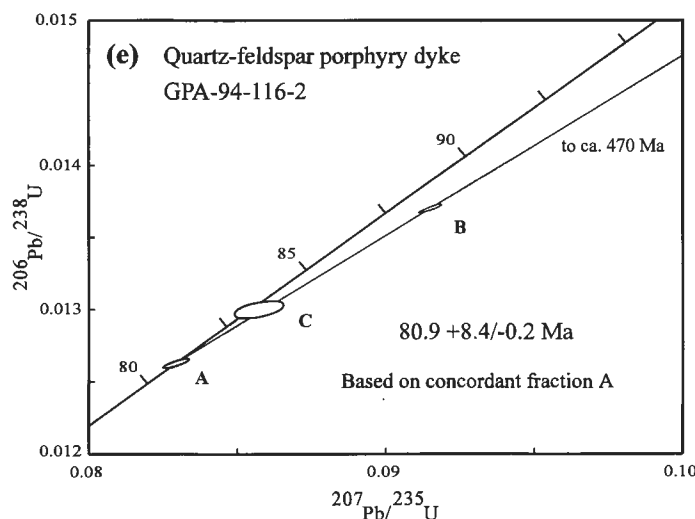


Figure 2. (cont.)

Table 1. U-Pb analytical data for samples from the northeast quadrant of Terrace area.

Fraction ¹	Wt mg	U ² ppm	Pb ³ ppm	²⁰⁶ Pb ⁴ ²⁰⁴ Pb	Pb ⁵ pg	²⁰⁸ Pb ⁶	Isotopic ratios (1s,%) ⁷			Apparent ages (2s, Ma) ⁷	
							²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²³⁵ U	²⁰⁷ Pb/ ²⁰⁶ Pb	²⁰⁶ Pb/ ²³⁸ U	²⁰⁷ Pb/ ²⁰⁶ Pb
GPA-94-118-2: Green tuff											
A,c,N1,eq	0.100	85	4	896	28	11.3	0.04621 (0.14)	0.3323 (0.45)	0.05215 (0.38)	291.2 (0.8)	292 (18)
C,c,N1,p,b	0.090	58	2	559	21	11.6	0.03637 (0.14)	0.2615 (0.56)	0.05215 (0.56)	230.3 (0.7)	292 (26)
E,m,M2,eq	0.041	288	14	1092	30	14.1	0.04460 (0.12)	0.3192 (0.33)	0.05190 (0.63)	281.3 (0.7)	281 (12)
GPA-94-16-4: Kleanza pluton											
A,m,N1,p,s	0.129	324	11	4131	20	12.9	0.03152 (0.09)	0.2192 (0.21)	0.05044 (0.13)	200.1 (0.4)	215.3 (6.1)
B,m,N1,p,e	0.108	485	15	2685	36	11.9	0.02980 (0.14)	0.2067 (0.26)	0.05030 (0.17)	189.3 (0.5)	209.1 (8.1)
C,m,N1,t	0.096	272	9	2220	23	13.7	0.03164 (0.11)	0.2193 (0.26)	0.05027 (0.19)	200.8 (0.4)	207.7 (8.7)
D,m,N1,p,s	0.095	421	14	5072	15	14.0	0.03154 (0.13)	0.2187 (0.22)	0.05030 (0.12)	200.2 (0.5)	208.9 (5.7)
T1,cc,M20	0.530	152	4	141	1234	7.6	0.02951 (0.47)	0.2030 (1.7)	0.04989 (1.4)	187.5 (1.7)	190 (63)
T2,c,M20	0.760	79	2	111	1262	8.2	0.03081 (0.59)	0.2125 (2.1)	0.05003 (1.7)	195.6 (2.3)	197 (82)
T3,c,M20	0.905	120	4	105	2490	7.8	0.03147 (0.62)	0.2180 (2.2)	0.05024 (1.8)	199.7 (2.4)	206 (85)
GPA-94-96-2b: Kitselas volcanics											
A,c,N1,p	0.050	511	19	2623	23	11.0	0.03713 (0.10)	0.2924 (0.21)	0.05711 (0.13)	235.0 (0.5)	495.8 (5.9)
B,m,N1,p	0.170	978	31	2278	146	10.5	0.03139 (0.12)	0.2186 (0.23)	0.05050 (0.13)	199.2 (0.5)	218.1 (6.3)
D,m,M2,p	0.142	952	30	3886	68	10.7	0.03105 (0.180)	0.2158 (0.25)	0.05039 (0.11)	197.1 (0.7)	213.0 (5.2)
E,c,M1,p	0.135	900	28	5432	44	10.5	0.03099 (0.07)	0.2158 (0.10)	0.05050 (0.05)	196.8 (0.3)	218.1 (2.3)
84WVV-58: Kitselas volcanics											
A,m,N5,p,s	0.070	1330	47	5448	33	21.4	0.03103 (0.12)	0.2160 (0.21)	0.05048 (0.11)	197.0 (0.5)	217.2 (5.1)
B,f,N5,p,s	0.041	1890	66	5453	27	21.5	0.03053 (0.15)	0.2104 (0.16)	0.04997 (0.05)	193.9 (0.6)	193.8 (2.2)
C,f,N5,p,s	0.070	2150	75	3080	91	21.5	0.03009 (0.17)	0.2084 (0.20)	0.05024 (0.10)	191.1 (0.6)	206.1 (4.9)
D,f,N5,p,s	0.020	688	24	5232	5	17.9	0.03138 (0.11)	0.2182 (0.21)	0.05043 (0.12)	199.2 (0.4)	215.1 (5.8)
GPA-94-116-2: Quartz-feldspar porphyry dyke											
A,f,N1,p	0.100	1281	15	2189	47	5.3	0.01263 (0.13)	0.0829 (0.26)	0.04763 (0.17)	80.9 (0.2)	81.1 (8.3)
B,m,N1,p	0.140	860	11	3374	31	4.6	0.01370 (0.11)	0.0915 (0.21)	0.04845 (0.12)	87.7 (0.2)	121.2 (5.7)
C,c,N1,p	0.080	646	8	1271	32	3.5	0.01300 (0.23)	0.0857 (0.49)	0.04783 (0.42)	83.3 (0.4)	91 (20)
GPA-94-6-4: North Kitsumkalum pluton											
A,c,N1,p,s	0.285	688	6	4537	25	6.6	0.00930 (0.10)	0.0606 (0.21)	0.04729 (0.13)	59.7 (0.1)	64.0 (6.2)
B,c,N1,p,ti	0.126	763	7	3311	17	5.2	0.00938 (0.11)	0.0613 (0.23)	0.04740 (0.15)	60.2 (0.1)	69.3 (7.3)
C,c,N1,p,ti	0.092	810	7	2321	19	6.4	0.00928 (0.10)	0.0604 (0.26)	0.04721 (0.19)	59.6 (0.1)	59.7 (9.2)
GPA-94-81-2: Carpenter Lake pluton											
A,cc,N2,p	0.302	448	4	3610	19	8.9	0.00802 (0.12)	0.0521 (0.22)	0.04714 (0.13)	51.5 (0.1)	56.2 (6.0)
B,cc,N2,p	0.436	577	5	3331	40	6.6	0.00835 (0.11)	0.0546 (0.21)	0.04741 (0.12)	53.6 (0.1)	69.8 (5.6)
C,c,N2,p,e	0.438	457	4	4783	22	8.5	0.00831 (0.11)	0.0542 (0.21)	0.04731 (0.11)	53.3 (0.1)	64.7 (5.4)
D,c,N2,p,e	0.315	530	5	6598	14	7.8	0.00886 (0.12)	0.0581 (0.20)	0.04758 (0.10)	56.8 (0.1)	78.2 (5.0)
E,m,N2,p,e	0.130	482	4	2803	12	9.3	0.00819 (0.13)	0.0532 (0.25)	0.04709 (0.18)	52.6 (0.1)	53.6 (88)
T1,cc,M5,b	0.685	68	1	44	969	38.2	0.00815 (0.21)	0.0529 (0.75)	0.04709 (0.63)	52.3 (2.2)	53.9 (307)
T2,cc,M5,b	0.820	70	1	43	1163	36.9	0.00814 (0.15)	0.0530 (0.63)	0.04723 (0.55)	52.3 (1.5)	60.8 (263)

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

¹ Upper case letter = zircon fraction; T+numeral=titanite fraction identifier; all zircon fractions air abraded; grain size, intermediate dimension: cc180 µm, c>180 µm and >134 µm, m<134 µm and >104 µm, f<104 µm; Magnetic codes: Franz magnetic separator sideslope at which grains are nonmagnetic (N) or Magnetic (M); e.g., N1=nonmagnetic at 1°; Field strength for all fractions =1.8A; Front slope for all fractions=20°; Grain character codes: b= broken fragments, e=elongate, eq=equant, p=prismatic, s=stubby, t=tabular, ti=tips.

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

³ Radiogenic Pb

⁴ Measured ratio corrected for spike and Pb fractionation of 0.0043/amu ± 20% (Daly collector) and 0.0012/amu ± 7% and laboratory blank Pb of 5±1pg to 10±2 pg. Laboratory blank Pb concentrations and isotopic compositions based on total procedural blanks analysed throughout the duration of this study.

⁵ Total common Pb in analysis based on blank isotopic composition

⁶ Radiogenic Pb

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

Ages from samples GPA-94-96-2b and 84WVV-58 are in agreement within error and we confidently interpret the Kitselas volcanics as an Early Jurassic assemblage. This age correlates well with ages of lithologically similar volcanic sequences found in Hazelton Group outside Terrace area. Examples include the Early Jurassic Toodoggone volcanic sequence in the Toodoggone area (ages summarized in Marsden and Thorkelson, 1992), and the Cold Fish volcanics in Spatsizi area from which U-Pb dates range between 191.5 and 196.8 (Thorkelson et al., 1995).

Based on the presence of penetrative ductile fabrics in Kitselas volcanics and the absence of such fabrics in adjacent Stikine terrane, it is clear that, even though the Kitselas volcanics probably belong in some fashion to Stikine terrane, the unit's geological history differs from that of conventionally defined Stikine terrane in the Terrace area. Dating of rocks cutting the Kitselas volcanics (see below) provides some constraints on the timing of deformation in Kitselas volcanics.

Foliated and lineated quartz and feldspar porphyry dyke

Sample GPA-94-116-2 is from a dyke which crosscuts the Kitselas volcanics. The dyke is strongly deformed, with ductile fabrics continuous across the contact between volcanic and dyke rock. The sample is composed of quartz and feldspar phenocrysts (up to 3 mm in length) in a fine matrix of mostly quartz, feldspar, and white mica. Epidote and partly chloritized biotite grains are generally coarser than the matrix (0.1–0.5 mm) and occur in large (2–6 mm) knots or disseminated in the matrix. Minerals are aligned and grains strongly flattened in the foliation plane.

The sample yielded good quality, clear, elongate prismatic zircon with faint zoning in some of the larger grains. No cores were seen. Three analyzed zircon fractions define a linear array which indicates the presence of inherited zircon in fractions B and C (Fig. 2e). A chord fit through the data gives a lower intercept of $81.1 \pm 1.3/-1.8$ Ma, which is considered to closely approximate the age of this rock. The upper intercept of $471 \pm 98/-95$ Ma gives an indication of the average age of the inherited zircon. The best estimate for the age of this rock, $80.9 \pm 8.4/-0.2$ Ma, is based on the $^{206}\text{Pb}/^{238}\text{U}$ and $^{207}\text{Pb}/^{206}\text{Pb}$ ages for concordant fraction A.

This age indicates that some, if not all, of the deformation in the Kitselas volcanics occurred in the Late Cretaceous or later.

North Kitsumkalum pluton

The North Kitsumkalum pluton intrudes the Kitselas volcanics and, like the Kitselas volcanics, has a strong foliation and lineation. Sample GPA-94-6-4 is a fresh, foliated, coarse grained biotite-hornblende granodiorite. Feldspar (50–55%) occurs in large (up to 3 mm), somewhat rounded grains. Fine quartz (35–40%) is concentrated in layers and lenses. Rarer larger quartz grains are broken into subgrains or show undulose extinction. Fine (<1 mm long) euhedral to anhedral biotite (~5%) wraps around large feldspar. Hornblende (≤3%)

is generally anhedral. Both biotite and hornblende are slightly chloritized. Accessory titanite reaches 1 mm in length and is euhedral to subhedral.

This rock yielded abundant, high quality, clear, pale pink euhedral prismatic zircon, most commonly with square cross-sections and aspect ratios of about 2:6. Neither visible cores, nor zoning were observed during zircon selection and only the coarsest, most nonmagnetic grains were chosen for analysis. Three analyzed fractions lie on or near concordia at about 60 Ma (Fig. 2f). The best estimate for the age of the rock, which is $59.6 \pm 0.2/-0.1$ Ma, is based on the $^{206}\text{Pb}/^{238}\text{U}$ ages of fractions C and A, which are concordant and marginally concordant respectively. Fraction B, and to a lesser extent A, likely contain minor inherited zircon, the average age of which can be constrained only as between the age of the sample and Mesoproterozoic.

The age of this pluton indicates that deformation in the Kitselas-Kitsumkalum block continued until at least Late Paleocene time. It also indicates that Late Paleocene plutonism, common in the eastern Coast Plutonic Complex, extends at least into a block emplaced tectonically at the western margin of the Intermontane belt, and possibly into the western Intermontane belt if other plutons thought to be part of the Kitsumkalum suite prove to be of the same age.

Carpenter Lake pluton

Sample GPA-94-81-2 is from an undeformed titanite-bearing biotite granite. Plagioclase (~55%) is euhedral prismatic to square; K-feldspar (~20–25%) is generally equant and anhedral; and quartz occurs either as coarse (≤2 mm) or as very fine rounded grains. Anhedral biotite grains (<5%) reach 0.75 mm in length. Coarse (up to 0.5 mm) titanite is characteristic of this unit. Crystals are neither bent, nor broken and are randomly oriented; no evidence of deformation was noted. Well-developed twinning and zoning in plagioclase, myrmekitic texture, and lack of sericitization of feldspars or chloritization of biotite strongly suggest that the rock was not recrystallized or altered.

The abundant high quality zircons recovered from this sample are clear, colourless to pale pink, and commonly of stubby to elongate prismatic morphology. Titanite from this rock consists of clear, pale yellow broken fragments of euhedral pyramids. Five analyzed zircon fractions indicate the presence of minor inherited zircon (B, C, and D) and possible minor Pb loss (A). Two relatively imprecise titanite fractions strongly overlap and the dates are statistically undistinguishable from those of four zircon fractions (Fig. 2g). The best estimate for the age of this rock is $52.6 \pm 1.2/-1.8$ Ma. It is based on concordant zircon fraction E, and has errors derived from the $^{206}\text{Pb}/^{238}\text{U}$ age of titanite T2, which provides a minimum age for this rock.

We interpret this age as indicating that metamorphism, ductile deformation, and folding in all units of the study area, including the Kitselas-Kitsumkalum block, had ceased by Early-Middle Eocene time. This age also provides a minimum age for movement along faults which bound the Kitselas-Kitsumkalum block.

DISCUSSION

Late Pennsylvanian or Early Permian intermediate to mafic volcanic rocks are the oldest and stratigraphically lowest rocks of Stikine terrane in the Terrace area. Volcanic rocks of this age are regionally uncommon in western Stikine terrane (R.G. Anderson, pers. comm., 1996) but are present near Telegraph Creek, where they underlie early Permian carbonate of the Ambition Formation (Gunning et al., 1994).

The overlying Stikine stratigraphy in the Terrace area includes Early Permian limestone, Triassic argillite, and Late Triassic to Middle Jurassic volcanic assemblages of Hazelton Group. Early Jurassic plutons of the Kleanza suite intrude Stikine terrane in the Terrace area; plutons of this age and similar composition are abundant in other parts of the Stikine terrane and in the Coast Plutonic Complex. Kleanza plutons are possibly comagmatic with volcanic rocks of Telkwa Formation and the two are part of the Hazelton arc complex. In contrast to northwestern British Columbia where deformation and metamorphism occurred between Middle and Upper Triassic time, most Stikine terrane of the Terrace area saw no regional metamorphism greater than prehnite-pumpellyite and no ductile deformation after Late Pennsylvanian or Early Permian volcanism.

The tectonic history of the Kitselas-Kitsumkalum block differs drastically from that of adjacent conventionally defined Stikine terrane. Dating of the Kitselas volcanics shows that this unit is not, as might have been expected from its strong deformation, derived from an older part of Stikine terrane, but that it is roughly contemporaneous with Telkwa Formation. As discussed earlier, the unit correlates with similar volcanic units of Hazelton Group outside the Terrace area and probably belongs to Stikine terrane. At least some of the fabric in the Kitselas volcanics postdates middle Late Cretaceous time, as indicated by the $80.9 \pm 8.4/-0.2$ Ma age of the foliated and lineated dyke cutting Kitselas volcanics. As well, the 59.6 ± 0.2 Ma age for the penetratively deformed North Kitsumkalum pluton which intrudes Kitselas volcanics indicate that deformation in the Kitselas-Kitsumkalum block continued until at least Late Paleocene time, but had ceased by $52.6 \pm 1.2/-1.8$ Ma, when the undeformed Carpenter Lake and other plutons of the titanite-bearing suite intruded the Kitselas-Kitsumkalum block, Stikine terrane, and Bowser Basin. We suspect that much of the penetrative ductile deformation in the Kitselas-Kitsumkalum block occurred during or soon after emplacement of the Kitsumkalum plutons and that deformation is related to tectonic exhumation of the block into its current position with respect to southern Bowser Basin and Stikine terrane. This tectonic activity was completed by Early-Middle Eocene time. Structural study of the Kitselas-Kitsumkalum block, and analysis of cooling patterns across the map area are planned to test this hypothesis.

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REFERENCES

- Bassett, K.N.
1995: A basin analysis of the Lower to mid-Cretaceous Skeena Group, west-central British Columbia: implications for regional tectonics and terrane accretion; Ph.D. thesis, University of Minnesota, 413 p.
- Gareau, S.A., Woodsworth, G.J., and Rickli, M.
1997: Regional geology of the northeastern quadrant of Terrace map area, west-central British Columbia, in *Current Research 1997-A*; Geological Survey of Canada.
- Gunning, M.H., Bamber, E.W., Brown, D.A., Rui, L., Mamet, B.L., and Orchard, M.J.
1994: The Permian Ambition Formation of northwestern Stikinia, British Columbia; in *Pangea: Global Environments and Resources*, (ed.) A.F. Embry, B. Beauchamp, and D.J. Glass; Canadian Society of Petroleum Geologists, Memoir 17, p. 589-619.
- Marsden, H. and Thorkelson, D.J.
1992: Geology of the Hazelton volcanic belt in British Columbia: Implications for the Early to Middle Jurassic evolution of Stikinia; *Tectonics*, v. 11, p. 1266-1287.
- Mortensen, J.K., Ghosh, D.K., and Ferri, F.
1995: U-Pb geochronology of intrusive rocks associated with copper-gold porphyry deposits in the Canadian Cordillera; in *Porphyry Deposits of the Northwestern Cordillera of North America*, (ed.) T.G. Schroeter; Canadian Institute of Mining and Metallurgy, Special Volume 46, p. 142-158.
- Richards, T.A., Woodsworth, G.J., and Tipper, H.W.
in press: Geology, Hazelton (93M) map area, British Columbia; Geological Survey of Canada, Map 1852A, scale 1:250 000.
- Stacey, J.S. and Kramers, J.D.
1975: Approximation of terrestrial lead isotope evolution by a two-stage model; *Earth and Planetary Science Letters*, v. 26, p. 207-221.
- Thorkelson, D.J., Mortensen, J.K., Marsden, H., and Taylor, R.P.
1995: Age and tectonic setting of Early Jurassic episodic volcanism along the northeastern margin of the Hazelton Trough, northern British Columbia; in *Jurassic Magmatism and Tectonics of the North American Cordillera*, (ed.) D.M. Miller and C. Busby; Geological Society of America, Special Paper 299, p. 83-94.
- Woodsworth, G.J., Hill, M.L., and van der Heyden, P.
1985: Geology, Terrace B.C. 103I east half; Geological Survey of Canada, Open File 1136, scale 1:125 000.

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Foraminifera from the Longarm Formation, Queen Charlotte Islands, British Columbia

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Abstract: Foraminiferal samples from mudstones of west-central Graham Island, Queen Charlotte Islands, British Columbia, show that Albian strata are present in the shale belt which trends northwest across the island. The foraminiferal assemblages are of low diversity and abundance, but preservation is sufficient to allow unambiguous identification of species. The presence of Albian mudstone in rocks previously mapped as Longarm Formation supports the interpretation of a deep-water marine basin west of the central Cretaceous outcrop belt of the Queen Charlotte Islands region. Most of the identified foraminifers are identical with taxa from the Western Interior of North America and may reflect a short period of marine connection between that region and the Pacific Coast region during Albian time.

Résumé : Des échantillons de foraminifères extraits de mudstones du centre ouest de l'île Graham dans les îles de la Reine-Charlotte en Colombie-Britannique indiquent que des strates albiennes sont présentes dans la bande de shale qui traverse l'île dans le sens nord-ouest. Les assemblages de foraminifères sont peu diversifiés et peu abondants, mais leur état de conservation est suffisant pour identifier sans ambiguïté les espèces. La présence de mudstone albien dans les roches auparavant cartographiées comme faisant partie de la Formation de Longarm appuie l'interprétation selon laquelle il existait un bassin marin profond à l'ouest de la zone d'affleurement centrale du Crétacé dans la région des îles de la Reine-Charlotte. La plupart des foraminifères identifiés sont identiques aux taxons de la partie ouest de la région intérieure de l'Amérique du Nord et pourraient refléter une courte période de connexion marine entre cette région et la région de la côte du Pacifique durant l'Albien.

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INTRODUCTION

Microfossils are rare for most stratigraphic intervals in Cretaceous rocks of Queen Charlotte Islands, British Columbia (Haggart and Carter, 1993; Haggart et al., 1994). As a result of the structurally disrupted aspect of most outcrops and stratigraphic sections, unravelling the biostratigraphy of any fossil group in these rocks is unusually difficult. None-the-less, we have initiated a study to attempt to interpret the biostratigraphic succession of foraminifera in Cretaceous rocks of the islands.

The value of such a study is several-fold. First, foraminifera are typically found in finer grained facies, mudstones and shales, where macrofossils are often lacking. They thus complement the macrofossils as biostratigraphic datum points upon which to combine disparate stratigraphic sections and exposures into a composite overall sequence. Secondly, foraminiferal dating of sedimentary exposures is valuable for geological mapping. Finally, the proportions of different foraminiferal types may tell something of the paleoecology

of the ocean environment in which the animals lived – for instance, open ocean or restricted embayment. These aspects of foraminifera, their biostratigraphic distribution and their paleoecological implications, provide necessary details of basin geometry which are vital in interpreting the geological history of a basin.

As part of a multidisciplinary study of Cretaceous strata of Queen Charlotte Islands (Fig. 1) most known exposures of fine grained clastic rocks have been sampled for foraminifera. Significant populations of foraminifera have been identified within the Haida Formation (Fig. 2), of Albian to Turonian age (Haggart, 1991). In addition, we have also recognized lesser numbers of foraminifera in strata assigned to the Longarm Formation, considered Valanginian to Aptian (Haggart, 1991, 1993). Foraminifera in the Longarm Formation have, to date, only been found in a narrow area of central Graham Island (Fig. 1). Road-cut exposures along the Rennell Sound Road, linking the west coast of Graham Island with its interior, have provided the fossiliferous collections. All of the productive collections were originally made by B.E.B. Cameron, formerly of the Geological Survey of

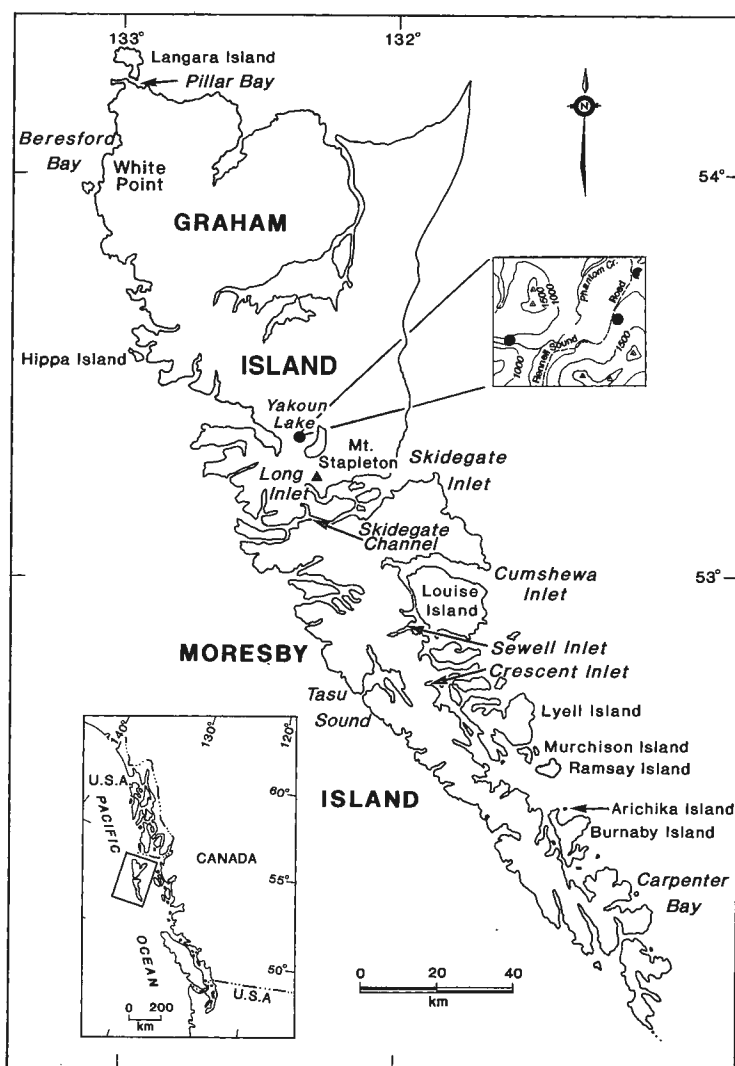


Figure 1.

Location map of Queen Charlotte Islands, British Columbia, showing major localities discussed in text. Black circles in inset show approximate locations of foraminiferal samples.

Canada, and the locations of the collections were determined from study of Cameron's field notes (presently in the senior author's possession). Cretaceous strata along the Rennell Sound Road are very poorly fossiliferous in molluscs, so the occurrence of microfauna in these rocks is very important.

In this report, we present initial results of our study of foraminifers of the Longarm Formation: we describe the stratigraphic distribution of some foraminifers from the formation and discuss important implications of their distribution.

STRATIGRAPHY

The Longarm Formation outcrops in a longitudinal belt across the Queen Charlotte Islands from the northwest coast of Graham Island on the north to Carpenter Bay on the south (Fig. 1). The unit typically comprises a fining-upward sequence, from coarse grained sandstone and conglomerate at its base to finer grained rocks, siltstone and shale, in its higher levels (Haggart, 1991). Coarser units of the formation are generally fossiliferous, and molluscs include ammonites

and inoceramid and trigoniid bivalves; these fossil groups have been valuable for determining the age of the formation (Sutherland Brown, 1968; Haggart, 1991).

Interpreting the age of the finer grained exposures of the Longarm Formation is problematic, however, due to a distinct lack of macrofossils. This is, in part, attributable to the fact that fine grained clastics are the focus of much of the subsequent deformation and intrusion which has affected the Cretaceous rocks of the islands. Some success has been obtained in dating some exposures using radiolarians contained within limy concretionary nodules within the silt-rich mudstones and shales of the Longarm Formation (Haggart and Carter, 1993). However, few stratigraphic sections include such facies; most sections are typically more silty. It is from these exposures that foraminifers are generally found.

SAMPLING AND PROCESSING

Little is known of Cameron's sampling methodology. However, multiple collections at single localities indicate that collections were made stratigraphically through the sections exposed at those localities. Bulk samples of approximately 5 kg were collected. Most bulk samples were processed at the Geological Survey of Canada's Pacific Geoscience Centre Paleontology Laboratory at Sidney, British Columbia, using the techniques for foraminiferal processing developed by that facility. Samples were then picked for foraminifers and other microfossils under a binocular microscope in the Paleontology Laboratory at the GSC Pacific office in Vancouver, with the picked foraminifers and producing residues forwarded to Carleton University for identification and analysis.

RESULTS

Only a few of the sampled horizons of the Longarm Formation have produced good collections of foraminifers. Diversity in these collections is low, as is numerical abundance of foraminifers. Still, material is preserved sufficiently to allow definitive identifications of some taxa.

Productive exposures along the Rennell Sound Road appear to be mostly of Albian age (Table 1). The structurally highest exposure with good assemblages of foraminifers includes GSC localities C-172857, C-172858, and C-172862. At the first of these, GSC loc. C-172857, the foraminifer *Haplophragmoides formosus* Takayanagi 1960 was found. This species has a reported range of Aptian to Maastrichtian and has been described from the Otoinep-Saku, Haboro, Obira, and Mombetsu areas of Japan (Takayanagi, 1960). At GSC loc. C-172858 *Haplophragmoides* cf. *rota* Nauss 1947 was collected. *H. rota* has a range of Cenomanian to Maastrichtian and it is not inconceivable that it could also exist in the Albian. The species has also been described from the Turonian to Santonian Kaskapau and Puskwaskau Shales of the Smoky River Area of Alberta, the Campanian Lea Park Formation of Saskatchewan, the Campanian Millwood

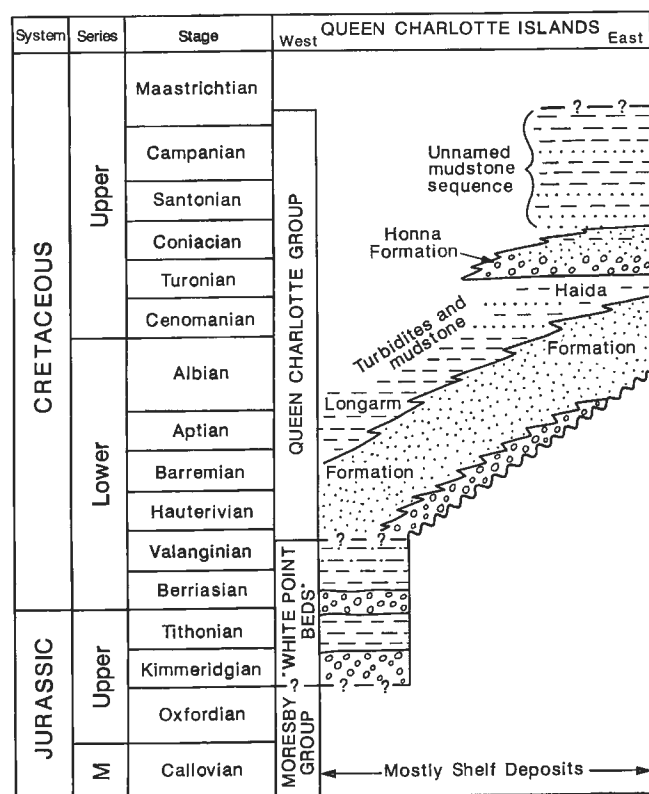


Figure 2. Schematic section of Cretaceous strata, Queen Charlotte Islands, British Columbia. (After Haggart, 1993).

Table 1. Foraminiferal species found at Geological Survey of Canada localities along Rennell Sound Road, Queen Charlotte Islands, British Columbia, and their known stratigraphic ranges.

GSC Number	Species	Range
C-172857	<i>Haplophragmoides formosus</i>	Late Aptian - Maastrichtian
C-172858	<i>Haplophragmoides cf. rota</i>	Cenomanian - Maastrichtian
C-172862	<i>Ammodiscus kiowensis</i>	Albian
C-172854	<i>Glomospira corona</i>	Albian - Maastrichtian
	<i>Uvigerinammina manitobensis</i>	Albian - Cenomanian
	<i>Hedbergella gorbachikae</i>	Upper Aptian - Middle Albian
	<i>Trochammina wetteri</i>	Albian - Campanian
C-172855	<i>Tritaxia tricarinata</i>	Albian
C-172846	<i>Reophax cylindracea</i>	Albian
	<i>Reophax minuta</i>	Albian
	<i>Hedbergella planispira</i>	Albian - Late Santonian

Member of the Riding Mountain Formation of Saskatchewan and Manitoba, the Campanian to Maastrichtian Pierre Shale and Fox Hills Sandstone of South Dakota, and the Cenomanian to Campanian Seabee and Schrader Bluff formations of northern Alaska (Tappan, 1962; McNeil and Caldwell, 1981). GSC loc. C-172862 produced *Ammodiscus kiowensis* Loeblich and Tappan 1950. This Albian species has also been described from the Kiowa Shale of Kansas, the Thermopolis Shale and Skull Creek Shale of Wyoming, the Joli Fou Formation of Alberta and Saskatchewan, and the Lower Colorado Group of Saskatchewan (McNeil and Caldwell, 1981).

A structurally lower exposure along the Rennell Sound Road includes GSC loc. C-172854 and C-172855. GSC loc. C-172854 contains *Glomospira corona* Cushman and Jarvis 1928, *Uvigerinammina manitobensis* (Wickenden 1932), *Hedbergella gorbachikae* Longoria 1974, and *Trochammina wetteri* Stelck and Wall 1955. *G. corona* has a reported range of Albian to Maastrichtian and has also been described from the Late Cretaceous Velasco Shale of Mexico, the Campanian-Maastrichtian Pierre Shale of South Dakota and Wyoming, the Campanian Lea Park Formation of Saskatchewan, the Campanian Millwood Member of the Riding Mountain Formation of Saskatchewan-Manitoba, the Albian to Cenomanian of the Nanushuk Group of northern Alaska, and the Campanian Cedar District Formation of Vancouver Island (Tappan, 1962; McNeil and Caldwell, 1981). *U. manitobensis* has a reported range of Albian to Cenomanian and has also been described from the Albian-Cenomanian Ashville Formation of Manitoba; the Albian Buckinghorse and Sikanni formations of northeastern British Columbia; the Albian Joli Fou Formation and the Lower Colorado Group of Saskatchewan; and the Albian Tuktu, Topagoruk, and Grandstand formations of northern Alaska (Tappan, 1962; McNeil and Caldwell, 1981). *H. gorbachikae* has a reported range of Upper Aptian to Albian (Caron, 1985).

Finally, *T. wetteri* has a reported range of Albian to Campanian and has also been described from the Albian Grandstand Formation of northern Alaska; the Cenomanian to Turonian Kaskapau Formation of Alberta; the Santonian-Campanian Puskwaskau Shale of Alberta; the Santonian-Campanian of the Wapiabi Formation of the Rocky Mountain Foothills (Alberta), the Albian Buckinghorse and Sikanni formations of northeast British Columbia; the Cenomanian Belle Fourche Shale of Colorado, Montana, South Dakota, and Wyoming; the Turonian Carlile Shale of South Dakota and Wyoming; the Albian Shell Creek Shale of Wyoming; and the Cenomanian to Turonian Greenhorn Limestone of Wyoming and South Dakota (Tappan, 1962; McNeil and Caldwell, 1981).

GSC loc. C-172855 produced the Albian foraminifer *Tritaxia tricarinata* (Reuss 1851). This species has also been described from the Late Aptian to Maastrichtian at DSDP Site 585 in the East Mariana Basin (Western Pacific) (Sliter, 1985).

An isolated exposure along the Rennell Sound Road is the site of GSC loc. C-172846. This locality produced *Reophax cylindracea* Chapman 1891, *Reophax minuta* Tappan 1940, and *Hedbergella planispira* (Tappan 1940). The first of these is an Albian species also known from the Gault of Folkestone, England (Chapman, 1891). *Reophax minuta* is also an Albian species, known from the Grayson Formation of Texas (Tappan, 1940). Finally, *Hedbergella planispira* has a range of Albian to Late Santonian and has also been described from the Albian Grayson Formation of Texas, the Albian Washita Group of Texas and Oklahoma, the Albian-Cenomanian Tamaulipas Limestone of Mexico, the Cenomanian-Santonian San Felipe Formation of Mexico, and the Turonian Eagle Ford Group and the Coniacian portion of the Austin Chalk of Texas (McNeil and Caldwell, 1981).

DISCUSSION

Recent study of Cretaceous stratigraphy of the Queen Charlotte Islands has resulted in revision of the previous stratigraphic interpretation. Sutherland Brown (1968) established the Longarm Formation for sandstone and shale with typical exposures in Long Inlet, on the southern part of Graham Island. Sutherland Brown's interpreted age range of the Longarm Formation, based on molluscs from Long Inlet and elsewhere on the islands identified by J.A. Jeletzky, was Valanginian to Barremian, and a hiatus was inferred to lie between the Longarm Formation and the younger (Lower Albian-Turonian) Haida Formation. Yorath and Chase (1981) suggested that a period of tectonic activity in the Queen Charlotte Islands region during the 'missing' interval of time, the Aptian.

Haggart (1991) subsequently reported Aptian ammonites from shallow-water clastics of the Longarm Formation and suggested that the Longarm and Haida formations were conformable. Haggart (1991) further suggested that no tectonic event marked Aptian time in the Queen Charlotte Islands region and proposed a model of deep-water, shale deposition spanning Barremian to Turonian time in the western part of the Cretaceous basin in the Queen Charlotte Islands region (summarized schematically in Fig. 2). Definite proof for the existence of this deeper-water basin was lacking, however, until radiolarians of Barremian, Aptian, and Albian ages were recognized in shale and mudstone previously assigned to the Longarm Formation in southern Queen Charlotte Islands (Haggart and Carter, 1993).

The foraminifers from Rennell Sound Road on central Graham Island further define the age of the shale belt of Queen Charlotte Islands. The Rennell Sound Road strata had previously been assigned to the Longarm Formation in mapping by Sutherland Brown (1968). Hesthammer et al. (1991) recognized the pitfall in assigning the homogenous shale exposures of central Graham Island to any specific formation in the absence of fossil control and thus mapped them as Cretaceous Shale undifferentiated. Temporally, the Rennell Sound Road exposures are correlative with the shale belt of the Haida Formation at its type locality (Sutherland Brown, 1968). Shallow-water sandstone facies of Aptian to Albian age outcrops in central Graham Island east and north of the Rennell Sound Road (Sutherland Brown, 1968; Hesthammer et al., 1991; Haggart, unpub. data, 1991) and is the shallow water equivalent of the deep water shale exposures found along the road.

The foraminiferal collections from Queen Charlotte Islands are dominated by taxa which are found commonly in the Western Interior region of North America. Previous models of Cordilleran paleogeography have suggested that the Pacific Coast region of North America was isolated from the Western Interior region throughout most of Cretaceous time (Jeletzky, 1971). The mid-Cretaceous was, however, a period of sea-level high and possible trans-Cordilleran marine connections have been suggested by Jeletzky (1971) for the

Albian and by Lang and McGugan (1988) for the Late Cenomanian. The strong Western Interior affinity of Albian foraminiferal assemblages of Queen Charlotte Islands may reflect connection of the Pacific Coast with the Western Interior region during the Albian.

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REFERENCES

- Caron, M.
1985: Cretaceous planktic foraminifera; in *Plankton Stratigraphy*, (ed.) H.M. Bolli, J.B. Saunders, and K. Perch-Nielsen; Cambridge University Press, Cambridge, p. 17-86.
- Chapman, F.
1891: The foraminifera of the Gault of Folkestone. Part II; *Journal of the Royal Microscopical Society*, Transactions October 1891, p. 319-330.
- Cushman, J.A. and Jarvis, P.W.
1928: Cretaceous foraminifera from Trinidad; *Contributions from the Cushman Laboratory for Foraminiferal Research* v. 4, no. 4, p. 85-103.
- Haggart, J.W.
1991: A synthesis of Cretaceous stratigraphy, Queen Charlotte Islands, British Columbia; in *Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia*, (ed.) G.J. Woodsworth; Geological Survey of Canada, Paper 90-10, p. 253-277.
- 1993: Latest Jurassic and Cretaceous paleogeography of the northern Insular Belt, British Columbia; in *Mesozoic Paleogeography of the Western United States - II*, (ed.) G.C. Dunne and K.A. McDougall; Society of Economic Paleontologists and Mineralogists, Pacific Section, Book 71, p. 463-475.
- Haggart, J.W. and Carter, E.S.
1993: Cretaceous (Barremian-Aptian) radiolaria from Queen Charlotte Islands, British Columbia: newly recognized faunas and stratigraphic implications; in *Current Research, Part E*; Geological Survey of Canada, Paper 93-1E, p. 55-65.
- Haggart, J.W., Burnett, J.A., and Bown, P.R.
1994: Notes on Cretaceous calcareous nannofloral biostratigraphy and paleobiogeography, Queen Charlotte Islands, British Columbia; in *Current Research 1994-E*; Geological Survey of Canada, p. 39-44.
- Hesthammer, J., Indrelid, J., Lewis, P.D., and Haggart, J.W.
1991: Geology of southern Graham Island, Queen Charlotte Islands, British Columbia; Geological Survey of Canada, Open File 2319, 2 sheets, scale 1:50 000.
- Jeletzky, J.A.
1971: Marine Cretaceous biotic provinces and paleogeography of western and Arctic Canada: illustrated by a detailed study of ammonites; Geological Survey of Canada, Paper 70-22, 92 p.
- Lang, H.R. and McGugan, A.
1988: Cretaceous (Albian - Turonian) foraminiferal biostratigraphy and paleogeography of northern Montana and southern Alberta; *Canadian Journal of Earth Sciences*, v. 25, no. 2, p. 316-342.
- Loeblich, A.R., Jr. and Tappan, H.
1950: Foraminifera of the type Kiowa Shale, Lower Cretaceous, of Kansas; *University of Kansas Paleontological Contributions*, Protozoa, Article 3, p. 1-15.

Longoria, J.F.

- 1974: Stratigraphic, morphologic and taxonomic studies of Aptian planktonic foraminifera; *Revista Española de Micropaleontología*, Numero Extraord, p. 1-107.

McNeil, D.H. and Caldwell, W.G.E.

- 1981: Cretaceous rocks and their foraminifera in the Manitoba Escarpment; Geological Association of Canada, Special Paper 21, 439 p.

Nauss, A.W.

- 1947: Cretaceous microfossils of the Vermilion area, Alberta; *Journal of Paleontology*, v. 21, no. 4, p. 329-343.

Reuss, A.E.

- 1851: Die Foraminiferen und Entomostraceen des Kreidemergels von Lemberg; *Naturwissenschaftliche Abhandlungen*, Wien, v. 4, p. 17-52.

Sliter, W.V.

- 1985: Cretaceous redeposited benthic foraminifers from Deep Sea Drilling Project Site 585 in the East Mariana Basin, western equatorial Pacific, and implications for the geological history of the region; in *Initial Reports of the Deep Sea Drilling Project Volume LXXXIX*, (ed.) R. Moberly, S.O. Schlanger et al.; Washington, United States Government Printing Office, p. 327-361.

Stelck, C.R. and Wall, J.H.

- 1955: Foraminifera of the Cenomanian *Dunveganoceras* zone from the Peace River area of western Canada; Alberta Research Council, Report 70, 62 p.

Sutherland Brown, A.

- 1968: Geology of the Queen Charlotte Islands, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 54, 226 p., 18 pl.

Takayanagi, Y.

- 1960: Cretaceous foraminifera from Hokkaido, Japan; *Tohoku University Science Reports*, v. 32, no. 2, p. 1-154.

Tappan, H.

- 1940: Foraminifera from the Grayson Formation of northern Texas; *Journal of Paleontology*, v. 14, no. 2, p. 93-126.
1962: Foraminifera from the Arctic Slope of Alaska. Part 3, Cretaceous foraminifera; United States Geological Survey, Professional Paper 236-C, p. 91-209.

Wickenden, R.T.D.

- 1932: New species of foraminifera from the Upper Cretaceous of the prairie provinces; *Transactions of the Royal Society of Canada*, Series 3, v. 26, pt. 4, p. 85-91.

Yorath, C.J. and Chase, R.L.

- 1981: Tectonic history of the Queen Charlotte Islands and adjacent areas - a model; *Canadian Journal of Earth Sciences*, v. 18, p. 1717-1739.

Geological Survey of Canada Project 880038

Regional geology of the northeastern quadrant of Terrace map area, west-central British Columbia

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Abstract: The study area is underlain by three distinctive tectonic and lithological units: Stikine terrane, southern tip of Bowser Basin, and Kitselas-Kitsumkalum block. Stikine terrane consists of Pennsylvanian/Permian to Middle Jurassic volcanic and sedimentary rocks. These are intruded by the Late Triassic/Early Jurassic Kleanza suite and overlapped by Bowser Lake and Skeena groups.

The Kitselas-Kitsumkalum block is a fault-bounded domain composed of Kitselas volcanics, metasedimentary rocks, and the Kitsumkalum plutons. It is characterized by penetrative ductile deformation and greenschist-facies metamorphism, contrasting with dominantly brittle deformation and very low grade metamorphism elsewhere. The block was probably tectonically exhumed into its current position between the middle Late Paleocene and Early-Middle Eocene. It need not be far-travelled, as Bowser Lake and felsic Hazelton groups are possible protoliths for metasedimentary rocks and the Kitselas volcanics respectively, and plutons resembling the Kitsumkalum plutons occur outside the block.

Résumé : La région d'étude comporte trois unités tectoniques et lithologiques distinctes : le terrane de Stikine, l'extrémité sud du bassin de Bowser et le bloc Kitselas-Kitsumkalum. Le terrane de Stikine est formé de roches volcaniques et sédimentaires qui s'échelonnent du Pennsylvanien/Permien au Jurassique moyen. Elles sont recoupées par la suite de Kleanza du Trias tardif/Jurassique précoce et recouvertes par les roches des groupes de Bowser Lake et de Skeena.

Le bloc de Kitselas-Kitsumkalum est un domaine limité par des failles, qui se compose des roches volcaniques de Kitselas, de roches métasédimentaires et des plutons de Kitsumkalum. Il est caractérisé par une déformation ductile pénétrative et un métamorphisme jusqu'au faciès des schistes verts, ce qui contraste avec la déformation principalement cassante et le métamorphisme très faible observés ailleurs. Le bloc a probablement été exhumé à sa position actuelle entre le milieu du Paléocène tardif et l'Éocène précoce-moyen. Il ne s'est pas nécessairement déplacé très loin, étant donné que les roches du Groupe de Bowser Lake et les roches felsiques du groupe de Hazelton pourraient être les protolites des roches métasédimentaires et des roches volcaniques de Kitselas, respectivement, et que des plutons qui ressemblent aux plutons de Kitsumkalum se rencontrent à l'extérieur du bloc.

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INTRODUCTION

Regional mapping in the northeastern quadrant of the Terrace area (103I/9, 10, 15, 16) aims at providing up-to-date geological information for the region which includes the town of Terrace (Fig. 1, 2) and is immediately east of an important geological boundary, that between Coast and Intermontane belts. Historically a logging community, Terrace still counts forestry at the core of its economy; it is a wood processing centre and the main service centre for logging operations in the region. Tourism is becoming increasingly important to local economy, mostly due to bountiful fishing in the Skeena and other rivers. Population is growing, with expansion putting an additional strain on the immediate region and increasing the need for good baseline geological information for use in environmental contexts, such as in regards to groundwater, geohazards, and slope stability.

The study area encompasses three geological domains: the southern tip of Bowser Basin, a late Paleozoic to Middle Jurassic portion of Stikine terrane, and the fault-bounded, ductilely deformed and metamorphosed Kitselas-Kitsumkalum block (Fig. 2). The tectonic history leading to emplacement of the Kitselas-Kitsumkalum block in its current position is enigmatic and may hold important clues concerning the nature of the nearby boundary zone between high grade, ductilely deformed Coast Belt rocks and low grade Intermontane Belt rocks. Previous mapping (Woodsworth et al., 1985) resulted in differentiation on textural and compositional criteria of several plutonic suites, which are being re-examined and dated with U-Pb, K-Ar, and $^{40}\text{Ar}/^{39}\text{Ar}$ techniques. Similarly, age and affiliation of volcanic suites are under study. Geochronological work is intended to pinpoint episodes of magmatism characterizing the various tectonic assemblages and to study cooling patterns; results to date are presented in a companion paper (Gareau et al., 1997). The broad Kitsumkalum and Skeena valleys (Fig. 2) form major linear features worthy of study in the context of Cenozoic tectonism. Mining and prospecting have historically been a small, but important industry in the area. Structural and magmatic



Figure 1. Looking west from Copper Mountain across the Skeena valley to the city of Terrace, with the Coast Mountains beyond.

controls on mineral occurrences are of interest. This study complements the ACCRETE geophysical program started in the fall of 1994 in Portland Canal, which aims to document major crustal features across the Coast Belt and into the Intermontane Belt.

The project builds on several past contributions including the regional studies of Duffell and Souther (1964) and Woodsworth et al. (1985). Other recent work includes theses by Mihalynuk (1987), Heah (1991), and Bassett (1995). Fieldwork in 1994 and 1996 focused predominantly on the northeastern quadrant of Terrace map area (103I/9, 10, 15, and 16).

GEOLOGICAL AND LITHOLOGICAL NOTES

Skeena Group

The youngest lithostratigraphic unit in northeastern Terrace area is the Early to earliest Late Cretaceous Skeena Group formed of easterly derived, back-arc clastics including marine and nonmarine volcanic wacke, sandstone with detrital white mica, siltstone, shale, chert pebble conglomerate, lithic and lithic-arkosic wackes, and coal (Tipper and Richards, 1976; Bassett, 1995).

In the map area, Skeena Group comprises well-bedded, light grey sandstone; massive dark grey siliceous siltstone; grey-brown greywacke; and lesser black shale. Sharp to gradational boundaries delimit metre-scale bedding. Sandstone contains up to 5% darker grey, finer grained, thin interlayers which outline bedding. It locally contains white mica, taken in the past as evidence for an eastern source for Skeena Group, because of the presence of abundant white mica in the Omineca belt and its comparative scarcity in the Coast Plutonic Complex. Study by Bassett (1995) of paleocurrent indicators, pebble and sandstone compositions, rare-earth element analyses of shales, and single-grain $^{40}\text{Ar}/^{39}\text{Ar}$ dating of detrital muscovite supports this inference. Rarely, twigs and leaf imprints are present. Plant fossils also occur in the dark pyrite-bearing siltstone. At one outcrop thought to belong to Skeena Group, rusty weathering black shale contains recrystallized belemnoids and compressed belemnoid molds likely of Hauterivian-Barremian age (J.W. Haggart, unpub. report JWH-1996-01, GSC loc. C-301850).

The upper part of Skeena Group, characterized by chert pebble conglomerate within sandstone and siltstone layers, is rare in the map area, but is present along West Kalum road, on the west side of Kitsumkalum Lake (Fig. 2). Sandstone and siltstone dominate. Conglomerate layers are less than 1 m (usually less than 30 cm) thick and grade upwards into sandstone. The conglomerate is clast-supported with rounded clasts generally about 1 cm or less in diameter. They are of black, grey, reddish-grey, and white chert, of black siltstone, and rarely of white crystalline quartz. Woodsworth et al. (1985) tentatively assigned an Albian age to this unit. An attempt at obtaining information about age and provenance of chert clasts from the conglomerate by conodont study was unsuccessful.

Bowser Lake Group

Middle Jurassic to mid-Cretaceous Bowser Lake Group has been interpreted as a back-arc(?) and foredeep clastic wedge on Stikinia. It is composed of marine to nonmarine sediments shed from uplift to the north, east, and south (Tipper and Richards, 1976). The components of Bowser Lake Group present in the Terrace area are: the Late Bajocian to Early Oxfordian Ashman Formation, the Late Oxfordian conglomeratic Trout Creek assemblage, and a Late Oxfordian to at least Early Kimmeridgian marine and nonmarine sedimentary sequence informally called the Thomlinson assemblage (Richards et al., in press). Ashman Formation consists of well-bedded (4–15 cm), rusty-brown-weathering, pyritiferous, light grey sandstone and chalk-white-weathering, dark grey siltstone; of massive grey, pyritiferous, siliceous sandstone to greywacke with minor black shaly clasts (<1 cm in size) and calcareous concretions of 5 to 40 cm size; and of dark brown-weathering calcareous bands (~10 cm thick). Belemnites are widespread and abundant. Gastropods and bivalves occur locally.

Two macrofossil collections suggest ages in the Middle Jurassic–Early Cretaceous range, perhaps Callovian (J.W. Haggart, unpub. report JWH-1996-01 and T.P. Poulton, unpub. report J1-TPP-1996, GSC loc. C-301851 and C-301853). Trout Creek assemblage, an informal name for an assemblage of sandstone, conglomerate, siltstone, and minor coal, conformably overlies the Ashman Formation. It occurs in the northeast corner of the map area only (Fig. 2). The most abundant Bowser Lake Group rocks in Terrace area are from the Thomlinson assemblage and consist of characteristically brown-rusty-weathering siltstone, calcareous siltstone, shale, and sandstone. Very faint, millimetre-scale compositional layering in black siltstone is most noticeable on weathered surfaces where alternating black and rusty bands are seen. Calcareous siltstone forms minor thin (≤ 30 cm) layers with abundant bivalves and belemnites, and lesser ammonites. Light grey sandstone contains minor, millimetre-scale black siltstone and rare, approximately 10 cm thick, limy interlayers.

The upper section of Bowser Lake Group is in places difficult to distinguish from rocks of Skeena Group. Generally, outcrops of upper Bowser Lake Group are more massive than those of Skeena Group and show less clearly defined bedding, because beds are generally much thicker such that one outcrop is often composed of only one bed. Outcrops of upper Bowser Lake Group are characteristically rusty-brown weathering, whereas Skeena outcrops generally lack such weathering and appear much fresher. Bivalves and belemnites are widespread and abundant in Bowser Lake lithologies, but are rare in Skeena sediments. On the other hand, sticks, twigs and woody debris commonly occur in Skeena sediments, but have not been observed in Bowser Lake Group in the Terrace area. The presence of detrital white mica is generally characteristic of Skeena Group. Such differentiating criteria are less pronounced along Kitsumkalum Road in the northwestern corner of the map area (Fig. 2). There, sedimentary rocks hold characteristics of both units and may be transitional between Bowser Lake and Skeena groups.

The same holds at about the same latitude, but farther east along Highway 16 (Fig. 2) at outcrops of interlayered siltstone and greywacke or fine conglomerate. Blue-grey greywacke/fine conglomerate forms metre-scale beds and is clast supported with clasts composing 60 to 100% of the rock. Clasts are up to 1.5 cm in size and consist of translucent grey quartz, a white aphanitic quartz+feldspar mixture, off-white cherty rock, quartz+feldspar+pyrite granitoid-looking rock, black siltstone, and aphanitic greenish rock. Black siltstone forms layers of 10 cm or less. These conglomeratic rocks were previously mapped (Woodsworth et al., 1985) as Trout Creek assemblage. However, they occur between (to the south) lower Oxfordian (ammonites; Duffell and Souther, 1964), rusty-weathering rocks clearly belonging to Bowser Lake Group and (to the north) grey, plant fossil-bearing, interbedded sandstone and siltstone typical of Skeena Group. As one travels north on the highway along an approximately 8 km stretch, one observes rocks with gradually fewer characteristics of Bowser Lake Group and more typical of Skeena Group; outcrops become less pyrite-rich and rusty weathering, and bedding thins from outcrop size to more regular 0.5 to 1 m thickness. Marine invertebrate fossils, abundant to the south, are not found in the transition zone; neither are plant fossils contained in Skeena Group rocks farther north. In the southern portion of the transition zone greywacke and conglomerate contain predominantly volcanic and shaly clasts. Quartz and possibly chert clasts occur in the northern section of the transition zone. This conglomeratic section appears to belong to a Bowser Lake/Skeena transition, rather than to Trout Creek assemblage.

Hazelton Group and older Stikine lithologies

The Hazelton Group is a Lower and Middle Jurassic volcanic arc assemblage of Stikine terrane. In Terrace area, it is composed of Smithers and Telkwa formations. Smithers Formation was mapped by Woodsworth et al. (1985) in the northeast quadrant of the area, where it consists of greenish volcanic sandstone, siltstone, tuff, tuffaceous sediments, and tuff breccia of Early Bajocian age. Telkwa Formation is widespread particularly on the eastern side of the map area (Fig. 2). It was described by Woodsworth et al. (1985) as Carnian and Early Sinemurian calc-alkaline basalt to rhyolite breccia, tuff, and flows with minor intravolcanic sediments. Where mapped in 1994 and 1996, it consists of tuff, flows, breccia, and ignimbrite. Red and green tuff and lesser breccia are composed of fine grained matrix with angular to rounded lithic clasts and, locally, feldspar fragments. Clasts vary in size between 0.5 and 100 cm and consist predominantly of Telkwa lithologies and rare granitoid rock. Red and green flows (locally sills or dykes?) are texturally massive, porphyritic, vesicular, or amygdaloidal. Feldspar porphyritic flows are relatively abundant, and feldspar porphyries are common clasts in tuff and breccia. Amygdules contain calcite, epidote, prehnite, pumpellyite, and/or zeolite minerals. Epidote lenses of 0.5 to 30 cm size occur locally. Flow composition ranges from dacitic to basaltic. Reddish-brown, flow-banded (at millimetre scale) rhyolitic feldspar porphyry is minor.

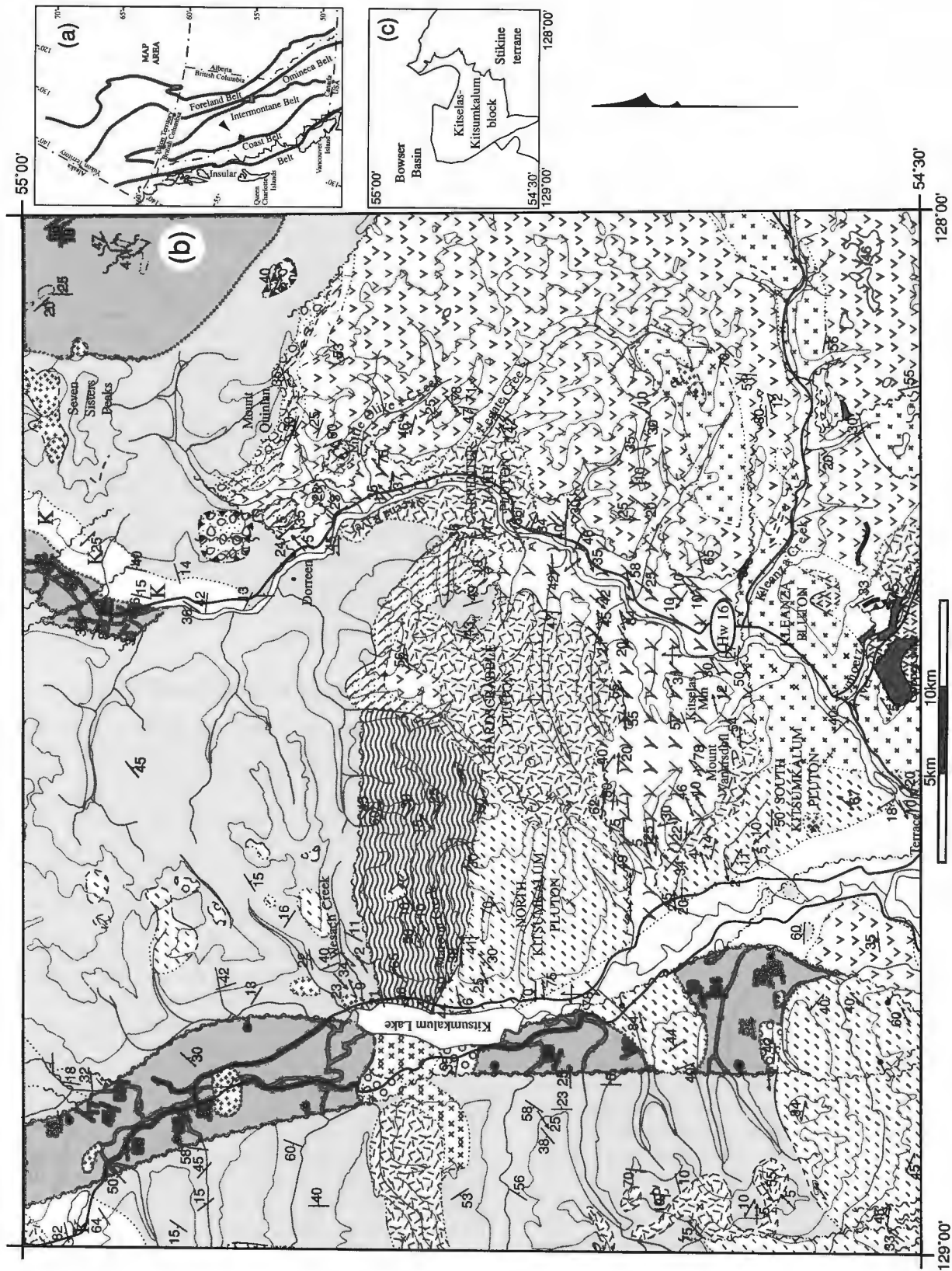
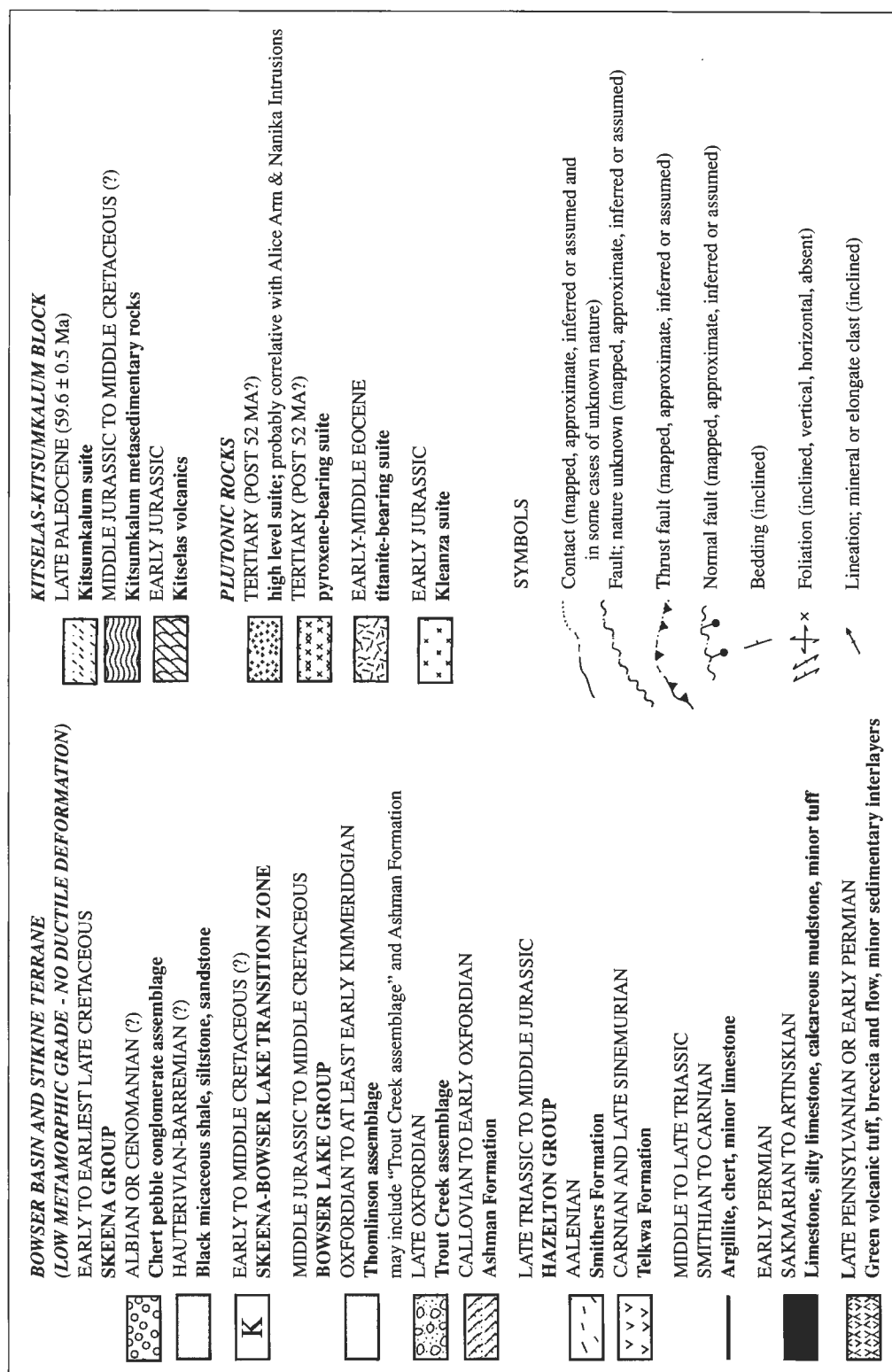


Figure 2. a) Location of map area. b) Geological map of the northeastern part (1031/9, 10, 15 and 16) of the Terrace map area, with sample locations and fossil localities. c) Approximate extent of the three major tectonic domains in the area.



Telkwa Formation unconformably overlies both Late Triassic argillite and Permian limestone. Permian limestone is a thin-bedded (5 to 30 cm) buff- to light grey-weathering, clean white limestone with minor brown-weathering dolomitic and or fine argillaceous interlayers. This rock grades upward into a thicker-bedded carbonate, and the uppermost part of the carbonate has conspicuous brick-red bands, possibly indicating some distal volcanism in Permian time. Layering is continuous and gently warped.

Dark green volcanic rocks in proximity to Permian limestone near Copper Mountain (Fig. 2) appear to stratigraphically underlie the limestone. At the one location where the contact was seen, it is a fault. This Pennsylvanian-Permian (Gareau et al., 1997) volcanic unit consists of feldspar-rich intermediate to mafic tuff and breccia, and possibly basalt flows. Much of the rock is pyritiferous, dark green, aphanitic to fine grained, siliceous plagioclase megacrystic volcanic with abundant epidote and lesser chlorite replacing the feldspar. Breccia is composed of pale green, epidote-rich matrix and dark green subangular to angular volcanic clasts. Minor rusty weathering, pyrite-bearing, chlorite-white mica-quartz interlayers are probably intravolcanic sediments.

Kitselas volcanics

North of Terrace, an area of about 7 by 25 km is underlain by an Early Jurassic unit (Gareau et al., 1997) informally called Kitselas volcanics, which is composed of predominantly felsic rock with minor (up to 10%) mafic interlayers. The volcanic unit is separated from roughly coeval Telkwa Formation based on compositional, metamorphic, and deformational criteria. It is predominantly felsic in nature, whereas Telkwa Formation in Terrace area is mostly composed of intermediate to mafic rocks. In contrast to surrounding Stikine terrane lithologies, Kitselas volcanics are locally metamorphosed to greenschist facies and strongly ductilely deformed. The unit is in fault contact with most surrounding rocks, and the relationship of Kitselas volcanics to neighbouring Stikine terrane or Coast Plutonic Complex is not yet fully understood.

The felsic portion of Kitselas volcanics comprises dacitic and rhyolitic tuff, breccia and flows, including feldspar-quartz porphyry layers. The rock is composed predominantly of fine grained quartz and feldspar, lesser white mica, and local pyrite, with up to 20% phenocrysts. In many samples, fine grained quartz and feldspar are aggregated in a rounded, elongate shape surrounded by fine grained white mica; lens-shaped quartz and feldspar aggregates are probably clast relicts. Mafic layers consist of green aphanitic rock, locally megacrystic or with chlorite knots after biotite or amphibole megacrysts; biotite±chlorite±actinolite±white mica schist; silvery-grey biotite>white mica quartzofeldspathic schist with quartz and feldspar augen; and greenish biotite-chlorite quartzofeldspathic semi-schist. Epidote and disseminated pyrite are widespread.

Although the volcanic unit preserves many primary features such as good bedding and local flow banding, it is locally foliated and lineated. In places, such as near the Skeena River, deformation is quite strong and penetrative. Elsewhere, such as on Kitselas and Vanarsdoll mountains (Fig. 2), deformation

appears somewhat weaker and stronger fabrics tend to be concentrated in narrow zones. Foliated feldspar-amphibole porphyry dykes cut the volcanic rock. A Late Cretaceous (Gareau et al., 1997) foliated and lineated biotite-feldspar porphyry dyke also cuts the Kitselas volcanics indicating that at least some of the deformation in the volcanic rock postdates emplacement of the dyke. Undeformed Eocene (Gareau et al., 1997) plutons intrude the Kitselas volcanics; the contacts between the two units are sharp and granitoid apophyses in the volcanic rock are abundant. Deformation in the Kitselas volcanics therefore predates the mid-Eocene.

Bowser Lake Group sedimentary rocks and Kitselas volcanics are probably in fault contact. The contact between Kitselas volcanics and Hazelton Group was nowhere seen, but is inferred to be a gently dipping fault based on the orientation of fabric in the Kitselas volcanics (see Fig. 2), and on the distribution of the two units on the slopes east of Highway 16 between Kleanza Creek and the village of Doreen. On a ridge between Little Oliver and Legate creeks, typical red and green Telkwa Formation tuffaceous rocks are in fault contact with white-weathering, fine grained grey siliceous rock with local quartz and/or feldspar megacrysts and local siliceous clasts. The unit resembles Kitselas volcanics, but does not appear to be metamorphosed to greenschist facies and does not exhibit any ductile fabrics. Down the ridge towards the inferred location of the Telkwa/Kitselas contact, sparse outcrops of siliceous rock show no evidence of ductile deformation down to 570 m elevation, below which outcrops are composed of siliceous volcanic rock with pervasive foliation and abundant biotite. We infer that the siliceous volcanic rock at low elevations belong to Kitselas volcanics proper. Siliceous volcanic rocks at higher elevations in which ductile fabric is absent are considered part of Hazelton Group and could well be the protolith to Kitselas volcanics. The contact between siliceous volcanic rock with ductile deformation and siliceous volcanic rock without ductile deformation was not seen, but it appears sharp rather than gradational, and is inferred to be a fault.

West of Hardscrabble pluton, the volcanic unit is bounded to the north by the variably deformed Paleocene (Gareau et al., 1997) North Kitsumkalum pluton. Apophyses of plutonic rock in the volcanic unit indicate an intrusive relationship. As well, the contact between the two units appears to be a steep shear zone. As the contact is approached, Kitselas volcanics are increasingly mylonitized. Near the contact, mylonites are coarser grained and resemble sheared plutonic rock more than sheared Kitselas volcanics. Across the contact, mylonitic plutonic rocks are interleaved with less deformed plutonic rock, mylonites disappear, and within approximately 1 km of the contact, the rock is unfoliated. The contact between Kitselas volcanics and the South Kitsumkalum pluton was not seen, but based on observations at an outcrop of Kitselas volcanics within the pluton, it is believed intrusive. The contact between the volcanic unit and the Kleanza pluton was not observed in this study, but it was previously mapped as a fault (Woodsworth et al., 1985).

Despite being compositionally different from adjacent and coeval Telkwa Formation, we believe that the Kitselas volcanic succession belongs to Hazelton Group, because

volcanic sequences of the same age and lithologically very similar to Kitselas volcanics occur elsewhere in Hazelton Group (Gareau et al., 1997).

Plutonic rocks

The earliest Jurassic (Gareau et al., 1997) Kleanza suite consists of unfoliated, medium grained biotite±hornblende quartz diorite to granite. The hallmarks of this suite are the absence of fabrics, abundant fractures giving the rock a crumbly texture, orange and green colour from feldspar alteration, presence of disseminated pyrite and locally other sulphides, weak to strong chloritization, presence of epidote veins, and aphanitic to fine grained, green, altered dykes (~5%). Kleanza plutons intrude rocks of Telkwa Formation, Permian limestone, and presumably older Stikine lithologies as well. South of Zymoetz River, the contact between green Telkwa volcanic rocks and a pluton assigned to the Kleanza suite is marked by an agmatite zone with angular to round xenoliths, up to 1 m across, of green volcanic rock in altered granodiorite. Near Copper Mountain, Permian limestone is contact metamorphosed adjacent to its sharp contact with plutonic rock of the Kleanza suite. Kitselas volcanics are probably in fault contact with Kleanza suite. Near Mount Vanarsdoll, the two units are separated by a younger intrusion. The contact between plutonic rocks of the Kitsumkalum and Kleanza suites was not observed.

North and northwest of Terrace, the heterogeneous Late Paleocene (Gareau et al., 1997) Kitsumkalum suite consists mainly of three rock types (Fig. 3). Most abundant is variably foliated and locally lineated, medium- to coarse-grained, titanite-bearing biotite>hornblende diorite to granodiorite with minor pyrite and local feldspar (both plagioclase and potassium feldspar) phenocrysts. Minor felsic, medium grained, titanite-bearing biotite tonalite occurs as dykes and apophyses in intermediate rock. More mafic titanite-bearing, biotite quartz diorite occurs as xenoliths in felsic and intermediate rock. Local fabric is ductile and probably resulted from deformation during or soon after plutonism. The North Kitsumkalum pluton is in sharp intrusive contact with penetratively deformed and metamorphosed, apparently predominantly sedimentary rocks, possibly, but not necessarily, of the Bowser Lake Group (see below). Plutons of the Kitsumkalum suite are in intrusive contact (locally sheared) with the Kitselas volcanics. Penetrative ductile fabrics are similar in nature and orientation in both units. At one location where the North Kitsumkalum pluton intrudes Kitselas metavolcanic rocks, the units are both foliated and the fabric is continuous across the contact (Fig. 4); this implies that the two units were deformed simultaneously.

Throughout the map area, plutons of biotite±minor hornblende granodiorite to granite crosscut other units, contacts, and fabrics. They are unfoliated, except at their margins where they locally are weakly foliated. Well-formed, very fresh crystals and abundant titanite are characteristic of these plutons. The presence of these 52–53 Ma (Gareau et al., 1997) plutons indicate that all metamorphism and deformation predates Early-Middle Eocene. For example, the unfoliated Hardscrabble pluton, of inferred Eocene age, intrudes the

foliated Paleocene North Kitsumkalum pluton, meta-sedimentary rocks north of the pluton, Kitselas volcanics south of the pluton, as well as the contacts between the three units and fabrics in those units. This indicates not only that deformation in the pluton, the Kitselas volcanics, and the metasedimentary rock predates Early-Middle Eocene, but that emplacement of these units in their current position with

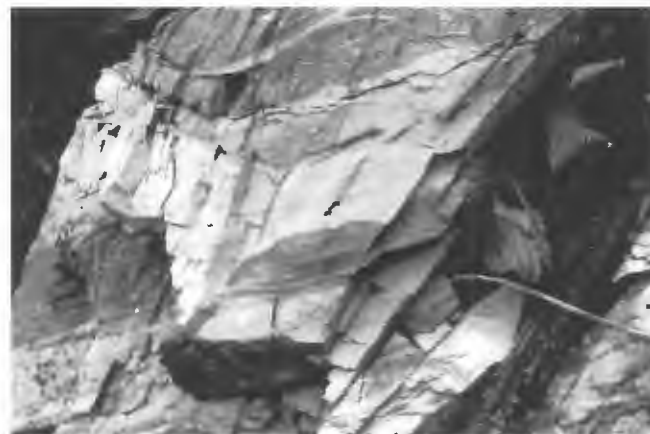


Figure 3. The north Kitsumkalum pluton, like others in the Kitsumkalum suite, is heterogeneous and variably deformed. Photograph taken from an outcrop along the eastern shore of Kitsumkalum Lake. Hammer for scale in upper right.



Figure 4. Intrusive contact between Kitselas volcanics (top) and North Kitsumkalum pluton (bottom). Note that foliation is continuous across the contact. Photograph taken at the northern margin of the pluton. There, the pluton mostly intrudes Kitsumkalum metasedimentary rocks (see Fig. 5), except in a small area where it intrudes Kitselas volcanics. This suggests that the Kitselas metavolcanic rocks were in contact with the Kitsumkalum metasedimentary rocks prior to intrusion of the North Kitsumkalum pluton, supporting an interpretation that the Kitselas-Kitsumkalum block was emplaced tectonically into Stikine terrane and Bowser Lake/Skeena overlap assemblages.

respect to each other also predates this time. As well, the Hardscrabble pluton intrudes Bowser Lake Group and Telkwa Formation, and the Eocene Carpenter Lake pluton intrudes the contact between Kitselas volcanics and Telkwa Formation, indicating that the Kitselas volcanics were in place relative to Bowser Lake Group and Telkwa Formation prior to Early-Middle Eocene.

West of Kitsumkalum Lake, Skeena and Bowser Lake lithologies are intruded by an undeformed pluton dissimilar to any other in the map area. It is a green weathering, fine- to medium-grained, pyroxene-potassium feldspar-rich rock, apparently of syenitic composition. Heavily sericitized feldspar is the most abundant mineral (~60%). Quartz is minor. Mafic components are pyroxene (~25%), chlorite (<5%), minor epidote, and locally biotite. Because it is undeformed, this pluton is thought to be young, probably Tertiary.

Small discordant bodies of undeformed, brown- or pink-weathering, leucocratic plutonic rock occur throughout the map area. These bodies are granodioritic to granitic in composition and often contain feldspar phenocrysts. Minor mafic minerals are hornblende and lesser biotite. Miarolitic cavities suggest emplacement at high levels. These plutons are interpreted as the youngest suite in the map area. Interestingly, many small such plutons occur in the Kitsumkalum valley near the boundaries between Skeena and Bowser groups. These boundaries have been interpreted (G.J. Woodsworth, unpub. data, 1984) as steep normal faults on either sides of a Tertiary graben structure in which Skeena lithologies were downdropped into juxtaposition with rocks of Bowser Lake Group forming the broad and straight Kitsumkalum valley.

Metamorphic rocks north of Kitsumkalum pluton

Metamorphic rocks north of the Kitsumkalum pluton have been divided into two units. Immediately north of the pluton, in a poorly defined 3-7 km wide zone, are biotite semi-schist, grey slate, white mica phyllite, metaconglomerate, quartzite, and epidote-bearing siliceous rock informally called the Kitsumkalum metasedimentary unit. This assemblage likely is metamorphosed Bowser Lake Group except at one location south of Maroon Creek where the rock resembles Kitselas volcanics. The assemblage is differentiated from rocks farther north by the presence of a penetrative fabric, including a well-developed schistosity, local lineation, and small-scale folds (Fig. 5). Penetrative deformation disappears abruptly approximately 2 km south of Wesach Creek. Rocks farther north clearly belong to Bowser Lake Group; they consist of hornfelsed, flinty siltstone with fine (approximately 5 mm apart) cleavage marked by thin phyllitic surfaces. Rare shaly layers are schistose. These rocks grade into uncleaved dark grey, pyritiferous siltstone/fine sandstone, graphitic shale, and minor calcareous lenses and layers.

The degree of deformation and metamorphism in the Kitsumkalum metasedimentary rocks and the sharp transition between these ductilely deformed rocks and cleaved hornfelsed Bowser Lake lithologies suggest that the metasedimentary rocks are not merely contact metamorphosed, but may have been emplaced along with the Kitsumkalum

pluton into Bowser Lake Group. The hornfelsed and cleaved rocks of Bowser Lake Group would thus represent the true contact aureole to both the Kitsumkalum pluton and associated metasedimentary rocks.

Deformation

All rocks show evidence of late brittle faulting. Ductile penetrative deformation is restricted to the Kitsumkalum plutonic suite, Kitselas volcanics, and Kitsumkalum metasedimentary rocks. In these rocks, foliation is absent to well developed and locally folded at small (<1 m) scale. Lineation is absent to strong, generally shallow, and within certain areas, of consistent orientation.

In the northeast corner of the map area, large (hundreds of metres amplitude), tight folds are present in Bowser Lake Group strata on Mt. Quinlan and the Seven Sisters (Fig. 2). Also in the north, between Skeena and Cedar rivers, Bowser Lake Group rocks have been deformed in a series of east-directed folds and thrusts. This belt is the southern extension of the Skeena Fold Belt described by Evenchick (1991).

Metamorphism

Rocks of Skeena, Bowser Lake, and Hazelton groups are surprisingly unmetamorphosed considering their proximity to large plutonic bodies and high grade metamorphic rocks of the Coast Plutonic Complex. Outside rare and narrow contact aureoles to plutons, Skeena and Bowser Lake lithologies have been subjected to no more than very low grade metamorphism. Metamorphic grade in Telkwa Formation is in the zeolite to prehnite-pumpellyite facies. Only the Kitselas volcanics and Kitsumkalum metasedimentary rocks have been metamorphosed to greenschist grade as indicated by biotite±chlorite±actinolite±white mica assemblage in mafic layers of the Kitselas volcanics. Kitsumkalum metasedimentary rocks contain biotite-muscovite-quartz-feldspar±chlorite±zoisite. Andalusite was also reported (G.J. Woodsworth, unpub. data, 1984).

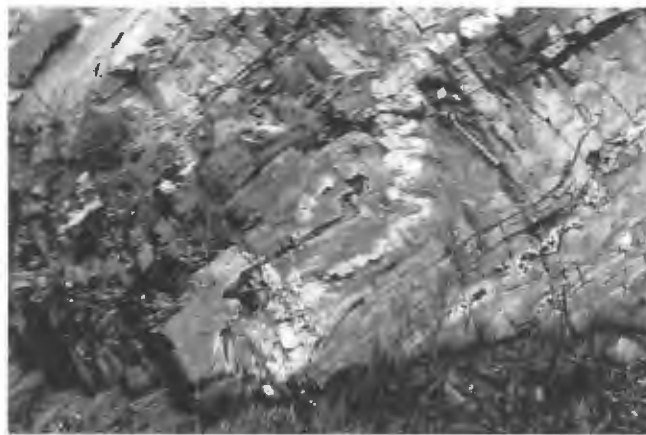


Figure 5. Kitsumkalum metasedimentary rocks. Photograph taken near northeastern end of Kitsumkalum Lake.

The Kitselas-Kitsumkalum block

The Kitselas volcanics, North and South Kitsumkalum plutons, and associated Kitsumkalum metasedimentary rocks share characteristics differentiating these rocks from surrounding Stikine terrane and Skeena-Bowser Lake overlap assemblages. Greenschist metamorphic grade in the Kitselas volcanics and Kitsumkalum metasedimentary rocks contrasts with very low metamorphic grade in the rest of the map area. The ductile deformational style in these three units differs from predominantly brittle deformation in the rest of the area. The timing of ductile deformation appears roughly coincident in all three units: deformation in the Kitsumkalum pluton is bracketed to Late Paleocene-mid-Eocene; in Kitsumkalum metasedimentary rocks and Kitselas volcanics it predates mid-Eocene; at least some fabrics in Kitselas volcanics post-date Late Cretaceous dyking. The three units are geographically associated and form a block that appears in fault contact with surrounding units. We infer that this block was tectonically exhumed into its current position during or after Kitsumkalum plutonism. We think that this Kitselas-Kitsumkalum block need not have travelled very far, because 1) nearby felsic volcanoclastic rocks of Hazelton Group form a potential protolith to Kitselas volcanics, 2) Kitsumkalum metasedimentary rocks could be metamorphosed Bowser lithologies, and 3) plutons similar to the North and South Kitsumkalum plutons intrude rocks outside the block within the map area.

ACKNOWLEDGMENTS

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REFERENCES

- Bassett, K.N.**
1995: A basin analysis of the Lower to mid-Cretaceous Skeena Group, west-central British Columbia: implications for regional tectonics and terrane accretion; Ph.D. thesis, University of Minnesota, 413 p.
- Duffell, S. and Souther, J.G.**
1964: Geology of Terrace map-area, British Columbia (103I E½); Geological Survey of Canada, Memoir 329, 117 p.
- Evenchick, C.A.**
1991: Geometry, evolution, and tectonic framework of the Skeena fold belt, north-central British Columbia; *Tectonics*, v. 10, p. 526-546.
- Gareau, S.A., Friedman, R.M., Woodsworth, G.J., and Childe, F.**
1997: U-Pb ages from the northeastern quadrant of Terrace map area, west-central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Heah, T.S.T.**
1991: Latest Cretaceous to Eocene extension along the eastern margin of the Central Gneiss Complex, Coast Belt, Shames River area, near Terrace, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, British Columbia, 136 p.
- Mihalynuk, M.J.**
1987: Metamorphic, structural and stratigraphic evolution of the Telkwa Formation, Zymoetz River area (NTS 103I/8 and 93L/5), near Terrace, British Columbia; M.Sc. thesis, University of Calgary, Calgary, Alberta, 128 p.
- Richards, T.A., Woodsworth, G.J., and Tipper, H.W.**
in press: Geology, Hazelton (93M) map area, British Columbia; Geological Survey of Canada, Map 1852A, scale 1:250 000.
- Tipper, H.W. and Richards, T.A.**
1976: Jurassic stratigraphy and history of north-central British Columbia; Geological Survey of Canada, Bulletin 270, 73 p.
- Woodsworth, G.J., Hill, M.L., and van der Heyden, P.**
1985: Geology, Terrace B.C. 103I east half; Geological Survey of Canada, Open File 1136, scale 1:125 000.

Geological Survey of Canada Project 940008

Nechako Plateau NATMAP Project overview, central British Columbia, year two¹

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Struik, L.C. and MacIntyre, D.G., 1997: Nechako Plateau NATMAP Project overview, central British Columbia, year two; in Current Research 1997-A; Geological Survey of Canada, p. 57-64.

Abstract: More than 25 government, university and industry researchers were active in the 1996 field season of the joint Geological Survey of Canada and British Columbia Geological Survey Branch Nechako Plateau project. Bedrock geology was mapped in ten 1:50 000 scale map areas and surficial geology in five 1:50 000 scale map areas. Researchers sampled till, silt, lodgepole pine, and rocks in various geochemical studies. Others measured gravity, magnetic, electromagnetic, and paleomagnetic signatures; studied biostratigraphy; sampled for radio-isotopic-age dating; and conducted detailed sedimentological and stratigraphic studies. New geoscience contributions include: 1) defining some protolith and uplift ages of the Vanderhoof Metamorphic Complex, 2) more clearly defining Tertiary volcanic stratigraphy and crustal structures, 3) detailed differentiation of the plutonic suites ranging from Late Triassic through to Eocene, 4) defining the northwestern extent of glacial Lake Fraser, 5) establishing the ice flow and glaciofluvial patterns west of Takla Lake, and 6) geophysically imaging boundaries to the Vanderhoof Metamorphic Complex.

Résumé : Au cours de la campagne de 1996 du projet du plateau de Nechako réalisé conjointement par la Commission géologique du Canada et la Commission géologique de la Colombie-Britannique, plus de 25 chercheurs du gouvernement, du milieu universitaire et de l'industrie ont participé à des travaux. La géologie du substratum rocheux a été cartographiée à l'échelle de 1/50 000 dans dix régions cartographiques et la géologie des dépôts de surface, à la même échelle dans cinq régions cartographiques. Des chercheurs ont échantillonné du till, du silt, des pins tordus et des roches dans le cadre de diverses études géochimiques. D'autres ont mesuré les signatures gravimétriques, magnétiques, électromagnétiques et paléomagnétiques, analysé la biostratigraphie, prélevé des échantillons en vue de leur datation radiométrique et réalisé des études sédimentologiques et stratigraphiques détaillées. Les nouvelles contributions aux sciences de la Terre sont notamment : 1) la datation de certains protolites et soulèvements du Complexe métamorphique de Vanderhoof, 2) la définition plus précise de la stratigraphie des roches volcaniques et des structures crustales du Tertiaire, 3) la différenciation détaillée des suites plutoniques qui s'échelonnent du Trias tardif à l'Éocène, 4) la délimitation du prolongement nord-ouest du Lac glaciaire Fraser, 5) la détermination de l'écoulement glaciaire et des configurations fluvioglaciaires à l'ouest du lac Takla et 6) l'enregistrement d'images géophysiques des limites du Complexe métamorphique de Vanderhoof.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

The Nechako Plateau NATMAP project is a joint mapping venture with the Geological Survey of Canada (GSC), British Columbia Geological Survey Branch (BCGSB), universities, and industry (Struik and McMillan, 1996; McMillan and Struik, 1996). The project encompasses over 30 000 km² in central British Columbia (Fig. 1). Its main focus is to improve the quality and detail of bedrock and surficial maps to help resolve several geological problems. In particular it addresses the following questions: 1) 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.

In this second field season of the Nechako Plateau NATMAP project, a total of 15 new 1:50 000 scale areas have been mapped for their bedrock (10) and surficial (5) geology (Fig. 2). In addition detailed sampling, geophysical and remote sensing surveys, and stratigraphic studies have been undertaken. Samples were collected for till, silt, lake, biological and lithological chemistry, and paleontological and radio-isotopic geochronology. Geophysical line surveys included ground-based magnetics, gravity, and electromagnetics. Stratigraphic studies concentrated on sections within the Cache Creek Group near Fort St. James and mainly volcanic sequences of the Ootsa Lake and Endako groups. Digital GIS projects included final compilations of data on the Quesnel Trough, compilation of mapping data from Placer Dome Incorporated, and cartography of some existing geology maps.

This paper outlines research that in many cases is preliminary. References are given to more in depth summaries in this volume and Geological Fieldwork 1996 of the British Columbia Ministry of Employment and Investment. The continuing research will lead to more comprehensive government and journal reports and maps. Analytical data are not reported in this paper.

Throughout the papers the following abbreviations may be used:

BCGSB	– British Columbia Geological Survey Branch
CD-ROM	– Compact Disk-Read Only Memory
GIS	– Computer Geographic Information Systems
GSC	– Geological Survey of Canada
KU	– Kyushu University, Japan
MDRU	– Mineral Deposits Research Unit at UBC
SFU	– Simon Fraser University
UA	– University of Alberta
UBC	– University of British Columbia
UCH	– Université de Chambéry, France
UJF	– Université Joseph Fourier, France
UL	– University of Lethbridge
UNB	– University of New Brunswick
UVIC	– University of Victoria
UWO	– University of Western Ontario

OVERVIEW OF NECHAKO PLATEAU PROJECT RESULTS TO DATE

Bedrock mapping

Don MacIntyre, Ian Webster and Pat Desjardins (BCGSB) with the assistance of summer students Joseph Schrank and Susan Hand completed 1:50 000 scale geological mapping of the Old Fort Mountain map area (93M/1) (Fig. 2, D) (MacIntyre and Webster, 1997). The main objective of this work is to produce detailed geological maps of the economically important Babine Porphyry belt that can be integrated with concurrent surficial and geochemical surveys in an attempt to define new exploration targets.

Mapping to date, which has focused on new areas of rock exposure created by logging activities, plus new fossil collections and isotopic age dating (Villeneuve and MacIntyre, in press), has helped to place previous mapping by Carter (1973), Tipper and Richards (1976), and Richards (1990) into a modern stratigraphic framework. As a result, the extent and evolution of Eocene volcanic basins, and associated porphyry copper deposits has been better defined.

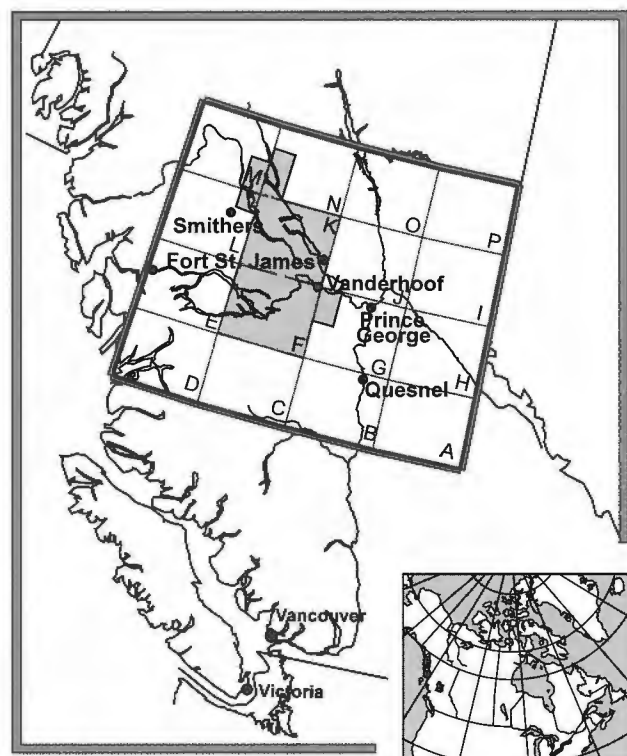


Figure 1. Location of the Nechako Plateau NATMAP project. The Parsnip River (NTS 93) 1:1 000 000 scale map area is shown for reference.

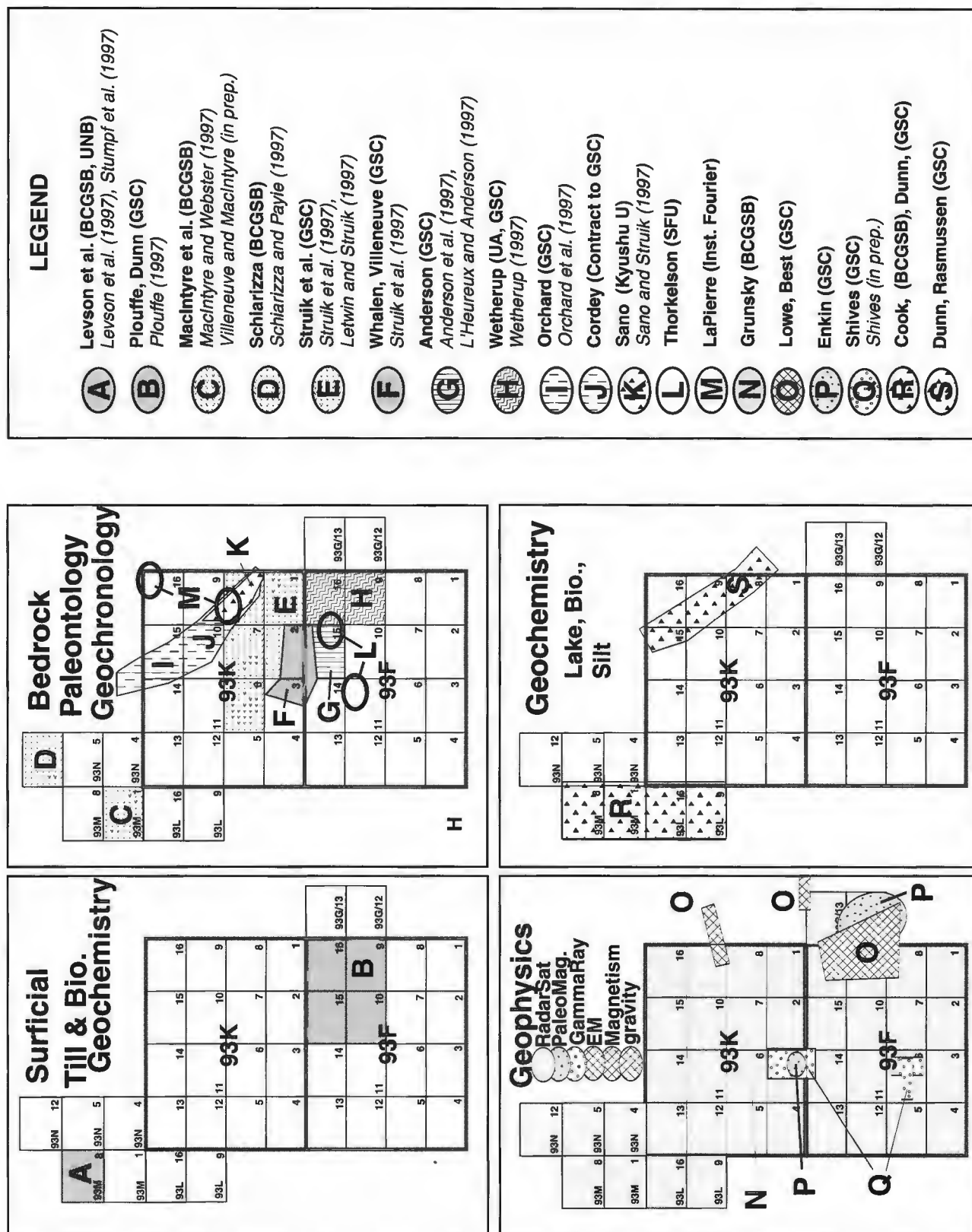


Figure 2. Location of various Nechako subprojects active in 1996.

Eocene volcanic basins are believed to have formed over several million years as pull-apart structures on right lateral transcurrent faults related to a regional Eocene transtensional tectonic event. Age dating and mapping suggest basin development began by building stratovolcanoes, emplacement of high level stocks, dykes and domes of biotite-feldspar porphyry and rhyolite, and formation of porphyry copper deposits. This was followed by block faulting and subsidence to form north-trending grabens.

A better understanding of the Jurassic stratigraphy of the area has evolved through this project. Of particular interest is a succession of Lower to Middle Jurassic bimodal volcanic rocks that overlie the Lower Jurassic Telkwa and Nilkitkwa formations. This unit, first recognized in the area west of Granisle (MacIntyre et al., 1996) where a 183.5 Ma U-Pb isotopic age was determined on an ash flow member. It is now known to extend as far northward as Hearne Hill. A major component of this package is an ash flow unit exposed in a clearcut on the south flank of Hearne Hill. This unit could be up to 1000 m thick. A sample of this ash flow was collected for U-Pb isotopic dating. The volcanic succession thickens and becomes more vent proximal northward suggesting a major eruptive centre is located in this direction.

Paul Schiarizza and Garry Payie (BCGSB) conducted bedrock mapping on the east side of Takla Lake in the western part of the Manson River map area (93N/12,13) (Fig. 2, C) (Schiarizza and Payie, 1997). This mapping has resulted in an improved understanding of the stratigraphy and structure of the Sitlika assemblage (Paterson, 1974), and its structural relationships with Cache Creek terrane to the east and Stikine Terrane to the west (Schiarizza and Payie, 1997).

Mapping of the Sitlika belt is supported by U-Pb radiometric dating and geochemical studies carried out by Fiona Childe of the Mineral Deposits Research Unit of University of British Columbia (Childe and Schiarizza, 1997). The lithology and stratigraphy, Permo-Triassic age, and primitive tholeiitic geochemistry of the Sitlika assemblage confirm its correlation with the Kutcho Formation of northern British Columbia (Monger et al., 1978). This formation hosts the Kutcho Creek volcanogenic massive sulphide deposit.

Bert Struik (GSC) and a crew of five university students conducted bedrock mapping in the southeast quadrant of Fort Fraser map area (93K/1,2,6,7,8; Struik et al., 1997; Whalen and Struik, 1997; Fig. 3, E). The mapping yielded new stratigraphic information for the Tertiary Endako and Ootsa Lake groups, and refined the distribution of the metamorphic facies of the Cache Creek Group. In addition, the work better defined the distribution and characterized contact relationships of some of the Mesozoic plutonic bodies and determined the tectonic block fault pattern in some of the Tertiary sequences.

Janice Letwin (University of Alberta), with the assistance of Jennifer Hobday (University of British Columbia), in addition to conducting regional mapping, initiated a Bachelors thesis on the geology of the Shass Mountain area underlain primarily by Cache Creek Group ultramafic, mafic and pelagic metasedimentary rocks (Letwin and Struik, 1997). Further mapping throughout the area was conducted by Rob

L'Heureux (University of Alberta), with the assistance of Susan Wiebe (University of Western Ontario). Holly Keyes (Simon Fraser University) assisted the project in all aspects and in particular in computer systems and data management.

As part of the regional mapping of the Cache Creek Group, a contract research project has been conducted by Fabrice Cordey on the radiolarian biostratigraphy (Fig. 2, L). This work will assist in defining the age range, paleogeographic setting, biostratigraphy, and structures of the Cache Creek Terrane in the central Canadian Cordillera. More detailed results from last summer's sampling are reported in Cordey and Struik (1996). Newly determined age relationships have been used to locate a thrust fault, and established a Triassic age range for ribbon cherts of the Cache Creek Group in the vicinity of Fort St. James.

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

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

Bob Anderson (GSC) with Rob L'Heureux conducted 1:50 000 mapping of the Hallet Lake map area (93F/15, Fig. 2G; Anderson et al., 1997). Mesozoic and Tertiary volcanic units were distinguished. Mesozoic sedimentary and volcanic sequences locally are overturned to the north-northwest; Jurassic, and Early and Late Cretaceous plutonic suites were mapped and some Early Cretaceous phases are correlative with the Endako Mine camp and host widespread molybdenite showings. Follow-up mineralogical, chemical, and geochronological work will define the composition and age of these suites. Rob L'Heureux's Bachelor's thesis at the University of Alberta concerns the geological, petrological, and geochronological character of the plutonic suites which host the Nithi Mountain Molybdenum showings (L'Heureux and Anderson, 1997).

Lithological, textural, and structural characteristics of the Eocene Ootsa Lake, Eocene-Oligocene Endako and Miocene Chilcotin groups were documented and contrasted. Mapping and analysis of plutonic rocks suggest at least five magmatic

episodes whose character, age, distribution, and composition were previously unknown; many are typical of plutonism recognized elsewhere in Stikine and Quesnel terranes; Early Cretaceous plutonism is unique to the Nechako Plateau NATMAP Project area and hosts the Endako porphyry molybdenite deposits.

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

Surficial mapping and geochemistry

Surficial geology, till geochemistry and Quaternary stratigraphy studies were conducted in the 1996 Nechalzo Plateau NATMAP project area by BCGSB staff (Vic Levson, Dan Meldrum, Erin O'Brien and Craig Churchill) in collaboration with researchers from the University of New Brunswick (Andrew Stumpf and Bruce Broster), the Geological Survey of Canada (Alain Plouffe) and the Ministry of Forests (Brent Ward) (Fig. 2, A) (Levson et al., 1997; Stumpf et al., 1997). Time-stratigraphic, 1:50 000, surficial geology mapping, incorporating local and regional ice flow history data, was conducted in map area 93M/8. This work extended 1995 mapping on 93L/16 and 93M/1 and provided a complete overview of the surficial geology of the Babine copper porphyry belt.

Ice flow studies in the porphyry belt show a dominant regional southeasterly flow. Glacial dispersal patterns of mineralized rock in the area reflect this dominant southeasterly flow. Surficial units, useful for tracing mineral anomalies to their bedrock source, and deposits such as glacial lake sediments, which limit the usefulness of soil geochemistry, were identified during the mapping program. Surficial geology data from the Babine area will also be integrated with new bedrock geology mapping in the region.

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

Detailed case study investigations were conducted in collaboration with Steve Cook (BCGSB) and industry geologists at the Hearne Hill, Lennac Lake, Nak and Trail Peak copper

porphyry prospects. The work included detailed lithological, sedimentological and geochemical studies of surficial sediments around areas of known mineralization. Processes of dispersal of mineralized bedrock debris from different deposit source types will be modelled to determine the size and shape of anomalies in various sediment facies and size fractions.

Steve Cook (BCGSB) conducted lake sediment, water and till geochemical studies in the map areas 93L/9, 93L/16, 93M/1, and 93M/8 (Fig. 2, R). The Babine regional lake sediment and water geochemistry survey was conducted over the entire Babine porphyry belt. Lake sediments and waters were obtained from 332 sites over the equivalent of four 1:50 000 scale map sheets in areas of ongoing bedrock mapping. In addition, case study investigations were conducted in collaboration with Vic Levson (BCGSB) at the Hearne Hill, Lennac, Nak, Trail Peak, and Dorothy prospects. The objective of these investigations is to document the till geochemical expression of the hydrothermal alteration zones associated with the Babine deposits.

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

Alain Plouffe (GSC), Francois Therrien and Holly Keyes conducted surficial mapping, and till and Lodgepole pine bark sampling throughout the northeast quadrant of the Nechako River map area (Fig. 2, B; Plouffe, 1997). The work has more clearly defined the distribution of Glacial Lake Fraser sedimentation in the area. Colin Dunn (GSC) worked with the group to establish and integrate the till and tree bark sampling program. The Lodgepole pine outer bark samples (236 sites) were collected throughout the same area and at most of the same till samples sites.

The complementary till and biogeochemical data will be used to assist regional mapping of till dispersal and concealed bedrock. In addition, bark analyses to date indicate zones of metal enrichment not previously reported near Nulki Lake (Mo, Cu, Ag), and north of Goldie Creek (Mo, Ba, Sr), both in 93F/16. The latter occurrence is in the vicinity of a quarry into layered felsic tuffs that have a tridymite coating on bedding surfaces.

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

Geophysical studies

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

Eric Grunsky (BCGSB) will be doing image analysis studies in the Nechako Plateau NATMAP area using RADARSAT data. Two standard images (100 x 100 km) and one ScanSAR (500 x 500 km) have been ordered through the Application Development and Research Opportunity Project.

The areas covered are:

Takla Lake area (93M/01, 08; 93N/04, 05; 93K/12, 13; 93L/09, 16)

Nechako River (93K/01, 02, 03; 93F/01, 02, 03, 06, 07, 08, 09, 10, 11, 14, 15, 16; 93C/06, 07, 09, 10, 11, 14, 15, 16)

NATMAP Project Area (93C,F,K,N)

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

Mel Best and Carmel Lowe (GSC), with students Michael Heyd (University of Victoria) and Jason Halko (University of Lethbridge), several conducted gravity, magnetic and electromagnetic (EM) surveys along transects that crossed the Pinchi Fault and the Vanderhoof Metamorphic Complex boundaries (Fig. 2, P). These integrated geophysical surveys were used to map three dimensionally faults, bedrock structures, and lithology beneath glacial drift.

Preliminary results indicate that drift-covered faults and contacts, and in some instances structural features, were detected using these methods. In addition the EM survey conducted by M. Best provided new information on the southern extent of glacial Fraser Lake sediments. C. Lowe has recently compiled the regional aeromagnetic and gravity data over the entire Nechako NATMAP area and has carried out a preliminary interpretation.

Geochronology

Mike Orchard (GSC) and Hillary Taylor (GSC) sampled the Mount Pope limestone of the Cache Creek Group near and northwest of Fort St. James (Fig. 2, F); this sampling also complemented the detailed stratigraphic studies of Hiroyoshi Sano (Kyushu University, Japan). This work is a follow up to

sampling and conodont determinations done prior to the NATMAP project (Orchard and Struik, 1996) and those that resulted from collections made during 1995 (Orchard et al., 1997). New conodont data from a northeast transect from Stuart Lake to Pinchi Lake show that the limestone youngs from Late Carboniferous (Bashkirian to Moscovian) to Early Permian (probably Gzhelian-Asselian). Limestone in basalt outcropping adjacent to Stuart River at Fort St. James is mid-Permian (Guadalupian). Anomalous Early Triassic conodonts are mixed with Carboniferous fauna in one collection from the region, implying a younger ?dissolution history for some of the Cache Creek limestones. Younger Triassic conodont fauna is now also known from west of Stuart Lake at Whitefish Bay.

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

Stratigraphy

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

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

Geographic Information Systems

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

Andrew Harries and Ralph Westera (GSC) completed the digitization of the Placer Dome Inc. geological maps and more than half of the accompanying approximately 35 books of field notes (Kimura et al., 1980). These maps were used as guides in the field mapping, and will be included in the compilation of the Nechako Plateau project maps.

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

REFERENCES

- Anderson, R.G., L'Heureux, R., Wetherup, S., and Letwin, J.**
1997: Geology of the Hallet Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous, and Eocene? plutonic rocks; in *Current Research 1997-A*; Geological Survey of Canada.
- Carter, N.**
1973: Preliminary geological map of northern Babine Lake area (93L/NE, 93M/SE); British Columbia Department of Mines, Preliminary Map 12.
- Childe, F. and Schiarizza, P.**
1997: U-Pb geochronology, geochemistry and Nd isotopic systematics of the Sitlika Assemblage, north-central British Columbia; in *Geological Fieldwork 1996*: British Columbia Ministry of Employment and Investment, Paper 1997-1.
- Cordey, F. and Struik, L.C.**
1996: Radiolarian biostratigraphy and implications, Cache Creek Group of Fort Fraser and Prince George map areas, central British Columbia; in *Current Research 1996-E*; Geological Survey of Canada, p. 7-18.
- Kimura, E.T., Bysouth, G.D., Cyr, J., Buckley, P., Peters, J., Boyce, R., and Nilsson, J.**
1980: Geology of parts of southeast Fort Fraser and northern Nechako River map areas, central British Columbia; Placer Dome Incorporated, Internal Report and Maps, Vancouver, British Columbia.
- L'Heureux, R. and Anderson, R.G.**
1997: Early Cretaceous plutonic rocks and molybdenite showings in the Nithi Mountain area, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Letwin, J.M. and Struik, L.C.**
1997: Geology of Shass Mountain, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Levson, V.M., Stumpf, A.J., and Broster, B.E.**
1997: Quaternary geology and regional till geochemical sampling, Babine Lake, British Columbia; in *Geological Fieldwork 1996*; British Columbia Ministry of Employment and Investment, Paper 1997-1.
- MacIntyre, D.G. and Webster, I.C.L.**
1997: Babine Porphyry Belt Project, bedrock geology of the Old Fort Mountain map area (NTS 93M01); in *Geological Fieldwork 1996*; British Columbia Ministry of Employment and Investment, Paper 1997-1.
- MacIntyre, D.G., Webster, I.C.L., and Bellefontaine, K.**
1996: Babine Porphyry Belt Project, bedrock geology of the Fulton Lake map area (NTS 93L16); in *Geological Fieldwork 1995*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1996-1.
- McMillan, W.J. and Struik, L.C.**
1996: Overview of the Nechako NATMAP project, central British Columbia; in *Geological Fieldwork 1995*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1996-1, p. 3-10.
- Monger, J.W.H., Richards, T.A., and Paterson, I.A.**
1978: The Hinterland Belt of the Canadian Cordillera: new data from northern and central British Columbia; *Canadian Journal of Earth Sciences*, v. 15, p. 823-830.
- Orchard, M.J. and Struik, L.C.**
1996: Conodont biostratigraphy, lithostratigraphy and correlation of the Cache Creek Group near Fort St. James, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 77-82.
- Orchard, M.J., Struik, L.C., and Taylor, H.**
1997: Conodont biostratigraphy and correlation, Cache Creek Group, Fort St. James, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Paterson, I.A.**
1974: Geology of Cache Creek Group and Mesozoic Rocks at the northern end of the Stuart Lake Belt, Central British Columbia; in *Report of Activities, Part B*; Geological Survey of Canada, Paper 74-1, Part B, p. 31-42.
- Plouffe, A.**
1996: Criteria for the recognition of "natural" mercury: An example from central British Columbia; *Geological Association of Canada, Annual Meeting, Winnipeg, Manitoba, Program with Abstracts*, v. 21, p. A76.
- 1997: Ice flow history and recessional phase of the Fraser Glaciation in central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Richards, T.A.**
1990: Geology of the Hazelton map area (93M); Geological Survey of Canada, Open File 2322.
- Sano, H. and Struik, L.C.**
1997: Field properties of Pennsylvanian-Lower Permian limestones of Cache Creek Group, northwest of Fort St. James, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Schiarizza, P. and Payie, G.**
1997: Geology of the Sitlika Assemblage in the Kenny Creek - Mount Olsen Area (93N/12, 13); in *Geological Fieldwork 1996*; British Columbia Ministry of Employment and Investment, Paper 1997-1.
- Struik, L.C. and McMillan, W.J.**
1996: Nechako Project overview, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 57-62.
- Struik, L.C., Whalen, J.B., Letwin, J., and L'Heureux, R.**
1997: General geology of southeast Fort Fraser map area, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Stumpf, A.J., Levson, V.M., and Broster, B.E.**
1997: Till geochemistry surveys in the Babine Porphyry Belt; in *Geological Fieldwork 1996*; British Columbia Ministry of Employment and Investment, Resources, Paper 1997-1.
- Tipper, H.W. and Richards, T.A.**
1976: Geology of the Smithers area; Geological Survey of Canada, Open File 351.
- Villeneuve, M.E. and MacIntyre, D.G.**
in press: Laser ^{40}Ar - ^{39}Ar ages of the Babine Porphyries and Newman Volcanics, Fulton Lake map area, west-central British Columbia; in *Radiogenic Age and Isotopic Studies: Report 10*; Geological Survey of Canada, Current Research 1996-F.

Wetherup, S.

1997: Geology of the Nulki Hills and surrounding area, central British Columbia; in Current Research 1997-A; Geological Survey of Canada.

Whalen, J.B. and Struik, L.C.

1997: Plutonic rocks of southeast Fort Fraser map area, central British Columbia; in Current Research 1997-A; Geological Survey of Canada.

Williams, S., Ballantyne, B., Balma, R., Bellefontaine, K., Dunn, C., Ferri, F., Grant, J., Plouffe, A., Shives, R., Sibbick, S., Struik, B., and GSC Geophysical Data Centre

1996: Quesnel Trough suite of digital data, central British Columbia; Geological Survey of Canada, Open File 3273, 1 CD-ROM; (also British Columbia Ministry of Employment and Investment, Open File 1996-19).

Geological Survey of Canada Project 950036

General geology of southeast Fort Fraser map area, central British Columbia¹

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Struik, L.C., Whalen, J.B., Letwin, J.M., and L'Heureux, R., 1997: General geology of southeast Fort Fraser map area, central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 65-75.

Abstract: Southeastern Fort Fraser map area is underlain primarily by rocks of the Upper Carboniferous to Lower Jurassic Cache Creek Group intruded by at least four suites of Mesozoic plutons and Tertiary felsic to mafic volcanic rocks of the Ootsa Lake, Endako, and Chilcotin groups. The oceanic rocks of the Cache Creek Group are variably metamorphosed to a maximum of greenschist grade both regionally and in igneous contact aureoles. The four plutonic suites have been subdivided into many phases and represent a step-wise transition from Early Jurassic strongly foliated mafic intrusives to Late Cretaceous undeformed felsic intrusives. The Tertiary mafic volcanic rocks of the Endako Group are tilted in regional, moderately southeast-dipping, fault blocks. The Chilcotin Group has limited distribution in some valleys.

Résumé : Le sud-est de la région cartographique de Fort Fraser repose principalement sur des roches du Groupe de Cache Creek du Carbonifère supérieur-Jurassique inférieur que recoupent au moins quatre suites de plutons du Mésozoïque et des roches volcaniques felsiques et mafiques du Tertiaire des groupes d'Ootsa Lake, d'Endako et de Chilcotin. Les roches océaniques du Groupe de Cache Creek sont métamorphosées inégalement, le faciès maximal étant celui des schistes verts à l'échelle tant de la région que des auréoles de contact de roches ignées. Les quatre suites plutoniques ont été subdivisées en de nombreuses phases et représentent une transition par étapes allant de roches intrusives mafiques fortement foliées du Jurassique précoce à des roches intrusives felsiques non déformées du Crétacé tardif. Les roches volcaniques mafiques du Tertiaire du Groupe d'Endako sont basculées dans des blocs faillés régionaux qui plongent doucement vers le sud-est. Le Groupe de Chilcotin a une répartition limitée dans certaines vallées.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

This paper reports on results of a second season of bedrock mapping in the Fort Fraser map area, a subproject of the Nechako Plateau NATMAP project in central British Columbia (NTS 93K, Fig. 1; Struik and MacIntyre, 1997). This year's mapping concentrated in the southeastern quadrant of the 1:250 000 scale Fort Fraser map area.

Included here are descriptions of some of the regionally extensive units and a few interpretations of their genesis and subsequent history. These descriptions are meant to give more context to the accompanying map figures and are not meant to be exhaustive.

GEOLOGY

Rocks of the southeast Fort Fraser map area are Upper Carboniferous to Pliocene in age. They include the Cache Creek, Ootsa Lake, Endako, and Chilcotin groups, and an extensive suite of Mesozoic and minor Tertiary intrusions (Fig. 2, 3, 4). These rocks are part of assemblages that outcrop along the length of the Cordillera (Wheeler and McFeely, 1991), save for the Early Cretaceous plutonic suite which is volumetrically unique.

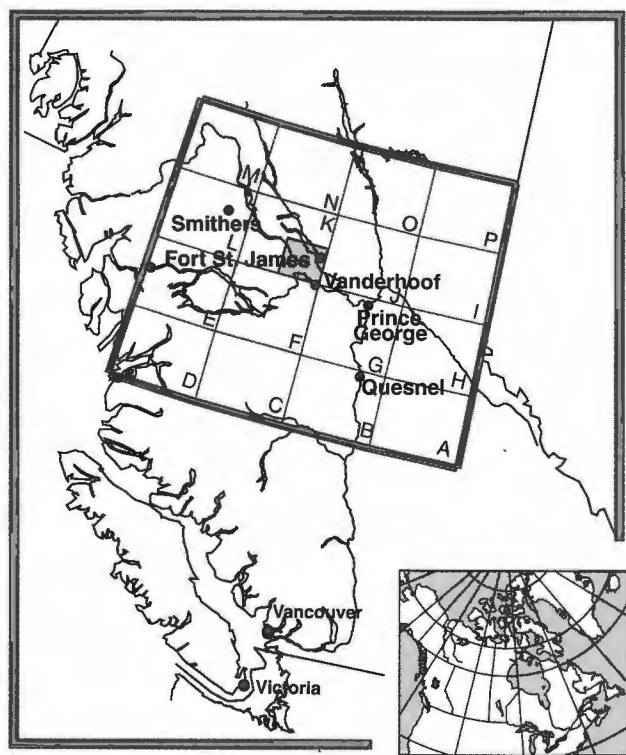


Figure 1. Location of southeast Fort Fraser map area in relation to surrounding NTS maps of the Parsnip River (NTS 93) 1:1 000 000 scale map and the Nechako Plateau NATMAP project area.

The Upper Carboniferous to Lower Jurassic Cache Creek Group represents an oceanic and forearc suite (Cache Creek Terrane) obducted onto the North American margin during Mesozoic time (Paterson, 1973). They were intruded by Triassic to Eocene plutons and subsequently overlapped by possible Cretaceous volcanic rocks, and the continental extensional Eocene Ootsa, and Eocene and Oligocene Endako groups and the possible mantle-plume Chilcotin Group. Locally Tertiary sediments are included in the Tertiary volcanic sequences.

This work builds on the regional mapping of Armstrong (1949) and the detailed mapping of Paterson (1973), Kimura et al. (1980), and Ash et al. (1993). These works should be referred to for more complete descriptions and distributions of some of the rocks units described here.

Upper Paleozoic to Lower Jurassic

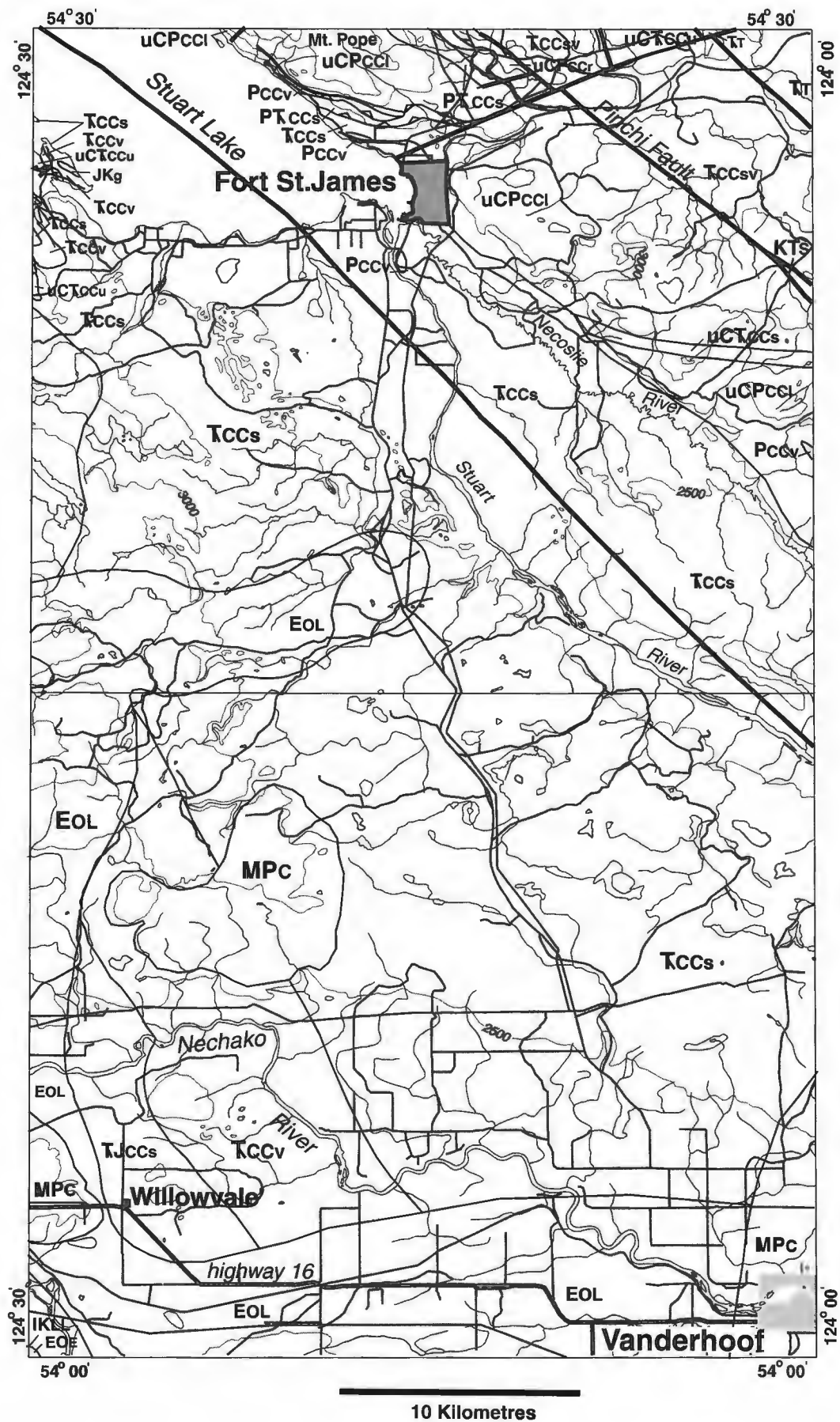
Cache Creek Group (uCTCCu-TJCCs)

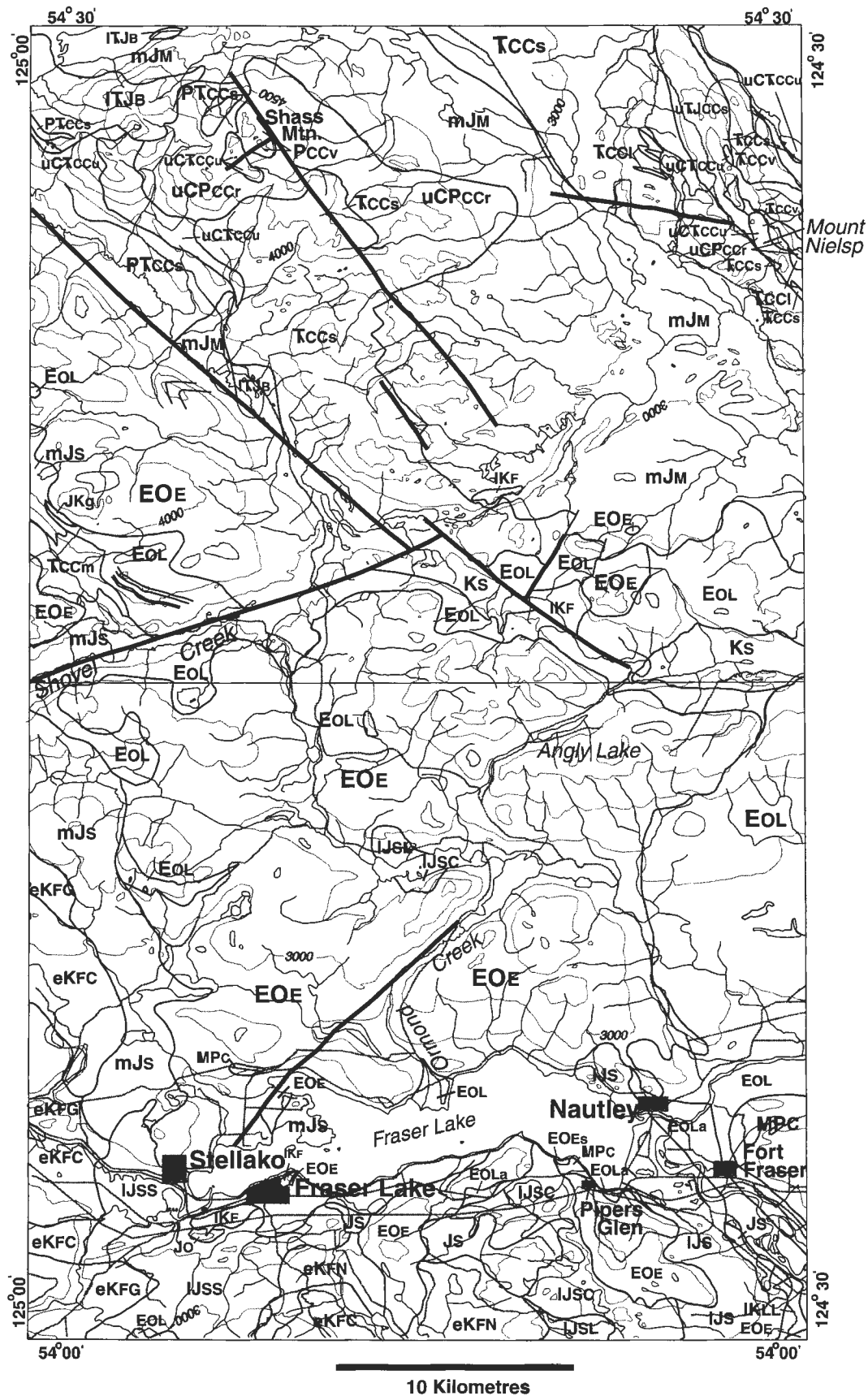
The Cache Creek Group in southeast Fort Fraser map area consists of four main units: The formal Trembleur Ultramafics (Armstrong, 1949), the informal Mt. Pope formation, and Railway and Sowchea sequences. The Sowchea sedimentary and tuff sequence is highly variable and may be subdivisible into many members. Three of these members include sequences of 1) ribbon chert and siltstone, 2) epiclastic and tuffaceous basalt and greywacke with minor limestone, and 3) greywacke, siltstone, slate, argillite, and limy volcanoclastics.

Trembleur Ultramafics (uCTCCu)

Armstrong (1949) and Paterson (1973) mapped these rocks as harzburgites and peridotites. Locally they are layered cumulates, and invariably have been partly altered to serpentinite. They form fault bounded blocks surrounded by other units of the Cache Creek Group. Within southeastern Fort Fraser map area they are limited to Shass Mountain (Letwin and Struik, 1997), Mount Nielsp, and the southern end of Murray Ridge (Fig. 2, 3). Ash et al. (1993) divided these rocks at Mount Nielsp and Murray Ridge into crustal and mantle representatives.

Figure 2. Geological map of 93K/1, 8 of southeastern Fort Fraser map area in central British Columbia. Adjoins the map of Figure 3 to the west and uses the geological legend of Figure 4. In addition to the authors' works, the map includes geology from Armstrong (1949), Paterson (1973), Kimura et al. (1980), Ash et al. (1993) and interpretations of Bellefontaine et al. (1995). Solid thin lines are approximate and assumed bedrock geological contacts, and thick lines are approximate and assumed faults. Contour interval is 500 ft. Scale should approximate 1:250 000.





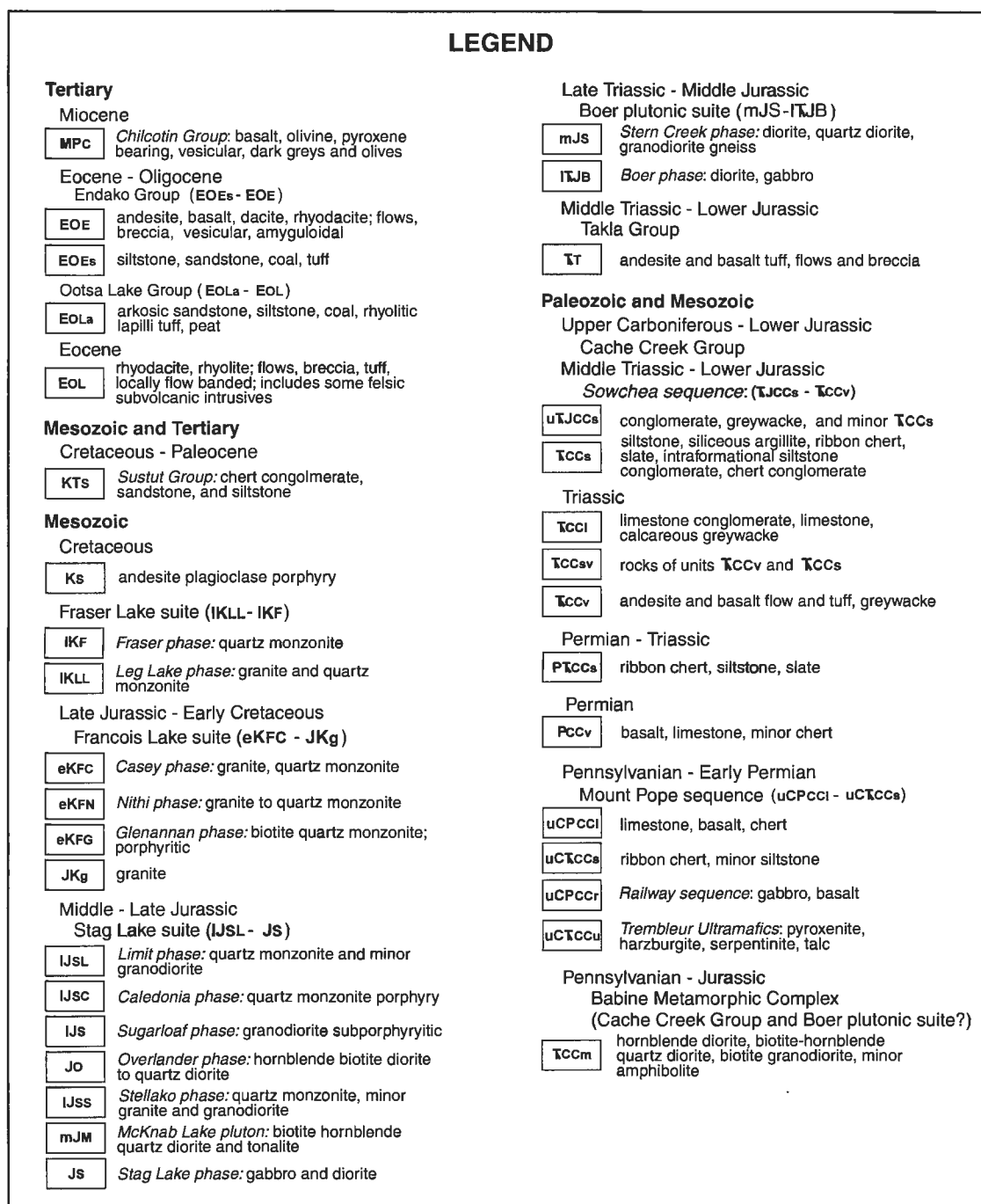


Figure 4. Legend to the geological maps of Figures 2 and 3.

Figure 3. Geological map of 93K/2, 7 of southeastern Fort Fraser map area in central British Columbia. Adjoins the map of Figure 2 to the east and uses the geological legend of Figure 4. In addition to the authors the map includes geology from Armstrong (1949), Paterson (1973), Kimura et al. (1980), Ash et al. (1993) and interpretations of Bellefontaine et al. (1995). Solid thin lines are approximate and assumed bedrock geological contacts, and thick lines are approximate and assumed faults. Contour interval is 500 ft. Scale should approximate 1:250 000.



Figure 5. Texture of pyroxenite and harzburgite augen in serpentine matrix of Trembleur Ultramafics on Mount Nielsp northwest of the peak.

The peak of the ridge of Mount Nielsp, south of Stuart Lake is a klippe of ultramafic rocks. The rock consists of dark lenses and augen of dismembered, partly serpentinized, pyroxenite in a light weathering serpentine matrix (Fig. 5).

Railway sequence (uCPCCr)

The Railway sequence consists of variably altered and metamorphosed gabbro and basalt. It underlies a narrow belt along the south side of Pinchi Lake, at Mount Nielsp, and a large area at Shass Mountain. The gabbro is intimately mixed with basalt and microgabbro, and all are crosscut by numerous veins and veinlets of plagioclase and cryptocrystalline quartz. The best exposures are found on the ridge just south of the B.C. railway line, south of Pinchi Lake, and east of Pinchi Creek. These rocks were mapped as "Basic rocks south of Pinchi Lake" by Paterson (1973). Paterson suggested the gabbro basalt sequence was unconformably overlain by upper Triassic limestone and volcanics to the north, and possibly underlain by Ultramafic rocks to the south.

Struik et al. (1996) provide some description of the gabbro and basalt unit near Pinchi Lake. At Shass Mountain the Railway sequence consists of dioritic gabbro and amphibolite (Letwin and Struik, 1997) and, as at other localities, it is in contact with Trembleur Ultramafics.

Middle Triassic to Lower Jurassic

Sowchea sequence (TCCv - TJCCs)

This unit underlies a large area mainly southwest of Stuart Lake (Struik et al., 1996). The rocks are siltstone, slate, ribbon chert, limestone, basalt tuff, greywacke, and conglomerate; locally they are interbedded with intraformational conglomerates and breccias. Most of the fine grained sediments are siliceous, varying from cherty argillites and slates to muddy cherts. Rocks of the unit are grey to dark grey, thinly bedded, and commonly disrupted by bedding parallel and nearly

bedding parallel slip. Typical clastic rocks are the easily accessible outcrops at the west end of the Sowchea Bay Provincial Park on Stuart Lake.

Included in the Sowchea sequence near Willowvale (Fig. 2) is a unit of chert-volcanic-limestone-siltstone pebble conglomerate and sandstone, basalt fine-grained lapilli tuff, greywacke, argillite, and minor dark grey limestone. These rocks are best exposed in the area of Willowvale Road north of Highway 16 to the east of the town of Fort Fraser. The volcanic component is much like the volcanoclastics and pyroclastics of the Pinchi sequence at the southeast end of Pinchi Lake and the northwest end of Murray Ridge (Struik et al., 1996).

The age of the Sowchea sequence is in part Triassic as it includes ribbon cherts near the Stuart Lake Sailing Club that have yielded Triassic radiolaria (Cordey and Struik, 1996a), and ribbon chert on the Stuart Lodge road that contain Triassic (Norian) conodonts (Orchard and Struik, 1996) and radiolaria (Cordey and Struik, 1996b). Radiolaria extracted from pebbles included in epiclastic basalts near Murray Ridge north of Fort St. James have ages as young as latest Triassic, indicating possible deposition of the host basalt in the Early Jurassic (Cordey and Struik, 1996b).

Middle Triassic to Lower Jurassic

Takla Group (TT)

Takla Group rocks form outcrops in the northeast corner of the map area and consist of andesite and basalt tuff, agglomerate, and minor flows. They are more fully described for the area immediately to the east in the McLeod Lake map area where they are better exposed (Struik, 1994).

Late Triassic - Middle Jurassic (Boer plutonic suite)

Triassic through Cretaceous plutonic rocks of the southeastern Fort Fraser map area are described by Whalen and Struik (1997). The subdivision into suites and phases and the composition of the rocks are briefly described here for completeness. The plutonic rocks are tentatively divided into four suites: Boer, Stag Lake, Francois Lake, and Fraser Lake. These suites consist of various phases and may have formed as the result of a number of separate plutonic episodes.

Boer phase (ITJB)

The Boer phase consists of biotite pyroxene and hornblende gabbro, diorite, and quartz diorite. It is light coloured, grey weathering, medium- to coarse- grained and equigranular.

Stern Creek phase (mJS)

The Stern Creek phase consists of gneissic to moderately foliated, biotite or hornblende-biotite diorite to quartz diorite and granodiorite. It includes potassium feldspar porphyritic portions and has significant textural and compositional variation on the outcrop scale.

Middle and Late Jurassic (Stag Lake plutonic suite)**Stag Lake phase (JS)**

The Stag Lake phase is compositionally variable, consisting mainly of fine- to medium-grained hornblende diorite to quartz diorite and lesser amounts of gabbro. The gabbro contains either hornblende or pyroxene, and the hornblende appears to be a replacement after pyroxene.

The Caledonia and Stellako phases of the Stag Lake plutonic suite intrude the Stag Lake phase. The contact with the Caledonia phase is deformed with strong fabric in the Caledonia phase. Mafic sheets in the Caledonia phase, plus small felsic dykes and veins cutting the mafic Stag Lake phase, clearly indicate the Stag Lake phase is older.

McKnab Lake pluton (mJM)

This pluton is part of the body originally mapped as Shass Mountain Pluton by Armstrong (1949) and Ash et al. (1993). It is differentiated here because Shass Mountain itself is underlain by metabasalt of the Cache Creek Group and plutonic rocks of the area can be divided in several small plutons and separated by areas of Cache Creek Group. McKnab Lake pluton, consists mainly of biotite and hornblende quartz diorite and tonalite. McKnab Lake pluton has been dated at $165 \pm 2/-1$ Ma on U-Pb from zircon (Ash et al., 1993).

Stellako phase (IJSS)

This unit consists mainly of a grey to beige, equigranular, biotite-hornblende quartz monzonite to granodiorite. Stellako phase has been observed to intrude the Stag Lake phase gabbro (older) at several sites. Hornblende and biotite K-Ar dates from this phase range in age from $137-136 \pm 6$ Ma (White et al., 1970; uncorrected).

Overlander phase (JO)

It consists of a medium-grained to coarse-grained equigranular hornblende-biotite gabbro and includes some very fine-grained mafic to felsic dyke rocks in its southern exposures.

Sugarloaf phase (IJS)

This phase consists of coarse grained, equigranular, grey, biotite, quartz diorite to diorite. The Stern Creek phase intrudes the Sugarloaf phase southeast of Nautley.

Caledonia phase (IJSC)

The Caledonia phase consists of medium-grained to coarse-grained, beige, biotite-hornblende-potassium feldspar megacrystic granodiorite to granite. The unit is distinguished by its large euhedral, multiply zoned, (2-7 cm), beige to dark pink, orthoclase megacrysts. In a boulder in the mapped contact area the Limit phase of the Francois Lake suite clearly intruded the Caledonia phase of the Stag Lake suite.

Limit phase (IJSL)

The Limit phase consists of grey, medium grained, equigranular biotite granodiorite. The Limit phase intrudes the Caledonia phase of the Stag Lake suite.

Late Jurassic-Early Cretaceous (Francois Lake Suite)**Glenannan phase (eKFG)**

This phase is a coarse- to very coarse-grained, white and pink, feldspar (usually only potassium feldspar) subporphyritic to porphyritic, biotite ($\pm$ hornblende) granite to granodiorite. The relative age relationships have not been observed. Biotite K-Ar dates from this phase range in age from 140 to 135 ± 6 Ma (White et al., 1970; uncorrected).

Nithi phase (eKFN)

The Nithi phase consists of coarse grained, beige to orange, semiequigranular, biotite granodiorite. Anhedral, orange potassium feldspar verges on porphyritic. Although relative age relationships have not been directly observed, it is probable that the Limit phase intrudes the Nithi phase and that both are younger than the Caledonia phase. Biotite K-Ar dates from this phase range in age from 141 to 138 ± 5 Ma (White et al., 1970; uncorrected).

Casey phase (eKFC)

This is a fine- to medium-grained, dark-pink granophyric biotite granite or aplitic granite. Mirolitic cavities are common, and some seriate portions contain potassium feldspar and ovoid quartz-eye phenocrysts. The Casey phase has been observed to crosscut the Glenannan phase northeast of the town of Endako (just west of the map area on Highway 16). Biotite K-Ar dates from this phase range in age from 139 to 137 ± 5 Ma (White et al., 1970; uncorrected).

Cretaceous (Fraser Lake suite)**Leg Lake (IKLL)**

The Leg Lake phase of the Fraser Lake suite consists mainly of a dark pink-brown plagioclase porphyry biotite-hornblende quartz monzonite or granodiorite. The Leg Lake phase intrudes the foliated Sugarloaf granodiorite.

Fraser phase (IKF)

On the south side of Highway 16 just west of the town of Fraser Lake, a medium grained, more equigranular phase than the Leg Lake phase is exposed and less coarse grained portions are exposed on the powerline immediately to the south. Biotite K-Ar dates from this phase range in age from 114 to 112 ± 4 Ma (White et al., 1970; uncorrected).

Cretaceous

Undifferentiated andesite porphyry (KS)

Pink plagioclase porphyritic andesite exposed in the central part of the Fraser Lake (93K/2) and Shass Mountain (93K/7) map areas (Fig. 3) are here interpreted as Cretaceous in age by lithological correlation. The plagioclase phenocryst prisms (4-8 mm) are pink and form 15 to 25% of the rock. Where exposed these rocks are strongly altered with epidote and cut by extensive epidote-quartz veins. These rocks resemble porphyritic andesite of the Spences Bridge Group (D. Thorkelson, pers. comm., 1996). These rocks may also be correlative with volcanics of the Rocky Ridge Formation of the late Cretaceous Skeena Formation (Bassett and Kleinspehn, in press).

Cretaceous and Paleocene

Sustut Group (KTS)

Sustut Group rocks outcrop along the Pinchi Fault, east of Fort St. James. They consist of brown-grey chert pebble conglomerate, sandstone, and siltstone. The steeply dipping beds are thin to moderately thick, mainly clast supported, poorly sorted, and massive. The clasts are rounded to subrounded and include mainly chert and siltstone. These rocks are interpreted to be Upper Cretaceous or Paleocene by correlation to sediments of that age in the McLeod Lake map area to the east (Struik, 1994).

Eocene

The following unit descriptions encompass primarily Tertiary volcanic units. These rocks unconformably overlie all of the preceding rocks, and dykes of the same composition and texture can be found crosscutting many of those older units.

Ootsa Lake Group (EOL, EOLa)

Eocene age felsic rocks of southeast Fort Fraser map area are entirely included in the Ootsa Lake Group. They consist of felsic and intermediate volcanic flows, breccias, and tuffs, and conglomerate. They outcrop mainly in the eastern and northern part of the map area. The best exposures are north-east of Angly Lake. The unit underlies the Endako Group possibly in paraconformity as there are local Endako Group sedimentary sequences.

Felsic volcanic rocks of the group consist mainly of rhyolite and rhyodacite flows show textures mainly of massive porphyritic, flowbanding, and lapilli tuff. Locally rhyolite breccia and volcanic polymictic conglomerate form units between the flows. Phenocrysts include mainly plagioclase, potassium feldspar, and biotite with lesser amounts of quartz. In places the rhyolite is soft consisting mainly of biotite phenocrysts, dark glassy rounded fragments in a matrix of clays. This unit is found primarily around the east end of Fraser Lake.

Conglomerate clasts are mainly of subrounded to subangular fragments of mauve, grey, and creamy vesicular dacite to rhyolite and cream lapilli tuff with minor crystals of biotite

and feldspar. The units are poorly exposed, show thin to massive bedding structures and are near the top of the sequence.

The local Eocene age of the Ootsa Lake Group has been determined from a whole rock isotopic date determined from north of the town of Nautley (M. Villeneuve, pers. comm., 1996).

Eocene and Oligocene

Endako Group (EOEs, EOE)

Overlying the Ootsa Lake Group in apparent paraconformity and unconformity are mafic- and intermediate-volcanic rocks and clastic rocks of the Endako Group. Endako Group underlies a large area of the central and southern part of the map area. Accessible well-exposed volcanic units are in the quarries at the towns of Nautley and Stellako and along the upper part of the microwave tower road on the hill south of the east end of Fraser Lake. Less accessible good exposures

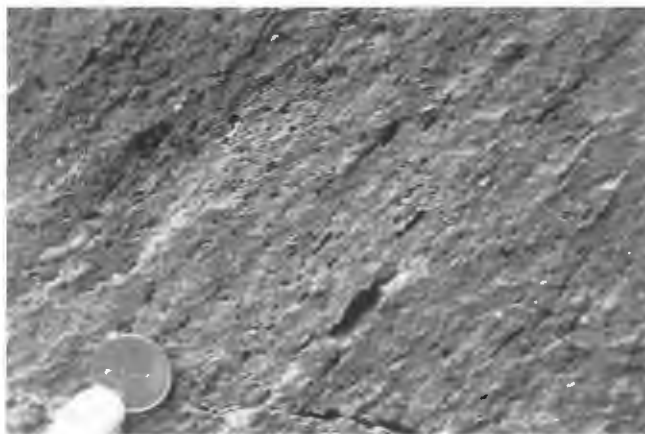


Figure 6. Common texture of flattened vesicles and fractures of the Endako Group andesite.

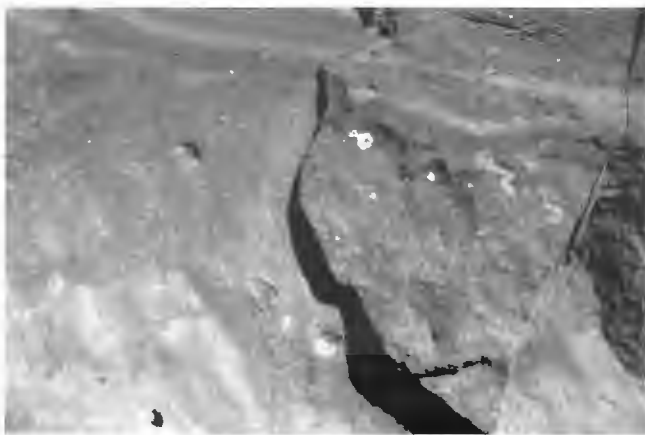


Figure 7. Sedimentary texture of lapilli tuff fragment bearing greywacke overlain by laminated wacke of the basal Endako Group at the Nautley quarry.

Table 1. Stratigraphic section of the Endako Group at the Nautley quarry, bottom to top.

Fraser Lake map area (93K/2), August 2, 1996		
Thickness metres	Rock types	Description
0-3.15	rhyolite	white, light olive, friable, clay rich, spotted with cream coloured clay patches that may be former plagioclase, although could be originally glass and gone to clay with no feldspar intermediary; quartz (0.5-1 mm, % ⁸), rounded grey glassy crystals; glass (0.3-1 mm, % ⁴) rounded dark grey opaque spots; clay bentonite? or some alteration of feldspar;
3.15-4.15	basalt talus	maroon-weathering basalt covering the outcrop;
4.15-5.25	rhyolite	white, light olive, like the base of section;
5.25-16.25	talus	basalt blocks and colluvium;
16.25-16.40	greywacke	grey, grey-blue; grains of quartz (0.5-1 mm) rounded, basalt (0.2-1.5 mm) subrounded, zircon (1 mm) dark;
16.40-16.48	clay	tan, bound at base and top by greywacke sands. Similar to "tuff" layer at the base of the section;
16.48-16.50	greywacke	grey, grey-blue; evenly bedded/laminated;
16.50-17.30	clay	creamy yellow; grains of glass; plagioclase, grades to top 12 cm which has grey and brown organic material maybe peat, or fine rotten vegetation, sampled for pollen;
17.30-17.42	peat	grey and brown organic material in clay matrix. Looks like rotten vegetation or mixed peat and clay, sequence was wet throughout;
17.42-19.62	sand	grey-brown; evenly bedded, recessive matrix, laminae to 400 mm layers, 1-4 mm grain size, some dark rock material, fragments subrounded to angular, sharp contact with underlying organic rich layer;
19.42-21.42	tuff	yellowish white; grains of quartz (1 mm) subrounded, dark hard fragments (1 mm) subrounded, ash tuff and rock fragments (2-25 mm), contains hornblende-biotite granodiorite to diorite fragments;
21.42-22.42	sand	grey; grit and pebble fine grained; fine grained interval, has purplish wood fragments in the ash tuff, fine breccia;
22.42-22.92	sand	blue, beige; blue weathering, has layers of ash tuff, breccia layers are variably dipping relative to basal and upper contacts, has both laminar and massive (debris flow-like characteristics); from crossbedding flow is probably from south to north, unit thins to west where top laminated unit appears to cut through base, top of sand unit has a grit bed 200-250 mm thick grains of diorite in the blue volcanic rock fragments and plagioclase matrix;
22.92-23.17	sand	fine sand;
23.17-30.17	basalt	dark grey; vesicles (20-30%) at contact in poorly preferred bedding orientation, vesicular with flattened parallel to bed, some basalt has penetrated bedding contact;
30.17-36.17	andesite	dark grey, matrix includes a portion of very finely crystalline plagioclase laths, vesicles (5-40 mm) are filled with a soft turquoise material as layered coatings and some complete filling, top of sequence has very large vesicles (60-100 mm) and rubbly appearance;
36.17-37.17	andesite tuff	local sandy layer;
37.17-41.27	basalt	rusty brown with olive grey, minor vesicles (less than 10 mm diameter), matrix sparkles with finely crystalline plagioclase, spotted with finely crystalline augite (0.1 mm, 10-20%), weathers in bulbous goethite forms; capped by 0.8 m of flow top;
41.27-55.27	basalt	olive, rusty weathering, has steam escape pipe at west end of exposure where it meets the talus pile;
55.27-65.37	basalt	olive

can be found north of Scovil Creek and west of Sutherland River. Volcanic rocks of the Endako Group can be distinguished from those of the overlying Chilcotin Group basalt by their greater alteration, moderate to intense flattening fabric, and thinner and more felsic and compositionally variable flows. The Endako Group is generally thicker than the Chilcotin Group. Throughout southeast Fort Fraser map area, the Chilcotin Group exposures are sparse, generally valley occurrences.

Volcanic rocks of the Endako Group are mainly andesite, basalt, and dacite massive flows, lahar, and lapilli to ash tuff. Generally the rock is aphanitic dark olive-grey, grey, dark grey, and weathers in various greys or maroon. Locally felted finely crystalline feldspar growths form the matrix. The volcanics commonly are vesicular and locally amygdaloidal (1-150 mm). The vesicles are generally flattened and lie along pervasive fractures parallel to the flattening plane (Fig. 6). In some areas the vesicles are completely squashed. Amygdule fillings are chlorite, calcite, and agate.

The massive volcanic rocks form well-defined flows generally 4 to 10 m thick. Within a flow sequence, the composition and textures of each flow are distinct and the contacts are sharp. The flow tops are vesicle rich and commonly consist of thin flow breccia.

Deposits of lahar are found along the road north of Fraser Lake just west of Ormond Creek. Devitrified and semiperlitic subrounded pebble to cobble size fragments of andesite are matrix- and clast-supported in a friable grey matrix. Thin, pink quartz veins cut some of the exposed flow.

Sedimentary rocks of the Endako Group are found at two sites around the east end of Fraser Lake; Nautley quarry and Pipers Glen (Fig. 3). These two sequences contain different types of rocks. The Nautley sequence contains grey, dacite fragment-rich greywacke and the Pipers Glen sequence contains cream epiclastic clay-altered rhyolite lapilli tuff and coal.

Nautley quarry section consists of poorly indurated clay-rich rhyolite lapilli tuff underlying 7 m of sand- and silt-size greywacke of intermediate volcanic fragments mixed in some beds with rhyolite lapilli tuff (Fig. 7) and with minor interbeds of claystone and peat (Table 1). The greywacke is sharply and conformably overlain by 40 m of 4-8 m thick olive andesite flows.

STRUCTURES AND METAMORPHISM

Most obvious structures in the map area are tilted Tertiary volcanic sequences and mineral foliation fabrics in some plutons and the more intensely metamorphosed Cache Creek sediments and volcanic rocks. Most of the rocks have been regionally metamorphosed to low greenschist and locally to

greenschist facies. The variation in the intensity of metamorphism throughout the map area follows several northwest-trending belts and distance from larger plutons.

Regional moderate dips of 20° to 30° to the southeast and east-southeast in the Endako Group andesite and basalt is ubiquitous. To maintain the distribution of the unit throughout large areas north of Fraser Lake, the Endako Group strata would have to be broken into several fault blocks. The faults separating the blocks would dip to the northwest and be somewhat listric. Faults such as these can be seen in the walls of the Endako mine to the west of the map area (Bysouth and Wong, 1995). The age of the fault blocks would be post-Eocene, the older age of parts of the Endako Group.

Along the railway track near the east end of Fraser Lake, the Chilcotin Group paraconformably overlies sandstone and coal beds, here included in the Endako Group. The beds are dipping to the east-southeast at 35-40°. These dips presumably are pre-Chilcotin Group, and the Chilcotin Group was deposited on a dipping bedding plane. These dips are the same as the regional dip of the Endako Group of the area.

Locally the Ootsa Lake Group rhyolite units have steep dips and are overlain by more shallowly dipping Endako Group, indicating an unconformity between the units.

Northwest-trending mineral foliation in several of the plutonic suites and in particular the Stern Creek suite reflect a crustal deformation and metamorphism, probably of Jurassic age. Within the Cache Creek Group, metamorphism and deformation are most intense in a belt through Shass Mountain southeastward through to Scovil Creek. The metamorphism decreases in intensity to the northeast towards Stuart Lake. To the southeast and south, the Cache Creek sedimentary sequences, such as those at Willowvale, are less metamorphosed and deformed than those at Shass Mountain. Part of the variation in metamorphism is due to the contact metamorphic effects of the McKnab Lake pluton although that effect appears to be superimposed onto a more regional metamorphism that intensifies to the west and northwest toward Babine Lake (Struik and Erdmer, 1990; Traub, 1996).

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Glenn Johnson of Endako mines generously shared with us, and several other groups, his time and experience with geology of and around the Endako mine. Placer Dome has made an enormous addition to the Cordilleran Geoscience community through contribution of information contained in their donation of ten 1:50 000 scale geological maps of central and southern Fort Fraser map area and northern Nechako River map area. Howard Tipper helped improve the manuscript with constructive comments and suggestions, and Bev Vanlier prepared the text.

REFERENCES

- Armstrong, J.E.**
1949: Fort St. James map-area, Cassiar and Coast Districts, British Columbia; Geological Survey of Canada, Memoir 252.
- Ash, C., MacDonald, R.W.J., and Paterson, I.A.**
1993: Geology of the Stuart and Pinchi Lakes area, central British Columbia (93K); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-9.
- Bassett, K.N. and Kleinspehn, K.L.**
in press: Mid-Cretaceous transtension in the Canadian Cordillera: evidence from the Rocky Ridge volcanics of the Skeena Group; *Tectonics*.
- Bellefontaine, K.A., Legun, A., Massey, N., and Desjardins, P.**
1995: Digital geological compilation of northeast B.C. – southern half (NTS 83D, E, 93F, G, H, I, J, K, N, O, P); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1995-24.
- Bysouth, G.D. and Wong, G.Y.**
1995: The Endako molybdenum mine, northwestern British Columbia: an update; in *Porphyry Deposits of the Northwestern Cordillera of North America*, (ed.) T. Schroeter; Canadian Institute of Mining and Metallurgy, Special Volume 46, p. 697-703.
- Cordey, F. and Struik, L.C.**
1996a: Radiolarian biostratigraphy, Fort Fraser and Prince George map areas, central British Columbia: scope and preliminary results; in *Current Research 1996-A*; Geological Survey of Canada, p. 83-90.
1996b: Radiolarian biostratigraphy and implications, Cache Creek Group of Fort Fraser and Prince George map areas, central British Columbia; in *Current Research 1996-E*; Geological Survey of Canada, p. 7-18.
- Kimura, E.T., Bysouth, G.D., Cyr, J., Buckley, P., Peters, J., Boyce, R., and Nilsson, J.**
1980: Geology of parts of southeast Fort Fraser and northern Nechako River map areas, central British Columbia; Placer Dome Incorporated, Internal Report and Maps, Vancouver, British Columbia.
- Letwin, J. and Struik, L.C.**
1997: Geology of Shass Mountain, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Orchard, M.J. and Struik, L.C.**
1996: Conodont biostratigraphy, lithostratigraphy and correlation of the Cache Creek Group near Fort St. James, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 77-82.
- Paterson, I.A.**
1973: The geology of the Pinchi Lake area, central British Columbia; Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 263 p.
- Struik, L.C.**
1994: Geology of the McLeod Lake map area, central British Columbia; Geological Survey of Canada, Open File 2439, 1:250 000 scale maps.
- Struik, L.C. and Erdmer, P.**
1990: Metasediments, granitoids, and shear zones, southern Babine Lake, British Columbia; in *Current Research, Part E*; Geological Survey of Canada, Paper 90-1E, p. 59-64.
- Struik, L.C. and MacIntyre, D.M.**
1997: Nechako Plateau NATMAP Project overview, central British Columbia, year two; in *Current Research 1997-A*; Geological Survey of Canada.
- Struik, L.C., Floriet, C., and Cordey, F.**
1996: Geology near Fort St. James, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 71-76.
- Whalen, J.B. and Struik, L.C.**
1997: Plutonic rocks of southeast Fort Fraser map area, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Traub, B.**
1996: Structure of the Cache Creek Group along the shores of southern Babine Lake, central British Columbia; B.Sc. thesis, University of Alberta, Edmonton, Alberta.
- Wheeler, J.O. and McFeely, P.**
1991: Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A.
- White, W.H., Sinclair, A.J., Harakal, J.E., and Dawson, K.M.**
1970: Potassium-argon ages of Topley intrusions near Endako, British Columbia; *Canadian Journal of Earth Sciences*, v. 7, p. 1172-1178.

Geological Survey of Canada Project 950036

Plutonic rocks of southeast Fort Fraser map area, central British Columbia¹

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Whalen, J.B. and Struik, L.C., 1997: Plutonic rocks of southeast Fort Fraser map area, central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 77-84.

Abstract: Southeastern Fort Fraser map area is underlain primarily by rocks of the Upper Carboniferous to Lower Jurassic Cache Creek Group intruded by at least four suites of Mesozoic plutons and Tertiary felsic to mafic volcanic rocks of the Ootsa Lake, Endako, and Chilcotin groups. The plutonic suites have been subdivided into many phases and represent a step-wise transition from Early Jurassic strongly foliated mafic intrusives to Late Cretaceous undeformed felsic intrusives.

Résumé : Le sud-est de la région cartographique de Fort Fraser repose principalement sur des roches du Groupe de Cache Creek du Carbonifère supérieur-Jurassique inférieur que recoupent au moins quatre suites de plutons du Mésozoïque et des roches volcaniques felsiques et mafiques du Tertiaire des groupes d'Ootsa lake, d'Endako et de Chilcotin. Les suites plutoniques ont été subdivisées en de nombreuses phases et représentent une transition par étapes allant de roches intrusives mafiques fortement foliées du Jurassique précoce à des roches intrusives felsiques non déformées du Crétacé tardif.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

This paper reports on the plutonic rocks mapped during the second season of bedrock mapping in the Fort Fraser map area, a subproject of the Nechako Plateau NATMAP project in central British Columbia (93K, Fig. 1; Struik and MacIntyre, 1997; Struik et al., 1997). The mapping concentrated in the southeastern quadrant of the 1:250 000 scale Fort Fraser map area and primarily in the Fraser Lake and Francois Lake areas (NTS 93K/2, 3).

Included are descriptions of the plutonic suites and a few interpretations of their genesis as determined from field relationships and geochemistry. They provide further details to the geology of the southeastern Fort Fraser map area as described by Struik et al. (1997). Anderson et al. (1997) described these same plutonic suites in the adjacent map area to the south (93F/15).

GEOLOGY

Plutonic rocks of southeast Fort Fraser map area intrude rocks of the Upper Carboniferous to Jurassic Cache Creek Group, and are overlain by Tertiary rocks of the Ootsa Lake, Endako, and Chilcotin groups (Fig. 2, 3, 4). These rocks are part of assemblages that outcrop along the length of the Cordillera (Wheeler and McFeely, 1991), save for the Early Cretaceous plutonic

suite which is volumetrically unique. In the southwestern part of the map area the plutons form the country rock and the rocks into which they have been intruded are undetected.

The Upper Carboniferous to Lower Jurassic Cache Creek Group represents an oceanic and forearc suite (Cache Creek Terrane) obducted onto the North American margin during Mesozoic time (Paterson, 1973). They were intruded by Triassic to Eocene plutons and subsequently overlapped by possible Cretaceous volcanic rocks, and the continental extensional Eocene Ootsa, and Eocene and Oligocene Endako groups and the possible mantle-plume Chilcotin Group. Locally Tertiary sediments are included in the Tertiary volcanic sequences.

This work builds on the regional mapping of Armstrong (1949) and the detailed mapping of Paterson (1973), Kimura et al. (1980), and Ash et al. (1993). These works and Struik et al. (1997) should be referred to for more complete descriptions and distributions of some of the rocks units described here.

The plutonic rocks in the map area are tentatively divided into four suites: Boer, Stag Lake, Francois Lake, and Fraser Lake. These suites consist of various phases and may have formed as the result of a number of separate plutonic episodes.

Late Triassic – Middle Jurassic (Boer plutonic suite)

Boer phase (ITJB)

The Boer phase consists of biotite pyroxene and hornblende gabbro, diorite, and quartz diorite. It is light coloured, grey weathering, medium- to coarse- grained and equigranular. Locally it has a weak foliation. It has similarities to the McKnab Lake pluton where it is exposed northwest of Shass Mountain (Letwin and Struik, 1997).

Stern Creek phase (mJS)

The Stern Creek phase consists of gneissic to moderately foliated, biotite or hornblende-biotite diorite to quartz diorite and granodiorite. It includes potassium feldspar porphyritic portions and has significant textural and compositional variation on the outcrop scale. The variation either reflects multideformational events, syndeformation intrusion, or both.

Some of the rock types in this unit are probably the oldest plutonic rocks in the area. They may represent dismembered remnants of an older batholith preserved as screens within younger plutonic suites.

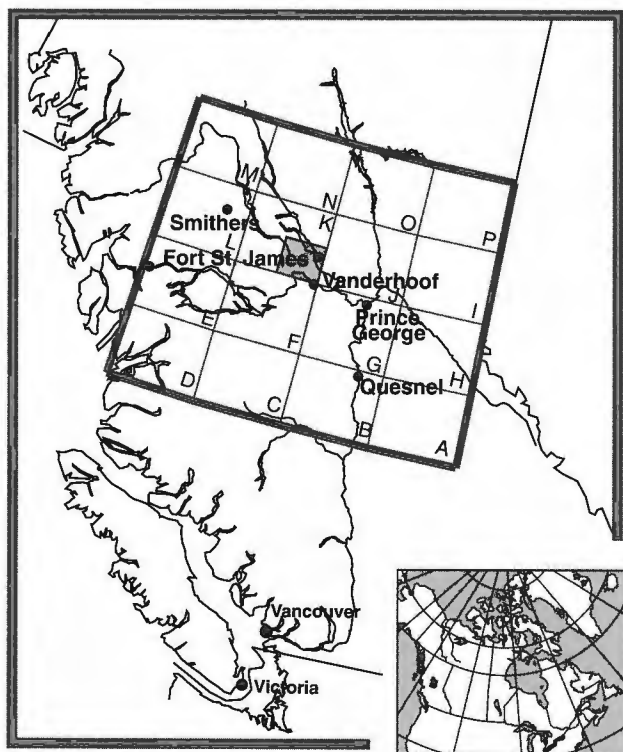
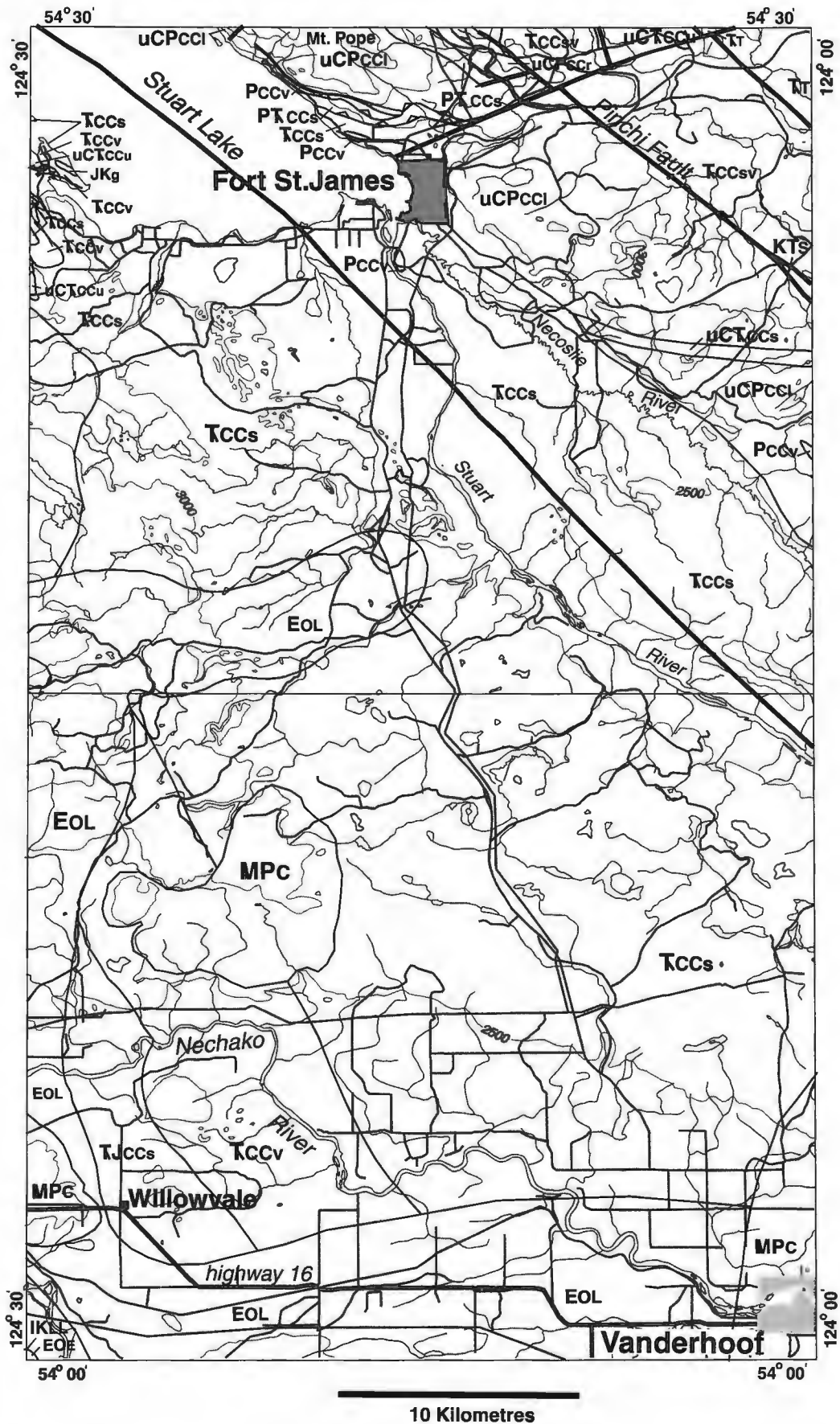
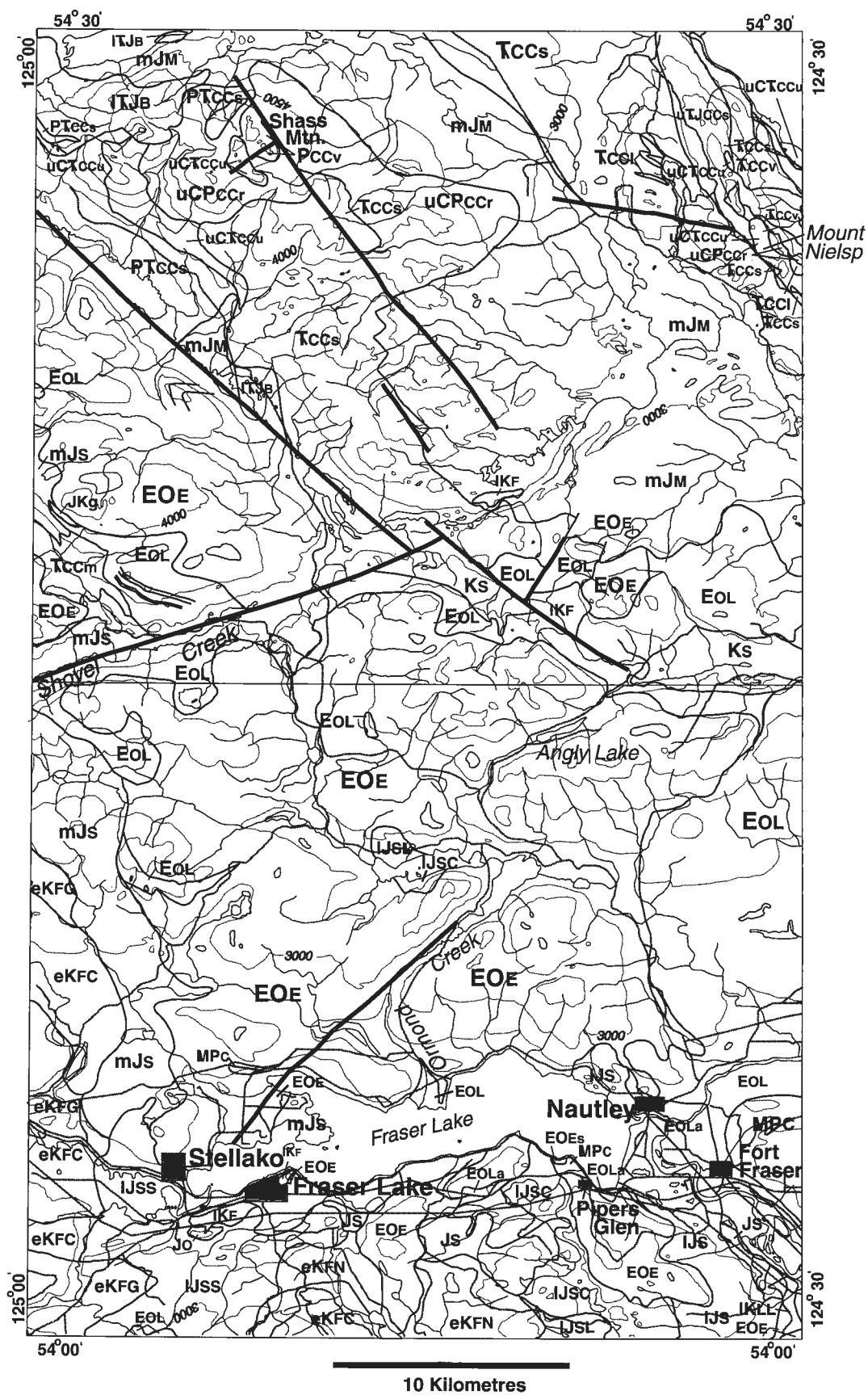


Figure 1. Location of southeast Fort Fraser map area in relation to surrounding NTS maps of the Parsnip River (93) 1:1 000 000 scale map and the Nechako NATMAP project area.

Figure 2. Geological map of 93K/1 and 8 of southeastern Fort Fraser map area in central British Columbia. Adjoins the map of Figure 3 to the west and uses the geological legend of Figure 4. In addition to the authors the map includes geology from Armstrong (1949), Paterson (1973), Kimura et al. (1980), Ash et al. (1993) and interpretations of Bellefontaine et al. (1995). Solid thin lines are approximate and assumed bedrock geological contacts, and thick lines are approximate and assumed faults. Contour interval is 500 ft. Scale should approximate 1:250 000.





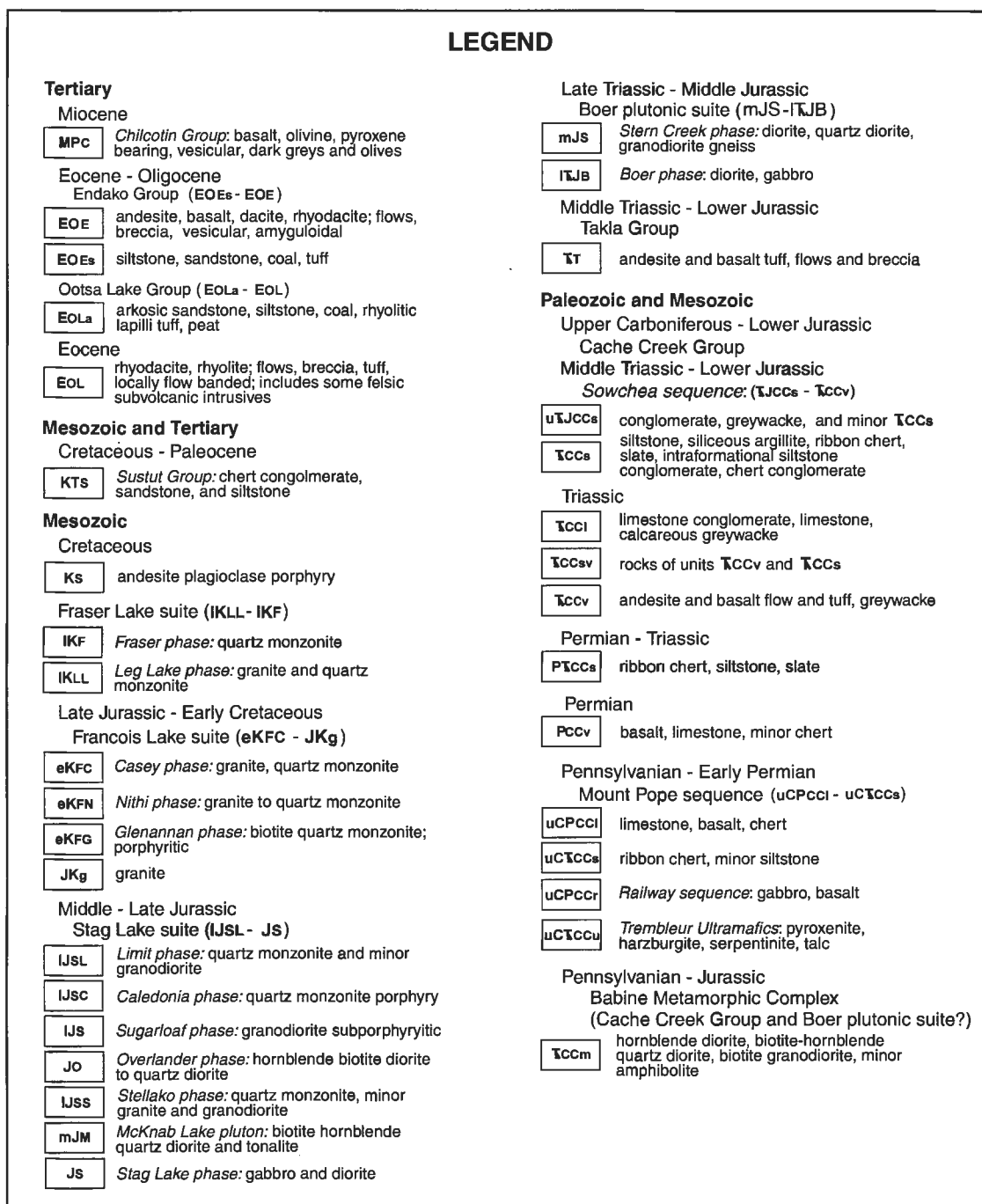


Figure 4. Legend to the geological maps of Figures 2 and 3.

Figure 3. Geological map of 93K/2 and 7 of southeastern Fort Fraser map area in central British Columbia. Adjoins the map of Figure 2 to the east and uses the geological legend of Figure 4. In addition to the authors the map includes geology from Armstrong (1949), Paterson (1973), Kimura et al. (1980), Ash et al. (1993) and interpretations of Bellefontaine et al. (1995). Solid thin lines are approximate and assumed bedrock geological contacts, and thick lines are approximate and assumed faults. Contour interval is 500 ft. Scale should approximate 1:250 000.

Middle and Late Jurassic (Stag Lake plutonic suite)

Stag Lake phase (JS)

The Stag Lake phase is compositionally variable, consisting mainly of fine- to medium-grained hornblende diorite to quartz diorite and lesser amounts of gabbro. The gabbro contains either hornblende or pyroxene, and the hornblende appears to be a replacement after pyroxene.

The hornblende porphyry quartz gabbro to gabbro is quite distinctive. It exhibits large variation in the size of hornblende and has local patches of pegmatite containing coarse-grained hornblende, quartz, and feldspar (2-5 cm). The pegmatite is crosscut by late hornblende-bearing veins. These features of high water content in mafic rock resembles those of appinite suites. Near Stag Lake it consists of coarse-grained pyroxene gabbro, with spongy pyroxene up to 5 cm in size, and is very strongly magnetic.

Intrusive contact

The Caledonia and Stellako phases of the Stag Lake plutonic suite intrude the Stag Lake phase. The contact with the Caledonia phase is deformed with strong fabric in the Caledonia phase. Mafic sheets in the Caledonia phase plus small felsic dykes and veins cutting the mafic Stag Lake phase clearly indicate the Stag Lake phase is older.

McKnab Lake pluton (mJM)

This pluton is part of the body originally mapped as Shass Mountain Pluton by Armstrong (1949) and Ash et al. (1993). It is differentiated here because Shass Mountain itself is underlain by metabasalt of the Cache Creek Group and plutonic rocks of the area can be divided in several small plutons and separated by areas of Cache Creek Group.

McKnab Lake pluton consists mainly of quartz diorite and tonalite and underlies an area around McKnab Lake and northeast to the flank of Mount Nielsp. The pluton may continue northwest to the north of Shass Mountain through the area covered by glacial deposits (Fig. 3). These rocks contain biotite and hornblende. The pluton is variably weakly foliated to unfoliated and mainly equigranular (4-7 mm). Its contacts with Cache Creek Group chert and greywacke are generally sharp and the direct hornfels halo is narrow.

Age

McKnab Lake pluton has been dated at $165 \pm 2/-1$ Ma on U-Pb from zircon (Ash et al., 1993).

Stellako phase (IJSS)

This unit consists mainly of a grey to beige, equigranular, biotite-hornblende quartz monzonite to granodiorite. In well exposed portions of this unit, significant variation in mafic and quartz content was noted. The most felsic portions contain 0.5-1.5 cm potassium feldspar phenocrysts which are

only obvious by reflections from their crystal faces. In some areas this unit is pervasively chlorite-altered and in other places is altered only adjacent to fractures.

Intrusive contact

Stellako phase has been observed to intrude the Stag Lake phase gabbro (older) at several sites.

Age

Hornblende and biotite K-Ar dates from this phase range in age from $137-136 \pm 6$ Ma (White et al., 1970; uncorrected).

Sugarloaf phase (IJS)

This phase consists of coarse grained, equigranular, grey, biotite, quartz diorite to diorite. Areas of the phase in south-eastern Fraser Lake map area (93K/2; Fig. 3) are lithologically homogeneous and have a slight foliation. In some places the unit contains undifferentiated Stern Creek phase, for example on the north shore of eastern Fraser Lake. There, Stern Creek and Sugarloaf phases are intimately intruded in the western portions of the Sugarloaf exposure. Much of the feldspar in the Sugarloaf phase, particularly on the northeast side of Fraser Lake, has a recrystallized sugary appearance. Mafic minerals consist of biotite flakes and fine-grained biotite aggregates, clearly after hornblende. This unit displays features of having been emplaced at a moderate depth and metamorphosed at a similar level.

Intrusive contacts

The Stern Creek phase intrudes the Sugarloaf phase southeast of Nautley. Contact relationships relative to Caledonia phase, the Stag Lake phase, and the Nithi phase are unknown.

Overlander phase (JO)

This unit is differentiated on the geological map of Kimura et al. (1980). It may be part of the Stag Lake phase. The differentiation is maintained here pending further study. This is a small body close to Fraser Lake and exposed along the powerline cut and in the adjacent area. It consists of a medium- to coarse-grained, equigranular hornblende-biotite gabbro and includes some very fine grained, mafic to felsic dyke rocks in its southern exposures.

Intrusive contacts

The relationship of the Overlander phase with adjacent Fraser phase is not exposed, but the gabbro is probably older.

Caledonia phase (IJSC)

The Caledonia phase consists of medium- to coarse-grained, beige, biotite-hornblende-potassium feldspar megacrystic granodiorite to granite. The unit is distinguished by its large euhedral, multiply zoned, (2-7 cm), beige to dark pink, orthoclase

megacrysts. The matrix to these megacrysts exhibits considerable grain size variation (medium- to coarse-grained) and compositional variation (quartz monzonite to granite). The megacrysts vary in concentration from scattered to fairly densely packed. Some of these variations are geographic; for example, the exposures southeast of Stag Lake are more felsic (granite) and have a medium-grained matrix.

Caledonia phase displays a good to moderate foliation, as defined by biotite, aligned potassium feldspar megacrysts, and elongated quartz. Some of these features, in particular the aligned megacrysts, could be magmatic flow.

Intrusive contact

In a boulder in the mapped contact area the Limit phase of the Francois Lake suite clearly intruded the Caledonia phase of the Stag Lake suite.

Limit phase (IJSL)

The Limit phase consists of grey, medium grained, equigranular biotite granodiorite. Biotite is evenly distributed as separate anhedral to euhedral flakes and generally forms a moderately defined fabric. At many locations, the unit weathers very deeply, forming in situ beach-like sand (a feature this unit shares with associated Nithi phase). Like the Nithi phase, the Limit phase commonly exhibits a mineral-defined foliation and a subparallel fracture cleavage or foliation, which facilitates deep weathering.

Intrusive contact

The Limit phase intrudes the Caledonia phase of the Stag Lake suite.

Late Jurassic-Early Cretaceous (Francois Lake Suite)

Glenannan phase (eKFG)

This phase is a coarse- to very coarse-grained, white and pink, feldspar (usually only potassium feldspar) subporphyritic to porphyritic, biotite ($\pm$ hornblende) granite to granodiorite. It is fairly distinctive and lithologically uniform over large areas. Generally this rock is massive and unaltered. At one site it is a medium grained, seriate, miarolitic phase that grades to drizzly (highly miarolitic), patchy, pegmatitic biotite aplite with sulphides (Py $\pm$ Cpy) disseminated and as miarolitic fillings. This unit may be a deeper level equivalent of Casey phase.

Intrusive contact

The relative age relationships have not been observed.

Age

Biotite K-Ar dates from this phase range in age from 140 to 135 ± 6 Ma (White et al., 1970; uncorrected).

Nithi phase (eKFN)

The Nithi phase consists of coarse grained, beige to orange, semi equigranular, biotite granodiorite. Anhedral, orange potassium feldspar verges on porphyritic. The phase forms very rounded, deeply weathered outcrops. Spatially it is closely associated with the Limit phase.

Generally the Nithi phase exhibits both a slight to moderate biotite-defined foliation and a closely spaced fracture cleavage or foliation.

Intrusive contact

Although relative age relationships have not been directly observed, it is probable that the Limit phase intrudes the Nithi phase and that both are younger than the Caledonia phase.

Age

Biotite K-Ar dates from this phase range in age from 141 to 138 ± 5 Ma (White et al., 1970; uncorrected).

Casey phase (eKFC)

This is a fine- to medium-grained, dark-pink granophyric biotite granite or aplitic granite. Miarolitic cavities are common, and some seriate portions contain potassium feldspar and ovoid quartz-eye phenocrysts. The mafic minerals are commonly oxidized or chloritized. This unit is texturally variable but seems always to be dark red to dark pink, mafic-poor, and granite (*senso stricto*). It is possible that Glenannan phase and Casey phase are approximately cogenetic phases.

Intrusive contact

The Casey phase has been observed to crosscut the Glenannan phase northeast of the town of Endako (just west of the map area on Highway 16).

Age

Biotite K-Ar dates from this phase range in age from 139 to 137 ± 5 Ma (White et al., 1970; uncorrected).

Cretaceous (Fraser Lake suite)

Leg Lake (IKLL)

The Leg Lake phase of the Fraser Lake suite consists mainly of a dark pink-brown plagioclase porphyry biotite-hornblende quartz monzonite or granodiorite (difficult to judge the quartz content as it is contained in a fine grained matrix). The best exposures are in the southeast corner of the Fraser Lake map area (93K/2; Fig. 3, 4) where this unit intrudes a slightly foliated, medium grained, grey, equigranular hornblende-biotite granodiorite. A distinctive feature of the Leg Lake phase at this locality is a spotty white appearance due to the plagioclase phenocrysts on a red-brown background.

Intrusive contact

The Leg Lake phase intrudes the foliated Sugarloaf granodiorite.

Fraser phase (IKF)

On the south side of Highway 16 just west of the town of Fraser Lake a medium grained, more equigranular phase than the Leg Lake phase is exposed and less coarse grained portions are exposed on the powerline immediately to the south. The Leg Lake and Fraser phases appear to represent a late-stage, high-level intrusive rock.

Intrusive contact

Contacts of the Fraser phase have not been seen.

Age

Biotite K-Ar dates from this phase range in age from 112-114 ± 4 Ma (White et al., 1970; uncorrected).

PRELIMINARY GEOCHEMICAL AND Nd ISOTOPIC INFORMATION ON THE PLUTONIC SUITES

The plutons in the study area can be classified as calc-alkaline based on AFM (Irvine and Barager, 1971), Peacock Index (Peacock, 1931), and FeO*-MgO-TiO₂ (Miyashiro, 1974) diagrams. The oldest Stern Creek phase of the Boer plutonic suite ranges in silica content from 54 to 65 wt.% and includes both medium- and high-K compositions. Phases included in the Stag Lake suite cover a compositional continuum from 44 to 74 wt.% silica and have medium- to high-K contents. Both the Francois Lake and Fraser Lake suites are evolved (66-76 wt.% SiO₂), high-K suites.

All the granitoid suites plot in the volcanic-arc-granite field on the tectonomagmatic classification diagrams of Pearce et al. (1984). Their designation as arc-type is supported by the ubiquitous presence of negative Nb-anomalies, relative to Th, on extended element primordial mantle normalized plots (cf. Stolz et al., 1996). Preliminary Nd isotopic data indicate the granitoids were derived from relatively juvenile sources (e.g., depleted mantle); i.e. the arc in which the plutons formed was probably not built on old continental crust.

Available granitoid geochemical and isotopic data are compatible with arc evolution from relatively immature to mature. Volumetrically significant mafic end-members in the Boer and Stag Lake suites indicate direct mantle contributions to the early arc plutonism. Generation of the younger, felsic, high-K compositions of the Francois Lake and Fraser Lake suites probably involved recycling of tectonically thickened, pre-existing arc crust.

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Glenn Johnson of Endako Mines generously shared with us, and several other groups, his time and experience with geology of and around the Endako mine. Contribution to the project of exploration geological mapping from Placer Dome Incorporated has been instrumental in providing substantially more detail to our work than could have been possible otherwise. Howard Tipper helped improve the manuscript with constructive comments and suggestions, and Bev Vanlier prepared the text.

REFERENCES

- Armstrong, J.E.
1949: Fort St. James map-area, Cassiar and Coast Districts, British Columbia; Geological Survey of Canada, Memoir 252.
- Anderson, R.G., L'Heureux, R., Wetherup, S., and Letwin, J.
1997: Geology of the Hallett Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous, and Eocene? plutonic rocks; in *Current Research 1997-A*; Geological Survey of Canada.
- Ash, C., MacDonald, R.W.J., and Paterson, I.A.
1993: Geology of the Stuart and Pinchi Lakes area, central British Columbia (93K); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-9.
- Bellefontaine, K.A., Legun, A., Massey, N., and Desjardins, P.
1995: Digital geological compilation of Northeast B.C. – southern half (NTS 83D, E, 93F, G, H, I, J, K, N, O, P); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1995-24.
- Irvine, T.N. and Barager, W.R.A.
1971: A guide to the classification of the common volcanic rocks; *Canadian Journal of Earth Sciences*, v. 8, p. 523-548.
- Kimura, E.T., Bysouth, G.D., Cyr, J., Buckley, P., Peters, J., Boyce, R., and Nilsson, J.
1980: Geology of parts of southeast Fort Fraser and northern Nechako River map areas, central British Columbia; Placer Dome Incorporated, Internal Report and Maps, Vancouver, British Columbia.
- Letwin, J. and Struik, L.C.
1997: Geology of Shass Mountain, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Miyashiro, A.
1974: Volcanic rock series in island arcs and active continental margins; *American Journal of Science*, v. 274, p. 321-355.
- Paterson, I.A.
1973: The geology of the Pinchi Lake area, central British Columbia; Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 263 p.
- Peacock, M.A.
1931: Classification of igneous rock series; *Journal of Geology*, v. 39, p. 54-67.
- Pearce, J.A., Harris, N.B.W., and Tindle, A.G.
1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; *Journal of Petrology*, v. 25, p. 956-983.
- Stolz, A.J., Jockum, K.P., Spettal, B., and Hofmann, A.W.
1996: Fluid- and melt-related enrichment in the sub-arc mantle: evidence from Nb-Ta variations in island-arc basalts; *Geology*, v. 24, p. 587-590.
- Struik, L.C. and MacIntyre, D.M.
1997: Nechako Plateau NATMAP Project overview, central British Columbia, year two; in *Current Research 1997-A*; Geological Survey of Canada.
- Struik, L.C., Whalen, J.B., Letwin, J.M., and L'Heureux, R.
1997: General geology of southeast Fort Fraser map area, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.
- Wheeler, J.O. and McFeely, P.
1991: Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A.
- White, W.H., Sinclair, A.J., Harakal, J.E., and Dawson, K.M.
1970: Potassium-argon ages of Topley Intrusions near Endako, British Columbia; *Canadian Journal of Earth Sciences*, v. 7, p. 1172-1178.

Field properties of Pennsylvanian-Lower Permian limestones of Cache Creek Group, northwest of Fort St. James, central British Columbia¹

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Sano, H. and Struik, L.C., 1997: Field properties of Pennsylvanian-Lower Permian limestones of Cache Creek Group, northwest of Fort St. James, central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 85-93.

Abstract: As part of the Nechako Plateau NATMAP project, the Upper Carboniferous to lower Lower Permian limestone of the Cache Creek Group, northwest of Fort St. James, was investigated. We discriminated four types of shallow-marine bioclastic limestone, including crinoid lime-mud/wackestone, *Tubiphytes* lime-mud/wackestone, fusulinid-*Tubiphytes* pack/wackestone, and bedded siliceous limestone, and also recognized local mats of *Tubiphytes* bindstone and related microbialites. Newly found and important are the limestone conglomerate and sandstone intercalated in a chert-siliceous micrite succession. These clastic limestones containing basaltic detritus are interpreted as sediment gravitationally displaced from a shallow-marine buildup into a deeper basin where the chert and siliceous micrite accumulated. The basaltic debris implies the presence of a basaltic substratum below the buildup. We postulate that the deep-marine chert-siliceous micrite and shallow-marine limestone units may have originally passed laterally into each other, linked by the clastic limestones.

Résumé : Dans le cadre du projet du plateau de Nechako du CARTNAT, on a étudié le calcaire du Carbonifère supérieur-base du Permien inférieur du Groupe de Cache Creek, au nord-ouest de Fort St. James. Nous avons distingué quatre types de calcaire bioclastique de mer peu profonde, notamment du calcaire à entroques à texture de mudstone-wackestone, du calcaire à *Tubiphytes* à texture de mudstone-wackestone, du packstone-wackestone à fusulinidés-*Tubiphytes* et du calcaire siliceux stratifié. Nous avons également identifié par endroits des tapis de bindstone à *Tubiphytes* et des microbialites associées. Du conglomérat à fragments de calcaire et du grès intercalés à une succession de chert-micrite siliceuse sont nouvellement découverts et importants. Ces calcaires clastiques contiennent des débris basaltiques et sont interprétés comme des sédiments transportés par gravité depuis un monticule en mer peu profonde vers un bassin plus profond où se sont accumulés le chert et la micrite siliceuse. Les débris basaltiques indiquent la présence d'un substratum basaltique sous le monticule. Selon notre hypothèse, les unités de chert-micrite siliceuse de mer profonde et de calcaire de mer peu profonde peuvent avoir passé latéralement les unes aux autres, tout en demeurant reliées par des calcaires clastiques.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

The area of central British Columbia is one of the major outcrop areas of the Cache Creek terrane rocks (Monger et al., 1992). As in the other two major outcrop areas of southern British Columbia and north-central British Columbia-southern Yukon Territory, distinct and huge masses of shallow-marine limestones largely of Pennsylvanian age (Thompson, 1965; Orchard and Struik, 1996) characterize Cache Creek Group in central British Columbia. However, their depositional environment, based upon thorough microscopic examination and microfacies analysis, has been little discussed. The limestone in this area has been simply referred to as a shallow-marine carbonate sediment (Orchard and Struik, 1996), despite its importance as the most characteristic component of the Cache Creek Group.

This report documents field properties of the limestone of the Cache Creek Group, northwest of Fort. St. James, central British Columbia (Fig. 1). Fieldwork was done in the summer of 1996 as part of Nechako Plateau NATMAP Project. The focus of the study was the limestone informally designated Mt. Pope formation at Mt. Pope, the unnamed peak to the east-northeast of Mt. Pope, and a few isolated outcrops.

Field observations revealed that the Mt. Pope formation includes four major types of the limestone: crinoid lime-mud/wackestone, *Tubiphytes* lime-mud/wackestone, fusulinid-*Tubiphytes* pack/wackestone, and bedded siliceous limestone. These have a bioclastic nature, and are characterized by diverse, shallow-marine benthic organisms embedded in a micritic matrix. Less abundant, but significant are *Tubiphytes* bindstone and related microbialites, which are attributable to sediment-binding and encrusting cyanobacterial and/or algal activities. These microbe-related sediments are thought to have formed reefal facies.

In places we also found the limestone conglomerate and limestone sandstone containing basaltic debris within a chert-siliceous micrite succession of deep-marine facies. These clastic limestones played a significant role as a lateral link between shallow-marine limestone and deep-marine chert-siliceous micrite facies. We present stratigraphic descriptions of the oceanic rocks of the Mt. Pope formation and preliminarily discuss their sedimentary framework.

Mt. Pope formation

The Mt. Pope formation has been defined to consist chiefly of grey to light grey, massive, bioclastic micritic limestone and contains subordinate beds of basaltic breccia and ribbon-bedded chert (Struik et al., 1996). All the rocks are densely fractured and the limestone is in places strongly recrystallized.

The rocks of the Mt. Pope formation outcrop to form an extensive belt with a general northwest trend in the area of Fort St. James (Fig. 2). The major outcrops are at Mt. Pope (Fig. 3) and unnamed peaks east-northeast of Mt. Pope (Fig. 4) and along the northwestward trending ridge on the northeastern side of Necoslie River (Thompson, 1965; Paterson, 1973; Ash et al., 1993; Struik et al., 1996).

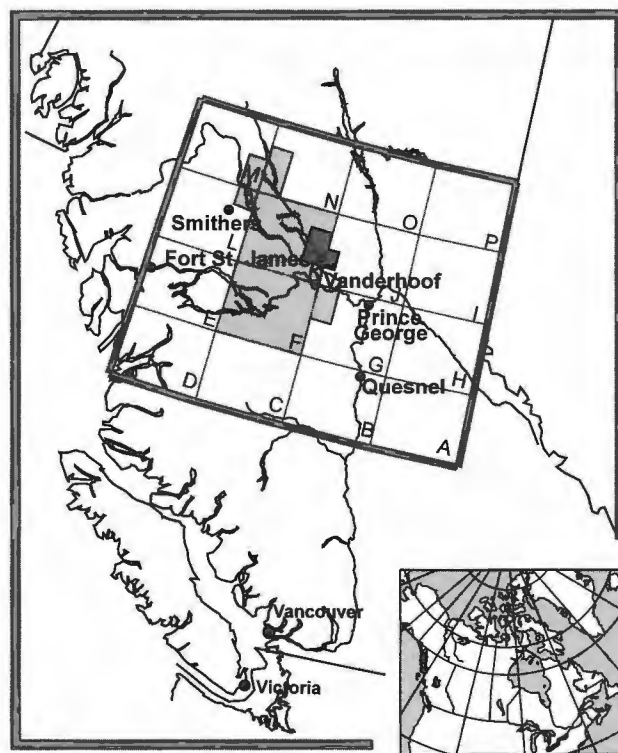


Figure 1. Location of the study area. The grid represents 1:1 000 000 scale map of Parsnip River (NTS 93).

The limestone of the Mt. Pope formation has been dated by fusulinids and conodonts (Thompson, 1965; Orchard and Struik, 1996). According to these authors, the limestone is largely of late Carboniferous age and subordinately of early Permian. Cordey and Struik (1996b) recently reported late Pennsylvanian to early Early Permian radiolarian fossils from the interbedded chert-micrite succession on Battleship Island in Stuart Lake.

FIELD DESCRIPTION OF LIMESTONES

Chiefly on the basis of properties recognizable in the field, including rock colours, major constituents, predominant particle size, particle/matrix ratio, bedding types, and sedimentary structures, four major types of the limestone were discriminated in the Mt. Pope sequence. They include (1) crinoid lime-mud/wackestone, (2) *Tubiphytes* lime-mud/wackestone, (3) fusulinid-*Tubiphytes* pack/wackestone, and (4) bedded siliceous limestone. A small amount of microbial bindstones occurs associated with the third type. In addition to these major types and associated bindstones, limestones having a distinct clastic nature and containing an appreciable amount of basaltic debris were found as intermittent beds within a chert-siliceous micrite succession of the Mt. Pope formation.

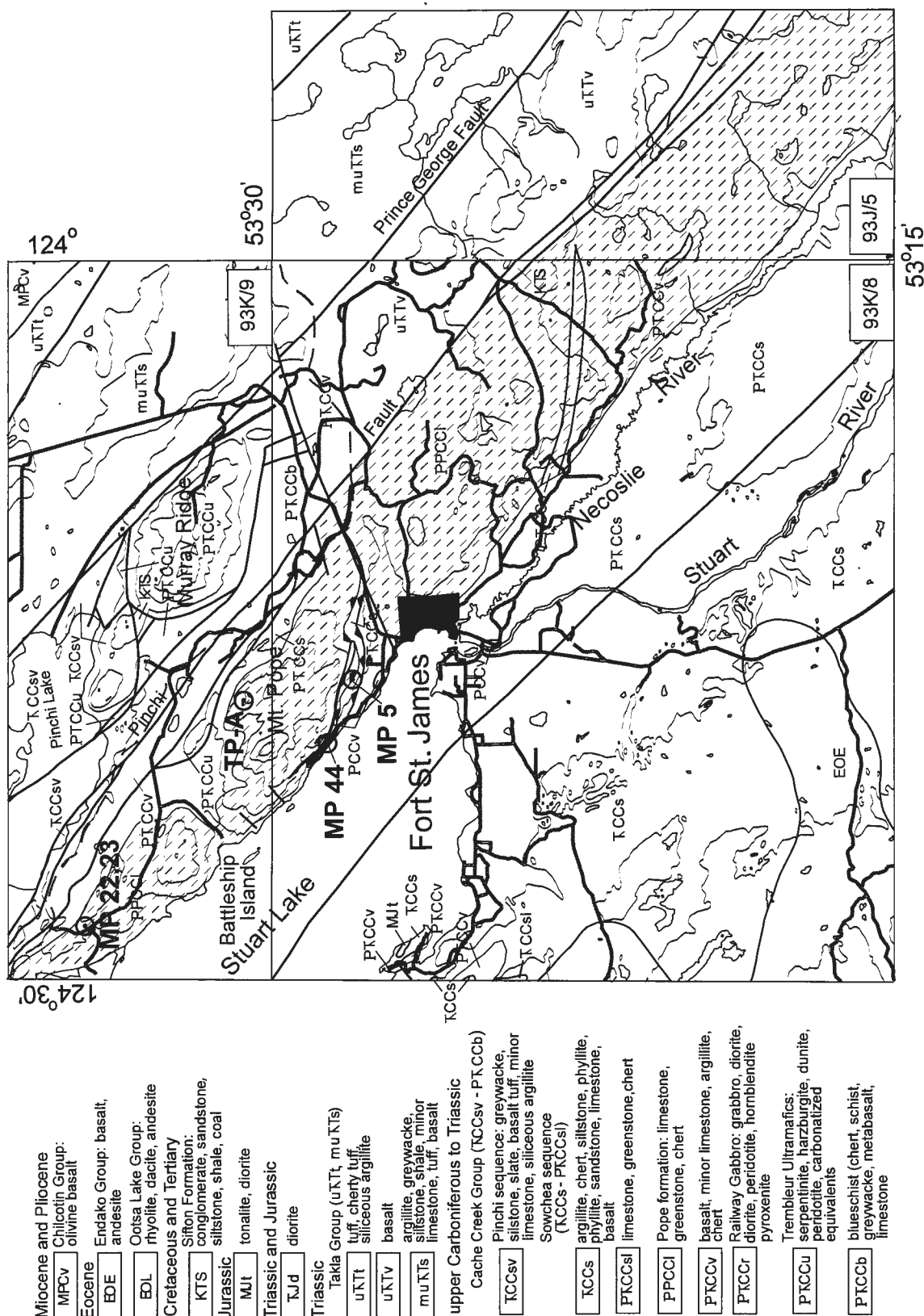


Figure 2. Geological map of Mt. Pope area, northwest of Fort St. James. Localities of outcrop photograph of Figure 5 and columnar sections of Figures 6, 8, and 9 are indicated. The base map is modified from Bellefontaine et al. (1995).



Figure 3. Outcrop view of strongly fractured and heavily crystalline limestone around the gazebo at the top of Mt. Pope.



Figure 4. Unnamed peaks underlain by massive limestones of Mt. Pope formation, looking to the northeast from the top of Mt. Pope. Columnar section of Figure 6 was measured at the top of the peak indicated by an arrow.

Crinoid lime-mud/wackestone

Crinoid lime-mud/wackestone is exposed chiefly on the southern foot of Mt. Pope. The typical rocks are exposed around the western end of Stones Bay Road and the nearby old trail to Mt. Pope. An isolated outcrop is along the new Mt. Pope trail about 900 m northeast from its entrance. The rocks of this type are tectonically overlain by a single layer of the basaltic breccia and volcanoclastic rocks, approximately attaining 40 m in thickness, which is, in turn, overlain by a thick pile of *Tubiphytes* lime-mud/wackestone. The basaltic breccia in places contains clasts of highly vesicular lavas.

The rocks are grey to dark grey, occasionally dark grey-speckled. No distinct bedding fabrics are recognized and the rocks are at many localities completely massive and structureless. Crude laminae, crowded with coarse sand-sized crinoidal debris are discernible in places (Fig. 5). Bedding surfaces indicated by the crinoidal laminae strike northwest to east and are moderately to steeply inclined to north.



Figure 5. Crinoid-condensed laminae (L) seen in massive micritic limestone. An arrow indicates the face of beds. Locality MP 44, approximately 400 m west-northwest from the entrance of the old Mt. Pope trail, is shown in Figure 2.

The most predominant skeletal component of this type is crinoid debris, which are usually coarse sand- to granule-sized and subrounded to subangular. Fusulinids, gastropods, *Tubiphytes*, and related micritic particles are present, but are rare and scattered. All organic debris are supported by a predominant micritic matrix.

Crinoid-Tubiphytes lime-mud/wackestone

Crinoid-*Tubiphytes* lime-mud/wackestone occupies most of Mt. Pope. The excellent exposures are on the middle to upper slope of Mt. Pope and around its top (Fig. 3). The isolated exposures of the rocks of this type are on the foot of the eastern slope of Mt. Pope, where they are separated by a layer of the basaltic breccia and volcanoclastic rocks, informally designated as undifferentiated basalt unit (Struik et al., 1996), from crinoid lime-mud/wackestone.

The lime-mud/wackestone usually contains rare skeletal debris, which is in many cases fine grained, poorly preserved, and scattered in a homogeneous-looking micritic matrix. All these rocks have a mud-support fabric. The recrystallization is markedly severe in places.

Tubiphytes and its related cyanobacteria occur as scattered debris composed of structureless-looking creamy-white micrite. They are usually a few millimetres in size and have irregular shapes and poorly-defined outlines. The local concentration of *Tubiphytes* and its related cyanobacteria is seen,

but no fabrics, where they are interconnected to form an organic frame, have been recognized. Short and tubular forms of possible filamentous cyanobacteria, including *Girvanella*, occur locally. Crinoid debris is less abundant than *Tubiphytes* debris, sand-sized, and randomly dispersed. Fusulinids occur, but are a very rare component.

These rocks are discriminated from crinoid lime-mud/wackestone by more abundant occurrence of *Tubiphytes* and related cyanobacterial debris and by the rarity of crinoid and fusulinid debris. These two types of limestone are, however, similar in having a predominant lime-mud matrix.

Fusulinid-Tubiphytes pack/wackestone

Fusulinid-*Tubiphytes* pack/wackestone is exposed, so far as surveyed, only at the top of the unnamed peak located approximately 2.5 km east-northeast of Mt. Pope (Fig. 4). Though the distribution is limited, these rocks are significant because of their abundance of fusulinids and close association of *Tubiphytes* bindstone and related microbialites (Fig. 6).

The pack/wackestone is light grey to grey, completely massive, and in places weakly dolomitized. The rocks are characterized by the prolific occurrence of fossil particles. Major organic components are fusulinids, crinoids, filamentous cyanobacteria, and *Tubiphytes*. All the rocks of this type have a micritic matrix. The organic debris are often densely

packed and form a packstone fabric. *Tubiphytes* bindstone and related microbialites occur where the pack/wackestone has a local concentration of oncoids (Fig. 6).

Tubiphytes, a predominant fossil component in this rock, occurs usually as isolated debris of irregular shape, up to a few millimetres in size. In places it forms thin, dome-shaped envelopes covering skeletal debris. Fusulinids are widespread and locally abundant. Crinoids are much less abundant than *Tubiphytes* and fusulinids.

Tubiphytes bindstone and related microbialites were found in a few intervals within a succession of fusulinid-*Tubiphytes* pack/wackestone (Fig. 6). The intervals rich in the bindstone layers are usually less than a few tens of metres thick.

Tubiphytes bindstone occurs as thin, laterally discrete, crudely laminated, micritic layers, or mats (Fig. 7). Skeletal debris, including fusulines and crinoids, have been trapped and complexly interconnected with one another in the bindstone layers. Their top and bottom surfaces are irregularly undulated and poorly defined. The bindstone layers range in thickness from a few centimetres to several tens of centimetres and are alternating with *Tubiphytes*-rich bioclastic packstone, in which skeletal particles have been often encrusted, or in places bound by *Tubiphytes*.

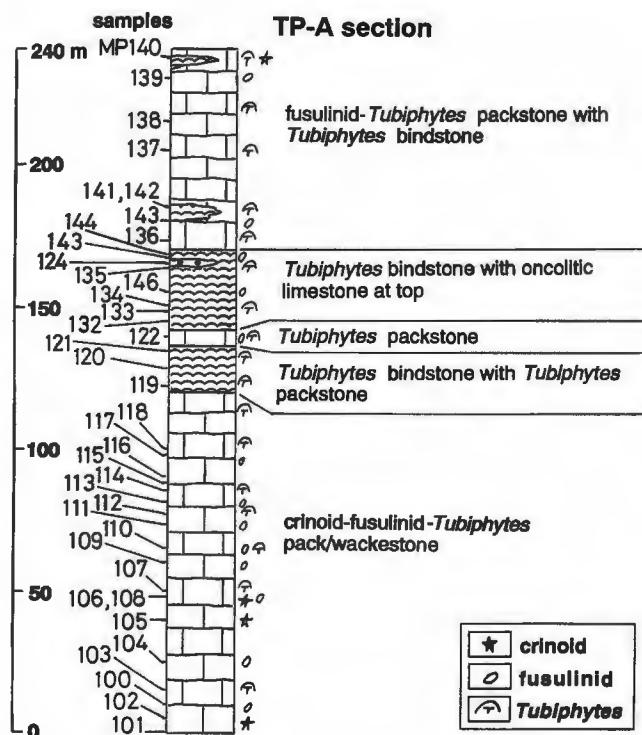


Figure 6. Columnar section illustrating intercalations of *Tubiphytes* bindstone within the fusulinid- and *Tubiphytes*-rich packstone succession at the top of the unnamed peak, northeast of Mt. Pope. Section TP-A. See Figure 2 for locality.

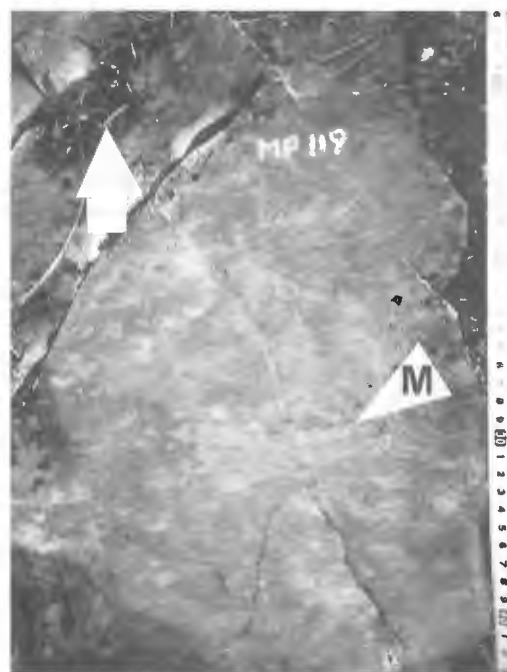


Figure 7. *Tubiphytes* bindstone containing thin, laterally discrete micritic laminae indicated as M. An arrow indicates the face of beds. Locality MP 119. Middle part of section TP-A shown in Figure 6.

Bedded siliceous limestone

The bedded siliceous limestone forms outcrops with the shaly marlstone (Fig. 8) at isolated, roadside exposures approximately 2 km northeast of the mouth of Pinchi Creek (MP 22, 23 in Fig. 2). These localities correspond to locality K9-1 of Orchard and Struik (1996), where Upper Carboniferous to Lower Permian conodonts have been extracted. The bedded limestone succession is overlain by basaltic rocks chiefly consisting of the calcite-cemented lava breccia and dark red volcanoclastic sandstone. The boundary between the basaltic rocks and the bedded siliceous limestone is covered by half a metre of colluvium. The sequence may be overturned.

The bedded siliceous limestone is dark grey, slightly carbonaceous and putrid, fine grained, and dense. Some chert nodules are embedded in places, and locally the rocks are dolomitized.

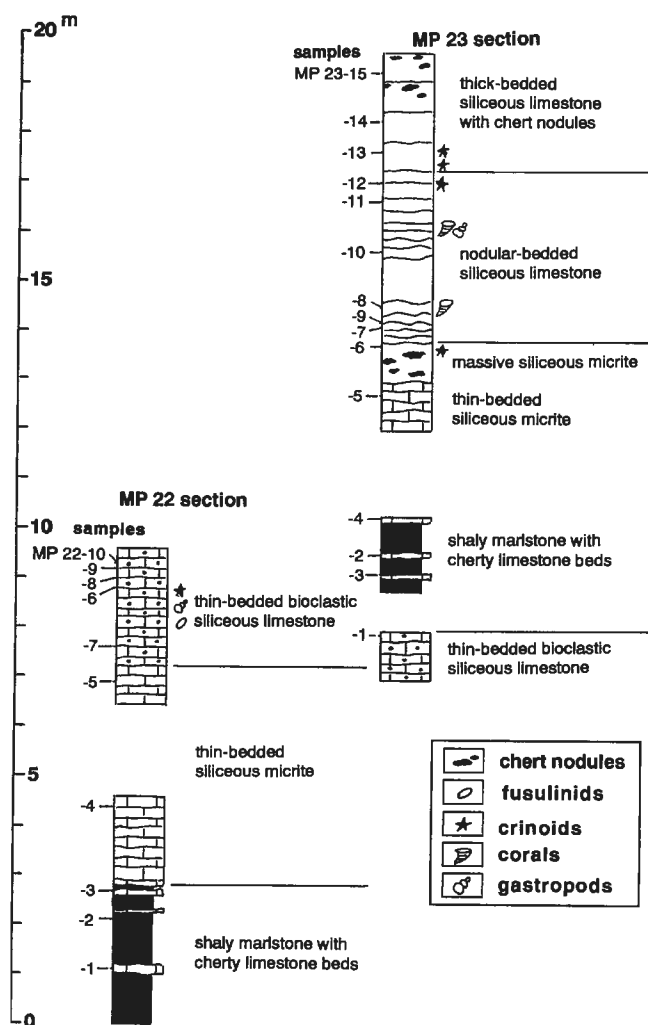


Figure 8. Columnar sections of bedded siliceous limestone and associated marlstone. Sections MP 22 and 23, approximately 2 km northeast of the mouth of Pinchi Creek. See Figure 2 for locality.

Skeletal debris recognized in the field include gastropods, corals, crinoids, and fusulinids. Rare shells probably of brachiopods and bivalves are present. Most of these skeletal debris are scattered, but abundant crinoidal debris occur at a few levels, where the rocks are properly described as crinoid wacke/packstone. All the skeletal debris is set in a micritic matrix and the rocks have a matrix-support fabric.

The bedded siliceous limestone is best discriminated by having a distinct bedding fabric from the other major types. Each of the siliceous limestone beds ranges in thickness from a few tens of centimetres to 1 m. The rocks are wavy-bedded and their bedding surfaces are often irregularly knobby. In addition to the nodular bedding, stylolite seams, subparallel to the bedding surface are often seen within the beds. Primary sedimentary fabrics of this type are considered to be modified by an intense pressure-solution effect.

The shaly marlstone occurs associated with the bedded siliceous limestone (Fig. 8). Intervals of the shaly marlstone are 2 to 3 m thick. The shaly marlstone is grey, fissile, thin-bedded, and crudely laminated. Thin, intermittent beds of dark grey siliceous limestone are intercalated in the shaly marlstone intervals.

Clastic limestones

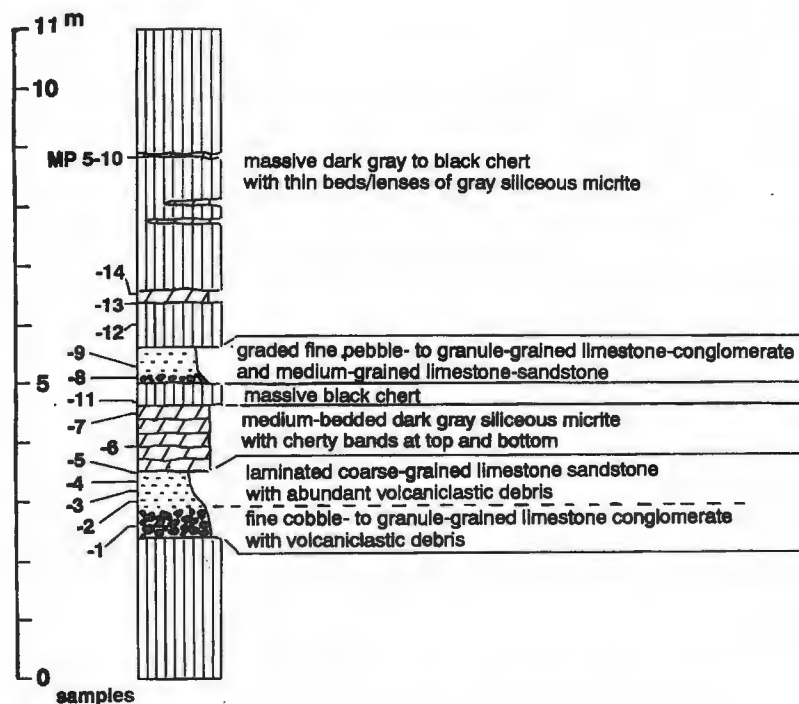
Intermittent beds of limestone conglomerate and limestone sandstone in a chert-siliceous micrite succession were found at an isolated outcrop along the new Mt. Pope trail (MP 5 in Fig. 2). These two types of the clastic limestone are allochthonous, having been gravitationally displaced into a chert-siliceous micrite succession, and are considered to play an important lateral link between deep-marine siliceous facies and shallow-marine carbonate facies of the Mt. Pope formation.

The chert-siliceous micrite succession consists largely of chert and contains a small amount of the siliceous micrite and clastic limestone (Fig. 9). The chert is black, highly crystalline, and massive to thick-bedded without argillaceous shaly partings. Ghosts of radiolarian remains were occasionally discernible in the field. The siliceous micrite is dark grey and aphanitic and occurs as interbeds ranging in thickness from a few centimetres to 1 m or more. Thin, laterally discrete bands and nodules of the black chert are contained in a thicker intercalation of the siliceous micrite. These lithological characteristics could be interpreted as deposition of the chert and associated siliceous micrite in deep water.

The clastic limestones comprise graded limestone conglomerate and limestone sandstone (Fig. 9, 10). Top and bottom surfaces of the clastic limestone beds are planar and lithologically well defined. No lithological transition into the chert nor siliceous micrite is recognized.

The limestone conglomerate consists of fine cobble- to granule-sized clasts of the limestone and contains an appreciable amount of sand- to granule-sized, dark green basaltic detritus. Individual crinoid debris occurs embedded together with these lithoclasts. The limestone clasts are subrounded to subangular, roughly oriented and laminated, and densely packed. The clast-association is polymictic and has a

MP 5 section

**Figure 9.**

Columnar section illustrating intercalation of graded limestone conglomerate and limestone sandstone within a chert-siliceous micrite succession. Section MP 5 along the new Mt. Pope trail. See Figure 2 for locality.

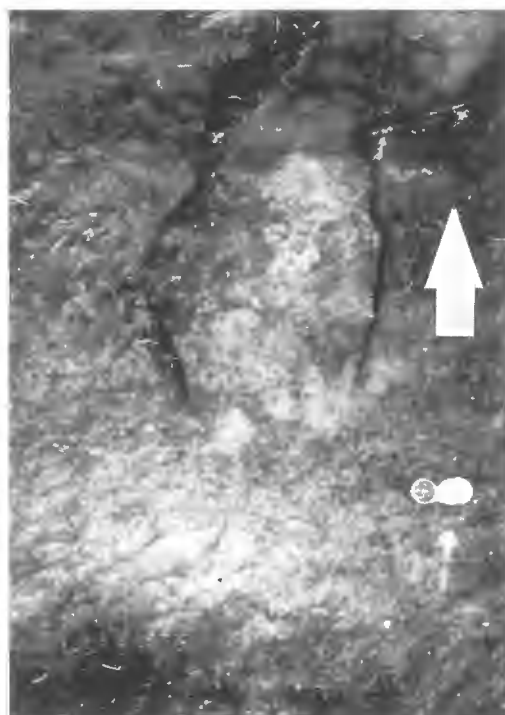


Figure 10. Graded limestone conglomerate (lower half of view) and crudely laminated limestone sandstone (upper half of view), both characterized by a densely packed fabric, intercalated in a chert succession. An arrow indicates the face of beds. Middle part of section MP 5 shown in Figure 9.

shallow-marine affinity. The matrix of the limestone conglomerate is generally poor, but is micritic where present. The limestone conglomerate grades upsection into the limestone sandstone. It consists of coarse- to medium-grained, sorted, crudely laminated limestone detritus of various rock-types and contains a considerable amount of basaltic detritus. The limestone and basaltic detritus are densely packed and exhibit an arenitic texture.

The field properties of these clastic limestones suggest that their deposition was by possible sediment-gravity flows including debris flow and turbidity currents. The limestone debris is interpreted to have been gravitationally displaced together with basaltic detritus from a shallow-marine buildup down into a deeper basin where the chert and siliceous micrite accumulated. The contamination of basaltic detritus implies the presence of a basaltic substratum below the shallow-marine buildup.

DISCUSSION

This discussion concentrates on the relationship between the main limestone mass of the Mt. Pope formation and the interbedded clastic limestone and chert-siliceous micrite succession. We preliminarily propose a subdivision of the Mt. Pope oceanic rocks into two stratigraphic units of a limestone unit and a chert unit. Components of these units may have originally passed laterally into each other, although the age control is at present insufficient to confirm

synchronous deposition. This stratigraphic subdivision of the Mt. Pope oceanic rocks may be closely related to the reconstruction of their sedimentary framework.

Cordey and Struik (1996a) report a succession of chert and micrite from Battleship Island, which is thought to structurally occupy the most southwestern extension of the Mt. Pope formation. This chert-micrite succession on Battleship Island is lithologically similar to the part of the chert-siliceous micrite succession along the new Mt. Pope trail (Fig. 9). These successions are commonly characterized by alternating radiolarian chert and micritic limestone beds and occasionally contain intermittent beds of the limestone conglomerate and sandstone. The micritic limestones are highly siliceous and often contain chert nodules and thin layers. The lithological character of the chert and siliceous micrite could be interpreted as due to deep-water sedimentation, as Cordey and Struik (1996b) already suggested for the Battleship Island chert-micrite succession.

The clastic limestones are interpreted as intermittent, gravitationally displaced shallow-marine carbonates down into a deeper basin where the chert and siliceous micrite were deposited. Analogous examples for displaced shallow-marine carbonates into deep-marine siliceous sediments are documented from ancient accretionary terranes of Japan (Sano, 1984; Uchiyama et al., 1986). In addition to the lithological affinity, these two chert-siliceous micrite successions are in the same structural position (Fig. 2). They may be structurally overlain by the thick pile of shallow-marine limestones. From the similarity in structural position, as well as the lithological affinity we propose that these chert-micrite successions of possible deep-marine facies are lithologically correlative with each other and form a single stratigraphic unit. The unit is characterized by alternating radiolarian chert and siliceous micrite that contains intermittent beds of the clastic limestone.

The age of the Battleship Island chert-micrite succession has been determined from radiolarians from the micrite as being within the range of late Pennsylvanian to Early Permian from (Cordey and Struik, 1996b). The chert-micrite succession could be chronologically overlapped by the shallow-marine limestones of the Mt. Pope formation (Late Carboniferous to Early Permian: Thompson, 1965; Orchard and Struik, 1996). The two stratigraphic units characterized by the chert-siliceous micrite alternation and the shallow-marine limestone are largely different in lithology, but could be nearly time-equivalent.

Struik et al. (1996) described the Mt. Pope formation as consisting predominantly of shallow-marine limestones with minor basalt and chert. Here we highlight the chert-micrite unit as distinct from the shallow-marine limestone facies and suggest that the two facies may be in part age-equivalent. The shallow-marine limestone-bearing unit is almost entirely comprised of bioclastic limestones with minor bindstones and basaltic rocks and may be entirely of shallow-marine facies. As highly vesicular in places, the basaltic rocks are thought to have been a volcanic substratum originally

underlying the shallow-marine limestones of this unit, though tectonically separated at present. The appreciable contamination of basaltic debris in the clastic limestones also support this interpretation. The other unit consists of an alternation of the radiolarian chert and the siliceous micrite having intermittent beds of the clastic limestone and exhibits deep-marine facies.

Sedimentary framework

Following the general interpretation of the Cache Creek oceanic rocks (Monger et al., 1992), with an emphasis upon the presently interpreted stratigraphy, we postulate that the Mt. Pope oceanic rocks originally accumulated as laterally continuous sedimentary cover on a topographic high of basaltic rocks, most likely a seamount. The shallow-marine limestone unit is interpreted as a sedimentary cap at the top of a seamount. The chert-siliceous micrite unit is considered to have accumulated on a lower slope of a seamount to its surrounding ocean floor. We consider that these two units, having completely different facies, were laterally linked with each other by the clastic limestones. An analogous sedimentary framework has been reconstructed in Mississippian to Guadalupian oceanic-rock assemblages in Japan (Sano and Kanmera, 1988; Sano, 1989).

CONCLUSIONS

The Upper Carboniferous to lower Lower Permian limestones of the Mt. Pope formation, northwest of Fort St. James, central British Columbia, were examined. This report described the major distribution and field properties of the shallow-marine bioclastic limestones and associated microbial bindstones and the clastic limestones embedded within a chert-micrite succession.

Lithological, structural, and chronological features led us to a preliminary stratigraphic subdivision of the Mt. Pope oceanic rocks. The oceanic-rock assemblage can be subdivided into a shallow-marine limestone unit and a deep-marine chert-siliceous micrite unit. These two units largely differ in lithology, but cannot at present be differentiated in age of deposition. The rocks of the two units are interpreted as sediment associated with a seamount, or a ridge. We postulate that shallow-marine carbonate and deep-marine siliceous facies originally passed laterally into each other, linked by the clastic limestones.

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REFERENCES

- Ash, C., MacDonald, R.W.J., and Paterson, I.A.**
1993: Geology of the Stuart and Pinchi Lakes area, central British Columbia (93K); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-9.
- Bellefontaine, K.A., Legun, A., Massey, N., and Desjardins, P.**
1995: Digital geological compilation of northeast B.C.-Southern half (NTS 83D, E, 93F, G, H, I, J, K, N, O, P); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1995-24.
- Cordey, F. and Struik, L.C.**
1996a: Scope and preliminary results of radiolarian biostratigraphic studies, Fort Fraser and Prince George map areas, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 83-90.
1996b: Radiolarian biostratigraphy and implications, Cache Creek Group of Fort Fraser and Prince George map areas, central British Columbia; in *Current Research 1996-E*; Geological Survey of Canada, p. 7-18.
- Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gehrels, G.E., and O'Brien, J.**
1992: Part B. Cordilleran terranes; in *Upper Devonian to Middle Jurassic assemblages*, Chapter 8 of *Geology of the Cordilleran Orogeny in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 281-327.
- Orchard, M.J. and Struik, L.C.**
1996: Conodont biostratigraphy, lithostratigraphy, and correlation of the Cache Creek Group near Fort St. James, British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 77-82.
- Paterson, I.A.**
1973: The geology of the Pinchi Lake area, central British Columbia; Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 263 p.
- Sano, H.**
1984: Displaced dolomites in radiolarian cherts in the Chichibu Belt on Shikoku Island, Southwest Japan; *Sedimentary Geology*, v. 37, p. 203-223.
1989: Permian oceanic rocks of Mino terrane, central Japan. Part IV. Supplement and concluding remarks; *Journal of Geological Society of Japan*, v. 95, p. 595-602.
- Sano, H. and Kanmera, K.**
1988: Paleogeographic reconstruction of accreted oceanic rocks, Akiyoshi, southwest Japan; *Geology*, v. 16, p. 600-603.
- Struik, L.C., Floriet, C., and Cordey, F.**
1996: Geology near Fort St. James, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 71-76.
- Thompson, M.L.**
1965: Pennsylvanian and Early Permian fusulinids from Fort St. James area, British Columbia; *Journal of Paleontology*, v. 39, p. 224-234.
- Uchiyama, T., Sano, H., and Kanmera, K.**
1986: Depositional and tectonic settings of cherts around the Akiyoshi Limestone Group; *Memoirs of the Faculty of Science, Kyushu University*, ser. D, v. 26, p. 51-68.

Geological Survey of Canada Project 950036

Conodont biostratigraphy and correlation, Cache Creek Group, Fort St. James, central British Columbia¹

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Abstract: Conodont collections from the Cache Creek Group of the Fort St. James in central British Columbia are provisionally differentiated into five upper Paleozoic faunas (A-E) and several Triassic faunas. The Pope formation (informal) is predominantly Late Carboniferous, with the majority of outcrops being Bashkirian. Moscovian limestones are far less common and largely confined to eastern exposures. A belt of limestones on the northern edge of the outcrop are Gzhelian-Asselian. The only definitive Permian conodont fauna dates a basalt unit as Guadalupian (Roadian-Wordian). Sparsely fossiliferous Lower-Upper Triassic clastic and chert strata occur widely. Correlatives of most of the conodont faunas presently identified in Fort St. James area are known from the eastern (mélange) belt of the Cache Creek Group in its type area in southern British Columbia; all those from the Paleozoic are also known from chert of the Slide Mountain terrane.

Résumé : Les collections de conodontes provenant du Groupe de Cache Creek à Fort St. James dans le centre de la Colombie-Britannique sont provisoirement classées en cinq faunes (A-E) du Paléozoïque supérieur et en plusieurs faunes du Trias. La formation de Pope (informelle) date principalement du Carbonifère tardif, la majorité des affleurements remontant au Bashkirien. Les calcaires du Moscovien sont beaucoup moins abondants et surtout limités aux affleurements situés dans l'est. Une zone de calcaires sur la limite nord de l'affleurement remonte au Gzhélien-Assélien. La seule faune de conodontes définitivement du Permien confère un âge guadalupien (roadien-wordien) à une unité de basalte. Des strates clastiques et cherteuses à fossiles épars du Trias inférieur-supérieur sont répandues. Les faunes corrélatives de la plupart des faunes de conodontes actuellement identifiées dans la région de Fort St. James proviennent de la zone orientale (mélange) du Groupe de Cache Creek dans sa région type dans le sud de la Colombie-Britannique; toutes celles qui datent du Paléozoïque proviennent également d'un chert dans le terrane de Slide Mountain.

¹ Contribution to the Nechako Plateau NATMAP Project

INTRODUCTION

A suite of carbonate samples collected from the Fort St. James region of central British Columbia (Fig. 1) during 1995 yielded a total of 23 conodont collections. These supplement an equal number of collections previously known from the area (Orchard and Struik, 1996). Assessment of the composition and age of all collections leads to a preliminary conodont biostratigraphic framework for the Cache Creek Group in the region, and facilitates correlation within the Canadian Cordillera.

In the Fort St. James area, sedimentary rocks of the Cache Creek Group are informally divided into the Pinchi sequence that forms a narrow northwest-trending belt north of Fort St. James, the more extensive Sowchea sequence to the south, and the massive carbonates of the Pope formation that forms a narrow parallel belt approximating the boundary between the two sequences (Fig. 2; Struik et al., 1996). Conodont collections come predominantly from the Pope formation but are also known from the Pinchi and Sowchea sequences. The faunal composition and age of each conodont collection processed from the area is documented in Table 1.

GEOLOGICAL SUMMARY

Cache Creek Group near Fort St. James can be divided into 6 units, most of which are informal designations (Struik et al., 1996; Cordey and Struik, 1996). They include: Trembleur

ultramafics, Railway gabbro, Mt. Pope formation, undifferentiated basalts, Sowchea sequence, and Pinchi sequence (Fig. 2). The Trembleur ultramafics consist of variably serpentinized harzburgite and peridotite, and occur as isolated ridges bound by faults. The Railway gabbro consists of gabbro and basalt in a nearly chaotic intermixture of intrusion. These rocks, with the Trembleur ultramafics are interpreted to be the igneous ophiolitic basement of Cache Creek Terrane in the area.

The Mt. Pope formation consists of variably fossiliferous limestone and dolostone that includes thin units of interbeds of ribbon chert and basalt in its lower section (for details see Sano and Struik, 1997). The undifferentiated basalts include isolated exposures of massive aphanitic to finely crystalline dark-olive basalt flows and fragmentals. The relationship of these basalts to other units is not clear.

The Sowchea and Pinchi sequences consist of greywacke, argillite, siltstone, basalt tuff, and limestone. The Pinchi sequence has more basalt than the Sowchea sequence and is exposed in a narrow belt along the northeast boundary of the Cache Creek Group (Fig. 2).

CONODONT FAUNA AND AGE

Most of the present conodont collections are Late Carboniferous in age. The only certain Permian conodont collection is newly reported from limestone interbedded with basalt. Middle?-Late Triassic conodont fauna is known from both the Pinchi and Sowchea sequences. An anomalous occurrence of Early Triassic conodonts is also reported in association with Late Carboniferous carbonate of the Pope formation.

None of the conodont collections are very well preserved but a few are large and diverse. The larger collections now available suggest that conodont colour alteration indices (CAI) are generally higher than formerly assessed, being within the range of CAI=4.5-5.5; locally they are as high as 7; temperatures of above 300° and locally upto 500+°C are indicated. In the following account, the conodont collections are described as broad age groupings in what is interpreted as ascending stratigraphic order, although it should be noted that none have yet been observed in direct superimposition within the map area.

Mt. Pope fauna A

The oldest conodont fauna known from the Cache Creek Group in the Fort St. James area is that reported by Orchard and Struik (1996) from close to the base of the limestone exposed below Mt. Pope. This fauna (Fig. 2, K8-7) is dominated by *Idiognathodus* aff. *klapperi* Lane and Straka 1974 which outnumbers co-occurring *Adetognathus lautus* (Gunnell 1931) by about 3:1. The latter species is about twice as abundant as *Idiognathoides sinuatus* Harris and Hollingsworth 1933; the remainder of the fauna consists of fewer *I. cf. convexus* (Ellison and Graves 1941), *I. cf. pacificus* Savage and Barkeley 1985, *Streptognathodus* ex gr. *expansus* Igo and Koike 1964, and *Hindeodus* sp.

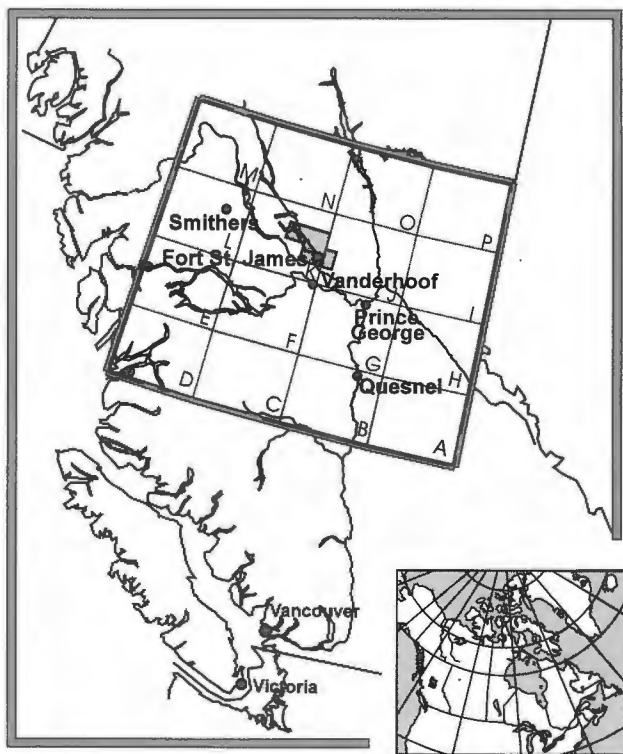


Figure 1. Location of Fort St. James and area of Figure 2 (shaded) in western Canada.

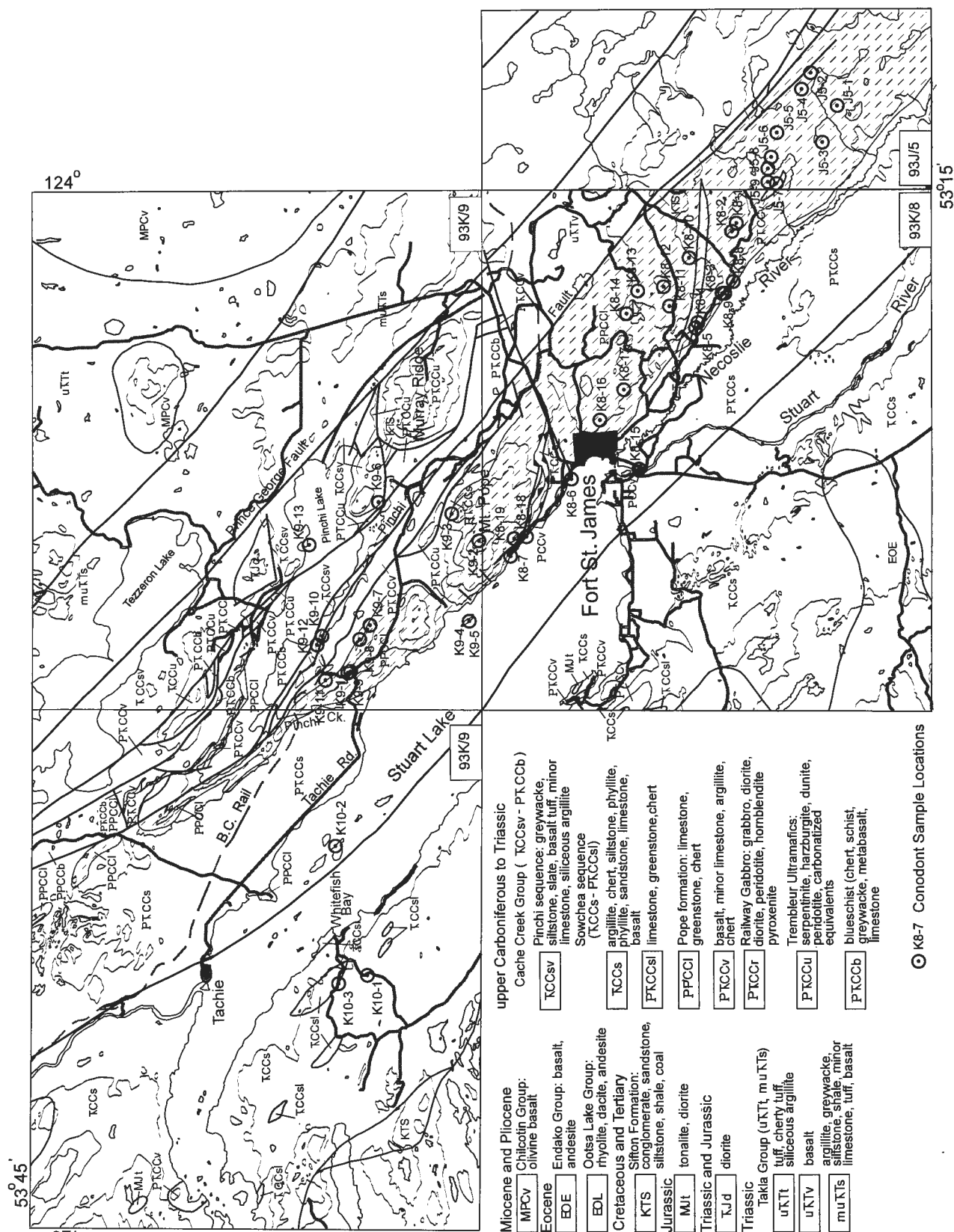


Figure 2. Geology of Fort St. James area with location of conodont samples.

Table 1. Faunal composition and age assignment of conodont collections from Fort St. James area.

Map no. (Field no.) GSC loc. no.	Conodont taxa	Fauna
McLeod Lake-Great Beaver Lake (93J/5)		
J5-4 (039) C-149724	ramiform elements	A-G
J5-1 (040) C-149725	<i>Diplognathodus</i> cf. <i>orphanus</i> , <i>Gondolella laevis</i> , <i>G.</i> ex gr. <i>magna</i> , <i>Idiognathodus delicatus</i> , <i>Idiognathoides</i> cf. <i>pacificus</i> , <i>Neognathodus</i> cf. <i>marginodosus</i> , <i>N.</i> ex gr. <i>atokaensis</i> , ramiform elements	C
J5-3 (041) C-149726	<i>Hindeodus</i> sp., <i>Idiognathodus delicatus</i> , <i>Idiognathoides sinuatus</i> , <i>I. tuberculatus</i> , <i>Neognathodus bothrops</i> , <i>N.</i> ex gr. <i>atokaensis</i> , <i>Neogondolella clarki</i> ramiform elements	B
J5-5 (044) C-149729	<i>Idiognathodus?</i> sp.	B?
J5-6 (056A) C-149730	<i>Diplognathodus</i> cf. <i>orphanus</i> , <i>Gondolella laevis</i> , <i>Hindeodus</i> sp., <i>Idiognathodus delicatus</i> , <i>Idiognathoides sinuatus</i> , <i>Neognathodus</i> cf. <i>bothrops</i> , <i>Neogondolella donbassica</i> , <i>Streptognathodus</i> ex gr. <i>concinus</i> , <i>S.</i> ex gr. <i>expansus</i> , ramiform elements	C
J5-8 (057) C-149731	<i>Gondolella</i> ex gr. <i>magna</i> , <i>Idiognathodus</i> cf. <i>delicatus</i> , ramiform elements	C
J5-7 (060) C-149732	<i>Gondolella</i> cf. <i>laevis</i> , <i>Idiognathodus</i> cf. <i>delicatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , ramiform elements	B
J5-2 (074) C-149734	<i>Idiognathodus?</i> sp. indet., <i>Neognathodus?</i> sp. indet., ramiform elements	B?
J5-9 (059) C-149743	<i>Idiognathodus</i> cf. <i>delicatus</i>	B-C
Fort Fraser-Fort St. James (93K/8)		
K8-5 (11A) C-103997	<i>Idiognathoides</i> cf. <i>sinuatus</i>	A-C
K8-4 (12) C-103998	gnathodid indet.	A-D

Map no. (Field no.) GSC loc. no.	Conodont taxa	Fauna
Fort Fraser-Fort St. James (93K/8)(cont.)		
K8-3 (13) C-103999	<i>Idiognathodus</i> cf. <i>delicatus</i> , <i>Idiognathoides</i> cf. <i>sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , ramiform elements	B
K8-7 (Pope-2A) C-118774	gnathodid indet., ramiform elements	A-B
K8-7 (Pope-2B) C-118775	<i>Adetognathus</i> cf. <i>lautus</i> , ramiform elements	A-C
K8-7 (Pope-2D) C-118777	<i>Adetognathus lautus</i> , <i>Gondolella cf. laevis</i> , <i>Hindeodus</i> sp., <i>Idiognathodus</i> aff. <i>klapperi</i> , <i>Idiognathoides</i> cf. <i>convexus</i> , <i>I. sinuatus</i> , <i>Streptognathodus</i> ex gr. <i>expansus</i> , ramiform elements	A
K8-6 (LAKE-8B) C-118787	<i>Epigondolella</i> ex gr. <i>bidentata</i> , <i>Neogondolella</i> sp., ramiform elements	G
K8-6 (LAKE-8D) C-118789	<i>Neogondolella</i> sp.?	G?
K8-2 (15A) C-149719	<i>Idiognathoides</i> cf. <i>convexus</i> , <i>I. sinuatus</i> , <i>Neognathodus</i> cf. <i>bothrops</i> , <i>N.</i> ex gr. <i>atokaensis</i> , ramiform elements	B
K8-1 (16A) C-149722	<i>Idiognathoides sinuatus</i> , <i>Neognathodus bothrops</i>	B
K8-13 (1602 A) C-302751	<i>Diplognathodus</i> cf. <i>orphanus</i> , <i>Idiognathodus delicatus</i> , <i>Neognathodus bothrops</i> , ramiform elements	B
K8-13 (1602 C) C-302753	<i>Gondolella laevis</i> , <i>Hindeodus</i> sp., <i>Idiognathodus</i> cf. <i>delicatus</i> , <i>Idiognathoides</i> cf. <i>sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , ramiform elements	B
K8-14 (1605 A) C-302754	<i>Hindeodus</i> sp., <i>Idiognathoides sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , <i>Streptognathodus</i> sp., ramiform elements	B
K8-12 (1703 B) C-302756	<i>Idiognathodus?</i> sp., <i>Idiognathoides?</i> sp., <i>Neogondolella sp. indet.</i> , ramiform elements	B

Table 1. (cont.)

Map no. (Field no.) GSC loc. no.	Conodont taxa	Fauna
Fort Fraser-Fort St. James (93K/8)(cont.)		
K8-11 (1705 B) C-302758	<i>Adetognathus?</i> sp., <i>Gondolella</i> aff. <i>laevis</i> , <i>Hindeodus</i> sp., <i>Idiognathodus</i> sp., <i>Idiognathoides convexus</i> , <i>I. aff. marginodosus</i> , <i>I. sinuatus</i> , ramiform elements	B
K8-16 (1803 B) C-302760	<i>Hindeodus</i> sp., <i>Idiognathoides sinuatus</i> , ramiform elements	B?
K8-10 (1901 A) C-302761	<i>Neogondolella</i> sp. indet., ramiform elements	B-E
K8-8 (2007 A) C-302762	<i>Diplognathodus?</i> sp., <i>?Idiognathodus</i> sp., <i>Idiognathoides</i> sp., ramiform elements	B
K8-9 (2009 B) C-302764	<i>Budurovignathus?</i> sp., <i>Idiognathodus</i> sp., <i>Idiognathoides</i> sp., <i>Metapolygnathus?</i> sp., <i>Neogondolella</i> ex gr. <i>jubata</i> , <i>Neogondolella</i> sp., <i>Neospathodus symmetricus</i> , ramiform elements	F
K8-19 (2103 A) C-302765	<i>Idiognathoides sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , <i>N. cf. bothrops</i> , ramiform elements	B
K8-15 (2801 B) C-302782	<i>Neogondolella nankingensis</i>	E
K8-18 (3101 A) C-302797	<i>Adetognathus</i> sp., <i>Idiognathoides</i> cf. <i>convexus</i> , ramiform elements	A-B
K8-17 (1807 B) C-302798	<i>Diplognathodus</i> cf. <i>orphanus</i> , <i>Hindeodus</i> sp., <i>Idiognathodus delicatus</i> , <i>Idiognathoides nodimarginatus</i> , <i>I. sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , <i>Neogondolella donbassica</i> , ramiform elements	B-C
Fort Fraser-Pinchi Lake (93K/9)		
K9-13 (Pinchi Lake) O-086398	<i>Epigondolella</i> sp. indet., <i>Neogondolella</i> sp. indet.	G

Map no. (Field no.) GSC loc. no.	Conodont taxa	Fauna
Fort Fraser-Pinchi Lake (93K/9)(cont.)		
K9-1 (Pinchi-1a) C-118771	<i>Idiognathoides?</i> sp., ramiform elements	B?
K9-1 (Pinchi-1b) C-118772	<i>Hindeodus?</i> sp., gnathodid indet., ramiform elements	B?
K9-9 (1503 A) C-302750	<i>Idiognathoides sinuatus</i> , <i>Neognathodus</i> ex gr. <i>atokaensis</i> , ramiform elements	B
K9-7 (2307 A) C-302767	<i>Diplognathodus</i> sp. indet., <i>Streptognathodus</i> cf. <i>elongatus</i> , ramiform elements	D
K9-8 (2312 B) C-302770	<i>Hindeodus</i> sp., <i>Streptognathodus</i> cf. <i>elongatus</i> , ramiform elements	D
K9-10 (2405 A) C-302771	<i>Metapolygnathus nodosus</i> , ramiform elements	G
K9-11 (2607 A) C-302775	<i>Hindeodus?</i> sp., <i>Streptognathodus</i> cf. <i>brownsvillensis</i>	D
K9-3 (2711 B) C-302780	<i>Hindeodus</i> sp., <i>Streptognathodus</i> cf. <i>elongatus</i> , ramiform elements	D
K9-6 (4402 A) C-302792	ichthyoliths	G?
K9-4 (1101 A) C-302794	<i>Diplognathodus</i> sp. indet., <i>Gondolella</i> sp., <i>Idiognathodus</i> sp., ramiform elements	B
Fort Fraser-Stuart Lake (93K/10)		
K10-1 (2908 A) C-302783	ramiform elements, <i>Budurovignathus?</i> sp., <i>Metapolygnathus?</i> sp., <i>Neogondolella</i> sp.	G
K10-3 (3004 A) C-302784	<i>Neogondolella</i> sp. indet.	B-G
K10-2 (802 A) C-302793	<i>Neogondolella</i> sp. indet., ramiform elements	B-G

Many of these species are widespread and long ranging. In North American terms, *Idiognathoides* species are present in the upper Morrowan through Atokan, and questionably into the Desmoinesian. Although *Idiognathodus* aff. *klapperi* differs from the Morrowan species from Arkansas with which it is compared, the similarity to that species supports an Early Pennsylvanian, that is an early-middle Bashkirian age for the Mt. Pope fauna (Fig. 3). The remainder of the fauna is consistent with this age, although an Atokan or late Bashkirian age cannot be ruled out. The common occurrence of *Adetognathus*, the absence of *Neognathodus*, and the occurrence of different species of *Idiognathodus* differentiates fauna A from what is regarded as the slightly younger fauna B.

Necoslie fauna B

The majority of conodont collections from the Pope formation contain *Idiognathoides* spp. in variable association with *Idiognathodus delicatus* Gunnell 1931 and neognathodids corresponding to members of the *Neognathodus bothrops* Merrill 1972 - *N. atokaensis* Grayson 1984 group described from the Arbuckle Mountains of Oklahoma by Grayson (1984). As in the Atokan of the latter area, *Adetognathodus*, *Diplogathodus* cf. *orphanus* (Merrill 1973), and *Hindeodus* also occur. In common with fauna A, *Idiognathoides sinuatus* is the most common species of that genus, but there are also occurrences of *I. convexus*, the Atokan species *I. marginodus* Grayson 1984, and the Bashkirian species *I. tuberculatus* Nemirovskaya 1975. Commonly, *Gondolella laevis* Kosenko & Kozitskaya 1975 and/or *Neogondolella clarki* (Koike 1967) also occur, indicating relatively off-shore/deeper water environments. The age of the Necoslie fauna is regarded as Atokan, or late Bashkirian.

McLeod Lake fauna C

In several collections from the Pope formation, elements characteristic of fauna B occur with elements close to *Neogondolella donbassica* Kossenko 1975 or *Gondolella* ex gr. *magna* Stauffer & Plummer 1932. These species are known from, respectively, the Moscovian and Desmoinesian. *Neogondolella donbassica* seems to have developed from *N. clarki* by posterior platform elongation, whereas *Gondolella* ex gr. *magna* evolved from *G. laevis* through platform crenulation. Therefore, the occurrence of the first two species is here regarded as indicative of a younger age than fauna B, and collections containing them are differentiated as the McLeod Lake fauna C.

In the case of a single collection (K8-17; Fig. 2, Table 1), most of the elements of fauna B are associated with *Neogondolella donbassica* rather than *N. clarki*. The predominance of *Idiognathoides* in this collection suggests it may be a little older than a second collection (J5-6) in which *Neogondolella* cf. *donbassica* is associated with *Streptognathodus* cf. *concinus* Kossenko 1975; both species were originally described from the Moscovian of the Donets Basin. In a nearby collection (J5-1), *Gondolella* ex gr. *magna* Stauffer & Plummer 1932 occurs in association with *Neognathodus*

?*metanodosus* Merrill 1975; again suggestive of a Desmoinesian age for the McLeod Lake fauna C, that is equivalent to the Moscovian (Fig. 3).

Pinchi fauna D

Between Mt. Pope and Pinchi Lake, several small collections contain elements formerly combined as *Streptognathodus* ex gr. *elongatus* Gunnell 1933 (Orchard, 1991), a complex of species that occurs on both sides of the Carboniferous-Permian boundary. One collection (K9-11) contains fragmentary elements that resemble *Streptognathodus brownsvillensis* Ritter 1994, a species that dominates the Brownsville Limestone (Wabaunsee Group) of Kansas, the uppermost part of the Virgilian Series. This species appears more elongate but otherwise similar to the Gzhelian species *S. ruzhencevi* (Kozur 1976). Similar elements recovered from nearby sample sites (K9-7, K9-8) have more anteriorly restricted carinas and resemble the contemporaneous and younger *S. elongatus*

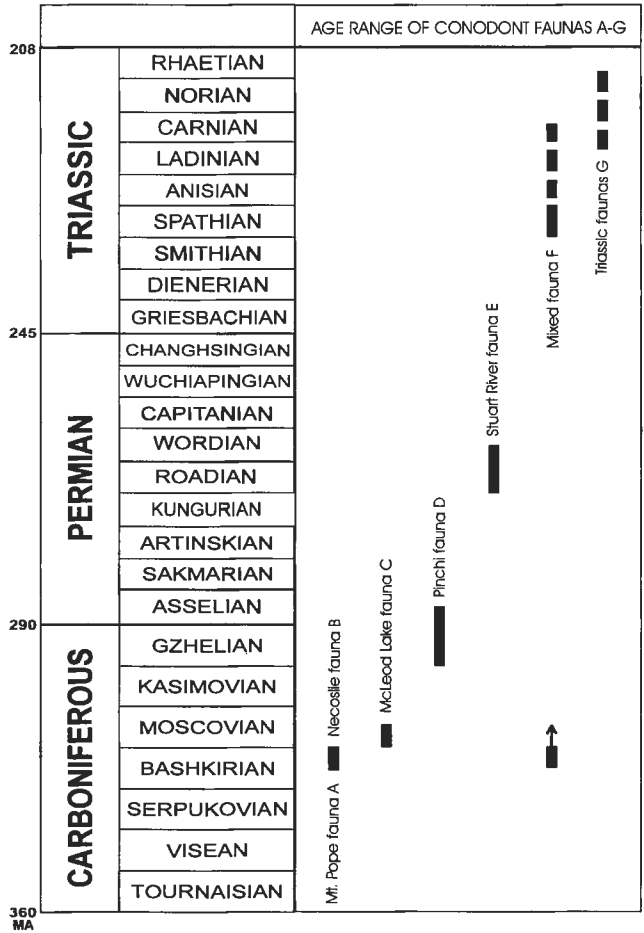


Figure 3. Ages of conodont faunas A-G. Fauna F has Carboniferous elements combined with Triassic fauna; several Upper Triassic levels are represented in composite fauna G.

Gunnell 1933 and younger Asselian species *S. constrictus* Reshetkova and Chernikh 1986. The Pinchi fauna D ranges within the Gzhelian-Asselian (Fig. 3).

Stuart River fauna E

On the north bank of the Stuart River close to Stuart Lake, limestone interbedded with basalt flows has yielded specimens of *Neogondolella nankingensis* (Ching 1960) (= *N. serrata* Clark and Ethington 1962). Under present definitions, this diagnostic species is definitive for the Roadian Stage of the Guadalupian Series, although it might also be found in the Wordian.

Mixed fauna F

At a single outcrop of limestone of the Pope formation outcropping north of the Necoslie River, a conglomeratic limestone has yielded at least two generations of conodont elements. The first population corresponds to the widespread Necoslie fauna B whereas the younger component includes elements of *Neospathodus symmetricus* Orchard 1995, which is indicative of the Lower Triassic Spathian stage. In addition there are several different, but less distinctive *Neogondolella* species and a possible *Budurovignathus* or *Metapolygnathus* species, suggestive of additional Middle and Upper Triassic elements. The explanation for this mixed fauna is uncertain, but stratigraphic leakage into breccia-filled solution cavities within the Carboniferous limestone is a possible explanation which is being tested through additional sampling (see also Sano and Struik, 1997).

Triassic fauna G

Several small collections of conodonts are dated as Triassic, and for the purposes of this paper are referred to a composite fauna G. One such collection from within the Sowchea sequence east of Whitefish Bay (K10-1) contains fragments of *Neogondolella* sp., ?*Metapolygnathus*, and a single ornate element of either *Budurovignathus* or *Epigondolella*. Both this, and a second collection (C-87513) made by H. Tipper in the Fraser Lake area (south of the area shown in Fig. 1) are only broadly constrained as Ladinian-Norian. Other samples within the Sowchea sequence east and west of Whitefish bay (K10-2, -3) have yielded only indeterminate neogondolellid fragments of late Paleozoic-Triassic age. Radiolarian chert from Stuart Lake (K8-6) is Norian based on both conodonts (Orchard and Struik, 1996) and radiolarians (Cordey and Struik, 1996).

To the north, from the Pinchi sequence, a new Late Triassic, late Carnian collection (K9-10) of *Metapolygnathus nodosus* (Hayashi 1968) is slightly older than that (GSC loc. 0-86398) reported from Pinchi Lake by Paterson (1977), which contains Norian *Epigondolella*. A diverse collection of ichthyoliths from a second northern locality (K9-6) are questionably assigned to the Triassic.

Hence, beyond the Pope formation, Triassic strata within the Cache Creek Group in the Fort St. James area are ?Ladinian, Carnian, and Norian.

CORDILLERAN CORRELATIONS

Many of the conodont taxa identified from the Cache Creek Group in Fort St. James area are known in other Cordilleran regions and each of the Carboniferous-Permian faunas can be assigned to one of several faunal divisions introduced by Orchard (1991) in his review of Cordilleran conodont occurrence.

Correlation within the Cache Creek Group can be made to differing extents to the north and south. The most notable difference that the present data show is the much older range of fauna recovered from massive limestones in the Cache Creek Group of the Atlin region in northern British Columbia, and the much younger carbonate development documented in southern British Columbia near Cache Creek (Orchard, 1984; Beyers and Orchard, 1991; Orchard and Danner, 1991). In Atlin, conodonts indicative of Serpukovian and other fossils as old as Tournaisian occur. Fauna B is the only one presently known from the Paleozoic limestones of the Cache Creek Group in both Atlin and Fort St. James. The better known situation in the south shows commonality of Paleozoic faunas C through E, but the main limestone development in the southern Cache Creek, the Marble Canyon Formation, is Upper Permian and Lower Triassic, much younger than the Pope formation.

Near the town of Cache Creek area, elements of Carboniferous faunas C and D are present only in the limestone olistoliths of the eastern Cache Creek Group belt (Orchard, 1984; faunules 2 and 12-14). A fauna similar to that of fauna E occurs in limestone turbidite in bedded chert forming the matrix of this eastern belt (Orchard, 1984, faunules 3, 9). Spathian conodonts are known from the Marble Canyon Formation but they are not mixed with Paleozoic conodonts as they are in fauna F from the Pope formation. Late Triassic clastics and chert (~fauna G) are now known from the Cache Creek Group throughout the length of the Cordillera.

Conodont faunas comparable to fauna A and/or B (faunas 7 and 8 of Orchard, 1991, p. 10) are common in chert from the Slide Mountain terrane (e.g., Struik and Orchard, 1985; Orchard, 1986), in the Dunira Formation and correlative units in Alexander terrane (Woodsworth and Orchard, 1985) and Wrangell terrane (Brandon et al., 1986). The faunas also occur in Yukon (Orchard, 1991).

Occurrences of fauna C (fauna 9 of Orchard, 1991, p. 10) are present but uncommon in the Slide Mountain cherts but are well displayed in the Alex Allen Formation in the Cariboo region of east central British Columbia (Orchard and Struik, 1985), where diverse faunas contain both *Neogondolella donbassica* and *Gondolella* ex gr. *magna*. Neither species are known elsewhere in western Canada.

Fauna D at Fort St. James corresponds broadly to fauna 11 of Orchard (1991, p. 11), which is characterized by *Streptognathodus* ex gr. *elongatus* Gunnell 1933. In the present collections, none of the accompanying species noted by Orchard (1991) have been recovered, and precise correlation is elusive. Similar streptognathodids are known from Slide Mountain, Stikine, and Wrangell terranes in the western Cordillera.

Fauna E at Fort St. James (fauna 16 of Orchard, 1991, p. 12) is uncommon in the Canadian Cordillera. Apart from the occurrence in Cache Creek, the fauna is known only from the Mount Christie Formation in south-central Yukon and from chert of the Slide Mountain terrane.

REFERENCES

- Beyers, J.M. and Orchard, M.J.**
1991: Upper Permian and Triassic conodont faunas from the type area of the Cache Creek Complex, south-central British Columbia; *in* Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera, (ed.) M.J. Orchard and A.D. McCracken; Geological Survey of Canada, Bulletin 417, p. 269-298.
- Brandon, M.T., Orchard, M.J., Parrish, R.R., Sutherland Brown, A., and Yorath, C.J.**
1986: Fossil ages and isotopic dates from the Paleozoic Sicker Group and associated intrusive rocks, Vancouver Island, British Columbia; *in* Current Research, Part A; Geological Survey of Canada, Paper 86-1A, p. 683-696.
- Cordey, F. and Struik, L.C.**
1996: Radiolarian biostratigraphy and implications, Cache Creek Group of Fort Fraser and Prince George map areas, central British Columbia; *in* Current Research 1996-E; Geological Survey of Canada, p. 7-18.
- Grayson, R.C., Jr.**
1984: Morrowan and Atokan (Pennsylvanian) conodonts from the north-eastern margin of the Arbuckle Mountains southern Oklahoma; *in* The Atokan Series (Pennsylvanian) and its Boundaries—a Symposium, (ed.) P.K. Sutherland and W.L. Manger; Oklahoma Geological Survey, Bulletin 136, p. 41-63.
- Orchard, M.J.**
1984: Pennsylvanian, Permian and Triassic conodonts from the Cache Creek Group, Cache Creek, Southern British Columbia; *in* Current Research, Part B; Geological Survey of Canada, Paper 84-1B, p. 197-206.
1986: Conodonts from Western Canadian chert: their nature, distribution and stratigraphic application; *in* Chapter 5 of Conodonts, Investigative Techniques and Applications, (ed.) R.L. Austin; Proceedings of the Fourth European Conodont Symposium (ECOS 1V), Ellis-Horwood, Chichester, England, p. 96-121.
- 1991: Conodonts, time and terranes: an overview of the biostratigraphic record in the western Canadian Cordillera; *in* Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera, (ed.) M.J. Orchard and A.D. McCracken; Geological Survey of Canada, Bulletin 417, p. 1-26.
- Orchard, M.J. and Danner, W.R.**
1991: The paleontology of the Cache Creek Terrane; *in* A Field Guide to the Paleontology of Southwestern Canada, (ed.) P.L. Smith; Canadian Paleontology Conference I, Vancouver, British Columbia, p. 169-202.
- Orchard, M.J. and Struik, L.C.**
1985: Conodonts and stratigraphy of Upper Paleozoic limestones in Cariboo Gold Belt, east-central British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 538-552.
1996: Conodont biostratigraphy, lithostratigraphy, and correlation of the Cache Creek Group near Fort St. James, British Columbia; *in* Current Research 1996-A; Geological Survey of Canada, p. 77-82.
- Paterson, I.A.**
1977: The geology and evolution of the Pinchi Fault Zone at Pinchi Lake, central British Columbia; Canadian Journal of Earth Sciences, v. 14, p. 1324-1342.
- Sano, H. and Struik, L.C.**
1997: Field properties of Pennsylvanian-Lower Permian limestones of Cache Creek Group, northwest of Fort St. James, central British Columbia; *in* Current Research 1997-A; Geological Survey of Canada.
- Struik, L.C. and Orchard, M.J.**
1985: Late Paleozoic conodonts from ribbon chert delineate imbricate thrusts within the Antler Formation of Slide Mountain Terrane, central British Columbia; Geology, v. 13, p. 794-798.
- Struik, L.C., Floriet, C., and Cordey, F.**
1996: Geology near Fort St. James, central British Columbia; *in* Current Research 1996-A; Geological Survey of Canada, p. 71-76.
- Woodsworth, G.J. and Orchard, M.J.**
1985: Upper Paleozoic to Lower Mesozoic strata and conodonts in the western Coast Plutonic Complex, British Columbia; Canadian Journal of Earth Sciences, v. 22, p. 1329-1344.

Geological Survey of Canada Project 950036

Geology of Shass Mountain, central British Columbia¹

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Letwin, J.M. and Struik, L.C., 1997: Geology of Shass Mountain, central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 103-106.

Abstract: Shass Mountain area, 40 km west of Fort St. James, consists primarily of mafic, ultramafic, and sedimentary rocks of the Upper Carboniferous to Lower Jurassic Cache Creek Group. These rocks are intruded on the north of Shass Mountain by biotite-hornblende diorite and quartz diorite of the Middle Jurassic McKnab Lake pluton. On the west flank of Shass Mountain, diorite and gabbro may be part of the Boer pluton, or a separate phase of McKnab Lake pluton. The mafic rocks are primarily amphibolite, diorite, and gabbro with a developed foliation, and the ultramafic rocks mostly serpentinite and partially serpentinized pyroxenites. Magnetic susceptibility does not distinguish the Cache Creek igneous rocks from later intrusions. The meta-sedimentary rocks include siltstone, greywacke, ribbon chert, and minor quartzite and marble. The juxtaposition of map units suggests they were structurally emplaced, rather than being a dismembered stratigraphic succession.

Résumé : La région du mont Shass, située à 40 km de Fort St. James, comporte principalement des roches mafiques, ultramafiques et sédimentaires du Groupe de Cache Creek du Carbonifère supérieur-Jurassique inférieur. Ces roches sont recoupées sur le flanc nord du mont Shass par des diorites à biotite-hornblende et des diorites quartziques du pluton de McKnab Lake du Jurassique moyen. Sur le flanc ouest du mont Shass, les diorites et les gabbros pourraient faire partie du pluton de Boer ou constituer une phase distincte du pluton de McKnab Lake. Les roches mafiques se composent principalement d'amphibolites, de diorites et de gabbros à foliation développée, et les roches ultramafiques incluent surtout des serpentinites et des pyroxénites en partie serpentinisées. La susceptibilité magnétique ne permet pas de distinguer les roches ignées de Cache Creek des intrusions plus récentes. Les roches métasédimentaires sont notamment des siltstones, des grauweekes, des cherts rubanés et un peu de quartzite et de marbre. La juxtaposition des unités cartographiques laisse supposer que leur mise en place est d'origine structurale et qu'il ne s'agit pas d'une succession stratigraphique démembrée.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

Shass Mountain (5825 ft., 1775 m) is a solitary mountain ridge 40 km west of Fort St. James in central British Columbia (Fig. 1, 2). It is a local landmark, standing above the surrounding plateau (770-1000 m). The area mapped here encompasses 125 km² of the western part of the ridge. Armstrong (1949) mapped the mountain as underlain primarily by a diorite pluton. Kimura et al. (1980), in their expansive 1:50 000 scale mapping of central and southern Fort Fraser map area, recognized various units of the Cache Creek Group as well as diorite pluton and Tertiary mafic volcanic rocks. The present study confirmed the presence of the Cache Creek Group, diorite plutonic rocks, and minor dykes of basalt possibly of Tertiary age.

In this report we briefly describe the units mapped in a detailed study of the mountain as part of the Fort Fraser mapping project, a subproject of the Nechako NATMAP project (93K; Struik and MacIntyre, 1997; Struik et al., 1997). The alpine to subalpine exposures of the ridge provided a unique opportunity to more clearly map the relationships of various rocks of the Cache Creek Group.

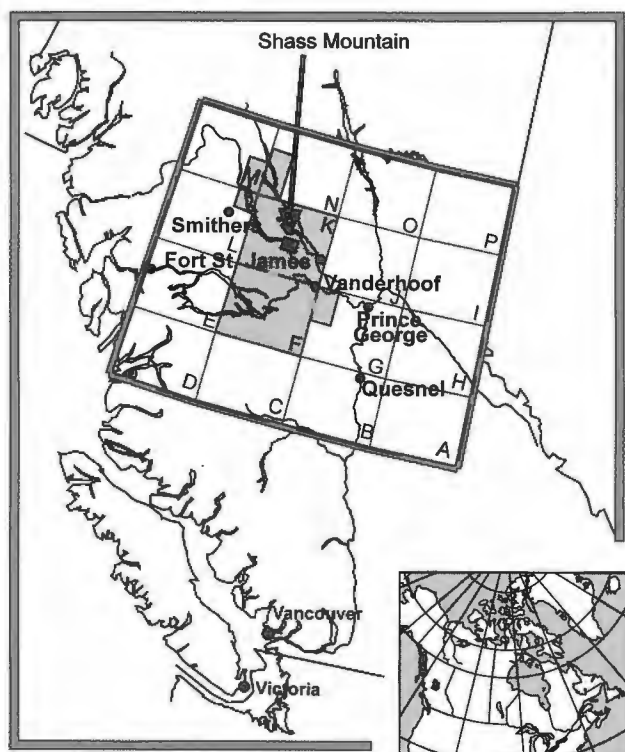
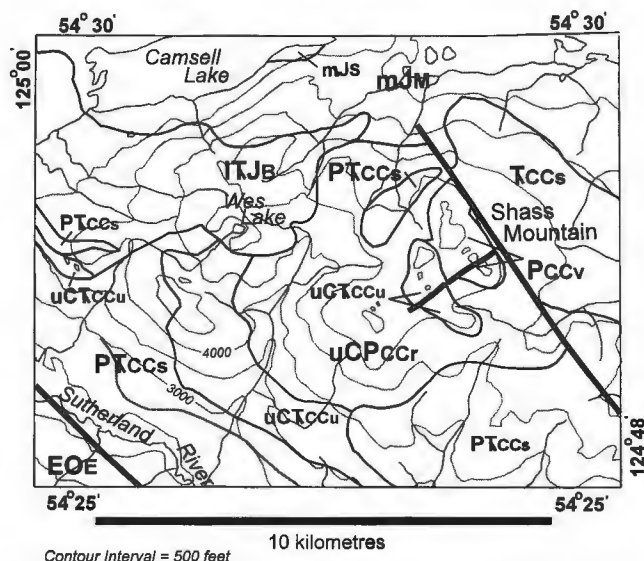


Figure 1. Location of Shass Mountain map area (black square) in relation to surrounding NTS maps of the Parsnip River (NTS 93) 1:1 000 000 scale map and the Nechako Plateau NATMAP project area (grey screen).



Tertiary

Eocene and Oligocene

Endako Group

EOE andesite, basalt, dacite, rhyodacite; flows, breccia, vesicular, amygdaloidal

Middle Jurassic

mJM McKrab Lake pluton: biotite hornblende quartz diorite and tonalite

Late Triassic - Early Jurassic

Boer plutonic suite

mJS Stem Lake phase: diorite, quartz diorite, granodiorite gneiss

ITJB Boer phase: diorite, gabbro

Upper Carboniferous to Lower Jurassic

Cache Creek Group

Middle Triassic - Lower Jurassic

TCCs siltstone, siliceous argillite, ribbon chert, slate, intraformational siltstone conglomerate, chert conglomerate

Permian - Triassic

PTCCs siltstone, slate, ribbon chert, greywacke, minor limestone

Permian

PCCv basalt, minor chert

Pennsylvanian - Early Permian

uCPGCr gabbro, diorite, basalt, amphibolite

uCTCCu Trembleur Ultramafics: pyroxenite, harzburgite, serpentinite, talc

Figure 2. Geological map of the Shass Mountain map area in central British Columbia. Solid thin lines are approximate and assumed bedrock geological contacts, and thick lines are approximate and assumed faults. In addition to the authors, the map includes geology from Kimura et al. (1980).

GEOLOGY

Geologically within the Canadian Cordillera, Shass Mountain rocks are mainly part of an exotic oceanic terrane accreted to the western continental margin of Jurassic North America. That exotic terrane, Cache Creek, was deformed, metamorphosed, and intruded by various gabbro and diorite plutons during accretion. Details of that oceanic terrane, and the consequences of the accretion process are the subject of the research introduced in this paper.

Post accretion, the Cache Creek Terrane and its amalgamated and intruded assemblages were further deformed and intruded during the Cretaceous and Tertiary. The Nechako Plateau NATMAP project's primary goal is to understand the Tertiary tectonic history of central British Columbia. This project contributes to that goal through its definition and understanding of the pre-Tertiary geological history of the Cache Creek Terrane.

Cache Creek Terrane is wholly defined by included rocks of the Cache Creek Group and their pre-Middle Jurassic structural history. Cache Creek Group rocks of Shass Mountain are assumed to range in age from Upper Carboniferous to Lower Jurassic, from information gathered in the adjacent area (Struik et al., 1996, 1997). They are intruded by the Mesozoic McKnab Lake pluton and the Boer plutonic suite (Fig. 2, 3).

Upper Paleozoic to Lower Jurassic

Cache Creek Group (uCTCCu to TCCs)

The Cache Creek Group at Shass Mountain consists of the Trembleur Ultramafics and three informal units; 1) meta-gabbro and basalt, 2) undifferentiated metabasalt and, 3) meta-sedimentary rocks.

Trembleur Ultramafic (uCTCCu)

Ultramafic rocks of Shass Mountain are included in the Trembleur Ultramafic suite of Armstrong (1949). This unit comprises most of the middle ridge of the three northwest-trending ridges atop Shass Mountain, and the southwest-facing slope along Sutherland River. The unit is discontinuous forming discrete belts of exposure.

The ultramafic rocks are characteristically dun weathering and green to black on fresh surfaces. They consist of variably serpentinized pyroxenes and perhaps olivine. Talc veins (0.5-10 cm) are common and occur in local concentrations of parallel to subparallel planar sets. Magmatic layering was observed in a few outcrops. Most of the ultramafic rocks at high elevations show a metamorphic cleavage, while those at lower elevations are massive. Magnetic susceptibility is extremely variable, with values ranging between 0.65 and 265×10^{-3} SI units.

The ultramafic rocks are locally crosscut by dykes of probable metabasalt. The dykes have undergone low grade metamorphism, probably during the same event that altered the ultramafic unit.

The age of this unit is unknown and for the time being is assigned the same age span as all local dated Cache Creek Group rocks as defined by Struik et al. (1997).

Meta-gabbro and basalt unit (uCPCCr)

Underlying much of the core of Shass Mountain is a unit of gabbro, diorite, and amphibolite. These rocks are best exposed west of the peak. The amphibolite unit contains dismembered lenses of the relatively undeformed to gneissic gabbro and diorite.

Hornblende diorite and gabbro occurs as small bodies and 0.1 to 3 m lenses within the amphibolite. They are grey to brown weathering and have peppered fresh surfaces. The diorite and gabbro are mostly fine grained and locally medium grained, composed of plagioclase (65-75%) and hornblende (25-35%) with minor accessories. Magnetic susceptibility of the rock varies from 5.0 to 28.3×10^{-3} SI units. The hornblende defines a weak to strong foliation, more prominent in the mafic-rich portions. The rock of this unit occurs as small bodies and small suboutcrop scale lenses within the amphibolite.

The amphibolite is fine grained, weathers medium brown, and is green-black to black on fresh surfaces. It consists of hornblende (70-85%) and calcic plagioclase (15-30%). The amphibolite has a magnetic susceptibility ranging between undetectable to 2.79×10^{-3} SI units.

The amphibolite is interlayered (20-100 cm) with the diorite and gabbro. Well developed amphibole foliation flows around weakly to nonfoliated diorite blocks. The thickness of the amphibolite surrounding the diorite blocks is generally 2-5 cm.

Quartz and epidote veins (1-5 cm thick) intrude throughout both the amphibolite and the diorite. Some of the veins are planar, and others show beautiful deformational structures.

These rocks may be equivalent to the gabbro and basalt of the Railway sequence near Pinchi Lake (Struik et al., 1996). Each of these sequences have the same irregular mixture of blobs and lenses of gabbro, diorite, and basalt.

Metasedimentary unit (PTCCs and TCCs)

Metasiltstone, ribbon chert, quartzite, and marble underlie scattered areas around Shass Mountain and along the Sutherland River. They form part of a regionally extensive sedimentary sequence of the Cache Creek Group informally called the Sowchea sequence (Struik et al., 1997).

The metasiltstone weathers brown and is generally grey and dark grey. It has a schistose texture defined by finely crystalline muscovite. Local mineral growths include plagioclase, hornblende, quartz, and biotite. The rock gives magnetic susceptibility readings near 1.00×10^{-3} SI units. The metasiltstone is interbedded with recrystallized ribbon chert and occurs locally as lenses in quartzite.

Recrystallized ribbon chert bundles interbedded with the metasiltstone consist of fine, sugary quartzite with thin slate interbeds. Locally chert is preserved as discontinuous lenses (perhaps dismembered).

Quartzite, exposed south west of Wes Lake, is grey weathering and fine grained. The magnetic susceptibility of this unit is low, generally around 0.55×10^{-3} SI units.

Marble is exposed at one place south of the west end of Camsell Lake. It forms a 7 m cliff and consists of mostly pure calcite (1-3 mm) with individual crystals showing strain striations. Magnetic susceptibility is zero. Some iron stain occurs at the base of the outcrop.

Metabasalt unit (PCCv)

The metabasalt unit underlies the peak of Shass Mountain. The rock is grey, mostly fine grained, and has local concentrations of plagioclase and hornblende porphyroblasts. Magnetic susceptibility ranges from 0.00 to 0.96×10^{-3} SI units. This unit appears to be cut by the diorite and amphibolite unit. In places the metabasalt possibly intrudes the ultramafic unit, the relationship being obscured by metamorphism.

Late Triassic to Early Jurassic

Boer plutonic suite

Biotite, pyroxene, or hornblende diorite and quartz diorite is exposed northwest of Shass Mountain. It is medium lightly coloured and grey weathering, medium- to coarse-grained, and equigranular. Locally it has a weak foliation. It is included in the Boer plutonic suite as defined by Kimura et al. (1980) in western Fort Fraser map area. The Boer diorite of the Shass Mountain area is similar to the McKnab Lake pluton and the two may be phases of the same pluton.

Middle Jurassic

McKnab Lake pluton (mJM)

McKnab Lake pluton consists of biotite-hornblende diorite and quartz diorite. It is exposed to the northwest of Shass Mountain, and extends to Camsell Lake.

The diorite and quartz diorite weather grey and have salt and pepper fresh surfaces. They are medium grained and are dominated by plagioclase (60-75%) which forms a coarse sugary matrix (0.5-2 mm). Mafic minerals include biotite (10-20%) and hornblende (20%), with minor epidote (1-2%). Biotite retains a subhedral to euhedral shape, commonly forming booklets. Hornblende consistently occurs as euhedral laths, with individual grains as large as 5 mm. Magnetic susceptibility for this unit varies between 12.2 to 60.1×10^{-3} SI units, with a mode of 30×10^{-3} SI units. The pluton is weakly foliated to unfoliated. Close to Camsell Lake, the pluton includes aplitic veins and very fine grained dioritic xenoliths. McKnab Lake pluton has been dated at 165 ± 2 -1 Ma on U-Pb from zircon (Ash et al., 1993).

DISCUSSION

The Cache Creek Group rocks of Shass Mountain are more metamorphosed than those described near Fort St. James (Ash et al., 1993; Struik et al., 1996). At Shass Mountain, basalt has been recrystallized into finely crystalline foliated amphibolites, whereas near Fort St. James, basalt retains igneous matrix and phenocryst textures. Near Shass Mountain, ribbon cherts have been recrystallized to finely crystalline quartzite.

Some of the recrystallization may be due to contact metamorphism because the Cache Creek Group rocks are locally intruded by the McKnab Lake pluton and the Boer plutonic suite diorite and gabbro. The wide-spread amphibole foliation may indicate development during regional metamorphism and shear.

The Trembleur Ultramafics and the gabbro-basalt units appear to form sheets of rock interlayered with the meta-sedimentary unit. It is unclear whether those sheets were stacked by structural imbrication or by sedimentary deposition and igneous processes. The present stacking order does not correspond to that of a standard ophiolitic assemblage. West and north of Shass Mountain the Cache Creek Group sequence is cut by the McKnab Lake and Boer suite plutons and therefore the sequence may have been in place prior to Middle Jurassic intrusion.

CONCLUSIONS

Shass Mountain area contains a diverse suite of rocks assigned to the Cache Creek Group intruded by Jurassic plutons. Cache Creek Group rocks form a sequence of metamorphosed and deformed oceanic ultramafic and mafic rocks, and sedimentary rocks. The weakly foliated McKnab Lake pluton intrudes that sequence to the north. The Boer plutonic suite on the west flank of the mountain, may be a distinct older suite, or a phase of McKnab Lake pluton.

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REFERENCES

- Armstrong, J.E.
1949: Fort St. James map-area, Cassiar and Coast Districts, British Columbia; Geological Survey of Canada, Memoir 252.
- Ash, C., MacDonald, R.W.J., and Paterson, I.A.
1993: Geology of the Stuart and Pinchi Lakes area, central British Columbia (93K); British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1993-9.
- Kimura, E.T., Bysouth, G.D., Cyr, J., Buckley, P., Peters, J., Boyce, R., and Nilsson, J.
1980: Geology of parts of southeast Fort Fraser and northern Nechako River map areas, central British Columbia; Placer Dome Incorporated, Internal Report and Maps, Vancouver, British Columbia.
- Struik, L.C. and MacIntyre, D.M.
1997: Nechako NATMAP Project overview, central British Columbia, year two; in Current Research 1997-A; Geological Survey of Canada.
- Struik, L.C., Floriet, C. and Cordey, F.
1996: Geology near Fort St. James, central British Columbia; in Current Research 1996-A; Geological Survey of Canada, p. 71-76.
- Struik, L.C., Whalen, J.B., Letwin, J.M., and L'Heureux, R.
1997: General geology of southeast Fort Fraser map area, central British Columbia; in Current Research 1997-A; Geological Survey of Canada.

Geology of the Hallett Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous, and Eocene? plutonic rocks¹

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Anderson, R.G., L'Heureux, R., Wetherup, S., and Letwin, J.M., 1997: Geology of the Hallett Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous and Eocene? plutonic rocks; in Current Research 1997-A; Geological Survey of Canada, p. 107-116.

Abstract: Plutonic rocks underlie more than one-third of the Hallett Lake map area southeast of Endako and vary in composition, texture, internal fabrics, mafic and accessory mineralogies, petrographic features, and associated metallic mineral showings.

Small Late Triassic intrusions comprise fine-grained pyroxenite and coarse-grained "bladed" plagioclase porphyry.

Jurassic intrusions are commonly mesocratic and xenolith- and titanite-bearing. They include sequentially intruded biotite-hornblende diorite and gabbro, hornblende-biotite quartz monzodiorite and granodiorite, and possibly, biotite quartz monzonite to monzogranite phases. Mineral and xenolith foliation is most common near contact zones between mafic and intermediate phases.

Early Cretaceous Francois Lake Plutonic Suite biotite monzogranite plutons are the most quartz-rich, leucocratic, and mineralized of all. Grain size, biotite abundance, alteration, intergranular textures, and intrusive relations permit further subdivision.

Small, leucocratic mid-Cretaceous and Eocene? biotite granite and monzogranite plutons are generally the finest grained and most leucocratic of the suites.

Résumé : Des roches plutoniques reposent sous plus du tiers de la région cartographique du lac Hallett, au sud-est d'Endako, et elles varient quant à leur composition, leur texture, leur fabrique interne, leurs minéraux mafiques et accessoires, leur pétrographie et les traces de minéraux métalliques associées.

Les petites intrusions du Trias tardif se composent de pyroxénite à grain fin et de porphyre à plagioclase «prismatique» à grain grossier.

Les intrusions jurassiques sont typiquement mésocrates et renferment des xénolites et de la titanite. Elles comportent les phases suivantes, injectées de façon séquentielle : diorite et gabbro à biotite-hornblende, granodiorite et monzodiorite quartzique à hornblende-biotite et peut-être monzonite et monzogranite quartziques à biotite. La foliation des minéraux et des xénolites est surtout présente près des zones de contact entre les phases mafiques et intermédiaires.

¹ Contribution to the Nechako Plateau NATMAP Project

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Les plutons de monzogranite à biotite de la Suite plutonique de Francois Lake du Crétacé précoce sont les plus quartzifères, leucocrates et minéralisés de tous. La granulométrie, l'abondance de biotite, l'altération, les textures intergranulaires et les relations entre les intrusions permettent de les subdiviser davantage.

Les petits plutons leucocrates de granite et de monzogranite à biotite du Crétacé moyen et de l'Éocène? sont généralement les suites les plus leucocrates et dont la granulométrie est la plus fine.

INTRODUCTION

Geological mapping of the Hallett Lake map area is part of the ongoing revision of the Nechako River 1:250 000 scale geological map (Tipper, 1963a) as part of the Nechako Plateau NATMAP Project (Fig. 1; Struik and McMillan, 1996; Struik and MacIntyre, 1997). It contributes to the regional study of plutonic suites in Nechako River (e.g. L'Heureux and Anderson, 1997) and Fort Fraser map areas (Struik et al., 1997; Whalen and Struik, 1997) and builds on the excellent mapping and age dating contributions by mineral exploration geologists in the area over the past 30 years (e.g. Kimura et al., Placer Dome Incorporated, internal report, 1980) which have helped focus this work.

The distribution and nature of plutonic rocks near and extending southeast from Francois Lake have been well studied since serious exploration began more than 35 years ago on the initial molybdenite discovery (Kimura et al., 1976). As a result, the regional and detailed distribution, nature, and K-Ar ages of granitic rocks near the Endako mine are well known (Armstrong, 1949; Baadsgaard et al., 1961; Tipper 1963a,b; Lowdon, 1963; Bright, 1967; Carr, 1965, 1966; White et al., 1968, 1970; Dawson, 1972; Dawson and Kimura, 1972; Kimura et al., 1976; Bysouth and Wong, 1995). Inclusion of the area's plutonic rocks in the early Mesozoic Topley Intrusives by Hanson and Phemister (1928) was adopted in later regional and mineral exploration mapping; however, Carter (1982) restricted Topley Intrusions to plutons of Jurassic age and Francois Lake intrusions to molybdenite-bearing, porphyritic quartz monzonite phases of 155-133 Ma age. Carter's divisions were expanded to include early, foliated diorite and gabbroic phases in the Early Cretaceous Francois Lake Plutonic Suite (PLPS) (Woodsworth et al., 1991; e.g., Fig. 2). Topley Intrusions or Plutonic Suite are not used to refer to newly recognized Jurassic plutons in Hallett Lake area because recent work by D. MacIntyre and M. Villeneuve at the Topley Landing type area (e.g. MacIntyre et al., 1996) suggests that the terms should be abandoned or revised.

Reconnaissance, radiogenic Sr (Fig. 2; R.L. Armstrong, unpublished data; Armstrong, 1988; Woodsworth et al., 1991), and stable oxygen and hydrogen (Margaritz and Taylor, 1976) isotopic values for the Francois Lake Plutonic Suite are primitive (initial $^{87}\text{Sr}/^{86}\text{Sr}$ (Sr_i) ≤ 0.704) or mantle-like ($\delta^{18}\text{O}\text{‰}$). The western re-entrant of the $\text{Sr}_i=0.704$ isopleth over the Francois Lake Plutonic Suite (Fig. 2) indicated by Armstrong (1988) is not supported by the unpublished database. In the Hallett Lake area, however,

there have been no integrated geochemical and isotopic studies of sample suites whose geological framework and age are well known.

PHYSIOGRAPHY, ACCESS, AND FIELD METHODS

The area's Interior Plateau physiography is characteristically low relief and entirely below treeline, although extensive logging is continually improving access to outcrop. Rock exposure is abundant, widespread, but discontinuous. Nearly all geological contacts (except in the Twentysix Mile Lake and Mount Greer areas) are inferred and the extrapolation of rock units shown in Figure 3 beyond areas of outcrop is derived from tracing of boulders and subcrop.

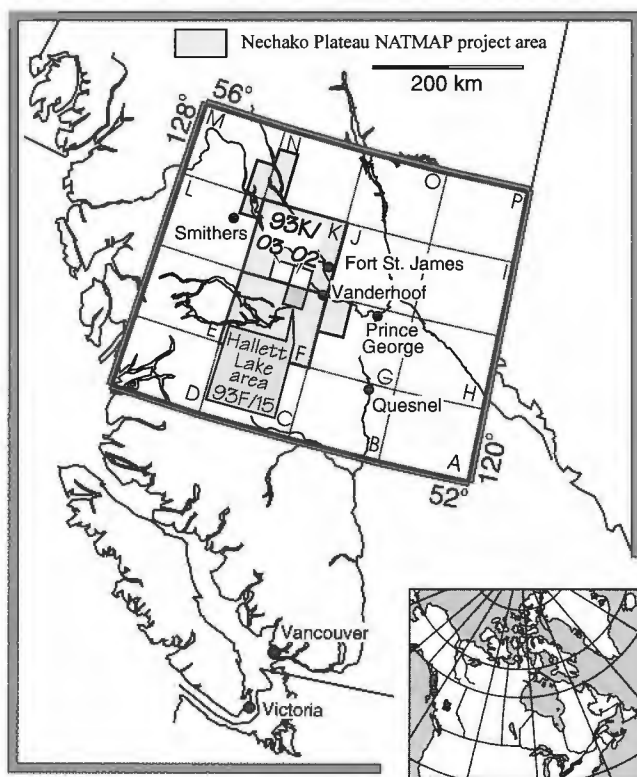


Figure 1. Location of the Hallett Lake (NTS 93F/15), Fraser Lake (NTS 93K/02), and Endako (NTS 93K/03) map areas within the Nechako Plateau NATMAP Project area.

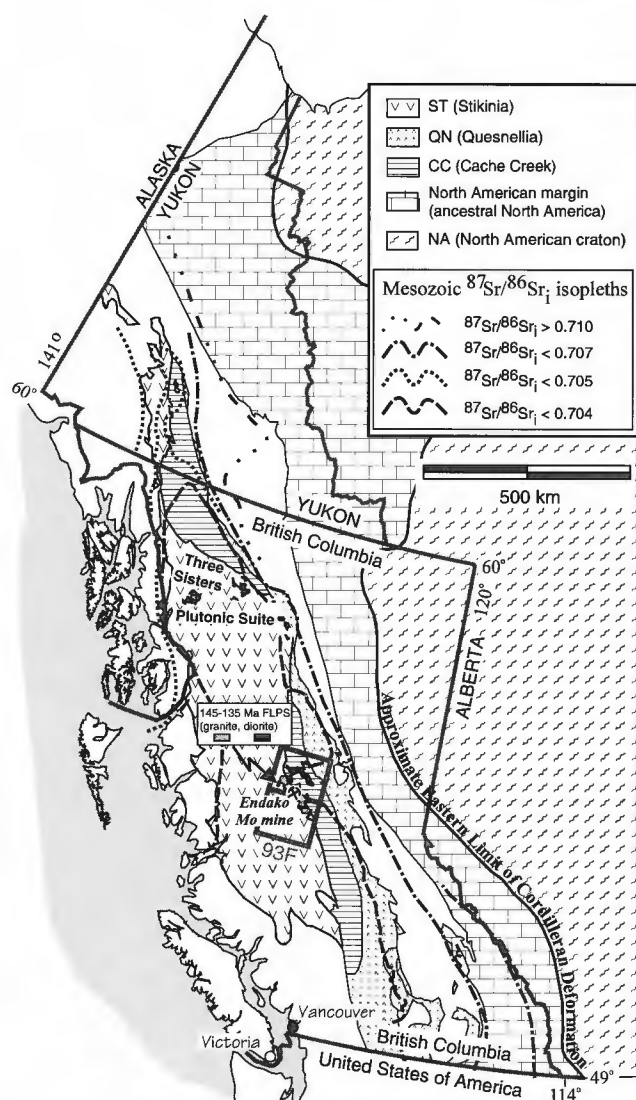


Figure 2. Terrane setting for the NTS 93F and K map areas, Early Cretaceous Francois Lake Plutonic Suite (FLPS) and Middle Jurassic Three Sisters Plutonic Suite (from Woodsworth et al., 1991; Wheeler and McFeely, 1991), and Endako mine. Initial $^{87}\text{Sr}/^{86}\text{Sr}$ (Sr_i) isopleths for Mesozoic rocks are from Armstrong (1988).

New data reported here were based upon 49 traverses in August 1996. 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, $^{40}\text{Ar}/^{39}\text{Ar}$ age-dating, geochemical, and whole rock radiogenic and stable isotopic tracer studies. The studies complement earlier regional and detailed mapping and petrographic studies by Tipper (1963a), Carr (1966), and Bright (1967). As well, magnetic susceptibility (m.s.) measurements were routinely obtained at each outcrop (L'Heureux and Anderson, 1997) over a 5 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 to delineating areas of alteration (m.s.<1). The database of magnetic susceptibility and specific gravity measurements for most samples will aid in the interpretation of potential field data (Struik and McMillan, 1996).

GEOLOGY

Plutonic rock suites may be effectively distinguished by: geophysical properties (potential fields and radiometric signatures); areal distribution; composition and texture; geological relationships external to the pluton and internal intrusive relationships; associated volcanic rocks, mineral deposits, and alteration zones; syn- ("magmatic") and post-emplacement fabrics; age; composition, grain size, texture, and petrography of felsic, mafic, accessory, and sulphide minerals; and chemical and isotopic composition. This preliminary report summarizes the geology of the plutonic rocks and the features used to subdivide them in the Hallett Lake area.

Previous mapping subdivided the plutonic rocks into phases of the Topley Intrusions based on relative and/or absolute chronology (e.g. "Early", "Middle", and "Late") and/or intrusive level based on presence of foliation (=low level) or aplitic textures and/or mirolitic cavities (=high level) (e.g. "Lowest Level", "Intermediate to Lower Level", "Intermediate Level" and "Higher Level") (e.g. Bright, 1967; Bysouth and Wong, 1995). The current subdivisions of the plutonic rocks into Jurassic, Early Cretaceous, mid-Cretaceous, and Eocene? suites presented here is based on field and on-going petrographic studies. The new subdivisions partly encompass the earlier classifications confirmed by unpublished geochronology (Endako Mines Division, Placer Dome Canada Ltd, unpublished data). The subdivisions are consistent with those recognized in Fraser Lake (NTS 93K/02) and Endako (NTS 93K/03) map areas to the north (Fig. 1; Struik et al., 1997; Whalen and Struik, 1997). In several cases, phases defined in previous work included rocks which so closely resembled each other that they were included in a single unit (e.g. rocks in the Smith Creek Diorite, Limit Lake Quartz Monzonite, Mary Lake Diorite are included in the new Limit Lake intermediate phase). In another case, a new unit restricted to mafic rocks was extracted from a more extensive, composite phase (e.g. Twentysix Mile Lake mafic phase derived from parts of the Mary Lake Diorite).

Country rocks

The contacts between plutonic rocks and flanking Mesozoic to Tertiary volcanic rocks were not observed. However, the nature of the stratified rocks is summarized below because the Hallett Lake area has the potential for the same volcano-plutonic associations observed elsewhere in Stikinia (e.g. Anderson, 1983, 1993); details will be published elsewhere. Undated Upper Triassic Takla, Lower to Middle Jurassic Hazelton Group(?) and Eocene Ootsa Lake (and Endako(?)) groups and Miocene Chilcotin Group volcanic rocks underlie at least half of the Hallett Lake map area. Clinopyroxene-phyrlic



Figure 3. Distribution of the Cretaceous to Tertiary plutonic suites in the Hallett Lake map area.

volcaniclastic rocks, laharic breccia, and siliceous siltstone make up the Takla Group. Maroon-grey heterolithic and monolithic, laharic boulder breccia, volcanic grit, and amygdaloidal basalt southwest of Hallett Lake resemble Hazelton Group rocks but the unit is unfossiliferous and the correlation uncertain.

Ootsa Lake Group includes felsic crystal tuff, pyroclastic rocks, rhyolite with local, moderately dipping flow-layering, and glassy rhyolite domes. At one locality the rocks are localized along synvolcanic normal faults; Mesozoic volcanic rocks in the hangingwall are overturned. A lower unit of the Ootsa Lake Group is distinguished by its moderate dips, cleavage development, and the presence of green zeolite groundmass minerals. Eocene Endako Group andesitic volcaniclastic rocks are best recognized near Mount Greer, in the southeastern part of the map area.

Scattered outcrops of fresh, vesicular olivine basalt typical of the Chilcotin Group occur throughout the map area.

Triassic? intrusions

Intrusions of possible Triassic age occur only locally, in a small area on 40 Road in southwestern Hallett Lake area (Fig. 3). Dun weathering, unfoliated fine-grained clinopyroxenite is associated with a distinctive, coarse-grained bladed feldspar porphyry (Fig. 4). The porphyry is typical of intrusions spatially associated with the western part of the Upper Triassic Takla Group in northeastern Stikinia (Monger et al., 1991), and the Upper Triassic Stuhini Group and Late Triassic Stikine Plutonic Suite in northwestern Stikina (Anderson, 1983, 1984).

Jurassic Stag Lake-Twenty-six Mile Lake plutonic suite

Subdivision of the Jurassic plutonic rocks in the Hallett Lake area follow definitions used in map areas to the north (Struik et al., 1997; Whalen and Struik, 1997) or so closely resemble

them that correlations seem obvious (e.g. the Twenty-six Mile mafic phase in the Hallett Lake area and Stag Lake mafic phase in the Fraser Lake area). The informal Stag Lake-Twenty-six Mile Lake plutonic suite refers to these rocks in all three map areas. They most closely resemble mafic and intermediate members of the Middle Jurassic (ca. 170 Ma) Three Sisters Plutonic Suite in northwestern Stikinia (Fig. 2; Anderson, 1983; Woodsworth et al., 1991).

Jurassic plutons include sequentially-intruded mafic (biotite-hornblende diorite and gabbro), intermediate (hornblende-biotite quartz monzodiorite, granodiorite and monzodiorite) and possibly, felsic (biotite quartz monzonite and monzogranite) compositions. Potassium-argon dates for biotite monzogranite of the Stellako and Caledonia phases are permissive of their inclusion in the Jurassic suite but the relationship between the felsic and more mafic phases is unknown. The plutons are the most extensive of the plutonic rocks in the Hallett Lake area (Fig. 3). Areally, the most to least important phases are intermediate, felsic? and mafic. The phases are grouped because of their intrusive relationships and shared petrographic characteristics (e.g. clinopyroxene cores in hornblende, irregular calcic plagioclase cores in andesine, and presence of titanite) and are considered Jurassic in age from unpublished K-Ar dates which suggest that none of the intermediate phases are younger than Late Jurassic.

Twenty-six Mile Lake mafic phase

A mafic hornblende or biotite-hornblende diorite phase defines a small northwest-trending intrusion best exposed east and northeast of Twenty-six Mile Lake (also called Mary or Mary-Jane Lake). The Brooks diorite complex east of the Nechako River (Wetherup, 1997) may be correlative with the Twenty-six Mile Lake mafic phase to the west but separated from it by subsequent intermediate phase intrusions. Distinctive features include: a "salt-and-pepper" mesocratic appearance (Fig. 5), and unfoliated and seriate to megacrystic texture imparted by squarish, subhedral to euhedral, poikilitic hornblende. Uncommon clinopyroxene cores in hornblende,

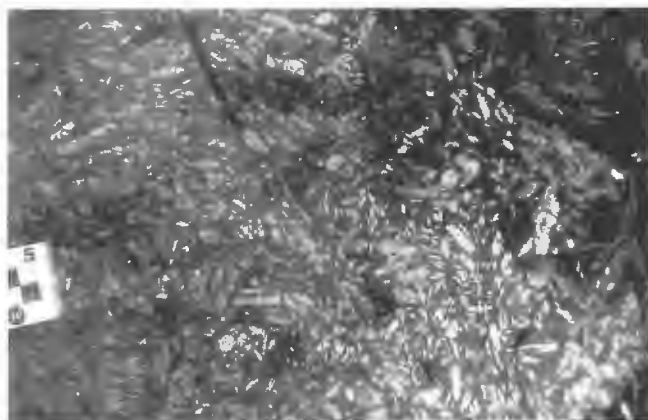


Figure 4. Coarse-grained, basaltic feldspar porphyry of the Triassic? intrusive suite on 40 Road. Circle and squares on scale card are 1 cm across.



Figure 5. Seriate to megacrystic hornblende diorite of the Jurassic mafic phase and younger aplite vein near Twenty-six Mile Lake. Hammer handle is 30 cm long.



Figure 6. Angular, seriate, hornblende diorite xenoliths of the mafic phase in unfoliated intermediate phase hornblende-biotite quartz monzodiorite near Twentysix Mile Lake (see also Fig. 8, 12).

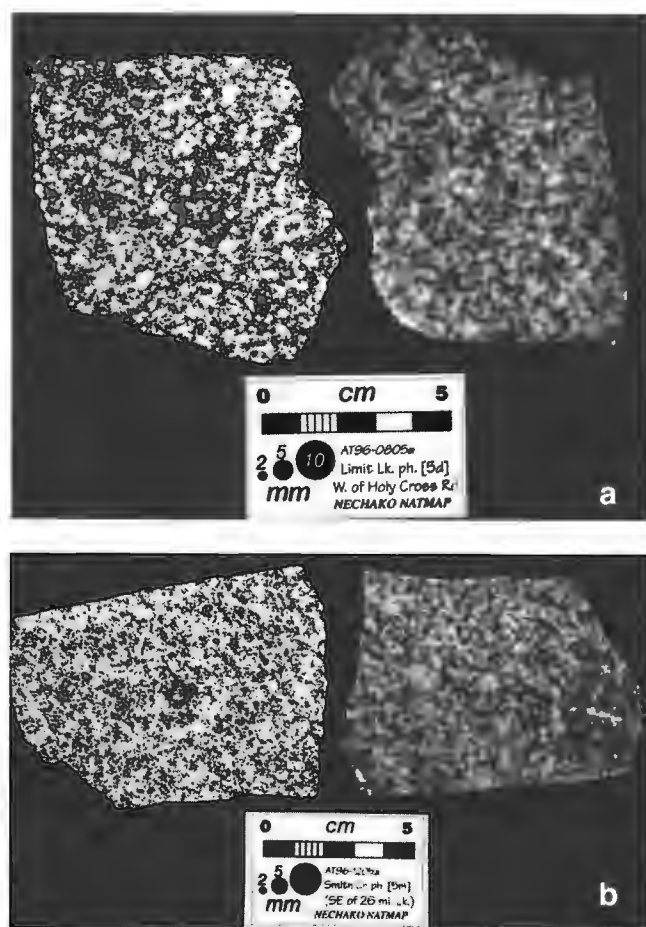


Figure 7. Polished (right) and stained slabs from the former Limit Lake Quartz Monzonite **a)** and Smith Creek Diorite **b)** phases of the Jurassic plutonic suite are indistinguishable.

high-relief calcic plagioclase cores in oscillatory-zoned andesine, and titanite and magnetite accessory minerals are characteristic. Epidote and aplite veins and veinlets are common. At structurally higher levels along trend, northeast of Twentysix Mile Lake, the medium-grained diorite changes to a fine-grained, equigranular diorite which resembles the fine-grained xenoliths found in the intermediate phase. The Twentysix Mile Lake mafic phase is intruded and forms xenoliths in nearby hornblende-biotite quartz monzodiorite of the Limit Lake intermediate phase (Fig. 6).

Limit Lake intermediate phase

The Limit Lake intermediate phase encompasses the Smith Creek Diorite, Limit Lake Quartz Monzonite, and parts of the Mary Lake Diorite that were defined in previous mapping and also strongly resembles the Sugarloaf phase, which is best exposed in southeastern Fraser Lake map area. The units strongly resemble one another (Fig. 7a,b) and are unfoliated, mesocratic hornblende-biotite quartz monzodiorite and minor granodiorite. Widespread and uncommon (1-5%) fine-grained diorite xenoliths are typical (Fig. 8). The presence of biotite, hornblende, titanite, magnetite, uncommon clinopyroxene cores in hornblende, and calcic plagioclase cores is

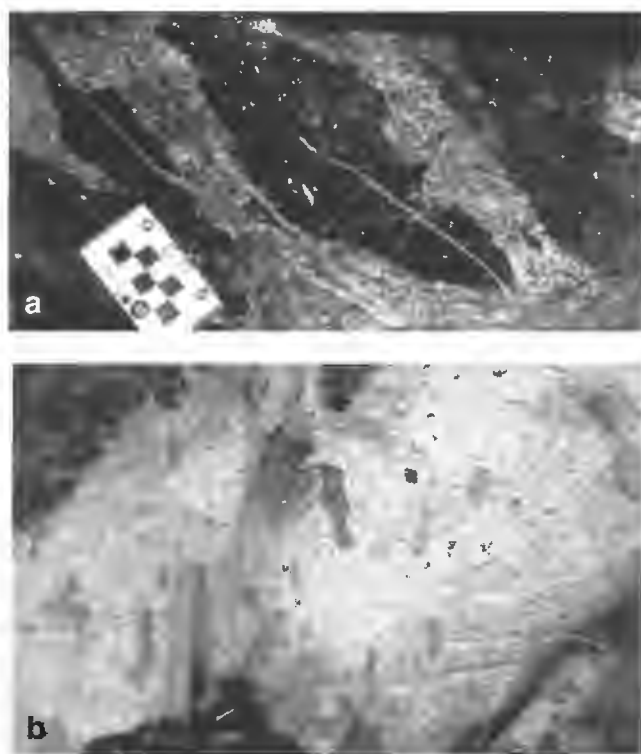


Figure 8. Examples of internal fabric in the intermediate phase hornblende-biotite quartz monzodiorite of the Jurassic plutonic suite east of Twentysix Mile Lake: **a)** mineral foliation in apophyses is subparallel to margins of mafic phase xenoliths; **b)** Foliation is defined by fine-grained dioritic xenoliths. Hammer handle is 30 cm long.

important. Mineral and xenolith foliation (Fig. 8) and lineation were locally developed subparallel to nearby intrusive contacts between mafic and intermediate phases. The fabric is neither as widespread as suggested in previous studies (e.g. Woodsworth et al., 1991) nor a reliable discriminant among plutonic suites of different ages. The fabrics are interpreted to be related to intrusion of the intermediate phase into the mafic phase.

Felsic phases?

The Caledonia and Stellako felsic phases may be part of the Jurassic Stag Lake-Twenty-six Mile Lake plutonic suite based on unpublished K-Ar dates. Both are poorly exposed and Stellako phase outcrops in the Hallett Lake map area were not visited in 1996. The Caledonia phase is characterized by randomly oriented, coarse-grained (2–3 cm) alkali feldspar megacrysts in an unfoliated, fine- to medium-grained biotite monzogranite matrix similar to the unit farther north.

Early Cretaceous Francois Lake Plutonic Suite

In the Hallett Lake area, this suite is restricted to the sequentially intruded Nithi and Casey phases which comprise mottled pink and white weathering, unfoliated, leucocratic, and inclusion-poor biotite monzogranite and granite (Fig. 3; L'Heureux and Anderson, 1997). Equigranular and alkali-feldspar megacrystic (Fig. 9) varieties of the Nithi phase are distinguished from the younger, aplitic Casey phase by crumbly weathering character, larger grain size, greater biotite abundance, locally intense alteration, hypidiomorphic-granular textures, and intrusive relationships (L'Heureux and Anderson, 1997). East-northeast-trending molybdenite-bearing and younger, barren east-southeast- and north-trending quartz veins were recognized; coarse-grained molybdenite is restricted to irregular fractures. Low magnetic susceptibility values (m.s. <1) for both phases, where veining, propylitic and clay alteration, and pyrite or molybdenite mineralization are prevalent, indicate magnetite destruction. Near Nithi

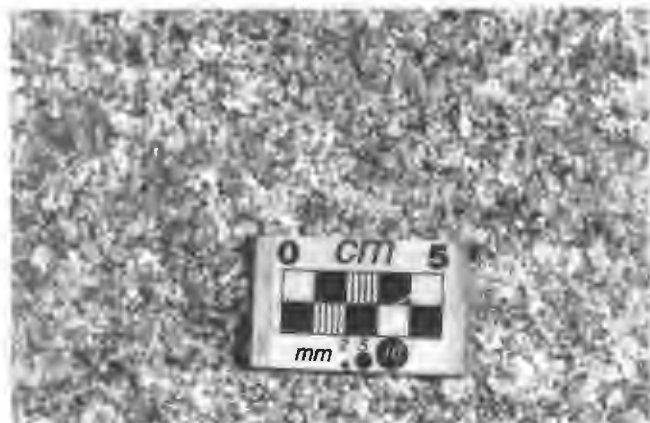


Figure 9. Grey, anhedral to subhedral, poikilitic alkali feldspar imparts a seriate texture to megacrystic biotite monzogranite variety of Nithi phase (Francois Lake Plutonic Suite).

Mountain, veining, alteration, mineralization, and MINFILE occurrences are distributed equally between outcrops of the Nithi and Casey phases within 3 km of their contact.

Mid-Cretaceous Leg Lake pluton and Eocene? Copley Lake pluton

Mottled pink and white, equigranular, fine- to medium-grained biotite monzogranite of the Leg Lake (Fig. 3, 10) and Copley Lake (Fig. 3, 11) plutons are distinguished from the compositionally similar Francois Lake Plutonic Suite by finer grain size, proximity to Eocene Ootsa Lake Group volcanic rocks (i.e. Copley Lake pluton), paucity of associated alteration or molybdenite showings and age. Both are characterized by myrmekitic or cuneiform quartz intergrowths in alkali feldspar. Leg Lake pluton intruded the Jurassic Sugarloaf phase (Fig. 12) and was correlated with other members of the mid-Cretaceous (115–92 Ma) Fraser Lake Plutonic Suite recognized in previous mapping and by Struik et al. (1997) and Whalen and Struik (1997). The Copley Lake pluton had been correlated with late, higher level Topley

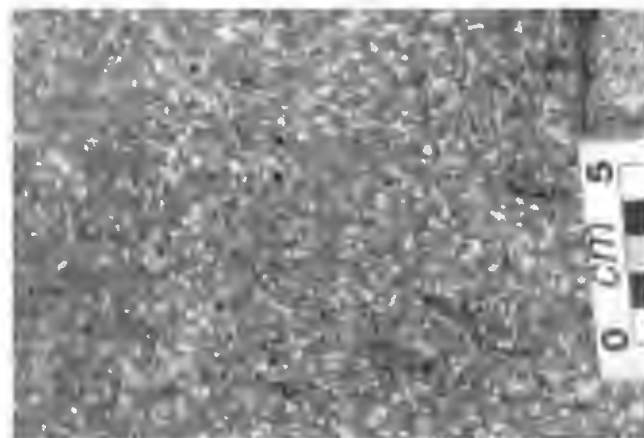


Figure 10. Intergranular texture exhibited by anhedral white plagioclase and dominant grey alkali feldspar in the mid-Cretaceous Leg Lake pluton.

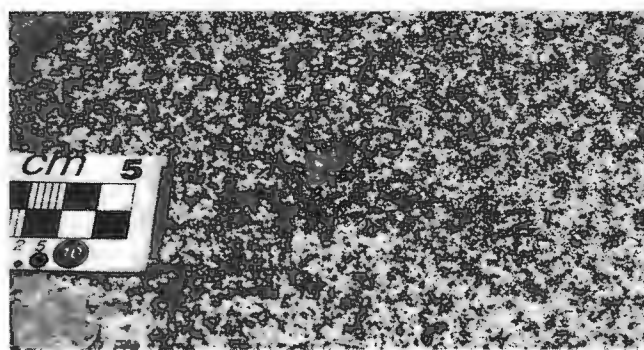


Figure 11. Equant and subequal alkali feldspar (grey) and plagioclase (white) help characterize the Eocene? Copley Lake pluton.

Intrusions; its close association with and resemblance to the extensive Eocene Ootsa Lake Group rhyolitic biotite-quartz-alkali-feldspar porphyry suggests it may be Eocene.

AGE

The best test of the suggested local and regional-scale correlations suggested above are precise age-dates for the phases and plutons. Previous dating of plutonic rocks in the area (e.g. Fig. 12a) focused on the metallogenically important Early Cretaceous Francois Lake Plutonic Suite in the Fraser Lake

and Endako map areas (Baadsgaard et al., 1961; Tipper, 1963b; Lowdon, 1963; White et al., 1968, 1970; Kimura et al., 1976; Armstrong, 1988; Woodsworth et al., 1991; Bysouth and Wong, 1995; Endako Mines Division, Placer Dome Canada Ltd, unpublished data) but few published or unpublished dates exist for plutonic rocks in the Hallett Lake area. The range of K-Ar dates for biotite and Rb-Sr whole rock isochron dates (187-85 Ma) shown in Figure 12a does not include some of the earliest-determined dates which did not incorporate atmospheric argon corrections (e.g. Lowdon, 1963; Tipper, 1963b; see discussion by Armstrong, 1978, 1988) or dates for imprecisely located or incompletely

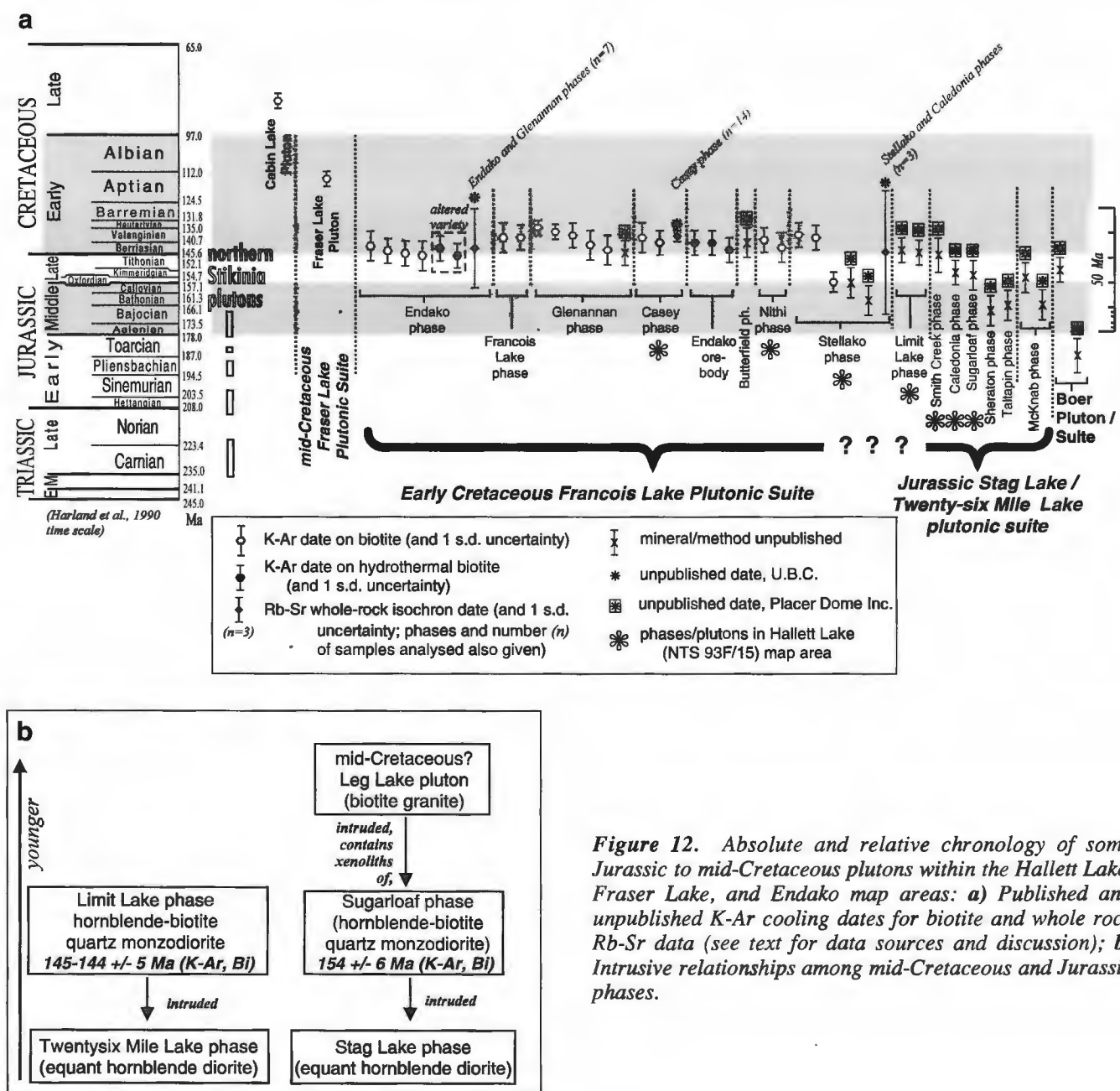


Figure 12. Absolute and relative chronology of some Jurassic to mid-Cretaceous plutons within the Hallett Lake, Fraser Lake, and Endako map areas: **a)** Published and unpublished K-Ar cooling dates for biotite and whole rock Rb-Sr data (see text for data sources and discussion); **b)** Intrusive relationships among mid-Cretaceous and Jurassic phases.

described samples which cannot be accurately correlated (e.g. Baadsgaard et al., 1961). Recalculation of all the isotopic dates to be consistent with the Steiger and Jäger (1977) decay constants increases them by 1.5 per cent (e.g. Armstrong, 1978, 1988); all are quoted at 1 standard deviation (s.d.) of uncertainty.

Jurassic phases in or near the Hallett Lake area (e.g. Limit Lake, Smith Creek, and Sugarloaf varieties of the intermediate phase) range in cooling age from 154–144 Ma according to earlier work (Endako Mines Division, Placer Dome Canada Ltd, unpublished data). The dates for the intermediate phase provide youngest age constraints for the older mafic phase (Fig. 12b). Multi-step $^{40}\text{Ar}/^{39}\text{Ar}$ dating of representative samples of the mafic phase and varieties of the intermediate phase in progress will test correlations and the apparently young age of the Jurassic intrusions. If confirmed, these intrusions would be among the youngest Jurassic intrusions in Stikinia and might be the easternmost record of the Middle to Late Jurassic sweep of magmatism from the Queen Charlotte Islands to the mainland (Anderson and Reichenbach, 1991; van der Heyden, 1992).

The correlation of potential felsic members of the Jurassic plutonic suite based on K–Ar cooling ages is more uncertain. Published and unpublished dates for the Stellako and Caledonia quartz monzonite phases range from 164–145 Ma and overlap the ranges for the intermediate phase but also include Early Cretaceous dates (139–138 Ma; see Fig. 12a). Additional work is warranted for these phases to test their inclusion in the Jurassic plutonic suite.

MINERAL DEPOSITS

The importance of the Early Cretaceous Francois Lake Plutonic Suite as the primary metallotect in the Hallett Lake area is emphasized by considering the host for the 15 low fluorine, porphyry molybdenum showings reported in the MINFILE compilation for the area (Bailey et al., 1995; Lefebvre and Höy, 1996): thirteen showings occur in the Casey or Nithi phases (see L'Heureux and Anderson, 1997), and two occur in the Caledonia alkali-feldspar megacrystic biotite monzogranite phase. A Cu–Zn–Mo showing occurs within a southern extension of the Stellako phase into the Hallett Lake map area.

The intermediate phase of the Jurassic plutonic suite hosts one copper showing west of Limit Lake and an imprecisely located Ag–Pb–Au showing (the so-called HIDDEN showing) may occur in the southern extension of the Sugarloaf phase into the Hallett Lake area.

CONCLUSIONS

Compositional, textural, structural, mineralogical, and petrographic attributes helped divide plutonic rocks in the Hallett Lake area into Triassic(?), Jurassic, Cretaceous, and

Eocene(?) plutonic suites. The Jurassic suite contains the most mafic and intermediate compositions, which were formerly considered a mafic component of the Early Cretaceous suite.

Phases included within the well-studied and dated Early Cretaceous (145–135 Ma) Francois Lake Plutonic Suite are entirely felsic and siliceous varieties of biotite monzogranite which were further subdivided on intergranular textures. As in the Endako (NTS 93K/03) map area to the north, the Early Cretaceous Francois Lake Plutonic Suite is the principal metallotect in the Hallett Lake map area.

Mid-Cretaceous and Eocene(?) Leg Lake and Copley Lake plutons are characterized by their finer grain size and more common quartz-alkali-feldspar intergrowths from the compositionally similar Early Cretaceous phases. The Copley Lake pluton is compositionally and texturally similar to and spatially associated with the Eocene Ootsa Lake Group felsic porphyritic volcanic rocks.

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REFERENCES

- Anderson, R.G.
1983: The geology of the Hotailuh Batholith and surrounding volcanic and sedimentary rocks, north-central British Columbia; Ph.D. thesis, Carleton University, Ottawa, Ontario.
1984: Late Triassic and Jurassic magmatism along the Stikine Arch and the geology of the Stikine Batholith, north-central British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 84-1A, p. 67–73.
1993: A Mesozoic stratigraphic and plutonic framework for northwestern Stikinia (Iskut River area), northwestern British Columbia, Canada; in *Mesozoic Paleogeography of the Western United States – II*, (ed.) G. Dunne and K. McDougall; Society of Economic Palaeontologists and Mineralogists, Pacific Section, v. 71, p. 477–494.
Anderson, R.G. and Reichenbach, I.
1991: U–Pb and K–Ar framework for Middle to Late Jurassic (172–158 Ma) and Tertiary (46–27 Ma) plutons in Queen Charlotte Islands, British Columbia; in *Evolution and Hydrocarbon Potential of the Queen Charlotte Basin*, (ed.) G.J. Woodsworth; British Columbia, Geological Survey of Canada, Paper 90-10, p. 59–87.
Armstrong, J.E.
1949: Fort St. James map-area, Cassiar and Coast Districts, British Columbia; Geological Survey of Canada, Memoir 252, 210 p.

Armstrong, R.L.

- 1978: Pre-Cenozoic Phanerozoic time scale – computer file of critical dates and consequences of new and in-progress decay-constant revisions; in *Contributions to the Geologic Time Scale*, (ed.) G.V. Cohee, W.F. Glaessner, and H.D. Hedberg; American Association of Petroleum Geologists, *Studies in Geology*, no. 6, p. 73-91.
- 1988: Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera; Geological Society of America, Special Paper 218, p. 55-91.

Baadsgaard, H., Folinsbee, R.E., and Lipson, J.

- 1961: Potassium-argon age of biotites from Cordilleran granites; Geological Society of America, *Bulletin*, v. 72, p. 689-702.

Bailey, D.G., Jakobsen, D.E., and Lane, R.

- 1995: MINFILE 093F Nechako River mineral occurrence map; British Columbia Ministry of Energy, Mines and Petroleum Resources, MINFILE, revised March 1995.

Bright, E.G.

- 1967: Geology of the Topley Intrusives in the Endako area, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, British Columbia, 111 p.

Bysouth, G.D. and Wong, G.Y.

- 1995: The Endako molybdenum mine, central British Columbia: an update; in *Porphyry Deposits of the Northwestern Cordillera of North America*, (ed.) T.G. Schroeter; Canadian Institute for Mining, Metallurgy and Petroleum, Special Volume 46, p. 697-703.

Carr, J.M.

- 1965: Nithi Mountain; British Columbia Minister of Mines and Petroleum Resources, Annual Report 1964, p. 62-63.
- 1966: Geology of the Endako area, British Columbia; in *Lode Metals in British Columbia*, British Columbia Minister of Mines and Petroleum Resources, Annual Report 1965, p. 114-135.

Carter, N.C.

- 1982: Porphyry copper and molybdenum deposits west-central British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, *Bulletin* 64, p. 44-45.

Dawson, K.M.

- 1972: Geology of Endako Mine, British Columbia; Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 337 p.

Dawson, K.M. and Kimura, E.T.

- 1972: Endako; in *International Geological Congress, Guidebook, Copper and Molybdenum Deposits of the Western Cordillera, Excursion A09-C09*, D.J. Glass (ed.); p. 36-48.

Hanson, G. and Phemister, T.C.

- 1928: Topley map area, British Columbia; Geological Survey of Canada, Summary Report, Part 1, p. 56-59.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G.

- 1990: A Geological Time Scale 1989; Cambridge University Press, 279 p.

Kimura, E.T., Bysouth, G.D., and Drummond, A.D.

- 1976: Endako; in *Porphyry Deposits of the Canadian Cordillera*, (ed.) A. Sutherland Brown; Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 444-454.

Lefebvre, D.V. and Höy, T. (ed.)

- 1996: Selected British Columbia mineral deposit profiles, Volume 2 – Metallic Deposits; British Columbia Geological Survey Branch, Open File 1996-13, Appendix 1.

L'Heureux, R. and Anderson, R.G.

- 1997: Early Cretaceous plutonic rocks and molybdenite showings in the Nithi Mountain area, north-central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.

Lowdon, J.A.

- 1963: K-Ar measurement on mineral pairs; in *Part I-Age Determinations by the Geological Survey of Canada, Isotopic Ages, Report 4; Age Determinations and Geological Studies*; Geological Survey of Canada, Paper 62-17, p. 20-22.

MacIntyre, D.G., Webster, I.C.L., and Bellefontaine, K.A.

- 1996: Babine porphyry belt project: Bedrock geology of the Fulton Lake map area (93L/16), British Columbia; in *Geological Fieldwork 1995*, (ed.) B. Grant and J.M. Newell; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1996-1, p. 11-35.

Margaritz, M. and Taylor, H.P.

- 1976: $^{18}\text{O}/^{16}\text{O}$ and D/H studies along a 500 km traverse across the Coast Range batholith and its country rocks, central British Columbia; *Canadian Journal of Earth Sciences*, v. 13, p. 1514-1536.

Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gebels, G.E., and O'Brien, J.

- 1991: Part B. Cordilleran terranes; in *Upper Devonian to Middle Jurassic assemblages, Chapter 8 of Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 281-327.

Steiger, R.H.J. and Jäger, E.

- 1977: Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology; *Earth and Planetary Science Letters*, v. 36, p. 359-362.

Struik, L.C. and MacIntyre, D.

- 1997: Nechako NATMAP project overview, central British Columbia, year two; in *Current Research 1997-A*; Geological Survey of Canada.

Struik, L.C. and McMillan, W.J.

- 1996: Nechako Plateau NATMAP project overview, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 57-62.

Struik, L.C., Whalen, J.B., Letwin, J., and L'Heureux, R.

- 1997: Bedrock geology of southeast Fort Fraser map area, British Columbia: general geology; in *Current Research 1997-A*; Geological Survey of Canada.

Tipper, H.W.

- 1963a: Nechako River map-area, British Columbia; Geological Survey of Canada, *Memoir* 324, 59 p.
- 1963b: Topley Intrusions; in *Age Determinations and Geological Studies*; Geological Survey of Canada, Paper 62-17, p. 134-136.

van der Heyden, P.

- 1992: A Middle Jurassic to Early Tertiary Andean-Sierran arc model for the Coast Belt of British Columbia; *Tectonics*, v. 11, p. 82-97.

Wetherup, S.

- 1997: Geology of the Nulki Hills and surrounding area, central British Columbia; in *Current Research 1997-A*; Geological Survey of Canada.

Whalen, J.B. and Struik, L.C.

- 1997: Bedrock geology of southeast Fort Fraser map area, British Columbia: plutonic rocks; in *Current Research 1997-A*; Geological Survey of Canada.

Wheeler, J.O. and McFeely, P.

- 1991: Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A, Scale 1:2 000 000.

White, W.H., Harakal, J.E., and Carter, N.C.

- 1968: Potassium-argon ages of some ore deposits in British Columbia; Canadian Institute of Mining and Metallurgy, *Bulletin*, v. 61, no. 679, p. 1326-1334.

White, W.H., Sinclair, A.J., Harakal, J.E., and Dawson, K.M.

- 1970: Potassium-argon ages of Topley Intrusions near Endako, British Columbia; *Canadian Journal of Earth Sciences*, v. 7, p. 1172-1178.

Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L.

- 1991: Plutonic Regimes, Chapter 15; in *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 491-531. (also Geological Society of America, *The Geology of North America*, no. G-2).

Early Cretaceous plutonic rocks and molybdenite showings in the Nithi Mountain area, central British Columbia¹

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Abstract: Three unfoliated biotite monzogranite phases of the Early Cretaceous Francois Lake Plutonic Suite host known and newly discovered molybdenite (Mo) veins and fracture coatings in the Nithi Mountain area. Equigranular and alkali-feldspar megacrystic varieties of the Nithi phase and the finer-grained equigranular and aplitic Casey phase are distinguished by grain size, biotite abundance, alteration, intergranular textures, intrusive relations, but not age.

East-northeast-trending Mo-bearing and younger, barren east-southeast- and north-trending veins were recognized; coarser-grained molybdenite is restricted to irregular fractures. Low magnetic susceptibility values ($<1 \times 10^{-3}$ SI units), indicate that magnetite destruction corresponds to propylitic and clay alteration and pyrite or molybdenite mineralization localized to outcrops within 3 km of the contact between the phases. Known MINFILE and newly discovered molybdenite veins and fracture coatings and alteration zones expand the areas favourable for mineral exploration in the Nithi Mountain area.

Résumé : Trois phases de monzogranite à biotite non folié de la Suite plutonique de Francois Lake du Crétacé précoce recèlent des filons et des revêtements de fractures de molybdénite (Mo) connus ou découverts récemment dans la région du mont Nithi. Les variétés isogranulaires et à mégacristaux de feldspath alcalin de la phase de Nithi et la phase isogranulaire et aplitique à grain plus fin de Casey se distinguent par les caractéristiques suivantes : granulométrie, abondance de biotite, altération, textures intergranulaires, relations entre les intrusions, mais pas par l'âge.

On distingue des filons molybdénifères à direction est-nord-est et des filons stériles plus récents à direction est-sud-est et nord; la molybdénite à grain grossier ne se trouve que dans les fractures irrégulières. La faible susceptibilité magnétique ($<1 \times 10^{-3}$ unités SI) indique que la destruction de la magnétite correspond à la propylitisation et à l'argilisation et à la minéralisation en pyrite ou en molybdénite localisées à des affleurements à moins de 3 km du contact entre les phases. Les filons et les revêtements de fractures de molybdénite dont la découverte est consignée dans MINFILE ou qui viennent d'être découverts ainsi que les zones d'altération accroissent le nombre de régions favorables à l'exploration minérale dans la région du mont Nithi.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

The Nithi Mountain area is in northern Nechako River map area, the southern of two 1:250 000 scale maps to be revised under the Nechako Plateau NATMAP Project (Fig. 1; Struik and MacIntyre, 1997). Nithi Mountain represents 590 m relief and although its measured elevation (4435 ft or 1352 m) is the highest in the Hallett Lake (NTS 93F/15) map area, the study area around Nithi Mountain is below treeline (Fig. 2). Numerous abandoned logging and mineral exploration roads and all-terrain-vehicle accessible tracks provide excellent access. As elsewhere in the area, outcrops are widespread, but discontinuous. Contacts between units are well bracketed but generally covered, and geological relationships are inferred (Fig. 3).

The area was chosen for detailed mapping and sampling by L'Heureux as part of a Bachelor of Science thesis project to contribute to the regional study of plutonic suites in Nechako River (Anderson et al., 1997) and Fort Fraser (Struik et al., 1997) map areas. Sampling for ^{40}Ar - ^{39}Ar age dating, geochemical, whole rock radiogenic and quartz-vein stable isotopic tracer studies complements earlier regional and detailed mapping, petrographic, and dating studies by Tipper (1963), Carr (1965, 1966), Bright (1967) and White et al. (1970), and builds on the excellent contributions from mapping by mineral exploration geologists in the area over the past 30 years which have helped focus this

work (e.g., Harris and LeBel, 1975; Kimura et al., 1976; Davis, 1981; Bysouth and Wong, 1995; E. Kimura, S. Gardiner and others, unpublished data).

The study will also provide bedrock control for U, Th, and K radiometric anomalies observed over the area (Struik and McMillan, 1996; R. Shives, pers. comm., January 1996). The new maps will also help delineate possible point sources for anomalously high Mo concentrations in lake sediments collected from Counts Lakes whose watersheds are immediately north in the study area (Fig. 3; Steve Cook, unpublished B.C. Geological Survey data).

The Nithi Mountain region contains about two-thirds of the MINFILE localities for the Hallett Lake map area (Bailey et al., 1995). The new data on location, orientation, relative timing, and host rock for a variety of mineralized and barren vein sets, and on the nature of newly-discovered and known alteration and mineralized zones help expand the areas most promising for new, low-fluorine porphyry molybdenite (Mo) type discoveries (e.g., Kimura et al., 1976; Carter, 1982; Bysouth and Wong, 1995; Lefebvre and Höy, 1996). As well, the correlation between the Casey phases and setting for mineralization in the Endako mine and Nithi Mountain areas will be tested via petrographic, geochemical, and geochronological studies in progress.

Fieldwork was completed in 10 days in early August 1996. Standard geological mapping techniques were supplemented by global positioning system measurements taken at each station which provide a precision of 50-100 m in station location (depending on number and orientation of satellites). Representative samples were collected for follow-up ^{40}Ar - ^{39}Ar age dating ($n = 4$) and geochemical analysis ($n = 11$) (Fig. 3). As well, routine magnetic susceptibility (m.s.) measurements were obtained at each outcrop (Fig. 4) with a hand-held Exploranium KT-9 Kappameter (all magnetic susceptibility measurements referenced are given in 10^{-3} SI units and are an average of at least 5 measurements). These proved invaluable in detecting areas of alteration (m.s. < 1). Finally, specific gravity measurements for most samples were completed in the field. All isotopic dates discussed were recalculated by R.L. Armstrong (Armstrong, 1988) to be consistent with the Steiger and Jäger (1977) decay constants and are quoted at 1 standard deviation (s.d.) uncertainty.

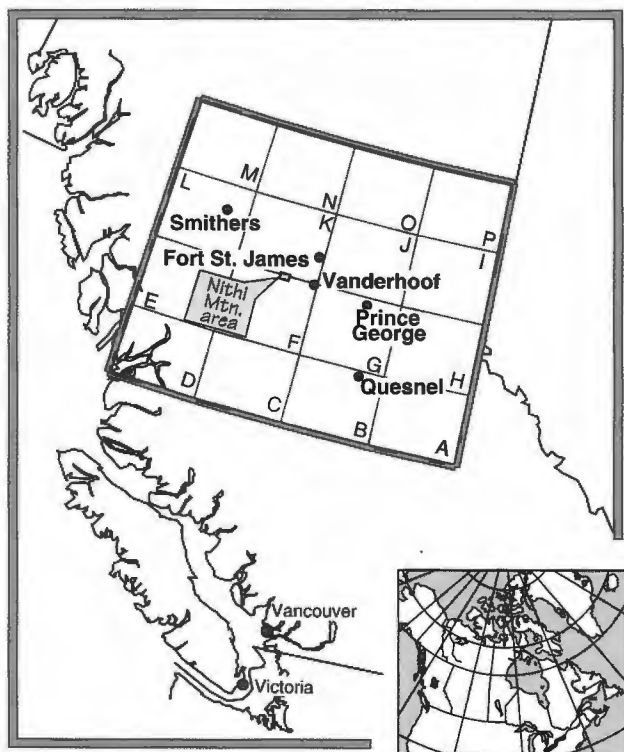


Figure 1. Geographic setting of the Nithi Mountain study area in the Nechako Plateau NATMAP area.



Figure 2. View north to Nithi Mountain.

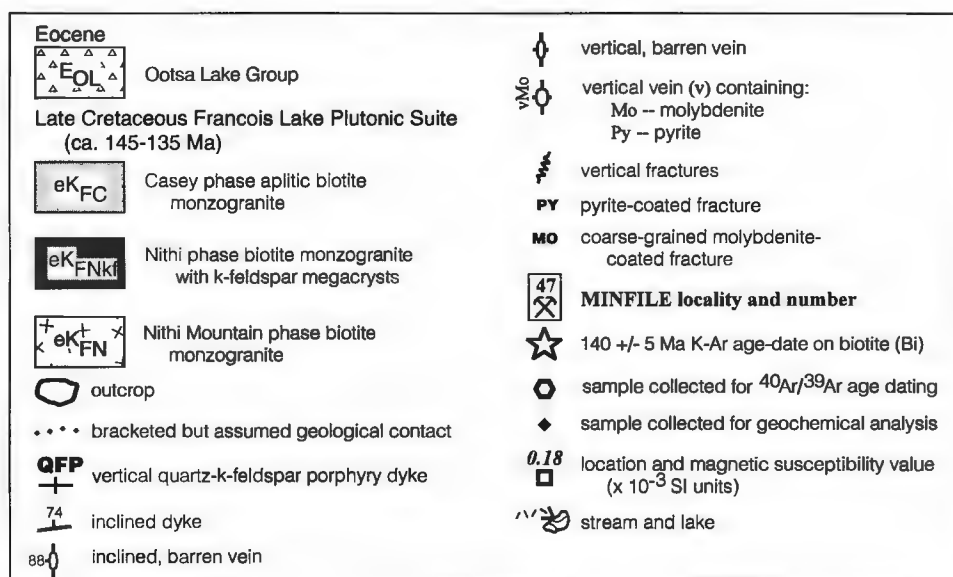
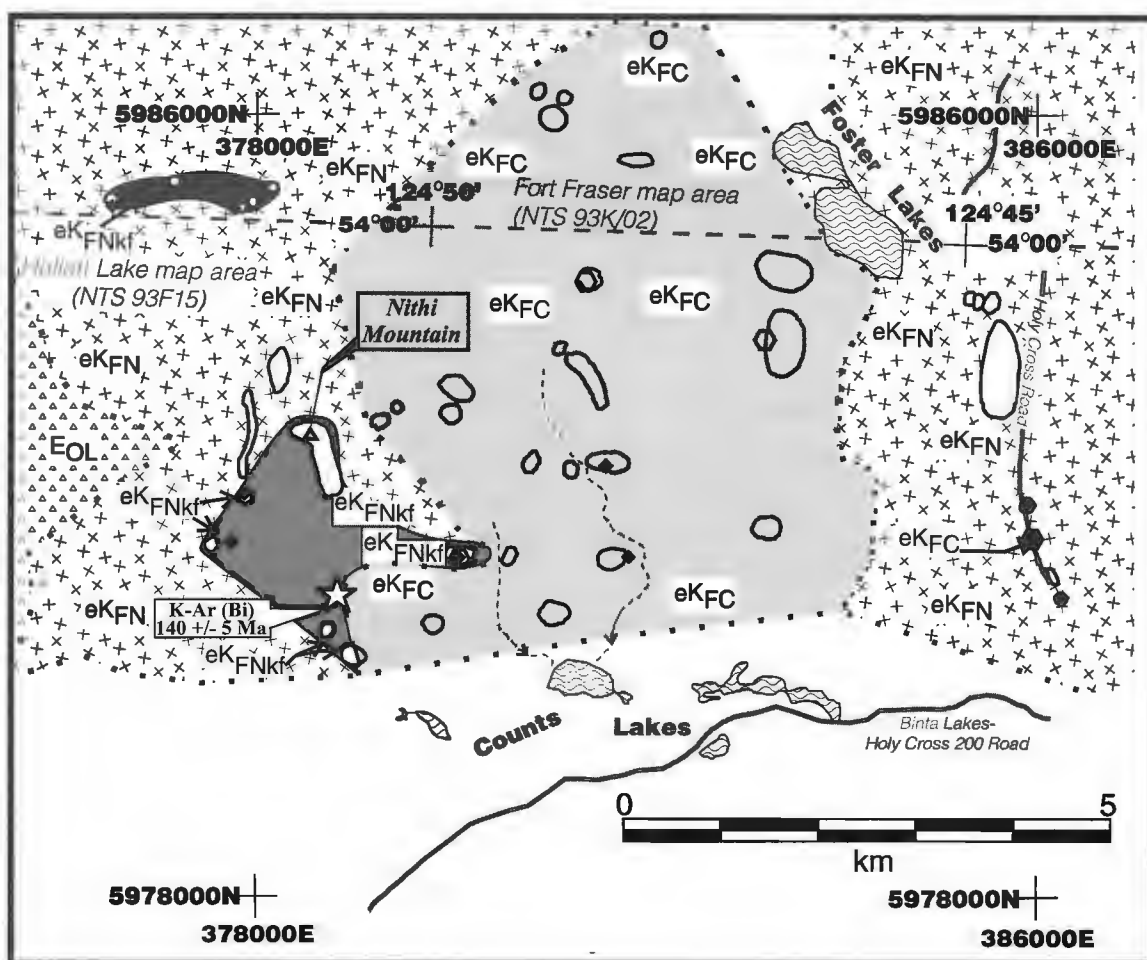


Figure 3. Geological and sample location map for the Nithi Mountain area.

GEOLOGY

The area is underlain mostly by the felsic Nithi and Casey phases of the Early Cretaceous Francois Lake Plutonic Suite (e.g., Carter, 1982; Woodsworth et al., 1991) and is flanked on the west by massive, white weathering, platy alkali-feldspar rhyolite of the Eocene Ootsa Lake Group (Fig. 3) and on the north (east of Foster Lakes) by the Miocene Chilcotin basalt. However, the descriptions below are restricted to the granitic rocks, the focus of the study.

Early Cretaceous Francois Lake Plutonic Suite

Inclusion of the Nithi and Casey plutonic phases in the Francois Lake Plutonic Suite follows the evolution of plutonic groupings and nomenclature developed in the previous mapping (Carr, 1966; White et al., 1970; Kimura et al., 1976; Bysouth and Wong, 1995), in Carter (1982), in the Decade of

North America synthesis by Woodsworth et al. (1991), and in the new regional mapping of Jurassic and Cretaceous plutonic suites described by Anderson et al. (1997) and Struik et al. (1997). The unfoliated, leucocratic, and inclusion-poor nature of biotite monzogranite typifies the phases near Nithi Mountain and the suite as a whole (Fig. 5, 6).

Nithi phase

Nithi phase biotite monzogranite underlies most of the Nithi Mountain area and differs from the Casey phase by a coarser grain size (2-6 mm in size), mottled grey to pink-and-white weathering colour and euhedral biotite. Two textural varieties are recognized based on the presence of a seriate texture imparted by anhedral to subhedral, poikilitic alkali feldspar (up to 2 cm in size) (e.g., Fig. 5); the transition from equigranular to megacrystic rock is gradational. The equigranular biotite monzogranite dominates; an alkali-feldspar megacrystic variety occurs locally in the west (Fig. 3). In the north-western area of megacrystic rocks shown in Figure 3, alkali-feldspar occurs as coarse-grained, poikilitic, anhedral grains otherwise indistinguishable from plagioclase in weathered appearance. The equigranular phase exhibits a weak mineral foliation north of Nithi Mountain (Carr, 1966); generally both varieties are unfoliated. Magnetic susceptibility values for unaltered rocks vary between 5 and 24 and specific gravity values are 2.39-2.62 (average 2.54).

The Nithi phase is believed to be older than the Casey phase (Fig. 7) because xenoliths resembling the Nithi phase occur in the Casey phase just east of Foster Lakes. Along the Holy Cross Road, near the contact with a small apophysis of the Casey phase, a distinctive east-trending and vertical, rhyolitic quartz-alkali-feldspar porphyry dyke (QFP) intrudes the Nithi phase; the dyke strongly resembles those recognized



Figure 4. Magnetic susceptibility measurements were routinely collected from outcrops using a hand-held Exploranium KT-9 Kappameter.

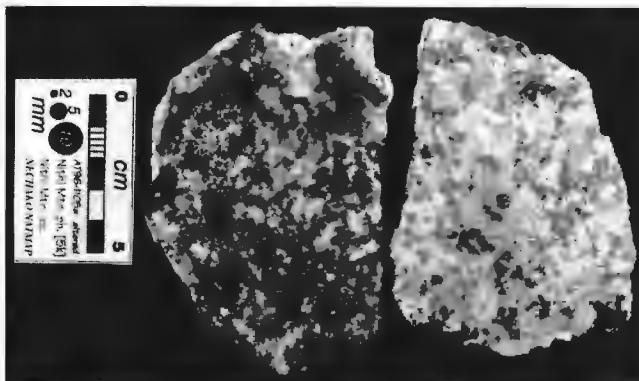


Figure 5. Stained (right) and polished slabs from sample of clay-altered, K-feldspar megacrystic variety of the Nithi phase. White areas are plagioclase, medium grey areas K-feldspar, and dark grey areas are quartz in the stained slab.

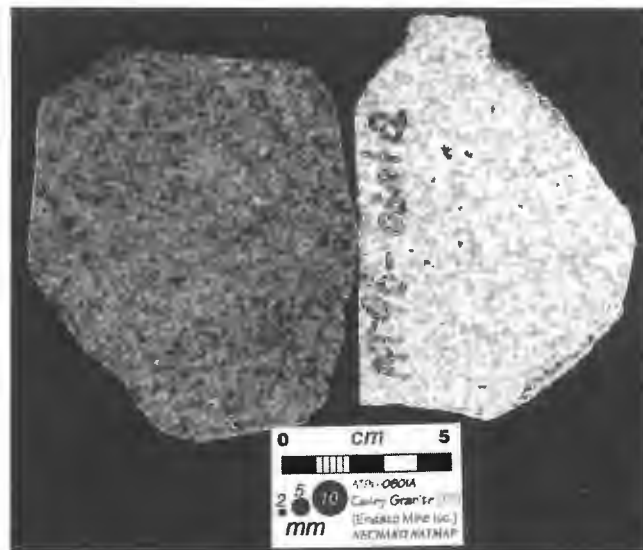


Figure 6. Stained (right) and polished slabs from sample of fine- to medium-grained equigranular Casey phase near the Endako Mine identical to the Casey phase in the Nithi Mountain area. Light grey areas are K-feldspar and dark grey areas are quartz in the stained slab.

as the latest of the pre-ore dykes in the Endako mine area (Kimura et al., 1976) and may be related to the latest-intruded plutonic Casey phase (G. Johnson, pers. comm., 1996).

Casey phase

Pink to buff, fine- to medium-grained (0.5-1 mm grain size), leucocratic, and aplitic biotite monzogranite of the Casey phase dominates the area bordered by Nithi Mountain, Binta Lake-Holy Cross 200 Road, Holy Cross Road, and Foster Lakes (Fig. 3). Coarser-grained varieties occur, but contacts are gradational (Carr, 1966 and this study). The rocks have an overall equigranular, sugary texture and no internal fabric; biotite is slightly coarser grained (1-2 mm grain size) than quartz and feldspar, and is anhedral to subhedral. Basalt and rare quartz-alkali-feldspar porphyry dykes, the latter similar to those at Endako and in the Nithi phase, intrude the Casey phase. Where the quartz-alkali-feldspar porphyry intrudes the Casey phase, the host yields an anomalously low magnetic susceptibility value ($m.s. = 0.07$) in contrast with the host's outwardly fresh appearance and lack of veins. Magnetic susceptibility values for unaltered rocks vary between 5 and 10 (Fig. 8) and specific gravity values are 2.39-2.75 (average 2.56).

Veins, molybdenite mineralization and alteration

Post-intrusion quartz veins, two modes of molybdenite mineralization, and alteration are common and widespread in Nithi and Casey phases in the Nithi Mountain area. This is also apparent in the even distribution between the phases of a dozen MINFILE localities (Fig. 8; Bailey et al., 1995). Near Nithi Mountain, the intensity of rusty alteration in a basalt dyke in the Nithi phase suggests mineralization also predates the dyke. Veins are generally 1-3 cm wide (and reach 7 cm in width) and occur in at least three orientations: a dominant and early 70°-trending set is locally crosscut by, or associated with, a common 000°-trending set or rare 120-130°-trending veins. Uncommonly, an alkali-feldspar selvage accompanies the 70°-trending vein set. In a few localities, fine-grained molybdenite (Fig. 8) and rare specularite are associated with the 70°-trending set. Pyrite and coarse-grained molybdenite are most common along irregular fractures scattered throughout the area (Fig. 8). The 70°-trending veins crosscut an aplite dyke at one locality. Elsewhere, late-stage aplite dykes and north-trending joints in the Casey phase, and aplite dykes, 134°-trending vertical joints, and a north-trending fracture system in Nithi phase locally crosscut and displace the 70°-trending set (Fig. 7). These relationships

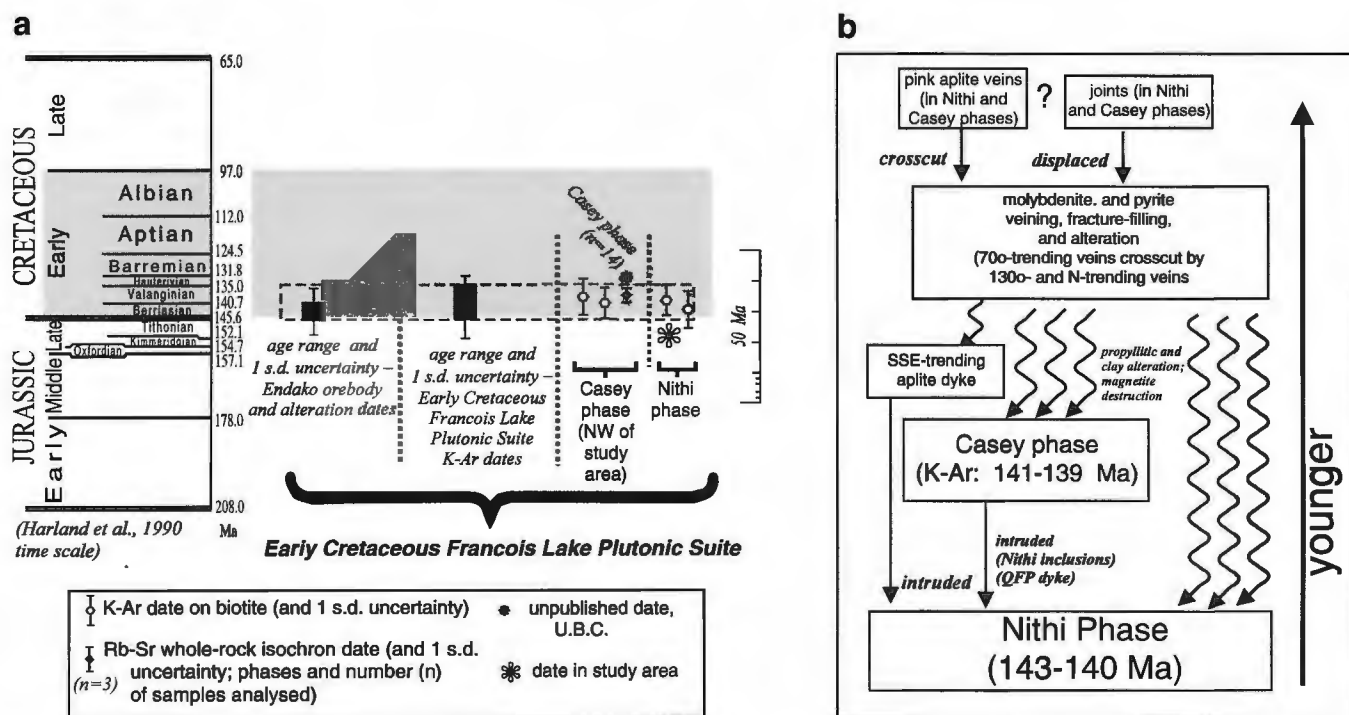


Figure 7. Absolute and relative chronology for the Nithi Mountain area: **a)** Potassium-argon cooling dates for biotite for the Nithi and Casey phases and unpublished Rb-Sr data for the Casey phase (Armstrong, 1988; Woodsworth et al., 1991) and the Harland et al. (1990) time scale. The dates are compared with dates from hydrothermal biotite from the Endako orebody and altered host rocks and cooling dates from the Francois Lake Plutonic Suite (White et al., 1968, 1970; Dawson and Sinclair, 1972; Kimura et al., 1976; Armstrong, 1988; Woodsworth et al., 1991; Bysouth and Wong, 1995); and **b)** relative timing of intrusive, veining, fracture-forming, alteration, and dyking events in the study area.

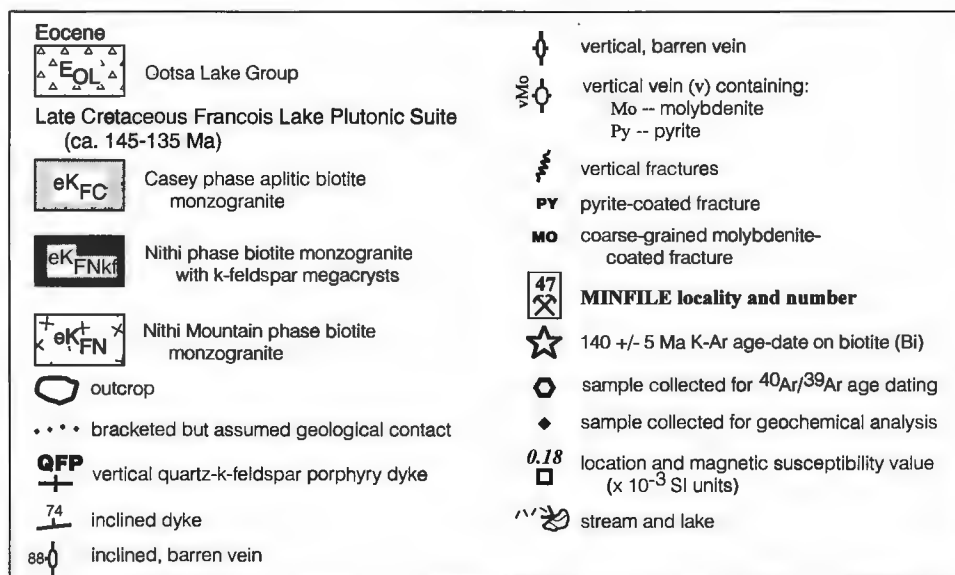
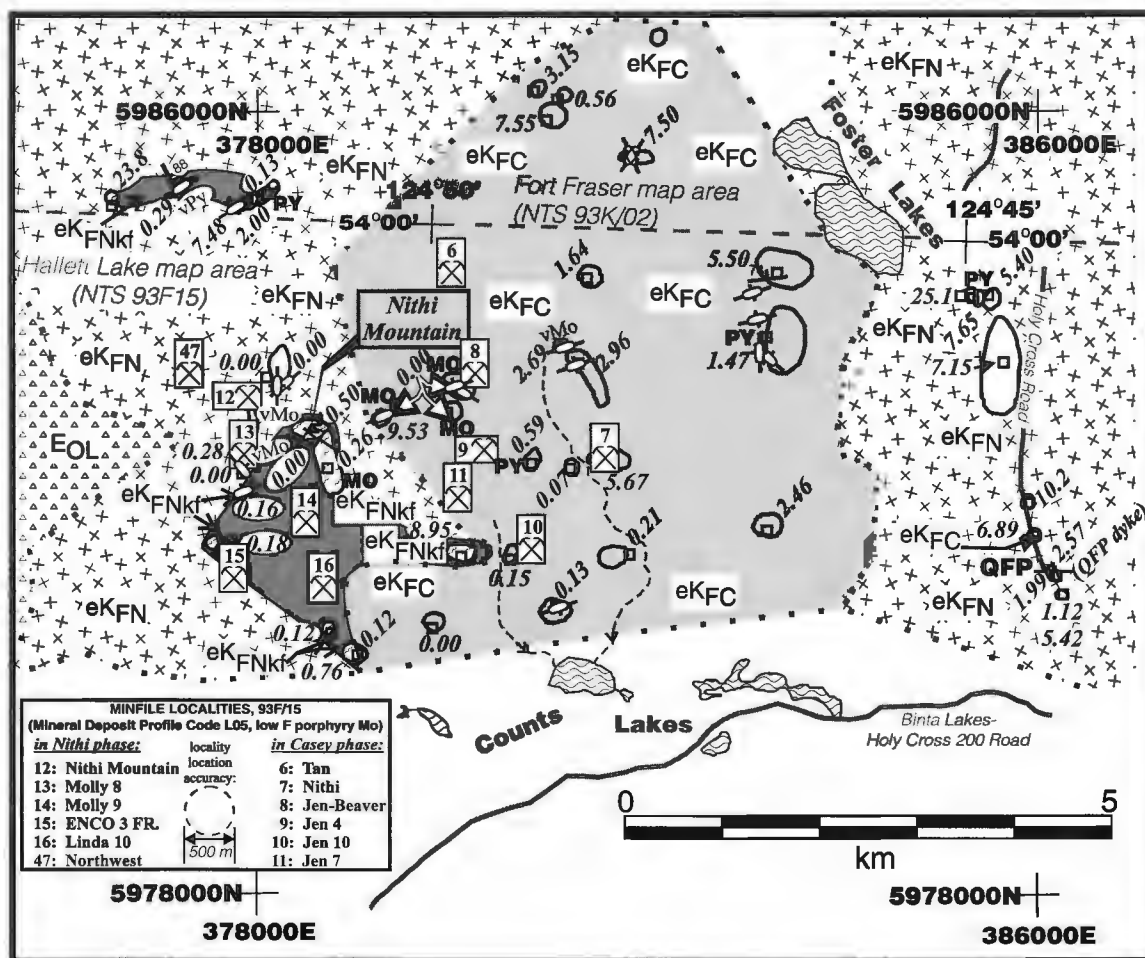


Figure 8. Location of magnetic susceptibility data, MINFILE localities, veins and dykes, and molybdenite and pyrite fracture-fillings for the Nithi Mountain area.

suggest veining and mineralization is an important component of the late-stage intrusive and cooling events associated with emplacement of the Casey phase.

Alteration of the Nithi and Casey phases are equally widespread within 3 km of their western contact (Fig. 8). Biotite alteration to chlorite and rare plagioclase alteration to epidote and intense alteration of feldspar to clay, particularly near the Nithi Mountain summit, are commonly, but not invariably associated with veining or mineralized fractures. Magnetite breakdown, indicated by magnetic susceptibility values less than 1, nearly invariably characterizes the areas of propylitic and clay alteration.

At least a dozen molybdenite-bearing showings are known from the MINFILE database for the Nithi Mountain area in NTS 93F (Bailey et al., 1995). All are considered to be of the low-fluorine variety of the porphyry molybdenum mineralization type (Lefebvre and Höy, 1996). Northwest of Nithi Mountain, MINFILE locality 12, called NITHI MOUNTAIN (Fig. 8), is unusual in that uraninite mineralization accompanies the more abundant molybdenite. This and the widespread alteration may account for the anomalies, localized over the Nithi Mountain area, noted in the U, Th, and K radiometric surveys flown over the Endako Mine and Nithi Mountain areas (Struik and McMillan, 1996; R. Shives, pers. comm., January 1996).

AGE

One Early Cretaceous (140 ± 5 Ma) K-Ar cooling age for biotite was determined by White et al. (1970; sample T66-20) for a sample identified as Nithi phase which is located in the megacrystic variety of the Nithi phase near its contact with the Casey phase (Fig. 3, 7). The date is concordant with another, slightly older date (143 ± 6 Ma) determined for biotite from a Nithi phase sample just north of the study area (White et al., 1970, sample 66-21; Fig. 7). No dates are available for the Casey phase in the Nithi Mountain area, but regionally, K-Ar ages for the phase range between 141-139 Ma. Dates for both phases are concordant with the general 145-135 Ma range of K-Ar mineral ages and unpublished Rb-Sr whole rock ages for the Early Cretaceous Francois Lake Plutonic Suite (Armstrong, 1988; see Anderson et al., 1997 for summary) and overlap the range of K-Ar dates (144-141 Ma) for hydrothermal biotite in and near the Endako mine (White et al., 1970; Bysouth and Wong, 1995).

CONCLUSIONS

At least three unfoliated biotite monzogranite phases of the Early Cretaceous Francois Lake Plutonic Suite which host molybdenite-bearing quartz vein and fracture fillings were recognized in the Nithi Mountain area of northern Nechako River (NTS 93F) map area. The older Nithi phase comprises equigranular and slightly alkali-feldspar megacrystic varieties that are coarser grained and more mafic rich than the younger, equigranular, aplitic Casey phase. Inclusions of

Nithi phase rocks in the Casey phase give a relative order of intrusion; both are intruded by a distinctive quartz-alkali-feldspar porphyry dyke which resembles a late pre-ore dyke at the Endako Mine. Earlier studies indicate that cooling dates for the Nithi (143-140 Ma; K-Ar, biotite) and the Casey phase (141-139 Ma) overlap.

The Nithi phase exhibits intense clay alteration near and southwest of Nithi Mountain; propylitic alteration is common in all phases. Routine magnetic susceptibility measurements on outcrops show that compared with values of $2-25 \times 10^{-3}$ SI units for fresh rocks, values less than 1×10^{-3} SI units indicate that magnetite destruction accompanied the widespread clay and propylitic alteration and/or formation of pyrite- or molybdenite-filled fractures or veins. East-northeast-trending Mo-bearing veins and later veining, aplite intrusion, jointing, and fracture formation record late stage events in emplacement of the Casey phase; all are localized to within 3 km of its contact with the Nithi phases.

The equigranular and megacrystic Nithi phase and Casey phase have equal abundance of MINFILE porphyry molybdenite showings of the low fluorine deposit profile type. The new mapping highlights other promising areas of molybdenite veins and fracture coatings, and alteration for follow-up exploration than were previously known. Routine measurement of magnetic susceptibility values for outcrops helps to detect areas of altered plutonic rocks.

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REFERENCES

- Anderson, R.G., L'Heureux, R., Wetherup, S., and Letwin, L.
1997: Geology of the Hallett Lake map area, north-central British Columbia: Triassic, Jurassic, Cretaceous and Eocene? plutonic rocks; in Current Research 1997-A; Geological Survey of Canada.
- Armstrong, R.L.
1988: Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera; Geological Society of America, Special Paper 218, p. 55-91.

- Bailey, D.G., Jakobsen, D.E., and Lane, R.**
1995: MINFILE 093F Nechako River Mineral Occurrence Map; British Columbia Ministry of Energy, Mines and Petroleum Resources, MINFILE, revised March 1995.
- Bright, E.G.**
1967: Geology of the Topley Intrusives in the Endako area, British Columbia; M.Sc. thesis, University of British Columbia, Vancouver, British Columbia, 111 p.
- Bysouth, G.D. and Wong, G.Y.**
1995: The Endako molybdenum mine, central British Columbia: an update; in *Porphyry Deposits of the Northwestern Cordillera of North America*, (ed.) T.G. Schroeter; Canadian Institute for Mining, Metallurgy and Petroleum, Special Volume 46, p. 697-703.
- Carr, J.M.**
1965: Nithi Mountain; British Columbia Minister of Mines and Petroleum Resources, Annual Report 1964, p. 62-63.
1966: Geology of the Endako area, British Columbia; in *Lode Metals in British Columbia*; British Columbia Minister of Mines and Petroleum Resources, Annual Report 1965, p. 114-135.
- Carter, N.C.**
1982: Porphyry copper and molybdenum deposits west-central British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 64, p. 44-45.
- Davis, J.W.**
1981: Road building, trenching and geochemical report on the Nithi Mountain molybdenum property, Fraser Lake, B.C.; British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 9110.
- Dawson, K.M. and Sinclair, A.J.**
1972: Factor analysis of minor elements data for pyrites, Endako Molybdenum Mine, British Columbia; *Economic Geology*, v. 69, p. 404-411.
- Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G., and Smith, D.G.**
1990: *A Geological Time Scale 1989*; Cambridge University Press, 279 p.
- Harris, F.R. and LeBel, J.L.**
1975: Nithi Mountain Property: Geological, geophysical and geochemical report; British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 5714.
- Kimura, E.T., Bysouth, G.D., and Drummond, A.D.**
1976: Endako; in *Porphyry Deposits of the Canadian Cordillera*, (ed.) A. Sutherland Brown; Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 444-454.
- Lefebvre, D.V. and Höy, T. (ed.)**
1996: Selected British Columbia mineral deposit profiles, Volume 2—Metallic Deposits; British Columbia Geological Survey Branch, Open File 1996-13, Appendix 1.
- Steiger, R.H.J. and Jäger, E.**
1977: Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochemistry; *Earth and Planetary Science Letters*, v. 36, p. 359-362.
- Struik, L.C. and McMillan, W.J.**
1996: Nechako Project overview, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 57-62.
- Struik, L.C. and MacIntyre, D.**
1997: Nechako Plateau NATMAP project overview, central British Columbia, year two; in *Current Research 1997-A*; Geological Survey of Canada.
- Struik, L.C., Whalen, J.B., Letwin, J.M., and L'Heureux, R.**
1997: Geology of southeast Fort Fraser map area, British Columbia: general geology; in *Current Research 1997-A*; Geological Survey of Canada.
- Tipper, H.W.**
1963: Nechako River map-area, British Columbia; Geological Survey of Canada, Memoir 324, 59 p.
- White, W.H., Harakal, J.E., and Carter, N.C.**
1968: Potassium-argon ages of some ore deposits in British Columbia; Canadian Institute of Mining and Metallurgy, Bulletin, v. 61, no. 679, p. 1326-1334.
- White, W.H., Sinclair, A.J., Harakal, J.E., and Dawson, K.M.**
1970: Potassium-argon ages of Topley Intrusions near Endako, British Columbia; *Canadian Journal of Earth Sciences*, v. 7, p. 1172-1178.
- Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L.**
1991: Plutonic Regimes, Chapter 15; in *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 491-531. (also *Geological Society of America, The Geology of North America*, no. G-2).

Geology of the Nulki Hills and surrounding area, central British Columbia¹

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Abstract: The Nulki Hills, southwest of Vanderhoof, British Columbia (NTS 93F/9,16) are entirely underlain by the Cretaceous Frank Lake pluton. Miocene Chilcotin Group plateau basalts extend around and onto the Nulki Hills to an elevation rarely exceeding 1220 m. Stratigraphically below the Miocene basalts are Eocene Endako group and Ootsa Lake group volcanic rocks, the monzodiorite to diorite Brooks diorite complex and Jurassic Hazelton Group volcanic rocks.

A prominent shear zone (the Nulki shear zone) terminates the Frank Lake pluton and the Nulki Hills on their west side. The shear zone is a shallow-dipping, north-northeast striking panel of mylonite and deformed plutonic rocks with top-to-the-northwest sense of motion. Interpretations suggest the Nulki shear zone is the northwestern side of an Eocene extension complex that is cored by the Vanderhoof gneisses and the Frank Lake pluton.

Résumé : Les collines Nulki, au sud-ouest de Vanderhoof, en Colombie-Britannique (SNRC 93F/9, 16) reposent entièrement sur le pluton crétacé de Frank Lake. Les basaltes de plateau du Groupe de Chilcotin du Miocène s'étendent autour des collines Nulki et sur ces collines jusqu'à une altitude dépassant rarement 1 220 m. Les roches volcaniques des groupes d'Endako et d'Ootsa de l'Éocène, le complexe dioritique de Brooks composé de monzodiorite et de diorite et les roches volcaniques du Groupe de Hazelton du Jurassique se trouvent stratigraphiquement au-dessous des basaltes du Miocène.

Le pluton de Frank Lake et le flanc ouest des collines Nulki se terminent contre la zone de cisaillement de Nulki. Cette zone de cisaillement importante est un panneau de mylonite et de roches plutoniques déformées à plongement doux et à direction nord-nord-est dont le sommet a été déplacé vers le nord-ouest. Selon les interprétations, elle représente le bord nord-ouest d'un complexe éocène formé par distension dont le coeur est composé des gneiss de Vanderhoof et du pluton de Frank Lake.

¹ Contribution to the Nechako Plateau NATMAP Project

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INTRODUCTION

Map areas 93F/16 (Nulki Lake) and F/9 (Tatuk Lake) containing the Nulki Hills were mapped in 1996 at a 1:50 000 scale as part of the Nechako Plateau NATMAP Project, in central British Columbia (Fig. 1; Struik and McMillan, 1996). The mapping of these two areas is a continuation of field work done in 1995 (Wetherup and Struik, 1996) in 93G/12 and G/13 as part of an MSc. thesis to examine the Vanderhoof metamorphic complex as an example of an Eocene extensional core complex. The previous work identified an eastern boundary to the complex and that the Frank Lake pluton is part of the complex along with the Vanderhoof gneisses. Geological mapping and investigation of the structures in 93F/9 and F/16 helped determine the western bounding structures of the metamorphic complex and the results are summarized below.

GEOLOGY

Topography in the map area is generally subdued with about 800 m of relief and no steep slopes. Much of the area is blanketed under glacial sediments especially in the northern two thirds of 93F/16 which is dominantly covered by glacial lake clays. Hence, the limited and isolated outcrop pattern makes finding contacts and contact relationships a challenge. Road access is good as there has been extensive pulp and lumber harvesting and the new roads provide many new outcrops.

Three ages of volcanism are represented in the area by (1) Jurassic Hazelton Group, (2) Eocene Endako and Ootsa Lake Group, and (3) Miocene Chilcotin Group basalts, and at least three ages of intrusions: (1) Jurassic high level intrusions related to the Hazelton Group and the Brooks diorite complex, (2) the Cretaceous Frank Lake pluton, and (3) Eocene felsic dykes and stocks. All of these units for the most part have not been metamorphosed or deformed. The only intense deformation found is in the Nulki shear zone and the only metamorphosed rocks in the area are members of the Vanderhoof gneisses that are either roof pendants within the Frank Lake pluton or extensions from the main gneiss body in 93G/12 and G/13 (Fig. 2, 3).

Miocene

Chilcotin Group

Basalt flows of the Chilcotin Group extend onto the flanks of the Nulki Hills rarely exceeding an elevation of 1220 m and are found in the Nechako River valley in 93F/16 and within the Tatuk Lake and Chilako River valley in 93F/9. Original mapping of the Nechako River map area by Tipper (1963) grouped these rocks and the Endako Group rocks as Miocene but recently they have been divided into distinct groups (Souther, 1991).

Chilcotin Group basalts contain uncommon olivine and pyroxene phenocrysts and rare vesicles that increase in size and abundance with proximity to a flow top. A Chilcotin flow is horizontally layered, between 5 and 8 m thick, and columnar-jointed with columns ranging from 30 cm to 1 m in diameter.

Flows resemble flood basalts in their extensive distribution and unconformably overlie all the other units; fortunately, glaciation and other erosive processes have exposed the basement rocks.

Eocene

Endako Group

Endako Group comprises basalt flows with minor andesite flows near the base of the succession. The best exposure of this unit is found on Mount Greer and on Brophy's ridge in the southwest corner of 93F/16, north of Greer Creek (Fig. 2, 3). Previous mapping by Tipper (1963) suggested a Miocene age for Endako Group rocks but revisions to the stratigraphic nomenclature and grouping of the Tertiary volcanic rocks in the area (Souther, 1991) restricts the Endako Group to Eocene mafic flows. Wheeler and McFeely (1991) had also included parts of the group in the Paleogene Kamloops Group.

The basalts differ from the Chilcotin Group in that they contain significant amounts (5-30%) of elongate to acicular plagioclase phenocrysts and limonite-, chlorite-, calcite-, or quartz-filled amygdules. Flows in the Endako Group are also much thinner, between 1 and 3 m thick, moderately vesicular to highly vesicular cinder, rarely columnar-jointed, and dip moderately from 20 to 30 degrees.



Figure 1. Location map of the study area (in black).

West of the 93F/16 map area, Endako Group basalts on Mount Greer appear to unconformably overlie felsic volcanic rocks belonging to the Ootsa Lake Group. However in 93F/16 and 93F/9 Endako Group rocks appear to grade into felsic volcanic rocks of the Ootsa Lake Group.

Ootsa Lake Group

Ootsa Lake Group consists of rhyolite, dacite, and minor andesite flows and pyroclastic units. Felsic Eocene rocks at a low structural level in the Greer Creek valley and at the

headwaters of Stoney Creek on the southwest corner of 93F/16, occur beneath the Endako Group volcanic pile. In Tatuk valley, on the southwestern corner of 93F/9 map area, there are excellent outcrops of Ootsa Lake Group rhyolitic and dacitic welded tuffs and flows (Fig. 2).

Flows are commonly flow-banded and aphyric whereas tuff units contain 0-15% quartz and K-feldspar crystals. Welding in the tuff varies from strongly welded, columnar-jointed, solid black glass units that retain vestiges of their original layering to friable ash and accretionary lapilli tuff.

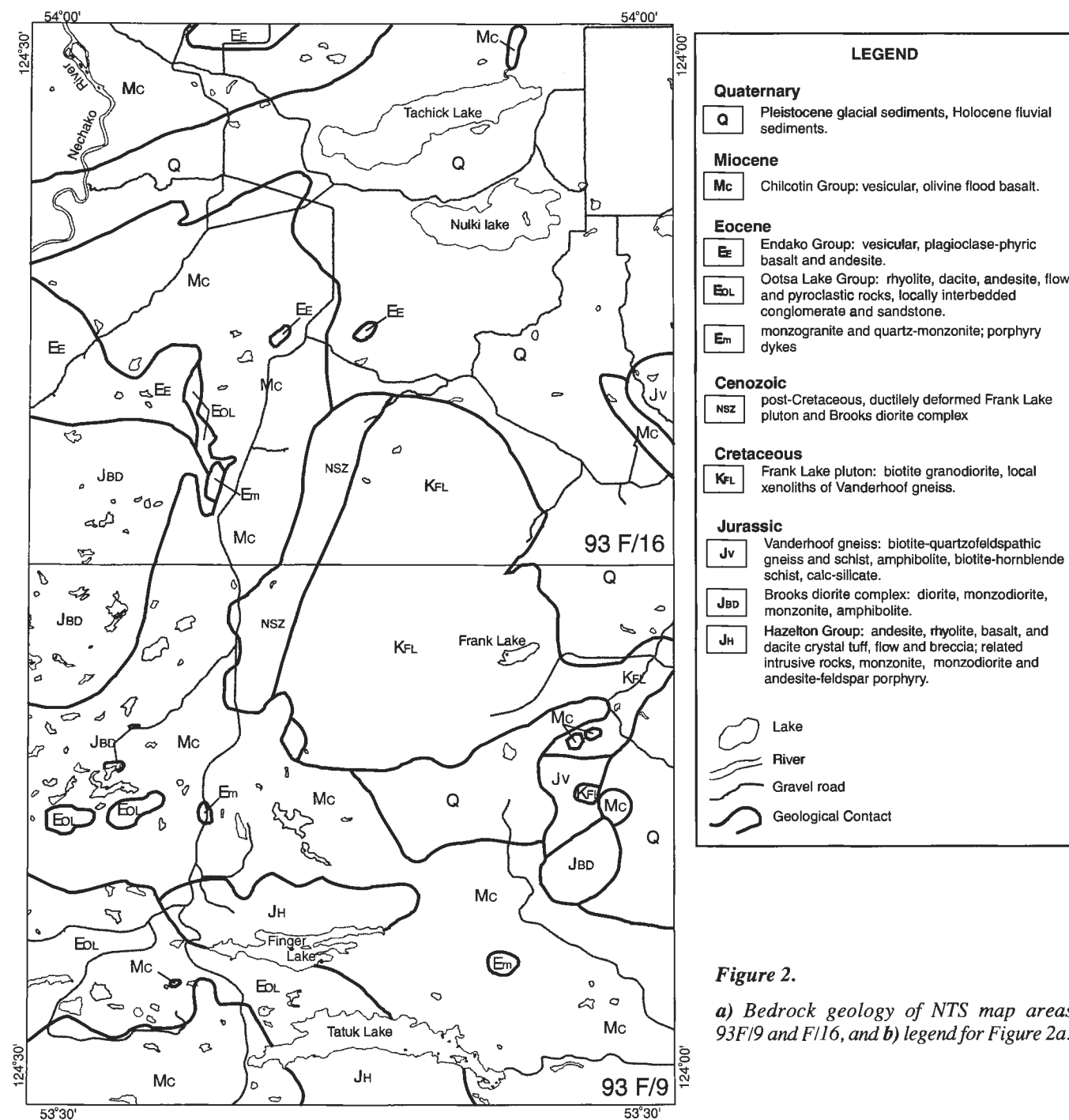


Figure 2.

a) Bedrock geology of NTS map areas 93F/9 and F/16, and b) legend for Figure 2a.

In the Greer Creek valley, a 20 to 30 m thick conglomerate section of alternating sandy layers and lenses and coarse pebble to cobble conglomerate beds is interbedded with Ootsa Lake Group volcanic units. Conglomerate beds are 20 cm to 1 m thick and consist of 90% rounded plutonic rock fragments, likely derived from the Brooks diorite complex and/or the Frank Lake pluton.

As with the Endako Group, Ootsa Lake Group beds dip 25-75°. Ootsa Lake Group rocks nonconformably overlie the Brooks diorite complex and likely the Hazelton Group volcanic and intrusive rocks, however their relationship to the Eocene? dykes and stocks is uncertain.

Plutonic rocks

The suite includes medium-grained quartz monzonite and monzogranite stocks and fine-grained, light pink quartz-feldspar- and feldspar-porphyry dykes that outcrop within and on the flanks of the Tatuk valley, in south and central areas of 93F/9 map area (Fig. 2, 3). Reconnaissance mapping by Tipper (1963) grouped the intrusions with Topley Intrusions or Takla volcanic rocks.

The fine-grained porphyritic dykes have a pink to light orange aphanitic matrix with 5-10%, potassium feldspar phenocrysts 0.5-3 mm in size and local 0.5-4 mm quartz phenocrysts. A few dykes are aphyric but all show some pyrite mineralization.

Dykes trend 290° and 330° and dip steeply near Cabin Creek where they crosscut Hazelton Group volcanic flows and epiclastic rocks. Outcrops of the granites are isolated and contact relationships with other rocks units, except for a nonconformably overlying Chilcotin Group basalt flow in one location, were not observed.

Feldspar porphyry and hornblende-feldspar porphyry dykes that strongly resemble the Eocene post-ore dykes at the Endako Mine site (93K/3) (L.C. Struik, pers. comm., 1996) crosscut the Brooks diorite complex south of Greer Creek in the southwest corner of 93F/16. The post-ore dykes at the Endako mine, dykes in the Brooks diorite, and dykes in the Tatuk area are considered correlatives.

Cretaceous

Frank Lake pluton

Frank Lake pluton outcrops in the south-central to southeastern corner of map area 93F/16 and the northeastern quadrant of 93F/9 and along the western borders of map areas 93G/12 and 13. The type locality for the Frank Lake pluton is in the Nulki Hills surrounding Frank Lake in 93F/9 (Fig. 2, 3). Vanderhoof gneisses and the Frank Lake pluton were previously included with the Topley Intrusions (Tipper, 1961, 1963) and later as "predominantly orthogneiss with uncertain protolith" (Wheeler and McFeely, 1991).

White feldspars, proportion of quartz and feldspar, accessory minerals magnetite and titanite, and subhedral biotite or hornblende distinguish the Frank Lake pluton. It is

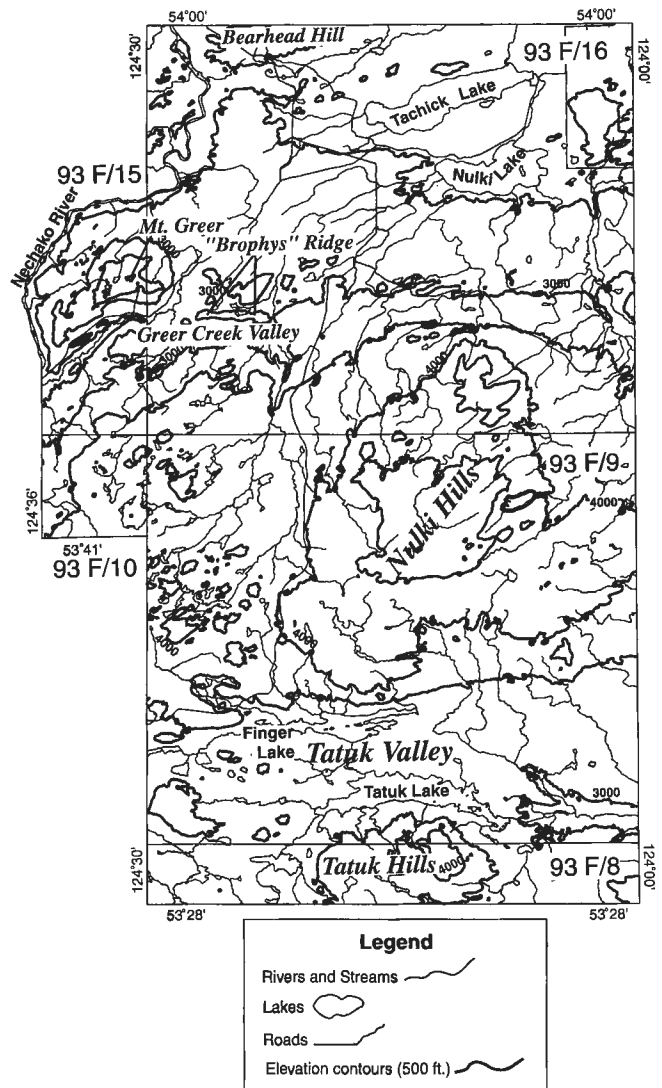


Figure 3. Geographical map of NTS map sheets 93F/9, F/16, and surrounding areas shows topographical features referred to in the text.

greyish white on weathered and white on fresh surfaces and is medium grained. White feldspar comprises 50-60% of the rock and quartz varies between 10-30%. Biotite (5-20%), rare hornblende, and minor amounts of magnetite and titanite are common mafic and accessory minerals.

The pluton is not metamorphosed, but local weak to intense foliation and folding suggest it is strained. Intense deformation occurs in a shear zone oriented about azimuth 220° dipping 20° northwest. Foliations parallel the shear zone and lineations are oriented along azimuth 330°, plunging 15-18°. Both decrease in intensity with distance from the shear zone for 1 to 2 km where most signs of strain have disappeared. The shear zone marks the north and west boundaries of the Frank Lake pluton and the Nulki Hills.

Preliminary interpretation of U-Pb data from zircon in a foliated sample of the Frank Lake pluton suggests a Late Cretaceous age (M. Villeneuve, pers. comm., 1996).

Jurassic

Vanderhoof gneisses

Vanderhoof gneisses principally occur in map areas 93G/12 and 13, however the gneisses extend to the east sides of 93F/16 and F/9 (Fig. 2, 3). Biotite-quartz-feldspar schist and amphibolite, which make up the gneiss unit, were included in the Topley Intrusions by Tipper (1961, 1963), as "predominantly orthogneiss with uncertain protoliths" by Wheeler and McFeely (1991), and as Vanderhoof gneisses by Wetherup and Struik (1996).

Feldspar-quartz-biotite-hornblende schist is light brown, weathers rusty brown and is fine to medium grained. Feldspars (30-50%), quartz (10-40%), biotite (5-50%), and hornblende (0-30%) are the main constituents but composition varies widely in a single outcrop as compositional layers range in thickness from 1 mm to 50 cm. Commonly, amphibolite units are intercalated with the schists.

Amphibolite units weather grey with dark green fresh surfaces. Hornblende account for 50 to 70% of the rock and plagioclase (30-50%) and biotite (0-10%) make up the remainder with rare garnet. Occasionally interlayered with the amphibolites are minor calc-silicate layers consisting of plagioclase with minor hornblende and accessory diopside and garnet.

Frank Lake pluton and a diorite body possibly correlative to the Brooks diorite complex concordantly intrude the paragneisses. The Frank Lake pluton crosscuts the paragneisses defining its western boundary, and hosts large xenoliths (up to 1 m in size) in one location in the southwestern corner of map area 93F/16. In the 93G/13 map area the paragneisses underlie Cache Creek ultramafic rocks beneath a low-angle detachment fault (Wetherup and Struik, 1996). Preliminary interpretation of detrital zircon U-Pb isotopic data on samples collected in 1995 suggests a minimum age of mid-Jurassic for the Vanderhoof gneisses in the 93F/16 map area (M. Villeneuve, pers. comm., 1996).

Brooks diorite complex

The Brooks diorite complex outcrops in the southwestern corner of 93F/16 and northwestern corner of 93F/9 as well as extending into sheets 93F/10 and 15 (Fig. 2, 3). The complex includes diorite, monzodiorite, monzonite, amphibolite, and micromonzonite feldspar porphyry. Together with the other plutonic rocks in the map area, the Brooks diorite complex was included in the Topley Intrusions by Tipper (1963) and later in the Late Jurassic to Early Cretaceous Francois Lake intrusions by Wheeler and McFeely (1991) and Woodsworth et al. (1991).

Diorite, monzodiorite, and monzonite phases are equigranular and fine to medium grained. Hornblende and biotite are common in all three, decreasing in abundance from diorite (hornblende 10-50%, biotite 5-20%) to monzonite (hornblende 0-20%, biotite 5-10%). Accessory minerals include magnetite (0-3%) and rare titanite.

Amphibolite xenoliths (2 to 30 cm in size) are common within diorite and monzodiorite bodies, and may be finer-grained (0.25-0.5 mm), more mafic phases of their host intrusion or part of the Vanderhoof gneisses. Xenoliths contain 50-90% hornblende, 10-50% feldspar, and 0-15% biotite. Most are round and some contain a weak fabric, but locally they are angular and may have been a quickly crystallized border phase that was disaggregated by subsequent intrusions.

A second amphibolite variety occurs as dykes that cross-cut the diorite and monzodiorite phases. These amphibolite dykes resemble the amphibolite xenoliths except for their hornblende phenocrysts (1-3 mm in size) and magnetic susceptibility ($\sim 3 \times 10^{-3}$) which is an order of magnitude less than the xenoliths (~ 30 to 40×10^{-3}).

The micromonzonite dykes appear to be identical in composition to the monzonite. Overall grain size of the micromonzonite is 0.25-0.5 mm with 5-10% euhedral plagioclase, 0-5% hornblende, and 0-5% biotite phenocrysts (1-3 mm in size).

The diorite and monzodiorite and amphibolite inclusions are the oldest units in the complex as they are crosscut by the monzonite and micromonzonite dykes as well as the porphyritic amphibolite dykes. An age for this complex is tentatively interpreted to be Middle Jurassic from a preliminary U-Pb zircon date (M. Villeneuve, pers. comm., 1996) on a sheared, potential correlative to this unit. Areally the later dykes and monzonite make up less than 5% of the complex and from their similarity to dykes in the Tatuk valley and in the Endako Mine could be Tertiary in age and not related to the earlier plutonism.

Hazelton Group

Volcanic rock mapped as Hazelton Group and related intrusive rocks are found north of Finger Lake and south of Tatuk Lake on the south end of 93F/9 and the extreme north of 93F/8 map areas (Fig. 2, 3). Basalt to rhyolite flows, pyroclastic rocks, epiclastic units, and high level porphyries are slightly chloritized and typical. Previously mapped as Takla Group (Tipper, 1963) and Stuhini (Wheeler and McFeely, 1991), they have been regrouped here as Hazelton because of the felsic volcanic units which are uncharacteristic of Takla Group and Stuhini Group (Tipper and Richards, 1976).

South of Tatuk Lake, Hazelton Group volcanic rocks include basalt to andesite flows, ash and crystal tuff, and breccia. Flows are massive with dark grey aphanitic matrices containing 15-25%, 1-4 mm plagioclase and 0-3% 1-2 mm hornblende phenocrysts. Crystal tuff has a similar crystal content as the flows and are difficult to distinguish from them except by fine tuffaceous layering evident on weathered surfaces. Ash tuff weathers dark grey to buff grey and is finely bedded along curvilinear surfaces. Breccia fragments (1-5 cm in size) are dominantly angular comprising of flow and crystal tuff material in a massive, aphanitic, dark grey matrix whose composition resembles the flow and crystal tuff units.

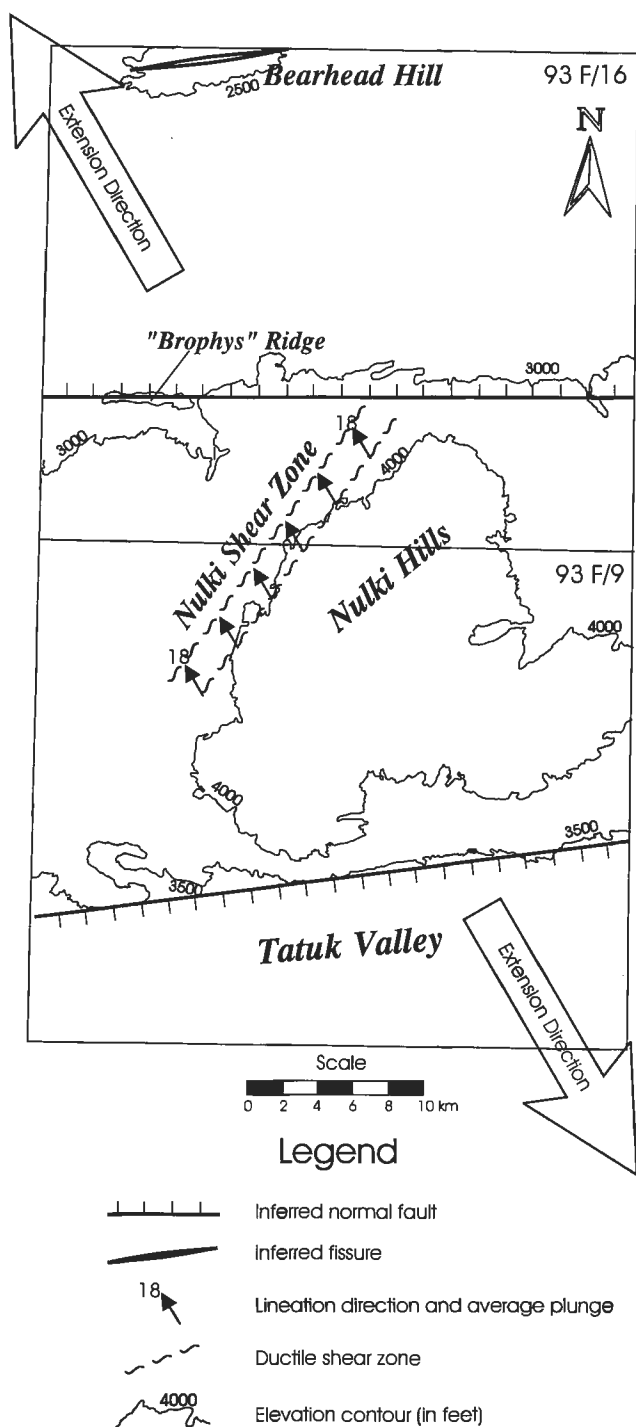


Figure 4. Cartoon drawing of the topography and interpreted structures in the map area. Large arrows depict inferred extension directions.

Rhyolite and dacite are uncommon south of Tatuk Lake with one rhyodacite flow unit and one large (250-300 m thick) rhyolite breccia unit on the north slope of the Tatuk Hills. Flows in the rhyodacite unit are buff coloured, massive, aphyric, and siliceous, similar to the fragments found in the rhyolite breccia. Rhyolite breccia fragments are generally angular, 1-4 cm in size, and consist almost exclusively of white-to buff-coloured rhyolite; round carbonate clasts are rare.

North of Finger Lake, the volcanic units are more difficult to identify as most units have been subjected to moderate to intense alteration and silicification. Units range in composition from andesite to rhyolite and comprise generally massive flows and agglomerates between 1 and 10 m thick. The rhyolite and dacite units are commonly aphyric whereas the andesite contains 5-20% plagioclase phenocrysts.

Units trend 205 to 330° south of Tatuk Lake and around 70° north of Finger Lake. Everywhere, dips are moderate from 20 to 45°. Tops indicators from scours and crossbedded sandy layers within the rhyolite breccia suggest a northward-younging direction.

Contact relationships involving the Hazelton Group include a few crosscutting Eocene dykes, a crosscutting diorite body (possibly a Brooks diorite complex equivalent), and unconformably-overlying Chilcotin Group basalts to the north and west. The rocks are tentatively correlated with the Lower to Middle Jurassic Hazelton Group because of their dissimilarity to other volcanic assemblages in the area.

Three related intrusive units include monzonite, micro-monzodiorite feldspar porphyry, and an andesitic "bladed" feldspar porphyry. The fine-grained (0.5-1 mm) monzonite contains hornblende (5-10%), biotite (0-5%), and rare quartz. Matrix within the porphyry units is dark grey, aphanitic, and contains phenocrysts (0.5-4 mm in size) of plagioclase (5-20%), hornblende (0-5%), potassium feldspar (0-5%), and biotite (0-5%). The andesitic "bladed" feldspar porphyry contains 10-20% plagioclase phenocrysts 2-10 mm in length and resembles units known to be Upper Triassic Takla Group. However, the other intrusive rock units appear related to the volcanic rocks and the andesitic "bladed" feldspar porphyry is a small isolated unit, hence it has been grouped with the Hazelton Group rocks on the map (Fig. 2). Vesicles occur in some micromonzodiorite dykes and in the andesitic "bladed" feldspar porphyry.

STRUCTURES

Three areas with important structures within the map area are (1) a north-northeast-striking ductile shear zone that marks the western boundary of the Nulki Hills, (2) the east-trending Tatuk valley, and (3) east-trending ridges of Eocene volcanic rocks (Fig. 2, 3, 4).

The Nulki shear zone

The Nulki shear zone is distinguished from other structural features by its 220° trend and ductile character. It is located in the south-central part of 93F/16 and the north-central part of 93F/9 map areas, and underlies the western extent of the Nulki Hills and the Frank Lake pluton. At its northern end, the shear zone and the Nulki Hills disappear beneath glaciofluvial gravel and glacial lake sediment. Chilcotin Group basalt and glacial till obscure the southern extent of the shear zone and its extent west of the Kluskus Forest road.

The shear zone is a 1-2 km wide area consisting mainly of deformed equivalents of the Cretaceous Frank Lake pluton that increase in deformation intensity westward from undeformed granitoids to mylonite orthogneiss in the centre of the shear zone. The western side of the zone also contains sheared mafic plutonic material. These are interpreted to be deformed Brooks diorite complex rocks and have been dated by U-Pb zircon analysis to be Middle Jurassic (M. Villeneuve, pers. comm., 1996).

The mylonites are well foliated where sufficient mica (biotite) produced a 220-230° trending, shallow (10-20°) westerly dipping planar fabric. A strong stretching lineation, developed mainly in quartz (~10:1, length:width) and uncommonly in the feldspar, trends 320-330° and plunges 10-15°. Kinematic indicators along this shear zone are rare but a few rotated feldspars and S-C fabrics give a top-to-the-northwest sense of shear.

Wetherup and Struik (1996) suggested the Vanderhoof paragneisses and Frank Lake pluton were the core of an Eocene extensional complex where Cache Creek ultramafic rocks slid off the metamorphic and plutonic rocks, towards the southeast atop a low angle detachment fault. The Nulki shear zone appears to be the other side of the core complex where the Brooks diorite complex slid off the Frank Lake pluton and Vanderhoof paragneisses to the northwest (Fig. 4). The inferred extension direction (parallel to stretching lineations in the Nulki shear zone) bisects the strike of the Nulki shear zone and the east trending extensional features and is consistent with a single extensional tectonic phase (Fig. 4).

Tatuk valley

In the east-trending Tatuk valley, flat-lying Miocene Chilcotin basalts overlie Eocene Ootsa Lake Group volcanic rocks which dip between 20 and 70 degrees and contain an east-trending subvertical joint set. North of Finger Lake and south of Tatuk Lake, Hazelton Group volcanic rocks underlie the valley walls and contain the east-trending joint set. In the rocks north of Finger Lake there is extensive alteration and mineralization is localized along these joints, as well as hydro-fractured, east-trending zones containing hematite and minor quartz.

Tilting and joint formation common in the Eocene rocks, in comparison with the Miocene rocks, bracket latest deformation between Eocene and Miocene. Joint-controlled alteration and mineralization in the Hazelton Group, unknown in the Chilcotin Group, are interpreted to be syn- or post-tectonic and Eocene to Miocene.

The formation of Tatuk valley predates Miocene flood basalt volcanism. Tilting of Eocene rocks and valley-parallel joints within them suggests the valley is a tectonic feature (graben?) of Eocene to Miocene age.

Eocene volcanic ridges

Two easterly oriented ridges include Bearhead Hill at the extreme north end of 93F/16 and Brophy's ridge on the north side of the Greer Creek valley in the southwestern corner of 93F/16. In the Greer Creek region, the linear, east-trending Greer Creek valley marks the boundary between the Middle Jurassic? Brooks diorite complex and Eocene volcanic rocks; aeromagnetic anomalies correlative with the diorite extend under the valley and terminate abruptly at the base of the Eocene volcanic ridge (?). This suggests Eocene magmas may have erupted along an easterly oriented fissure? that crosscuts the diorite.

A dilational feature such as a fissure may also represent a down-to-the-north normal fault that offsets the Brooks diorite complex (Fig. 4). Independent evidence for Eocene normal faulting is lacking but Brooks diorite complex fragments in the Eocene conglomerate sequence is supportive of a fault scarp and/or basin being formed in the Eocene. The moderate to steep dips exhibited by the Eocene rocks indicate post-Eocene tectonism.

The Greer Creek valley is a post-Miocene feature as it contains no Chilcotin Group plateau basalt and Greer Creek incises through them in several locations.

CONCLUSIONS

Unmetamorphosed plutonic and volcanic rocks underlie most of the NTS 93F/16 and F/9 map areas and record at least six ages of volcanism and plutonism. Most deformation is interpreted to be Eocene to Eocene-Miocene in age. The rocks at this time were subjected to an extensional stress that was oriented north-northwest and south-southeast with a subhorizontal plunge. This stress resulted in the formation of a low angle ductile shear zone (the Nulki shear zone) that allowed the upper plate (Brooks diorite complex) to slide to the north-northwest off a core complex comprising the Vanderhoof paragneisses and Frank Lake pluton. Later, east-west- oriented brittle faults and fissure volcanism developed which apparently crosscut the ductile Nulki shear zone.

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REFERENCES

- Souther, J.G.**
1991: Volcanic regimes, Chapter 14; in *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 457-490. (also *Geological Society of America, The Geology of North America*, v. G-2).
- Struik, L.C. and McMillan, W.J.**
1996: Nechako Project overview, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 57-62.
- Tipper, H.W.**
1961: Prince George map area, British Columbia; Geological Survey of Canada, Preliminary Map 49-1961.
1963: Nechako River map area, British Columbia; Geological Survey of Canada, Map 1131A.
- Tipper, H.W. and Richards, T.A.**
1976: Jurassic stratigraphy and history of north-central British Columbia; Geological Survey of Canada, Bulletin 270, 73 p.
- Wetherup, S. and Struik, L.C.**
1996: Vanderhoof Metamorphic Complex and surrounding rocks, central British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 63-70.
- Wheeler, J.O. and McFeely, P.**
1991: Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A.
- Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L.**
1991: Plutonic Regimes, Chapter 15; in *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 491-531. (also *Geological Society of America, The Geology of North America*, v. G-2).

Geological Survey of Canada Project 950036

Ice flow and late glacial lakes of the Fraser Glaciation, central British Columbia^{1,2}

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Plouffe, A., 1997: Ice flow and late glacial lakes of the Fraser Glaciation, central British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 133-143.

Abstract: A model for the ice flow history of the last glaciation (Fraser Glaciation) of central British Columbia is presented based on the interpretation of macro- and micro-landforms, and till lithologies. It suggests that ice flow patterns were influenced by three main ice sources: the Coast, Skeena, and Cariboo mountains. In addition, the mapping of glacial lake sediments and glacial landforms, such as meltwater channels, were utilized to reconstruct the glacial lake history. Glacial lakes were dammed in valleys while melting ice blocked the drainage. Water levels in some of these lakes were controlled by meltwater channels cut across drainage divides.

Résumé : Un modèle de l'histoire de l'écoulement glaciaire au cours de la dernière glaciation (Glaciation de Fraser) dans le centre de la Colombie-Britannique est présenté, basé sur l'interprétation de la macrotopographie et de la microtopographie et de la lithologie des tills. Selon ce modèle, trois sources principales de glace ont influencé les modes d'écoulement des glaces : la chaîne Côtière, la chaîne Skeena et la chaîne Cariboo. En outre, la cartographie des sédiments glaciolacustres et des formes glaciaires, tels les chenaux d'eau de fonte, a servi à reconstituer l'histoire des lacs glaciaires. Des lacs glaciaires ont été retenus dans des vallées tandis que de la glace en fusion bloquait l'écoulement des eaux. Le niveau d'eau dans certains de ces lacs a été contrôlé par des chenaux d'eau de fonte traversant les lignes de partage des eaux.

¹ Contribution to the Nechako Plateau NATMAP Project

² Contribution to Canada-British Columbia Agreement on Mineral Development (1991-1995), a subsidiary agreement under the Canada-British Columbia Economic and Regional Development Agreement

INTRODUCTION

Surficial geology mapping as part of the Canada-British Columbia Agreement (1991-1995) and the Nechako Plateau NATMAP Project (1995-2000) as enable the reconstruction of the ice flow and glacial lake histories of the Fraser Glaciation in central British Columbia. The study area for this report is confined to Fort Fraser (93K) and Manson River (93N) map areas (Fig. 1). The ice flow history was reconstructed, in order of importance, from: (1) air photo interpretation of macro-landforms oriented parallel to ice flow direction (flutings, crag-and-tails, drumlins), (2) measurements of glacial striae and grooves on bedrock outcrops, and (3) the study of till lithologies. The type of ice retreat and the extent and evolution of retreat phase glacial lakes were determined from air photo interpretation and field identification of surficial sediments and glacial landforms such as meltwater channels and moraines.

PHYSIOGRAPHY

The study area is divided into four major physiographic subdivisions (Holland, 1976) (Fig. 2): (1) the Omineca Mountains consists of a high relief region with peaks, arêtes, cirques, and U-shaped valleys; (2) the Rocky Mountain Trench is a relatively flat area with an average elevation of ca. 750 m; (3) the Nechako Plateau is characterized by rolling topography and rounded hills; and (4) the Fraser Basin is generally more flat and lower than the Nechako Lowland.

Most of the major rivers drain to the east except Sutherland River which flows into Babine Lake which empties to the west into Skeena River drainage (Fig. 1, 2).

PREVIOUS STUDY

Ice flow history

Maps depicting ice flow patterns for central British Columbia were presented by Armstrong and Tipper (1948) and Tipper (1971a, b). Essentially, these authors suggested that piedmont glaciers, derived from three high elevation accumulation zones (Coast, Skeena, and Cariboo mountains), developed into major ice lobes which coalesced over the central interior. The model was derived from air photo interpretation and the authors could not suggest a relative chronology for the ice advance from the major source areas. More recently, Plouffe (1991), Ryder and Maynard (1991), and Ryder et al. (1991) published small-scale maps with more detailed ice flow patterns which agree with a multi-source model for the last glaciation of this region.

Late glacial lake system

A glacial lake system, informally named "glacial lake Fraser" (Clague, 1987), developed as a result of the ice damming of the Fraser River drainage during the retreat phase of the Fraser Glaciation (Fulton, 1965; Shaw, 1975; Clague, 1988; Eyles and Clague, 1991). Despite all the work that has been



Figure 1. Location of study area with some major physiographic subdivisions. The Rocky Mountain Trench is shaded.

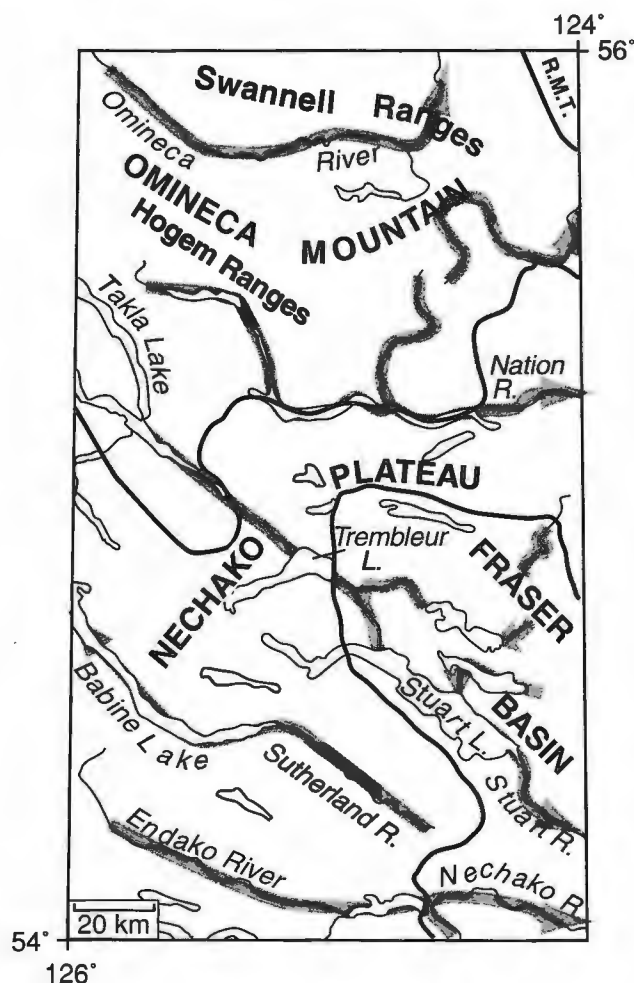


Figure 2. Physiographic subdivisions; boundaries are shown with heavy lines (after Holland, 1976). R.M.T.-Rocky Mountain Trench. Grey arrows represent drainage direction.

completed on this late glacial lake and its sediments, and because of its great extent, the location of the ice and/or sediment dams, along with the position of the outlets that controlled the lake levels are still unclear. In addition, the northwestern extent of this glacial lake system was still ambiguous because of the remoteness of this area.

FRASER GLACIATION – ICE FLOW HISTORY

Macro-landforms

The orientation of drumlins, crag-and-tails, and flutings identified on air photographs shows the dominant ice flow directions which prevailed during the last glaciation (Fig. 3). Because of the small scale of Figure 3, each depicted symbol represents a group of landforms. No evidence of nunataks, such as moraine ridges around mountain peaks, has been identified. Drumlins have been found close to mountain summits at elevations of up to 1800 m in the Hogen Ranges and these landforms parallel drumlins located at lower elevations in the Omineca valley.

The orientation of the macro-landforms demonstrate that the major sources of ice were located in the Skeena and Coast mountains, and only in the eastern sector was there a deflection of ice flow to the northeast which resulted from the influence of northerly flowing ice derived from the Cariboo Mountains (Fig. 3). The dominant ice flow parallel to the valleys and the absence of nunataks indicate that ice completely covered the higher peaks, but was not thick enough to flow independently of topography. Although the macro-landforms' orientations illustrate the regional ice flow patterns, they only represent a moment in time during the last glaciation and do not show shift of ice flow directions. Their orientation could represent ice flow directions at the climax of the last glaciation because landforms in the valleys parallel the ones at higher elevation.

Micro-landforms

Bedrock striae have been measured at a total of 130 sites (Fig. 4). Striated outcrop surfaces are rare because (1) over large regions, thick deposits of unconsolidated sediments conceal the bedrock surface, and (2) some lithologies are poorly indurated, deeply weathered, or jointed so that bedrock surfaces polished by glaciers are not well preserved. Striae were generally found to be parallel to the regional macro-landforms including drumlins measured at an elevation of 1800 m in the Hogen Ranges. Some striated sites record more than one ice flow direction and the chronology of ice movements could be established from truncated surfaces or the presence of striae on the stoss side of larger grooves.

Shift in ice flow direction as determined from glacial striae can be related to ice build up, that is, as the glacier got thicker it was able to flow above obstacles rather than around them. However, in two regions, the shift in ice flow directions was thought to reflect the chronology of ice advances from the major source regions. To the west of NTS 93K map area boundary, in the lower portion of Maxan valley (Fig. 4, 5),

striae have a general orientation northwest-southeast, i.e. subparallel to the valley. Rat tails and striae predominantly on the stoss side of outcrops indicate that the glacier was generally flowing to the southeast. Drumlins and glacial lineations east of Maxan Lake, also record this ice movement (Tipper, 1994) (Note: The preliminary interpretation of glacial landforms in Maxan valley by Tipper (1994) has been slightly modified following field work and air photo interpretation). At several sites in the valley, east-west striae have been measured, and according to the crosscutting relationship of one site, the east-west movement is younger than the movement to the southeast. The glacier movement to the east corresponds to the regional ice flow pattern as revealed by macro-landforms (Plouffe, 1991; Tipper, 1994). This chronology suggests that the first ice to have reached Maxan valley (flow to southeast) was most likely derived from the southern portion of the Skeena or Hazelton mountains because these mountains with cirques are the closest to the Maxan valley (Fig. 6). This first movement was followed by a regional ice flow, generally to the east, which had its source in the Coast Mountains.

North of Stuart Lake, in the Pinchi Lake area, east-west glacial grooves and striae are transected by northeast-southwest striae (Fig. 4). This chronology of ice movement suggests that easterly flowing ice from the Coast Mountains was the first to invade the area and was subsequently deflected to the northeast by the Cariboo Mountains ice lobe (Fig. 6).

Till lithologies

Pebbles in the 4-16 mm size range separated from till samples were classified into broad lithological categories that could be linked to provenance areas so that the till lithologies could indicate direction of glacial transport. The use of till lithologies as an indicator of regional ice flow direction is constrained by: (1) the scale of available bedrock geology maps which depict large lithological units with abundant internal variability, (2) the persistent thick cover of unconsolidated sediments which limits bedrock mapping accuracy, and (3) the proper identification of bedrock lithological units in the 4-16 mm clast size range (Plouffe, 1995). Despite those limitations, where contrasting bedrock lithologies have been mapped, till lithologies indicate glacial transport in the same direction as the macro-landforms (see examples in Plouffe, 1995).

Within Maxan valley, two till samples collected at different levels on a 5 m high exposure reveal contrasting lithological composition. The greater abundance of acid intrusive rocks in the lower portion of the till could be linked to the first ice movement to the southeast, as the only intrusive bedrock is located north-northwest of the valley (Tipper et al., 1979). More recent bedrock mapping being conducted in this region as part of the Nechako Plateau NATMAP Project (Struik and MacIntyre, 1997) will help to better interpret the till lithologies.

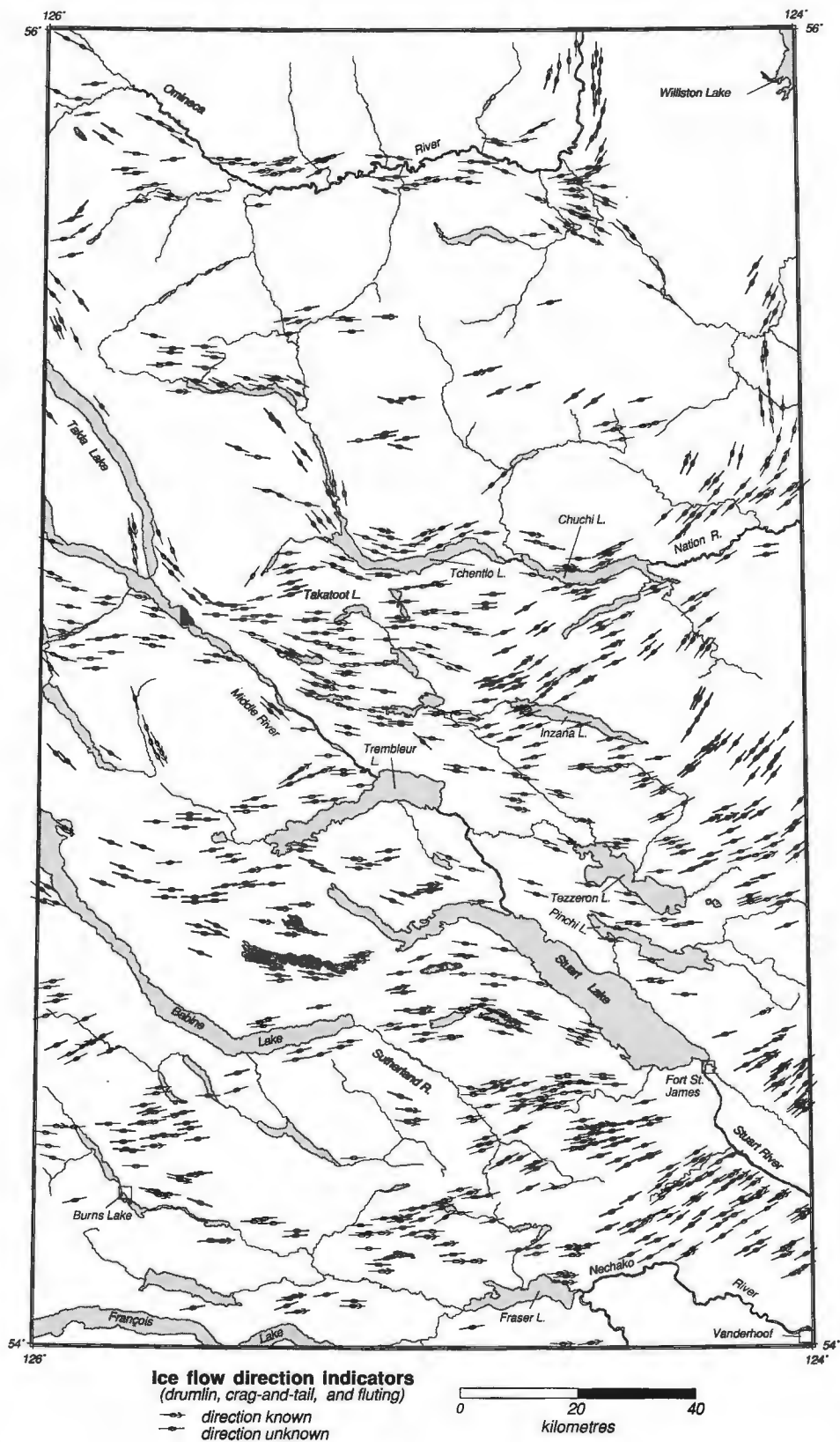


Figure 3. Ice flow direction indicators: macro-landforms.

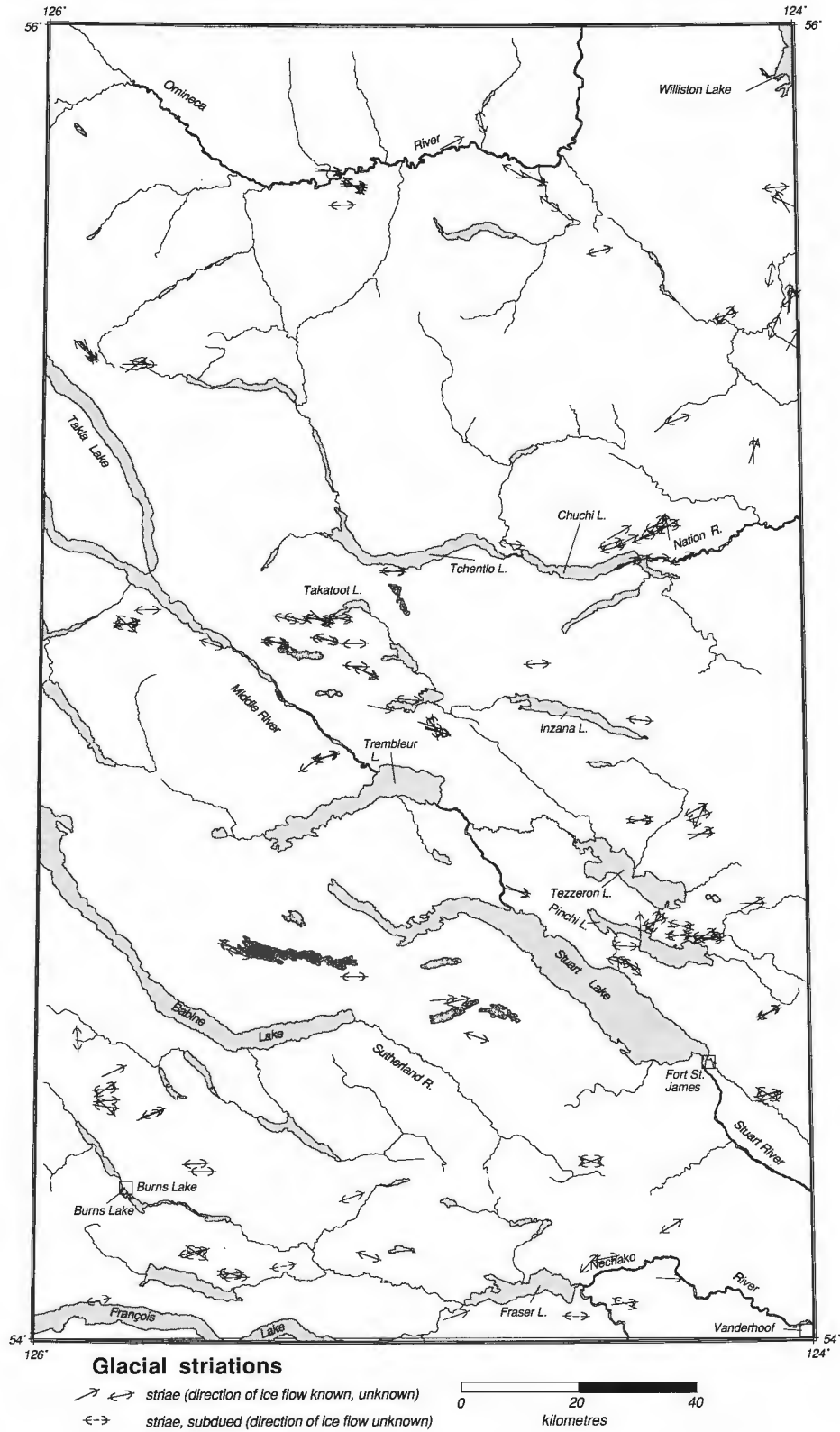


Figure 4. Ice flow direction indicators: glacial striae.

FRASER GLACIATION – LATE GLACIAL LAKE SYSTEM

A series of glacial lakes have formed in some of the valleys of the area, during the waning phase of the Fraser Glaciation, as retreating ice and/or sediments blocked the drainage. These are referred to here as late glacial lakes (as opposed to lake) because of the notable influence of ice on sedimentation in these basins.

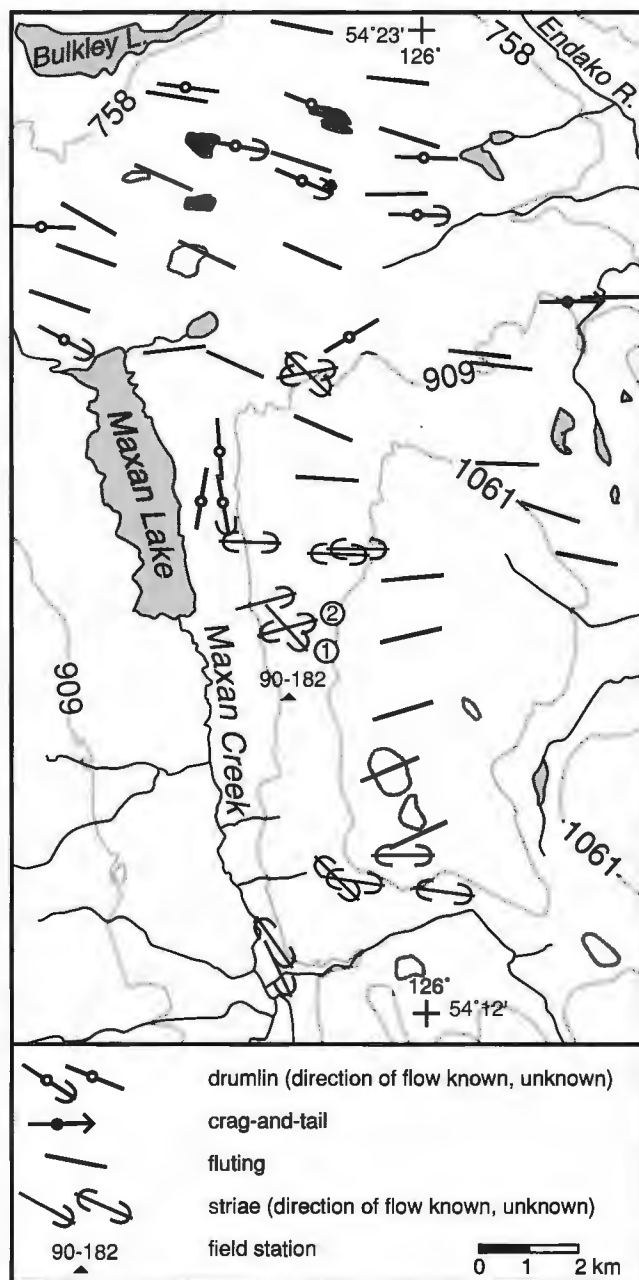


Figure 5. Ice flow direction indicators of the Maxan valley. Contours in metres (converted from feet). Drumlins, crag-and-tails, and flutings modified from Tipper (1994) and Plouffe (1996b). Chronology of ice movement indicated with numbers: 1-first, 2-second.

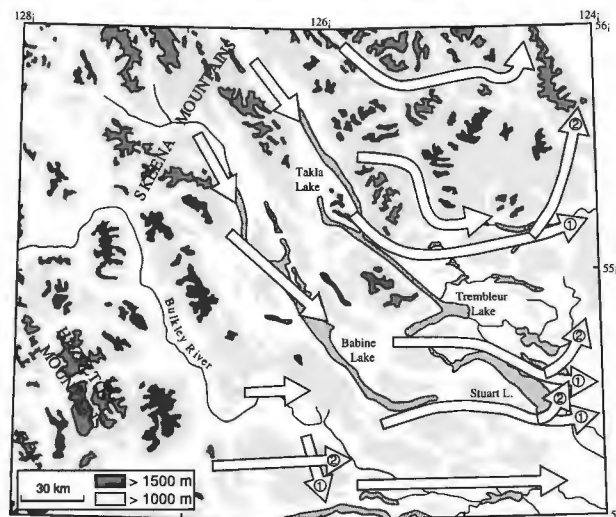


Figure 6. Regional ice flow patterns. Chronology of ice movements is indicated where appropriate. C.M. – Coast Mountains.

Glaciolacustrine sediments: description, distribution and interpretation

Glaciolacustrine sediments deposited at the end of the Fraser Glaciation have been identified in several of the valleys of the area (Fig. 7). The maximum elevation at which glacial lake sediments were found in each of these basins was determined using 1:50 000 scale topographic map sheets and an altimeter.

Rhythmites composed of fine sand, silt and clay couplets are the most prevalent glacial lake sediments (Fig. 8, 9). Cross- and planar-laminations, fining and coarsening upward cycles, and massive beds are common sedimentary structures of the coarser layers of the rhythmites. Dropstones have been identified in several exposures. The couplets generally fine and thin up-section and at the best exposures, in the Nechako River and Takla Lake valleys, their maximum number reaches between 25 and 32. However, in the Kuzkwa River valley, up to 45 couplets have been counted. Nevertheless, bioturbation in the upper parts of sections prevent an exact count of the couplets. The rhythmites were found to be mostly horizontal, but in some localities they are tilted or folded (Fig. 9). In addition, these fine-grained sediments are found in close association with stratified sand and gravel with diamicton and clay interbeds.

No glacial lake strandline was identified probably because (1) the glacial lakes were of short duration, (2) the most prominent sediment reworked by the waves, a clayey till, was not easily eroded, (3) the water level in these basins, controlled by one or more outlets, might have fluctuated widely throughout the life span of the glacial lake, and (4) the forest cover hampers the identification of any subtle shoreline bench. Therefore, without well defined strandlines, no iso-bases were constructed.

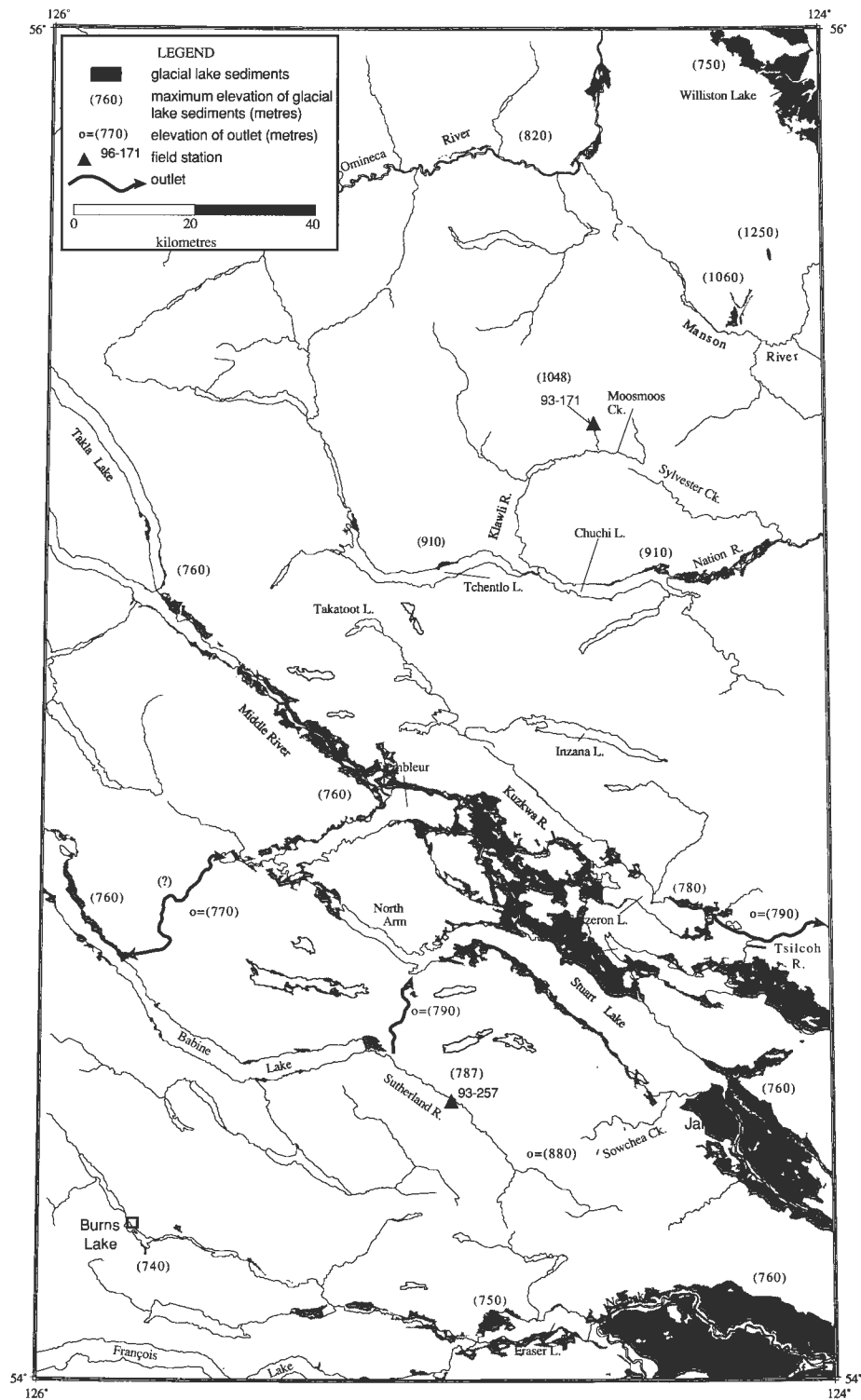


Figure 7. Maximum elevation of fine-grained glacial lake sediments and glacial lake outlets.

Interpretation

The fine-grained rhythmites were deposited distally from the glacier snout or any major meltstream that was entering the glacial lake basin. Based on sedimentological characteristics of the rhythmites and correlation of similar sediments in the Fraser River valley they can be interpreted as varves (Fulton, 1965; Smith and Ashley, 1985; Eyles and Clague, 1991; Plouffe, 1991). If their interpretation as varves is correct, it indicates that the glacial lake(s) probably lasted at least 32 years in the Nechako River and Takla Lake valleys and



Figure 8. Looking west at glaciolacustrine sediments south of Fraser Lake. Note the thinning upward of the silt layers.

possibly more than 45 years in the Kuzkwa valley. The coarser sand and gravel was deposited in proximity to ice, possibly as subaqueous fans or as deltas, in places where meltstreams loaded with sediments entered the glacial lake basin. Post- and syn-depositional deformations in the glacial lake deposits indicate that sedimentation took place, at least locally, on dead ice.

Deglaciation and glacial lake history

The mode of deglaciation greatly influenced the development of glacial lakes. The presence of lateral moraines in proximity to cirques suggests that frontal retreat solely occurred in the mountainous regions (Ryder, 1994; Plouffe, 1996a). On the other hand, at lower elevation, abundant meltwater channels cut diagonally across hill sides are thought to have been eroded by meltwater which flowed along the margin of ice tongues located in the valleys (see maps of Plouffe, 1994a,b, 1996a,b,c,d; in press a,b). In other words, while the uplands were deglaciated, ice tongues remained in the valleys. This pattern of deglaciation disrupted the drainage and glacial lakes developed in trunk and tributary valleys as they were ponded by melting ice. A similar mode of deglaciation has been described in the southern portion of British Columbia (Fulton, 1967, 1975).

The maximum elevations of fine-grained glacial lake sediments depicted in Figure 7 represent the minimum elevation of the highest phase of each glacial lake, because no sedimentation of fine-grained sediments took place above the wave base. Therefore, the controlling outlet of a glacial lake has to be located above the maximum elevation of the glacial lake sediments. The following glacial lake history was reconstructed by linking the maximum elevation of glacial lake sediments with most plausible controlling outlets such as drainage divides or meltwater channels, and by using a down-wasting deglaciation scenario as suggested by the glacial



Figure 9. Looking north at folded glaciolacustrine sediments exposed along Kuzkwa River. Total section height: 12 m.

landforms. It presents the major glacial lakes that formed during deglaciation; smaller lakes, which developed in the upland areas and for which data are limited, are not discussed.

Manson River area

The highest glacial lake sediments that have been mapped in the area are located in two tributary valleys of Manson River (Fig. 7). They are thought to be amongst the first glacial lakes to have formed in the area, i.e. they developed at a time when ice in the Manson River valley was thick enough to allow damming of lakes at elevations of 1250 and 1060 m. No clear outlets have been identified for these lakes; they might have drained subglacially and/or along the ice margin.

Omineca River and Rocky Mountain Trench

The glacial lake sediments in the Omineca River valley (820 m) might have been deposited in a glacial lake that was connected with one in the Williston Lake valley which had strandlines at 855, 820, and 710 m (Rutter, 1977). However, such a connection remains to be proven as no surficial mapping was completed north of the study area in the Omineca River valley and mapping conducted in the Williston Lake valley as part of this project identified glacial lake sediments at a maximum elevation of 750 m (Fig. 7). The water level in the glacial lake of Williston Lake valley, and possibly Omineca River valley, was controlled by ice and/or sediment damming of Peace River (see Rutter, 1977; Mathews, 1980; Bobrowsky, 1989).

Valleys of Nation and Klawli rivers

Farther south, in the Klawli River valley, scarce evidence of glacial lake sediments has been found on natural bluffs at a maximum elevation of 1048 m (Fig. 7, 10, and Plouffe, 1992). The extent of this glacial lake(s) is still unclear. It might have been dammed by ice in the Chuchi Lake valley and its outlet could have been through Moosmoos and Sylvester creeks (Fig. 7). More field work is required in this region to better define its extent.

In the Tchentlo Lake, Chuchi Lake, and Nation River valleys, glacial lake sediments mapped at up to 910 m (Plouffe, 1994a) were most likely deposited in a glacial lake which was probably not connected with the glacial lake of the Williston Lake valley. Indeed, the glacial lake sediments in Nation River valley, at up to 910 m, are above the highest strandline identified in the Williston Lake area (855 m; Rutter, 1977). Furthermore, Kerr (1991) did not map glacial lake sediments in the Nation River valley east of the study area. Therefore, this glacial lake which seems to have been of short duration (ca. 10 years; Plouffe, 1992) was probably controlled by an ice and/or sediment dam in the Nation River valley.

Westward drainage to Skeena River

Two glacial lake levels have been identified in the Babine Lake and Sutherland River valleys. The highest exposure of glacial lake sediments found in the Sutherland River valley,

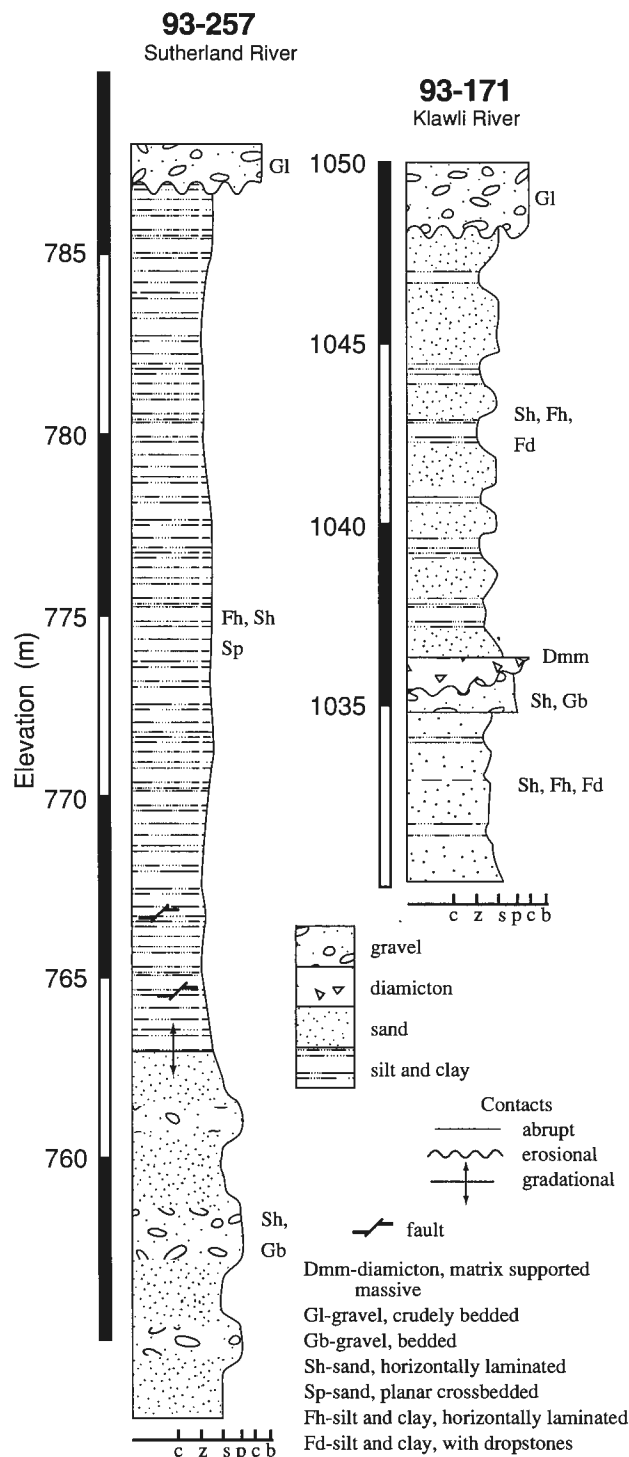


Figure 10. Stratigraphic column of glacial lake sediments in Klawli River and Sutherland River valleys (see Fig. 7 for locations). The sediments exposed at these sections have been interpreted as glacial lake deposits except for the upper gravels which were deposited during a fluvial or glaciofluvial aggradation period prior to the incision of the sediment pile.

at 787 m, is linked to the higher one (Fig. 7). This glacial lake, informally referred to as "glacial lake Sutherland", was most likely dammed by ice located in the Babine Lake valley and it overflowed through a meltwater channel cut across the drainage divide, at 790 m, between the east end of Babine Lake and North Arm of Stuart Lake (Fig. 7) (see map Plouffe, 1996a). It is unlikely that its controlling outlet was a meltwater channel at the drainage divide, at 880 m, between Sutherland River and Sowchea Creek (see map Plouffe, 1996c). However, an earlier phase of glacial lake Sutherland might have been confined in the upper Sutherland River valley when ice was still present in the Babine Lake and lower Sutherland River valleys. More field work would be required in this remote region to test this hypothesis. In the Babine Lake valley, glacial lake sediments which occur at a maximum elevation of 760 m (Huntley et al., 1996; Plouffe, 1996a,b; Stumpf et al., 1996), were deposited in a glacial lake, informally named "glacial lake Babine" (Huntley et al., 1996), that developed because of the blockage of the westward drainage. If it is assumed that the ice present in the Skeena Mountains was thick enough to block any possible westward drainage at the time of existence of glacial lake Babine, the controlling outlet of glacial lake Babine was a meltwater channel cut across the divide between Babine and Trembleur lakes, at 770 m (Fig. 7). On the other hand, if the westward drainage was only partly blocked by ice and/or sediments during existence of glacial lake Babine, the meltwater channel at 770 m between Babine and Trembleur lakes could have been an outlet of the glacial lake which occupied Stuart Lake valley.

Eastward drainage

The Tezzeron Lake region, with glacial lake sediments mapped at up to 780 m, was probably deglaciated prior to the Stuart Lake valley. Damming of the westward outlet of Tezzeron Lake resulted in the development of a glacial lake with a minimum elevation of 780 m (Fig. 7), which is informally named "glacial lake Tezzeron". It overflowed to the east through meltwater channels at the east end of Tezzeron Lake (Plouffe, 1994b) which were connected farther east to the Tsilcoh River (Fig. 7). Following further deglaciation, a regional glacial lake inundated all valleys connected to the Fraser River drainage. This glacial lake was likely connected to the east, at least for some time, with glacial lake Fraser (Clague, 1981, 1987, 1988; Eyles and Clague, 1991).

Most of the valleys that were inundated contain glacial lake sediments to a maximum elevation of 760 m (Fig. 7) with the exception of the Burns Lake and Fraser Lake areas with glacial lake sediments up to 740 m and 750 m, respectively. The occurrence of glacial lake sediments at lower elevations towards the west could indicate (1) differential isostatic uplift with a component of rise to the east and north (compare data from Burns Lake, west end of Fraser Lake, Nechako River area, and Takla Lake in Fig. 7) and/or (2) that during a higher phase of glacial lake Fraser, Burns Lake and Fraser Lake valleys were still occupied by ice and by the time these regions were deglaciated, glacial lake Fraser had dropped, as its level was controlled by lower outlets.

Chronology

The glacial lakes chronology is known with a very limited degree of precision. Because of the lack of datable organic matter in late glacial and postglacial sediments, no numerical dating is yet available on the inception of the glacial lakes. By 9.5-10 ka valleys and plateaus of the interior of British Columbia were ice free (Clague, 1981) which suggests that by that time, all glacial lakes were drained with possibly, local water ponding behind sediment dams. This is in accordance with the oldest postglacial date available in the study area, on marl in the Omineca River valley: $10\ 100 \pm 90$ years BP (GSC-2036; Alley and Young, 1978).

CONCLUSIONS

The reconstruction of the ice flow history of the last glaciation of central British Columbia, based on interpretation of macro- and micro-landforms and till lithologies, demonstrates that there were three major sources of ice which influenced ice flow patterns.

The distribution and maximum elevation of glacial lake sediments along with the identification of meltwater channels were used to reconstruct the glacial lake history of the study area. It suggests that, at least for the plateau and lowland areas, deglaciation took place predominantly by ice downwasting with the higher ground being deglaciated first. Glacial lakes were dammed in valleys while melting ice was blocking the drainage. A few moraines found in proximity to some cirques might indicate that frontal retreat occurred in the highest mountainous areas.

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REFERENCES

- Alley, N.F. and Young, G.K.
1978: Environmental significance of geomorphic processes in the northern Skeena Mountains and southern Stikine Plateau; British Columbia Ministry of the Environment, Resource Analysis Branch, Bulletin 3, 83 p.
- Armstrong, J.E. and Tipper, H.W.
1948: Glaciation in north central British Columbia; American Journal of Science, v. 246, p. 283-310.
- Bobrowsky, P.T.
1989: Late Cenozoic geology of the northern Rocky Mountain Trench, British Columbia; Ph.D. thesis, University of Alberta, Edmonton, Alberta, 463 p.
- Clague, J.J.
1981: Late Quaternary geology and geochronology of British Columbia, Part 2: Summary and discussion of radiocarbon-dated Quaternary history; Geological Survey of Canada, Paper 80-35, p. 40.
1987: Quaternary stratigraphy and history, Williams Lake, British Columbia; Canadian Journal of Earth Sciences, v. 24, p. 147-158.

Clague, J.J. (cont.)

- 1988: Quaternary stratigraphy and history, Quesnel, British Columbia; *Géographie physique et Quaternaire*, v. 42, p. 279-288.

Eyles, N. and Clague, J.J.

- 1991: Glaciolacustrine sedimentation during advance and retreat of the Cordilleran Ice Sheet in central British Columbia; *Géographie physique et Quaternaire*, v. 45, p. 317-331.

Fulton, R.J.

- 1965: Silt deposition in late-glacial lakes of southern British Columbia; *American Journal of Science*, v. 263, p. 553-570.
- 1967: Deglaciation studies in Kamloops region, an area of moderate relief, British Columbia.; Geological Survey of Canada, Bulletin 154, 36 p.
- 1975: Quaternary geology and geomorphology, Nicola-Vernon area, British Columbia (82 L W 1/2 and 92 I E 1/2); Geological Survey of Canada, Memoir 380, 50 p.

Holland, S.S.

- 1976: Landforms of British Columbia, a physiographic outline; British Columbia Department of Mines and Petroleum Resources, Bulletin 48, p. 138.

Huntley, D.H., Stumpf, A., Levson, V.M. and Broster, B.E.

- 1996: Babine Porphyry Belt Project: Quaternary geology and regional till geochemistry sampling in the Old Fort Mountain (93M/01) and Fulton Lake (93L/16) map areas, British Columbia; in *Geological Fieldwork 1995*, (ed.) B. Grant and J. M. Newell; British Columbia Ministry of Energy Mines and Petroleum Resources, Paper 1996-1, p. 45-53.

Kerr, D.E.

- 1991: Surficial geology of the Mount Milligan area, NTS 93N/1A, 93O/4A; British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1991-7, scale 1:50 000.

Mathews, W.H.

- 1980: Retreat of the last ice sheets in northeastern British Columbia and adjacent Alberta; Geological Survey of Canada, Bulletin 331, 22 p.

Plouffe, A.

- 1991: Preliminary study of the Quaternary geology of the northern interior of British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 91-1A, p. 7-13.
- 1992: Quaternary stratigraphy and history of central British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 92-1A, p. 189-193.
- 1994a: Surficial geology, Chuchi Lake, British Columbia (93N/SE); Geological Survey of Canada, Open File 2842, scale 1:100 000.
- 1994b: Surficial geology, Tezzeron Lake, British Columbia (93K/NE); Geological Survey of Canada, Open File 2846, scale 1:100 000.
- 1995: Geochemistry, lithology, mineralogy and visible gold grain content of till in the Manson River and Fort Fraser map areas, central British Columbia (NTS 93K and N); Geological Survey of Canada, Open File 3194, 119 p.
- 1996a: Surficial geology, Cunningham Lake, British Columbia (93K/NW); Geological Survey of Canada, Open File 3183, scale 1:100 000.
- 1996b: Surficial geology, Burns Lake, British Columbia (9K/SW); Geological Survey of Canada, Open File 3184, scale 1:100 000.
- 1996c: Surficial geology, Fraser Lake, British Columbia (93K/SE); Geological Survey of Canada, Open File 3182, scale 1:100 000.
- 1996d: Surficial geology, Tsayta Lake, British Columbia (93N/SW); Geological Survey of Canada, Open File 3071, scale 1:100 000.

Plouffe, A. (cont.)

- in press a: Surficial geology, Germansen Lake, British Columbia (NTS 93N/NE); Geological Survey of Canada, Open File 3312, scale 1:100 000.

- in press b: Surficial geology, Humphrey Lake, British Columbia (NTS 93N/NW); Geological Survey of Canada, Open File 3313, scale 1:100 000.

Rutter, N.W.

- 1977: Multiple Glaciation in the area of Williston Lake, British Columbia; Geological Survey of Canada, Bulletin 273, 31 p.

Ryder, J.M.

- 1994: Stuart-Takla watersheds: terrain and sediment sources; British Columbia Ministry of Forests, Prince George Forest Region, internal report, 26 p.

Ryder, J.M. and Maynard, D.

- 1991: The Cordilleran Ice Sheet in northern British Columbia; *Géographie physique et Quaternaire*, v. 45, p. 355-363.

Ryder, J.M., Fulton, R.J., and Clague, J.J.

- 1991: The Cordilleran Ice Sheet and the glacial geomorphology of southern and central British Columbia; *Géographie physique et Quaternaire*, v. 45, p. 365-377.

Shaw, J.

- 1975: Sedimentary successions in Pleistocene ice-marginal lakes; in *Glaciofluvial and Glaciolacustrine Sedimentation*, (ed.) A.V. Jopling and B.C. McDonald; Society of Economic Paleontologists and Mineralogists, Special Publication 23, p. 281-203.

Smith, N.D. and Ashley, G.

- 1985: Chapter 4. Proglacial lacustrine environment; in *Glacial Sedimentary Environments*, (ed.) G.M. Ashley, J. Shaw, and N.D. Smith; Society of Paleontologists and Mineralogists, Short Course No. 16, Tulsa, p. 135-216.

Struik, L.C. and MacIntyre, D.

- 1997: Nechako Plateau NATMAP project overview, central British Columbia, year two; in *Current Research 1997-A*; Geological Survey of Canada.

Stumpf, A.J., Huntley, D.H., Broster, B.E., and Levson, V.M.

- 1996: Babine Porphyry Belt Project: detailed drift exploration studies in the Old Fort Mountain (93M/01) and Fulton Lake (93L/16) map areas, British Columbia; in *Geological Fieldwork 1995*, (ed.) B. Grant and J.M. Newell; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1996-1, p. 37-44.

Tipper, H.W.

- 1971a: Glacial geomorphology and Pleistocene history of central British Columbia; Geological Survey of Canada, Bulletin 196, 89 p.
- 1971b: Multiple glaciation in central British Columbia; *Canadian Journal of Earth Sciences*, v. 8, p. 743-752.
- 1994: Preliminary interpretation of glacial and geomorphic features of Smithers map area (93L), British Columbia; Geological Survey of Canada, Open File 2837, 7 p.

Tipper, H.W., Campbell, R.B., Taylor, G.C., and Stott, D.F.

- 1979: Parsnip River; Geological Survey of Canada, Map 1424A, scale 1:1 000 000.

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Anatomy of the Neoproterozoic-Palaeozoic continental margin, Vernon map area, British Columbia

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Abstract: The (Lower Paleozoic?) Tsalkom, Sicamous, and Eagle Bay formations are in stratigraphic sequence and represent a relatively local volcanic-carbonate-volcanic assemblage within a basin that extended over much of what is now Vernon map area (82L). These formations stratigraphically overlie Neoproterozoic quartzofeldspathic schist and micaceous quartzite.

Contact between the Tsalkom and Sicamous formations is a mixed gradation. These formations change facies (northwestward) to carbonaceous clastic rocks that were previously assigned to the exotic Quesnel Terrane. Therefore, the boundary separating exotic rocks from those that were part of the North American continental terrace wedge requires redefinition.

At least one fault cutting the Sicamous and Eagle Bay formations is a reactivated growth fault.

The succession of micaceous and calcareous rocks south and west of Queest Mountain is more typical of the Neoproterozoic quartzofeldspathic metasedimentary succession rather than the Eagle Bay Formation.

Résumé : Les formations de Tsalkom, de Sicamous et d'Eagle Bay (Paléozoïque inférieur?) se trouvent dans une séquence stratigraphique et représentent un assemblage relativement local de roches volcaniques-roches carbonatées-roches volcaniques accumulées dans un bassin qui couvrait la grande partie de ce qui est actuellement la région cartographique de Vernon (82L). Ces formations sont stratigraphiquement sus-jacentes à un schiste quartzofeldspathique et un quartzite micacé du Néoprotérozoïque.

Le contact entre les formations de Tsalkom et de Sicamous est une zone de passage mixte. Ces formations changent de faciès vers le nord-ouest, passant à des roches clastiques carbonées que l'on avait attribuées auparavant au terrane allochtone de Quesnel. Aussi, la limite séparant les roches allochtones des roches qui faisaient partie du biseau de sédiments de la terrasse continentale de l'Amérique du Nord doit-elle être redéfinie.

Au moins une des failles coupant les formations de Sicamous et d'Eagle Bay est une faille synsédimentaire réactivée.

La succession de roches micacées et calcaires qui repose au sud et à l'ouest du mont Queest est plus typique de la succession métasédimentaire quartzofeldspathique du Néoprotérozoïque que la Formation d'Eagle Bay.

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INTRODUCTION

Fieldwork in 1996 focused on the Shuswap Lake region between the towns of Sicamous and Chase (Fig. 1) in north-western Vernon map area (82L). The purpose was threefold: 1) to assess the nature of the contact between miogeoclinal, quartzofeldspathic mica schist and gneiss (Silver Creek Formation of Jones, 1959) of probable Neoproterozoic age; and overlying carbonaceous clastic, carbonate, and volcanogenic eugeoclinal strata (Tsalkom, Sicamous, and Eagle Bay formations of Jones, 1959) of probable Palaeozoic age; 2) to study internal stratigraphic relations within the eugeoclinal rocks; and 3) to assess the potential for stratigraphic correlation of these eugeoclinal rocks with clastic rocks to the west (unit 13 of Jones, 1959) which have been previously included within the exotic Quesnel Terrane (Monger et al., 1991).

REGIONAL CONTEXT

Eugeoclinal rocks, known variously as Roberts Mountains allochthon, Kootenay-Yukon/Tanana- or Nisling-terrane (or parts therein), extend from central Nevada and southern Idaho, through British Columbia and Yukon to eastern Alaska before reversing trend southward as a narrow strip within the Coast Mountains of British Columbia and southern Alaska (e.g., Gehrels et al., 1991; Mihalynuk et al., 1994). These rocks may be as old as Neoproterozoic and as young as Early Mesozoic; they consist primarily of low- to moderate-grade metamorphosed clastic and volcanic rocks, some carbonate, occasional mature quartz sandstone, local conglomerate, and immature grit sandstone. Unlike the miogeoclinal succession, wherein formations can be traced along strike for hundreds of kilometres (or more), continuity of lithostratigraphy within the eugeoclinal succession is less pronounced, indicative perhaps of a more varied paleogeography. Isotopic signatures (Sr, Nd/Sr) are consistent with deposition on crustal lithosphere typical of the North American craton. Similarly, detrital zircon ages from units within both miogeoclinal and eugeoclinal rocks record an age spectrum from 3.0 Ga to 750 Ma, strong evidence that these grains were derived, ultimately, from a contiguous North American craton (Canadian Shield) or "block" of craton (Gehrels et al., 1995).

Vernon map area (82L) sits astride the stratigraphic and structural boundaries interpreted to separate miogeoclinal from eugeoclinal rocks, and eugeoclinal from rocks that are exotic with respect to the North American craton margin – volcanic arc related clastic and volcanic assemblages such as Quesnel Terrane (and subterrane therein), and volcanic and clastic rocks of ocean floor affinity known collectively as Slide Mountain Terrane. Not surprisingly, the location and nature of the boundaries separating miogeoclinal from eugeoclinal from exotic rocks are less apparent and more open to reinterpretation as the scale of observation decreases from compilation scale (e.g., 1:2 000 000; Wheeler et al., 1991) to field mapping scale (1:50 000). We present evidence to suggest that eugeoclinal rocks stratigraphically overlie miogeoclinal strata, that they were deposited into one or more marginal basins superimposed on what had been a relatively

stable Eocambrian shelf prior to "the bottom dropping out" from beneath the outer portion of the craton margin early in Cambrian time, and that they include strata previously interpreted as exotic.

The Early Cambrian heralded a profound change in the lithostratigraphic character of craton margin sedimentation, from deposition of mature clastics derived from the craton that prograded onto a shallow water marine shelf, to a more complex and segmented carbonate shelf/reef edge/shale basin regime that received little clastic input from the craton. This change in depositional character is reflected, structurally, as half grabens formed in response to craton margin extension and concomitant subsidence during Early Cambrian time (Bond and Kominz, 1984; Lickorish and Simony, 1995). In Vernon map area, the most distal exposed portion of the old craton margin sedimentary succession, this period of crustal extension is reflected in the change from miogeoclinal quartz-rich strata, to carbonaceous and associated volcanic strata.

The term "eugeoclinal rocks" used here and applied to south-central British Columbia, denotes the mainly fine-grained carbonaceous succession of metamorphosed shale, siltstone, and volcanogenic rocks of Palaeozoic age. They include the Lardeau Group, the Milford Formation, and the Tsalkom, Sicamous, and Eagle Bay formations.

The miogeoclinal and eugeoclinal assemblages exposed in Vernon map area are viewed as autochthonous with respect to the ancient North American margin, that is, they were linked depositionally to it. This approach is at odds with recent interpretations (e.g., Monger et al., 1991 and references therein) that describe eugeosynclinal assemblages (including those in Vernon map area) as pericratonic, that is, "... (as having) occupied unknown or uncertain paleogeographic positions with respect to each other and with the ancient western margin of cratonic North America (Monger et al., 1991, p. 283)". The rocks were grouped into a separate terrane called Kootenay. The terrane map (Map 1713A, Wheeler et al., 1991) defines the boundaries of Kootenay Terrane to include not only the Upper Paleozoic and Lower Mesozoic clastic and volcanic assemblages referred to above, but the older Lower and Middle Paleozoic eugeoclinal successions together with a vast region of micaceous quartzite, quartzofeldspathic schist, and paragneiss – a higher metamorphic grade central core – called the Shuswap Metamorphic Complex (Selkirk Allochthon and Monashee Complex) much of which is thought to represent metamorphosed litho- and time-stratigraphic equivalents of the Neoproterozoic and Eocambrian succession (Windermere and Hamill groups) that are now exposed within folds and thrust slices farther to the east. This definition of Kootenay Terrane blurs the important distinction between miogeoclinal and eugeoclinal lithofacies and does not take into account recent data that suggest a depositional and therefore physical stratigraphic linkage between these rocks and the continental terrace wedge farther east (Colpron and Price, 1995). For this reason we have decided not to use the term Kootenay Terrane, preferring instead to describe the distribution and character of miogeoclinal facies relative to eugeoclinal facies, accepting that they were part of a physically continuous assemblage deposited across a heterogeneously thinned craton margin.

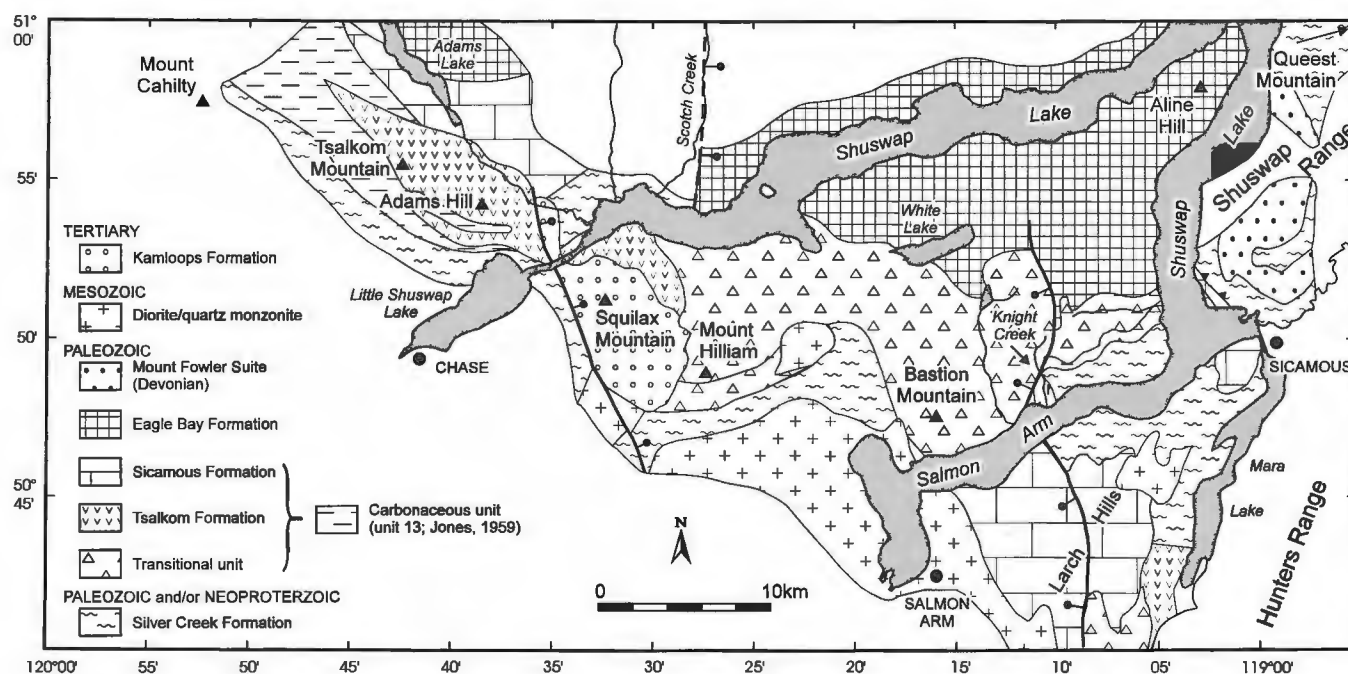


Figure 1. Generalized geological map of the Shuswap Lake area.

Within Vernon and adjacent Lardeau map areas there are two belts of eugeoclinal strata. Lardeau Group (Palaeozoic) and Milford Formation (Carboniferous) form a narrow concave west arc extending from north of the town of Revelstoke southward along the axis of Kootenay Lake and into the United States; the second belt is represented by the Tsalkom, Sicamous, and Eagle Bay formations which outcrop throughout the Shuswap Lake region between the towns of Sicamous and Chase (Fig. 1), as well as unnamed strata (units 13, 14, and 15 of Jones, 1959) that form an outcrop belt that extends from Mt. Cahilly at the northwestern limits of Vernon map area, south-southeast to the town of Vernon and thence eastward, within a structural low, to near Upper Arrow Lake (Read, 1979; Carr, 1990; Thompson and Daughtry, 1996b). Separating these two belts of eugeoclinal rocks is an elevated and elongate metamorphic core, the Shuswap Metamorphic Complex, which is stratigraphic basement to eugeoclinal strata and consists of pelitic schist, quartzite, paragneiss, and orthogneiss interpreted here and by others to form at least part of the Neoproterozoic and Eocambrian miogeoclinal succession (e.g., Johnson, 1990). Fortunately, the structural low described above, transverse to the strike of the metamorphic core, preserves portions of the eugeoclinal succession and provides a physical stratigraphic link between eugeoclinal rocks on the west, in the western half of Vernon map area, with those farther east belonging to the Lardeau Group.

Detrital zircons (abraded multicycle as well as euhedral first-cycle populations) recovered from Proterozoic and Palaeozoic strata (Horsethief Creek Group, Hamill Group, Ajax Formation, Broadview Formation, Covada Group) range in age from 2.7 to 1.76 Ga (Smith and Gehrels, 1991), results consistent with derivation from three sources: from miogeoclinal and/or lower Palaeozoic eugeoclinal units, from

adjacent portions of the North American craton, and from an adjacent "outboard" crustal block(s) (Thompson and Daughtry, 1996a). Detrital zircons from immature clastic strata of Permian age at the southern end of Kootenay Arc (Mt. Roberts Formation) contain two populations: abraded, multicycle grains between 2.72 and 1.0 Ga; and euhedral, first cycle grains between 0.40 and 0.37 Ga (Roback et al., 1994; Roback and Walker, 1995). The latter are locally derived, evidence that Devonian age plutonic/gneissic rocks were emergent during the Permian.

At least some Lower Paleozoic eugeoclinal strata were deformed and metamorphosed prior to deposition of overlapping conglomerates of Early Mississippian age (Milford Group; Wheeler, 1970). Earliest Mississippian deformation is well documented farther south in Nevada where the eugeoclinal assemblage was thrust (Roberts Mountains allochthon) onto miogeoclinal rocks accompanied by deposition of a synorogenic clastic wedge (overlap assemblage) (e.g., Johnson and Pendergast, 1981). In Vernon map area, the case for at least pre-Late Triassic deformation has been presented by Read and Okulitch (1977). Farther north, the case for Devonian age contractional deformation is moot (e.g., Sutherland Brown, 1963; Struik, 1981).

DISTINCTION BETWEEN MIOGEOCLINAL AND EUGEOCLINAL ASSEMBLAGES

There is a fundamental upward change in lithostratigraphy in Vernon map area (Thompson and Daughtry, 1996b) from quartz- and feldspar-rich lithologies including micaceous quartzite, schist, paragneiss, and orthogneiss, to carbonaceous, often

volcanogenic, lithologies such as metamorphosed shale and mudstone, phyllite, and greenstone. The former are most typical of the Neoproterozoic and Eocambrian Windermere and Hamill groups whereas the latter are typical of the Lower Paleozoic Lardeau Group, the Triassic Slocan Formation, and the eastern facies belt belonging to the Nicola Group. The boundary separating one from the other occurs within the transitional facies (Fig. 1) that separates micaceous quartz- and feldspar-rich schists from overlying greenstone (Tsalkom Formation), carbonate (Sicamous Formation), or metamorphosed shale (map unit 13 of Jones, 1959).

Contact between miogeoclinal and eugeoclinal successions

The distinction between miogeoclinal and eugeoclinal successions in northwestern Vernon map area (Fig. 1) is based on a fundamental change in lithostratigraphic composition from (older) quartzose pelite, micaceous quartzite, paragneiss, and carbonate/calc-silicate rocks to (younger) carbonaceous clastic rocks, carbonaceous limestone, and volcanic rocks. In terms of local stratigraphic nomenclature this change occurs at the top of the Silver Creek Formation (Jones, 1959) where it gives way either to the carbonaceous limestone of the Sicamous Formation or phyllite and greenstone belonging to the Tsalkom Formation.

In detail the change from miogeoclinal lithologies to eugeoclinal lithologies is transitional both vertically and laterally. Near Bastion Mountain, on the north shore of Salmon Arm (Fig. 1), there is an upward transition, estimated at 100 to 200 m thick, from quartzose muscovite-biotite-garnet schist (Silver Creek Formation of Jones, 1959) through a calcareous schist, calcareous and micaceous quartzite, and siliceous limestone into carbonaceous limestone belonging to the Sicamous Formation. The transitional succession also contains layers of amphibolitic schist, marble, and carbonaceous schist. In the Bastion Mountain area Jones (1959) mapped a unit called the Mara Formation beneath the Sicamous Formation. Like Okulitch (1979), we have discontinued using this formation, confident at this locality that it represents the Silver Creek Formation of Jones (1959) and/or the transition between Silver Creek and overlying Sicamous Formation. Farther west, the Silver Creek and Sicamous formations are separated by a greenstone and phyllite succession called the Tsalkom Formation (Jones, 1959), however greenstone typical of the Tsalkom is not present here.

West of Bastion Mountain, along the south flank of Mt. Hilliam (Fig. 1), the stratigraphic transition from Silver Creek to Sicamous formations constitutes a relatively thick succession of black carbonaceous phyllitic schist, carbonaceous limestone, some micaceous quartzite and pelite, and intercalations of greenstone up to a few metres thick. The proportion of black limestone increases upward and eventually gives rise to argillaceous limestone belonging to the Sicamous Formation. Here, the transitional unit is a few hundred metres thick at least and is interpreted to be a dominantly clastic facies that was deposited adjacent to and interfingering with the Tsalkom Formation – a volcanic and

volcaniclastic succession that can be traced from Mount Hilliam, along the northern flank of Squilax Mountain to form the bulk of Adams Hill and Tsalkom Mountain.

On the western flanks of Adams Hill, Tsalkom Mountain, and Bruhn Ridge, the contact between miogeoclinal (Silver Creek) and eugeoclinal (Tsalkom Formation) strata is not exposed, however the basal unit of the Tsalkom Formation is a black metamorphosed shale and clastic succession about 100 m thick that is overlain, in turn, by massive greenstone.

Closer to Mt. Cahilty, the transition from miogeoclinal to eugeoclinal strata consists of a mixed gradation of lithologies that includes fine-grained black phyllitic argillite, carbonaceous quartzite, brown muscovite-biotite schist, recrystallized limestone, and volcanic tuff. The upward progression is to increasingly thick units of black, phyllitic rocks. It is a zone a few hundred metres thick (at least) and is, perhaps, the clearest indication of a fundamental change in stratigraphic character from shallow marine quartz-rich sands and silts of Eocambrian age (Hamill Formation?) to carbonaceous, fine-grained rocks typical of a starved depositional basin.

Lithostratigraphic relations within the eugeoclinal succession

The Tsalkom Formation represents a relatively local volcanic edifice centred in and around Adams Hill and Tsalkom Mountain. To the northwest, on Bruhn Ridge, the stratigraphic edge of the volcanic pile is enveloped by carbonaceous clastic rocks belonging to Jones' map unit 13 (1959). Similarly, to the southeast, along the southern flank of Mt. Hilliam, only a few thin volcanic members occur within a predominantly clastic succession. There is no evidence of Tsalkom Formation volcanic rocks in the Bastion Mountain area or farther north at Scotch Creek. Tsalkom volcanic rocks, at least greenstones at the same stratigraphic level, do reappear between Mara Lake and Grindrod on both sides of the North Okanagan Valley (Thompson and Daughtry, 1996b).

The Sicamous Formation, though more areally extensive than the Tsalkom, changes facies in a northwesterly direction as well becoming increasingly more argillaceous until it too passes laterally into carbonaceous phyllite belonging to map unit 13 of Jones (1959) between Mt. Cahilty and Adams Lake. This transition is best seen along the northeast flank of Bruhn Ridge. There, carbonaceous limestone units, a few metres to a few tens of metres thick, occur within thicker units of black, phyllitic rocks. Along strike to the northwest, at the edge of the map area, the same interval lacks limestone.

We suggest the Sicamous Formation was a relatively small carbonate platform built on a local "basement high" within a much larger, deeper water basin in which fine clastic and volcanic rocks are dominant. Consequently, the Sicamous Formation may not extend much beyond the limits of north-central Vernon map area.

In summary, both the volcanic Tsalkom Formation and the limestone Sicamous Formation change facies toward the northwest to carbonaceous clastic rocks (Jones, 1959; unit 13).

Recognition of syndepositional growth faults

At least one and possibly other syndepositional growth faults affected the thickness and lithostratigraphy of the Sicamous Formation and possibly the Eagle Bay Formation.

A steep fault that trends north from Knight Creek on the north side of Salmon Arm (of Shuswap Lake) into the Larch Hills on the south side of the Arm, is the locus of a significant change in thickness of the Sicamous Formation. On the west or Bastion Mountain side of the fault, the Sicamous Formation is at least 1500 m thick where it forms the sheer cliffs adjacent to the lake; on the east side of Knight Creek, the Sicamous Formation is perhaps 300 m thick. Basal contact of the Formation forms a steep, west-dipping ramp that was subsequently offset by later movement along the fault. South of Salmon Arm a similar thickness change occurs from west to east, across the Larch Hills. Later west-side-down motion across the fault has obscured original geometric relationships.

A significant change in internal facies is reported within the Eagle Bay Formation at Scotch Creek. Although no new fieldwork was undertaken there, we speculate that Scotch Creek may also be the locus of a syndepositional growth fault affecting depositional patterns within the Eagle Bay Formation.

Implications with respect to terrane definition

Previous interpretations suggested that the "Cache Creek Group" of Jones (1959; map units 13 through 15) is part of an exotic terrane (Harper Ranch and or Okanagan subterrane within Quesnel Terrane) accreted to the North American cratonic margin early in Mesozoic time (Monger et al., 1991). Our results support an alternative view, that Jones' (1959) units 13 through 15 are part of a eugeoclinal basin assemblage that included the Tsalkom, Sicamous, and Eagle Bay formations. Remnants of units 13 through 15 extend to the southwest quadrant of Vernon map area as well as across its southern half. We think the basin was significantly larger than Vernon map area and was probably linked physically with Palaeozoic age successions farther east, successions such as the Lardeau Group.

We also note Jones' (1959) reference to the Chapperon Group as having physical affinity with the Eagle Bay Formation: "The Chapperon group consists of a mixed assemblage of sedimentary and volcanic rocks that closely resemble those of the Eagle Bay formation in lithology, general mutual association, and metamorphism." (p. 27). It would seem that the Chapperon group is a prime candidate for correlation with units within the eugeoclinal assemblage discussed above rather than assigning it to the exotic Quesnel Terrane.

STRATIGRAPHY SOUTH OF QUEEST MOUNT IN THE SHUSWAP RANGE

Except for a small outcrop area of Sicamous limestone and Eagle Bay greenstone/phyllite at the southernmost limit of the Shuswap Range, Jones (1959) mapped this area as the northward continuation of schists and gneisses he called Monashee

Group. Later, Okulitch (1979) and more recently Johnson (1990) assigned rocks in the area to the Eagle Bay Formation. There are three dominant lithologies: quartzite, micaceous quartzite, and siliceous schist; marble, recrystallized limestone, and calc-silicate schist; and moderately to strongly foliated diorite. The quartzite and schist succession is typical of the Silver Creek Formation. Black-weathering, biotite rich schists strongly resemble biotite schist elsewhere in the Silver Creek Formation and along the eastern margin of Mara Lake (meta-amphibolite of Johnson, 1990). The calc-silicate schist and marble are also typical of the Silver Creek Formation as well as schist and gneiss making up parts of the Hunters Range. The foliated granitoid unit is part of the Devonian Mount Fowler Batholith (Okulitch et al., 1975; Okulitch, 1985). We observe no similarity between these rocks and those belonging to the Eagle Bay Formation west of Shuswap Lake, between White Lake and Aline Hill on Figure 1, where the dominant lithologies are green chloritic phyllite, greenstone, and carbonaceous phyllite with a thin, white marble a few metres to tens of metres thick.

We suggest, as an alternative interpretation, that much of the Shuswap Range is underlain by rocks belonging to a miogeoclinal basement which is dominated by quartz-rich lithologies. These rocks were thrust southward over younger Sicamous and Eagle Bay formations along an offset extension of the Birk Creek (Thrust) Fault (or similar fault) mapped by Schiarizza and Preto (1987) to the northwest, either side of Adams Lake (southern Adams Lake map area, 82M W1/2). Although we show a short thrust fault segment on Figure 1, to illustrate our interpretation, regional structural interpretation will require additional field observations.

CONCLUSIONS

We conclude that Neoproterozoic and Eocambrian miogeoclinal rocks extended across Vernon map area to near its western limit. Over most of the western part of the map area they are represented by the quartz- and feldspar-rich schists of the Silver Creek Formation (Jones, 1959). A eugeoclinal assemblage represented by carbonaceous fine-grained metamorphosed shale and siltstone (map unit 13 of Jones, 1959), and the tripartite volcanic-limestone-volcanic succession represented by the Tsalkom, Sicamous, and Eagle Bay formations, conformably overlies the miogeoclinal rocks. This profound change in lithostratigraphic character is inferred to coincide with the period of Eocambrian crustal extension documented farther east (Bond and Kominz, 1984; Lickorish and Simony, 1995). Segmentation of the outer reaches of the ancestral North American continental margin led to small carbonate platforms, like the Sicamous Formation, within a more complex basin that included deeper-water shale/siliciclastic troughs and volcanic edifices like the Tsalkom Formation.

This stratigraphic interpretation implies that rocks, previously thought to be exotic and part of Quesnel Terrane are, in fact, part of North American craton margin stratigraphy. Precise definition and description of what is "exotic" from what is "not exotic" remains outstanding.

Assignment of the rocks underlying the Shuswap Ranges to the miogeoclinal succession rather than the eugeoclinal Eagle Bay Formation, suggests that definition of the Eagle Bay Formation requires additional constraint. We think Jones' (1959) definition restricting the unit to greenstones, chloritic and carbonaceous phyllites with occasional carbonate, and quartzite marker horizons is preferable. Much of what Okulitch (1979), Schiarizza and Preto (1987), and Johnson (1990) assigned to the Eagle Bay Formation belongs, in our opinion, to the older (Windermere and/or Hamill groups) miogeoclinal assemblage.

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REFERENCES

- Bond, G.C. and Kominz, M.A.**
1984: Construction of tectonic subsidence curves for the early Palaeozoic miogeocline, southern Canadian Rocky Mountains: implications for subsidence mechanisms, age of breakup, and crustal thinning; *Canadian Journal of Earth Sciences*, v. 95, p. 155-173.
- Carr, S.D.**
1990: Late Cretaceous-Early Tertiary tectonic evolution of the southern Omineca Belt, Canadian Cordillera; Ph.D. thesis, Carleton University, Ottawa, Ontario, 223 p.
- Colpron, M. and Price, R.A.**
1995: Tectonic significance of the Kootenay terrane, southeastern Canadian Cordillera: an alternative model; *Geology*, v. 23, no. 1, p. 25-28.
- Gehrels, G.E., Dickinson, W.R., Ross, G.M., Stewart, J.H., and Howell, D.G.**
1995: Detrital zircon reference for Cambrian to Triassic miogeoclinal strata of western North America; *Geology*, v. 23, no. 9, p. 831-834.
- Gehrels, G.E., McClelland, W.C., Scott, D., and Patchett, P.J.**
1991: U-Pb geochronology of detrital zircons from a continental margin assemblage in the northern Coast Mountains, southeastern Alaska; *Canadian Journal of Earth Sciences*, v. 28, p. 1285-1300.
- Johnson, B.J.**
1990: Geology adjacent to the western margin of the Shuswap Metamorphic Complex; Province of British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1990-30, 15 p.
- Johnson, J.G. and Pendergast, A.**
1981: Timing and mode of emplacement of the Roberts Mountains allochthon, Antler Orogeny; *Geological Society of America Bulletin*, Part 1, v. 92, p. 648-658.
- Jones, A.G.**
1959: Vernon map-area, British Columbia; Geological Survey of Canada, Memoir 296, 186 p.
- Lickorish, W.H. and Simony, P.S.**
1995: Evidence for late rifting of the Cordilleran margin outlined by stratigraphic division of the Lower Cambrian Gog Group, Rocky Mountain Ranges, British Columbia and Alberta; *Canadian Journal of Earth Sciences*, v. 32, p. 860-874.
- Mihalynuk, M.G., Nelson, J., and Diakow, L.J.**
1994: Cache Creek Terrane entrapment: oroclinal paradox within the Canadian Cordillera; *Tectonics*, v. 13, p. 575-595.
- Monger, J.W.H., Wheeler, J.O., Tipper, H.W., Gabrielse, H., Harms, T., Struik, L.C., Campbell, R.B., Dodds, C.J., Gehrels, G.E., and O'Brien, J.**
1991: Part B. Cordilleran terranes; in *Upper Devonian to Middle Jurassic assemblages*, Chapter 8 of *Geology of the Cordilleran Orogen in Canada*, (ed.) H. Gabrielse and C.J. Yorath; Geological Survey of Canada, *Geology of Canada*, no. 4, p. 281-327 (also *Geological Society of America, The Geology of North America*, v. G-2).
- Okulitch, A.V.**
1979: Lithology, stratigraphy, structure and mineral occurrences of the Thompson-Shuswap-Okanagan area, British Columbia; Geological Survey of Canada, Open File 637.
1985: Paleozoic plutonism in southeastern British Columbia; *Canadian Journal of Earth Sciences*, v. 22, p. 1409-1424.
- Okulitch, A.V., Wanless, R.K., and Loveridge, W.D.**
1975: Devonian plutonism in south-central British Columbia; *Canadian Journal of Earth Sciences*, v. 12, p. 1760-1769.
- Read, P.B.**
1979: Geology and mineral deposits, eastern part of Vernon east-half map-area; Geological Survey of Canada, Open File 658.
- Read, P.B. and Okulitch, A.V.**
1977: The Triassic unconformity of south-central British Columbia; *Canadian Journal of Earth Sciences*, v. 14, p. 606-638.
- Roback, R.C. and Walker, N.W.**
1995: Provenance, detrital zircon U-Pb geochronometry, and tectonic significance of Permian to Lower Triassic sandstone in southeastern Quesnellia, British Columbia and Washington; *Geological Society of America, Bulletin*, v. 107, p. 665-675.
- Roback, R.C., Sevigny, J.H., and Walker, N.W.**
1994: Tectonic setting of the Slide Mountain terrane, southern British Columbia; *Tectonics*, v. 13, no. 5, p. 1242-1258.
- Schiarizza, P. and Preto, V.A.**
1987: Geology of the Adams Plateau-Clearwater-Vavenby area; Province of British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Survey Branch, Paper 1987-2.
- Smith, M.T. and Gehrels, G.E.**
1991: Detrital zircon geochronology of Upper Proterozoic to lower Palaeozoic continental margin strata of the Kootenay Arc: implications for the early Palaeozoic tectonic development of the eastern Canadian Cordillera; *Canadian Journal of Earth Sciences*, v. 28, p. 1271-1284.
- Struik, L.C.**
1981: A re-examination of the type area of the Devonian-Mississippian Cariboo Orogeny, central British Columbia; *Canadian Journal of Earth Sciences*, v. 18, p. 1767-1775.
- Sutherland Brown, A.**
1963: Geology of the Cariboo River area, British Columbia; British Columbia Department of Mines and Petroleum Resources, Bulletin 47.
- Thompson, R.I. and Daughtry, K.L.**
1996a: Kootenay Terrane: Yukon-Tanana analogues in British Columbia?; Abstract, Cordilleran Mineral Exploration Roundup, Vancouver, British Columbia, January, 1996.
1996b: New stratigraphic and tectonic interpretations, north Okanagan Valley, British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 135-141.
- Wheeler, J.O. (ed.)**
1970: Summary and Discussion; in *Structure of the Southern Canadian Cordillera*; Geological Association of Canada, Special Paper No. 6, p. 155-166.
- Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W., and Woodsworth, G.J. (comp.)**
1991: Terrane Map of the Canadian Cordillera; Geological Survey of Canada, Map 1713A, scale 1:2 000 000.

Geological Survey of Canada Project 930036

Revised stratigraphy of the Pasayten Group, Manning Park, British Columbia

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Kiessling, M.A. and Mahoney, J.B., 1997: Revised stratigraphy of the Pasayten Group, Manning Park, British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 151-158.

Abstract: The Upper Cretaceous Pasayten Group in Manning Park is subdivided into three lithological units. These units include, in ascending order: 1) Winthrop Formation, a thick succession of trough cross-stratified micaceous feldspathic arenite with interbedded argillite; 2) Ventura Member of the Midnight Peak Formation, a thin, red succession of volcanic sandstone, conglomerate, and mudstone; and 3) the conglomerate of Hampton Creek, a succession of chert-lithic sandstone and chert pebble conglomerate. This subdivision approximately corresponds to the map-units defined by Coates in 1974, but this description more accurately reflects regional stratigraphic relationships. The Winthrop Formation in Manning Park conformably overlies the Jackass Mountain Group, and includes a prominent plutonic cobble conglomerate near its base that had been previously assigned to the Jackass Mountain Group.

Résumé : Le Groupe de Pasayten du Crétacé supérieur dans le parc Manning est subdivisé en trois unités lithologiques, soit, par ordre ascendant : 1) la Formation de Winthrop, épaisse succession de feldsparénite micacée à stratification oblique en auge et à interstratifications d'argilite; le Membre de Ventura de la Formation de Midnight Peak, mince succession rougeâtre de grès, de conglomérat et de mudstone volcaniques; et 3) le conglomérat de Hampton Creek, succession de grès à débris de chert et de conglomérat à cailloux de chert. Cette subdivision correspond approximativement aux unités cartographiques définies par Coates en 1974, mais cette description reflète avec plus de précision les relations stratigraphiques régionales. La Formation de Winthrop dans le parc Manning repose en concordance sur le Groupe de Jackass Mountain et comprend un conglomérat proéminent à galets plutoniques près de sa base qu'on avait attribué auparavant au Groupe de Jackass Mountain.

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INTRODUCTION

The provenance, depositional environment, and paleogeographic setting of Upper Cretaceous clastic strata of the Methow terrane are important to resolving the ongoing debate over large scale latitudinal displacements of major segments of the Canadian Cordillera (Cowan, 1994; Wynne et al., 1995; Irving et al., 1995, 1996; Monger and Price, 1996). The Methow terrane is situated in the eastern Coast Belt, along the eastern margin of the Insular superterrane, and is separated from rocks of the Intermontane superterrane to the east by the Pasayten fault (Fig. 1). Paleomagnetic data suggest 1800 to 2000 km of relative motion occurred between the Insular and Intermontane superterrane between 83–45 Ma (Wynne et al., 1995; Irving et al., 1995, 1996). Conversely, geological data indicate that allochthonous terranes of the Canadian Cordillera were largely amalgamated by mid-Cretaceous time, and have been subject to <1000 km of margin-parallel translation since the Late Cretaceous (Monger et al., 1982; Garver, 1992; Monger and Journeay, 1994; Mahoney, 1994; Monger et al., 1994; Monger and Price, 1996; Umhoefer and Miller, 1996). Stratigraphic investigations suggest Jurassic and Cretaceous strata of the Methow terrane were deposited in a forearc setting adjacent to the western margin of the Intermontane superterrane, although definitive linkages have not been established (Kleinspehn, 1982; Garver, 1992; O'Brien et al., 1992; Mahoney, 1992). Late Cretaceous (ca. 100–90 Ma) stratigraphic ties across the Insular/Intermontane superterrane boundary are critical, because strata deposited prior to 83 Ma on either superterrane cannot have been deposited in the same depositional system if large-scale latitudinal displacement has occurred along the boundary (Cowan, 1994; Mahoney et al., 1996). We have begun a detailed examination of the Upper Cretaceous Pasayten Group in Manning Park in conjunction with a regional investigation of Albian-Cenomanian strata along the Insular/Intermontane superterrane boundary (Mahoney et al., 1996). This report provides the first detailed description of the Pasayten Group in Manning Park, and uses stratigraphy of the group that more accurately portray facies relationships. Documentation of internal facies relations will facilitate comparison with coeval strata of the Tyaughton basin to the north and with rocks at the southern end of the Methow terrane in Washington State.

REGIONAL GEOLOGY

The Methow terrane is dominated by a thick succession of Jurassic and Cretaceous clastic strata that overlie Triassic oceanic basement. The terrane is bounded on the east by the Pasayten fault, which separates it from Mesozoic volcanic and plutonic rocks of Quesnellia, along the western margin of the Intermontane superterrane (Fig. 1). North and east of Manning Park, the western edge of the Intermontane superterrane is dominated by Triassic Nicola Group andesitic volcanic rocks, Jurassic to Cretaceous plutonic rocks of the Eagle Complex, and volcanic rocks of the Cretaceous Spences Bridge Group (Monger, 1989; Monger and Journeay, 1994). The Methow terrane is bounded on the west by the Hozameen

and Yalakom faults, which separate it from oceanic chert, argillite, and volcanic rocks of the Bridge River terrane (Monger, 1989; Monger and Journeay, 1994) (Fig. 1). The Methow and Bridge River terranes were stratigraphically linked by at least middle Albian time (Garver, 1992; Haugerud et al., 1996), and may have been tied together as early as middle to late Jurassic time (Mahoney and Journeay, 1993). The Methow terrane is structurally imbricated with the Bridge River, Cadwallader, and Wrangellia terranes along the Upper

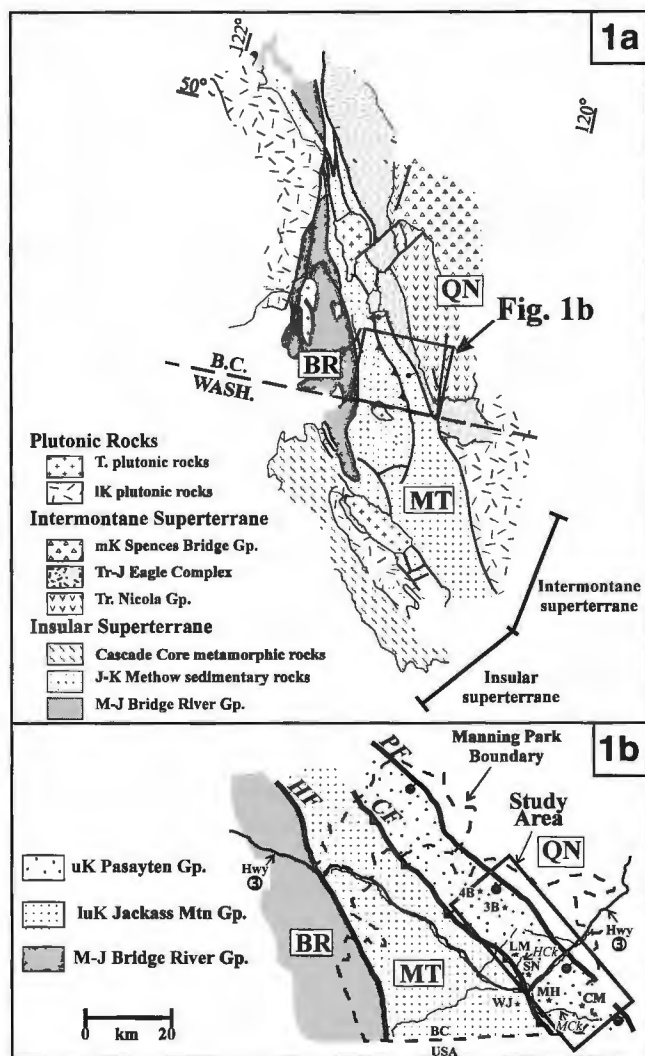


Figure 1a) Schematic geological map of the southern Methow terrane and surrounding region. MT=Methow terrane; BR=Bridge River terrane; QN=Quesnellia. **1b)** Generalized geological location map of Manning Park, with schematic representation of major geological units. Volcanic and plutonic rocks of Quesnellia east of Pasayten fault are unshaded. WJ=Windy Joe Mountain; 4B=Four Brothers Mountain; 3B=Three Brothers Mountain; LM=Lone Man Ridge; SN=Spotted Nellie Ridge; MH=Monument Hill; CM=Chuwanten Mountain; HCK=Hampton Creek; MCK=Monument Creek; PF=Pasayten Fault; HF=Hozameen Fault; CF=Chuwanten Fault.

Cretaceous Coast Belt Thrust System (Journeay and Friedman, 1993), and was therefore definitively tied to the Insular superterrane to the west by 90 Ma.

Methow terrane strata consist primarily of feldspathic sandstone of the Lower to Upper Cretaceous Jackass Mountain Group and the Upper Cretaceous Pasayten Group (Coates, 1974; Monger, 1989) (Fig. 2). The Pasayten Group is a nonmarine succession of sandstone and conglomerate exposed in the footwall of the east-vergent Chuwanten thrust fault; coeval rocks have not been identified in the hanging wall (Coates, 1974) (Fig. 1). The Group is exposed in a northwest-trending fault block that extends from south of the International border to a termination against the Fraser fault system north of Manning Park (Fig. 1).

PREVIOUS WORK

The Pasayten Group was originally defined in Manning Park for an assemblage of nonmarine strata exposed in the eastern half of the park (Daly, 1912; Rice, 1947). Coates (1974) described the group as a sequence of nonmarine sandstone, conglomerate, and mudstone of probable Albian age that overlies marine strata of the Jackass Mountain Group. He divided the Group into three subdivisions, comprising about 3300 m of strata: 1) map-unit 11, dominated by micaceous arkosic sandstone; 2) map-unit 12 (the Red Bed unit), consisting of distinctly red siltstone, sandstone, and conglomerate; and, 3) map-unit 13, weakly indurated, poorly sorted sandstone and conglomerate. He attributed a nonmarine origin to each unit, and hypothesized an eastern source for map-unit 11 and a western source for map-units 12 and 13.

Barksdale (1948, 1975) correlated the Pasayten Group in Manning Park with Upper Cretaceous strata in the Methow Valley of Washington. He subdivided these Upper Cretaceous clastic strata into, in ascending order, the chert-rich Virginian Ridge Formation, the arkosic Winthrop Sandstone, and the volcanic Midnight Peak Formation (Fig. 2). Barksdale (1975) recognized that the Virginian Ridge Formation was not exposed in Manning Park, correlated the Winthrop Sandstone with map-unit 11, and correlated the Ventura Member of the Midnight Peak Formation with map-unit 12. He recognized that there were no strata in Washington directly correlative with map-unit 13.

Cole (1973), Tennyson (1974), and Tennyson and Cole (1978) correlated the Pasayten Group of Manning Park with strata in Washington. The Winthrop Sandstone and the lower member of the Pasayten Group both display northeast to southwest paleocurrents, and are similar petrographically (Cole, 1973). Cole (1973) noted strong lithological similarities between the Ventura member of the Midnight Peak Formation and the middle member of the Pasayten Group (map-unit 12). Tennyson (1974) suggested that the upper member of the Pasayten Group (unit 13 of Coates, 1974) in Manning Park was also correlative with the Ventura Member of the Midnight Peak Formation.

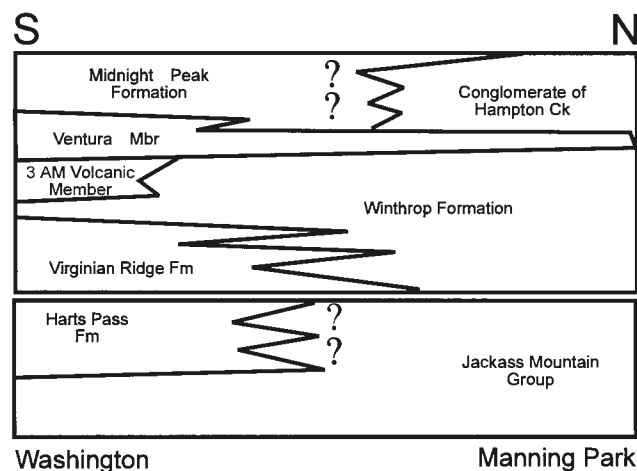


Figure 2. Stratigraphic column of the southern Methow terrane.

Various other workers in the region have referred to rocks of the Pasayten Group as “Winthrop facies” (Monger, 1989), a combination of formations and map-unit numbers (McGroder, 1991), and as Winthrop Formation (Journeay and Monger, 1994). A primary goal of our investigation is a redefinition of the Pasayten Group that will integrate with regional nomenclature and eliminate confusion surrounding the stratigraphic affinity of units within the Pasayten Group (Fig. 2).

STRATIGRAPHY

The stratigraphy of the Pasayten Group in Manning Park has not been described in detail beyond the original work of Coates (1970, 1974). We adopt the three-fold subdivision of Coates (1970, 1974), but revise stratigraphic nomenclature, refine unit descriptions, and define unit boundaries more precisely. We herein subdivide the Pasayten Group into: 1) Winthrop Formation (map-unit 11 of Coates, 1974), a thick succession of trough cross-stratified micaceous feldspathic arenite with interbedded argillite; 2) Ventura Member of the Midnight Peak Formation (map-unit 12 of Coates, 1974), a thin red succession of volcanic sandstone, conglomerate, and mudstone; and 3) the conglomerate of Hampton Creek (map-unit 13 of Coates, 1974), a succession of planar trough cross-stratified chert-lithic sandstone with minor amounts of argillite and chert pebble conglomerate (Fig. 3).

Winthrop Formation

The Winthrop Formation is the basal unit of the Pasayten Group in Manning Park, where it is exposed in a westward dipping monocline in the footwall of the Chuwanten thrust fault (Fig. 1). We adopt this nomenclature following Haugerud et al. (1996), who upgraded the “Winthrop Sandstone” of Washington (Barksdale, 1975) to formation status. The Winthrop Formation in Washington is laterally contiguous with the basal member of the Pasayten Group and therefore directly correlative.

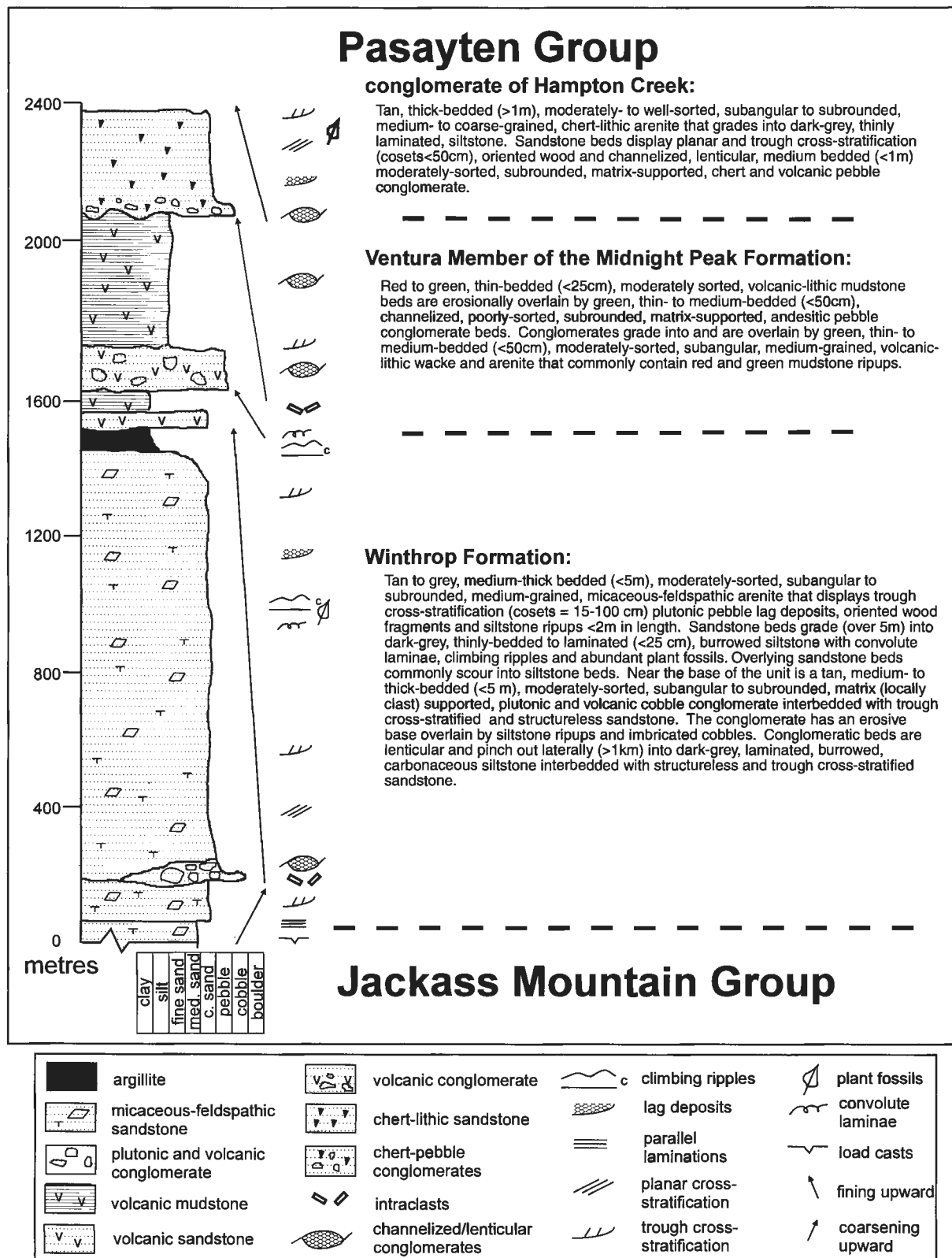


Figure 3. Generalized stratigraphic section of the Pasayten Group in Manning Park.

The Winthrop Formation is conformably underlain by the mid-Cretaceous (Albian?) Jackass Mountain Group and overlain by the Ventura Member of the Midnight Peak Formation (Fig. 3). The Winthrop Formation forms prominent ridges characterized by lichen-covered outcrops. Particularly good exposures occur north of Highway 3 on Spotted Nellie Ridge and south of Highway 3 on the eastern slopes of Chuwanten Mountain (Fig. 1). The Winthrop Formation in Manning Park is 1400 m to perhaps 5000 m thick and consists of micaceous feldspathic arenite intercalated with siltstone and shale. Plutonic cobble conglomerate is locally present near the base. Lateral variations in thickness may be the result of structural duplication, although the recessive nature of fine-grained interbeds and a lack of distinctive marker horizons prohibits detailed structural analysis.

Contact relations

Coates (1974) suggested that the lower contact of the Winthrop Formation be placed above the stratigraphically highest marine strata of the Jackass Mountain Group. The youngest marine strata recognized by Coates (1974) are characterized by the locally abundant Albian ammonite *Hamites*, found within dark shale intercalated with sandstone. Fossiliferous strata are only locally present and do not constitute an easily recognizable lithological boundary. We herein define the base of the Winthrop Formation as the first appearance of trough cross-stratified sandstone above structureless to planar cross-stratified sandstone of the Jackass Mountain Group. South of Three Brothers Mountain, this new definition places 129 m of strata previously recognized as the Jackass Mountain Group into the Winthrop Formation. This reassignment is significant because it places a prominent plutonic and metamorphic cobble conglomerate (map-unit 10 of Coates, 1974) near the base of the Winthrop Formation, instead of at the top of the Jackass Mountain Group. The definition is consistent with the distinction of Coates (1974), as the basal Winthrop contact separates marine strata of the Jackass Mountain Group from fluvial and marginal marine strata of the Winthrop Formation.

The Winthrop Formation gradationally overlies or is in faulted contact with the underlying Jackass Mountain Group. The gradational lower contact of the Winthrop is exposed on Three Brothers Mountain, north of Highway 3 (Fig. 1b). On Three Brothers Mountain, the contact consists of a transition from thin-bedded, structureless, pebbly sandstone intercalated with laminated, burrowed siltstone (Jackass Mountain Group) to trough cross-stratified sandstone interbedded with laminated siltstone (Winthrop Formation). South of Three Brothers Mountain, structureless sandstone of the Jackass Mountain Group is interbedded with and gradationally replaced by trough-cross stratified sandstone of the Winthrop Formation. The trough cross-stratified sandstone is overlain by 40 m of dark grey, laminated, burrowed, carbonaceous siltstone that resembles fine-grained strata of the Jackass Mountain Group, but is placed in the Winthrop Formation due to the occurrence of trough cross-stratification above and below. North of Chuwanten Mountain, the lower contact contains discordant attitudes and slickensides and is interpreted as a fault.

Lithology

The Winthrop Formation is lithologically monotonous, and may be described in terms of two lithofacies (Fig. 3). The majority of the formation is micaceous-feldspathic arenite intercalated with dark grey laminated siltstone to shale. A prominent plutonic cobble conglomerate occurs near the base of the formation in the Three Brothers Mountain area, but this lithofacies has not been identified elsewhere in Manning Park.

The arenite lithofacies contains trough cross-stratified, medium to thick-bedded, medium- to coarse-grained, silica-cemented, micaceous-feldspathic arenite. Sandstones contain about 55% feldspar, 30% quartz, 13% biotite, and 2% muscovite. Near the base of the Winthrop Formation, conglomeratic sandstone contains plutonic and gneiss pebble lags, siltstone rip-up clasts (<50 cm), oriented wood fragments, and rare logs. These beds grade upward into dark grey, thin- to medium-bedded, laminated siltstone with climbing ripples, and convolute laminae. The upper dark-coloured portions of some siltstone beds are intensely bioturbated and contain wood fragments and plant leaf fossils. Trough cross-stratified sandstone and overlying siltstone intervals occur in cyclic successions averaging 5–15 m in thickness. These cyclic successions result in an outcrop pattern characterized by sandstone outcrops separated by areas of non exposure containing distinct dark coloured regolith.

The conglomerate lithofacies at the base of the Winthrop Formation on Three Brothers Mountain consists of approximately 30 m of grey, thick-bedded (<5 m), matrix- to clast-supported conglomerate. Cobbles are about 40% volcanic, 25% plutonic, 20% gneiss, 10% sandstones, and 5–10% vein quartz and intrabasinal mudstone. All conglomeratic beds grade normally into grey, thick-bedded (<5 m), moderately sorted, subangular to subrounded, medium- to coarse-grained, micaceous-feldspathic arenite that contains plutonic and gneiss pebbles. Sandstone beds may display weak trough cross-stratification but more commonly appear structureless.

Lateral and vertical variations

The Winthrop Formation appears to become thicker bedded but finer grained toward the southern margin of Manning Park. The entire formation may be described as a single fining-upward succession, although a coarsening upward succession is locally evident at the base (Fig. 3). In the Three Brothers Mountain area, the Winthrop Formation is 1950 m thick and becomes finer grained upward from matrix-to clast-supported plutonic cobble conglomerate to coarse-grained micaceous feldspathic arenite. On Spotted Nellie Ridge, north of Highway 3, at least 1400 m is exposed, with the basal portion containing <100 m of locally pebbly, trough cross-stratified, micaceous feldspathic arenite that grades upwards into 40 m of dark grey carbonaceous siltstone with local wood fragments. This siltstone interval is overlain by coarse-grained, trough cross-stratified, micaceous feldspathic arenite that probably represents a lateral facies variation of the cobble conglomerate on Three Brothers Mountain. In the southern portion of the park, on and south of Chuwanten Mountain, the Winthrop Formation displays vertical relations similar to those north of Highway 3, but in this area the unit may be as

thick as 5000 m. Although this may represent a depositional thickening, both previous and recent mapping have revealed discordant dips that suggest this unit is over-thickened by faulting and/or folding (Coates, 1974).

Ventura Member of the Midnight Peak Formation

The middle (Red Bed) unit of the Pasayten Group in Manning Park is herein redefined as the Ventura Member of the Midnight Peak Formation (Cole, 1973; Coates, 1974; Tennyson, 1974). The prominent red coloration of the unit, its high volcanic clast content, and its stratigraphic position above the Winthrop Formation support this redefinition, although the unit apparently lacks the chert clast component common in exposures to the south. The volcanic facies of the Midnight Peak Formation is absent in Manning Park (Barksdale, 1975). The Ventura Member weathers recessively, and is poorly exposed except on Spotted Nellie Ridge, Lone Man Ridge, and Monument Hill. In the northern and southern portions of the park, the unit is truncated by east-vergent splays of the Chuwanten fault (Coates, 1974).

Contact relations

The base of the Ventura Member is defined as the first appearance of red, volcanic-lithic mudstone overlying trough cross-stratified feldspathic arenite of the Winthrop Formation. The lower contact is exposed in the hanging wall of a splay of the Chuwanten thrust about 1 km south of Monument Hill and in discontinuous exposures on Spotted Nellie Ridge. South of Monument Hill, the contact is transitional across approximately 50 m, with tan, medium-bedded (<50 cm), micaceous-feldspathic arenite of the Winthrop Formation interbedded with red, thin-bedded mudstone of the Ventura Member. This transitional zone is overlain by about 100 m of mudstone and conglomerate of the Ventura Member. The upper contact of the Ventura Member is a disconformity with the overlying conglomerate of Hampton Creek (see below).

Lithology

The Ventura Member forms a dominantly fine-grained succession of mudstone and volcanic sandstone and conglomerate. The succession comprises two lithofacies: a fine-grained facies and a conglomerate facies (Fig. 3).

The fine-grained facies contains red, thin- to medium-bedded, poorly sorted mudstone intercalated with lesser medium-grained, calcareous volcanic-lithic feldspathic wacke. Mudstone beds commonly contain floating clasts (<2 cm) of white tuff and local cobbles (<15 cm) of fine-grained micaceous feldspathic arenite. Sandstone beds have erosive bases, contain mudstone rip-up clasts, and grade upward to mudstone.

The conglomerate facies forms less than 20% of the Ventura Member. The conglomerate facies consists of red to green, medium- to thick-bedded (<5 m), lenticular, matrix- to clast-supported conglomerate, with maximum clast size of 50 cm and average clast size of 3 cm. The average clast assemblage is 45% volcanic, 28% micaceous feldspathic arenite, 25% mudstone, and 2% quartz, plutonic, and chert clasts. Volcanic

clasts are mostly hornblende plagioclase porphyritic andesites. Lenticular conglomerate beds (<5 m in length) display undulose bases overlain by clast-supported, imbricated pebbles and cobbles that grade normally into volcanic sandstone.

Lithofacies of the Ventura Member are rhythmically interbedded, with 1-10 m mudstone sequences intercalated with 1-1.5 m lenticular conglomerate beds. This interbedding results in an outcrop pattern characterized by resistant conglomerate beds standing in bold relief above recessively weathering red mudstone intervals.

Lateral and vertical variations

The Ventura Member varies from 135 to 477 m thick in Manning Park. The unit displays two coarsening upward successions and appears to increase in thickness but decrease in grain size from south to north. A maximum thickness of 477 m was measured on Lone Man Ridge, where conglomerate comprises <15% of the strata. On Monument Hill, the Ventura Member is 135 m thick, and conglomerate forms >20% of the section. It is uncertain if this thickness variation is depositional, or is the result of structural truncation along splays of the Chuwanten thrust (Fig. 1b).

Conglomerate of Hampton Creek

The conglomerate of Hampton Creek, informally defined here, forms the uppermost unit of the Pasayten Group and comprises the youngest strata in Manning Park. The informal designation reflects our present uncertainty regarding the regional stratigraphic affinity of the unit. The conglomerate of Hampton Creek forms the westernmost beds of the west-dipping monocline in the footwall of the Chuwanten thrust Fault. The unit is underlain by the Ventura Member and the upper portion of the unit is truncated by the Chuwanten Fault. The type section of the unit is on Lone Man Ridge, north of Hampton Creek. The unit is also well exposed on Monument Hill, where it forms prominent cliffs, but the section on Lone Man Ridge is thicker and more easily accessible.

Contact relations

The conglomerate of Hampton Creek disconformably overlies the Ventura Member. The lower contact is best exposed on Monument Hill, where a sharp, erosional contact separates calcareous volcanic lithic arenite, wacke, and conglomerate of the Ventura Member from thick-bedded chert pebble conglomerate and chert lithic arenite of the conglomerate of Hampton Creek. The lower contact coincides with a distinctive zone of iron stained, chert pebble conglomerate and chert-lithic arenite containing calcareous concretions (<10 cm). The upper contact of the conglomerate of Hampton Creek is not exposed due to truncation along the Chuwanten thrust fault.

Lithology

The conglomerate of Hampton Creek is dominated by a chert-lithic sandstone lithofacies that consists of chert lithic sandstone intercalated with chert-pebble conglomerate

(~15%). The sandstone is composed of tan, thin- to medium-bedded, medium- to coarse-grained chert lithic arenite. Isolated chert, and volcanic and plutonic pebbles are locally present. Sandstone beds display trough and planar cross-stratification (cosets ~25 cm) and commonly grade normally (over a distance of 1-2 m) into dark grey, locally laminated, fossiliferous siltstone. Wood fragments are locally concentrated along the base of siltstone and sandstone beds. Lenticular, medium- to thick-bedded, clast-supported conglomerates are intercalated with the chert lithic arenite. The average clast composition is ~50% chert, 35%-40% volcanic and <10% vein quartz, plutonic, and siltstone/shale clasts. Clast-supported conglomerate commonly grades normally (over a distance of <4 m) into matrix-supported conglomerate, with faint trough cross-stratification overlain by trough and planar cross-stratified pebbly sandstones. The conglomerate beds contain sharp basal contacts.

In one locality on Lone Man Ridge, immediately east of Blackwall Peak, the chert-lithic sandstone lithofacies is interbedded with tuffaceous sandstone. Approximately 30 m of red-grey, thin- to medium-bedded tuffaceous sandstone with circular green devitrification spots are present 280 m above the base of the conglomerate of Hampton Creek.

Lateral and vertical variations

The conglomerate of Hampton Creek displays a single fining upward succession throughout Manning Park (Fig. 3). At the type section, the succession fines upward from chert-lithic arenite intercalated with lenticular conglomerate to chert-lithic arenite interbedded with siltstone and minor lenticular conglomerate and tuffaceous sandstone. Similar fining upward successions occur on Spotted Nellie Ridge and Monument Hill.

Lateral thickness variations within the conglomerate of Hampton Creek are obscured due to structural truncation beneath the Chuwanten thrust fault. The maximum thickness observed is 374 m in the type section; the minimum thickness of 173 m occurs on Monument Hill.

AGE OF THE PASAYTEN GROUP

The age of the Pasayten Group is poorly constrained. Coates (1970, 1974) suggested an Albian age for strata within Manning Park based on plant fossil assemblages and an apparent gradational lower contact with Albian *Hamites*-bearing strata. Barksdale (1975) suggested a Cenomanian to possibly Turonian age for the Winthrop Formation in northern Washington based on the occurrence of marine fossils in the underlying Virginian Ridge Formation. The Ventura Member is assumed to be Albian or Cenomanian in age based on the interfingering relationship with the Albian(?) Winthrop Formation (Barksdale, 1975). Coates (1974) suggested an Albian age for the conglomerate of Hampton Creek because he interpreted the units of the Pasayten Group to be internally conformable. Documentation of a disconformity between the Ventura Member and the conglomerate of Hampton Creek suggests that the conglomerate unit could be younger

than previous believed. The Pasayten Group is broadly constrained to be Albian(?) to Turonian(?) in age, based on plant assemblages, underlying marine fauna, and crosscutting Turonian-Coniacian (ca. 90-88 Ma) dykes documented in correlative strata in Washington (Haugerud et al., 1996). Palynological samples have been submitted for more accurate age determinations.

PALEOCURRENTS

Cole (1973) measured oriented wood fragments, foresets, and trough axes from the Winthrop Formation in Washington (n = 201) and the Winthrop Formation and Ventura Member of the Pasayten Group (n = 18) in Manning Park. His data suggested westward transport with vector means of 225° in Washington and 263° in British Columbia. Trough axes, wood fragments, and imbricated pebbles from the Winthrop Formation measured during this study (n = 150) indicate east to west transport, consistent with Cole's (1973) interpretation. Paleocurrents determined from channel axes and imbricated pebble orientation measured in the Ventura Member (n = 23), however, suggest transport was from southwest to northeast. Wood fragments and channel axes from the conglomerate of Hampton Creek (n = 14) suggest that paleocurrents were from west to east.

ONGOING INVESTIGATIONS

This paper presents preliminary results from the 1996 field season. Petrographic, geochemical, isotopic, palynological, and detrital zircon studies are ongoing to document the age, provenance, and depositional setting of the Pasayten Group in Manning Park. Specific questions include:

1. What is the provenance of the volcanoclastic rocks within the Pasayten Group? Isotopic, geochemical and petrographic studies will facilitate correlation of these units with other Upper Cretaceous volcanic assemblages.
2. What is the age of the Pasayten Group? Accurate age determinations are essential for definitive correlations with Mesozoic strata in British Columbia and northern Washington.
3. What is the source area for the Pasayten Group? Petrographic, geochemical, isotopic, and detrital zircon analysis will fingerprint potential source terranes, and detailed paleocurrent analysis will constrain transport directions for each unit.

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REFERENCES

- Barksdale, J.D.**
1948: Stratigraphy in the Methow quadrangle, Washington; Northwest Science, v. 22, p. 164-176.
1975: Geology of the Methow Valley, Okanogan County, Washington; Washington Division of Geology and Earth Resources, Bulletin 68, 72 p.
- Coates, J.A.**
1970: Stratigraphy and structure of Manning Park area, Cascade Mountains, British Columbia; Geological Association of Canada, Special Paper Number 6.
1974: Geology of the Manning Park area, British Columbia; Geological Survey of Canada, Bulletin 238, 177 p.
- Cole, M.R.**
1973: Petrology and dispersal patterns of Jurassic and Cretaceous sedimentary rocks in the Methow River area, North Cascades, Washington; Ph.D. thesis, University of Washington, Seattle, Washington, 110 p.
- Cowan, D.S.**
1994: Alternative hypotheses for the Mid-Cretaceous paleogeography of the Western Cordillera; GSA Today, v. 4, p. 181-186.
- Daly, R.A.**
1912: Geology of the North American Cordillera near the forty-ninth parallel; Geological Survey of Canada, Memoir 38, 857 p.
- Garver, J.I.**
1992: Provenance of Albian-Cenomanian rocks of the Methow and Tyughton basins, southern British Columbia: a mid-Cretaceous link between North America and Insular terranes; Canadian Journal of Earth Sciences, v. 29, p. 1274-1295.
- Haugerud, R.A., Mahoney, J.B., and Dragovich, J.D.**
1996: Geology of the Methow Block; Washington Division of Geology Bulletin, 38 p.
- Irving, E., Thorkelson, D.J., Wheadon, P.M., and Enkin, R.J.**
1995: Paleomagnetism of the Spences Bridge Group and northward displacement of the Intermontane Belt, British Columbia: a second look; Journal of Geophysical Research, v. 100, p. 6057-6071.
- Irving, E., Wynne, P.J., Thorkelson, D.J., and Schiarizza, P.**
1996: Large (1000-4000) northward movements of tectonic domains in the northern Cordillera, 83-45 Ma; Journal of Geophysical Research, v. 101, p. 17 901-17 916.
- Journeay, J.M. and Friedman, R.M.**
1993: The Coast Belt Thrust System: evidence of Late Cretaceous shortening in southwest British Columbia; Tectonics, v. 3, p. 756-775.
- Journeay, J.M. and Monger, J.W.H.**
1994: Geology and crustal structure of the southern Coast and Intermontane Belts, Southern Canadian Cordillera, British Columbia; Geological Survey of Canada, Open File, scale 1:500 000.
- Kleinspehn, K.L.**
1982: Cretaceous sedimentation and tectonics, Tyughton-Methow basin, southwestern British Columbia; Ph.D. thesis, Princeton University, Princeton, New Jersey.
- Mahoney, J.B.**
1992: Facies reconstructions in the Lower to Middle Jurassic Ladner Group, southern British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 93-1A, p. 173-182.
- Mahoney, J.B. (cont.)**
1994: Nd isotopic signatures and stratigraphic correlations: examples from western Pacific marginal basins and Middle Jurassic rocks of the southern Canadian Cordillera, Ph.D. thesis, University of British Columbia, Vancouver, British Columbia, 328 p.
- Mahoney, J.B. and Journeay, J.M.**
1993: The Cayoosh assemblage, southwestern British Columbia: last vestige of the Bridge River ocean; in Current Research, Part A; Geological Survey of Canada, Paper 93-1A, p. 235-244.
- Mahoney, J.B., Monger, J.W.H., and Hickson, C.J.**
1996: Albian-Cenomanian conglomerates along the Intermontane/Insular superterrane boundary, Canadian Cordillera, British Columbia: a critical test for large-scale terrane translation?; in Current Research 1996-A; Geological Survey of Canada, p. 101-109.
- McGroder, M.F.**
1991: Reconciliation of two-sided thrusting, burial metamorphism, and diachronous uplift in the Cascades of Washington and British Columbia; Geological Society of America Bulletin, v. 103, p. 189-209.
- Monger, J.W.H.**
1989: Geology, Hope, British Columbia; Geological Survey of Canada, Map 41-1989, sheet 1, scale 1:250 000.
- Monger, J.W.H. and Journeay, J.M.**
1994: Guide to the geology and tectonic evolution of the southern Coast Mountains; Geological Survey of Canada, Open File 2490, 77 p.
- Monger, J.W.H. and Price, R.A.**
1996: Comment on "Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow: evidence for 3000 km of northward displacement of the eastern Coast Belt, British Columbia", P.J. Wynne et al., 1996; Journal of Geophysical Research, v. 101, no. B6, p. 13 793-13 799.
- Monger, J.W.H., Price, R.A., and Tempelman-Kluit, D.J.**
1982: Tectonic accretion and the origin of the two major metamorphic and plutonic belts in the Canadian Cordillera; Geology, v. 10, p. 70-75.
- Monger, J.W.H., van der Heyden, P., Journeay, J.M., Evenchick, C.A., and Mahoney, J.B.**
1994: Jurassic-Cretaceous basins along the Canadian Coast Belt: their bearing on pre-mid-Cretaceous sinistral displacements; Geology, v. 22, p. 175-178.
- O'Brien, J.A., Gehrels, G.E., and Monger, J.W.H.**
1992: U-Pb geochronology of plutonic clasts from conglomerates in the Ladner and Jackass Mountain groups and the Peninsula Formation, southwestern British Columbia; in Current Research, Part A; Geological Survey of Canada, Paper 91-1A, p. 209-214.
- Rice, H.M.A.**
1947: Geology and mineral deposits of the Princeton map-area, British Columbia; Geological Survey of Canada, Memoir 243, 136 p.
- Tennyson, M.E.**
1974: Stratigraphy, structure, and tectonic setting of Jurassic and Cretaceous sedimentary rocks in the west-central Methow-Pasayten area, northeastern Cascade Range, Washington and British Columbia; Ph.D. thesis, University of Washington, Seattle, Washington, 112 p.
- Tennyson, M.E. and Cole, M.R.**
1978: Tectonic significance of upper Mesozoic Methow-Pasayten sequence, northeastern Cascade Range, Washington and British Columbia; in Mesozoic Paleogeography of the Western United States, (ed.) D.G. Howell and K.A. McDougall; Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 499-508.
- Umhoefer, P.J. and Miller, R.B.**
1996: Mid-Cretaceous thrusting in the southern Coast Belt, British Columbia and Washington, after strike-slip fault reconstruction; Tectonics, v. 15, p. 545-565.
- Wynne, P.J., Irving, E., Maxson, J.A., and Kleinspehn, K.L.**
1995: Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow: evidence for 3000 km of northward displacement of the eastern Coast Belt, British Columbia; Journal of Geophysical Research, v. 100, p. 6073-6091.

Borehole measurements of shear wave velocity discontinuities in Quaternary sediments, Fraser River delta, British Columbia

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Hunter, J.A., Dallimore, S.R., and Christian, H.A., 1997: Borehole measurements of shear wave velocity discontinuities in Quaternary sediments, Fraser River delta, British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 159-165.

Abstract: Borehole shear wave velocity measurements indicate the presence of significant velocity discontinuities within thick, unconsolidated Quaternary sediments of the Fraser River delta. In the four representative boreholes examined, such velocity boundaries range between approximately 20 m and 240 m below surface, and exhibit shear wave velocity ratios between 1:1.47 and 1:2.25. These abrupt low-to-high velocity transitions are associated with the Holocene-Pleistocene geological boundary. Such velocity discontinuities, along with the associated bulk density contrasts, may represent an important seismic impedance boundary for earthquake ground motion amplification modelling, and may contribute to general site resonance effects. The areal variability of both depth and velocity contrast of the boundary in turn suggests possible variability of site responses within the Fraser River delta.

Résumé : Des diagraphies de la vitesse de propagation des ondes S indiquent la présence de discontinuités significatives dans les sédiments quaternaires meubles épais du delta du fleuve Fraser. Dans les quatre sondages examinés, ces discontinuités se trouvent à entre 20 m et 240 m environ sous la surface et affichent des rapports de vitesse des ondes S entre 1/1,47 et 1/2,25. Ces transitions montantes nettes de la vitesse sont associées à une limite géologique holocène-pléistocène. Ces discontinuités combinées aux contrastes de masse volumique apparente pourraient représenter une limite d'impédance sismique importante pour la modélisation de l'amplification du déplacement du sol par les séismes et pourraient contribuer à des effets généraux de résonance des sites. La variabilité spatiale du contraste tant au niveau de la profondeur que de la vitesse de la discontinuité indique à son tour une variabilité possible des réponses des sites dans le delta du fleuve Fraser.

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INTRODUCTION

Ground motion response to earthquake shaking depends primarily on earthquake source, travel path of the earthquake waves, and the geological/geotechnical setting of the receiver site (Reiter, 1990). For a given source type and magnitude, as well as the travel path of the earthquake waves, it has long been known that the near surface geology may strongly modify the amplitude and frequency response of earthquake shaking. Often, amplification of ground motion, as well as resonance amplitude maxima at particular frequencies, can occur at a site where thick unconsolidated sediments overlie competent bedrock, despite general strain-dependent attenuation properties of such soils (Shearer and Orcutt, 1987).

The lower mainland of British Columbia is a high seismic hazard area (Rogers, 1994); in particular, the Fraser River delta is an area of concern in that thick, soft soil conditions occur throughout. Several 1-dimensional (1-D) ground motion amplification models have been generated for the delta area (Byrne and Anderson, 1987; Finn and Nichols, 1988; Lo et al., 1991; Sy et al., 1991) in order to assess the regional characteristics of ground motion amplification for representative earthquake types. Most of these studies have used estimated soil parameters over a hypothetical range of layered-soil models, since, until recently, there has been a paucity of deep (>50 m) geological/geotechnical data within the Quaternary sediments. In the past few years, new information on the character, thicknesses, and engineering properties of the Quaternary sediments in the Fraser River delta has been obtained from regional studies, (Dallimore et al., 1995; Britton et al., 1995) and new 1-D ground motion amplification models utilizing measured parameters at specific sites are now being produced (Harris et al., 1995).

Recently the Geological Survey of Canada has drilled a number of boreholes in the Fraser River delta for geoscientific investigations. Several of these holes have penetrated the Holocene-Pleistocene boundary (Luternauer and Hunter, 1996). This study presents the results of shear wave velocity measurements in four representative boreholes, where we have observed a range of shear wave velocity contrasts, as well as depths to possibly significant seismic impedance contrasts associated with the Holocene-Pleistocene boundary. The locations of the boreholes discussed herein are shown in Figure 1. Detailed geological/geophysical/geotechnical descriptions for GSC borehole FD94-3 and FD94-4 are given by Dallimore et al. (1995), for GSC borehole FD95-S1 by Christian et al. (1995), and for GSC borehole FD95-2 by Luternauer and Hunter (1996).

BACKGROUND

As a starting point for modelling, one of the important input parameters is the variation of the elastic small-strain dynamic shear modulus (G_{MAX}) within the unconsolidated material overlying competent rock. From elastic wave propagation theory, G_{MAX} is related to shear wave velocity as follows:

$$G_{MAX} = \rho V_S^2$$

where: ρ = mass density

V_S = shear wave velocity

Hence, data gathering for input parameters to the basic 1-D layered model of a soft-soil site often begins with estimation or measurement of the shear wave velocity variation within the overburden materials.

Considerable insight can be gained for a particular site by considering first order site response effects which are governed by soil thickness and seismic velocity contrasts alone. For simple 1-D elastic models consisting of one low velocity soil layer overlying a semi-infinite horizontal bedrock surface, ground motion amplification resonance from vertically incident, horizontally polarized earthquake shear waves (SH) would be expected to occur at a fundamental site frequency and at higher harmonics given by (Bard and Bouchon, 1980):

$$f_n = (2n+1) V_1/4H$$

where:

V_1 = average shear wave velocity of the soil layer (m/s)

H = thickness of the soil layer (m)

$f_{0,1,\dots}$ = the fundamental frequency (Hz), the first harmonic, etc.

The resonance frequencies result from shear wave (SH) energy trapped (or internally reflected) between two large seismic impedance boundaries consisting of the Earth's surface and the overburden-bedrock interface. In addition, the amplification factors of both the free-surface displacements

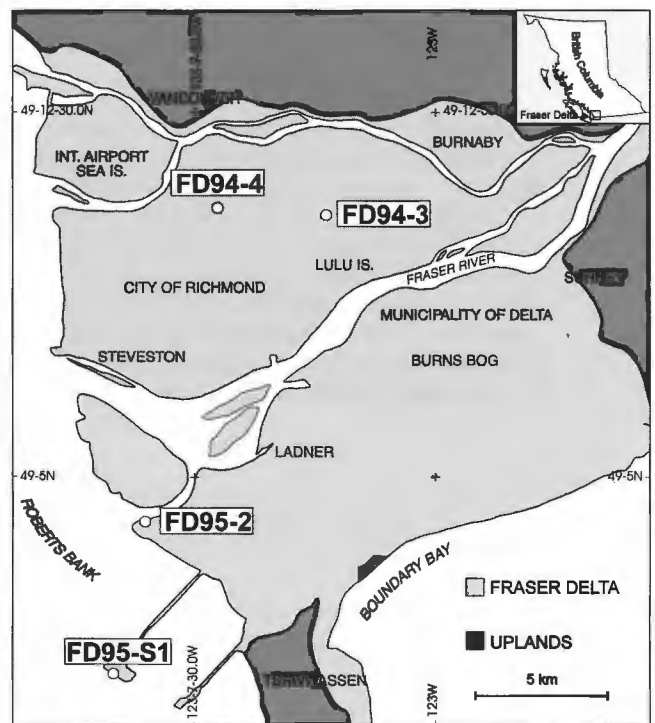


Figure 1. Fraser River delta area showing the locations of the four boreholes discussed in the text.

as well as the resonant peaks (without considering an elastic attenuation within the soil) are functions of the seismic impedance contrast at the overburden-bedrock boundary (Bard and Bouchon, 1980; Shearer and Orcutt, 1987; Reiter, 1990; Fukushima et al., 1995). The shear wave impedance ratio is:

$$I = \rho_2 V_2 / \rho_1 V_1$$

where: $\rho_1 V_1$ = impedance (density x shear wave velocity) of the upper layer (soil)
 $\rho_2 V_2$ = impedance (density x shear wave velocity) of the lower layer (rock)

Measured overburden-bedrock shear wave impedance ratios, associated with site amplification effects, can be as low as 1.3 (Sato et al., 1995; Quaternary sediments overlying Tertiary rock, Sendai region, Japan), or as high as 6.3 (Joyner et al., 1976; Quaternary sediments overlying Tertiary rock, San Francisco Bay).

Because of the substantial thickness of Quaternary sediments within the Fraser River delta, Harris et al. (1995) have shown that in most areas the fundamental site periods for the overburden-bedrock interface (Quaternary-Tertiary), would be in the range of 4 to 5 seconds; the shear wave velocity ratio (bedrock/overburden), derived from compressional wave measurements, is estimated to be on the order of 2 to 3 (Hunter et al., 1996).

If significant velocity contrasts also occur within Quaternary overburden, resonance effects might develop from these boundaries which may have fundamental site periods in the higher frequency range than the overburden-bedrock models. Such intra-overburden velocity contrasts have been included in many of the previous models referenced above, and are generally associated with the Holocene (deltaic silts and sands)-Pleistocene (overconsolidated till) boundary. Estimates used for these impedance contrasts have been in the order of 2 to 3, and for modelling purposes, depths to these contrasts have been in the range of 40 m to 150 m (Sy et al., 1991).

BOREHOLE SHEAR WAVE VELOCITY DATA

For the four boreholes discussed here, the down-hole shear wave velocity measurements were made with a three-component (2 orthogonal horizontal and 1 vertical) borehole geophone system, which was lowered down PVC-cased boreholes and mechanically locked in position at each recording depth. The arrival time and waveform of energy produced by a horizontally polarized shear wave source at the surface were recorded using a digital engineering seismograph. Records were obtained with two opposing surface source orientations at each downhole location, in order to ensure accurate interpretation of the onset of polarized shear wave motion.

The surface source consisted of either a wooden post or a steel I-beam coupled to the ground by the weight of a truck, and struck horizontally by a large sledgehammer or by a horizontally pivoted wooden battering ram. Shear energy of opposing polarities was produced by striking opposite ends of the loaded beam. The down-hole geophone system was designed and constructed by Frontier Geosciences Inc. of

Vancouver; the three orthogonal geophone elements have natural frequencies of 8 Hz with 0.6 critical electronic damping for broad-band response. Boreholes FD94-3, FD94-4, and FD95-2 were shot with a 1 m spacing between successive geophone locations; FD95-S1 was shot with a 2 m spacing. The data from FD95-S1 were obtained for a separate experiment in horizontal shear wave velocity anisotropy (Harris et al., 1996); the travel-times for each geophone location were obtained from four independent sets of measurements made with differing polarities and orientations of the surface source.

The shear wave arrival times were interpreted by comparing polarity reversed records at each geophone location and identifying the onset of the polarized shear wave. To obtain velocity estimates, running least-squares fits of travel-times over a specified vertical distance were performed. For boreholes FD94-3, FD94-4, and FD95-2, the vertical distance chosen was 8 m (9 -point fit), and for FD95-S1 a 4 m interval (3-point fit x 4 independent data sets).

The shear wave velocities obtained are shown in Figure 2a, b, c, and d for boreholes FD94-3, FD95-2, FD95-S1, and FD94-4 respectively. The error bars shown are ± 2 standard deviations of the least squares fits (ranging between 9 points and 12 points), and are shown only as a guide to the relative statistical uncertainty. Also shown in Figure 2 are the interpreted locations of the Holocene-Pleistocene boundary from geological and other geophysical logging studies. In all cases, a significant step-wise velocity discontinuity is associated with the Holocene-Pleistocene boundary.

To examine the boundary in more detail, 50 m vertical sections spanning the boundary in each of the boreholes were selected. Shear wave travel-times were plotted with depth (z) in "reduced travel-time" format such that:

$$t_R = t - z/V_R$$

where: t_R = the "reduced" travel time
 t = observed travel time
 z = source-receiver depth
 V_R = "reducing" velocity

By selecting a reducing velocity approximately midway between the observed velocities on either side of the velocity boundary, the apparent reduced travel-time vs. depth gradients are enhanced. This type of presentation is commonly employed in teleseismic crustal refraction analyses as an aid to interpreting the onset of seismic refraction events; however, the technique is equally applicable to borehole seismic velocity interpretations. Straight-line segments of the travel-times adjacent to the boundaries were selected and interpreted as shear wave velocity layers. The reduced travel times with interpreted velocity layers are shown in Figures 3a, b, c, and d for the four boreholes (FD94-3, FD95-2, FD95-S1, and FD94-4 respectively), along with available bulk density data obtained from sample measurements.

At the Holocene-Pleistocene boundary at 19.6 m in borehole FD94-3 (Fig. 3a) a large velocity contrast is evident (176 m/s to 414 m/s). The apparent intermediate velocity gradient between 18 m and 20 m has been ignored in this interpretation, since the vertical thickness of this zone is small

compared to the seismic wavelengths of investigation for earthquakes. From the available data only a small bulk density variation, 1.92 to 1.97 g/cm³, can be associated with the boundary (the material types on either side of the boundary are sand).

In borehole FD95-2 the Holocene-Pleistocene boundary has been interpreted at 52 m depth with a velocity contrast at the boundary of 240 m/s to 446 m/s (interpreted to be deltaic silts overlying diamicton). No bulk density information is available for this borehole. The estimated bulk densities shown in Figure 3b are taken from borehole FD95-S1, which exhibits similar geological and geophysical characteristics at this interface.

In borehole FD95-S1 the Holocene-Pleistocene boundary has been interpreted at 109 m depth (deltaic clayey silts overlying diamicton) and is associated with a velocity boundary between 311 m/s and 455 m/s and an approximate density contrast of 1.85 to 2.15 g/cm³.

In borehole FD94-4 (Fig. 3d) the Holocene-Pleistocene boundary has been identified from geological studies at approximately 236 m depth (deltaic silts overlying diamicton). Ignoring the small velocity gradient within the boundary area, as previous discussed, two distinct velocity layers have been interpreted (472 m/s and 700 m/s). Although bulk density values show considerable scatter, the average contrast between the two seismic layers is approximately 1.9 to 2.2 g/cm³.

TABULATION OF RESULTS

Table 1 summarizes the data for the four representative boreholes in order of increasing thickness of Holocene deltaic materials. The average shear wave velocity for the Holocene section (V_{AVE}) was obtained from the total travel time of the shear wave and distance from surface to the 3-component geophone position at the interpreted top of Pleistocene. The fundamental site period $T_0 = 1/f_0$ for the Holocene-Pleistocene boundary has been calculated using V_{AVE} .

DISCUSSION OF RESULTS

From the above results, the following points should be noted:

1. The derived seismic impedance ratios associated with the Holocene-Pleistocene boundary, for the four examples given, are in the range of 1.7 to 2.3, similar to, but perhaps slightly lower than, estimated parameters previously used in modelling. It is suggested that this impedance boundary may influence the shape of modelled ground motion amplification spectra.

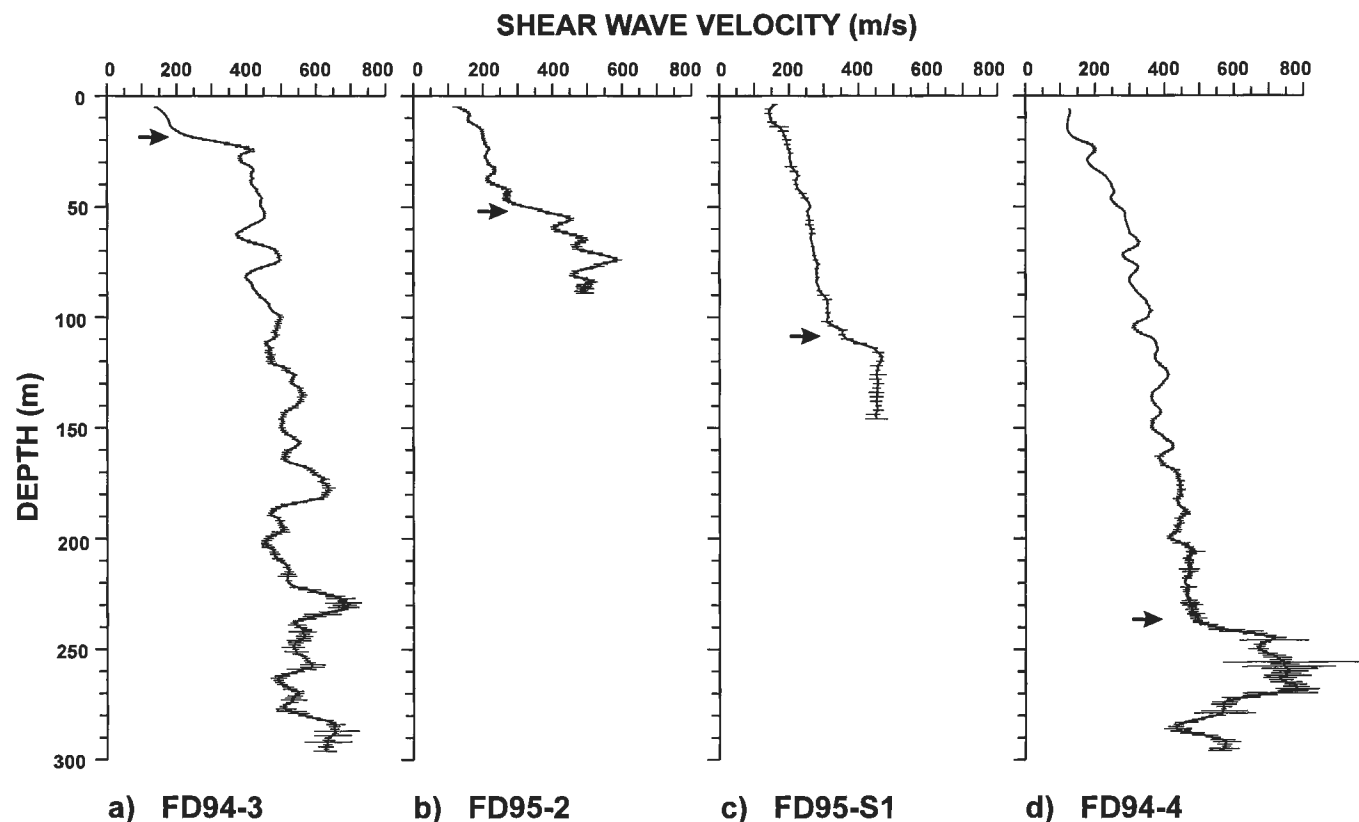


Figure 2. Shear wave velocity vs. depth for GSC boreholes a) FD94-3, b) FD95-2, c) FD95-S1, and d) FD94-4 obtained from running least squares fits on the travel-time-depth data (see text for details). The error bars shown are ± 2 standard errors of the velocity fits. Arrows indicate the Holocene-Pleistocene boundary interpreted from geological and geophysical logs.

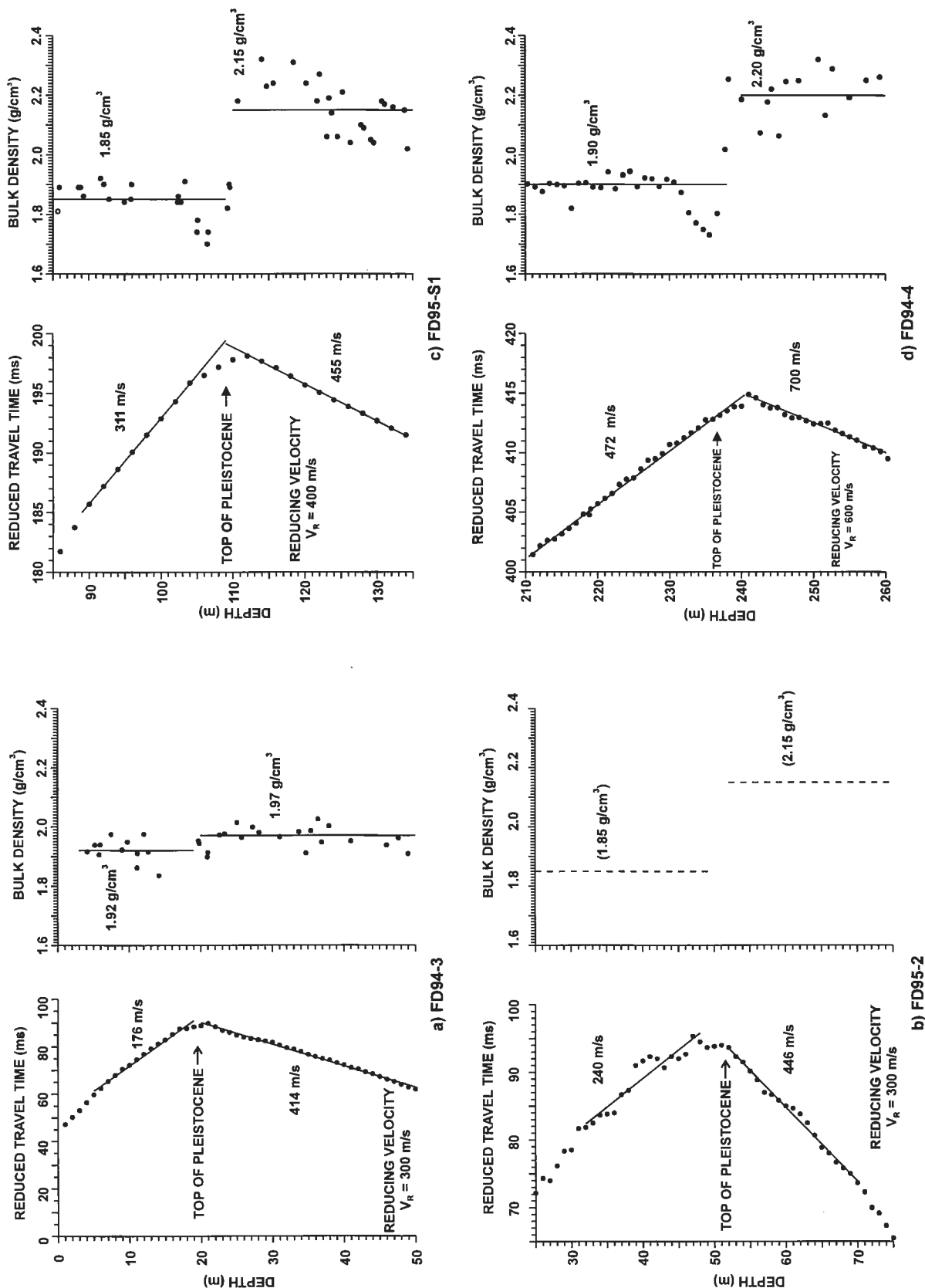


Figure 3. Fifty metre vertical sections spanning the Holocene-Pleistocene boundary, showing least-squares velocity fits from reduced shear wave travel-times and measured (or estimated) bulk densities for boreholes a) FD94-3, b) FD94-2, c) FD95-S1, and d) FD94-4.

Table 1. Summary of shear wave velocities and derived seismic impedance contrasts at the Holocene/Pleistocene interface in four boreholes in the Fraser River delta.

Borehole	FD94-3	FD95-2	FD95-S1	FD94-4
Holocene thickness H (m)	19.6	52	109	236
Holocene average shear velocity V_{AVE} (m/s)	124	195	232	295
Sediment types at the Holocene/Pleistocene boundary	Sand/Sand	Silt/Diamicton	Silt/Diamicton	Silt/Diamicton
Holocene/Pleistocene fundamental site period $T_0=4H/V_{AVE}$ (s)	0.63	1.07	1.88	3.25
Holocene shear velocity/density at boundary V_1 (m/s) / ρ_1 (g/cm ³)	176 / 1.92	240 / (1.85)	311 / 1.85	472 / 1.90
Pleistocene shear velocity/density at boundary V_2 (m/s) / ρ_2 (g/cm ³)	414 / 1.97	446 / (2.15)	455 / 2.15	700 / 2.20
Pleistocene/Holocene seismic impedance ratio $\rho_2 V_2 / \rho_1 V_1$	2.31	2.14	1.71	1.72

- The shear wave velocities measured in Pleistocene sediments immediately beneath the Holocene-Pleistocene boundary are greater than 400 m/s; no significant depth-of-burial vs. velocity relationship is apparent from this data set. It is suggested that the velocities reflect the degree of consolidation of the sediments rather than sediment type under normal loading.
- The shear wave velocities measured in Holocene sediments immediately above the Holocene-Pleistocene boundary range between 176 and 472 m/s and appear to be depth-of-burial dependent, as may be expected in normally consolidated deltaic sediments (Hunter, 1995).
- The derived fundamental site periods for the Holocene sediment layer, based on average shear wave velocities, span the range between 0.63 and 3.25 seconds; this is in the range of interest for engineering structural response to earthquakes. The thickness dependence is nonlinear, as might be expected, due to the average velocity-depth variation within the Holocene sediments.
- The thickness of the Holocene deltaic materials ranges from approximately 20 m to 240 m for the data shown here.

Although the subsurface Quaternary geology data-base is relatively sparse (Luternauer and Hunter, 1996), it should be noted that there is no apparent relationship between the depth to the Pleistocene surface and distance from the edge of the Fraser River delta (see borehole locations in Fig. 1). Regional geology studies suggest that Fraser River delta sediments were probably not deposited on a uniform "bowl-shaped" submarine topographic Pleistocene surface; but rather, the

Pleistocene surface was probably irregular in shape. Topographic highs (hence shallow depths to large seismic impedance contrasts) may occur at locations away from the delta edge (e.g. borehole FD94-3). Further, such impedance boundaries probably contribute to more complex earthquake-generated surface ground motions resulting from 2- and 3-dimensional shape effects (Bard and Bouchon, 1985; Rial et al, 1992; Frankel and Vidale, 1992; Graves, 1993).

We hope that the velocity-density-depth data given here for the buried Holocene-Pleistocene boundary, from four representative boreholes in the Fraser River delta, will provide some regional constraints on input parameters required for ground motion amplification modelling. It is suggested that future geo-architectural studies in the Fraser River delta should concentrate, in part, on the delineation of the buried Holocene-Pleistocene boundary as well as the measurement of the associated shear wave seismic impedance contrasts.

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REFERENCES

- Bard, P.Y. and Bouchon, M.**
1980: The seismic response of sediment-filled valleys. Part I. The case of incident SH waves; *Bulletin of the Seismological Society of America*, v. 70, p. 1263-1286.
- 1985: The two-dimensional resonance of sediment-filled valleys; *Bulletin of the Seismological Society of America*, v. 75, no. 2, p. 519-541.
- Britton, J.R., Harris, J.B., Hunter, J.A., and Luternauer, J.L.**
1995: The bedrock surface beneath the Fraser River delta in British Columbia, based on seismic measurements; in *Current Research 1995-E*; Geological Survey of Canada, p. 83-89.
- Byrne, P.M. and Anderson, D.L.**
1987: Earthquake design in Richmond, B.C.; Department of Civil Engineering, University of British Columbia, Vancouver, British Columbia, Soil Mechanics Series No. 109.
- Christian, H.A., Barrie, J.V., MacDonald, R., Monahan, P.A., Hunter, J.A., and Luternauer, J.L.**
1995: Slope instability on Roberts Bank, Fraser River delta, Vancouver, British Columbia; Proceedings, 48th Canadian Geotechnical Conference, 25-27 September, Vancouver, v. 2, p. 937-946.
- Dallimore, S.R., Edwardson, K.A., Hunter, J.A., Clague, J.J., and Luternauer, J.L.**
1995: Composite geotechnical logs for two deep boreholes in the Fraser River delta, British Columbia; Geological Survey of Canada, Open File 3018.
- Finn, W.D.L. and Nichols, A.M.**
1988: Seismic response of long-period sites: lessons from the September 19, 1985, Mexican earthquake; *Canadian Geotechnical Journal*, v. 25, p. 128-137.
- Frankel, A. and Vidale, J.**
1992: A three-dimensional simulation of seismic waves in the Santa Clara Valley, California, from a Loma Prieta aftershock; *Bulletin of the Seismological Society of America*, v. 28, no. 5, p. 2045-2074.
- Fukushima, Y., Gariel, J., and Tanaka, R.**
1995: Site-dependent attenuation relations of seismic motion parameters at depth using borehole data; *Bulletin of the Seismological Society of America*, v. 85, no. 6, p. 1790-1804.
- Graves, R.W.**
1993: Modelling three-dimensional site response effects in the Marina District basin, San Francisco, California; *Bulletin of the Seismological Society of America*, v. 83, no. 4, p. 1042-1063.
- Harris, J.B., Hunter, J.A., Burns, R.A., Good, R.L., and Luternauer, J.A.**
1996: Observations of shear wave splitting in Holocene sediments of the Fraser River delta, British Columbia; 7th International Workshop on Seismic Anisotropy, February 19-23, Miami, 1996, Programs and Abstracts, p. 16.
- Harris, J.B., Hunter, J.A., Luternauer, J.L., and Finn, W.D.L.**
1995: Site response modelling of the Fraser River delta, British Columbia: preliminary results from two deep boreholes; in *Current Research 1995-E*; Geological Survey of Canada, p. 69-75.
- Hunter, J.A.**
1995: Shear wave velocities of Holocene sediments, Fraser River delta, British Columbia; in *Current Research 1995-A*; Geological Survey of Canada, p. 29-32.
- Hunter, J.A., Harris, J.B., and Britton, J.R.**
1996: Compressional and shear wave interval velocity data for Quaternary sediments in the Fraser River delta from Multichannel Seismic Reflection Surveys; Geological Survey of Canada, Open File 3325, 228 p.
- Joyner, W.B., Warrick, R.E., and Oliver, A.A.**
1976: Analysis of seismograms from a downhole array in sediments near San Francisco Bay; *Bulletin of the Seismological Society of America*, v. 66, no.3, p. 937-958.
- Lo, R.C., Sy, A., Henderson, P.W., Siu, D.Y., Finn, W.D.L., and Heidebrecht, A.C.**
1991: Seismic site amplification study for Fraser delta, British Columbia; Proceedings, 6th Canadian Conference on Earthquake Engineering, Toronto, Ontario, p. 509-516.
- Luternauer, J.L. and Hunter, J.A.**
1996: Mapping Pleistocene deposits beneath the Fraser River delta; preliminary geological and geophysical results; in *Current Research 1996-E*; Geological Survey of Canada, p. 41-48.
- Reiter, L.**
1990: *Earthquake Hazard Analysis: Issues and Insights*; Columbia University Press, New York, 254 p.
- Rial, J.A., Saltzman, N.G., and Ling, H.**
1992: Earthquake-induced resonance in sedimentary basins; *American Scientist*, v. 80, p. 566-578.
- Rogers, G.C.**
1994: Earthquakes in the Vancouver area; in *Geology and Geological Hazards of the Vancouver Region, Southwestern British Columbia*, (ed.) J.W.H. Monger; Geological Survey of Canada, Bulletin 481, p. 221-229.
- Satoh, T., Kawase, H., and Sato, T.**
1995: Evaluation of local site effects and their removal from borehole records observed in the Sendai Region, Japan; *Bulletin of the Seismological Society of America*, v. 85, no. 6, p. 1770-1789.
- Shearer, P.M. and Orcutt, J.A.**
1987: Surface and near-surface effects on seismic waves-theory and borehole seismometer results; *Bulletin of the Seismological Society of America*, v. 77, no. 4, p. 1168-1196.
- Sy, A., Henderson, P.W., Lo, R.C., Siu, D.Y., Finn, W.D.L., and Heidebrecht, A.C.**
1991: Ground motion response for the Fraser delta, British Columbia; Proceedings, 4th International Conference on Seismic Zonation, Stanford, California, v. 2, p. 343-350.

Geological Survey of Canada Project 950029

East Kootenay multiparameter geophysical survey, southeastern British Columbia: regional synthesis

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Lowe, C., Brown, D.A., Best, M., and Shives, R., 1997: East Kootenay multiparameter geophysical survey, southeastern British Columbia: regional synthesis; in Current Research 1997-A; Geological Survey of Canada, p. 167-176.

Abstract: Electromagnetic, total field magnetic, radiometric, and VLF data were recently acquired in three survey areas covering approximately 3000 km² in the Purcell Mountains of southeastern British Columbia (82F, G, K). These are the first high-resolution, public-domain data for the region and the first radiometric survey over a SEDEX deposit in Canada. An initial analysis of the data, coupled with brief ground follow-up studies, indicate refinement of the mapped geology is warranted in several areas. In particular, new exposures of Moyie sills are identified, the Reade Lake stock is shown to be much less extensive than previously mapped, and a possible extension to the Emily Creek fault is identified. Collectively the data offer improved screening of exploration targets in the region.

Résumé : On a récemment réalisé des levés électromagnétiques, magnétiques (champ total), radiométriques et VLF dans trois secteurs couvrant environ 3 000 m² dans les monts Purcell dans le sud-est de la Colombie-Britannique (82F, G, K). Ce sont les premières données haute résolution du domaine public acquises dans la région et les premières données radiométriques enregistrées au-dessus d'un gisement sédimentaire exhalatif au Canada. Une première analyse des données, conjuguée à de brèves études de suivi sur le terrain, révèle qu'il est justifié d'affiner les cartes géologiques de plusieurs secteurs. En particulier, de nouveaux affleurements des filons-couches de Moyie ont été localisés, le stock de Reade Lake est beaucoup plus étendu que ne le figuraient les cartes antérieures et un prolongement possible de la faille d'Emily Creek est relevé. L'ensemble des données permet de mieux sélectionner les cibles d'exploration dans la région.

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INTRODUCTION

The East Kootenay multiparameter geophysical survey which was recently conducted in the Purcell Mountains of southeastern British Columbia (82F, G, K) was funded by the Government of British Columbia and co-ordinated by the Geological Survey of Canada. Its objective was to provide high-quality,

public-domain geoscience data to assist mineral explorationists and enhance understanding of the region's geology and known mineral deposits. Electromagnetic (EM), total field magnetic, radiometric, and VLF data were acquired in three areas (St. Mary River, Findlay Creek, and Creston areas, Fig. 1). Survey target areas were selected in consultation with industry. Digheem I Power of Mississauga, Ontario conducted the surveying between August 1995 and September 1996.

The three survey areas lie within the Purcell Anticlinorium of southeastern British Columbia and are primarily underlain by the prospective Aldridge Formation (Fig. 1). The St. Mary River area, approximately 2000 km², includes the Sullivan mine (a world class sedimentary exhalative (SEDEX) mineral deposit) as well as past producers at North Star and Stewindor mines. The Findlay Creek area covers about 400 km² south of Findlay Creek and west of Canal Flats. The Creston area extends east from Creston towards Yahk and south to the United States border, comprising about 600 km². Although the last two areas have numerous base-metal showings neither has any history of significant economic mineral production.

The data have provided new perspectives on the geology of the survey areas and led to the identification of several new exploration targets. Since announcement of the survey there has been about 200 km² of new staking in the St. Mary River survey area, representing an increase of 30% over 1995 staking levels. New claims staked by Cominco Ltd., Miner River Resources Ltd., and Eagle Plains Resources Ltd. encompass conductive units and apparent bedrock conductors in the Dutch Creek Formation (Fig. 2: LaFrance Creek Group of Reesor, 1996) north of Sawyer Creek, and in the Horsethief Creek Formation (see Fig. 4). Cominco also staked apparent bedrock conductors in the middle and upper Aldridge Formation in the Tower Creek area.

In the Findlay Creek area about 105 km² of new claims were staked, representing a 440 % increase over 1995 staking levels. Staking occurred predominantly around Rusty Ridge (see Fig. 5) and west of Doctor Creek. Grass-roots exploration is underway and Miner River Resources Ltd. conducted a drill program based on the several coincident EM and magnetic anomalies detected by the new geophysical data.

In this paper we describe the main features observed in each geophysical parameter from the St. Mary River and Findlay Creek areas (Fig. 1; note: data from the Creston area is not yet available for analysis) and evaluate their utility for geological mapping. A companion paper (Brown et al., in press) correlates observed geophysical responses with known mineralization in the Sullivan-North Star corridor and elsewhere in the regions surveyed. While much of our evaluation is based on correlations between the geophysical parameters and existing public domain data, follow-up ground investigations were critical for constraining the geology of anomalies. Discussions with local prospectors and companies currently exploring within the area provided useful additional information. As page restrictions limit the reproduction of geophysical images in this paper, the reader should refer to the published 1:50 000 scale images (British Columbia Ministry of Employment and Investment, 1996) to accurately locate features discussed in the following text.

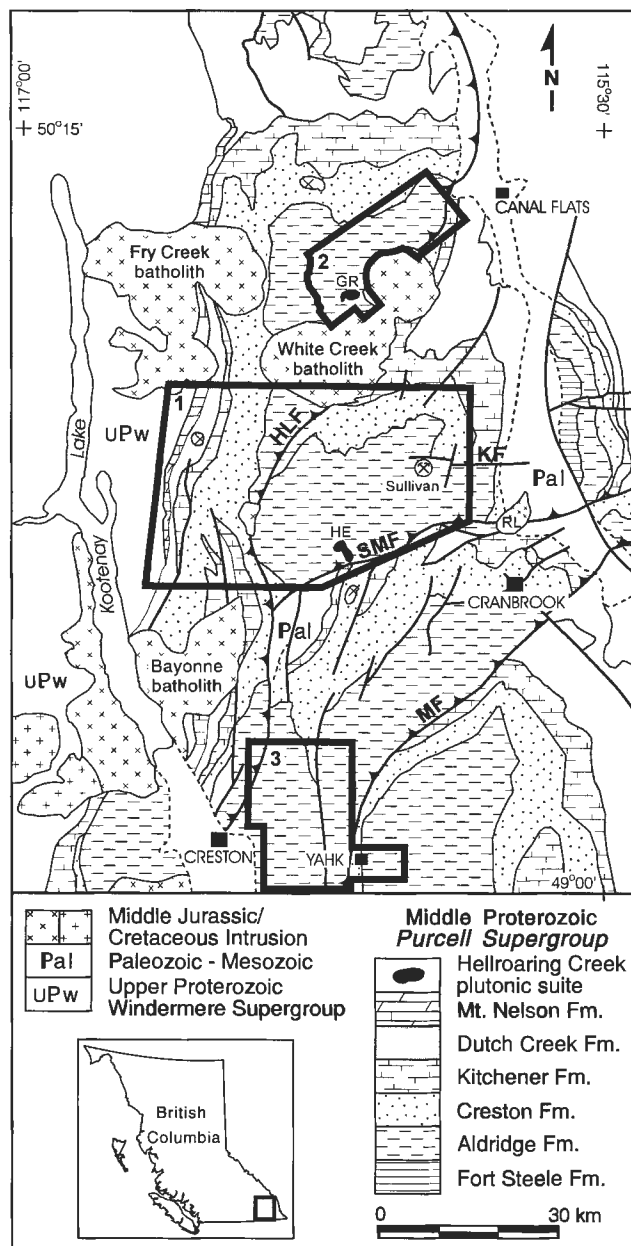


Figure 1. Regional geological setting of Purcell Supergroup illustrating the location of the three geophysical survey areas within the Purcell anticlinorium (modified from Höy et al., 1995). 1, St. Mary River area; 2, Findlay Creek area; 3, Creston area. Abbreviations: HLF, Hall Lake Fault; MF, Moyie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

GEOPHYSICAL DATA-ACQUISITION DETAILS

EM, magnetic, radiometric, and VLF data were acquired in each of the three survey areas using an Aerospatiale (AS350B1) helicopter flown at a mean terrain clearance of 60 m. Flight lines (oriented east-west in St. Mary River and Creston areas and northwest-southeast in the Findlay Creek area) were 400 m apart with control lines approximately 5 km apart. Figure 3 shows the deployment configuration.

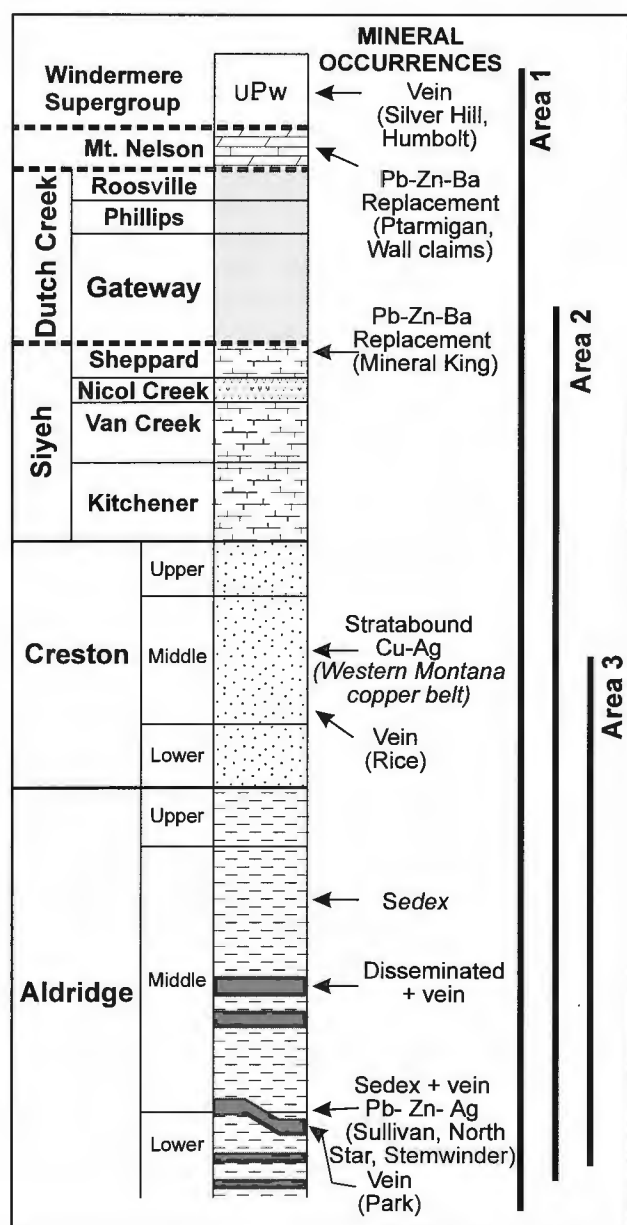


Figure 2. Stratigraphic column of the Purcell and Windermere supergroups showing the position of selected mineral occurrences and the extent of stratigraphy covered in each survey area (modified from T. Höy, unpub. figure 1996). See Figure 1 for area locations.

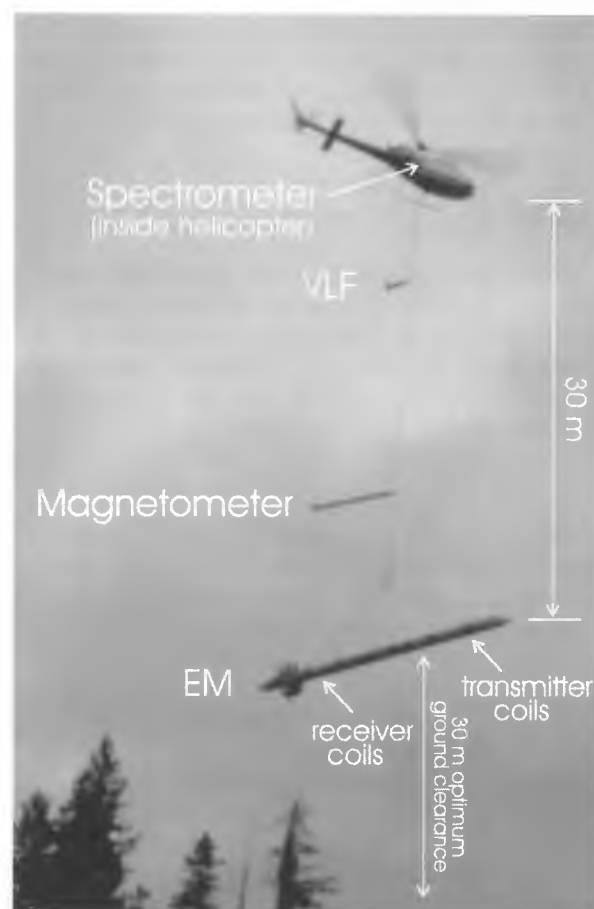


Figure 3. Helicopter illustrating bird configuration for the survey.

The DigheM frequency domain EM system consists of 5 different frequency and coil orientation combinations (900 Hz coaxial coil pair; 900 Hz coplanar coil pair; 5000 Hz coaxial coil pair; 7200 Hz coplanar coil pair; and 56 KHz coplanar coil pair). The transmitter-receiver coil separation is 8 m and the entire system is housed in a 12 m long Kevlar bird. In-phase and quadrature components of the secondary (induced) magnetic field in parts per million (ppm) of the primary field are measured for each coil combination. Absolute values for each of the 5 sets of in-phase and quadrature data were produced through levelling so that conductivity maps could be generated.

The magnetic data were acquired using a Scintrex CS2 cesium vapour magnetometer with a resolution capability of 0.01 nT. Following correction for the diurnal variation, the data were levelled to a common datum of 1000 m, and residual anomalies were calculated using the 1995 International Geomagnetic Reference Field.

The VLF data are dominated by a low signal-to-noise ratio, due in part to the resistive nature of the exposed geological units. For this reason they are not considered in this report, although locally they may contain information useful for identifying and/or refining conductors in the near surface.

The gamma ray spectrometric system consisted of a 16 L sodium iodide crystal attached to a 256 channel Exploranium GR820 spectrometer. A 4 L upward-looking crystal was used to monitor and correct for background radiation.

PRODUCTS

All of the geophysical data acquired in the St. Mary River and Findlay Creek areas are available in digital format and as selected 1:50 000 scale hard copy images with geological overlays from the National Geophysical Data Centre in Ottawa (British Columbia Ministry of Employment and Investment, 1996). To aid interpretation, existing LANDSAT data were also acquired for the survey areas and reprocessed to enhance geological features (R. Kung, unpub. data, 1996). In addition, portions of the three geophysical survey areas were examined using interferometric synthetic aperture radar (InSAR) images produced by the Canada Centre of Remote Sensing (digital InSAR data may be obtained from the British Columbia Geological Survey Branch).

REGIONAL CHARACTERISTICS

In order to utilize the geophysical data as a tool for mineral exploration it is necessary to understand the regional geology and the geophysical characteristics of this geology. In this way "anomalies" possibly related to mineralization can be more readily recognized.

Geological setting

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

Aldridge Formation and overlying Creston Formation lithologies predominate in the survey areas and the Sullivan SEDEX deposit occurs near the transition from lower to middle Aldridge in the St. Mary River area. Faulted and structurally complex upper Purcell and Windermere Supergroup strata outcrop in the western third of the St. Mary area and Cambrian Cranbrook and Eager formations occur along the southern edge of this area. Small pegmatitic plutonic rocks of Middle Proterozoic age include Hellroaring Creek (4 km²) and Greenland Creek stocks (1.6 km²; Reesor, 1996). Large Cretaceous plutons, including parts of the White Creek and Fry Creek batholiths and their satellitic equivalents, plug many of the faults. More detailed maps and unit descriptions

are presented by Rice (1937, 1941), Leech (1957), Reesor (1958, 1973, 1983, 1996), Höy (1984a, b; 1993), Carter and Höy (1987), and others.

Mineral occurrences

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

Sullivan is a world class Pb-Zn-Ag SEDEX deposit formed in an intracratonic rift setting within deep water turbidites. It occurs close to the intersection of the Kimberley fault with the Sullivan-North Star corridor (Höy et al., 1995). The Sullivan deposit and its regional setting have been the focus of a 5-year multidisciplinary study (J.W. Lydon, unpub. manuscript, 1996). Associated with the mineralization at Sullivan are fragmental units, albite and tourmaline alteration, as well as discordant sills of Moyie gabbro.

Electromagnetics

The stratigraphy within the surveyed areas is characteristically resistive with thin surficial cover and therefore few conductors are observed (Fig. 4). The most prominent and significant concentration is within the Sullivan-North Star corridor (Brown et al., in press). In addition, clusters of conductors are observed in the Sawyer Creek and Vulcan prospect areas. Isolated conductors are recognized in several areas and are particularly common along major drainages. Conductors produced from cultural features (power lines, buildings, train tracks, etc.) are recognized in several areas and are identified on the hard copy images (British Columbia Ministry of Employment and Investment, 1996).

Conductivity contours north of Sawyer Creek outline exposures of Dutch Creek and Horsethief Creek formations and parallel the north-northeast-trending faults which cut these formations (Fig. 4a). Finite conductors in this area remain unexplained and warrant further study.

Several narrow bedrock conductors located near the Vulcan (Fig. 4a) prospect have moderate conductance values (conductivity times thickness of the half plane vertical conductor) between 5 and 20 S. Some of these conductors were also detected by ground UTEM surveys (Webber, 1979) and subsequently drilled; hole Vu-19-1 (Webber, 1979) encountered pyrrhotite in laminations and disseminated in smaller

patches at depths of 85 to 95 m below surface and hole Vu-85-2 (Anderson, 1985) encountered disseminated and massive pyrrhotite zones locally containing magnetite at depths of 40 to 45 m below surface.

Some of the scattered conductors that lie within major drainages are due to clay-rich surficial material; for example those within the St. Mary River valley. Others are related to pyrrhotite laminations in the underlying bedrock; for example, those encountered in drill holes in Matthew Creek valley.

In the Findlay Creek area (Fig. 4b) the eastern half of the survey area is more conductive than the western half, perhaps due to a relatively thicker overburden. In the northwest conductivity contours outline the trace of a mapped fault. Here the conductivity may either be related to gouge material in the fault zone or thicker overburden along the fault trace.

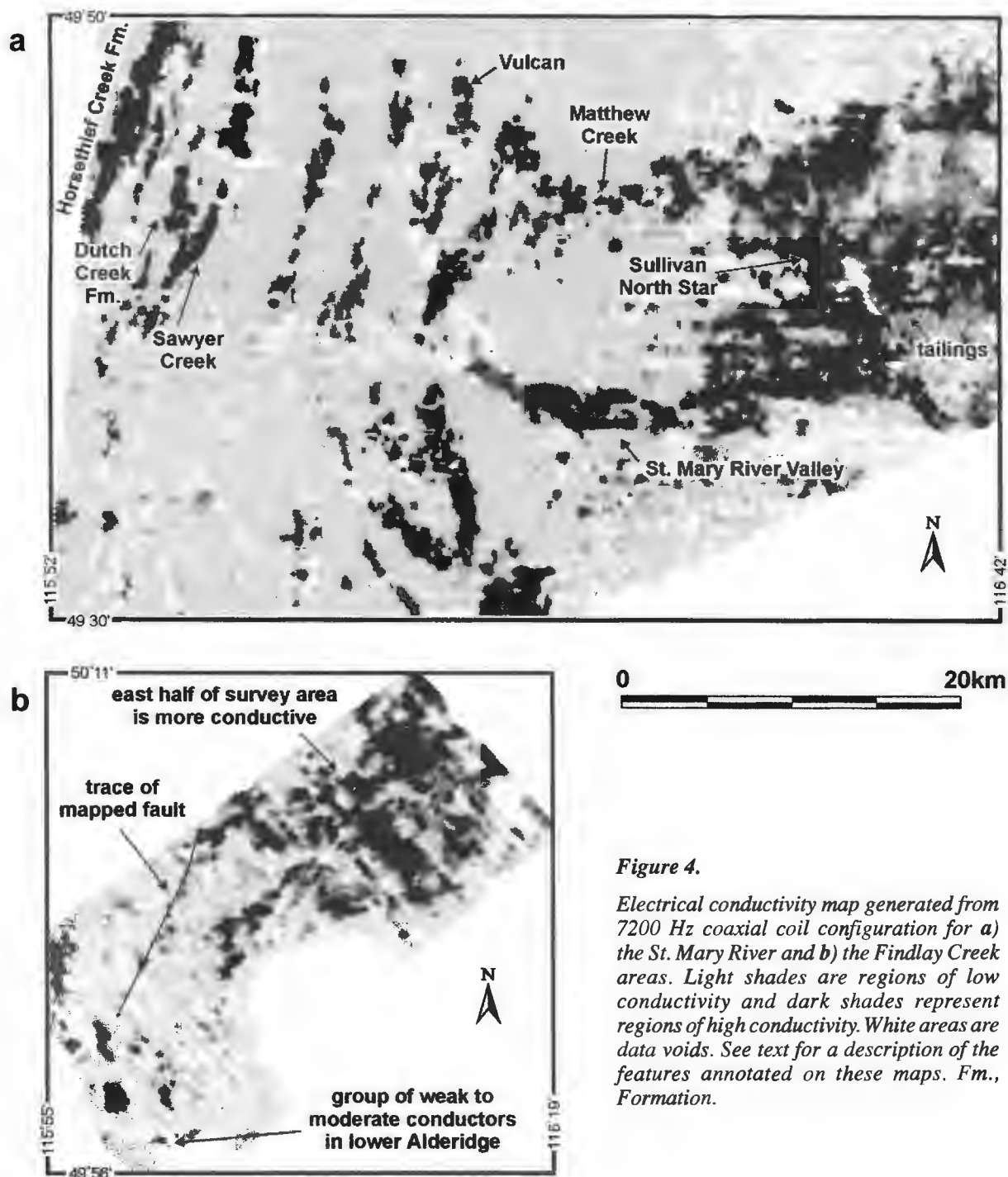


Figure 4.

Electrical conductivity map generated from 7200 Hz coaxial coil configuration for a) the St. Mary River and b) the Findlay Creek areas. Light shades are regions of low conductivity and dark shades represent regions of high conductivity. White areas are data voids. See text for a description of the features annotated on these maps. Fm., Formation.

Magnetics

The new magnetic data significantly enhance anomalies visible in previously available regional data, and in addition, identify numerous small and/or low gradient anomalies not previously recognized by these coarser data sets.

The largest and most intense anomalies correlate with mapped granitic bodies and their metamorphic aureoles (Fig. 5). Small positive anomalies are commonly associated with exposures of Moyie sills, particularly where the sills are adjacent to mapped faults or granitic intrusions. Although the Purcell Supergroup is for the most part weakly magnetic, strong positive anomalies are characteristic of the middle Creston Formation as well as some units of the Dutch Creek and Horsethief Creek formations. Within the St. Mary River area the Sullivan-North Star corridor is associated with a modest positive magnetic anomaly, and an intense positive anomaly correlates with the waste dump (tailings) of the Sullivan mine (Brown et al., in press). A low amplitude positive anomaly which is approximately coincident with the St. Mary River valley may be related to detrital magnetite in the unconsolidated sediments. In addition, weak positive anomalies are associated with mafic sills which intrude the Kitchener Formation to the south of Marysville. Exposures of Nicol Creek lavas in the St. Mary River area cannot be distinguished on magnetic maps, although outside the survey area these lavas are so intensely magnetized that their distribution may be mapped by magnetic data alone.

Numerous small, isolated, sub-oval to elongate (the largest are < 1 km wide and usually 2-3 km long) positive (up to 910 nT) anomalies are observed within the otherwise weakly magnetic Aldridge Formation (Fig. 5). Their steep magnetic gradients and overall size indicates that the magnetic sources must lie in the uppermost few kilometres. Many of these small positive anomalies overlie mapped exposures of Moyie sills; ground investigations of others identified previously unmapped Moyie sills, some with magnetic susceptibilities up to 120 times higher than their host rocks (Table 1). Gabbroic sills are an important mineral control in the Sullivan deposit and their recognition elsewhere is important for mineral exploration.

The magnetic response of Moyie sills is quite variable: the majority are poorly magnetized and in many instances an anomaly is observed only over a portion of a sill, the remainder being weakly magnetic. Several samples from both magnetic and weakly magnetic sills have been obtained and are being analyzed to determine the cause for this variation and whether the magnetism is primary or secondary. An initial analysis indicates that the majority of magnetic sills outcrop near mapped faults and/or Cretaceous intrusions suggesting a secondary thermal, or possibly hydrothermal magnetism. This is especially clear for a package of sills which outcrops south of the White Creek batholith; sill segments proximal to the intrusion are more strongly magnetic than those farther away. Similarly, strings of small magnetic anomalies along and proximal to the Hall Lake and St. Mary fault systems, as well as a string extending west-southwest from Emily Creek Fault also correspond with mapped Moyie sills (Fig. 5b).

Moderate to intense (up to 340 nT) magnetic anomalies are characteristic of portions of the middle Creston Formation (Fig. 5a) comprising quartz arenites and arenaceous siltstones, which have been metamorphosed to at least upper greenschist facies (Reesor, 1996). Hand specimens from magnetic units show pervasive disseminated porphyroblastic magnetite in green arenites. Lower and upper Creston Formation phyllites with little visible magnetite, as well as maroon arenites (containing hematite rather than magnetite) in the middle Creston Formation are, by comparison, poorly magnetized. Magnetic susceptibility measurements are, on average, higher in the green quartz arenites than in other units of the Creston Formation, and where these arenites are proximal to large intrusions, such as the White Creek batholith, magnetic intensities are up to 20-30 times greater (Fig. 5). We infer the magnetism is a secondary phenomenon resulting from regional and contact thermal metamorphism. Its apparent restriction to a particular strata indicates a somewhat unique chemistry and/or petrophysical history for the green arenites relative to other units in the Creston Formation.

A series of weakly positive (+55 to +70 nT) anomalies is observed within the St. Mary valley from approximately 3 km north of the junction with Redding Creek to 5.5 km west of Marysville. The intensity of the anomalies is greatest beneath the western portion of St. Mary Lake and for approximately 5 km upstream. These anomalies, which are discordant with mapped lithologies and structures in the area, may result from detrital magnetite concentrations in the unconsolidated sediments beneath the lake and river. To test this hypothesis, unconsolidated samples from several localities in the river valley have been collected for analysis. Although some of the anomalies correspond with the present day location of the river, others are offset slightly to the north or south, indicating a possible change in the course of the river since sediment deposition. The source of the magnetite is likely magnetic Moyie sills, or the middle Creston Formation exposed in the upper reaches of Redding Creek and the St. Mary River valley.

Of the two Proterozoic bodies exposed within the survey area, the Greenland Creek stock cannot be distinguished from its middle Aldridge Formation host, whereas the lithologically comparable Hellroaring Creek stock, which intrudes similar rocks, correlates with a strong magnetic low. This difference may be attributed to very low concentrations of magnetic minerals in the Hellroaring Creek stock (Table 1).

Two magnetically distinctive suites of Cretaceous intrusions are recognized within the survey areas. The White Creek batholith, Hall Lake pluton, and Sawyer Creek stock (and Mount Skelly pluton outside the survey area) are all characterized by weakly magnetic to nonmagnetic central regions and strongly positive magnetic margins. The margins are usually both heterogeneous and discontinuous; in the White Creek batholith peak margin amplitudes vary from ~140 nT to > 850 nT and the margin varies in width from < 500 m to > 3 km (Fig. 5). In the case of the Hall Lake stock the magnetic margin is only observed over the northern portion of the body and in the case of the Sawyer Creek stock only over the southern portion. In all cases high anomaly values in the margins of the intrusions extend beyond their

mapped boundaries suggesting the bodies are more areally extensive at depth. However, hornfelsing of the host rocks adjacent to the intrusions is common and in some cases the measured susceptibility of hornfelsed units is significantly elevated indicating secondary thermal magnetization of the host units. More detailed analyses are required to determine the extent to which the high anomalies near the borders of these bodies are due to buried magnetic marginal phases rather than thermal remagnetization of the host formations.

In contrast, the Fry Creek batholith, Angus Creek stock, and Reade Lake stock (exposed a few kilometres east of St. Mary River area) are characterized by high magnetic anomaly values throughout their mapped exposures. Petrographic studies of the Reade Lake stock (Höy, 1993) indicate the source of the magnetism is pervasively disseminated magnetite. Exposures of this stock are very limited and its mapped contact was drawn from regional magnetic anomaly data (Höy and van der Heyden, 1988). Ground follow-up studies

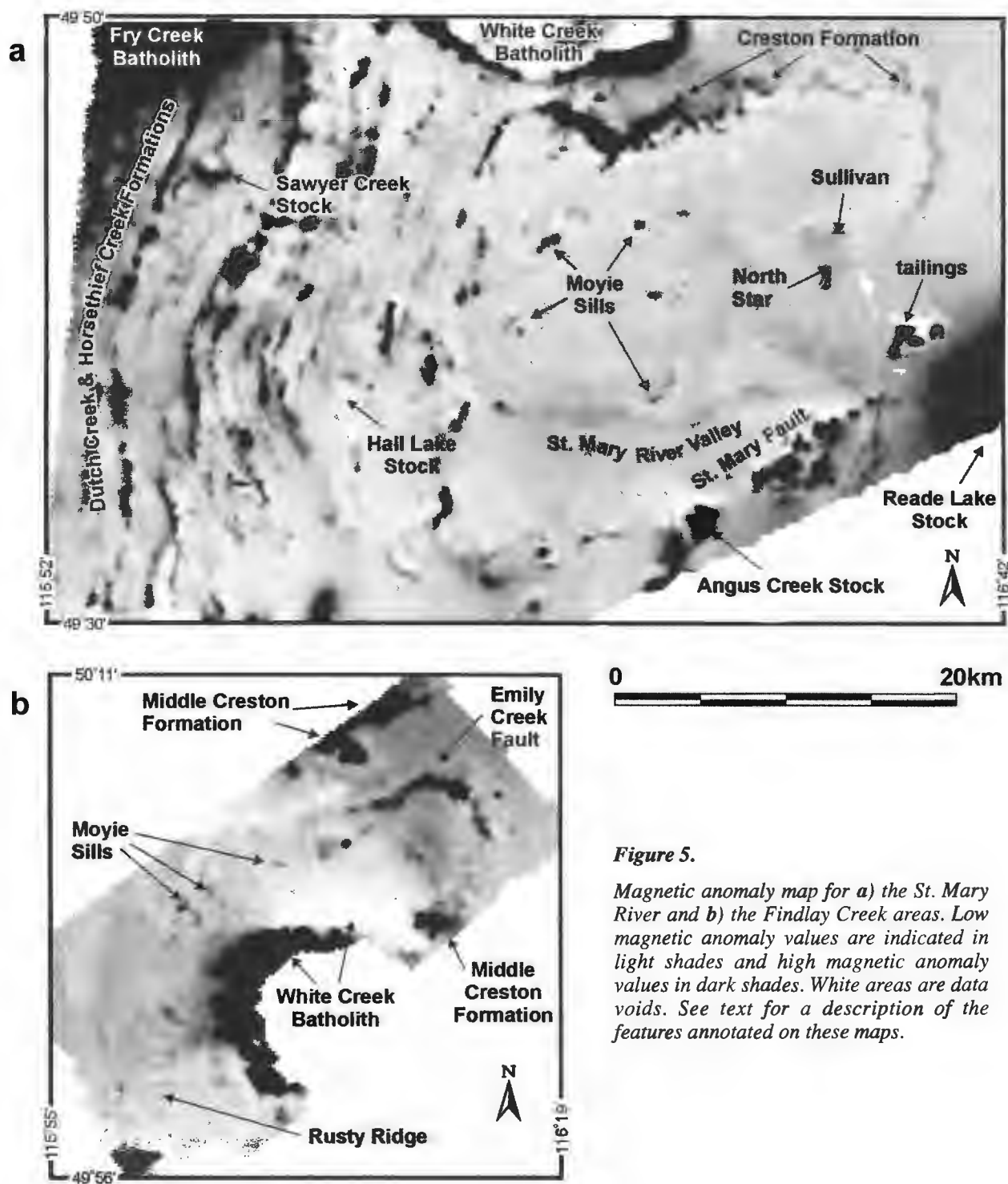


Figure 5.

Magnetic anomaly map for a) the St. Mary River and b) the Findlay Creek areas. Low magnetic anomaly values are indicated in light shades and high magnetic anomaly values in dark shades. White areas are data voids. See text for a description of the features annotated on these maps.

Table 1. Magnetic susceptibility values of rocks in the Purcell Supergroup. Abbreviation: Fm., Formation.

Age	Geological Unit	Range x 10 ⁻³ SI	Mean x 10 ⁻³ SI
Mesozoic	Intrusive rocks	0.3 - 88.0	12.04
	Hall Lake stock	1.9 - 6.5	4.20
	White Creek batholith	5.0 - 8.0	6.70
	Reade Lake stock	0.3 - 24.0	7.44
	Angus Creek stock		7.00
Paleozoic	Cranbrook/Eager Creek Fm.		1.40
	Cranbrook Fm.	0.01 - 0.4	0.27
Late Proterozoic	Horsethief Creek Fm.	0.0 - 1.3	0.87
	Toby Fm.	0.14 - 0.40	0.27
Middle Proterozoic	Hellroaring Creek stock	0.02 - 0.05	0.04
	Creston Fm.	0.0 - 150.8	17.40
	Moyie Intrusions	0.0 - 160.0	27.60
	upper Aldridge Fm.	0.0 - 0.88	0.31
	middle Aldridge Fm.	0.04 - 1.3	0.68
	lower Aldridge Fm.	0.0 - 1.8	0.59

discovered outcrops of siltstone correlative with the Eager Creek Formation exposed in what was previously mapped as Reade Lake pluton. The siltstones together with nearby exposures of Creston Formation have elevated magnetic susceptibility values compared with the measured averages of these formations indicating thermal remagnetization around the stock also.

Gamma-ray spectrometry

Although airborne and ground gamma ray spectrometry have been successfully applied to geological mapping and exploration for a variety of mineral deposit types worldwide, this survey provides the first Canadian test over SEDEX deposit settings.

Gamma-ray spectrometry is a geophysical technique which provides geochemical information about the top few tens of centimetres of the Earth's surface. As with any near surface geochemical method, such as lake, stream, soil, or biogeochemistry, interpretation requires an understanding of the nature of any surficial materials present, such as tills, or outwash, fluvial, or lacustrine deposits and their relationship to the underlying bedrock.

Potassium (K), uranium (U), and thorium (Th) are, respectively, major, mobile trace, and immobile trace elements which are present in variable amounts in all rocks and derived materials. We use the corresponding radioelement signatures (K, eU-equivalent uranium, eTh-equivalent thorium) determined from the gamma-ray spectrometric survey to characterize and map the distribution of various lithologies. Where the normal distribution of these elements is disrupted by a mineralizing process the resulting radioelement anomaly provides direct exploration guidance.

In general, radioelement patterns complement magnetic data, as they are elevated in non- to weakly-magnetic, evolved felsic rocks and relatively low in less evolved, more magnetic,

mafic units. A more thorough summary of gamma-ray spectrometry theory, techniques, and Canadian case histories is presented in Shives et al. (1995).

Within the areas surveyed, rugged topography and variable bedrock exposure significantly influence the total radioactivity measured. South-facing slopes generally present drier, better exposed bedrock and talus than north-facing slopes and consequently yield higher radioelement concentrations. This is especially obvious from an examination of K concentrations. These effects are minimized by using the radioelement ratios (eU/eTh, eU/K, and eTh/K) to reflect important relative variations between the three elements.

Regionally, a number of distinct radioelement anomalies and patterns are recognized in the new data. Pronounced eTh/K (Fig. 6) lows delineate the unique chemistry of the Hellroaring Creek and Greenland Creek stocks. These highly evolved intrusives contain either aplitic or pegmatitic phases comprised of quartz, muscovite, sodic plagioclase, and microcline feldspar, minor garnet, beryl, tourmaline, and pyrite. Field relations and a zircon U-Pb age of 1365 Ma suggest these stocks were emplaced during deformation associated with the end of the Belt-Purcell sedimentation (Höy et al., 1995).

Outcropping Moyie sills are characterized by low concentrations of all three radioelements, but are best delineated by very low eU concentrations. This correlation offers assistance for improved sill mapping. (Note that water-covered areas, and wet swampy areas also produce very low total radioactivity.)

Unconsolidated deposits along the major drainages, such as the St. Mary River valley (Fig. 6) and Redding Creek, produce high eTh/K ratio patterns. This signature is characteristic of fluvial deposits in many areas throughout Canada, reflecting the low K associated with the water, swamps, and wet clays/sands/gravels (see K map in British Columbia Ministry of Employment and Investment, 1996), coupled

with elevated levels of stable thorium-bearing minerals associated with heavy mineral concentrations (see also discussion on *Magnetics* above).

Along the western edge of the St. Mary River survey area, high eTh/K ratio levels accurately demarcate quartzite within the Horsethief Creek Formation, (Fig. 6; unit HH₂ of Reesor, 1996). The anomaly is caused by the extremely low K content and elevated thorium-bearing accessory minerals in the quartzite.

East of this trend a series of low eTh/K ratio anomalies define a linear trend, associated with Late Proterozoic Toby Formation. In this case, the airborne pattern reflects the very low eTh contents of this unit (6 ppm eTh) and offer future mapping assistance.

Within the stratigraphic section southwest of the Sullivan mine area, broad areas of elevated eU and eTh patterns correlate with argillaceous upper Aldridge and lower Creston formations. Reesor's (1996) subdivision of these units in this

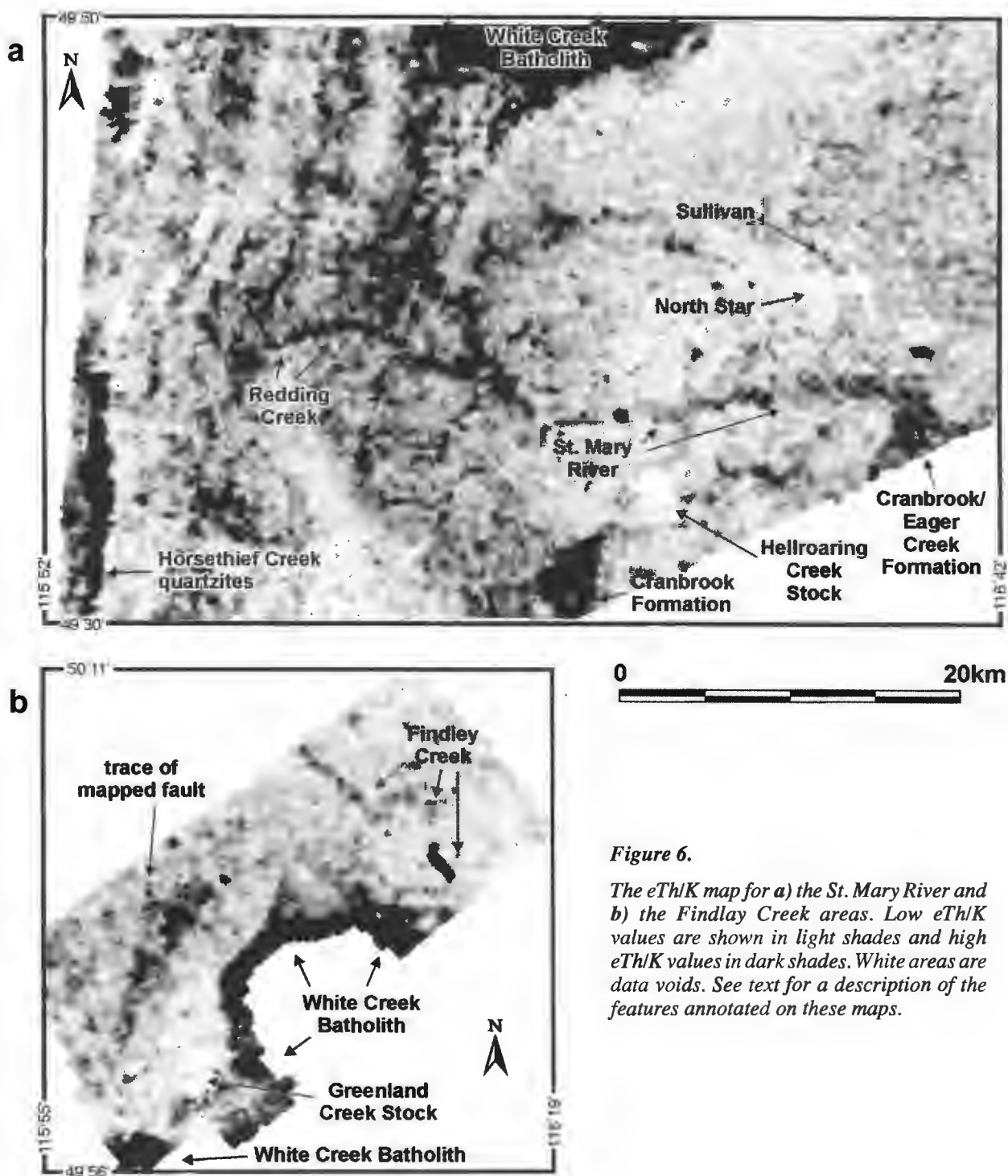


Figure 6.

The eTh/K map for a) the St. Mary River and b) the Findlay Creek areas. Low eTh/K values are shown in light shades and high eTh/K values in dark shades. White areas are data voids. See text for a description of the features annotated on these maps.

area supports this correlation, suggesting extension of contacts into unmapped areas is possible. The lower/middle Creston boundary, defined by a decrease in eU and eTh levels, is coincident with the transition from low to moderate magnetic anomaly values described above. These strong, complementary radioelement/magnetic relationships continue to the east, along Matthew Creek and are truncated to the south by the Kimberley Fault.

Radioelement variations in the White Creek batholith correlate with mapped phases (Reesor, 1996) and clearly distinguish this batholith from the smaller Cretaceous stocks within the St. Mary River area which are characterized by lower radioelement concentrations.

SUMMARY

The data discussed above are the first high-resolution, public-domain multiparameter geophysical data available for the Purcell Anticlinorium. Our initial analysis indicates they offer a significant opportunity to refine our understanding of the regional geology. In particular, ground follow-up of coincident low eU concentrations and high magnetic anomaly values led to the recognition of previously unmapped Moyie sills in the St. Mary River area. Extension of the Emily Creek Fault in the Findlay Creek area is suggested by the string of magnetic Moyie sills which trend west-southwest from the mapped fault trace. In addition, investigations show the Reade Lake stock is less extensive at surface than previously mapped. Significant hornfelsing and thermal remagnetization around several of the mapped Cretaceous bodies is indicated in the magnetic data and was confirmed in ground follow-up studies of the Eager Creek and Creston formations outcropping in the aureoles around a number of these bodies. The extent to which the hornfelsed zones are mineralized is yet to be determined. Radioelement variations within and between lithologies in several areas indicates revision of the mapped geology is possible. Coincident conductivity anomalies, finite conductors, and elevated magnetic anomaly values characterize several known mineral deposits and occurrences in the survey areas. The new data identify several others which were not previously recognized. For all these reasons the data will be valuable for focusing mineral exploration initiatives in these areas.

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REFERENCES

- Anderson, D.**
1985: Diamond drilling report, Vulcan Property; British Columbia Energy, Mines, and Petroleum Resources, Assessment Report 14, 198 p.
- Anderson, H.E. and Davis, D.W.**
1996: U-Pb geochronology of the Moyie sills, southeastern British Columbia: implications for the Middle Proterozoic geologic history of the Purcell (Belt) basin; *Canadian Journal of Earth Sciences*, v. 32, p. 1180-1193.
- British Columbia Ministry of Employment and Investment**
1996: East Kootenay Geophysical Survey, British Columbia, Geological Survey of Canada, Open File 2628.
- Brown, D.A., Lowe, C., Shives, R.B.K., and Best, M.E.**
in press: The East Kootenay Multiparameter geophysical survey, southeastern British Columbia (82F, G, K) – Sullivan-North Star Area; in *Geological Fieldwork 1996*; British Columbia Ministry of Employment and Investment, Paper 1996-1.
- Carter, G. and Höy, T.**
1987: Geology of the Skookumchuck map area (W1/2), southeastern British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1987-8.
- Höy, T.**
1984a: Structural setting, mineral deposits, and associated alteration and magmatism, Sullivan camp, southeastern British Columbia; in *Geological Fieldwork 1983*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1984-1, p. 24-35.
1984b: Geology of the Cranbrook sheet and Sullivan map area; British Columbia Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 54.
1993: Geology of the Purcell Supergroup in the Fernie west-half map area, southeastern British Columbia; British Columbia Ministry of Energy, Mines, and Petroleum Resources, Bulletin 84, 157 p.
- Höy, T. and van der Heyden, P.**
1988: Geochemistry, geochronology, and tectonic implications of two quartz monzonite intrusions, Purcell Mountains, Southeastern British Columbia; *Canadian Journal of Earth Sciences*, v. 25, p. 106-115.
- Höy, T., Turner, R., and Leitch, C.**
1995: Depositional environment, alteration, and associated magmatism, Sullivan and related massive sulphide deposits, southeastern B.C.; *Geological Association of Canada-Mineralogical Association of Canada, Field Trip Guidebook*, 80 p.
- Leech, G.B.**
1957: St. Mary Lake, Kootenay District, British Columbia (82F/9); Geological Survey of Canada, Map 15-1957.
- Reesor, J.E.**
1958: Dewar Creek map-area with special emphasis on the White Creek Batholith, British Columbia; Geological Survey of Canada, Memoir 292, 78 p.
1973: Geology of the Lardeau map-area, east-half, British Columbia; Geological Survey of Canada, Memoir 369, 129 p.
1983: Geology of the Nelson map-area, east-half; Geological Survey of Canada, Open File 929.
1996: Geology of Kootenay Lake, British Columbia; Geological Survey of Canada, Map 1864A.
- Rice, H.M.A.**
1937: Cranbrook map-area, British Columbia; Geological Survey of Canada, Memoir 207.
1941: Nelson map-area, east-half; Geological Survey of Canada, Memoir 228, 86 p.
- Shives, R.B.K., Ford, K.L., and Charbonneau, B.W.**
1995: Applications of gamma ray spectrometric-magnetic-VLF/EM surveys; Workshop manual; Geological Survey of Canada, Open File 3061.
- Webber, G.L.**
1979: Diamond drilling report on Vulcan group of mineral claims; British Columbia Ministry of Energy, Mines and Petroleum Resources, Assessment Report 7, 689 p.

Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 4: investigation of continental and montane advances in the Beaver Mines map area, southwestern Alberta¹

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Holme, P.J., 1997: Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 4: investigation of continental and montane advances in the Beaver Mines map area, southwestern Alberta; in Current Research 1997-A; Geological Survey of Canada, p. 177-182.

Abstract: The all time limits of montane and continental glacial ice were determined from field mapping and stratigraphic investigations of Beaver Mines map area (82G/8). Preliminary interpretation of Quaternary sediments in six major cliff-bank exposures suggests evidence for a retreat of montane ice following the climax of the late Wisconsinan Glaciation in Rocky Mountains and a subsequent smaller readvance. A single clast from the Canadian Shield was found within a till at one exposure. Preliminary glacial histories compatible with the stratigraphy are: an initial primary montane advance followed by retreat and a smaller readvance prior to a continental advance into the map area or a continental advance in the interim between the primary and secondary montane advances.

Résumé : Les limites maximales d'avancée du glacier alpin et du glacier continental ont été déterminées à partir d'études cartographiques et stratigraphiques effectuées sur le terrain dans la région cartographique de Beaver Mines (82 G/8). L'interprétation provisoire des sédiments quaternaires exposés dans six falaises indiquent un retrait du glacier alpin après le pléniglaciaire du Wisconsinien supérieur dans les Rocheuses et une réavancée subséquente moins importante. On n'a trouvé qu'un seul claste provenant du Bouclier canadien dans un till exposé. L'histoire provisoire des avancées qui est compatible avec la stratigraphie comporte une première avancée du glacier alpin suivie par un retrait et par une réavancée moins importante avant une avancée du glacier continental dans la région cartographique ou une avancée du glacier continental entre l'avancée et la réavancée du glacier alpin.

¹ Contribution to the Eastern Cordillera NATMAP Project

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INTRODUCTION

The surficial geology of the 1:50 000 Beaver Mines (82G/8) map area (Fig. 1) was mapped during the field seasons of 1995 and 1996. This paper presents the preliminary findings of the mapping and Quaternary stratigraphic investigations. Beaver Mines is the last of twelve 1:50 000 map sheets completed as part of the surficial geology component of the National Geoscience Mapping Program (NATMAP) in southwestern Alberta. Data gathered in the field and results of the laboratory analysis will, in addition to contributing to the NATMAP project, form the basis of the author's Masters of Science thesis in the Department of Earth Science at the University of Western Ontario, London, Ontario.

PREVIOUS WORK AND THE PRESENT STUDY

Investigations of the Quaternary stratigraphic record of southwestern Alberta have been conducted by many authors. These studies have produced two incompatible interpretations of Quaternary history and stratigraphy. The first and, until recently, the established view interprets multiple till units in the Oldman Valley and high erratics and paleosols in the adjacent Foothills and Rocky Mountains as supporting multiple glaciation of the region by ice originating in the continental interior (the Laurentide Ice Sheet and its predecessors from earlier glaciations) (Alley, 1973; Stalker and Harrison, 1977; Jackson, 1980; Jackson et al., 1989; Jackson, 1994). The second view, recently corroborated by stratigraphic investigations in central Alberta (Liverman et al., 1989; Young et al., 1994) is a revival of the interpretations of Horberg (1954), Wagner (1966), and Bayrock (1969), by Leboe (1995), Little (1995), and Jackson et al. (1996) who concluded continental till and high erratics in the Oldman River basin are the result of a single (Late Wisconsinan) incursion of continental ice into the region during the Pleistocene. This paper provides further preliminary results that have bearing upon this evolving stratigraphic revision.

FIELD METHODS

Preliminary surficial geology mapping was done through airphoto interpretation using 1:60 000 scale airphotos. Extensive ground-truthing was then conducted to achieve more detail and better resolution of the map unit boundaries. The ground-truthing work consisted mainly of using a hand-held auger to retrieve material from the top metre of the ground for description. In addition, all artificial or natural exposures of sediment were examined and their stratigraphy described. Other goals of the ground-truthing included establishment of the former upper limits of montane and continental ice by locating the highest glacial erratics, sampling of surficial sediments, and establishment of geochronological control of deglaciation using late Quaternary tephra. Sediment sampling concentrated on till. Samples are undergoing grain-size, geochemical, and Chittick analyses. In addition, pebble lithology and heavy mineral analyses will be carried out to

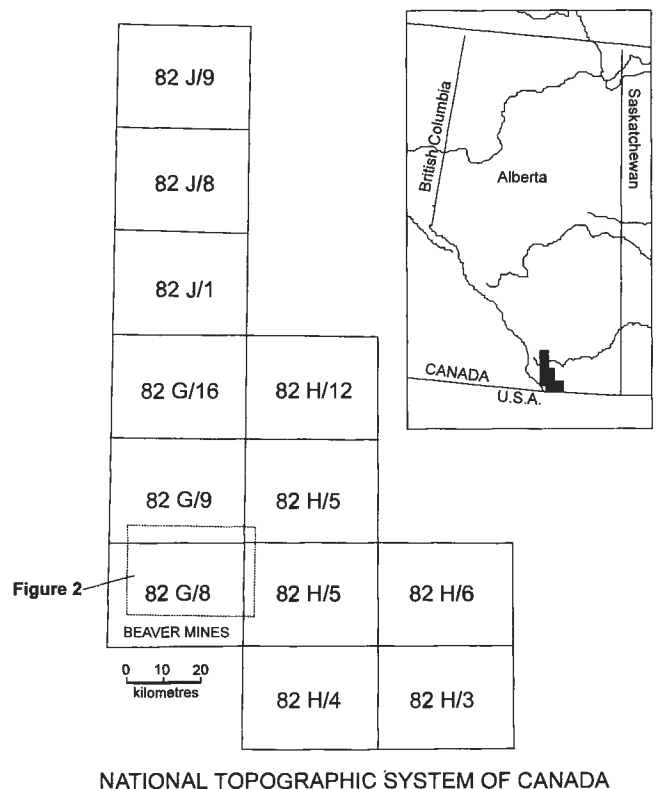


Figure 1. Location of the Southeastern Cordillera NATMAP project and Beaver Mines map area.

determine till provenance. Atterberg limits will be determined on selected samples in order to classify till units within the Unified Soil Classification Scheme. All field notes were entered into a relational database (Fieldlog) and maps were digitized using AutoCAD. Travel was by 4x4 truck, Quadrunner all-terrain vehicles, helicopter, mountain bike, and on foot.

PRELIMINARY FINDINGS

Surficial geology

For the purposes of describing the surficial geology, the map area will be divided into four topographically significant regions: Rocky Mountains, Rocky Mountain front, Foothills, and Castle River Lowland.

Rocky Mountains

This subregion encompasses both the Clarke Range, which comprises the southern third of the map area and the Blairmore Range in the northwest corner of the map area. Emphasis was placed on ground-truthing within valleys because few Quaternary sediments are present on the upper slopes and ridge tops. Lower slopes are predominantly mantled by montane till deposits overlain by colluvial material from the upper slopes. Landslide deposits were found throughout this region (Jackson, 1995).

Rocky Mountain Front

This subregion refers to the mountain front of the Clarke Range east of the Castle River. Extensive deposits of colluvial material, some of it colluviated till, were found on the upper slopes of the mountain front, whereas the lower slopes were dominated by till, either as a veneer or a blanket. The lowermost slopes and the lowland between the mountain front and the southwesternmost foothills were blanketed by extensive glaciofluvial deposits.

Foothills

The Foothills occur as roughly parallel rows of disconnected sandstone ridges trending northwest/southeast which reflect the general strike of their bedding. Montane provenance till was found to blanket most slopes of the southwesternmost Foothills up to an elevation of about 1615 m, whereas the remainder of slopes are covered in colluvium. Above 1615 m, montane erratics are the only evidence of past glacial ice cover. Close to the mountain front, montane erratics occur on Foothills ridges as high as 1735 m, but are scarce above about 1675 m.

The Foothills ridges in the northeast quarter of the map area are lower than those closer to the mountains. The all-time Laurentide maximum limit in this area was determined based on the locations of Laurentide erratics found while mapping

(Fig. 2). Erratics of Canadian Shield provenance were found up to 1340 m on a low hill in the northeast corner of the map area (UTM N5483200, E712640) and up to 1325 m on the northeast slope of a hill 6 km to the southwest (UTM N5479800, E707470). Scattered lacustrine or glaciolacustrine deposits were found in the small valleys between the Foothill ridges.

Castle River Lowland

The Castle River valley in the northeast corner of the map area is largely incised into an extensive lowland underlain by thick glaciolacustrine sediments. The approximate upper limit of these glacial lake sediments is 1310 m, although it is lower in some areas. These lake sediments generally overlie Laurentide till where exposures occur along their margins.

Quaternary stratigraphy

The subsurface Quaternary stratigraphy of the study area is based upon the study of six extensive cliff-bank exposures (Fig. 2, 3). These give a representation of the stratigraphy from the Rocky Mountains northeastward into the Castle River Lowland (Fig. 2). They are summarized in that order. Sections are described from the base of the exposure upward. All tills described are montane in origin. Units designated in

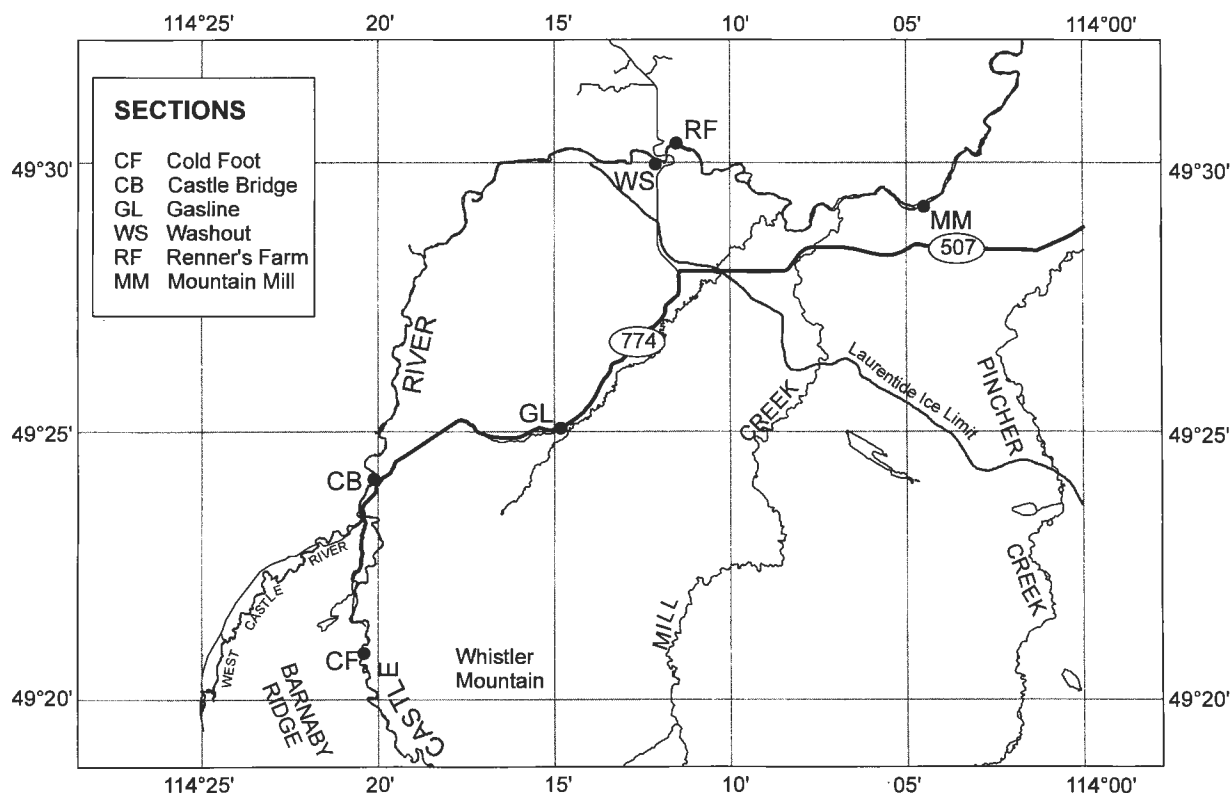


Figure 2. Locations of described sections and limits of surface Canadian Shield erratics transported into Foothills by the Laurentide Ice Sheet. The Rocky Mountain front lies immediately to the southwest of Barnaby Ridge. The Castle River Lowland parallels the Castle River beginning as Washout section (WS).

each section and are not necessarily correlative to same numbered units in other sections. Lines between sections indicate tentative correlations.

Coldfoot section

This exposure is located on the south arm of the Castle River between Whistler Mountain and the north end of Barnaby Ridge.

Unit 1: Imbricated boulder gravel fining upward into a pebble gravel which is overlain by rhythmically bedded clay and silt.

Unit 2: Poorly sorted gravel which coarsens upward and is slightly imbricated in the lower part of the unit.

Unit 3: Indurated diamicton.

Unit 4: Poorly to moderately sorted gravel, foreset bedded at the upstream end of the exposure.

Unit 5: Thinly bedded sand. Some beds have soft sediment deformation features.

The upper part of the succession (units 2 to 4) constitutes a classic alpine glacial advance/retreat sequence of upward coarsening outwash gravel overlain by a till which is overlain by retreat phase outwash gravel. Unit 3 is interpreted as a lodgement till due to its induration. Unit 5 is interpreted as lacustrine and not glaciolacustrine due to the lack of drop-stones in the sediment. The base of the Quaternary fill in the valley was not exposed.

Castle Bridge section

This exposure is located on the Castle River almost 6 km due north of the Coldfoot section. It is an extensive exposure up to 38 m in height by approximately 300 m in length.

Unit 1: Stratified sand overlain by generally unsorted, weakly stratified gravel.

Unit 2: Indurated diamicton, blocky ped structure.

Unit 3: Unsorted, less indurated diamicton.

Unit 4: Imbricated, moderately sorted pebble and cobble gravel.

Unit 5: Silt and fine sand.

Unit 6: Eolian sand.

Unit 2 was interpreted as a basal till based on its strong southwest fabric (S1 Eigen value = 0.56, S3 value = 0.10), induration, and ped structure. The overlying diamicton (unit 3) also has a very strong fabric (S1 value = 0.70, S3 value = 0.10). The principal mode is transverse to the ice flow direction indicated in the fabric from the underlying till. The transverse fabric suggests the possibility that the overlying diamicton (unit 3) is a flow till. Further work on the environment of deposition of these units is planned for the 1997 field season.

Gasline section

This section is located about 5.5 km southwest of the hamlet of Beaver Mines alongside the Secondary Road 774. This gully exposure, up to 3 m deep, was created by the scouring out of the roadside ditch by flood water in June 1995. It has since been completely filled as a part of postflood reconstruction. Its stratigraphy was very similar to the previous exposures (diamicton overlain by glaciofluvial gravel).

Unit 1: Highly indurated diamicton.

Unit 2: Indurated diamicton with soft sediment flow features.

Unit 3: Sand, silt, and clay.

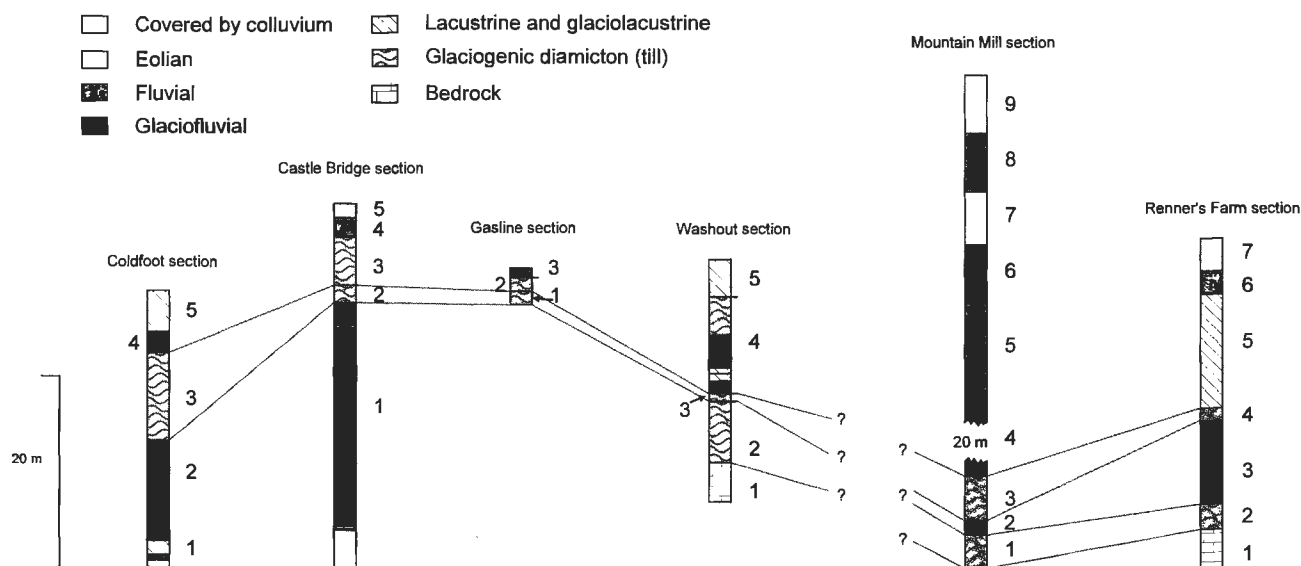


Figure 3. Generalized stratigraphy. Numbers refer to the units discussed in the text. Like-numbered units are not necessarily correlative. Tentative correlations are denoted by lines linking sections.

Unit 1 is interpreted as a lodgement till mainly due to its high degree of consolidation. The preliminary interpretation of unit 2 is a flow till due to the presence of flow features. Bedrock exposed nearby, but was not exposed at the base of the described exposure.

Mountain Mill section

This section is located on the Castle River along the north edge of the map sheet about 8 km due west of Pincher Creek. It was described first by Stalker (1969) and his descriptions are incorporated in Figure 3 (units 3-9). The June 1995 flood washed away much of the slump material at the base of the cliff revealing stratigraphy unavailable to Stalker. The newly exposed sediments consisted of a diamicton (unit 1) overlain by two glaciofluvial gravel layers (unit 2), all underlying the lowest diamicton (unit 3) described by Stalker. Fabrics were measured on units 1 and 3. Unit 3 has a strong fabric reflecting ice-flow from the west-south (principal S1 Eigen value = 0.71, S3 value = 0.07). The fabric from unit 1 indicates ice-flow from the southwest (S1 value = 0.56, S3 = 0.12). Both diamictons are interpreted to be basal tills due to their induration, montane clast lithologies and fabrics. The 34 m of glaciofluvial gravel (unit 4) overlying the upper diamicton (Stalker, 1969) contains clasts from the Canadian Shield. There are no Shield clasts found in units 1-3.

Washout section

This exposure is located at the northern edge of the map area on the west side of Highway 507 North immediately south of the bridge over Castle River. The exposure was created by flood water scouring out a gulley along the roadside in June 1995. The exposure was up to 3 m in depth, but has since been back-filled completely by highways crews. The exposure descended through the Quaternary fill in this area of the Castle River valley over a distance of about 330 m from north to south and thus gave a good horizontal as well as vertical cross-section.

Unit 1: Striated bedrock.

Unit 2: Indurated, fissile diamicton.

Unit 3: Diamicton. Contains at least one clast of granodiorite from the Canadian Shield which was noted at the contact with the underlying unit.

Unit 4: A complex assemblage of interstratified sand, silt, clay, diamicton, and gravel.

Unit 5: Glaciolacustrine sand, silt, and clay. This unit underlies the glaciolacustrine plain of the Castle River Lowland.

Unit 2 was interpreted to be a lodgement till due to its high degree of fissility and induration. Unit 3 is interpreted as a distinct till due to the presence of a Shield clast.

Rener's Farm section

This 30 m cliff-bank exposure is located just north of the northern boundary of the map on the Blairmore map sheet (82 G/9).

Unit 1: Bedrock

Unit 2: Indurated diamicton

Unit 3: Glaciofluvial gravel.

Unit 4: Indurated diamicton

Unit 5: Glaciolacustrine clayey silt. Underlies the glaciolacustrine plain of Castle River Lowland.

Unit 6: Poorly sorted gravel.

Unit 7: Eolian sand.

The diamictons (units 2 and 4) and intervening gravel (unit 3) lack any clasts from the Canadian Shield. The diamictons were interpreted to be basal till based on fabric data, clast lithologies, and correlation with till units at other exposures. A fabric determined in the lower diamicton indicated flow from the west (S1 Eigen value = 0.67, S3 value = 0.13). A fabric determined in the upper diamicton indicated ice flow from the northwest (S1 = 0.56, S3 = 0.20).

PRELIMINARY INTERPRETATIONS

The following preliminary findings have been reached based upon surficial geology mapping and stratigraphic interpretations.

Montane glacial advances

Montane till correlated to the late Wisconsinan "Maximum Glaciation" (informal term) of Jackson et al. (1996) was found at all six stratigraphic exposures (Fig. 3). Two montane tills, separated by fluvial sediments, are present at only two of the exposures: Mountain Mill and Rener's Farms sections. Of the other four major exposures, only one (the Washout Section) has the Quaternary valley fill exposed to bedrock. The succession of two montane tills separated by glaciofluvial deposits at Mountain Mill and Rener's Farm sections is interpreted as documenting retreat of ice to near the Rocky Mountain front after the major montane glacial advance of the Maximum Glaciation followed by a subsequent smaller readvance. Since the Coldfoot, Gasline, or Castle Bridge sections are not exposed to bedrock and intertill outwash is lacking at Washout section, it is not possible to determine the extent of ice retreat upstream from the Mountain Mill and Rener's Farm sections. The single or basal tills exposed at these three upstream sections have been preliminarily correlated with the upper till at Washout section (Fig. 2).

Laurentide Ice Sheet advance

Although till from the all time (late Wisconsinan) advance of the Laurentide Ice Sheet (Jackson et al., 1996) was mapped along the edge of the glaciolacustrine lake plain in the northeast corner of the map area and shield erratics are found as high as 1340 m, a single Canadian Shield stone was found in only one till unit at one of the six exposures (Washout section) described above. However, clasts from the Canadian Shield were found in abundance in the thick glaciofluvial deposits

(unit 4) overlying the upper till unit at the Mountain Mill section. The almost complete absence of Laurentide till and Canadian Shield erratics in an area close to and in part at a lower elevation than the known limit of the Laurentide Ice Sheet must be explained. In this preliminary report, the author suggests two possible hypotheses to explain the absence of Shield clasts.

Hypothesis 1: Laurentide ice advanced into the area after montane ice had retreated but the deposits were eroded by subsequent glaciofluvial activity resulting from the continued retreat of the montane ice. Some of the Canadian Shield-provenance clasts were incorporated into the montane outwash. This would account for the incorporation of Shield material in the glaciofluvial deposits at the Mountain Mill exposure and the lack of Shield stones in the underlying till and intervening gravel there.

Hypothesis 2: The Shield stone noted along the contact between diamictons at the Washout section was deposited during the climax of the Laurentide Ice Sheet which occurred between the primary montane advance of the Maximum Glaciation and a secondary montane readvance.

Outwash from the montane readvance deposited reworked Shield clasts in the unit 4 gravels of the Mountain Mill section.

Plans are being made to test these working hypotheses during the fieldwork in 1997.

CONCLUSIONS

The Beaver Mines area was glaciated up to 1735 m elevation in the Foothills near the mountain front and up to 1340 m farther east and north. The maximum known advance of montane glacial ice was followed by retreat to the Foothills and then a readvance. Evidence for readvance is based upon the presence of two tills units at two key stratigraphic exposures. Although a single Laurentide till from the Late Wisconsinan Maximum Glaciation is present in the northeast corner of the map area (up to 1340 m), it is not present in exposures of sediment only 10 km to the west although a single shield stone was found between two montane tills. Two working hypotheses are currently being entertained: the absence of Laurentide till within the Castle River valley is the result of glaciofluvial erosion and removal of the till after deposition or, alternatively, the Laurentide Ice Sheet advanced into the map area between montane advances with its drift being incorporated into deposits of the subsequent montane readvance.

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REFERENCES

- Alley, N.F.
1973: Glacial stratigraphy and the limits of the Rocky Mountain and Laurentide ice sheets in southwestern Alberta, Canada; *Bulletin of Canadian Petroleum Geology*, v. 21, p. 153-177.
- Bayrock, L.A.
1969: Incomplete continental glacial record of Alberta, Canada; *Quaternary Geology and Climate*, Publication 1701, National Academy of Sciences, Washington, D.C., p. 99-103.
- Horberg, L.
1954: Rocky Mountain and continental Pleistocene deposits in the Waterton region, Alberta, Canada; *Bulletin of the Geological Society of America*, v. 66, p. 1093-1150.
- Jackson, L.E., Jr.
1980: Glacial stratigraphy and history of the Alberta portion of the Kananaskis Lakes map area; *Canadian Journal of Earth Sciences*, v. 17, p. 459-477.
1994: Quaternary geology and terrain inventory, Foothills and adjacent plains, southwestern Alberta: some new insights into the last two glaciations; in *Current Research 1994-A*; Geological Survey of Canada, p. 237-242.
1995: Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 1: regional landslide characterization; in *Current Research 1995-A*; Geological Survey of Canada, p. 159-166.
- Jackson, L.E., Jr., Little, E.C., Leboe, E.R., and Holme, P.J.
1996: A re-evaluation of the paleoglaciology of the maximum continental and montane advances, southwestern Alberta; in *Current Research 1996-A*; Geological Survey of Canada, p. 165-173.
- Jackson, L.E., Jr., Rutter, N.W., Hugues, O.L., and Clague, J.J.
1989: Glaciated fringe; in Chapter 1 of *Quaternary Geology of Canada and Greenland*, (ed.) R.J. Fulton; Geological Survey of Canada, *Geology of Canada*, no. 1 (also *Geological Society of America, The Geology of North America*, v. K-1).
- Leboe, E.R.
1995: Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 2: surficial geology and Quaternary stratigraphy, Pincher Creek and Brocket map areas, Alberta; in *Current Research 1995-A*; Geological Survey of Canada, p. 167-175.
- Little, E.C.
1995: Quaternary geology and terrain inventory, Eastern Cordillera NATMAP Project. Report 3: two continental glacial advances in Waterton and Cardston map areas, Alberta; in *Current Research 1995-A*; Geological Survey of Canada, p. 177-182.
- Liverman, D.G.E., Catto, N.R., and Rutter, N.W.
1989: Laurentide glaciation in west central Alberta: a single (Late Wisconsinan) event; *Canadian Journal of Earth Sciences*, v. 26, p. 266-274.
- Stalker, A. MacS.
1969: A probable late Pinedale terminal moraine in Castle River valley, Alberta; *Geological Society of America, Bulletin*, v. 80, p. 2115-2122.
- Stalker, A. MacS. and Harrison, J.E.
1977: Quaternary glaciation of Waterton-Castle River region; *Bulletin of Canadian Petroleum Geology*, v. 25, p. 882-906.
- Wagner, W.P.
1966: Correlation of Rocky Mountain and Laurentide glacial chronologies in southwestern Alberta, Canada; PhD. thesis, Department of Geology, University of Michigan, Ann Arbor, Michigan, 141 p.
- Young, R.R., Burns, J.A., Smith, D.G., Arnold, L., and Rains, R.B.
1994: A single, late Wisconsin, Laurentide glaciation, Edmonton area and southwestern Alberta; *Geology*, v. 22, p. 683-686.

Geological Survey of Canada Project 930043-01

Quaternary geology of the Nass River region, British Columbia

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McCuaig, S.J., 1997: Quaternary geology of the Nass River region, British Columbia; in Current Research 1997-A; Geological Survey of Canada, p. 183-189.

Abstract: Evidence of one major glaciation was found in the Nass River region. At the glacial maximum, ice flowed southwest from an ice divide northeast of the study area. It overrode soft metasedimentary rocks in the northeast and deposited compact, clay-rich till derived from them over the entire region. Active ice flow continued throughout deglaciation. Complex frontal retreat and downwasting resulted in the confinement of glaciers to major valleys and fiords. Glaciofluvial sediments were deposited in front of receding ice and small proglacial lakes formed locally. Glaciomarine clays were laid down in fiords and possibly in the Nass Valley. The timing of these events is not yet known.

Résumé : Des indices d'une glaciation majeure ont été relevés dans la région de la rivière Nass. À l'époque du pléniglaciaire, la glace s'écoulait vers le sud-ouest à partir d'une ligne de partage glaciaire au nord-est de la région à l'étude. Elle a surmonté des roches métasédimentaires tendres au nord-est et déposé un till argileux compact dérivé de ces roches sur toute la région. L'écoulement glaciaire s'est poursuivi pendant la déglaciation. Le retrait et l'amaigrissement complexes du front ont contribué à confiner les glaciers aux vallées et aux fjords principaux. Des sédiments fluvioglaciaires ont été déposés devant un glacier en retrait et de petits lacs proglaciaires se sont formés par endroits. Des argiles glaciomarines se sont accumulées dans les fjords et peut-être dans la vallée de la rivière Nass. La chronologie de ces événements n'est pas encore connue.

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This paper reports on a regional Quaternary geology mapping project carried out during the summer of 1996. Goals of the project include the production of regional Quaternary geology maps and the determination of the area's glacial history. To this end, airphoto interpretation was completed and followed by ground truthing. Fieldwork included foot, boat, truck, and helicopter reconnaissance. Approximately 40% of the map area was visited and eleven 1:50 000 scale draft maps of Quaternary geology were completed. These are being compiled into two regional maps at 1:100 000 scale.

SETTING

The map area encompasses parts of the Western and Interior physiographic regions of the Canadian Cordillera (Holland, 1976), represented by the Coast Mountains and Nass Basin respectively. The Nass Basin is a wide, bedrock influenced

The map displays the Kootenai River drainage area in British Columbia, Canada. The Kootenai River flows from the north, through the Boundary Ranges, and into the Kitimat Ranges. Key features include the Kootenai River, Boundary Ranges, Kitimat Ranges, and the Kootenai River. The map also shows the location of the Kootenai River, Boundary Ranges, and Kitimat Ranges. The map includes an inset map of Canada, a scale bar (0-20 km), and coordinates (56°N, 130°15'W).

lowland which trends southeastward in the northeastern part of the study area. The Coast Mountains are divided into the Boundary Ranges in the north and the Kitimat Ranges in the south, the former comprising most of the map area (Fig. 1). Mountain peaks range from 1100 to 2200 m a.s.l. and alpine ice caps such as the Cambria Ice Field (Fig. 1) are present at high elevations. The landscape has been carved and smoothed by glaciation. Jagged and rounded mountain peaks and ridges separate numerous U-shaped valleys. Horns, aretes, and cirques are prevalent at higher elevations, while rounded ridges are common at lower ones. Hanging valleys are characteristic features of the larger valleys and fiords. Steep-sided coastal fiords in the west extend for tens of kilometres, emphasizing the considerable vertical relief in this region. In the eastern part of the map area, relief is not as pronounced, and the mountains are often flat-topped, possibly part of a former plateau. The Nass River occupies a major southwest-trending valley in the south, separating the Boundary and Kitimat ranges. It also flows along the Nass Basin.

Climate

The region has cold, wet winters and cool summers due to the influence of Polar Maritime air (Farley, 1979). Mean annual precipitation ranges from 150 to 350 cm, with the higher mountain peaks receiving the most precipitation, mainly in the form of snow (Farley, 1979). January temperatures average between 0° and -15°C, while July temperatures average 14–16°C in the lowlands and less than 14°C in the mountains.

The biogeoclimatic zones of the map area include coastal western hemlock in valleys and fiords, as well as Engelmann spruce/subalpine fir, subalpine mountain hemlock and alpine tundra, listed in order of increasing elevation (Farley, 1979).

Bedrock

The Jura-Cretaceous Bowser Lake Group forms the bedrock in the east and south sectors of the map area. The rocks of this group are slightly metamorphosed, consisting of sandstone (lithic or arkosic arenite), siltstone, and mudstone turbidite sequences (Evenchick and Mustard, 1996). Bowser Lake Group rocks are grey or dark grey in the Nass Basin (Evenchick and Mustard, 1996) and blue-grey elsewhere.

Paleozoic to Cenozoic plutons are major bedrock constituents in the western part of the map area, consisting of quartz monzonite, granodiorite, and granite (Greig and Gehrels, 1995; Evenchick and Mustard, 1996).

Interbedded metavolcanic and metasedimentary rocks of Triassic-Jurassic age are found in the north and northwest, as well as in the Anyox region. Detailed mapping of these units has been done in a few selected areas. Mudstone, siltstone, sandstone, wacke, and conglomerate of the Kitsault Valley area are interbedded with porphyritic basalt, volcanic breccia, and andesitic tuff (Dawson and Alldrick, 1986). Tertiary quartz monzonite and granodiorite intrusions and micro-diorite to lamprophyre dykes are present locally. In the vicinity of Kinskuch Lake, siltstone, sandstone, limestone, chert, and turbidite sandstone sequences alternate with mafic

pyroclastics, felsic tuff, felsic tuff-breccia, and porphyritic dacite (Greig, 1992). These rocks are subdivided into the Stuhini and Hazelton groups (Greig, 1992). Rhyolite dykes and sills intrude the youngest formations. Sandstone, siltstone, mudstone, tuff, and basalt are also found in the Anyox area (Sharp, 1980).

Young lava flows of columnar basalt are present locally in the Kwinatahl and Nass valleys (Evenchick and Mustard, 1996). Their age is not yet known, but they may be Quaternary or Tertiary. A Holocene lava flow spans the Tseax River valley and extends into the Nass River area, near the town of New Aiyansh. The Aiyansh flow is an alkali basalt flow that occurred about 220 years ago and appears to have altered the course of the Nass River (Sutherland Brown, 1969).

PREVIOUS WORK

Detailed Quaternary studies for the region are available only to the south of the present study area, in the Lower Skeena Valley and in the Kitsumkalum-Kitimat Trough (Clague, 1984a, b). Extensive glaciomarine, glaciofluvial, and deltaic deposits have been mapped in this area, but till is uncommon. At the onset of deglaciation, when sea level was about 200 m higher than present, glaciomarine sediments were deposited in fiords as ice retreated. Large delta-sandur complexes formed at the ice margins when retreating valley glaciers stabilized for short periods. In the late stages of deglaciation, a large glacial lake formed in the Kitsumkalum Lake area (Clague, 1984a, b).

Brief descriptions of Quaternary deposits can be found in reports on the bedrock geology of a few mineralized areas within the study region. Rounded mountain peaks, U-shaped tributary valleys, erratics and high elevation striations were identified in the Kitsault River valley (Hanson, 1921). Boulder clay (till) was noted in the Kitsault and Bear River valleys and stratified blue clay was seen near Anyox and in valleys near Kitsault and Stewart (Hanson, 1921, 1935). Till was identified on valley floors and walls near Anyox and clay deposits were seen at 45 to 60 m a.s.l. in this area (Sharp, 1980). Fossils in the latter sediments were found to be similar to modern marine fauna in Observatory Inlet (Hanson, 1935; Sharp, 1980), so a glacial origin for these sediments is considered unlikely by the present author. A similar conclusion may be reached regarding marine fossils that Hanson (1935) stated were found in clay deposits near Bear River. Gravel terraces in the Kitsault area (Hanson, 1935) have been determined by the author to be part of a glaciofluvial delta. Raised gravel deposits in the Kitsault Valley, thought to be the product of modern fluvial processes (Hanson, 1935), are here considered to be glaciofluvial deposits, after examination by the author in the field.

PRELIMINARY FINDINGS

Some preliminary conclusions about regional glacial history can be made as a result of this summer's fieldwork.

Ice flow history

Two distinct ice flow histories were identified from field evidence: early regional southwestward flow and later flow directed along major valleys and fiords.

Striations, grooves, and other directional features measured at numerous sites in the study area show a consistent early trend of 210° - 230° regardless of topography. These early ice flow indicators are well preserved at high elevations (Fig. 2, 3). They are present at low elevations as striations or grooves in bedrock facets that were not eroded by subsequent ice flow. Less commonly, early southwesterly flow is indicated at low elevations by crosscutting relationships between striations and/or grooves.

Late ice flow was controlled by topography and ice was limited to fiords and valleys. Late ice flow indicators generally erase evidence of the earlier flow direction (Fig. 4). They are common at low elevations and on valley walls.

Thus, ice flow during the climax of the last glaciation was dominated by regional southwesterly flow, presumably from the Cordilleran Ice Sheet. Any evidence of pre-climax flow from local ice centres such as the Cambria Ice Field was completely obliterated by erosion during this regional advance. As the Cordilleran Ice Sheet thinned during deglaciation, ice became restricted to fiords and valleys, but continued to flow actively. Steep sided fiords in the western part of the study area and drumlinoid ridges in the Nass Valley are evidence of continued erosive flow over bedrock. Glacially sculpted bedrock can also be seen in Observatory Inlet and on the north shore of the Nass River, near its delta.

Glacial deposits

Two informally named tills of probable late Pleistocene age were identified in the region: Kwinatahl till and Kinskuch till. The latter is restricted in extent, whereas Kwinatahl Till is common throughout the map area, occurring as thick valley fill that thins to veneer on valley walls. Both tills weather to yellow-brown.

A typical example of Kwinatahl till is a very poorly sorted, very compact, massive diamicton with angular to subround striated clasts and a silty clay matrix (Fig. 5). Kwinatahl till is a distinctive blue-grey colour in most of the study area. Clast lithology is dominated by sandstone and siltstone of the Bowser Lake Group, which give the till its characteristic colour. Bowser Lake rocks are blue-grey in much of the map area, but are dark grey and black in the Nass Basin, resulting in a grey Kwinatahl till in this area.

The Nass Basin is much flatter than the rest of the study area and till deposits of this physiographic region are quite different. Two stratigraphically superimposed tills underlie fluted and drumlinized plains that occur between bedrock highs covered with till veneer. The stratigraphically lower till is the Kwinatahl till, with its characteristic dark grey colour, angular clasts of Bowser Lake Group lithology, high degree of compaction, and clay matrix. The upper (Kinskuch) till, in contrast, is grey-brown, with an abundance of highly rounded clasts, a moderate degree of compaction, and a silt matrix.



Figure 2. Grooves and chattermarks on monzonite, Campbell Ridge, looking south. Flow was from left to right (231°). A 60 cm high backpack is present for scale (indicated by arrow).



Figure 3. Roche moutonnées with grooves in porphyritic biotite granite, mountain ridge west of Kincolith Valley, near the mouth of the Nass River. Looking south toward the Kitimat Ranges, flow from lower left to upper right.

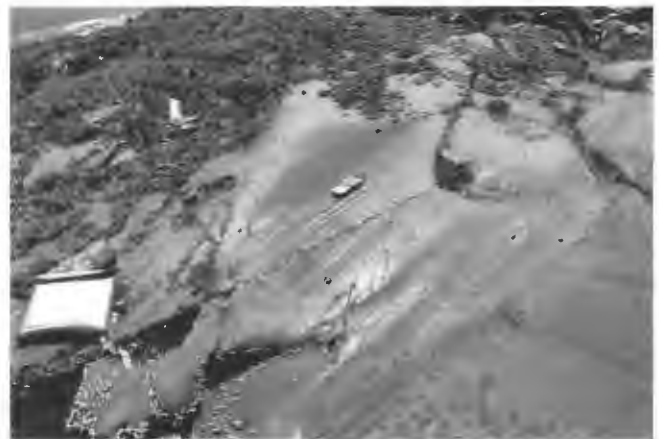


Figure 4. Striations on black siltstone hornfels, south Hastings Arm. These late southward flow indicators are parallel to Hastings Arm. Flow from lower left to upper right.

Most clasts are of Bowser Lake Group lithology, but higher quantities of volcanic clasts are evident. At one site, the lower till was observed to be incorporated into the upper till in intraclast-like patches. Kinskuch till is not simply reworked Kwinatahl till, however, as evidenced by its clast composition and texture, but its source and mode of deposition are currently unknown.

Deglaciation

There is little evidence of ice stagnation during deglaciation. The flutes and drumlins of the White and Kinskuch River areas in the Nass Basin are evidence of active flow during retreat (Fig. 6). Hummocky till and kettled deposits were not observed in the study area, but normal faults in sand and clay beds were found at one site in the Nass Valley. In the fiords, ice retreated by calving, with icebergs releasing dropstones into the glaciomarine clays. Retreat therefore must have occurred largely by calving, frontal retreat, and downwasting.

Deglacial deposits

Deglaciation in the study area appears to have been time transgressive, with ice remaining longer in the northern fiords than in the major valleys. As a result, tills were being laid down at the same time as deglacial deposits, but the exact timing of these events is not yet known. Glaciofluvial, glaciolacustrine, and glaciomarine sediments all formed at this time.

Glaciofluvial deposits discontinuously overlie till and bedrock in all parts of the study area (Fig. 7). Where they form glaciofluvial plains in smaller valleys, their upper surfaces are commonly boggy, probably due to underlying clay-rich till. A large glaciofluvial plain north of New Aiyansh may be a delta in part, but exposures are limited and disrupted foreset beds were seen at only one site. Glaciofluvial sands and gravels are generally of more local provenance than tills, due to the confinement of glaciers to valley systems. This is especially pronounced in tributary valleys of the southwest

Nass Valley, where till with Bowser Lake Group meta-sedimentary clasts contrasts sharply with granitic glaciofluvial deposits.

Thick (up to 50 m) blue-grey clay deposits which weather to pale brown are extensive in the Nass Valley north of the Aiyansh lava flow. They are also present in the southwest Nass region near Greenville and at various low elevation sites along Observatory Inlet, Alice Arm, and Hastings Arm, including the Anyox town site. These deposits are generally massive and no macrofossils were seen despite the large number of exposures visited. Dropstones are present at some sites. Weakly laminated clay deposits in the Kitsault town site area underlie a large glaciofluvial delta. Rhythmic laminations with dropstones are present near Anyox.

Fossil marine shells have been found in clay deposits near Anyox and Stewart (Hanson, 1935; Sharp, 1980), but their glacial context is uncertain, and it is possible that these sediments are Holocene. No shells were found by the author



Figure 6. Southeast-trending till drumlins in Kinskuch Valley, looking northeast. Flow direction indicated by arrows on individual drumlins.



Figure 5. Clay-rich Kwinatahl till. Scale in decimetres.



Figure 7. Kwinatahl till (KT) overlain by lighter toned, poorly sorted, glaciofluvial gravel and sand (GG).

in any glacial clay deposits in the region. Consequently, a marine origin for these sediments is not certain. However, the presence of the Kitsault delta, which is graded to a marine limit of 230 m, implies that the clay deposits of fiord areas are glaciomarine. The depositional environment of extensive massive clay sequences in the Nass Valley is at present unclear. They are likely glaciomarine sediments because they lie below maximum marine limits and are highly cohesive (sticky). However, a lacustrine origin for these deposits is possible. Disseminated organics at one site and woody debris at another imply a lacustrine origin and the lack of marine fossils in the area is unusual. Fossil marine shells are common in glaciomarine clays of the Terrace-Prince Rupert region to the south (Clague, 1984b).

Earthflows have occurred in clay deposits at various locations within the Nass Valley. Similar earthflows have occurred in marine sediments near Terrace (Geertsema and Schwab, 1995), but this is not necessarily an indication that the Nass Valley sediments are also marine, as earthflows can also occur in lake sediments.

The Nass Valley clay strata generally overlie till or glaciofluvial deposits and locally underlie glaciofluvial gravel and sand. Horizontally bedded granule gravel and gravel beds in the southwest part of the Nass Valley and sand/clay beds in the Kwinamuck Lake area that contain dropstones represent either marine or lacustrine ice-distal facies. Clays and gravels are interspersed irregularly in the region north of New Aiyansh and south of Kwinamuck Lake, but the exact relationship of these deposits is uncertain. There are no distinct deltas with distally finer marine deposits as in the Terrace-Kitimat region (Clague, 1984b).

Highly localized laminated, but not rhythmically bedded, clays with dropstones were found in Ksedin Valley, Hoan Valley, and the Nass Basin. These clays are underlain and overlain by more extensive glaciofluvial gravels and sands. Silt/clay rhythmics were identified at one site near Anyox. Organic debris for radiocarbon dating was found at some of these sites, and hence a glaciolacustrine origin is inferred for several of these isolated deposits.

Sea level history

The earliest marine limit is given by a 230 m delta at the town site of Kitsault and a 230 m delta remnant in the southern part of the Nass Valley. A delta on Portland Canal at the mouth of Donahue Creek, a delta at Anyox and raised outwash plains of Sutton and Kshwan valleys are graded to a later marine limit of 150-160 m.

The different marine limits imply that ice with a source in the Cambria Ice Field area retreated last, leaving Portland Canal and Hastings Arm glaciated long after ice retreated up the Nass and Kitsault valleys. Consequently, the Nass Valley clay deposits may have formed in a lake ponded by an ice readvance along Portland Canal and Observatory Inlet which blocked the Nass Valley.

Postglacial deposits

Colluvial deposits are the most abundant postglacial deposits of this predominantly mountainous region. On steep valley slopes, colluvial debris consists of a mixture of reworked till, glaciofluvial or marine deposits, and local bedrock, and most commonly occurs as a thin veneer over bedrock (drift veneer of Clague, 1984b). Debris flow scars and avalanche tracks are common features on steeper slopes.

Alluvial plains, alluvial fans, and fan deltas are prevalent throughout the area and most are still active, possibly due to the high rainfall and high relief of this area.

Felsenmeer, which sometimes obscures striations, is present at high altitudes. It is a common feature of both granitic rocks and siltstone/sandstone successions.

Neoglacial till is present at the margins of modern glaciers, all of which are currently retreating toward present ice caps. These loose, sandy tills are entirely of local provenance and flights of recessional moraines are not uncommon. Many glaciers have a frontal complex of till and glaciofluvial deposits.

FUTURE WORK

The following future laboratory and field investigations are planned:

1. The timing of deglaciation will be clarified by radiocarbon dating.
2. Foraminiferal and diatom analyses will be undertaken to determine whether the clay deposits of the Nass Valley are marine or lacustrine in origin. This work will further elucidate the glacial history of the area.
3. Geochemical analyses of regional till samples will be done to determine regional background values for a number of elements important to the mining industry.
4. Detailed analysis of tills in the Nass Basin during future field seasons will be undertaken to evaluate their environments of deposition.
5. An extensive shallow seismic reflection survey will be done in conjunction with Simon Fraser University, as part of the author's PhD. work. The goal of this study is to delineate the type and relationship of deposits in the Nass Valley, north of New Aiyansh, and to provide clues as to the style of glaciation and deglaciation in the area.

SUMMARY

At the height of the last glaciation, ice apparently from the Cordilleran Ice Sheet flowed southwestward over the Nass River region, rounding and smoothing many of the Coast Mountains. It incorporated large quantities of soft meta-sedimentary rocks of the Bowser Lake Group as it passed over

the Nass Basin and deposited them in all parts of the map area as a compact, clay-rich till. This event must have been highly erosive, as no evidence of earlier glaciations was found.

Ice then thinned and became restricted to fiords and valleys. Retreat was accomplished through calving, thinning, and frontal wastage, but ice was still actively flowing during deglaciation. Glaciofluvial gravels and sands were deposited in front of retreating glaciers and small glacial lakes formed locally. Marine clays were deposited in fiord areas below marine limit (230 m). Glaciers still occupied Hastings Arm and Portland Canal long after ice receded along Alice Arm and the Nass Valley. It is not known whether extensive clay deposits in the Nass Valley are marine or lacustrine.

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REFERENCES

- Clague, J.J.**
 1984a: Deglaciation of the Prince Rupert-Kitimat area, British Columbia; *Canadian Journal of Earth Sciences*, v. 22, p. 256-265.
 1984b: Quaternary geology and geomorphology, Smithers-Terrace-Prince Rupert area, British Columbia; Geological Survey of Canada, Memoir 413, 71 p.
- Dawson, G.L. and Alldrick, D.J.**
 1986: Geology and mineral deposits of the Kitsault Valley; in *Geological Fieldwork, 1985*; British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1986-1, p. 219-224.
- Evenchick, C.A. and Mustard, P.S.**
 1996: Bedrock geology of north-central and west-central Nass River map area, British Columbia; in *Current Research 1996-A*; Geological Survey of Canada, p. 45-55.
- Farley, A.L.**
 1979: Atlas of British Columbia, people, environment and resource use; University of British Columbia Press, Vancouver, 136 p.
- Geertsema, M. and Schwab, J.**
 1995: The Mink Creek earthflow; *Forest Sciences, Prince Rupert Forest Region, Extension Note 4*, 5 p.
- Greig, C.J.**
 1992: Fieldwork in the Oweegee and Snowslide ranges and Kinskuch Lake area, northwestern British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 92-1A, p. 145-155.
- Greig, C.J. and Gehrels, G.E.**
 1995: U-Pb zircon geochronology of Lower Jurassic and Paleozoic Stikinian strata and Tertiary intrusions, northwestern British Columbia; *Canadian Journal of Earth Sciences*, v. 32, p. 1155-1171.
- Hanson, G.**
 1921: Upper Kitsault Valley, British Columbia; Geological Survey of Canada, Summary Report, Part A, p. 7-21.
 1935: Portland Canal area, British Columbia; Geological Survey of Canada, Memoir 175, p. 30-34.
- Holland, S.S.**
 1976: Landforms of British Columbia, a physiographic outline; British Columbia Department of Mines and Petroleum Resources, Bulletin 48, p. 38-41, p. 57.
- Sharp, R.J.**
 1980: The geology, geochemistry, and sulfur isotopes of the Anyox massive sulfide deposits; M.Sc. thesis, University of Alberta, Edmonton, Alberta, p. 5-6, 28.
- Sutherland Brown, A.**
 1969: Aiyansh lava flow, British Columbia; *Canadian Journal of Earth Sciences*, v. 6, p. 1460-1468.

Geological Survey of Canada Project 930043-02

INTERIOR PLAINS
AND ARCTIC
CANADA

PLAINES INTÉRIEURES
ET RÉGION ARCTIQUE
DU CANADA

The Blind Fiord Formation and Blaa Mountain Group (Triassic) of northwestern Axel Heiberg Island, Canadian Arctic Archipelago

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Embry, A.F., 1997: The Blind Fiord Formation and Blaa Mountain Group (Triassic) of northwestern Axel Heiberg Island, Canadian Arctic Archipelago; in Current Research 1997-B; Geological Survey of Canada, p. 193-198.

Abstract: A stratigraphic section was measured through the Blind Fiord Formation (Lower Triassic) and Blaa Mountain Group (Middle- Upper Triassic) north of Bukken Fiord on northwestern Axel Heiberg Island. The succession is relatively thin (808 m) suggesting that the northwestern zero edge for Triassic strata lies 30 to 40 km northward on the inner continental shelf. Shallow-marine sandstone units, which change facies to deeper-marine shale and siltstone to the south, are also common throughout these strata at this locality, indicating that during the Triassic, a landmass was present to the north in the area now occupied by much of the polar shelf. It is doubtful that Triassic strata occur over much of the shelf as has been previously speculated.

Résumé : On a mesuré une coupe stratigraphique dans la Formation de Blind Fiord (Trias inférieur) et le Groupe de Blaa Mountain (Trias moyen-supérieur) au nord du fiord Bukken dans le nord-ouest de l'île Axel Heiberg. La succession est relativement mince (808 m), ce qui laisse supposer que la bordure nord-ouest à épaisseur nulle des strates triasiques se situe entre 30 et 40 km vers le nord sur la plate-forme continentale interne. Des unités de grès de mer peu profonde, dont le faciès passe au sud à du shale et du siltstone de mer plus profonde, sont également fréquentes dans toutes les strates de cette localité, ce qui indique que durant le Trias, une masse terrestre était présente au nord dans la région maintenant occupée par une grande partie de la plate-forme continentale polaire. Il est très douteux que les strates du Trias couvrent une grande partie de la plate-forme continentale comme on l'avait postulé antérieurement.

INTRODUCTION

Triassic strata are widespread in the Canadian Arctic Archipelago and are part of the thick Sverdrup Basin succession that accumulated from the Carboniferous to early Tertiary (Balkwill, 1978) (Fig. 1A). One of the controversial issues surrounding the distribution of Triassic strata and of Triassic paleogeography of the Arctic involves whether or not a thick section of Triassic strata also occurs on the continental shelf north of Axel Heiberg Island (Fig. 1A). Jackson (1990), on the basis of velocity data from seismic refraction surveys on the shelf (Asudeh et al., 1989), interpreted Triassic strata as being widespread on the shelf and kilometres in thickness. Conversely Embry (1991, 1992), on the basis of regional

thickness and facies trends, interpreted the northwest zero edge of the Triassic succession as lying just offshore on the innermost shelf.

To help resolve this controversy, a section of Blind Fiord Formation and Blaa Mountain Group was measured on north-western Axel Heiberg Island, about 25 km south of the shelf (Fig. 1B, C). The Blind Fiord Formation and Blaa Mountain Group together make up most of the Triassic succession in the Sverdrup Basin, and this was the first stratigraphic section measured in these units in the area north of Bunde Fiord. The thicknesses and facies compositions of these strata provide important data for estimating the distance to both a zero edge of the Triassic succession and the Triassic shoreline.

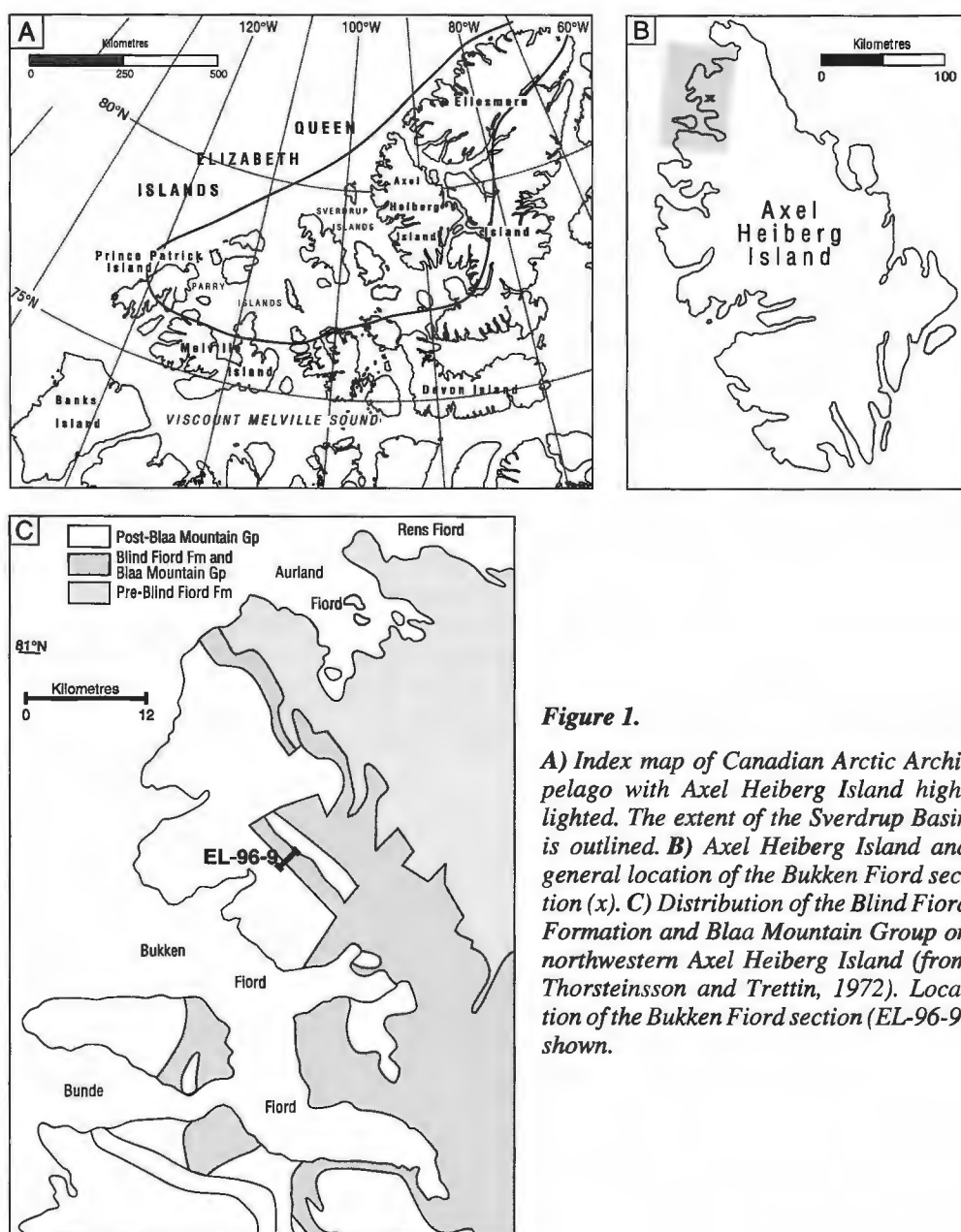


Figure 1.

A) Index map of Canadian Arctic Archipelago with Axel Heiberg Island highlighted. The extent of the Sverdrup Basin is outlined. **B)** Axel Heiberg Island and general location of the Bukken Fiord section (x). **C)** Distribution of the Blind Fiord Formation and Blaa Mountain Group on northwestern Axel Heiberg Island (from Thorsteinsson and Trettin, 1972). Location of the Bukken Fiord section (EL-96-9) shown.

REGIONAL STRATIGRAPHY

Within much of the Sverdrup Basin the Blind Fiord Formation and Blaa Mountain Group comprise the Griesbachian to lower Norian succession and thus represent most of the Triassic. The youngest Triassic strata (upper Norian-Rhaetian) occur in the lower portion of the overlying Heiberg Formation/Group.

Blind Fiord Formation

The Blind Fiord Formation consists mainly of Lower Triassic shale and siltstone and represents shelf to basin deposits (Embry 1991). The strata are up to 2000 m thick in the basin centre. On the southern and eastern margins of the basin the Blind Fiord strata thin and change facies to fluvial and strandline sandstones assigned to the Bjorne Formation.

Three members have been recognized in the Blind Fiord Formation. They are, in ascending order, the Confederation Point, Smith Creek, and Svartfjeld (Embry, 1986). Each member consists of shale in its lower portion and gradually coarsens upward, with siltstone becoming common in the upper portion. The return to shale marks the contact with the overlying member.

The Blind Fiord Formation overlies a variety of Permian lithologies, chert being most common. The contact varies from conformable to unconformable. Over much of the basin, the Blind Fiord is overlain by the Murray Harbour Formation of the Blaa Mountain Group. The Murray Harbour Formation is characterized by black, calcareous shale with phosphate concretions. The contact is conformable.

From a sequence stratigraphy point of view, the Blind Fiord Formation can be readily divided into three, third-order, transgressive-regressive (T-R) sequences (Embry, 1988).

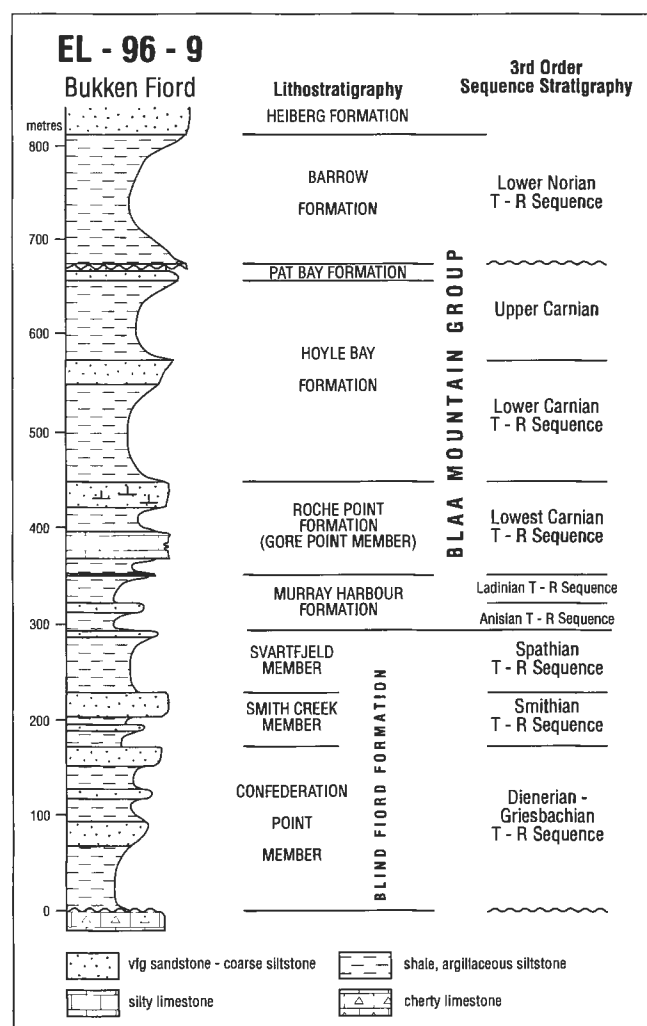


Figure 2. General lithotypes, lithostratigraphy and sequence stratigraphy of the Blind Fiord Formation and Blaa Mountain Group at the Bukken Fiord section.

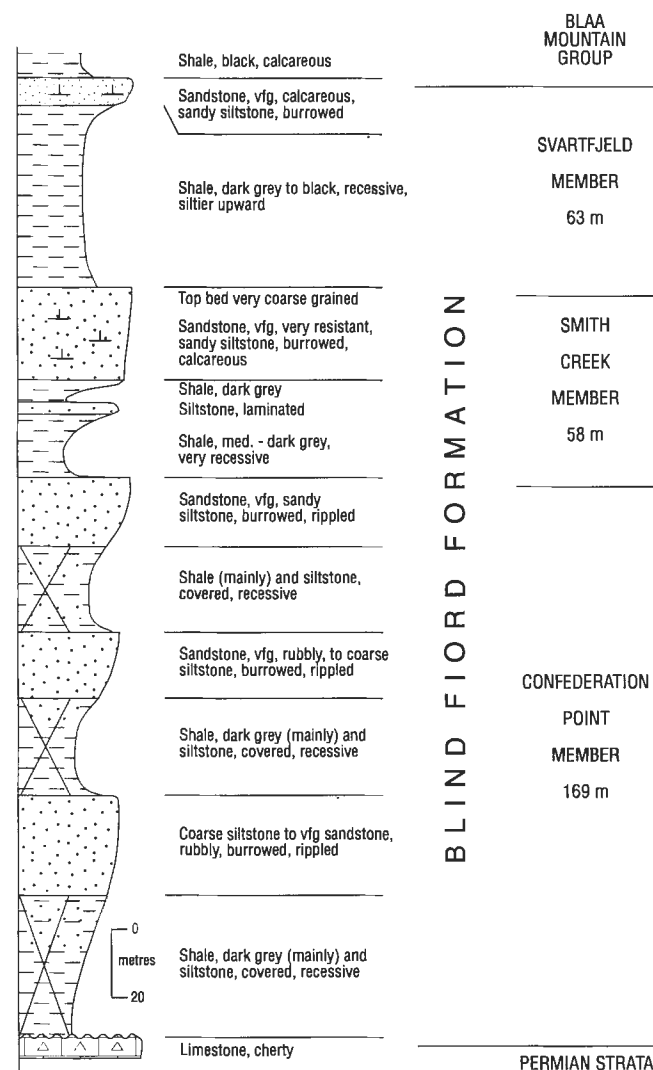


Figure 3. Lithology and lithostratigraphy of the Blind Fiord Formation at the Bukken Fiord section.

These sequences are bounded by conformable transgressive surfaces and are approximated by the three formal members. The ages of the sequences are Griesbachian-Dienerian, late Dienerian-late Smithian, and late Smithian-Spathian.

Blaa Mountain Group

The Blaa Mountain Group also consists mainly of shale and siltstone throughout the basin and represents the shelf to basinal deposits of the Middle to Upper Triassic. The Blaa Mountain Group comprises five formations: the Murray Harbour (black, phosphatic shale, siltstone), Roche Point (sandstone, limestone), Hoyle Bay (shale, siltstone, limestone), Pat Bay (sandstone), and Barrow (shale, siltstone)

(Embry, 1984a). Blaa Mountain strata are up to 2500 m thick in the basin and thin rapidly toward the basin edges. On the southern and eastern margins, equivalent strata dominated by sandstone and limestone are assigned to the Schei Point Group (Embry, 1984a).

The Blaa Mountain Group contains five, complete, third-order T-R sequences and the lower half of a sixth (Embry, 1988, 1991). For the most part, the sequence boundaries are conformable transgressive surfaces but on the basin flanks, unconformities (ravinement surfaces that have replaced subaerial unconformities) also form sequence boundaries. The ages of the sequences are Anisian, Ladinian, earliest Carnian, early Carnian, late Carnian and early Norian.

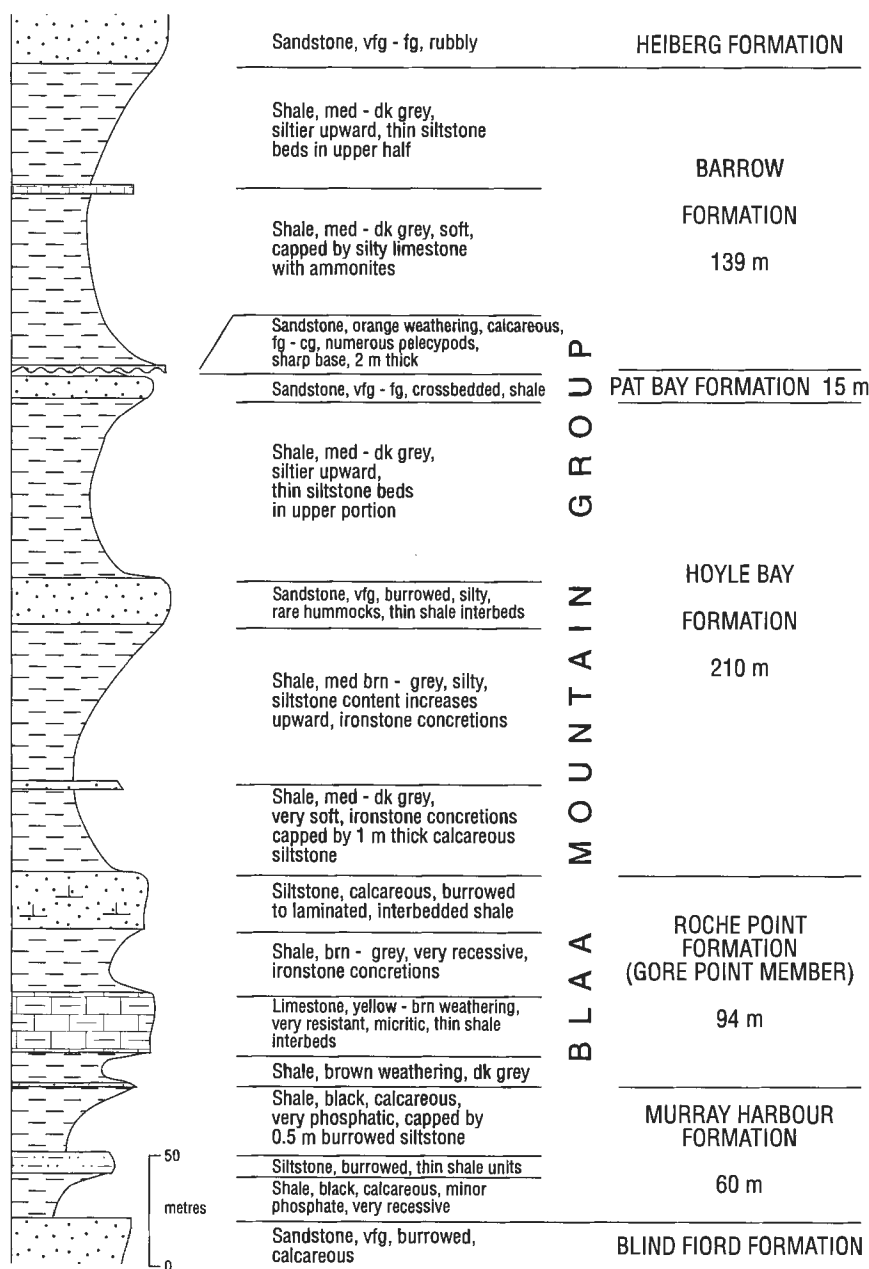


Figure 4.

Lithology and lithostratigraphy of the Blaa Mountain Group at the Bukken Fiord section.

Basinal Stratigraphic Relationships

On the eastern and southern margins of the basin the Triassic strata contain higher proportions of shallow-water to strandline rock types and are truncated by various internal and younger unconformities (Embry, 1991). Similar stratigraphic relationships appear to occur on the northwest flank of the basin although data from this area are relatively sparse. Using all available surface and subsurface data, Embry (1992) interpreted that a land area, named Crockerland, lay to the northwest of the islands, in the vicinity of the present-day polar continental shelf. The section north of Bukken Fiord, on northwestern Axel Heiberg Island, was examined to test this interpretation.

BUKKEN FIORD SECTION

Introduction

The Bukken Fiord section was measured by the author and Steve Irwin (GSC Pacific) using a Jacob's staff. Measurements and outcrop examinations were made along the sides of a creek that flows into a prominent inlet on the north side of the fiord near its mouth (lat. 80°49'N; long. 94°35'W). Exposure is generally excellent except in the basal 150 m, and 810 m were measured. The strata dip westward at 50 to 60° (Thorsteinsson and Trettin, 1972).

Blind Fiord Formation

The Blind Fiord Formation is 290 m thick at the Bukken Fiord section. This is one of the thinnest known occurrences of the formation. The Blind Fiord can be readily divided into its three component members (Fig. 2, 3) as well as the three T-R sequences. Each of the members is characteristically very argillaceous in the lower portion and displays a general coarsening-upward trend. However, in this area, sandstone also occurs in the upper portion of each member. The sandstones are generally very fine grained and burrows are the main sedimentary structure, indicating an offshore shelf to lower shoreface environment of deposition. Similar lithologies occur in the Blind Fiord Formation on the eastern and southern flank of the basin, close to the transition with the sandstone-dominant Bjorne Formation.

Blaa Mountain Group

The Blaa Mountain Group is also very thin (518 m) at the Bukken Fiord section. The various component formations are readily recognizable as are the six T-R sequences (Fig. 2, 4). The Murray Harbour Formation, which consists of dark grey to black phosphatic shale of offshore shelf origin, is only 60 m thick. On the eastern and southern flanks of the basin such a thickness for the Murray Harbour is found only very near the basin edge (Embry, 1991). Notably, siltstone units cap both of the two sequences found in the Murray Harbour Formation.

The overlying Roche Point Formation is represented by the Gore Point Member (Embry, 1984b), which consists of a distinctive assemblage of brown-grey shale with ironstone

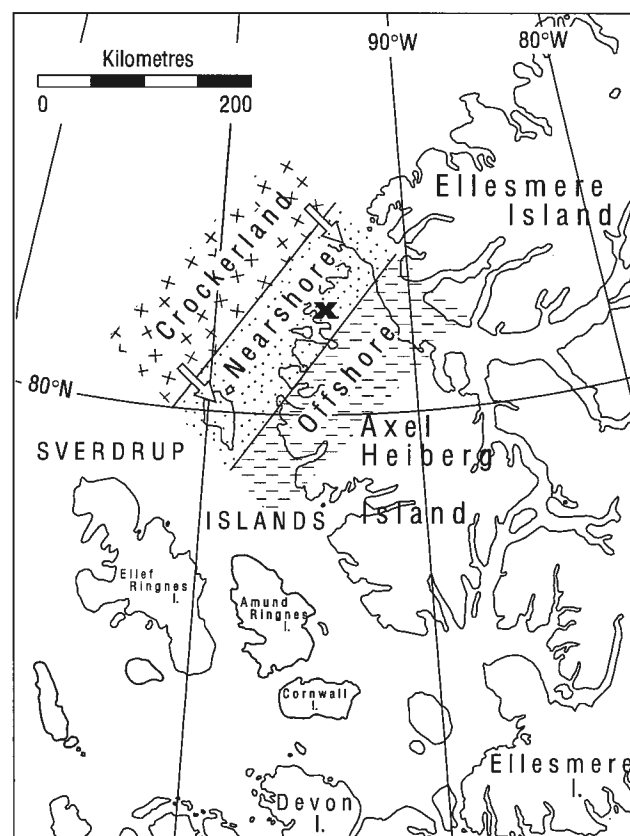


Figure 5. General paleogeography during the Triassic, northwestern Axel Heiberg Island. The southwestern edge of Crockerland has been drawn coincident with the interpreted northwestern zero edge of the Triassic strata. The location of the Bukken Fiord section is marked by an "x".

concretions, argillaceous, micritic limestone, and calcareous siltstone. These strata are 94 m thick and are interpreted as being of offshore shelf origin.

The Hoyle Bay Formation consists mainly of medium to dark grey shale and argillaceous siltstone of offshore shelf origin. It is 210 m thick, which is comparable to thicknesses found on the eastern and southern edges of the basin (Embry, 1991). A conspicuous unit of very fine grained, burrowed sandstone occurs in the middle of the formation and marks the top of the lower Carnian sequence.

The overlying Pat Bay Formation is only 15 m thick and consists of two distinct units. The lower 13 m comprises very fine to fine grained, burrowed to crossbedded sandstone of nearshore origin. This unit is abruptly overlain by 2 m of calcareous, fine- to coarse- grained sandstone with abundant pelecypod shells. The basal contact of this unit is erosional and represents a ravinement surface. This unconformity marks the base of the lower Norian sequence. The overlying fossiliferous sandstones are transgressive deposits that accumulated in a shoreface environment.

The uppermost formation of the Blaa Mountain Group is the Barrow Formation, which is 139 m thick at this location. This thickness is also typical of the eastern and southern basin

margins (Embry, 1991). The Barrow Formation consists of medium to dark grey shale and siltstone of offshore marine origin. The formation is gradationally overlain by the near-shore sandstones of the Heiberg Formation.

DISCUSSION

The thicknesses and facies of the various stratigraphic units in the Blind Fiord Formation and Blaa Mountain Group at the Bukken Fiord section all indicate that the section lies relatively close to the northwestern edge of the basin. The thicknesses of the Lower Triassic (290 m), Middle Triassic (60 m), and Carnian (318 m) strata are all typical of thicknesses found 35 km or less from the Triassic zero edge on the eastern and southern basin margins (see isopach maps in Embry, 1991).

Except for the nearshore strata in the Pat Bay Formation, the facies all generally indicate an offshore marine shelf environment. The occurrence of sandstone and coarse siltstone within each sequence indicates the sediment source is to the northwest because southward such rock types become rare and are eventually replaced by deeper water, argillaceous siltstones and shales (Embry, 1991, 1992). The varying facies within each sequence indicate that the shoreline position fluctuated. Comparisons with facies relationships established on the eastern and southern flanks suggest the shoreline was about 20 to 60 km northwestward at the peak of the regressions (Fig. 5). The occurrence of an unconformity within the Pat Bay Formation (base Norian sequence) indicates the shoreline lay to the south of the section in latest Carnian and that the Bukken Fiord area was part of Crockerland at this time.

In summary, the thicknesses and facies of the various units of the Blind Fiord Formation and Blaa Mountain Group on northwestern Axel Heiberg Island support the concept of a zero edge for the Triassic succession on the innermost shelf. Furthermore, it is likely that in the Triassic, a landmass was present over much of the area now occupied by the continental shelf. Thus it is highly unlikely that a thick Triassic succession occurs over much of the shelf, as postulated by Jackson (1990). As noted by Asudeh et al. (1989), the strata on the continental shelf, which Jackson (1990) interpreted as Triassic on the basis of interval velocity, can be reasonably interpreted as Cretaceous to early Tertiary. There is no compelling argument for the existence of Triassic strata over much of the northeastern shelf.

CONCLUSION

A stratigraphic section was measured through the Blind Fiord Formation (Lower Triassic) and Blaa Mountain Group (Middle-Upper Triassic) north of Bukken Fiord on northwestern Axel Heiberg Island. The succession here is only 808 m thick, which contrasts sharply with a thickness of 4000 m for equivalent strata in the basin centre to the south. The strata contain shallow-marine sandstones at various

levels indicating that a source area lay to the northwest. Overall the thickness and facies data from this section are compatible with the interpretation that the northwestern zero edge of the Triassic succession lies only a few kilometres offshore on the shelf. An interpretation that a very thick Triassic succession underlies much of the continental shelf north of Axel Heiberg does not appear to be tenable.

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REFERENCES

- Asudeh, I., Forsyth, D.A., Stephenson, R., Embry, A.F., Jackson, H.R., and White, D.
1989: Crustal structure of the Canadian polar margin: results of the 1985 seismic refraction survey; *Canadian Journal of Earth Sciences*, v. 26, p. 853-866.
- Balkwill, H.R.
1978: Evolution of Sverdrup Basin, Arctic Canada; *American Association of Petroleum Geologists Bulletin*, v. 62, p. 1004-1028.
- Embry, A.F.
1984a: The Schei Point and Blaa Mountain groups (Middle-Upper Triassic), Sverdrup Basin, Canadian Arctic Archipelago; in *Current Research, Part B; Geological Survey of Canada, Paper 84-1B*, p. 275-283.
1984b: Stratigraphic subdivision of the Roche Point, Hoyle Bay and Barrow formations (Schei Point Group), western Sverdrup Basin, Arctic Islands; in *Current Research, Part B; Geological Survey of Canada, Paper 84-1B*, p. 299-308.
1986: Stratigraphic subdivision of the Blind Fiord and Bjorne formations (Lower Triassic), Sverdrup Basin, Arctic Islands; in *Current Research, Part B; Geological Survey of Canada, Paper 86-1B*, p. 329-340.
1988: Triassic sea-level changes: evidence from the Canadian Arctic Archipelago; in *Sea-level Change, an Integrated Approach*, (ed.) C.K. Wilgus; *Society of Economic Paleontologists and Mineralogists, Special Publication 42*, p. 249-259.
1991: Mesozoic History of the Arctic Islands; in *Innuition Orogen and Arctic Platform of Canada and Greenland*, (ed.) H.P. Trettin; *Geological Survey of Canada, Geology of Canada*, no. 3, p. 369-433.
1992: Crockerland - the northern source area for the Sverdrup Basin, Canadian Arctic Islands; in *Arctic Geology and Petroleum Potential*, (ed.) T.O. Vorren; *Norwegian Petroleum Society, Special Publication 2*, p. 205-216.
- Jackson, H.R.
1990: Evolution and regional stratigraphy of the northeastern polar margin; *Marine Geology*, v. 93, p. 179-192.
- Thorsteinsson, R. and Trettin, H.P.
1972: Bukken Fiord; *Geological Survey of Canada, Map 1310A*, scale 1:250 000.

Geological Survey of Canada Project 850036

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