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THE GEOLOGY AND MINERAL DEPOSITS OF NORTH-CENTRAL QUESNELLIA; TEZZERON LAKE TO DISCOVERY CREEK, CENTRAL BRITISH COLUMBIA

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SUMMARY

North-central Quesnellia includes Late Paleozoic island arc and oceanic subterranes, the Lay Range and Slide Mountain, respectively; but its identity is based primarily on the voluminous deposits associated with the Early Mesozoic Quesnel arc, a fossil intraoceanic island arc. The Quesnel arc had two phases of development, Late Triassic and Early Jurassic. Its Late Triassic inception is represented by the Takla Group. In the Takla Group, basal Carnian (to Norian?) basinal sedimentary rocks of the Slate Creek succession are overlain by late Carnian to Norian volcanic and volcaniclastic successions: the Inzana Lake, Witch Lake, Willy George and Plughat Mountain successions. Considerable facies variability within the Late Triassic arc is reflected by the application of these local names, which depict discrete volcanic centres that overlie but also grade laterally into epiclastic deposits. The Triassic early phase of arc development was dominated by augite-phyric basalt and alkalic basalt (shoshonite suite) volcanism, although rocks of more felsic compositions are also present. The Triassic arc volcanic successions are overlain paraconformably by Early Jurassic volcanic suites, the Chuchi Lake and Twin Creek successions. This depositional break corresponds to a volcanic hiatus but not to any discernible deformation. The Early Jurassic suites show much greater compositional heterogeneity than the Late Triassic successions, and also dominance by plagioclase and plagioclase-augite phyric, subalkaline to shoshonitic lithologies. They probably represent a more mature arc developed on thicker crust. A sedimentary interval within the Chuchi Lake volcanic succession is of early to late Pliensbachian age.

The Quesnel arc is important from an economic point of view, due to a rich endowment of alkalic porphyry copper-gold mineral deposits. The very large Mt. Milligan deposit, discovered in 1987, lies within the project area. It centres on two minor intrusive bodies, the MBX and Southern Star stocks, which are crowded-porphyritic monzonites texturally similar to those that host all of the alkalic porphyry deposits of Quesnellia. Mt. Milligan is part of a much more extensive local swarm of porphyry deposits and potassic-propylitic alteration zones, located south of the southeastern end of the Hogem batholith. Early Jurassic zircon ages from intrusive bodies associated with porphyry-style mineralization in this area, clustered around 204 and 189-182 Ma, show that intrusive/metallogenetic episodes occurred during the later history of the Quesnel volcanic arc, near the ends of the two volcanic episodes described above.

Major transcurrent and related faults of Cretaceous and Early Tertiary age transect the project area, juxtaposing strata of widely varying ages including Early Tertiary graben fill. Strands of the Manson-McLeod system, the Discovery Creek fault, and one splay of the Pinchi fault are recognized. These faults have made geologic mischief in obscuring previous structural relationships between the Lay Range and Slide Mountain terranes and the Quesnel arc, and in truncating the eastern edge of the Mt. Milligan deposit.

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INTRODUCTION

LOCATION, ACCESS AND TOPOGRAPHY

The Nation Lakes project area is located in north-central British Columbia, north of Fort St. James and west of Germansen Landing. It extends from near Tezzeron Lake in the south to Discovery Creek, north of the Omineca River (Figure 1). Logging roads provide access to large parts of the area. Some regions are still remote and require helicopter access. These include the area around Mount Milligan; the Valleau Creek watershed, most of the Kwanika Creek map area, and the mountains east of Discovery Creek. (Note that throughout this report the named geographic feature will be called Mount Milligan, and the porphyry deposit will be called Mt. Milligan, to aid in distinction. This is consistent with usage by Placer Dome Inc.)

Topography varies from subdued in the south, through ranges of low mountains near the Nation Lakes and Valleau Creek to ruggedly mountainous with broad alpine areas in the north near Kwanika and Discovery Creeks. Large wild animals are scarce, probably because of the extensive road network.

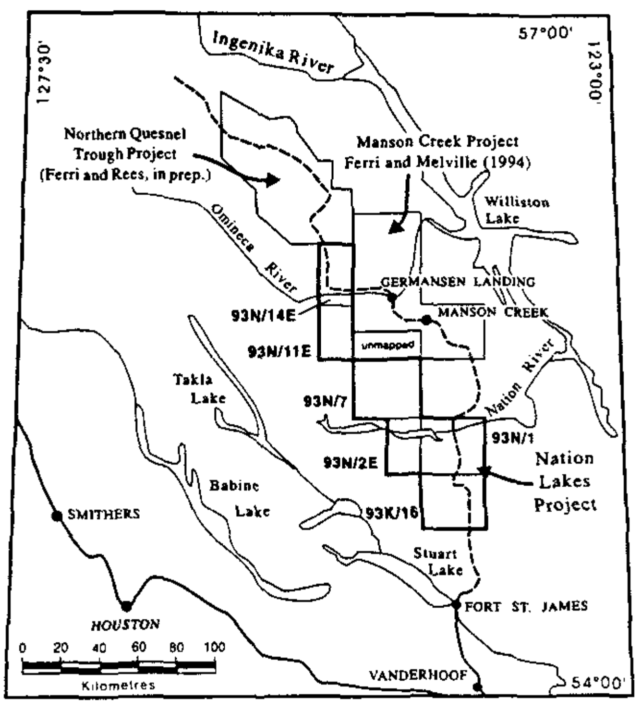

Figure 1. Location map of the Nation Lakes project area.

GLACIATION

The geomorphology of the Nation Lakes area bears a strong glacial imprint, particularly from the Fraser glaciation, the most recent ice advance. Glacial straie trend east to northeasterly, and large-scale glacial grooves are aligned at about 060°. Northeasterly regional ice-flow from the Coast Mountains was deflected by smaller ice masses originating in the Skeena Mountains to the north and the Cariboo Mountains to the south, resulting in flow directions that varied through time (Plouffe, 1991). Till and fluvioglacial deposits are thickest in the lowlands south and southwest of Witch Lake. Elsewhere, in most areas, scattered bedrock outcrops emerge from blanket to veneer till and outwash. Perched glacial channels occur on hillsides and are incised into the highest plateaus.

Spruce forests tend to grow on the lowland till deposits, because of the high soil water content in the clay matrix. Outwash terraces in the major valleys support jackpine forests. Such terrain is also marked by braided river channels, kettles and eskers. Several generations of channels are visible on air photographs, for instance in the broad valley west of Mount Milligan. Kerr and Bobrowsky (1991) mapped the surficial geology around the Mt. Milligan deposit at 1:50 000 scale. Heidi Lake lies within a major, easterly directed paleochannel that cut a canyon through the ridge south of Mount Milligan (Photo 1). East of the canyon, fluvial channels spread out into a broad outwash fan in the lowlands of the present Rainbow Creek watershed.

REGIONAL GEOLOGIC SETTING

The Nation Lakes area lies within Quesnellia (Figure 2a), a Mesozoic island arc terrane with Late Paleozoic arc and marginal basin basement, which is tectonically juxtaposed with the ancestral North American continental margin (Monger *et al.*, 1990). Most of the project area is underlain by Upper Triassic and Lower Jurassic volcanic and sedimentary units of island arc affinity, the Triassic Takla Group and the Jurassic Chuchi Lake and Twin Creek successions. The Hogem intrusive suite borders much of the area on the west (Figure 2b). It is dominated by Late Triassic and Early Jurassic composite plutons, presumably the deep-seated equivalents of the Lower Mesozoic arc volcanic units. The upper Paleozoic Lay Range assemblage and Slide Mountain Terrane (Nina Creek Group) are exposed on the ridges east of Discovery Creek. They are not locally overlain by the Takla Group, but regional evidence suggests that these asssemblages form the basement of the Mesozoic Quesnel arc (Monger *et al.*, 1990). The Lay Range assemblage is an epiclastic to pyroclastic sequence interpreted as have formed marginal to an island arc; the Slide Mountain Ter-

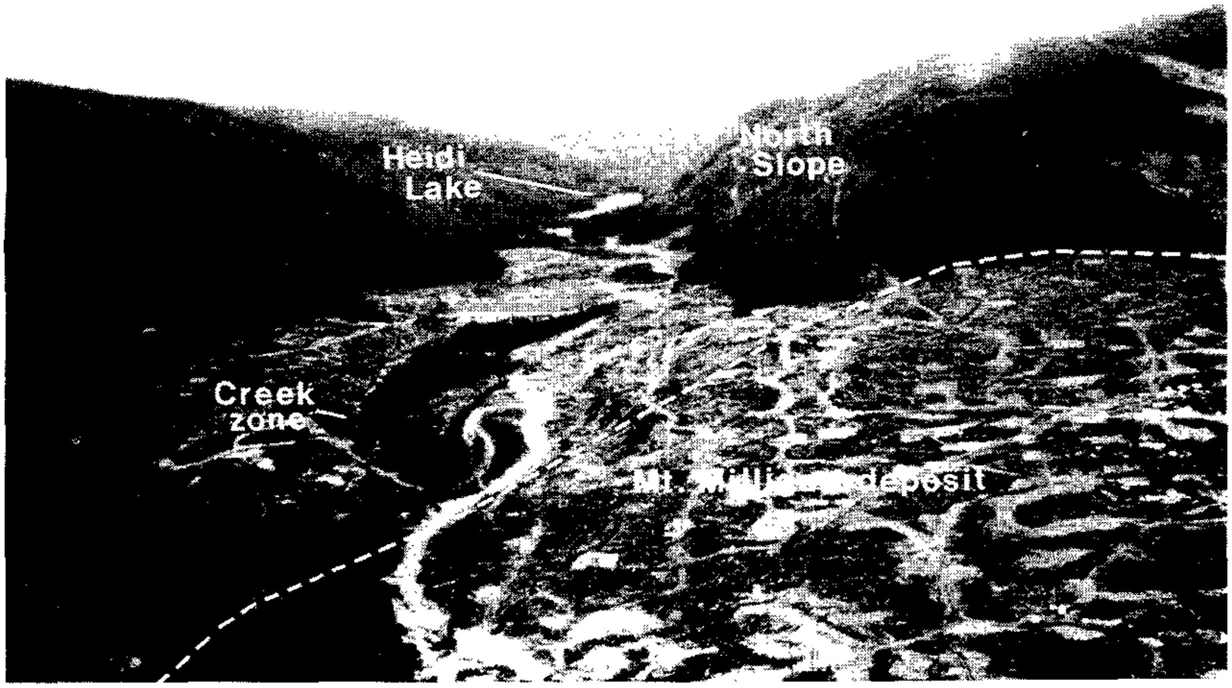

Photo 1. Mt. Milligan deposit viewed from the east, looking along the access road from MacKenzie. Heidi Lake (centre background) occupies a fluvioglacial channel that breached the low ridge. Paleoflow was west to east.

rane is a marginal basin that separated the Lay Range arc and North America in late Paleozoic time (Ferri and Rees, in preparation).

At this latitude, Quesnellia is bounded to the west by the Pinchi fault (Figure 2b). A structurally complex ophiolitic assemblage, the Cache Creek Terrane, lies west of the Pinchi fault. It includes upper Paleozoic carbonates and pelagic sedimentary rocks, alpine ultramafic bodies, and Triassic and Jurassic sedimentary units that include arc-derived clastic material: these may represent forearc components of the Takla arc. Late Triassic blueschists (Paterson and Harakal, 1974) occur locally near the Pinchi fault.

The Mesozoic Quesnel arc developed in an intra-oceanic setting, but shortly after its late Early Jurassic demise, the arc and its Paleozoic basement were thrust eastward onto the North American margin (Ferri and Melville,1994; Nixon, 1993). North American miogeoclinal rocks and possibly cratonic basement structurally underlie Quesnellia as far west as the Pinchi fault. A small outcrop area of Lower Cambrian carbonate lies west of the Takla Group near Quesnel (Struik, 1984); and the southern Wolverine Complex (Figure 2b) is a core complex of Proterozoic metasediments exposed by detachment faults in the middle of the Takla Group 20 kilometres southeast of the Nation Lakes project area.

The northwesterly trending Manson-McLeod fault system lies immediately east of the project area (Figure 2), passing through Manson Creek and the lowlands east of Mount Milligan. This system is one of the "great faults" of the Canadian Cordillera (Figure 2a, 2b). Its anastomosing strands isolate panels of strongly contrasting structural levels, such as Slide Mountain Terrane against Proterozoic North American metasediments, or Takla Group against Early Tertiary basin fill. These dramatic vertical movements were probably the result of much greater overall transcurrent displacement. Strain indicators on the main strands of the Manson system show nearly pure dextral displacement. The amount of transcurrent offset is unknown. Several episodes of motion, ranging in age from pre-Late Cretaceous (Ferri and Melville,1994) to Late Eocene-Oligocene (Struik, 1989; 1993) occurred on different fault strands.

Cretaceous to Early Tertiary faulting was accompanied by localized felsic intrusion and volcanism and by clastic sedimentation. Post-Jurassic sedimentary units occur in grabens, probably modified versions of their original fault-controlled depositional basins.

RELEVANT GEOLOGICAL STUDIES, PAST AND PRESENT

J.E. Armstrong and colleagues of the Geological Survey of Canada produced the first 1 inch to 6 mile geological map of the Fort St. James area (map areas 93K and N; Armstrong, 1948) and accompanying memoir (Armstrong, 1965), which introduced the now-familiar terms Takla Group and Hogem batholith. The Pinchi mercury deposit was discovered by one of the project geologists in 1937. Interest in porphyry copper deposits in the early 1970's cre-

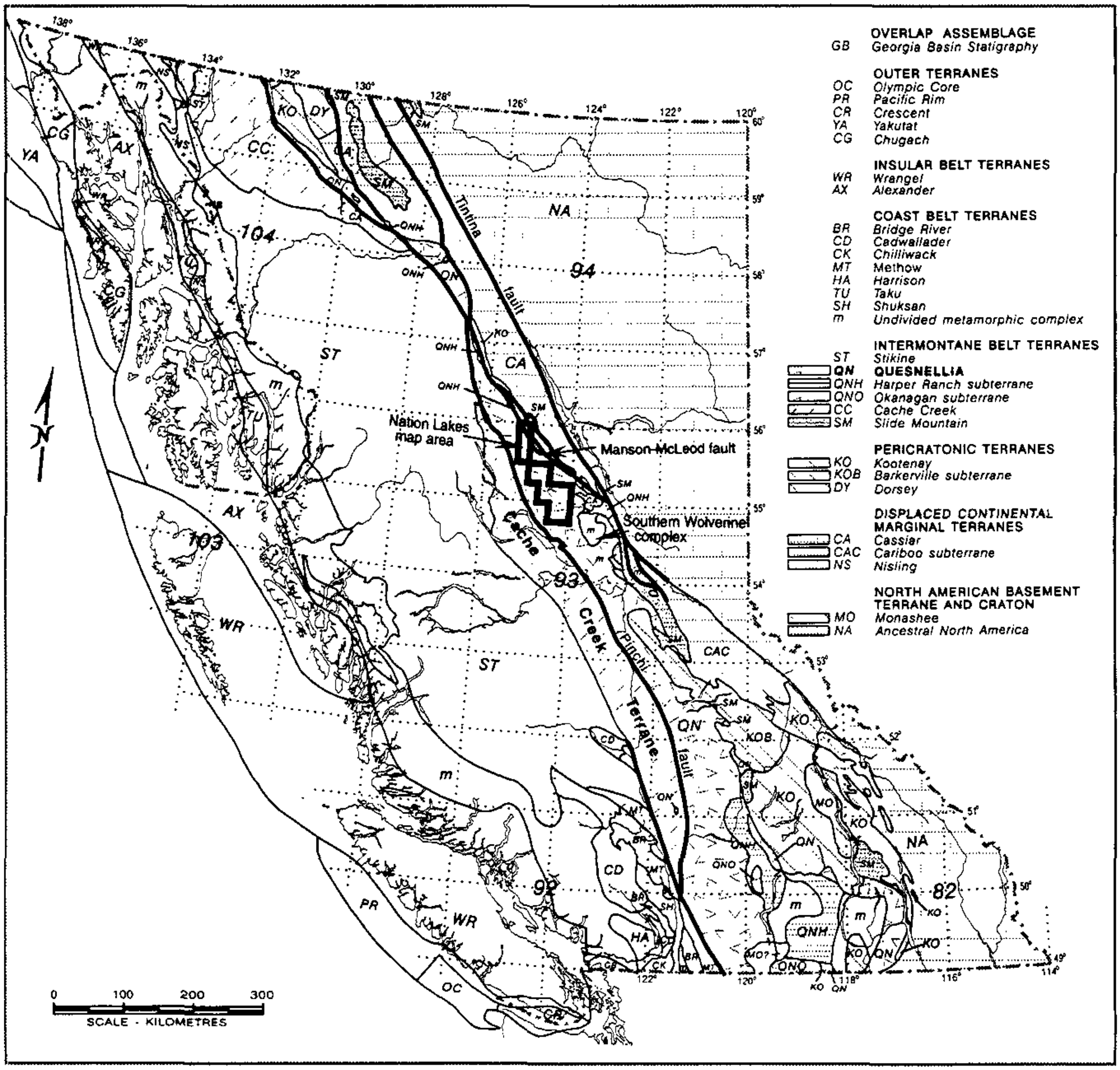

Figure 2a. Tectonic framework of the project area.

ated a demand for further geological studies. J.A. Garnett of the British Columbia Ministry of Mines and Petroleum Resources mapped the southern part of the Hogem batholith and documented the porphyry copper occurrences within it (Garnett, 1978). Harlan Meade, a Ph.D. student working with Garnett, produced a lithologic map that subdivided the Takla Group between Germansen Lake and the eastern edge of the Hogem batholith (Meade, 1977). Outside the present project area, the work of Ian Paterson (1973, 1977; Paterson and Harakal; 1974) on the Cache Creek Group near Fort St. James illuminated its tectonic history and role as exotic accreted terrane and probable forearc to the Quesnel arc.

A long lull in geologic studies from the later 1970s to the late 1980s corresponded to the lull in exploration activity described below. In 1987 L.C. Struik of the Geological Survey of Canada began a revision mapping project of the McLeod Lake map area (93J), southeast of the Nation Lakes project area; this study continued through 1990 (Struik and Fuller, 1988, Struik, 1989, Deville and Struik, 1990). Information and insights from Struik's work directly aided our interpretations, particularly about Cretaceous-Tertiary tec-

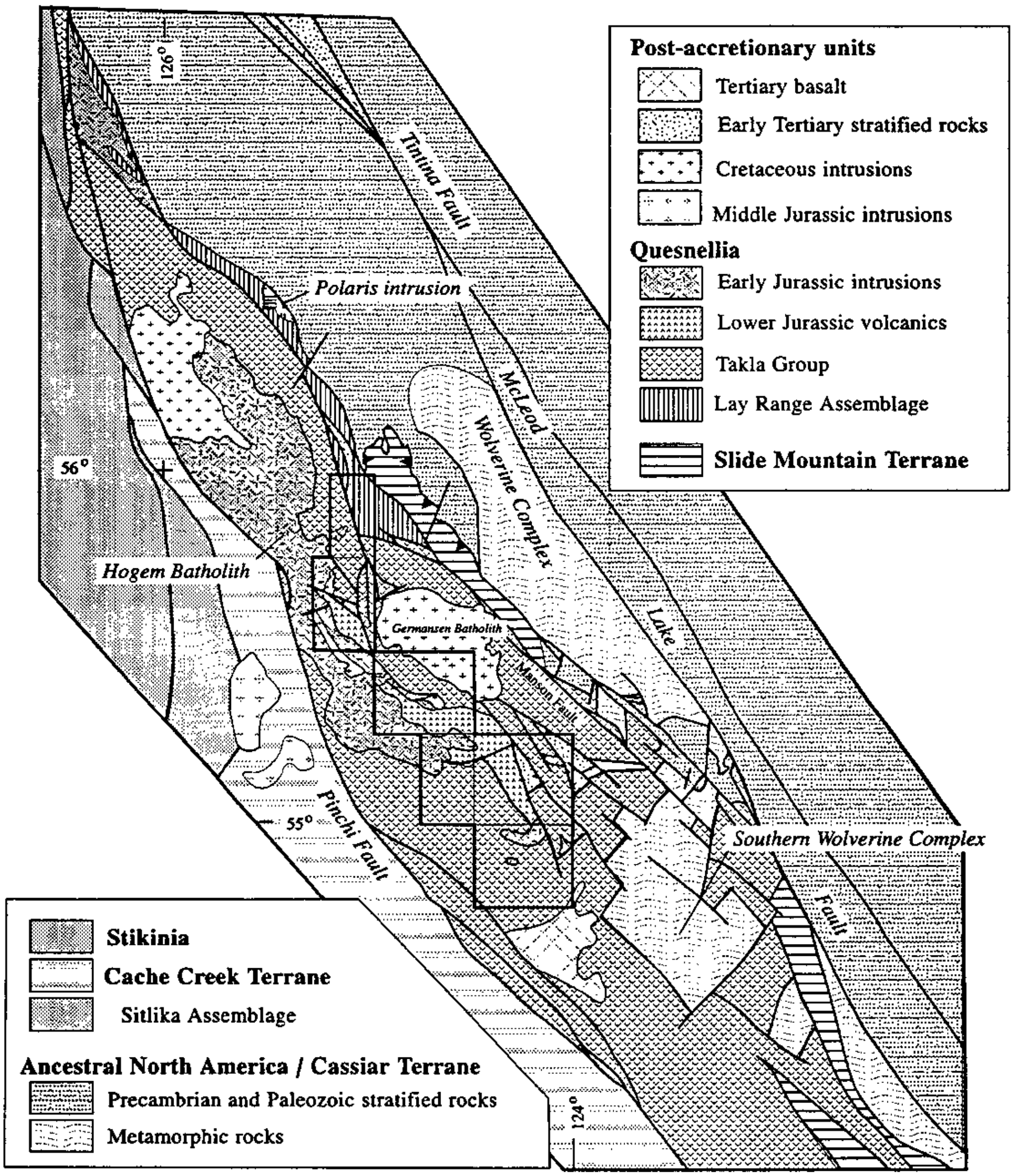

Figure 2b. Regional geology and tectonic setting of the project area in north-central Quesnellia. Geology from Wheeler and McFeely (1991), Struik (1989, 1992), Ferri and Melville (1994), Ferri (unpublished compilation) and this study.

tonics, the timing of strike-slip faulting and the nature of the southern Wolverine Complex. Filippo Ferri of the British Columbia Ministry of Employment and Investment conducted extensive 1:50 000 geological mapping in the Manson Creek and Aiken Lakes areas, which partly abut the Nation Lakes area on the east and north (Ferri and Melville, 1994; Ferri and Rees, in preparation; Ferri *et al.*, 1992, 1993). D.G. Bailey, while consulting for Eastfield Resources Ltd., produced a proprietary geologic map at 1:50 000 scale of the Kwanika Creek area (93N/11 East Half). This map provided the basis for a joint field project with Bailey in 1992, during which a revised Open File map was completed (Bailey *et al.*, 1993).

The discovery and exploration of the Mt. Milligan porphyry copper-gold deposit resulted in a flood of geological studies, including this project. Alain Plouffe of the Geological Survey of Canada began a 4-year regional study of glacial and surficial geology in 1990 (Plouffe, 1991, 1992), and Robert Shives, also of the Geological Survey of Canada, coordinated and interpreted regional airborne radiometric surveys of map areas in 1991 (Shives and Holman, 1992; Shives and Carson, 1994). R.C. Delong and others of the Mineral Deposits Research Unit undertook various studies of the Mt. Milligan porphyry system between 1990 and 1993 (DeLong *et al.*, 1991).

EXPLORATION HISTORY

The Nation Lakes region has seen two cycles of intense exploration activity in the last quarter-century. The first cycle, part of the Cordillera-wide porphyry copper rush of the

1960s and early 1970s (Mustard, 1976), concentrated on deposits in and near the Hogem batholith. This led to the delineation of significant tonnages at the Lorraine deposit by Granby Mining Corporation (Wilkinson *et al.*, 1976) and initial discovery of the Takla Rainbow prospect (Bailey, 1991). Porphyry systems were also identified south of Chuchi Lake (Campbell, 1990b). Interest in porphyry systems then declined until the mid-1980s. The most important result so far of this resumed interest in the Nation Lakes area was the 1987 discovery of the circa 300 million tonne Mt. Milligan deposit and its subsequent exploraration to pre-feasibility stage by Lincoln Resources Ltd. and Continental Gold Corp. In 1990 Placer Dome Inc. bought the Mt. Milligan property.

Major drilling programs were conducted in the summer of 1990 by BP Resources Canada Limited on the Cat property, by Cathedral Gold Corporation onTakla Rainbow, by Rio Algom Exploration Inc. on the Klawli property, and by BP Resources on the Chuchi property north of Chuchi Lake, optioned from Digger Resources Limited. The Lorraine was investigated by Kennco Explorations (Canada) Limited. In addition, large alteration systems with anomalous copper and gold values were explored south of Chuchi Lake by Rio Algom, Westmin Resources Limited, and Noranda Exploration Company Limited, on the Max claims by Rio Algom, on Grand American Minerals Ltd. Webb claims and on Placer Dome Inc.'s Windy property.

The 1991 decision by Placer Dome to shelve the Mt. Milligan project precipitated a sharp decline in exploration interest throughout the area. By 1992 only a few companies were still active, mostly on small-scale projects, and by 1993-94 this major porphyry district once again entered a mainly dormant phase. However, continuing work on the Lorraine by Lysander Gold and on the Jean Marie porphyry by Ragnar Bruaset and Associates Ltd. demonstrate the ongoing potential of the area.

PRESENT STUDY

Intense interest in the Mt. Milligan alkalic porphyry copper-gold deposit and its geologically poorly known surroundings led to the inception of the Nation Lakes 1:50 000 mapping project in 1990. In all, 4½ map sheets were covered between 1990 and 1992, 93K/16, 93N/1 (on which the Mt. Milligan deposit is located), 93N/2 East Half, 93N/7, 93N/11 East Half, and 93N/14 East Half (Nelson *et al.*, 1991a,b; 1992a,b; 1993a,b,c; Bailey *et al.*, 1993) (Figure 1). This area covers the Takla Group over 125 kilometres of strike length, and from its westward truncation by the Hogem intrusive suite to its faulted eastern contact. D.G. Bailey aided in the production of 93N/11 East Half and Filippo Ferri and coworkers in 93N/14 East Half, where this project area abuts that of the Manson and Northern Quesnel Trough mapping projects near the Omineca River (Figure 1).

ACKNOWLEDGMENTS

A great many geologists from industry and government contributed their knowledge and insights to this project. Vic Preto, the Man from the Iron Mask, gave early shape to our ideas about alkalic porphyry systems. Discussions with industry geologists Mike Harris of Continental Gold Corporation, Peter Leriche of Reliance Geological Limited and Chris Bates, Russ Wong, Russ Barnes, Bernie Augsten, and Tucker Barrie of BP Resources Canada Limited improved our understanding of the Mt. Milligan and BP-Chuchi deposts. Filippo Ferri contributed from his extensive knowledge of the Manson-Germansen area. Geological Survey of Canada geologist Alain Plouffe illuminated aspects of the glacial geology. Howard Tipper, Michael Orchard, Giselle Jacobs, Fabrice Cordey, Art Sweet and Elisabeth McIver of the Geological Survey of Canada provided fossil identifications (Appendices 1 to 4) and Janet Gabites and Richard Friedman of the U.B.C. Department of Geological Sciences supplied radiometric date determinations (Appendix 7) that were invaluable in the construction of our geologic story. John Thompson and particularily Cliff Stanley of the Mineral Deposits Research Unit offered a plethora of insights, both scintillating and arcane.

We are very grateful for field conference support by the town of Fort St. James: Mayor Sandy Kovacs, Chamber of Commerce members Robin Colley and Ron Timothy, and Chamber staff Franziska Zwygart and Chris Nielson. Many local residents gave us help and hospitality: Pete and Shirley Koropatnisky, Harry Coldwell, Larry and Inge Erickson, and Ron and Ruth Repko. Prospectors Richard Haslinger and Derry Halloran generously provided information about their discoveries.

Geologists Kim Green, Mary MacLean, Chris Rees, and Keith Mountjoy participated in the field mapping. The pervasiveness of their contributions is reflected in their coauthorship of the Open File maps: to this we add our most sincere thanks. Draft versions of this manuscript were edited by Bill McMillan, Jim Lang, Bert Struik, Filippo Ferri, John Newell and Mark Regabliati. Their comments are much appreciated. Final production is due to the able efforts of Verna Vilkos, John Armitage and Janet Holland.

CHAPTER 2
STRATIFIED AND INTRUSIVE UNITS

STRATIFIED UNITS

NINA CREEK GROUP (Slide Mountain Terrane)

Upper Paleozoic oceanic rocks of the Slide Mountain Terrane, informally termed the Nina Creek group, form a large klippe above the miogeoclinal Cassiar Terrane in the Nina Creek area (Ferri and Melville,1994). The Nina Creek group comprises a structurally lower package of Pennsylvanian-Permian pelagic sedimentary strata intruded by gabbro sills, termed the Mount Howell formation, and an upper, Pennsylvanian-Permian basaltic pile with minor chert and argillite, called the Pillow Ridge formation (Table 1). The age overlap between the two formations suggests that they are separated by a thrust fault rather than a stratigraphic contact. They probably represent two distinct but related, partly or wholly coeval facies packages, which have been subsequently telescoped. Older-over-younger relationships have been established within the Nina Creek group by conodont dating (Ferri, personal communication 1993), and thrust faults are common within the Slide Mountain Terrane elsewhere (Struik and Orchard, 1985; Nelson and Bradford, 1990).

The northeastern corner of the project area, north of the Omineca River, is underlain by a typical sequence of the Nina Creek group (Figure 3, in pocket). Although outcrop control on the contact is poor, this succession apparently rests structurally on the lower Mississippian Gilliland felsic tuff unit of the Cassiar Terrane just north of the project area, near Wazi Lake (Ferri and Melville,1994).

MOUNT HOWELL FORMATION

The lower part of the Nina Creek group, exposed in the northeastern corner of the mapped area (Figure 3 in pocket), is a monotonous sequence of grey to black argillite/chert and green chert that dips moderately to the southwest. No base is exposed. This package is overlain by 50 to 75 metres of distinctive bright blood-red and bright green ribbon chert with thin argillite partings, which forms prominent, ribby outcrops. This upper red chert unit is of regional extent and can be traced over 3 kilometres of strike length in the present map area. Identical cherts occur at the top of the Mount Howell formation from northwest of Nina Lake to south of Wasi Lake (F. Ferri, personal communication, 1992). Minor diabase-gabbro sills intrude both it and the underlying argillites and cherts.

PILLOW RIDGE FORMATION

To the west, near the Manson fault zone, red and green cherts of the Mount Howell formation are overlain by 200 metres of gabbro and diabase sills with minor chert remnants, above what is inferred to be a thrust fault in accordance with the more complete map coverage and paleontological constraints of Ferri and Melville (1994). This unit thins to the northeast; at the eastern edge of the map area pillow basalts of the Pillow Ridge formation directly overlie the pelagic sequence.

The contact between the diabase-gabbro sill unit and the pillow basalts above it is well exposed and apparently transitional. The average grain size in the diabase decreases upwards. Chert disappears only tens of metres below the lowest occurrence of variolites that marks the first basalt flow. The sill unit is probably a feeder zone to the overlying flows and is included within the Pillow Ridge formation. A thrust fault between the sills and the underlying cherts and argillites cannot be demonstrated locally, but is inferred based on regional evidence.

The highest part of the Nina Creek Group is a 200-metre sequence of commonly pillowed basalt. These basalts are generally fine grained and equigranular, aphanitic or diabasic. Variolites are common in the finer grained and glassy flows. Pillow morphologies show upright tops that dip gently southwest. In one area pillow imbrications indicate a southerly paleoslope.

The Nina Creek group shows strong similarities to other Slide Mountain Terrane exposures. The brightly coloured red and green ribbon chert at the top of the Mount Howell formation is identical in appearance, age and structural/stratigraphic position to the Pennsylvanian-Permian chert unit at the top of Division I in the Sylvester allochthon, 400 kilometres to the north (Nelson and Bradford, 1993). Pennsylvanian-Permian basalt flows, fed by sills in chert-argillite sequences, are common in the Slide Mountain Terrane (Schiarizza and Preto, 1987; Nelson and Bradford, 1993). The thrust fault that places the Pillow Ridge formation on top of the roughly coeval Mount Howell formation corresponds to the thrust contact between the mainly sedimentary Division I and the ophiolitic Division II in the Sylvester allochthon. Compared with Division II, however, the Pillow Ridge formation is far less complex. It lacks imbricated ultramafic slices; and it is restricted to Pennsylvanian-Permian in age, containing no Mississippian basalts.

LAY RANGE ASSEMBLAGE (Harper Ranch Terrane)

The Lay Range assemblage is named for extensive exposures in the Lay Range, 100 kilometres northwest of the present map area. There, it consists of a lower division of Mississippian to middle Pennsylvanian mixed siliciclastic, epiclastic, carbonate and pelagic-hemipelagic strata overlain by a middle Pensylvanian limestone marker, and then several kilometres of volcanic sandstone, fine lapilli tuff and ash tuff of Permian age (Ferri *et al.*, 1993a, b; and authors' 1992 observations). Ferri *et al.* (1992a, b) recognized Lay

TABLE 1
TABLE OF FORMATIONS

AGE				
		OVERLAP UNITS		
Miocene to Pleistocene	MPb	olivine-bearing basalt		
Eocene (to Oligocene?)	Esb	volcanic wacke, plant-bearing, ash-rich mudstone, basalt		
Eocene	EU	Uslika Formation: conglomerate, sandstone, siltstone, mudstone, coal	Evs	quartz-eye rhyolite tuffs and flows; minor mafic lapilli tuff; siltstone, sandstone and quartzo-feldspathic conglomerate
Cretaceous and/or Tertiary	KTv	maroon, orthoclase and quartz-bearing tuff with plagioclase-phyric volcanic fragments		
		QUESNELLIA		
LOWER JURASSIC				
Upper Toarcian	lJs	arkose, greywacke, sandstone, siltstone, minor conglomerate		
		Kwanika Creek area		*Chuchi Lake area*
Sinemurian -Pleinsbachian (-lower Toarcian?)	lJTC	**Twin Creek succession:** heterolithic lapilli tuff, plagioclase±quartz phyric flows (andesite, dacite, basalt) and agglomerate/tuff breccia (Sinemurian)	lJCL	**Chuchi Lake succession:** plagioclase±augite, hornblende, olivine phyric flows (latite, andesite, basalt, dacite); heterolithic agglomerate, lahars; intravolcanic sedimentary sequence (Pliensbachian)
		Germansen/Kwanika Creek Discovery Creek area		*Chuchi Lake/Valleau Creek*
UPPER TRIASSIC (TAKLA GROUP)	uTrPM	**Plughat Mtn. succession:** augite±plagioclase±olivine phyric basalt flows, agglomerate; maroon amygdaloidal basalt; minor reefal limestone	uTrWL	**Witch Lake succession:** augite±plagioclase±olivine phyric agglomerate, lapilli tuff, flows; epiclastic sediments; minor latite and trachyte flows
	uTrWG	**Willy George succession:** augite-plagioclase lapilli tuff, crystal tuff, sedimentary breccia, arkose/wacke, argillite, siltstone, polymictic breccia.	uTrIL	**Inzana Lake succession:** volcanic sandstone, green tuff, grey siltstone, argillite, slate, sedimentary breccia
MIDDLE? TO UPPER TRIASSIC :	muTrSC	**Slate Creek succession**: grey slate and siltstone, tuff, lapilli tuff, amygdaloidal flows		

TABLE 1 continued

		SLIDE MOUNTAIN TERRANE		HARPER RANCH TERRANE
		Nina Creek Group		
PENNSYLVANIAN-PERMIAN	PPPR	**Pillow Ridge Formation:** pillow basalt, basalt/diabase sills, chert and argillite	PPLR	**Lay Range assemblage:** lapilli tuff, volcanic and mixed-source sandstone and grit, siltstone, argillite, siliceous tuff, chert
	PPMH	**Mount Howell Formation:** argillite, chert, diabase sills		
MISSISSIPPIAN			Mvs	plagioclase-phyric lapilli tuff with crinoidal limestone clasts; crystal tuff

Range sequences in the southern part of 94C/3, which adjoins the Discovery Creek map area, the northeastern part of the Nation Lakes project area (Figure 3 in pocket). In 1992 we redefined contiguous parts of the Discovery Creek area as Lay Range assemblage that were previously included in the Takla Group by Armstrong (1948). Except for fault-bounded exposures in the Cook Creek panel, all are generally correlatable to the well defined stratigraphic sequence referred to here as the main sequence, a thick section of epiclastic rocks overlain by basalt flows.

MAIN SEQUENCE

The Lay Range assemblage outcrops on the high ridges east of Discovery Creek (Figure 3). The regular bedding in the steeply dipping panels results in the formation of ribby, ridge-top exposures (Photo 2). The assemblage consists of two conformable stratigraphic units; a lower siliceous fine-grained epiclastic division (PPLRb) and an upper volcanic unit of lapilli tuffs, agglomerates and flows (PPLRc). The contact between the two is transitional and is marked by an upward increase in coarse volcanic units over several hundred metres.

The lower unit is dominated by olive green volcanic sandstone and siltstone, siliceous argillite and crystal, fine lapilli and ash tuff. Graded bedding in sandstones provides consistent facing indicators. Rare but diagnostic grit beds contain clasts of a variety of volcanic types and textures as well as chert, vein quartz, quartzite and metasiltstone, minor limestone and granitoids (Photo 3). In thin section, the siliciclastic clasts are bimodal sandstones and siltstones, consisting mainly of quartz grains with low sphericities, along with minor plagioclase, sericite and chlorite. Some quartz polygrains have metamorphic fabrics that are not shared by the rock as a whole. The presence of this quartz-rich detritus hints at the existence of at least patches of deformed pericratonic basement under the late Paleozoic Quesnel Terrane. A few beds and pods of turquoise, green and red radiolarian chert form part of this sequence. Maximum thickness in apparently unfaulted sections is about 2000 metres.

The upper unit, about 1000 metres thick, is dominated by heterolithic lapilli tuff that contains a variety of volcanic clasts: plagioclase and clinopyroxene porphyries with aphanitic green or, less commonly, maroon matrix; clinopyroxene-plagioclase crowded porphyry in which clinopyroxenes are larger and less abundant than plagioclase; and clinopyroxene and fresh olivine porphyry with an aphanitic groundmass. Other less abundant lapilli include brick-red aphanitic to glassy fragments and black cumulate clinopyroxenites. Green to maroon augite-olivine porphyritic flows and flow breccias, and brown-weathering andesites with small, sparse plagioclase phenocrysts form an important part of the upper division in some areas. Epiclastic units such as sandstones and apple green ash tuffs are also present. In lithotypes and low metamorphic grade this sequence strongly resembles parts of the Upper Triassic Plughat Mountain succession (*see* below), but its transitional contact with the underlying Lay Range rocks establishes it as late Paleozoic in age.

Fault-bounded units on the ridges northeast and north of Lounge Lizard Mountain are included within the main sequence of the Lay Range assemblage, based on lithologic similarities. Grits with rounded chert and quartz pebbles and clasts of green and red lapilli tuffs are found within these sequences.

Radiolaria are commonly visible in the sparse chert pods in the lower part of this sequence. One such pod, located 200 metres below the base of the coarse pyroclastic unit, yielded well-preserved, diagnostic species. Fabrice Cordey identified a collection from this locality (f2 on Figure 3; *see* also Appendix 1) as late Pennsylvanian - Early Permian. This corresponds with the youngest ages obtained from the Lay Range assemblage in the type area (Ferri, in preparation). Lower in the section, a conodont collection from a small limestone pod (f1) is of early to middle Pennsylvanian (?Bashkirian-Moscovian) age (Appendix 2).

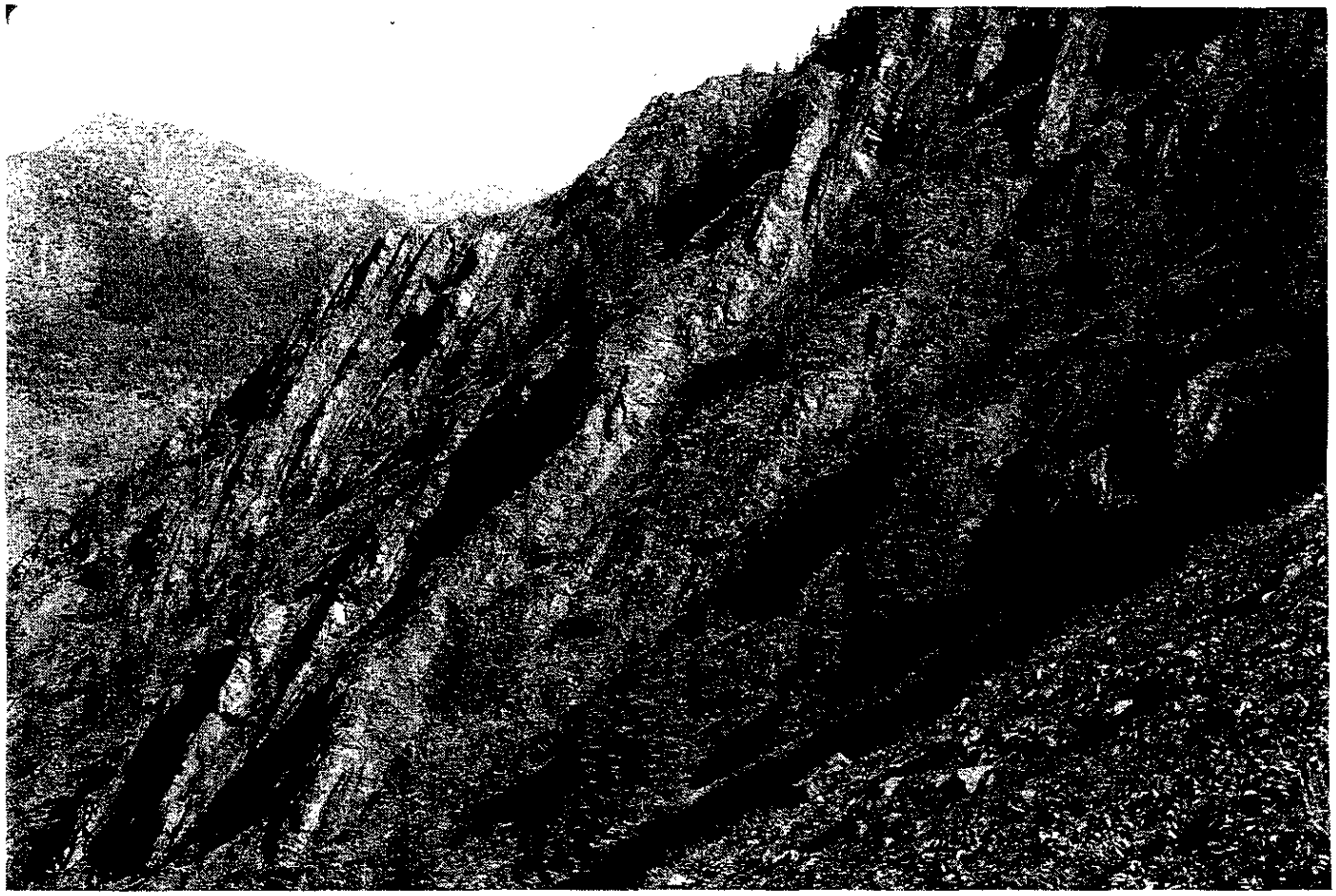

Photo 2. Ribby outcrop of Lay Range assemblage: well-bedded lapilli tuff and volcanic sandstone of unit PPLRb, with minor quartz-rich grit interbeds.

Photo 3. Bed of pebbly quartz-rich grit in Lay Range assemblage.

The lower tuff sequence (unit PPLRb) near Discovery Creek is lithologically and temporally comparable to the upper part of the type stratigraphy, above the main Pennsylvanian limestone in the Lay Range. Here, it passes upward into a kilometre-thick volcanic section that is not observed farther north, either because of volcanic facies changes or because it represents a higher stratigraphic level than is preserved in the type area. The lower Mississippian-middle Pennsylvanian heterogeneous sedimentary sequence and middle Pennsylvanian limestone in the type Lay Range assemblage are missing near Discovery Creek: this supports the idea that only higher stratigraphic levels are exposed there.

COOK CREEK PANEL

The valley at the head of Cook Creek is underlain by a distinctive lithologic assemblage that is bounded by as well as transected by major faults (Figure 3, in pocket). It contains more chert and less epiclastic detritus than the main Lay Range sequence. Lithologies include thin-bedded siliceous sandstone and siltstone, siliceous tuff, bedded chert and siliceous argillite. One sample of volcanic siltstone from the headwaters of Cook Creek contains approximately 1% detrital muscovite and traces of green tourmaline. There is no source for muscovite within the Lay Range assemblage, thus it, together with quartzite and rare plutonic fragments in the main sequence, may provide a link to a pericratonic or continental terrane with a Paleozoic plutonic component. The Lay Range arc may have formed adjacent to or on a suspect pericratonic terrane similar to the Yukon-Tanana Terrane.

LOWER(?) MISSISSIPPIAN VOLCANIC-SEDIMENTARY UNIT

A few small outcrops of lapilli to crystal tuff with limestone clasts are located about a kilometre north of the main road, 1 to 1.5 kilometres east of Discovery Creek. The dominant clast lithology is plagioclase-phyric dacite, moderately crowded with small, equant grains. The limestone clasts contain tiny crinoids and fossil hash. Green and maroon chert pebbles, vein(?) quartz, and siliceous argillite clasts with soft-sediment forms are also present.

The Early Carboniferous (Visean?) age of this unit is established by conodont identifications from a sample collected 1 kilometre east of Discovery Creek (Locality f3 on Figure 3; Appendix 2). Howard Tipper (personal communication 1992) reports that a fusulinid collected from this area was assigned a Pennsylvanian age. Correlation of this unit is somewhat problematic. During initial field mapping it was misidentified as an early Mesozoic arc unit (Nelson *et al.*, 1993). Lapilli tuffs are very rare in the lower (Misssippian) part of the Lay Range assemblage in the type area. Where seen, they are plagioclase phyric, and interbedded with chert and grey argillite. Perhaps this limited exposure hints at locally(?) more active Mississippian volcanism than is represented in the Lay Range proper.

12 MILE BASALT

One thrust panel north of the Omineca River contains aphyric to small-olivine porphyry pillow basalts (Photo 4) that are intruded by the Lounge Lizard suite. The southeastern continuation of this panel into 93N/15 is a narrow, fault-bounded sliver of pillow basalt and green and red basalt lapilli tuff. To the north, it is in fault contact with Middle to Upper Triassic limestone and dark grey, limy siltstone cor-

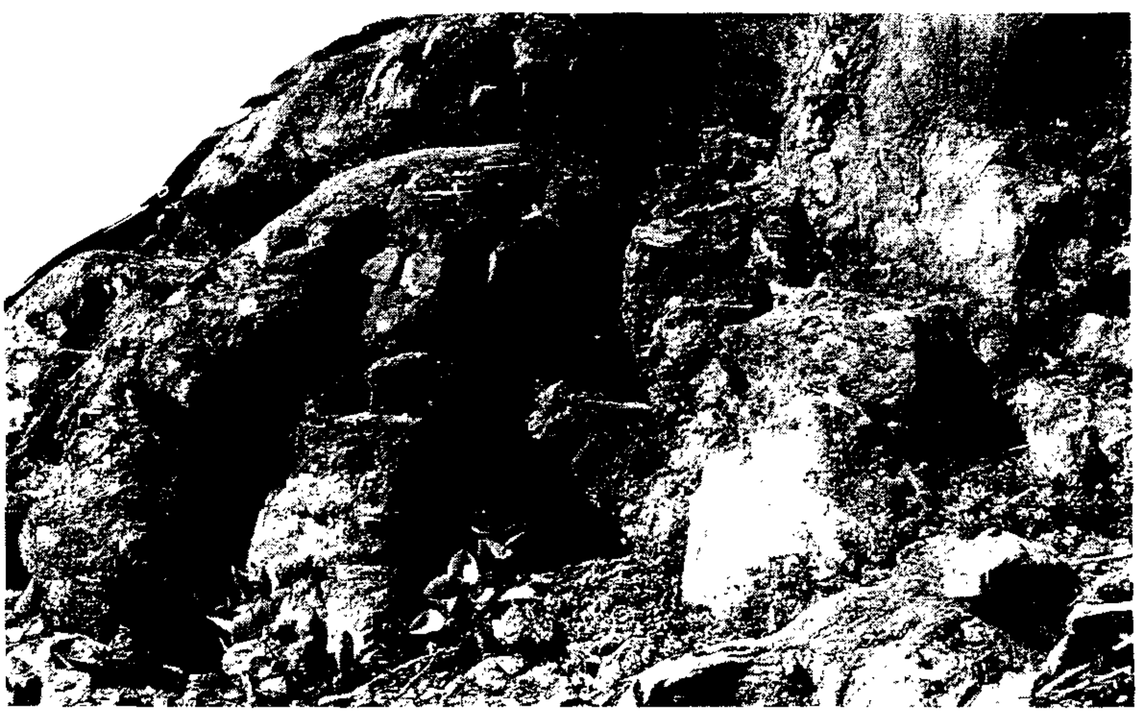

Photo 4. Pillow basalt, 12 Mile basalt

related with the Slate Creek succession. To the south, it is in fault contact with either the Plughat Mountain succession on Plughat Mountain, with the Jurassic (?) felsic unit south of the Omineca River, or with the lower(?) Mississippian unit described above. The texture of the basalts from this unit contrasts with typical Takla augite porphyries. They are virtually aphyric, dominated by a matte of very elongate quench (?) plagioclase crystals with tiny augite grains and glass in the interstices. Their high titanium contents place them in oceanic basalt fields on Ti-Zr and Ti-V diagrams (*see* Chapter 3). The ages of these basalts and of the Lounge Lizard mafic intrusive suite are unknown. Their oceanic affinities ally them either to the Slide Mountain Terrane or to pillow basalts that occur within the Slate Creek formation in the Manson Creek area (F. Ferri, personal communication 1993).

TAKLA GROUP

The Upper Triassic Takla Group in the Nation Lakes project area consists of a number of distinguishable subunits, each of regional extent amenable to 1:50 000 scale mapping. Each unit, however, shows considerable internal variability, and interfingering relationships are as common as stratigraphic contacts. We therefore amend a previous practice of assigning informal formation names to the various units (*c.f.* Nelson *et al.*, 1991) in favour of the term "succession". Ferri and Melville (1994) use this term for Takla Group subunits. It is looser than the term "formation" and more appropriate to volcanic stratigraphy, for which reference to type sections can create an unjustified sense of consistency. Of the units previously defined in this project, we retain the Inzana Lake, Witch Lake and Willy George successions, but rename the Rainbow Creek formation the Slate Creek succession, in reference to the more complete and well-dated exposures in the Manson-Germansen area. The Plughat Mountain succession extends from the mountains around Germansen Lake into the project area.

SLATE CREEK SUCCESSION

The lowest part of the Takla Group in the Manson-Germansen area consists of grey slate, limy slate and argillite with lesser thin-bedded siltstone, both siliciclastic and epiclastic. Near the Omineca River it includes a limestone over 500 metres thick. Ferri and Melville (1994) designate this the Slate Creek succession, after its exposures in slices within the Manson fault system near Slate Creek. West of the Manson fault, grey slates equivalent to those in the type exposure pass upward into a mixed basinal-epiclastic sequence, the upper Slate Creek succession. Late Anisian to early Ladinian and Carnian conodont ages from the limestone and a single Carnian age from the upper part of the succession establish it as the oldest Takla Group unit (Ferri and Melville,1994).

Equivalents to the Slate Creek succession occur in three localities in the Nation Lakes map area: around the northern and western periphery of the Germansen batholith, in fault-bounded panels near Rainbow Creek, and near Dem Lake in the southwest corner of the area. Grey slates, siltstones and minor tuffaceous sediments of the Slate Creek succession outcrop around the northern contact of the Germansen batholith in the Germansen Landing map area (Ferri *et al.*, 1989). They continue into the southeastern corner of 93N/11, around the western edge of the batholith (Figure 3 in pocket). The slates are often strongly foliated and foliations appear to wrap around the margin of the batholith. Exposure of the oldest unit of the Takla Group encircling most of the Germansen batholith might suggest that diapiric emplacement entrained and uplifted the base of the Mesozoic section.

The exposures north of Rainbow Creek are divided into two sub-blocks based on different trending schistosities (Figure 3). Both are dominated by grey slate with sparse, thin siltstone interbeds and minor plagioclase-rich greywackes. Quartz sandstones like those in the Slate Creek succession near Slate Creek are not present. They also contain volcanic and volcaniclastic components, which place them in the upper part of the Slate Creek succession. Black slate intersected in diamond drill hole 274 southeast of the Mt. Milligan deposit is limy, graphitic and soot-black. It is mapped in a separate fault-bounded panel (Figure 3). Near Dem Lake, the grey slate contains very common siltstone interbeds (Photo 5) and also sedimentary breccias composed of slate interclasts. Thin sandstone interbeds contain abundant detrital quartz. Quartz grains are single, not polygrains, and except for mild undulatory extinction, they are not deformed. A plutonic or volcanic, as opposed to a metamorphic, source is preferred. One grain of chromite was seen in thin section. It indicates a minor or distant ultramafic source, perhaps accreted ultramafic rocks in the fore-arc region. The Dem Lake exposures are only 8 kilometres from the Pinchi fault. Patterson (1977) reports amphibolized gabbro, metadiabase, chert and basalt pebbles in an upper Norian conglomerate on the north shore of Pinchi Lake.

A conodont collection from a Slate Creek limy siltstone interbedded with shale on the east shore of Dem Lake, next to its faulted contact with the Inzana Lake succession, is of Late Triassic, probably late Carnian age (Locality f4 on Figure 3; Appendix 2).

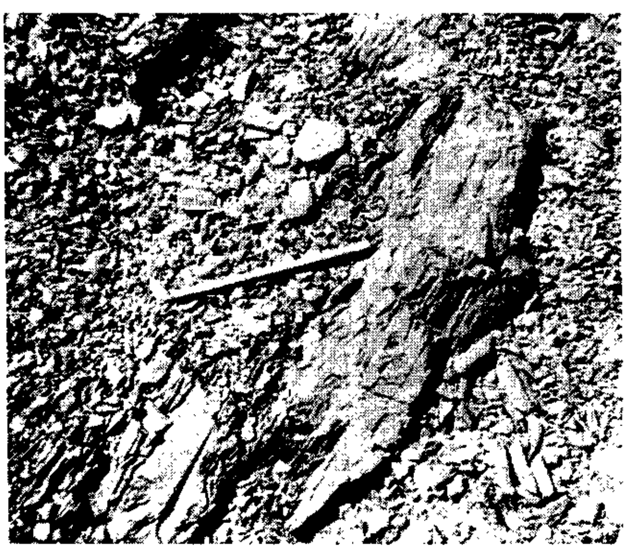

Photo 5. Well-cleaved fine grained siltstone, Slate Creek succession near Dem Lake. Detrital phenocrystic quartz and chromite were identified from this locality.

Regionally, the lowest unit of the Takla Group is a package of dark grey to black slates or phyllites with interbedded quartz-rich siltstones and sandstones and minor limy beds and limestones that grades upward into a mixed slate, siltstone and epiclastic sequence. Near Quesnel this unit is termed the "Triassic black phyllite" (Struik, 1988, Panteleyev *et al.*, in press). It also correlates with the Slocan Group in southeastern British Columbia (Klepacki and Wheeler, 1985) and with the Table Mountain sediments in the Sylvester allochthon (Nelson and Bradford, 1993), both of which have yielded Carnian and Norian conodont ages. Regionally, siliciclastic material is only present in the lower and eastern parts of the succession.

INZANA LAKE SUCCESSION

The Inzana Lake succession is named for exposures around Inzana Lake. The outcrop area of this unit is very extensive in the southern part of the map area (Figure 3). It is a mixed unit of fine to coarse epiclastic to pyroclastic material and black argillite, with minor sedimentary breccia and coarse pyroclastic lenses. It stratigraphically underlies the main augite-porphyry volcanic unit, the Witch Lake succession (Figure 4) but also interfingers with it. The general upward sequence from epiclastic to volcanic is comparable to the upper Slate Creek - lower Plughat Mountain - upper Plughat Mountain sequence in the Manson-Germansen area; however there is a great enough degree of difference,

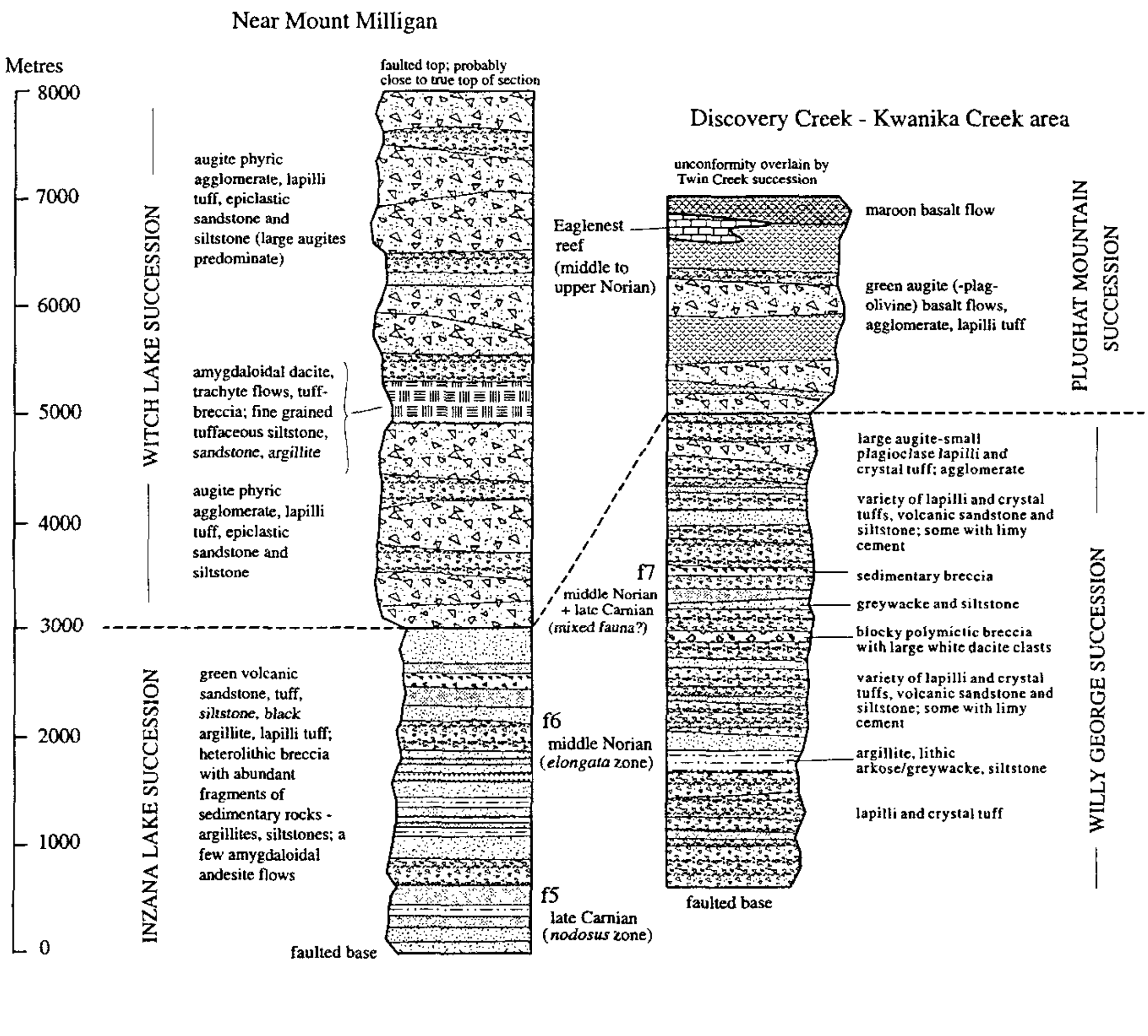

Figure 4. Stratigraphic columns for the Takla Group.

and sufficient regional consistency in the character of the Inzana Lake succession, to merit a separate name. It outcrops over a large area, at least from the north shore of Tezzeron Lake into the low hills south of Witch Lake, where it is in part overlain by and in part interfingers eastward into the Witch Lake succession. It reappears below the Witch Lake volcanic pile in the lowlands around Valleau and Tsaydachi creeks and east to the Germansen batholith. It is bounded to the north by the Slate Creek succession near Moly Lake, although the contact is not exposed.

The transition from the Slate Creek to the Plughat Mountain succession near Germansen Lake is fairly abrupt and well defined (Ferri and Melville,1994). The upper Slate Creek succession contains only subordinate fine-grained epiclastic horizons; the lower Plughat Mountain succession consists entirely of medium to coarse tuffs and volcanic conglomerate. There is no extensive intervening package that includes medium to coarse epiclastic and pyroclastic material mixed with persistent argillite and slate, like the Inzana Lake succession.

In 93K/16, the southern part of the map area, the Inzana Lake succession consists of abundant grey, green and black siliceous argillite with lesser green to grey volcanic sandstones and siltstones, green, augite-bearing crystal and lapilli tuffs, sedimentary breccia, siliceous waterlain dust tuffs, heterolithic volcanic agglomerates and rare, small limestone pods. The argillite is siliceous and poorly cleaved; it contrasts strongly with the alumina-rich grey slates of the Slate Creek succession. Although the sandstones tend to be thick bedded and relatively featureless, graded bedding and load casts are common within the thin-bedded siltstones. They provide extensive control on sedimentary tops. Two separate sets of flame structures, and imbricated volcanic agglomerates, indicate arc-parallel northwesterly transport into the basin, suggesting a volcanic centre to the south. Crystal and lapilli tuffs are most abundant to the west, near Chuius Mountain. Fragments in the lapilli tuffs are characteristically sparse, less than 10% in a sandy matrix. These units may represent an upward transition to the overlying augite porphyry flows and coarse pyroclastic deposits. They contain fragments of augite and lesser hornblende (-plagioclase) porphyry. Fresh olivine crystals are rare but notable. Some greywackes south of Inzana Lake contain clasts that are foreign to the Takla Group: metamorphosed gabbro, chert, foliated marble, and fine-grained biotite and sericite schist. Like the chromite grain in the Inzana Lake succession, these may have been derived from uplifted low-grade metamorphic rocks in the fore-arc region.

The sedimentary breccias (Photo 6) are a distinctive rock type within the Inzana Lake succession. They contain mostly intrabasinal clasts of argillite, sandstone and fine-grained, green siliceous tuff. Volcanic and high-level plutonic clasts are also present, including plagioclase and pyroxene porphyry and inequigranular, medium-grained monzonite. At one exposure 300 metres east of the Fort St.

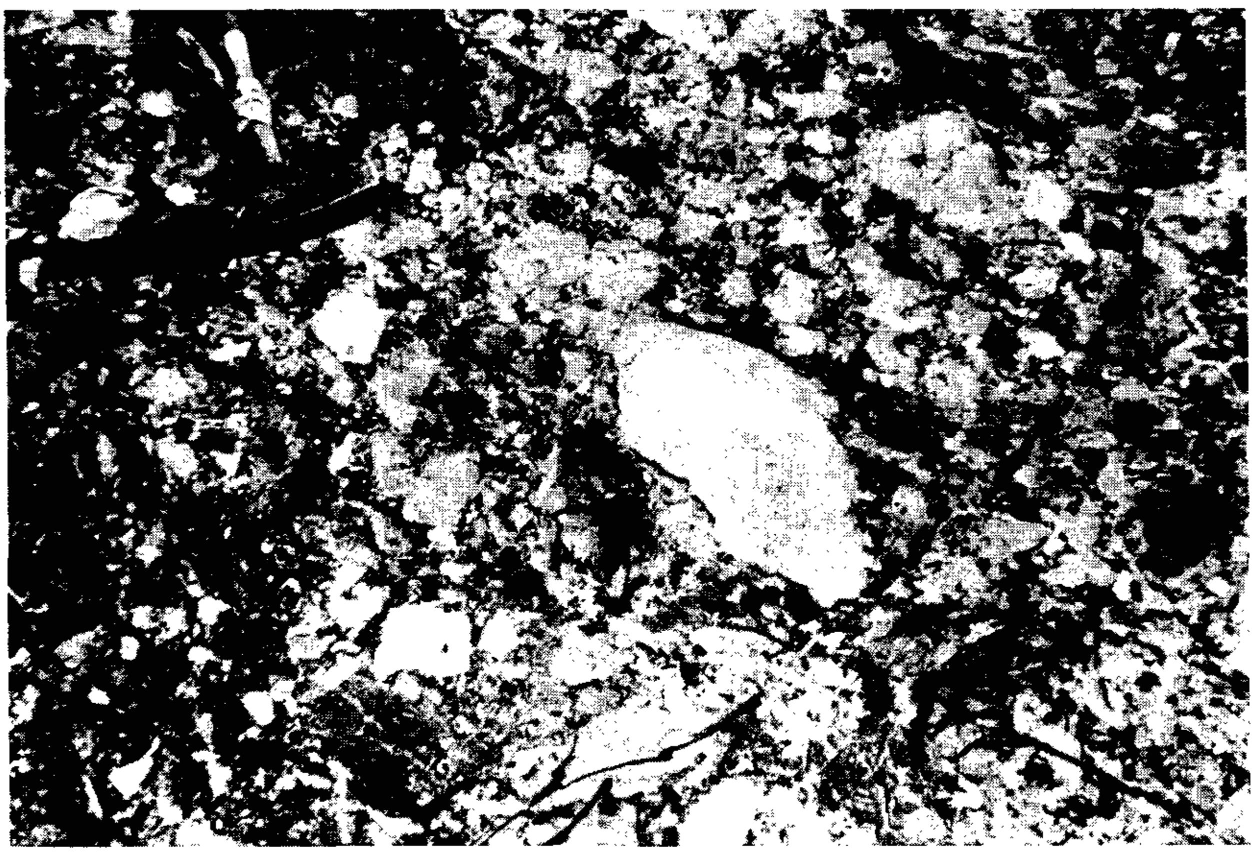

Photo 6. Polymictic breccia with abundant sedimentary clasts, Inzana Lake succession. The large light-coloured clast is volcanic siltstone; darker ones are argillite. All could be cannibalized from other Inzana Lake units.

James - Germansen road and 200 metres north of the Germansen-Cripple subsidiary road, a broad channel in the sedimentary breccia is filled with a slump of rounded augite porphyry clasts. These breccias attest to high-energy conditions within the basin, possibly induced by synsedimentary faulting.

The Inzana Lake succession is transitionally overlain by augite porphyry agglomerates of the Witch Lake succession on the low ridge north of Mudzenchoot Lake. The contact interfingers to the north and west, with Inzana Lake succession west of the Witch Lake volcanic pile in what may be an arc - forearc configuration.

The Inzana Lake succession between the Hogem batholith and Germansen batholith is penetratively deformed, in contrast to the more southern exposures. Foliation and bedding strike northwest and dip steeply. In contrast, the fairly abrupt but locally transitional contact with the overlying Witch Lake succession, defined by outcrops in the hills east of Valleau Creek, is nearly horizontal (Figure 3). The lithologic jumble of coarse and fine epiclastic to pyroclastic beds and grey slate over a wide area is like that in the type area near Inzana Lake. Augite-phyric volcanic sources were similarly dominant.

Two conodont collections from the Inzana Lake succession in the southwestern corner of Figure 3, taken nearly along strike with each other, have late Carnian and middle Norian ages, respectively (f5 and f6; Figures 3 and 4; Table 2; Appendix 2). The older collection is roughly age-equivalent to the Slate Creek succession near Dem Lake, although actual overlap cannot be proved because of the range of the fossil determinations. The significant time span between the two collections suggests that the Inzana Lake succession was originally fairly thin. Perhaps its large areal extent is due to structural thickening.

The Inzana Lake succession correlates regionally with the Tabor Mountain succession near Prince George, and with units in the upper part of the "black phyllite" near Quesnel (L. Struik personal communication 1995).

WITCH LAKE SUCCESSION

The best known lithologies of the Takla Group are augite porphyry flows and pyroclastics. In the Nation Lakes area these are assigned to the Witch Lake succession, named for the thick, well-exposed sequences around Witch Lake (Figure 3). The Witch Lake succession is exposed in three areas, one between Mudzenchoot and Chuchi lakes, where it is in stratigraphic continuity with the underlying Inzana Lake and overlying Chuchi Lake successions; in fault-bounded structural panels on the eastern side of the Wittsichica Creek map sheet, where it hosts the Mt. Milligan deposit; and capping the tops of low ridges northwest from where it appears beneath the Chuchi Lake succession south of the Klawli River north into the Valleau Creek drainage.

The Witch Lake succession appears to represent the products of a single volcanic centre, or related centres. As an entity, it is bounded to the south by a stratigraphic contact with the Inzana Lake succession, and to the west by interfingering with it. Its eastern contact is truncated by faults. Near Mt. Milligan, measured stratigraphic thickness of the Witch Lake succession exceeds 5000 metres and it is dominated by coarse agglomerates. It thins considerably to the north. East of Klawli Lake (93N/7), where Witch Lake lapilli tuffs and agglomerates appear beneath the gently south-dipping Chuchi Lake succession, they interfinger with finer grained epiclastic sediments. Their inferred thickness is between 500 and 1300 metres. This area may lie near the northern extent of the volcanic pile. Overall, the volcanic edifice extends over 1000 square kilometres in this region and probably formed by coalescing fissure eruptions.

The augite porphyry suite that dominates the Witch Lake succession is typical of explosive intermediate volcanism. It includes all gradations from flows and probable hypabyssal intrusions to coarse volcanic breccias and agglomerates, lapilli and crystal-rich tuffs and thinly bedded, subaqueous epiclastic sandstones and siltstones. Many of the clasts in the agglomerates have curvilinear outlines, overall convex with gentle reentrants (Photo 7). They are not mechanically rounded. They may be crude pillows or bombs. Both small-augite porphyry and large-augite porphyry variations are present. Large clinopyroxenes concentrate in certain eruptive units. Plagioclase and hornblende phenocrysts are generally subordinate and olivines rare. Compositionally, most clasts are basalts and basaltic andesites. The distribution of obviously alkalic basalts with primary matrix potassium feldspar is spotty. They have been identified in stained thin sections from several localities on the ridge south of Mount Milligan and near Witch Lake (Photo 8). Overall, they are intermixed with less alkalic basalts.

The abundance of potassium feldspar in the volcanic rocks at and near the Mt. Milligan deposit has led some authors (Rebagliati, 1990) to classify them as augite-porphyritic latites and banded trachytes. However, microscopic examination of andesites and derived sediments up to 4 kilometres from the MBX and Southern Star stocks shows the invasion of secondary potassium feldspar occurring as veinlets, as clumps with pyrite and epidote, as seams in pla-

Photo 7. Typical augite phyric agglomerate, Witch Lake succession. This unit contains clasts of several distinct textures, some large-augite phyric and others with pin-prick size phenocrysts. Note the overall rounded contours of the clasts.

TABLE 2
MACROFOSSIL AND CONODONT COLLECTIONS FROM STRATIFIED UNITS

MACROFOSSILS

Unit	Map No.	Sample No.	GSC No.	Lithology	Age	Species	Paleontologist
Plughat Mountain succession (Eaglenest limestone)	F1 F2	95JN14-10a 95JN14-10b		limestone	middle-late Norian	*Heterastridium*	G. Stanley, University of Montana
	F3, F4	95JN14-5, 6		limestone	Middle-Late Triassic	sponges: *Nevadathalmia* sp., *Cinnabaria* sp.; corals: *Retiophylla* sp., ?*Kuhnastraea* sp., *Chondrocoenia* sp.	G. Stanley, University of Montana
	F5	92KB 14-6		limestone	Middle-Late Triassic	poorly preserved sponges like F3-F4	
Chuchi Lake succession	F6	91CRE7-3	C-189720	shale/siltstone	early Pliensbachian	ammonites: *Tropidoceras* sp., *Acanthopleuroceras* sp., *Metaderoceras evolutum* (Fucini), *Gemmellaroceras*?? sp., *Phricodoceras* ? sp.; bivalves	H.W. Tipper, Geological Survey of Canada
	F7	91JN93N8W	C-189719	shale/siltstone	late Pliensbachian	ammonites: *Amaltheus* sp., *Fanninoceras*? sp., *Leptaleoceras* aff. *accuratum* (Fucini), *Arieticeras*? sp.	H.W. Tipper, Geological Survey of Canada
	F8	91JN19-4	C-189721	shale/siltstone	late Pliensbachian	ammonites: *Leptaleoceras* aff. *accuratum* (Fucini), *Leptaleoceras* sp., *Fuciniceras*? sp., *Arieticeras* cf. *algovianum* (Oppel)	H.W. Tipper, Geological Survey of Canada
Toarcian sedimentary unit, Discovery Creek	F9	92JN24-1	C-189742	shale/siltstone	late late Toarcian	ammonites: *Pleydellia* n. sp.; *Lytoceras* sp.; Phymatoceratidae n. gen. et n. sp.; ammonite aptychi; bivalves	G.K. Jacobs, Geological Survey of Canada
	F10	92JN21-4	C-189663	shale/siltstone	younger than middle Toarcian	bivalves; rhynchonellid brachiopods belemnite with internal radiating structure	G.K. Jacobs, Geological Survey of Canada
	F11	92JN21-5	C-189664	shale/siltstone	late late Toarcian	ammonites: *Dumortieria* n. sp.; *Phytmatoceritidae* n. gen. et n. sp.	G.K. Jacobs, Geological Survey of Canada
Early Tertiary sedimentary-basalt unit, Gidegingla Lk	F12	90JN34-1	C-168233	shale	Eocene or Oligocene	*Metasequoia occidentalis*; *Pinus* and *Picea* seeds; Betulaceae; *Lomatia lineata* (Lesquereux) MacGinitie; *Comptonia hesperia* Berry	Elizabeth McIver, University of Saskatoon

MICROFOSSILS

Unit	Map No.	Sample No.	GSC No.	Lithology	Age	Species	Paleontologist
Lay Range Assemblage	f1	92KB21-7	C-189738	limestone	Late Carboniferous ?Bashkirian-Moscovian	*Idiognathodus* sp. *Neogondolella* sp. cf. *N. clarki* (Koike 1967)	M. Orchard, Geological Survey of Canada
	f2	92KM26-6	C-189661	red chert	Late Pennsylvanian to Early Permian; Missourian-Wolfcampian	**radiolarian taxa:** *Albailella* sp. *Pseudoalbailella U-forma* Holdsworth and Jones *Pseudoalbailella bulbosa* Ishiga	F. Cordey, Geological Survey of Canada
Mississippian unit, Omineca River	f3	92JN22-1	C-189739	limestone clast in lapilli tuff	Early Carboniferous Visean	ramiform elements *Gnathodus cuneiformis* Mehl & Thomas 1947 *Gnathodus homopunctatus* Zeigler 1960	M. Orchard, Geological Survey of Canada
Slate Creek succession	f4	90JN32-10	C-153846	limestone outcrop immediately west of major fault	Late Triassic, probably late Carnian	*Metapolygnathus ex gr. nodosus* (Hayashi 1968)	M. Orchard, Geological Survey of Canada
Inzana Lake succession	f5	90JN26-5	C-159248	limey pod in black argillite and grey sandstone	Late Triassic, late Carnian, nodosus zone	*Metapolygnathus lindae* Orchard 1991 *Metapolygnathus nodosus* (Hayashi 1968) ramiform elements	M. Orchard, Geological Survey of Canada
	f6	90KG20-5	C-168237	limestone	Late Triassic, middle Norian, elongata zone	*Epigondolella carinata* Orchard 1991 *Epigondolella elongata* Orchard 1991 *Epigondolella spiculata* Orchard 1991 *Epigondolella* sp. indet.	M. Orchard, Geological Survey of Canada
Willy George succession	f7	92KB24-1	C-189652	limestone clast in sedimentary breccia	Late Carnian and Middle Norian (mixed fauna?)	*Epigondolella* sp. cf. *E. multidentata* Mosher 1970 *Metapolygnathus* sp. aff. *M. communisti* Hayashi 1968 *Metapolygnathus* sp. cf. *M. pseudoechinatus* (Kozur 1989) *Metapolygnathus nodosus* (Hayashi 1968)	M. Orchard, Geological Survey of Canada
Plughat Mountain succession (Eaglenest ls.)	f8	92KB14-7	C-189729	limestone	Middle to Late Norian	*Neogondolella* aff. steinbergensis (Mosher 1968)	M. Orchard, Geological Survey of Canada
	f8a	95-JN-EN27-1	C-1666	limestone slump breccia	Late Triassic, Middle? Norian	*Neogondolella* cf. steinbergensis (Mosher 1968) *Neogondolella* cf. *Navicula* (Huckride 1958)	M. Orchard, Geological Survey of Canada
Uslika Formation	f9	92JN24-6	C-189662	coal	Eocene	Selected flora: *Alnipollenites verus* Potonié, 1931 Betulaceae *Ericipites compactipolliniatus* (Traverse) Norris, 1986 *Sphagnum* sp. *Paraalnipollenites alterniporus* (Simpson) Srivistava, 1975 *Ulmipollenites undulosus* Wolff, 1934	A.R. Sweet, Geological Survey of Canada

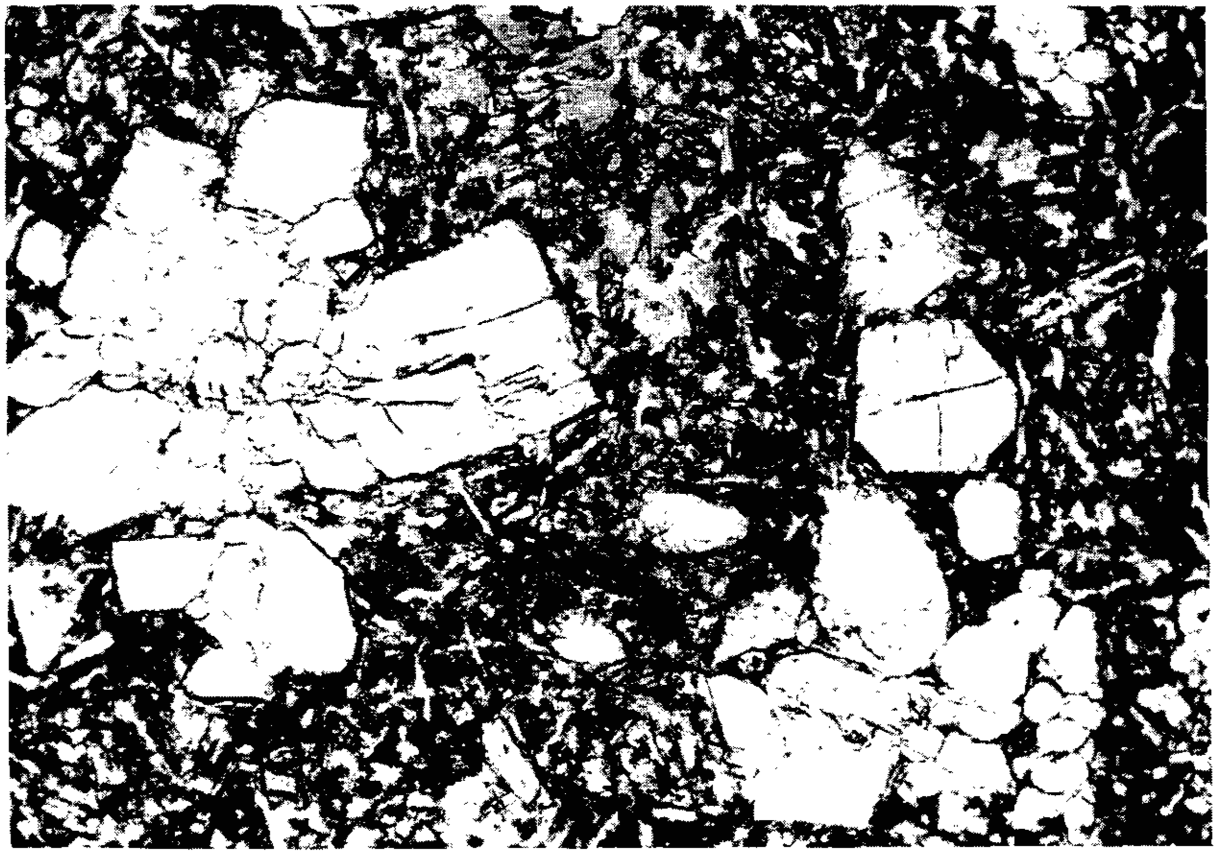

Photo 8. Photomicrograph of augite phyric alkalic basalt, Witch Lake succession. Cloudy potassium feldspar is abundant in the groundmass. The augite phenocrysts are clear and unaltered. Serpentinized olivines occur elsewhere in the thin section. Field of view (short dimension) 1 millimetre

gioclase phenocrysts, and as fine-grained aggregates along bedding planes in the sediments (Photos 33 and 34, Chapter 5). This persistence of potassic alteration even distal to the deposit suggests that the highly potassic nature of the rocks within the deposit is due to pervasive replacement, converting andesites to "latites" and bedded andesitic sediments to "trachytes".

In addition to augite porphyry, a thick section dominated by plagioclase-porphyritic latites occurs in the Witch Lake succession south of Witch Lake. Acicular hornblende-plagioclase porphyries are locally abundant, particularly south of Rainbow Creek and extending southward into the northeastern corner of the Tezzeron Creek map sheet. Here, hornblende porphyries are the dominant clast type in heterolithic agglomerates and lapilli tuffs, accompanied by lesser augite porphyries. At one locality south of Rainbow Creek, hornblendite and amphibolite clasts occur within the hornblende phyric clasts. One clast consists of clinopyroxenite in contact with amphibolite, reminiscent of Polaris-type ultramafic bodies (G. Nixon personal communication 1990).

Trachyte breccia occurs near the top of the western Witch Lake succession in the headwaters of the south fork of Wittsichica Creek. In the Mount Milligan panel, two thin trachyte units can be traced over several kilometres. They are composite units that include pale coloured flows with large, ovoid amygdules, flow breccias, and lapilli tuffs that contain deformed glass shards.

The Witch Lake succession east of Valleau Creek consists of predominantly green and minor maroon augite porphyry flows, with lesser aphanitic flows, augite plagioclase porphyry agglomerates, hornblende-phyric flows and plagioclase-phyric subvolcanic bodies. Subordinate volcaniclastics include tuffaceous sandstone, crystal tuff and lapilli tuff. The prominence of flows within these exposures is more akin to the Plughat Mountain succession than to the Witch Lake succession to the south. The large-plagioclase latite and vesicular trachyte do not persist northward into this area. On the other hand, the rocks lack olivine phenocrysts and large amygdules which are often present in the Plughat Mountain succession. This volcanic suite could represent either a zone of interfingering between eruptive units from two separate centres, or a single centre with transitional characteristics between typical Witch Lake and Plughat Mountain.

The age of the Witch Lake succession is not tightly constrained. It overlies the Inzana Lake succession, which has yielded late Carnian and middle Norian conodonts only at localities far from the contact. It is overlain by the Early Jurassic Chuchi Lake succession. Most reasonably, it is of Norian age; but how much of the Norian it represents is unknown; and as it interfingers with the Inzana Lake succession, a late Carnian age for its base cannot be ruled out.

WILLY GEORGE SUCCESSION

A distinctive pyroclastic-epiclastic succession is exposed on the ridge east of Willy George Creek, west of Discovery Creek (Figure 3). Overall, this section is strongly heterolithic, although many of the individual lapilli tuff units within it are monolithic. The lapilli tuffs represent variations on a theme of augite-plagioclase, augite, plagioclase-augite and plagioclase porphyry volcanic clasts. Consistent volcanic textures of the clasts within many individual units suggest that their sources were single volcanic events. Other units are strongly heterolithic, suggesting either recycling or entrainment of older surface material in pyroclastic debris flows. One unit, traceable over several kilometres, contains white, plagioclase-microphyric dacite blocks with sedimentary and other volcanic clasts. Thin section examination and chemical analysis of the dacite confirms the field identification (Chapter 3). It has elevated niobium contents, compared to the rest of the analyzed suite in which Nb is at detection levels. The lapilli tuffs are interbedded with crystal tuffs and sandstones, which make up about half of the section. Sedimentary breccias like those in the Inzana Lake succession are also present, and a few coarse grained diorite clasts occur. Limestone clasts occur in the sedimentary breccias and also in the volcanic-dominated fragmental units. Some lapilli tuffs have a limy matrix (Photo 9). Within the Willy George succession, a hundred-metre thick interval of pale grey weathering lithic arkose/wacke, dark grey argillite and siltstone outcrops on several spur ridges east of the main ridge, with a total observed strike length of 4 kilometres.

The Willy George succession strikes northwest and dips and faces steeply west. Its uppermost unit is a fine to coarse monolithic pyroclastic rock, in which clasts show a distinctive texture of very large augite and tiny plagioclase phenocrysts in a grey groundmass. This unit apparently underlies the Plughat Mountain succession in lowland exposures north of the Omineca River (Figure 3). Thus, the Willy George succession is a stratigraphic and facies equivalent of the Inzana Lake succession, but the prominence of plagioclase within it contrasts strongly with the Inzana Lake.

A succession dominated by lapilli tuffs, with plagioclase just barely subordinate to augite and with some plagioclase-dominated units, underlies Little Ridge Mountain southwest of the Germansen batholith. This package was tentatively assigned a Jurassic age based on its felsic character (Bailey *et al.*, 1993). However, minor contents of grey argillite and limy-matrix lapilli tuff suggest that it may correlate with the Willy George succession. This interpretation is shown on Figure 3. Perhaps the characteristic Inzana Lake succession passes northward into the Willy George succession, with its predominance of coarser lapilli tuffs and significant proportion of plagioclase phyric clasts.

A conodont collection from a soft-sediment-deformed limestone clast in a polymictic breccia on Willy George Ridge is a mixed fauna, containing elements of late Carnian

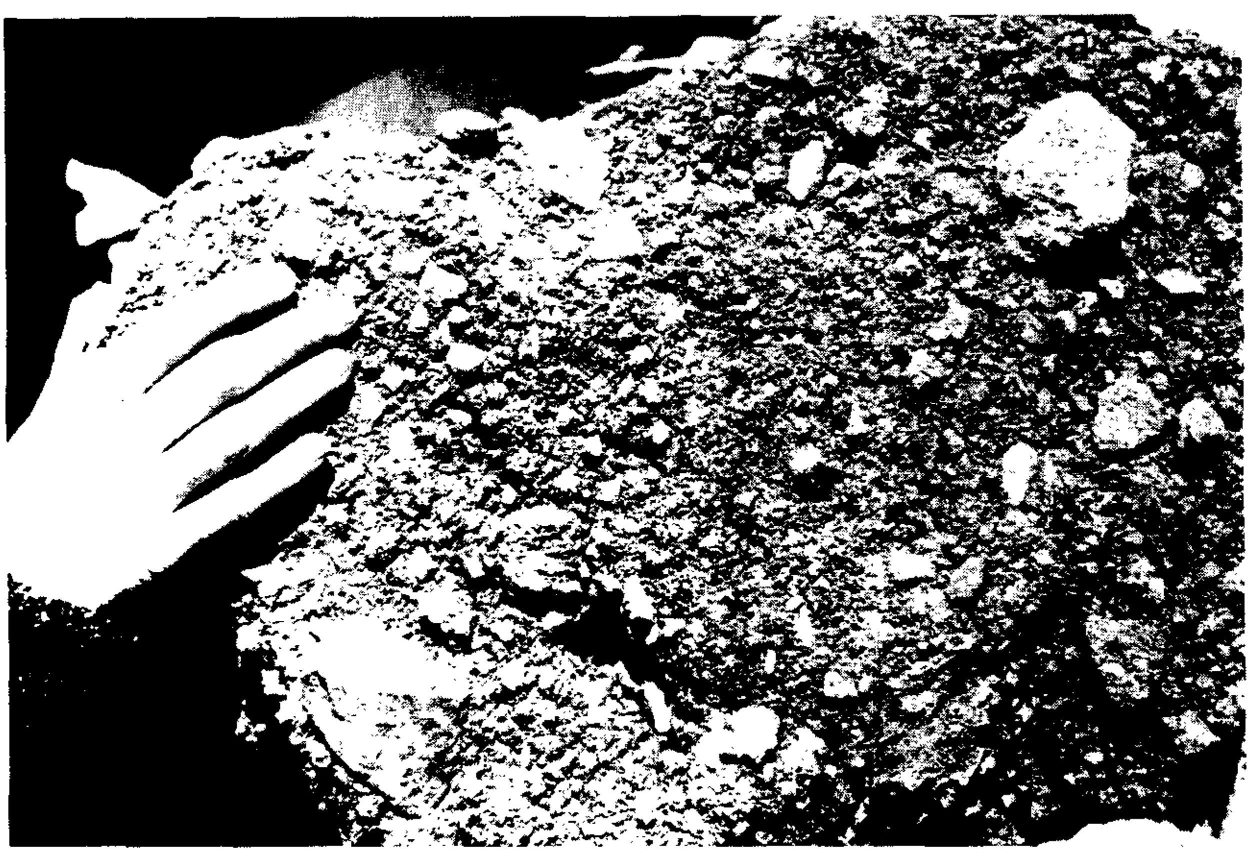

Photo 9. Lapilli tuff with limy matrix, Willy George succession. All clasts appear to have come from the same eruptive unit, an augite-plagioclase phyric basalt.

and middle Norian age (f7 on Figure 3; Table 2; Appendix 2). This age is contemporaneous with the Inzana Lake succession. It implies the existence of a thus-far undocumented Late Triassic intermediate volcanic centre in the Takla Group. Such centres must have existed in Late Triassic time, as plagioclase-porphyritic volcanic clasts, thin trachytic tuff beds and intermediate hypabyssal intrusive clasts occur within the Inzana Lake, Witch Lake and Plughat Mountain successions. The Upper Triassic, in part lower Norian Moosevale Formation (Monger, 1977) represents such a centre within Stikinia.

PLUGHAT MOUNTAIN SUCCESSION

The Plughat Mountain succession outcrops in most of the eastern Kwanika Creek - Twentymile Creek watershed and on both sides of the Omineca River (Figure 3). These exposures are contiguous with the type Plughat Mountain succession near Germansen Lake. This basalt-dominated volcanic pile nevertheless varies markedly in texture (*e.g.* pyroclastic *vs.* flows) and phenocryst composition from place to place. The most southerly exposures on Caribou Mountain east of Kwanika Creek consist of interbedded green augite-phyric vesicular basalt flows and fragmentals with lesser maroon heterolithic agglomerate and flows. Minor quantities of plagioclase-phyric crystal tuff and a monzonite intrusive clast were noted on the north side of the mountain. The ridge north of West Dog Creek consists entirely of green augite-plagioclase-phyric agglomerate and lapilli tuff with one maroon augite-olivine porphyry flow at the base of the succession near the road. Eaglenest Mountain is dominated by green augite-olivine-plagioclase-bearing flows and agglomerates. There are similar porphyritic flows and agglomerates on the mountain southeast of Eaglenest,

Photo 10. Pillow basalt, Plughat Mountain succession northeast of Kwanika Creek.

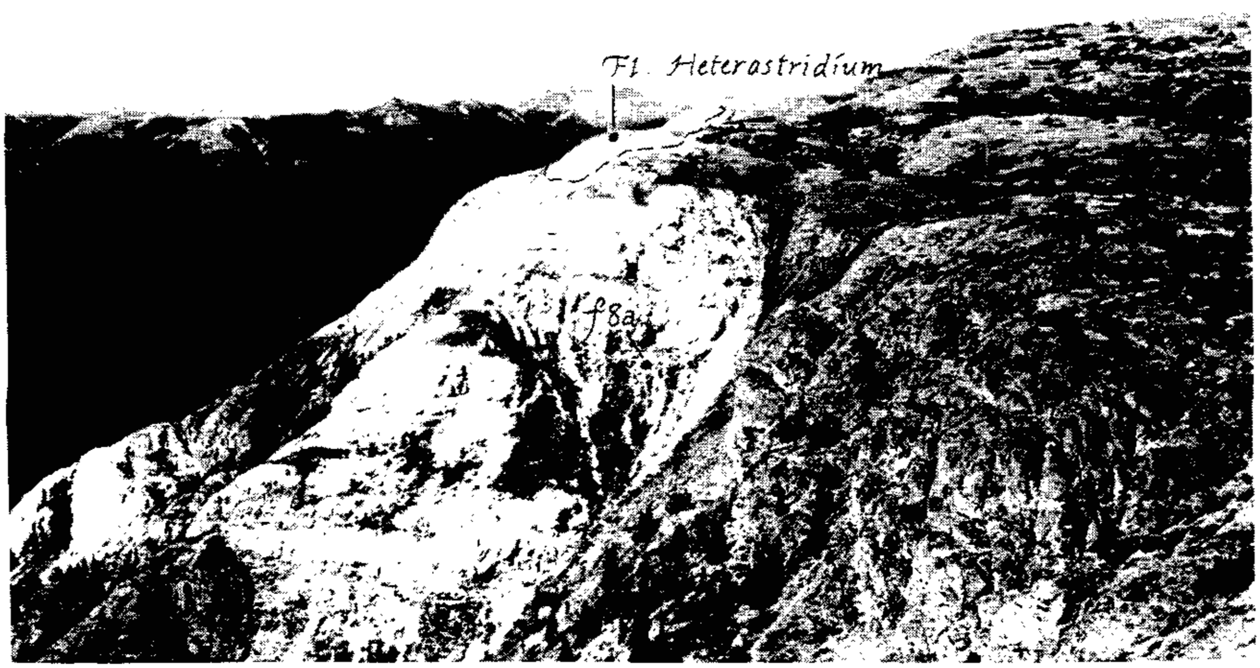

Photo 11. Limestone reef on Eaglenest Mountain, Plughat Mountain succession. Looking north towards the Omineca River valley. The discordant bedding attitudes in the cliff-forming limestone are the result of block rotations in the debris flow. Locality f8a below the upper limestone cliff yielded middle Norian conodonts. Heterastridium limestone caps the exposure.

as well as large outcrops of well-formed pillow basalt (Photo 10). In contrast with the 12 Mile pillow basalts, these contain abundant augite and also olivine phenocrysts.

In the Omineca River valley the Plughat Mountain succession contains large-augite, small-plagioclase porphyry flows and agglomerates, large-amygdule flows, maroon and green amygdaloidal, large-olivine porphyry flows and heterolithic lapilli tuffs dominated by plagioclase and/or augite-phyric clasts. Limestone clasts occur within such lapilli tuffs near Twentymile Creek. Also along Twentymile Creek, aphanitic basalt flows, small-hornblende porphyry flows, heterolithic lapilli tuffs with augite- and hornblende-phyric clasts, and minor interbeds of tuffaceous sandstone form part of the succession. In general, maroon colours are more common in the south whereas plagioclase contents of the volcanic rocks increase to the north.

An Upper Triassic limestone body (uTrPMl) perches on the western buttress of Eaglenest Mountain (Photos 11, 12). It is interpreted as a slumped reef by Stanley and Nelson (1996). In the Eaglenest reef, large olistoliths of sponge-coral reefal limestone are surrounded by coarse to fine limestone debris flow breccia with subordinate volcanic clasts. The reef blocks contain a rich and varied fauna in discrete packstone beds that are interbedded with crinoid wackestones and calcirudites. Included in the fauna are the sponge species *Nevadathalamia and Cinnabaria*, and in lesser abundance the coral species *Retiophylla, ?Kuhnastraea, Chondrocoenia*, and *Pamiroseris* (Stanley and Nelson, 1996). Also present are abundant crinoids, including five-sided *"Isocrinus"*, disjectoporoids, hydrozoans, bivalves and gastropods.

The intimate relationship of the Eaglenest reef with Plughat Mountain basalts is shown by abundant volcanic debris in the wackestones (Photo 13), and by limestone clasts in nearby lapilli tuffs. Rich beds of the floating hydrozoan *Heterastridium*, identified by T. Tozer in 1993 from a photograph (Photo 14) and confirmed by G. Stanley in 1995 (personal communication), lie at the top of the limestone body . Their presence is consistent with a upper Norian age for at least the upper limestone (Stanley and Nelson 1996). A conodont collection (f8a) from debris flow breccia in the middle of the limestone body, about 40 metres stratigraphically below the *Heterastridium* beds, is considered to be Norian, most probably middle (Table 2). A second conodont collection, f8, is middle to late Norian.

A continuous, mappable subunit forms the top of the Plughat Mountain succession west of the headwaters of Twentymile Creek. It is a bright red to maroon augite-olivine-phyric basalt flow (uTrPMb). The red basalt is generally highly vesicular to scoriaceous. Flow breccia is common near its top. The presence of scattered bright red sandstone lenses overlying the breccia suggests reworking

Photo 12. Nearly horizontal bedding in limestone on Eaglenest Mountain, projecting into the volcanic section (dark ridge in foreground). Interdigitation of the two units and mixing of clasts shows this to be an original contact.

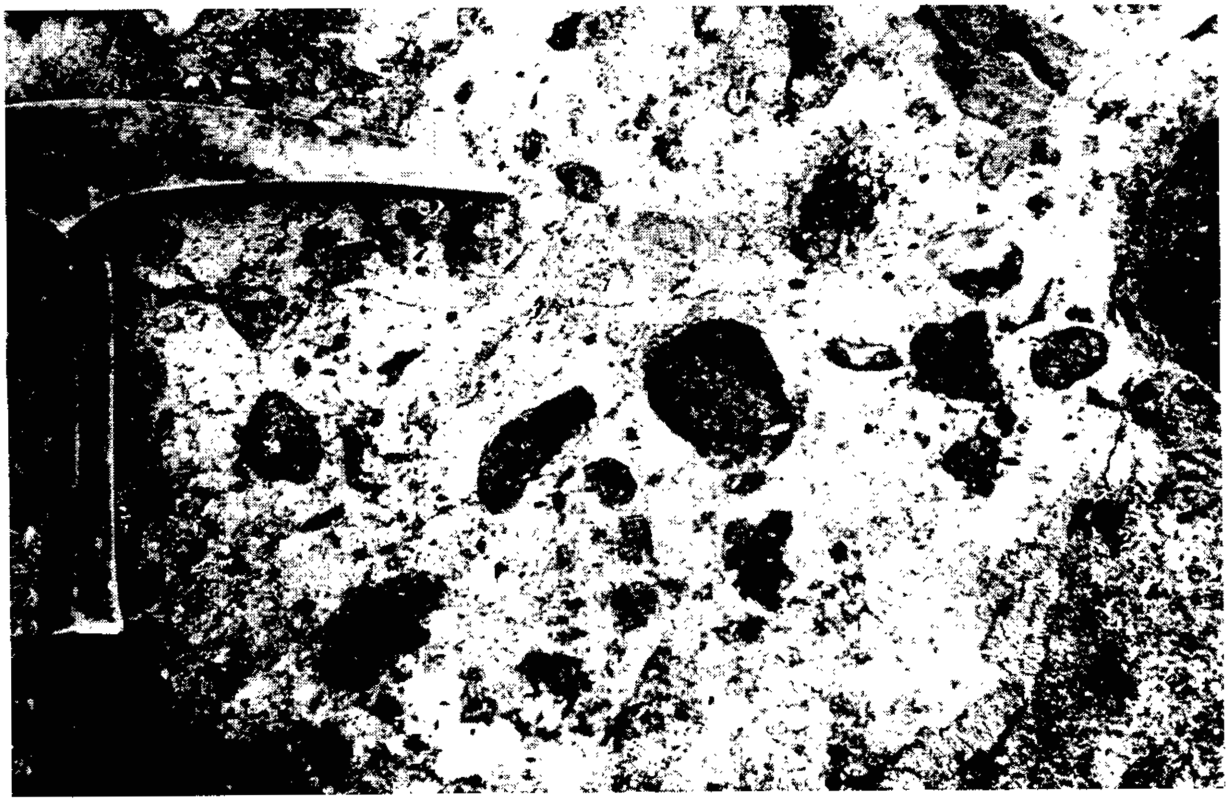

Photo 13. Maroon augite phyric basalt clasts in micritic matrix, Eaglenest Mountain.

Photo 14. *Heterastridium*, Eaglenest limestone. This establishes a Norian age for the limestone.

in shallow water. This maroon basalt marker unit overlies green augite-olivine-phyric agglomerates and flows of the main Plughat Mountain succession.

The Plughat Mountain succession superficially resembles the Witch Lake succession, in that both are dominated by augite-phyric basalts. However each has distinctive elements. Flows are much more abundant in the Plughat Mountain succession. Bright maroon units, unknown in the Witch Lake, are characteristic, as are flows with large, irregular amydules. Together, these two features indicate relatively shallow water deposition. Olivine is common. Aphyric and pillowed flows occur. Limestone, notably the Eaglenest reef but also scattered clasts, is present. The Witch Lake succession is mostly a monotonous pile of augite-phyric agglomerate, lapilli tuff and lesser volcanic sandstone and siltstone. Its minor components - large-plagioclase phyric latite and amygdaloidal trachyte - form consistent horizons and represent a radical compositional break in the succession, in contrast to the compositionally/texturally heterogeneous but consistently basaltic Plughat Mountain succession.

REGIONAL FACIES RELATIONSHIPS IN THE TAKLA GROUP

In the combined Nation Lakes and Manson - Germansen project areas, the Takla Group has been subdivided into a number of units: the Slate Creek succession, the Plughat Mountain succession, the Inzana Lake succession, the Witch Lake succession, and the Willy George succession (Figure 3; *see* also Ferri and Melville, 1994; Ferri *et al.* 1993a,b). Superficially, Takla stratigraphy seems to reflect an upwards transition from basinal sediments through increasing epiclastic and then pyroclastic components, into thick volcanic piles. However, fossil dating and interfingering relationships show that the predominantly epiclastic units may overlap the augite porphyry volcanic units in age. Moreover, significant differences between the Witch Lake succession and Plughat Mountain succession, as well as the northward thinning of the Witch Lake, support their reconstruction as two separate volcanic accumulations that may or may not have been coeval. Some parts of the Takla arc probably never were the site of a major volcanic edifice. Near Aiken Lake, the entire Takla Group consists entirely of distal tuffs (Ferri *et al.* 1993a,b). Like modern volcanic chains, the Takla arc probably consisted of a series of discrete basaltic centres, surrounded by blankets of epiclastic products. Such blankets also extended into the fore-arc and back-arc regions. Our mapping has contributed to the understanding of the Takla arc by defining two broad basaltic centres, each of the order of 1000 square kilometres. Metamorphic debris in the western Inzana Lake succession suggests the active tectonic environment of a forearc region, west of the volcanic front but east of the Cache Creek Terrane.

LOWER JURASSIC UNITS

Three new Lower Jurassic units, the Chuchi Lake, Twin Creek and Discovery Creek successions, were defined in the course of this project, for rocks previously included within the Takla Group. We have separated them from the Takla Group for the following reasons:

- The Chuchi Lake and Twin Creek successions are volcanic, but differ clearly from the Witch Lake and Plughat Mountain successions in their lithologic heterogeneity and the dominance of more felsic compositions.
- They overlie the Upper Triassic volcanic rocks. The base of the Twin Creek succession is a well-exposed, easily recognized unconformity.
- Ammonites from the Chuchi Lake succession are early to late Pliensbachian in age, considerably younger than the youngest known Takla Group in the area.
- The upper unit in the Twin Creek succession is 199.7 million years old by U/Pb dating, or Sinemurian.
- The Discovery Creek clastic sedimentary beds contain upper Toarcian ammonites.
- In the McConnell Creek area, Upper Triassic rocks are included in the Takla Group but Lower Jurassic rocks are in the Hazelton Group (Monger and Church, 1977).

These successions could in the future be subsumed within a group that includes other Lower Jurassic units of Quesnellia, most notably the felsic volcanic and sedimentary strata near Quesnel (Bailey, 1988; Panteleyev *et al.*, in press).

CHUCHI LAKE SUCCESSION

The Chuchi Lake succession is named for excellent exposures on the north shore of Chuchi Lake. It also outcrops extensively in the mountains between Klawdatelle Creek and the Klawli River. Although some dark green, augite-phyric basalt flows within it resemble the Triassic augite porphyries, as a whole the Chuchi Lake succession has a distinctive character. Unlike the underlying Witch Lake succession, it is compositionally and texturally heterogeneous, with feldspar-phyric volcanic lithologies predominant.In further contrast, it shows evidence of deposition in a partly subareal environment: maroon colours and large, irregular amygdules are common, and lahars form part of the section. One such lahar in a roadside exposure north of the east end of Chuchi Lake is a grey-green to maroon, highly heterolithic but plagioclase-dominated, matrix-supported volcanic conglomerate/breccia. It directly overlies a thin volcanic sandstone bed that contains abundant wood fragments on bedding planes, further evidence of near-shore deposition. Black, remnant cores of carbonaceous material with reaction rims denote wood fragments caught up in the hot lahar. Two hapless brachiopods, found in the same lahar, show that it was deposited in a shallow marine setting.

The Chuchi Lake succession includes heterolithic volcanic agglomerates and lapilli tuffs, plagioclase and plagioclase±augite-phyric latites and andesites, lesser augite (and even olivine)-phyric basalts and trachytes. Internal facies variations from flow to fragmental occur within individual eruptive units. Local flow packages show consistency in rock textures and even in the shapes of phenocrysts. They grade laterally into heterolithic agglomerates and lahars which represent much broader textural and compositional parentage. Flows are especially prominent from the north shore of Chuchi Lake to Klawdatelle Creek and northwestwards towards 'Adade Yus Mountain. A major volcanic centre may be masked by the intrusive rocks of the Hogem suite.

Considerable overall facies variation is characteristic. A sedimentary marker horizon, unit lJCL(d) on Figure 3, provides a convenient reference line 20 kilometres long. This marker horizon dips moderately south and extends northwestwards from the roadside lahar exposure discussed above through the BP-Chuchi alteration halo, where sediments outcrop minimally but are intersected in many drill holes. North of Klawdetelle Creek, the sediment horizon is exposed in the cirques of 'Adade Yus Mountain, where it dips gently south and strikes nearly east-west, with an estimated thickness of 250 metres. It pinches out into volcanic flows toward the west. The sediments include brown-weathering sandstone, siltstone, dark grey shale and variable amounts of cherty, pale green dust tuff. The external relationships of the sedimentary marker illustrate the petrologic and lithologic variability of the Chuchi Lake succession, as shown by the stratigraphic columns on Figure 5. On 'Adade Yus Mountain, a lower sedimentary interval, 10 metres thick, is interbedded with green and maroon amygdaloidal clinopyroxene±plagioclase-phyric and aphanitic basalt flows 150 metres below the main sedimentary unit. The major interval of sediments is overlain by heterolithic agglomerates with plagioclase±augite, augite±plagioclase, plagioclase + acicular hornblende porphyry clasts and locally altered and pyritized monzonite fragments (Photo 15). This unit is indistinguishable from the heterolithic agglomerate that lies below the sediments. East of 'Adade Yus Mountain, the sediments contain abundant fine-grained tuff and overlie a green porphyritic agglomeratic flow unit with plagioclase laths, up to 1 centimetre in size, and lesser augite. The sediments coarsen upwards into thick sandstone beds with abundant rip-up clasts of shale. These are overlain by pebbly grit and conglomerate with clasts of pink glassy flow-banded trachyte, welded trachytic tuff, quartz-jasper veins, subvolcanic intrusions and strongly epidotized volcanic rocks which represent both local and exotic source rocks. These conglomerates are overlain by heterolithic agglomerate.

East of the "elbow" in Chuchi Lake (Figure 5, column F), the sedimentary interval lies between identical heterolithic lahars. This package overlies an augite-olivine phyric basalt flow (or flows?) that outcrops on the prominent ridge along the southern border of 93N/8, just north of the mapped area. The basalt may correlate with the flows below the sediments on 'Adade Yus Mountain. On the BP-Chuchi property, the sediment package overlies and also interfingers with heterolithic agglomerates and lapilli tuffs that

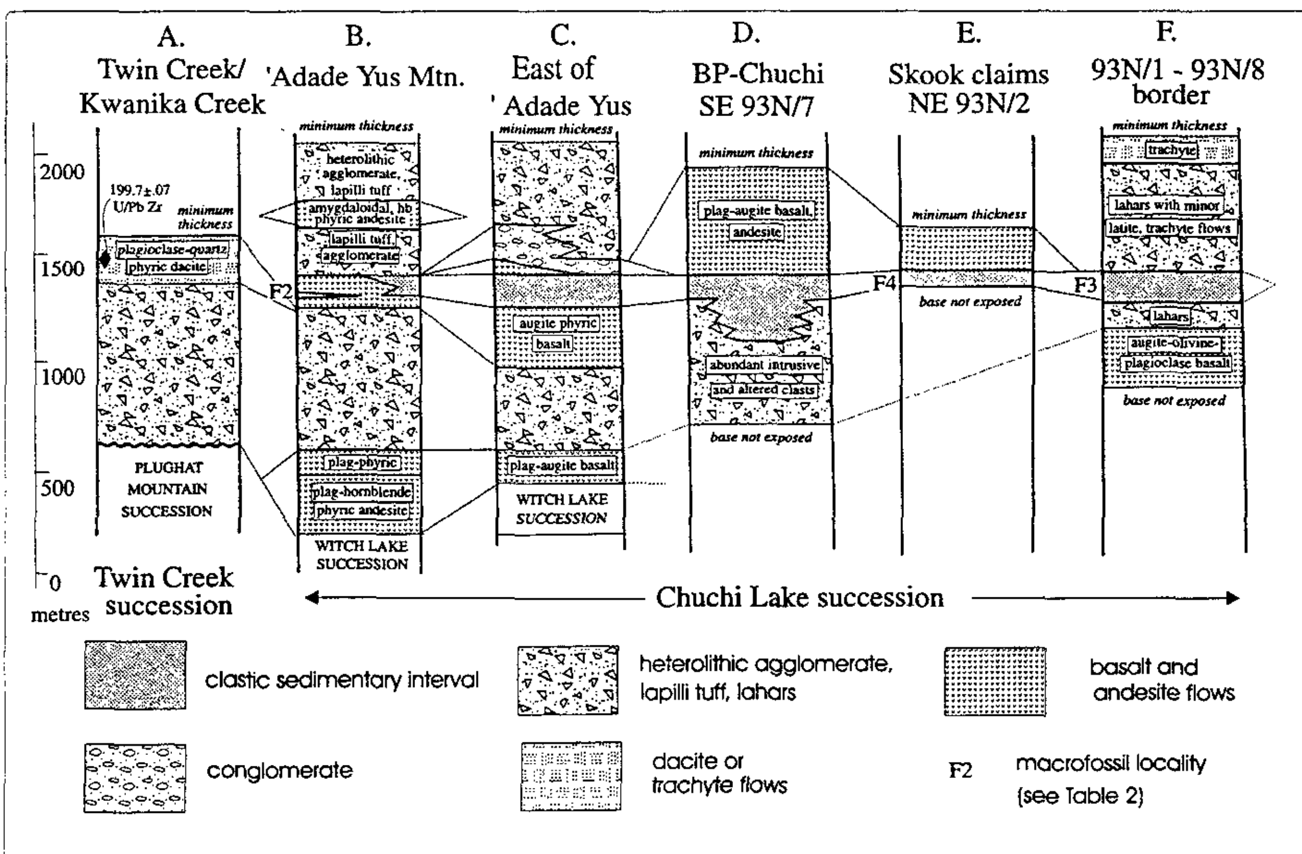

Figure 5. Stratigraphic columns for the Chuchi Lake and Twin Creek successions.

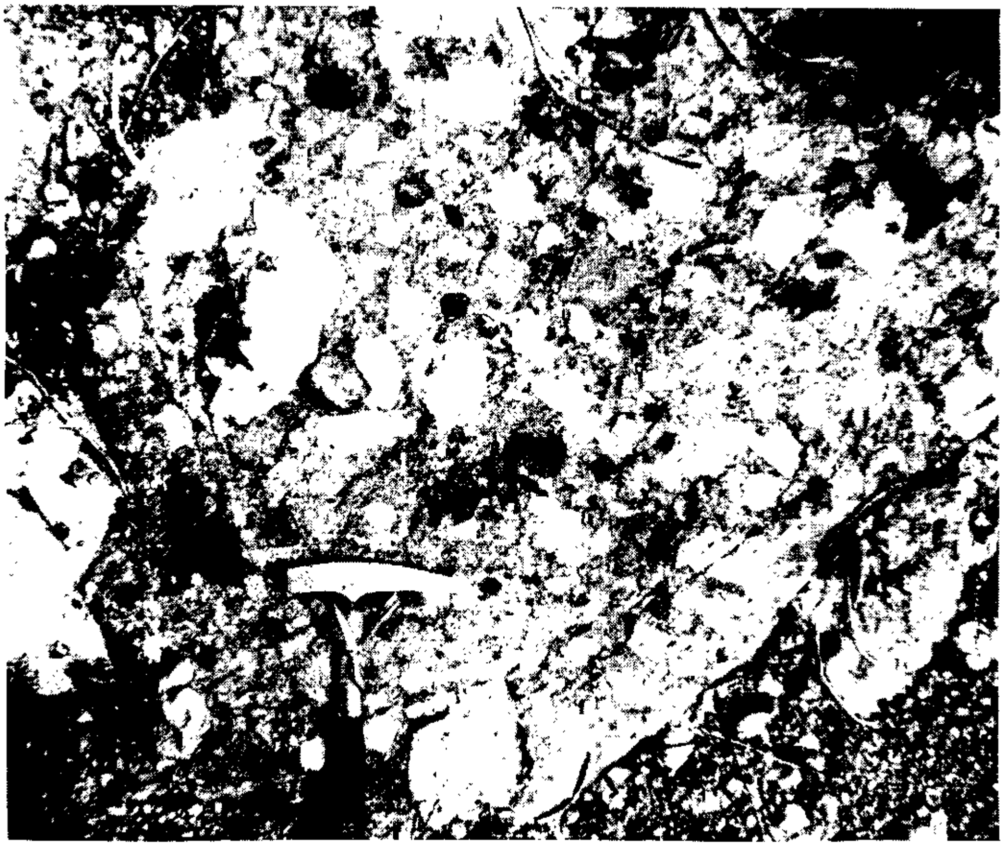

Photo 15. Typical heterolithic volcanic breccia, Chuchi Lake succession, north of Chuchi Lake (lJCLa). Most abundant fragments are plagioclase-hornblende phyric; also maroon plagioclase porphyries and augite-plagioclase porphyries.

contain abundant crowded porphyry intrusive clasts. As well, it is intruded by crowded monzonite porphyry. Textures indicative of intrusion into soft sediments are seen in drill core: these are discussed further in the property description. The age of the monzonite at BP-Chuchi is 188.5±2.5 Ma by uranium-lead dating of zircons (Appendix 7).

The sedimentary interval is capped by a distinctive suite of plagioclase and augite-phyric intermediate flows with large phenocrysts. The flow unit continues south, interrupted by an apophysis of the Hogem batholith, to the Skook claims. There volcanic flows overlie an inlier of the marker horizon, consisting of sandstones, siltstones and white-weathering cherty tuffs with limy nodules.

The Chuchi Lake succession overlies the Witch Lake succession south of Chuchi Lake, along a northwesterly trending, unexposed contact that parallels the regional strike (Figure 3). Maroon, large-plagioclase phyric latite outcrops on the south shore of the lake and in the lower canyon of the Witch Lake outlet creek. Farther south, heterolithic, green to slightly maroon agglomerate and lapilli tuff are assigned to the Chuchi Lake succession.

The total thickness of the Chuchi Lake succession north of Chuchi Lake is about 1650 metres (Figure 3). Its top is eroded. Its basal contact is only exposed on one ridge 5 kilometres north of Klawdatelle Lake. There, augite-porphyry lapilli tuffs pass upwards, apparently in a transitional contact, into dull maroon, heterolithic plagioclase±augite-phyric agglomerates. At this locality there is no suggestion of unconformable relationships between the two successions. However, between western Chuchi and Witch lakes, a few outcrops of maroon plagioclase porphyritic flows and fragmentals occur within an area otherwise underlain by dark green augite porphyritic agglomerates and volcanic sediments of the Witch Lake succession. The maroon rocks are archetypical of the Chuchi Lake succession and may represent its base. If this interpretation is correct, then the base of the Chuchi Lake succession here is morphologically irregular and lithologically abrupt and thus may be a unconformity. This interpretation agrees with the clearer basal contact relations of the Twin Creek succession to the north.

The sources of Chuchi Lake pyroclastic and flow deposits were evidently large magma chambers in which considerable differentiation occurred. Mafic to felsic, and alkalic to subalkalic lithologies are intermixed, with no clear stratigraphic evolution from one to the other. The plagioclase (-augite-hornblende) porphyries contain from 70 to 80% plagioclase and from zero to 15% matrix potassium feldspar. They range from andesites and dacites to latites. The flows between Chuchi Lake and the BP-Chuchi property contain large, isolated plagioclase phenocrysts. They are interbedded with large-augite-phyric basalts. By contrast, clasts in the lahars tend to be more crowded with smaller plagioclase phenocrysts: their textures most resemble the high-level intrusions. Perhaps the intrusions and the lahars were associated with more explosive volcanic events.

The most felsic flow and fragmental units occur in the uppermost exposed part of the Chuchi Lake succession east of the "elbow" in Chuchi Lake [subunit lJCL(f)]. Dark maroon felsic latite to trachyte flows, some plagioclase phyric and others very fine grained to nearly glassy, contain a high percentage of matrix potassium feldspar and large, irregular, amygdules partly filled with calcite and albite. A single large-plagioclase intrusion and flow unit, with individual phenocrysts averaging several centimetres long, is exposed north of Chuchi Lake. Although megacrystic intrusions are fairly common near Heidi Lake and elsewhere, this is the only documented volcanic occurrence of megacrystic feldspar porphyry in the map area. Farther north and down-section, a partly welded trachyte tuff-breccia, unique in the map area, is cut off by the Hogem batholith. It contains a few clasts of coarse grained syenite.

Hornblende porphyry with acicular phenocrysts occurs as clasts in polymictic breccias at the base of the Chuchi Lake succession between Witch and Chuchi lakes, and also up-section north of Chuchi Lake. This textural variant is also seen in dikes. In some exposures the acicular hornblende porphyries, whether dikes or clasts in fragmental deposits, contain small inclusions of hornblendite, clinopyroxenite (strongly actinolitized), and amphibolite.

Three collections of ammonites and two collections of brachiopods were made from the sedimentary marker in the Chuchi Lake succession. Collection F6 is from the 10-metre interval below the main marker on 'Adade Yus Mountain (Figure 3, Photo 16). Collection F7 is from a logging cut at the southwest corner of map sheet 93N/8. Collection F8 is from a stream gully 2 kilometres from the eastern border of 93N/2 and 500 metres north of the Germansen-Indata road (Figure 3). The ammonites were identified by Howard Tipper of the Geological Survey of Canada (Table 2; Appendix 3b). Collection F6 is early Pliensbachian, and collections F7 and F8 are late Pliensbachian and probably equivalent to each other. The intravolcanic sedimentary marker, then, is Pliensbachian. The volcanic rocks above it represent the youngest volcanism in Quesnellia so far documented (late Pleinsbachian or possibly younger). The uppermost volcanic units near Quesnel, and the augite porphyries of the Elise Formation near Rossland, are overlain by sedimentary strata of Pliensbachian age (Bailey, 1989; Höy and Andrew, 1989; Tipper, 1984).

The monzonite intrusion on the BP-Chuchi property appears to have intruded the sedimentary interval prior to lithification (for detailed description, see below Intrusions Related to Early Jurassic Volcanism, and the BP-Chuchi property description. Its age, 188.5 ± 2.5Ma, provides a possible absolute date on the Pleinsbachian.

TWIN CREEK SUCCESSION

West of the Twentymile Creek and Kwanika Creek headwaters, near Twin Creek, the red basalt at the top of the Plughat Mountain succession is overlain by heterolithic lapilli tuff, agglomerate, crystal tuff and local heterolithic volcanic conglomerate, all with significant to dominant plagioclase phenocrysts as well as augite and hornblende. Augite-hornblende, plagioclase-augite, plagioclase and plagioclase-quartz porphyry flows also occur. These are all included in the informal Twin Creek succession. Heterolithic

Photo 16. Ammonite locality F6, Chuchi Lake succession, 'Adade Yus Mountain. Lower Pliensbachian sandstone overlies basalt flow. Looking east.

lapilli tuffs predominate in the lower, more northerly exposures, and augite is more prominent as a phenocrystic phase near the base. Less abundant, strongly heterolithic plagioclase-rich fragmental units are also present and high-level intermediate intrusive clasts occur in the conglomerate (Photo 17). Stratigraphically higher exposures southwest of Twin Creek include large-plagioclase and plagioclase-quartz porphyry flows and related fragmental units. In general, the section is consistent with progressive felsic differentiation of volcanic magmas through time. The presence of quartz in the uppermost units contrasts with the Chuchi Lake succession, which is characteristically alkalic to subalkalic and contains plagioclase-phyric dacite but not phenocrystic quartz.

A quartz-plagioclase-phyric dacite from the upper part of the Twin Creek succession south of Twin Creek yields a concordant U/Pb zircon age of 199.7±0.7 Ma (Table 3, Appendix 7). This Sinemurian age is older than the Pleinsbachian faunal ages from the sedimentary marker in the middle of the Chuchi Lake succession. The entire Twin Creek succession is correlative with the lower part of the Chuchi Lake (Figure 5).

The base of the heterolithic Twin Creek lapilli tuffs rests sharply on the red basalt (Photo 18). The contact is well exposed, and irregular on both minor and major scales. It undulates over 50 to 100 metres of elevation on mountain sides. In outcrop and hand-sample scale the top of the basalt shows sharp irregularities, with angular clasts incorporated or partly incorporated in the overlying debris. Bedding in the red sandstones of the underlying basalt unit approximately parallels the overall attitude of the contact. Both dip very gently to the south. These attributes describe a low-angle unconformity or paraconformity, corresponding to a volcanic hiatus with no significant deformation.

We assume that the Plughat Mountain succession is entirely Late Triassic in age. There is no specific control on the age of the red basalt, but it lithologically resembles basalts around the upper Norian Eaglenest limestone. The upper part of the Twin Creek succession is of Sinemurian age. The mildly unconformable lapilli tuff - red basalt contact detailed above is thus best considered to represent the Triassic-Jurassic boundary.

LOWER JURASSIC? VOLCANIC-SEDIMENTARY UNIT, SOUTH OF THE OMINECA RIVER

A mixed volcanic-volcaniclastic-epiclastic sequence crops out in the southeasternmost corner of 93N/14E (Figure 3). It extends into the low mountains west of Plughat Mountain in 93N/15. This unit has a large component of felsic material, and sandstones contain abundant volcanic quartz. Typical lithologies include heterolithic lapilli tuff, agglomerate-conglomerate, amygdaloidal augite-porphyritic flows and crystal-ash tuffs with plagioclase dominant over augite phenocrysts. Fragments in the coarser units include plagioclase-augite-phyric andesites, granodiorite to diorite intrusive lithologies, maroon augite-porphyritic volcanics, silicified tuffaceous sediments and cherty argillite. On the

Photo 17. Heterolithic conglomerate, Twin Creek succession. Intermediate, plagioclase (-hornblende-augite) porphyry clasts predominate. Dark clast is from underlying Triassic basalt. Hammer handle points at hypabyssal intrusive clast.

TABLE 3
RADIOMETRIC AGE DATA FROM THE NATION LAKES PROJECT AREA

Sample number	Unit	Location	Method/Material	Date (Ma)
JN-90-7-3[1]	rhyolite dyke	fault zone west of Mt. Milligan 93N/1	U/Pb zircon	169.3 ± 5
KB-90-20-4e[1]	crowded porphyritic monzodiorite	Tas claims 93K/16 UTM Zone 10, 415730E, 6084745N	U/Pb zircon	204.2 ± 9
JN-92-16-8[1]	quartz-plagioclase dacite flow	ridge top between Twin and Groundhog creeks, 93N/11 UTM Zone 10, 358100E, 6167525N	U/Pb zircon	199.7 ± 0.7
MM-90-2-1[1]	plagioclase-phyric granite	ridge top south of Mount Milligan 93N/1 UTM Zone 10, 431800E, 6113750N	U/Pb zircon, titanite	168.6 ± 0.6
JN-91-17-2[1]	crowded porphyritic monzonite	BP-Chuchi property UTM Zone 10, 402015 E, 6124700N	U/Pb titanite	188.5 ± 2.5
JN-90-2-3[1]	crowded porphyritic monzonite	Rainbow dike, Mt. Milligan property UTM Zone 10, 434500E, 609000N	U/Pb rutile, zircon	182.5 ± 4
KB-921-13[2]	Evs; rhyolite flow	roadcut .5 km west of Germansen Lake 93N/10 UTM Zone 10, 376900 E, 6172450N	K/Ar biotite	48.2 ± 1.2
G-72-36[3]	EJH: Hogem monzonite	Chuchi Mountain, next to Chuchi syenite 93N/2	K/Ar biotite	183 ± 5
KWANIKA[3]	EKH: Hogem quartz monzonite	west of project area 93N/6	K/Ar biotite	114 ± 4
COL-12[3]	EJH: Hogem monzonite	Col occurrence 93N/2	K/Ar biotite	179 ± 5
Southern Star Stock (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	182.5 + 4.3/-0.6
North Slope intrusion (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	183 ± 3
Heidi Lake Stock (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	189 +3.3/-1.5

1. This study. Analysis at the University of British Columbia Geochronology Laboratory. *See* Appendix 7 for full analytical data.
2. This study.. Analysed material -40 to -60 mesh biotite, very clean fresh separate with no visible alteration, <0.5% impurities. K=6.67± 04%, n=2; Ar^{40*} = 12.649 x 10^{-6} cc/gm (5.644 x 10^{-10} mol/gm); 92.6% Ar^{40*}. J.Harakal, D. Runkle, Geochronology Laboratory, Department of Geological Sciences, University of British Columbia.
3. Garnett (1978)
4. Mortensen *et al.* (1993)

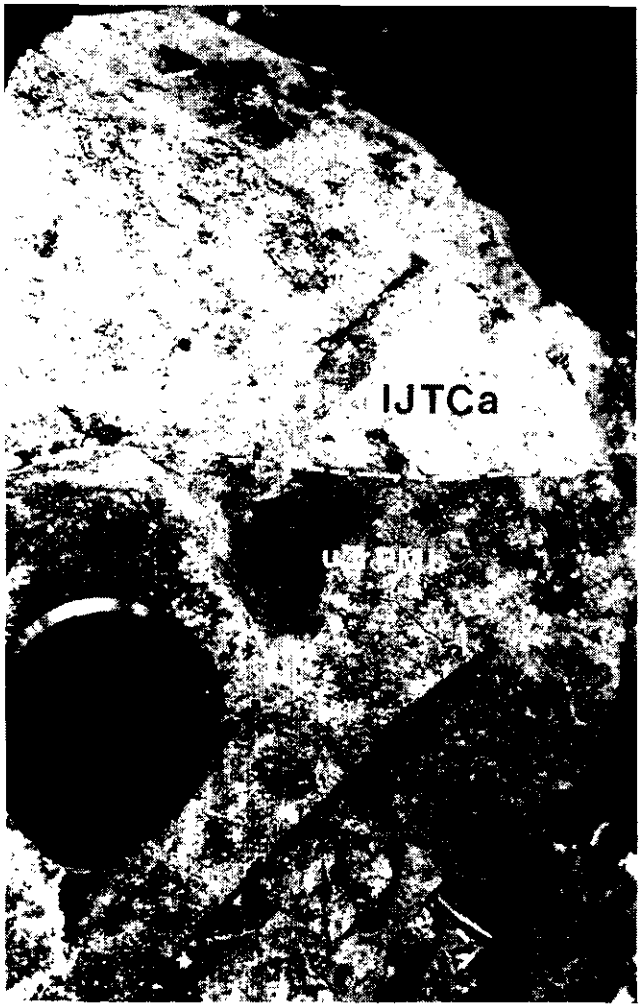

Photo 18. Triassic-Jurassic unconformity, Kwanika Creek area. Heterolithic, plagioclase-rich lapilli tuff (lJTCa) overlies maroon amygdaloidal basalt (uTrPMb).

low ridges northwest of Plughat Mountain in map area 93N/15 correlative rocks include planar bedded, quartz-rich conglomeratic sandstones, sandstone, siltstone and cherty sediments and maroon quartz-bearing amygdaloidal plagioclase-porphyritic volcanics (Unit T3a of Ferri *et al.*, 1989; personal communication and traverse data from this project). In thin section the clasts in the sandstones are seen to be subangular plagioclase and single-crystal quartz grains of entirely volcanic derivation. One volcanic rock was analyzed for major and trace elements (*see* Chapter 3). In terms of major elements, it is a low-potassium andesite. Its relatively high niobium content distinguishes it from all other samples, except for a dacite from Willy George Ridge.

The correlation of this unit is uncertain. It is most probably of early Mesozoic age, because major fault relationships between it and the type Plughat Mountain succession are precluded. Ferri and Melville (1994) include it as an anomalous part of the Plughat Mountain succession. It could also be a correlative of the Twin Creek succession: this is suggested by the predominance of dacites and the presence of detrital volcanic quartz.

UPPER TOARCIAN (JURASSIC) SEDIMENTARY UNIT

Lower Jurassic clastic sedimentary rocks form small cliffs along Discovery Creek for approximately 4 kilometres north of the road bridge (Figure 3). The most abundant lithologies are green to brown-weathering lithic arkose and greywacke with interbedded siltstones. Minor, local conglomerates contain green to maroon plagioclase-augite porphyritic volcanic clasts. Some of the sandstones are composed of grit-sized grains and crystals of plagioclase, orthoclase, hornblende, biotite and augite that appear to be the immature detritus from a plutonic source (Photo 19). The most likely candidate is the nearby Hogem intrusive suite. Less than 1% detrital muscovite occurs in some of the beds.

Three fossil localities were identified on Discovery Creek (F9, F10 and F11). The macrofossil collections were examined by Giselle Jakobs and Howard Tipper of the Geological Survey of Canada. Two localities with ammonites similar to the one in Photo 20 yielded latest Toarcian ages; A belemnite suggests a post-middle Toarcian age for the third locality (Table 2 and Appendix 3b).

The presence of plutonic debris and detrital muscovite in these Toarcian sediments provide important information on Jurassic tectonics. Potassium-argon mineral ages for the Jurassic phases of the Hogem intrusive complex range from 206±8 to 171±6 Ma (Garnett, 1978; data converted to new decay constants, R.L. Armstrong, unpublished data). Potassium-argon ages of both biotite and hornblende from the nearby Duckling Creek syenite are 171 to 178 ma, the latest phases of the Mount Milligan pluton are 168-169 Ma (*see* Intrusive Rocks, below), and Parrish and Tipper (1992) report a 168±1 Ma zircon age of a syenite clast in the Uslika Formation, which they suggest was derived from the Hogem suite. Toarcian time is bracketed between 187±15 and 178±11 Ma in the time scale of Harland *et al.* (1990); and since that compilation, Evenchick and McNicoll (1993) have reported a high-quality uranium-lead zircon date of 183.5±0.5 Ma from a pluton that crosscuts lower to mid-Toarcian strata in the Bowser basin. Based on the preceding isotopic age constraints, the plutonic debris in the latest Toarcian sedimentary sequence in Discovery Creek suggests erosion of the Hogem intrusive suite while parts of it were still forming and cooling.

The muscovite in this Toarcian succession requires a pericratonic, miogeoclinal or cratonic source. The deposition of these sediments was approximately coeval with the early stages of accretion of Quesnellia to the North American margin (181 Ma; Murphy *et al.*, in press; or possibly as early as 186 Ma, Nixon, 1993). They predate the subsequent uplift of metamorphic core complexes in the Omineca Belt. The oldest known cooling age for a metamorphic rock in the Ingenika Group is 174 Ma (K-Ar whole rock; Ferri and Melville, 1994). The source of muscovite may lie farther east, perhaps in the craton; or alternatively, within an accreted pericratonic terrane.

CRETACEOUS TO LOWER TERTIARY UNITS

The youngest stratified rocks in the area are Cretaceous (?) to Early Tertiary in age, described here from north to

Photo 19. Toarcian sedimentary unit in Discovery Creek. Very immature plutonic debris - angular crystals of orthoclase, plagioclase, quartz, biotite and hornblende - forms a thin debris flow with load casts at base. At fossil locality F9.

Photo 20. Ammonite from Toarcian sedimentary unit in Discovery Creek (locality F9).

south. Each of the sequences is a fault-bounded exposure, separated from the others by large areas of older bedrock (Figure 3). There are pronounced lithologic differences between exposures, such as coarse conglomerates versus fine-grained sandstone, siltstone, basalt and coal; wholly clastic versus volcanic-clastic. Only some of these differences may be ascribed to possible variations in age. Three of the five exposures are dated as of probable Eocene age. Their contrasting histories probably reflect deposition in local basins, accompanied in some cases by local volcanism.

USLIKA FORMATION

The Uslika Formation is a clastic unit bounded by strands of the Discovery Creek fault zone. The rocks are contiguous with the Conglomerate Mountain exposures in 94C/3, north of the area shown on Figure 3 (Ferri *et al.*, 1992c). In the northern part of 93N/14E (Figure 3) conglomerate and coarse sandstone predominate with minor occurrences of siltstone and mudstone with rare broadleaf and coniferous macrofossils. The conglomerate is composed of well-rounded cobbles and boulders of monzonite, syenite, augite-porphyritic volcanics, plagioclase-porphyritic volcanics, green and maroon tuffs, green, red and pale beige chert, black and grey siliceous argillite, quartzite (often weakly foliated) and vein quartz. The rocks are clast supported, poorly sorted and very well indurated. Hematite in the matrix gives clasts a shiny coating and imparts a reddish hue to outcrops. Bedding is weakly visible in conglomerate beds and better defined in sandstones and conglomeratic sandstones. In general the stratigraphy strikes northwest to north. Dips vary from gentle to steep.

Approximately 15 kilometres south of these exposures, in the banks of Discovery Creek, grey and black conglomerate occurs with interbeds of arkosic sandstone, siltstone, and mudstone. A bituminous coal bed 1 metre thick outcrops along the stream bank. The conglomerates contain small cobbles and pebbles of two main lithologies, dark grey to black chert and siliceous argillite, and grey arkose interformational clasts (Photo 21). Minor components include vein quartz, turquoise green chert and quartz-biotite granite. This clast population is different from that in the conglomerates farther north, but they are approximately on strike and are therefore both included in the Uslika Formation.

Clasts in the Uslika Formation are probably derived from local sources; intrusive clasts from the Hogem intrusive suite, volcanic rocks from the Takla Group, quartzite from the Atan Group and cherts from the Lay Range assemblage and the Nina Creek group. Parrish and Tipper (1992) report an anomalously young U-Pb zircon age of 168 Ma for one syenitic clast collected near Uslika Lake, which they consider to be derived from the Hogem suite. Data from this study show that the youngest local Jurassic intrusive phases are 168-169 Ma, identical in age to this clast (*see* Intrusive Rocks, below). Metamorphic clasts were not recognized in the study area; however Roots (1954) described rare clasts of quartz-mica schist and quartz-mica-feldspar gneiss less than 2 centimetres in diameter. The Uslika Formation is bounded by faults of the Discovery Creek fault system. Al-

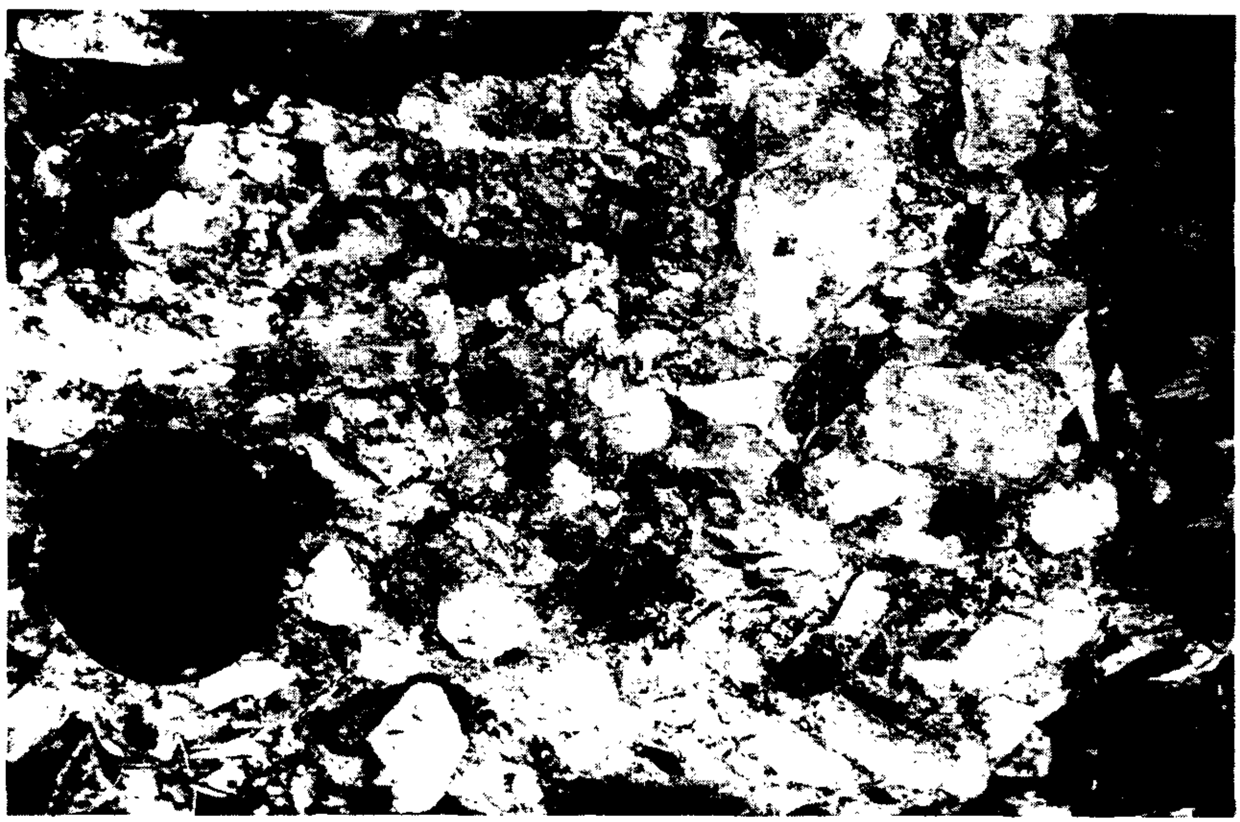

Photo 21. Uslika Formation conglomerate, pollen locality f9. Clasts are of white (cannibalized?) arkose and dark grey chert.

though these faults may not represent original depositional limits, most likely the Uslika Formation was deposited in transtensional graben structures within an overall transcurrent regime (Chapter 4; Ferri *et al.*, 1992a). The grabens are probably long-lived growth structures that contain different fans of clastic material derived from various areas. This structural scenario would also explain the large variation in inclination of beds in a seemingly undeformed sequence.

The coal horizon in Discovery Creek has yielded a well preserved and diverse pollen collection, identified by A.R. Sweet of the Geological Survey of Canada as of probable Eocene age (Collection f9, Figure 3; Table 2; Appendix 4). As such, its deposition was roughly contemporaneous with motion on parts of the Manson fault system and uplift of the main and southern parts of the Wolverine Complex (Ferri and Melville, 1994; Parrish, 1976; Deville and Struik, 1990). The paucity of metamorphic clasts may reflect local drainage patterns, or alternatively deposition prior to extensive surface exposure of the basement rocks.

CRETACEOUS - TERTIARY(?) MAROON TUFFS IN DISCOVERY CREEK

Bright maroon, friable crystal-lithic tuffs outcrop in the lower part of Discovery Creek in narrow fault-bounded panels. The lack of bedding and the homogeneous texture of these tuffs suggests subaerial deposition, perhaps as an ash flow. They contain phenocrysts of plagioclase, orthoclase and embayed quartz with lithic fragments of feldspar porphyry and carbonate. In one exposure the massive tuff grades into bedded red sandstone and mudstone. A similar unit is exposed in the eastern tributary creek next to a splay of the Discovery Creek fault.

The age of these rocks is unknown. No evidence of interbedding with other lithologies, or of relationship with the nearby Uslika Formation was seen. These small felsic accumulations may have been localized along the faults, or in ancient stream valleys that followed faults.

EOCENE SEQUENCE WEST OF GERMANSEN LAKE

A variable suite of volcanic and clastic rocks is exposed at the west end of Germansen Lake in West Dog Creek (Figure 3). Pale pinkish grey to buff-coloured hornblende-biotite-bearing, quartz-eye rhyolite is the most abundant lithology. It is locally flow banded and has a chalky weathering appearance. Less abundant but diagnostic quartzofeldspathic conglomerate with angular and rounded fragments of rhyolite, medium-grained equigranular biotite granite, volcanic quartz and vein quartz occurs with green sandstone, siltstone and volcaniclastics.

The contact of this unit with the Takla Group is not exposed, although it describes a straight, topographically insensitive trace on the map that suggests a very steep dip. The steep bedding dips in this section, its restricted aerial extent, and the lack of Takla volcanic fragments in the conglomerates, support deposition in a small graben - not necessarily identical to the present one, which is bounded by Takla Group rocks. The volcanic quartz is probably derived from the rhyolites and the vein quartz and intrusive clasts may have been shed from the Germansen batholith. This graben represents the southernmost extent of the Discovery Creek fault system and probably developed during Eocene time, the age of the infilling volcanic rocks.

A high-quality potassium-argon age of 48.2 $\pm$1.2 Ma, or early Middle Eocene, was obtained from a biotite separate from a rhyolite flow exposed along the Germansen-Kwanika road 0.5 kilometres west of Germansen Narrows (Table 3).

EOCENE-OLIGOCENE(?) SEDIMENTARY-BASALTIC UNIT, SOUTH OF THE NATION RIVER

Recessive Lower Tertiary strata may underlie fairly extensive lowland regions south of the Nation River. Evidence for this comes from a few drill holes east of the Mt. Milligan deposit (DDH-426, DDH-433, DDH-440, DDH-445, DDH-446, DDH-449) and one near Gidegingla Lake (DDH NR-89-2; Ronning, 1989). East of the Mt. Milligan deposit lithologies include sandstone, mudstone, coal, pebble conglomerate and basalt. Clasts in the pebble conglomerate are of Takla lithologies, some of which are altered, suggesting local derivation from the deposit area. This may be a slump breccia associated with the Great Eastern fault, which now separates the Lower Tertiary rocks from the Takla Group (Figure 3). No fossil ages were obtained from these strata. Their assumed Early Tertiary age is based on lithologic correlation with the Gidegingla Lake strata. More thorough sampling of the coal horizons might yield pollen ages.

Near Gidegingla Lake, sandstone, siltstone, shale and thin-bedded volcanic ash form an interval 19 metres thick between basalt flows. Abundant broad-leaf and *Metasequoia* prints are well preserved on bedding surfaces. A collection submitted to Elisabeth McIver of the University of Saskatoon, includes *Metasequoia occidentalis*, *Pinus* and *Picea* seeds, *Betulaceae* (birch) family, *Lomatia lineata* and *Comptonia hesperia* Berry (Collection F12, Figure 3; Table 2; Appendix 3b). This flora is of Early Tertiary (Eocene or Oligocene) age. According to McIver (personal communication, 1990), the pine seeds show signs of considerable abrasion, compared with the perfect preservation of delicate birch leaves and *Metasequioa* fronds. She suggests that the pine seeds were transported by streams from dry uplands and deposited in wetter lowland areas where hardwoods and *Metasequoia* flourished. This paleogeography of high relief is consistent with evidence of Early Tertiary strike-slip faulting.

The basalts in the Gidegingla Lake drill core are brown to black and aphanitic to finely plagioclase phyric. They contain partly filled vesicles that vary from pin-prick size to cavities several centimetres in diameter. Filling minerals include chalcedony, crystalline calcite, celadonite and zeolites such as mordenite. These basalts strongly resemble Lower Tertiary basalts in the Gang Ranch area as well as basalts of the Endako Group (K.C. Green, personal communication, 1990).

MIOCENE TO PLEISTOCENE BASALT

Very fresh olivine-bearing flow basalts underlie an east-trending ridge near Willowy Creek near the southeastern limit of mapping (Figure 3). The basalts are brown weathering and columnar or platey jointed. They contain xenoliths of dunite and also of gneissic leucogranite derived from North American basement that structurally underlies the Takla Group (Deville and Struik, 1990). They uncomformably overlie the Inzana Lake succession on a bevelled surface. This may be a separate outlier of the Cenozoic basalts mapped by Armstrong (1948, unit 15A) on Hunitlin Mountain 15 kilometres to the south, although he assigned them to the older Endako Group. A Miocene or younger age is preferred for these basalts, because of their freshness, the presence of olivine phenocrysts and ultramafic xenoliths, characteristics generally of Late Tertiary-Quaternary, as opposed to Eocene-Oligocene flows in British Columbia.

INTRUSIVE UNITS

Intrusive units of a wide variety of sizes, ages, compositions and textures occur in the project area. The largest bodies are the Hogem and Germansen batholiths. The Hogem batholith is composed of many discrete plutons of various ages, and we refer to it as an intrusive suite. It comprises mafic to syenitic Late Triassic to Early Jurassic intrusions, the roots of the early Mesozoic Quesnel arc, as well as mid-Cretaceous granites, which show lithologic and chronologic affinities to the Germansen batholith and Klawli pluton. The intrusion on Mount Milligan is probably related to the early Mesozoic part of the Hogem intrusive suite, which it resembles in age, composition and texture. Its latest, quartz-bearing phases are of Middle Jurassic age. Myriads of small intrusions and some larger ones, scattered throughout the map area, are equivalents to the Early Jurassic volcanic units and to the late stages of Triassic Takla Group volcanism. Larger bodies in this category include the Max, Kalder Lake, and Tas plutons and the mafic Aplite Creek and Valleau Creek suites. In terms of economic geology, big is not better for early Mesozoic intrusions: the MBX and Southern Star stocks, which core the Mt. Milligan deposit, practically vanish on a 1:100 000 scale geologic map (Figure 3). As a whole, the early Mesozoic intrusions are characteristically quartz-poor to undersaturated, ranging from hornblendite and clinopyroxenite through gabbro, monzodiorite and monzonite to syenite and quartz syenite. By contrast, the Cretaceous and younger intrusions, the Germansen batholith, the Klawli pluton, bodies of the Hogem intrusive suite near Twin Creek and Valleau Creek, and numerous small quartz-porphyry intrusions and dikes, are quartz-rich granodiorites to granites.

LOUNGE LIZARD INTRUSIVE SUITE

Most of Lounge Lizard Mountain north of the Omineca River and east of Discovery Creek is underlain by a composite diorite-gabbro body with a wide variety of textural variants that is unique in the project area (Figure 3). In general, the body shows increasing average grain size away from its southern margin, where it intrudes the enigmatic and undated 12 Mile basalt. Finer grained phases usually cut coarser units, although the reverse is sometimes observed. Near the southern contact, fine to medium-grained diorite is most abundant. The summit of the mountain is underlain by very coarse grained to pegmatitic, plagioclase-rich leucodiorite to plagiogranite with areas of igneous layering, intruded by white plagioclase-clinozoisite pegmatites. Large plagioclase-phyric diorite dikes cut all other phases. The age of this body is not known. The gradation from coarsest in the north to finest in the south, where it intrudes the pillow basalts, is compatible with southward tilting. It somewhat resembles mafic border phases of the Hogem intrusive suite, although its lack of potassium feldspar in more leucocratic phases is a notable, probably key difference. This body is also comparable to coarse-grained gabbro-leucogabbro bodies within the Sylvester allochthon, which have been interpreted as oceanic middle crust (Nelson and Bradford, 1993). However, the Lounge Lizard body differs from typical oceanic intrusions in the presence of large-plagioclase-phyric diorite dikes. Is it a deep-level portion of the Slide Mountain Terrane like the Wolf Ridge gabbro near Manson Creek (Ferri and Melville, 1994)? A part of a Triassic marginal basin behind the Takla arc? Or is it simply a mafic intrusion cutting an unusual package of Takla basalts? These questions are unresolved.

INTRUSIONS RELATED TO EARLY JURASSIC AND (?) TAKLA GROUP VOLCANISM

Minor intrusions, ranging in size from metre-wide dikes to composite bodies of more than 10 square kilometres in extent, are scattered throughout exposures of the Takla Group and Lower Jurassic volcanic units. A major concentration of intrusions extends south from the southern tail of the Hogem batholith towards Hatdudatehl Creek. Most of them are considered to be feeders to the intermediate extrusive accumulations of the Chuchi Lake succession. Their compositions, and in many cases their textures, correspond to the range of Jurassic volcanic lithologies. Intrusive clasts are common in the Lower Jurassic volcanic units but also occur in the Upper Triassic units, suggesting Late Triassic plutonism as well.

The most characteristic feature of the Early Jurassic intrusions is their extreme variability, in composition, texture and size. They span a range from pyroxenite/hornblendite through syenite, with a predominance of monzonite and monzodiorite.These intrusions tend to contain little or no modal quartz. Textures range from coarse-grained equigranular, generally in the larger bodies, to sparsely porphyritic. Coarse grained equigranular textures dominate in the Max and Tas plutons, and the small granodiorite body south of Mudzenchoot Lake. Many bodies are hypabyssal and porphyritic. Textures range from sparsely porphryritic with large phenocrysts to the "crowded porphryries", a texture that has been linked to alkalic-suite porphryry copper-gold systems throughout British Columbia (V.A. Preto, personal communication 1990). In a typical crowded porphyritic monzonite, small, blocky plagioclase phenocrysts, typically 1 to 2 millimetres in length, with lesser hornblende, biotite, and/or augite touch each other in a fine grained matrix of plagioclase, potassium feldspar, mafic and oxide minerals (Photo 22). Crowded porphyritic monzonites occur at the Mt. Milligan deposit and at BP Chuchi, the two most significant porphyry copper-gold deposits in the area.

The Early Jurassic suite is described in terms of its lithologic variants from the most felsic to the most mafic, to show how compositional/textural themes recur at scattered localities. This summary is followed by individual descriptions of the larger intrusions. Further details on intrusive suites associated with the porphryry deposits and prospects, such as the Heidi Lake suite, are presented in Chapter 5, because of their intimate association with mineralized systems.

Syenite: Coarse-grained, equigranular syenites contain sparse to moderately abundant 5-8 millmetre plagioclase phenocrysts in an interlocking mafic-poor matrix of orthoclase and plagioclase. They form small intrusions west of Dem Lake, within the Dem alteration halo, and 6 kilometres south of Witch Lake. They are also found as inclusions in a welded trachyte tuff/brecccia of the Chuchi Lake succession. In one dike south of Witch Lake, large, centimetre-sized, tabular white plagioclase and pink orthoclase (microcline?) phenocrysts occur in a felsic matrix. North of Heidi Lake, orthoclase megacrysts are present in a dike which occurs in a swarm with sparsely porphyritic monzonites and latites. This dike is late in the intrusive sequence. Dikes of similar texture and composition post-date mineralization in the MBX stock, as observed in core (M. Harris personal communication 1990).

Monzonite: In general, coarse-grained monzonite is restricted to the Hogem intrusive suite, the intrusion on Mount Milligan and the Max pluton, where it underlies extensive areas and commonly grades into more mafic compositions. A very small plug or dike of equigranular, medium-grained, grey-green hornblende monzonite is exposed 3.5 kilometres southeast of 'Adade Yus Mountain.

Crowded Plagioclase Porphyritic Monzonite: This lithology is key to porphyry copper-gold deposits in the Nation Lakes area, as it is throughout Quesnellia (V.A. Preto, personal communication, 1990). It makes up the MBX and Southern Star stocks at the Mt. Milligan deposit and is also seen north of Heidi Lake, at BP-Chuchi, the Tas, in the Witch alteration halo, on the hill immediately south of Cripple Lake, and on the ridge at the centre of the Max claims. Farther north, a small, pink, crowded plagioclase-acicular hornblende porphyritic monzonite crops out in a glacial gully 4 kilometres north of Klawdetelle Lake. Its margins are composed of intrusive breccias with clasts of monzonite and volcanic lithologies.

In general the crowded porphyritic monzonites are quite felsic and poor in mafic minerals. Plagioclase phenocrysts 1 to 2 millimetres in size predominate, loosely touching each other to create a fine grained intrusive texture in hand sample (Photo 22). Hornblende, clinopyroxene and biotite may also be present. The MBX and Southern Star stocks and the intrusion on the BP-Chuchi property are plagioclase-biotite-augite porphyries. These are the only instances of phenocrystic biotite in crowded porphyritic monzonite in the area. The fine grained interstitial groundmass is mostly plagioclase and potassium feldspar, with mi-

Photo 22. "The Right Stuff": crowded monzonite porphyry from the Rainbow dike, Mt. Milligan deposit.

nor quartz, some of which may be secondary (Photo 23). Texturally, these rocks are transitional between intrusive and extrusive. In thin section they strongly resemble some extrusive latite clasts that make up pyroclastic units in the Chuchi Lake and Twin Creek successions (Photos 24, 25), although none of these contain biotite.

Several U-Pb zircon ages have been obtained from the crowded-porphyritic monzonites to monzodiorites. One, from the Tas, is 204.2± 9 Ma or earliest Jurassic, coeval with the oldest potassium-argon ages of the Hogem intrusive suite and with the Triassic-Jurassic hiatus shown by the unconformity near Twin Creek (Table 3, Appendix 7). The intrusion at BP-Chuchi was dated in this study at 188.5±2.5 Ma by U/Pb method on titanite. Geologic relations, discussed in the BP-Chuchi property description, suggest that it was intruded during the late Pleinsbachian intravolcanic sedimentary interval, which represents a volcanic lull during the accumulation of the Chuchi Lake succession. Uranium-lead ages from the Heidi Lake suite at the Mt. Milligan deposit are 189, 183, and 182.5 Ma, with the oldest age from near Heidi Lake and the younger ones from the North Slope and the Southern Star stock (Mortensen *et al.*, 1993). A uranium-lead age from rutile in the Rainbow dike obtained in this study, 182.5±4 Ma (Appendix 7), agrees with the younger ages of Mortensen *et al.* The zircon fractions in this sample are less reliable because of inheritance.

The youngest ages from the Heidi Lake suite provide a reasonable limit to Quesnel arc plutonism: they are younger than any known Chuchi Lake succession volcanism, and roughly coeval with the Toarcian sedimentary sequence in Discovery Creek. They were literally the last gasp of this long-lived arc as it was snuffed out during emplacement onto the margin of Ancestral North America.

Sparsely Porphyritic Latite: Plagioclase±hornblende and\or clinopyroxene porphyritic latite occurs mainly as dikes. Small, elongate plagioclase phenocrysts with subordinate hornblende and/or clinopyroxene are sparse in a very fine grained, pale greenish groundmass that consists of plagioclase, potassium feldspar and mafic minerals. Many such dikes occur south of Heidi Lake on the western fringes of the Mt. Milligan deposit. They have also been mapped near Mitzi Lake, north and south of Chuchi Lake, on the Max claims, and near Cripple Lake. They occur either as isolated bodies or as parts of larger intrusive suites. The composition, mineralogy and texture of these intrusive rocks are comparable to some of the extrusive plagioclase-phyric latites within the Witch Lake and Chuchi Lake successions: they may be feeders to the more evolved volcanic flows.

Acicular hornblende±plagioclase porphyritic latite is a highly distinctive intrusive type, which contains abundant needle-like hornblende crystals between 5 millimetres and 1 centimetre long. More irregular or blocky hornblendes

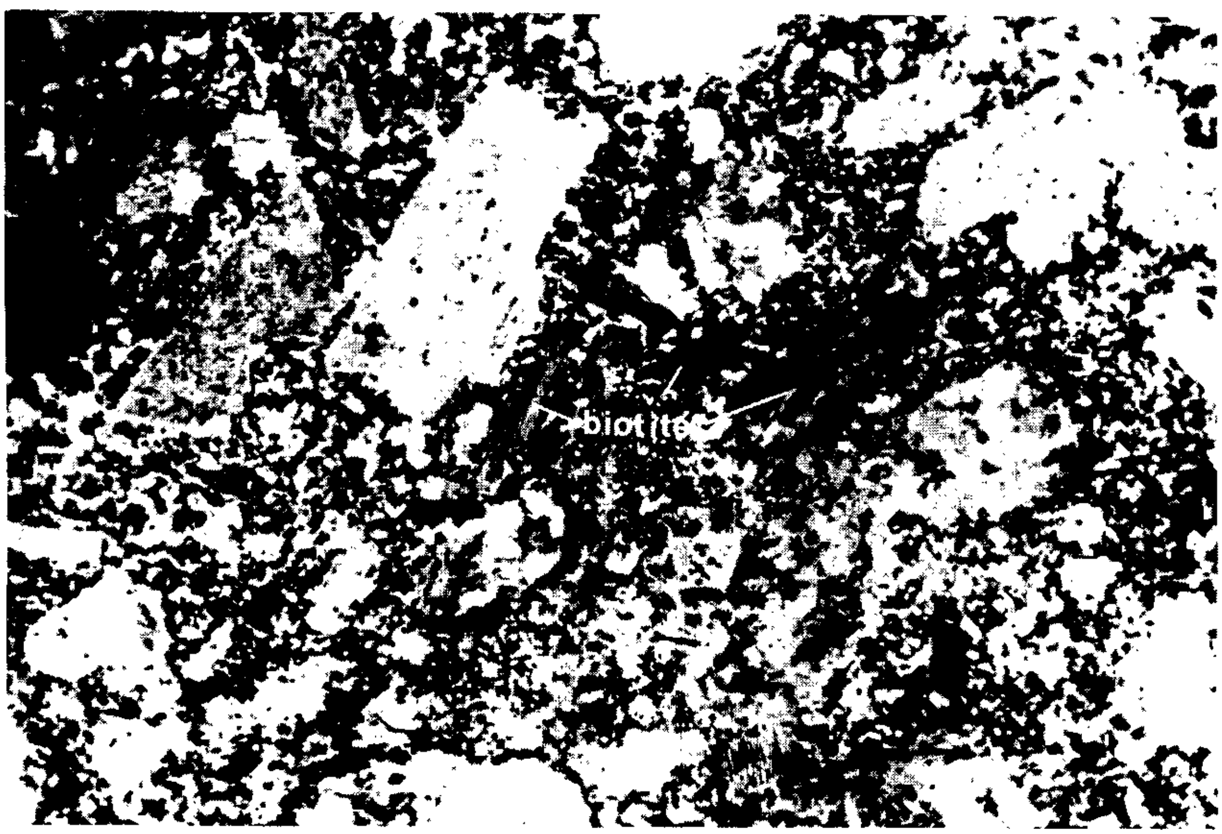

Photo 23. Photomicrograph of Creek zone crowded monzonite porphyry, Mt. Milligan deposit. Typical texture of tabular plagioclase and sparse, partly chloritized biotite phenocrysts in groundmass of potassium feldspar (dark, stained; primary and secondary), plagioclase, quartz, and clumps of very fine grained secondary biotite. Field of view (short dimension) 3 millimetres.

Photo 24. Photomicrograph of crowded diorite porphyry in Chuchi Lake succession. Clast in agglomerate. Unlike the porphyries at Mt. Milligan and BP-Chuchi, there is no potassium feldspar in this rock. Note large apatites with brown rims. Field of view (short dimension) 3 millimetres.

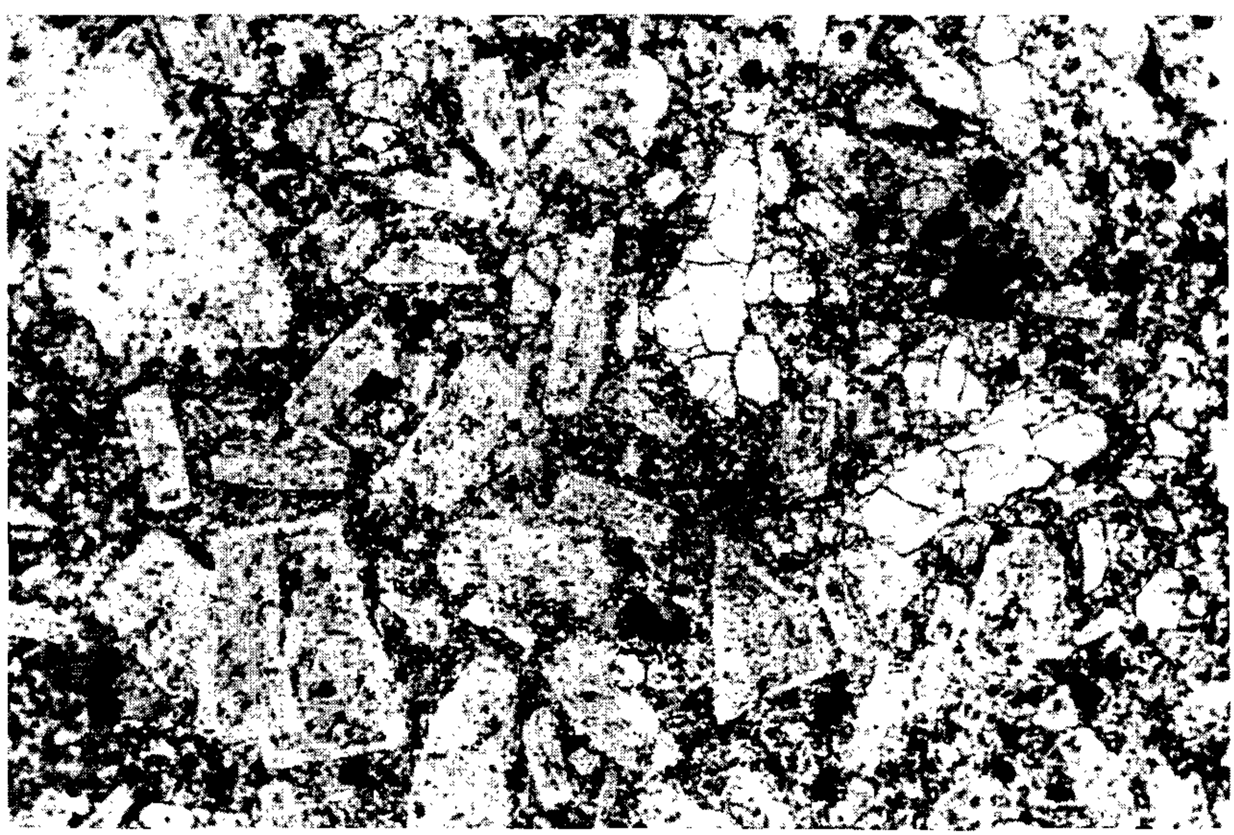

Photo 25. Photomicrograph of crowded texture in clasts in latite-dominated heterolithic lapilli tuff, Chuchi Lake succession north of Chuchi Lake. Except for the absence of biotite, this would not be out of place in the Rainbow dike. Field of view (short dimension) 3 millimetres.

may also be present, as well as xenoliths of hornblendite and amphibolite. The groundmass consists of plagioclase, orthoclase and smaller hornblende and augite crystals. Dikes of this lithology occur immediately west and south of the Mt. Milligan deposit, near Mitzi Lake, south of Chuchi Lake, near Rainbow Creek, and in the southwestern corner of the Wittsichica Creek map area. Their composition, mineralogy and texture are comparable to extrusive hornblende porphyries near Rainbow Creek and along the outlet of Witch Lake. A few andesite (potassium feldspar free) dikes have an identical field character to these hornblende latites; they can only be distinguished by staining.

Diorite/Monzodiorite: Coarse-grained diorites intrude the Inzana Lake succession north of Benoit Lakes and on the Tas claims. The Tas pluton is unusual for the Early Jurassic suite in that it is generally orthoclase poor, mostly diorite to granodiorite, although syenite with large orthoclase phenocrysts is also present. Coarse-grained diorite also forms part of the intrusive suite on the Max claims.

Crowded plagioclase porphyritic diorite occurs on the top of the hill on the Tas property, south of Chuchi Lake, and in a dike north of Chuchi Lake that cuts the Chuchi Lake succession. On the Tas, plagioclase-hornblende porphyry intrudes earlier, blocky hornblende phyric andesite dikes. South of Chuchi Lake, the crowded porphyritic diorite shows intrusive-breccia and shattered textures in thin section.

Megacrystic plagioclase (±augite) porphyritic diorite is restricted to the Kalder pluton. Large, pale greenish plagioclase phenocrysts over a centimetre in size, and much smaller blocky augites, occur in a fairly dark green, very fine grained groundmass. The groundmass contains plagioclase and secondary actinolite needles. An accompanying, later phase contains smaller plagioclases.

Sparsely Porphyritic Andesite: A swarm of hornblende porphyritic andesite dikes is exposed on the hill at the centre of the Tas property. Well-formed blocky hornblende phenocrysts, roughly 5 millimetres in length, and smaller plagioclase crystals are sparse to abundant in a dark green, nearly aphanitic groundmass of plagioclase and hornblende. Scattered examples of these "Tas" dikes are seen as far west as Inzana Lake. A swarm of large-hornblende porphyritic dikes occurs on the Camp property south of Witch Lake. The large blocky hornblende crystals in these dikes are strongly reminiscent of the dikes on the Tas property Similar dikes, and also crowded plagioclase porphyries and one intrusive breccia occur as far as 5 kilometres southeast of the main Camp showing.

Gabbro: Coarse-grained hornblende-rich gabbros form a small part of the intrusive suite on Mount Milligan. A small coarse-grained augite-biotite-magnetite gabbro body is exposed near the northwestern corner of 93N/1. Another small, but very interesting variable-textured gabbroic dike crops out south of Hat Lake. Its composition ranges from monzodiorite to hornblendite over a few metres; it varies in texture from an intrusive breccia to hornblende pegmatite. The gabbro and hornblendite clasts that occur as xenoliths in the Tas crowded porphyries and in intrusive and extrusive acicular hornblende±biotite porphyries may well have been derived from such a source.

Sparsely porphryritic basalt: Clinopyroxene phyric basalt dikes and plugs, the intrusive equivalents of the Witch Lake augite porphyries are rare and small, but notable. They occur north of Heidi Lake, north of the monzonite intrusive suite on the Max claims, and at the Lynx showing.

Ultramafites: Coarse-grained hornblendite and clinopyroxenite are most common as small pods enclosed in diorite, part of the Valleau Creek intrusive suite. They also occur in widespread localities as inclusions in volcanic clasts and in hypabyssal intrusions (see discussion following). Three instances of coarse-grained biotite-bearing clinopyroxenite were noted in the project area. Two are isolated dikes: one on the Tas property (93K/16) and one in the northwestern corner of 93N/1. A third locality is part of the Valleau Creek intrusive suite.

VALLEAU CREEK INTRUSIVE SUITE

The Valleau Creek intrusive suite forms a tabular, composite mafic to ultramafic body that extends southeasterly from the southern part of 93N/11 along the Valleau Creek valley for 30 kilometres to the vicinity of Klawli Lake. There the body turns abruptly eastwards and ends (Figure 3). This complex is reflected by a very strong linear northwesterly trending aeromagnetic anomaly. Most of it is fine to medium-grained diorite and gabbro, with scattered plugs or rafts of coarse-grained pyroxenite and hornblendite containing up to 10% magnetite. Near Klawli Lake, its southern "tail", exposed on the fringes of the younger Klawli pluton, consists of a variety of textural and compositional variants including equigranular diorite with 0 to 5% quartz , a border phase of microdiorite, and rare biotite-bearing lamprophyre composed entirely of altered mafic minerals. The microdiorite is partly interbanded on a centimetre scale with a more leucocratic igneous phase, which gives a fallacious gneissic appearance. Later contact metamorphism by the Klwli pluton has converted pyroxenes to amphiboles and hornfelsed the volcanic country rocks. Fragments of the equigranular diorite occur in the surrounding volcanic agglomerates, indicating that intrusion was contemporaneous with Chuchi Lake volcanism. The linear nature of the Valleau Creek complex and the presence of mylonitic float on its eastern margin suggest the complex is fault bounded and structurally controlled. A Late Triassic to Early Jurassic age for the complex is inferred as its northern end is truncated by a probable Early Jurassic monzonite phase of the Hogem intrusive suite.

APLITE CREEK INTRUSIVE SUITE

The Aplite Creek intrusive suite is centred on a low mountain 5 kilometres southeast of Ahdatay Lake, where it intrudes the Chuchi Lake succession (Figure 3). Like the Valleau Creek complex, it is dominated by fine to medium-grained diorite and gabbro. Textures range from nearly equigranular to porphyritic with large augite phenocrysts. These rocks, mapped as volcanic in previous work (Paterson and Barrie, 1991), are distinguished by their holocrystalline groundmass and lack of fragmental or amygdaloidal textures. Minor amounts of intrusive breccia, consisting of hy-

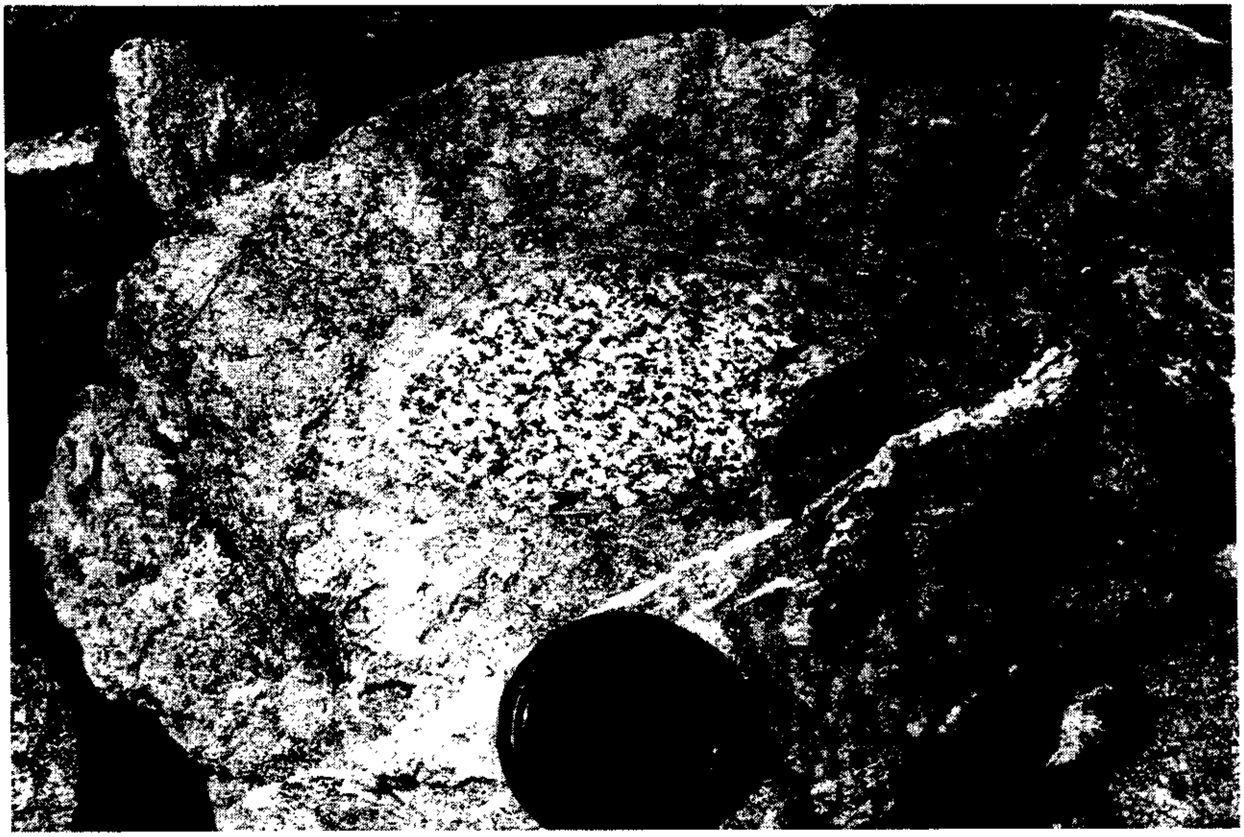

Photo 26. Clast of coarse grained diorite(?) in Willy George succession pyroclastic unit.

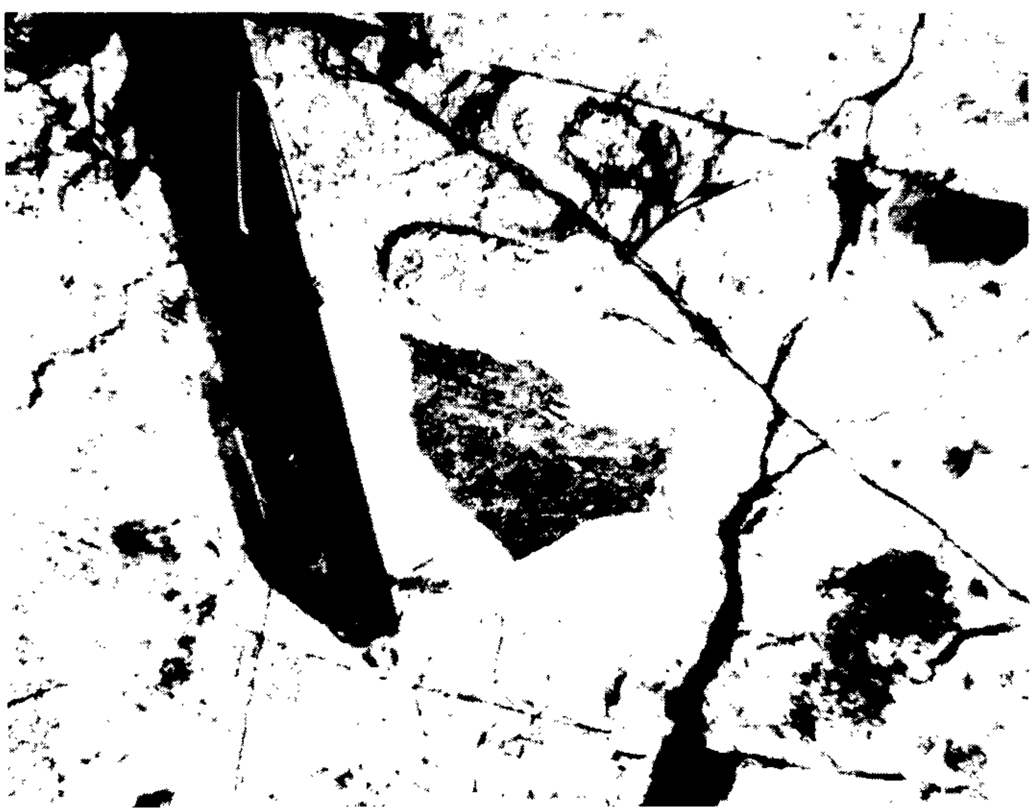

Photo 27. Hornblendite xenoliths in crowded monzonite/monzodiorite porphyry, Tas property.

pabyssal augite hornblende porphyritic monzodiorite and epidotized clasts, occur in Aplite Creek. Several small outcrops of hypabyssal crowded monzonite porphyry are present and later, perhaps unrelated phases of aplite, syenite and monzonite dikes have been included within the suite on Figure 3.

MAX, TAS AND KALDER PLUTONS

The intrusive suite that makes up the Max pluton includes monzonite, diorite and monzodiorite, cut by hornblendite and aplite dikes. Highly variable textures range locally from coarse grained equigranular through medium grained "salt and pepper" diorite to plagioclase, augite and hornblende-phyric hypabyssal lithologies.

The northern edge of the main Tas pluton is sparsely exposed near the Freegold Zone and on the southern slopes of the hill where the East Zone lies. Its southern extent is extrapolated based on regional magnetic data. Dominant lithologies seen in outcrop and subcrop are coarse grained equigranular diorite and granodiorite, cut by sparse pink orthoclase pegmatite veins. This pluton is assumed to be comagmatic with and roughly age equivalent to the small crowded porphyritic monzonite immediately to the north, which returned an early Jurassic zircon age.

The Kalder pluton outcrops on the hills southeast of Kalder Lake. Small scattered outcrops occur in the sea of till and outwash west of the road: they have been included in a single intrusive body, although it is also possible that they are related dikes, exposed by serendipity. The Kalder Lake pluton includes two phases, plagioclase megacrystic diorite and cross-cutting small-plagioclase phyric diorite. The matrix in both phases is fine grained plagioclase, remnant augite and actinolite. Strong subsolidus fabrics are seen in the pluton southeast of Kalder Lake.

IGNEOUS CLASTS IN VOLCANIC HOSTS

Keying intrusive episodes to the volcanic cycle is an important aspect of porphyry deposit modelling. The existence of plutonic and subvolcanic clasts in surface deposits provides indirect evidence for the development of magma chambers through time. Plutonic clasts are most abundant in, but are not restricted to, the Lower Jurassic volcaniclastic units. The Upper Triassic units contain a few intrusive clasts, which show that crystallization and differentiation in magma chambers had begun well before intermediate volcanism became widespread. Coarse-grained monzonite clasts are found in polymictic breccia of the Inzana Lake succession, in hilltop exposures northeast of the junction of the Germansen-Cripple spur road with the main Germansen road, in 93K/16. A few coarse-grained monzodiorite to diorite clasts occur in mixed pyroclastic units of the Willy George succession (Photo 26), and scattered hypabyssal intermediate intrusive clasts are seen in the Plughat Mountain succession.

Hornblendite/clinopyroxenite clasts are commonly associated with Triassic and Jurassic hornblende-phyric units, both extrusive fragmentals and high-level intrusions. Notable localities include the Tas property (Photo 27), a dike swarm that cuts the top of the Inzana Lake succession southwest of Mudzenchoot Lake, heterolithic agglomerate near the base of the Chuchi Lake succession 6 kilometres north of Klawdatelle Lake, and hornblende-dominated fragmental units in the Witch Lake succession along the outlet of Witch Lake and south of Rainbow Creek. The textures in these ultramafic clasts range from cumulate to pegmatitic, with interstitial epidote.

Crowded monzonite porphyry clasts are restricted to the Lower Jurassic units, the Chuchi Lake and Twin Creek successions (Photo 28). In the Chuchi Lake succession, concentrations of such clasts are seen around the intrusions on the BP-Chuchi and adjoining Rio-Klaw properties. These concentrations are intimately connected to the history of mineralization there, and are discussed further in the property descriptions. Somewhat less abundant pyrite-rich monzonite clasts occur in heterolithic agglomerate on 'Adade Yus Mountain, conceivably a distal expression of BP-Chuchi explosive events. One other possible source for the monzonite clasts is a small, inclusion-rich crowded-porphyritic monzonite north of 'Adade Yus Mountain. Textures of most plagioclase phyric clasts in lahars north of Chuchi Lake are equally supportive of hypabyssal or volcanic origin. Coarse-grained monzonites and syenites are noted at three localities. The stratigraphically lowest locality south of Chuchi Lake contains acicular hornblende monzonites in a host of plagioclase-hornblende polymictic breccia. The two localities north of Chuchi Lake contain coarse, equigranular, felsic clasts that are hosted by plagioclase phyric agglomerate and a partly welded trachytic tuff-breccia. Porphryritic and equigranular medium-grained monzonite clasts are also abundant in the fragmental rocks of the Twin Creek succession.

Hornblendite, clinopyroxenite, actinolized clinopyroxenite, coarse-grained gabbro, and rare amphibolite clasts are found in and near hornblende porphyries. They are present in both of the the Lower Jurassic units and in the Witch Lake succession south of Rainbow Creek and near the outlet of Witch Lake. They also occur within dikes and hypabyssal intrusions. Notable localities include: within crowded-porphyritic monzonite and diorite at the Tas; in acicular hornblende porphyry dikes on the low ridge southwest of Mudzenchoot Lake; and in heterolithic lapilli tuff near the base of the Chuchi Lake succession north of Klawdatelle Lake. These inclusions provide a linkage between surface volcanism and mafic-ultramafic intrusions such as the Valleau Creek suite, and even Alaskan-type ultramafites such as the Polaris body in the Lay Range. In these clasts, we see the extensive crystallization of augite and hornblende and succession of crystal cumulates in crustal magma chambers, which finally resulted in the production of the monzonites.

HOGEM INTRUSIVE SUITE

The Nation Lakes project area includes portions of the eastern edge of the Hogem batholith. Two broad lithologic suites are present within it: a quartz-deficient suite of monzonite, quartz monzonite, granodiorite, diorite and syenite of probable Early Jurassic age (EJH, EJHy) and a quartz-rich granite suite of probable Cretaceous age (EKH) with textures identical to those in the Germansen batholith (EKG) and Klawli pluton (EKK; Figure 3). The Early Mesozoic

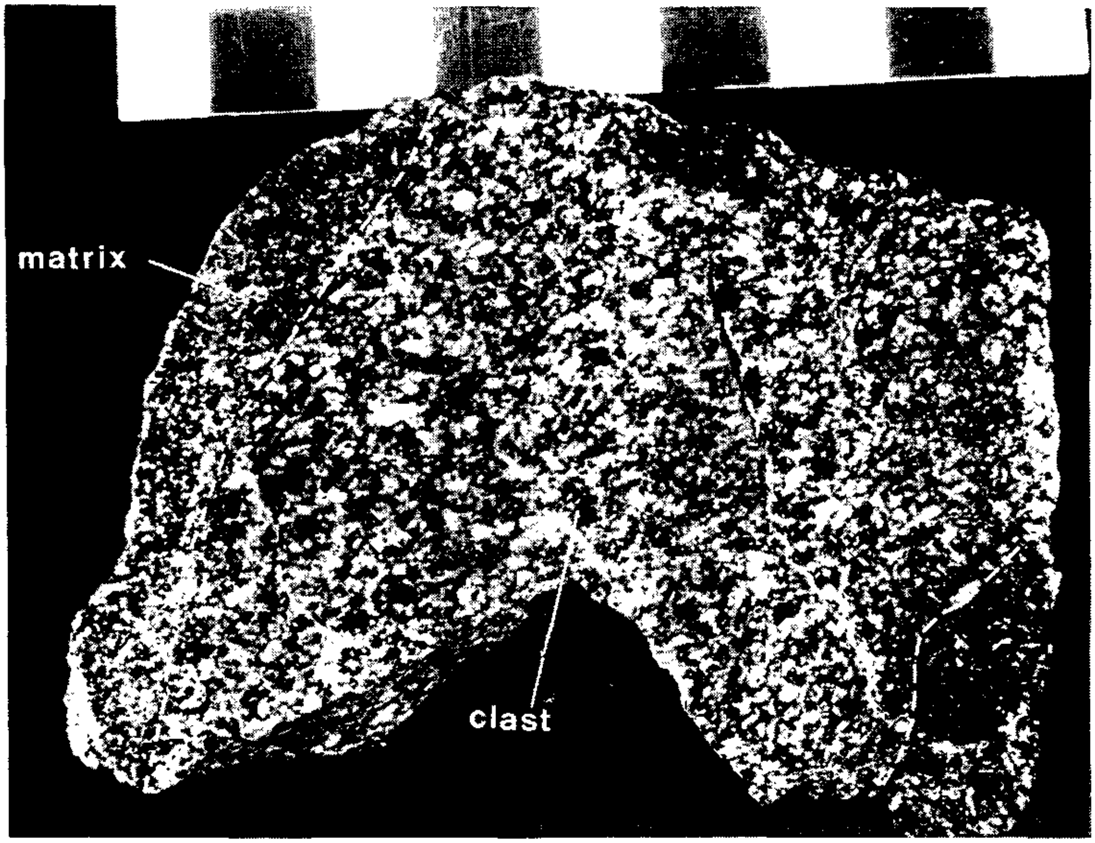

Photo 28. Crowded porphyry monzonite clast in Chuchi Lake succession heterolithic lapilli tuff.

part of the suite consists of a variety of separate phases of differing compositions and textures. This high degree of inhomogeneity suggests that, although the Hogem comprises a large, contiguous area of intrusive rock, its internal nature may be better described as an intrusive suite than as a batholith. Therefore throughout this report, the traditional term "Hogem batholith" is used to refer to the overall outlines of the body, but the preferred lithodemic term "Hogem intrusive suite" is used in discussing its component phases.

The early Mesozoic part of the Hogem suite includes at least three temporal phases, ranging from mafic to felsic. Early, mafic phases are concentrated along the eastern edge of the batholith, from Kwanika Creek to the north shore of Chuchi Lake. The Valleau Creek suite may be related to them, but is separated from the main intrusive suite by a panel of Chuchi Lake succession. The Chuchi monzonite (usage of Garnett 1978), north of Chuchi Lake, is unfoliated and varies in texture from coarse-grained to medium-grained "salt-and-pepper" textured to porphyritic. Diorite is also present in this body. The main mafic minerals are clinopyroxene and biotite. A pod of gabbro and pyroxenite rims the northern margin of the "tail" of the batholith south of the BP-Chuchi property. Igneous layering is well developed in it, suggesting a cumulate origin (Photo 29). It is cut by hornblende-plagioclase-epidote-magnetite pegmatite stringers and pods. Cross-cutting dikes of coarse, pegmatitic monzonite and syenite establish this mafic marginal phase as older than the remainder of the suite.

Medium to coarse-grained equigranular monzonite dominates the second and most extensive Hogem phase. It extends from the Kwanika Creek area to the shores of Chuchi Lake. In some areas the pluton appears uniform, but overall this phase is highly variable and includes textures ranging from fine grained to pegmatitic, equigranular to porphyritic and compositions spanning gabbro, monzogabbro, monzodiorite, diorite±quartz) and syenite. These lithotypes appear to grade into each other, although in some areas the more mafic phases are cut by felsic dikes. Porphyritic monzonite contains phenocrysts of plagioclase, hornblende and augite. Biotite forms regular plates and large, poikilitic crystals; and magnetite contents range up to 7%.

The youngest Early Mesozoic pluton of the Hogem intrusive suite underlies Lhole Tse Mountain (also called Chuchi Mountain) and is referred to as the Chuchi syenite (Garnett, 1978). It includes pink syenite and quartz syenite, with quartz ranging up to 7% but generally much less. True granite is very rare. The predominant texture of the Chuchi syenite is medium grained, equigranular to aplitic, with hornblende and/or biotite ranging from 2 to 10%. Medium to coarse-grained phases with megacrystic orthoclase are also present. They show that orthoclase was on the liquidus when the syenite was forming. This is in direct contrast to the less-evolved monzonite phase where potassium feldspar does not form phenocrysts. Dikes of syenite cut the coarse-grained monzonite on the flanks of Lhole Tse Mountain and on the Col property and xenoliths of monzonite occur in syenite; therefore the Chuchi syenite is the latest phase of

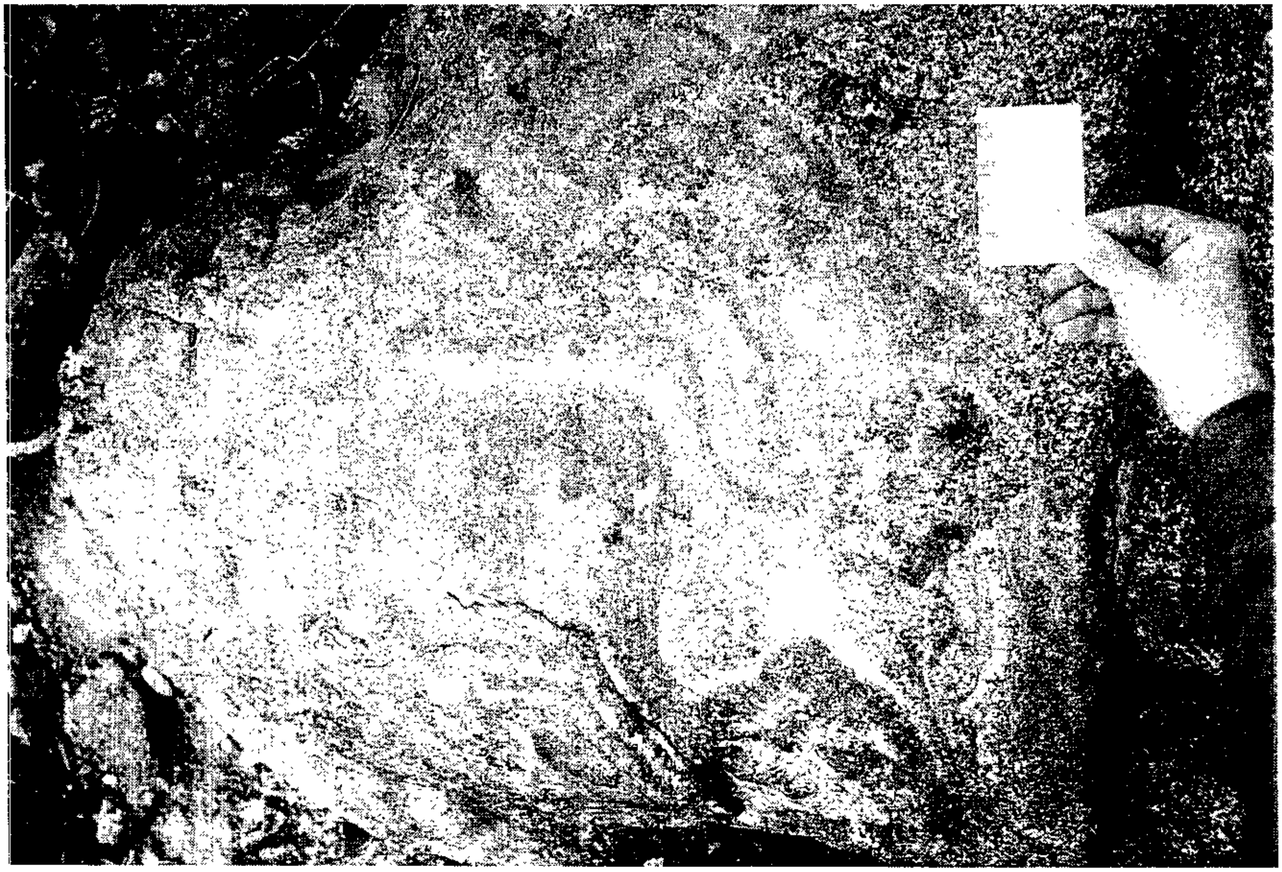

Photo 29. Layered gabbro in the southeastern margin of the Hogem intrusive suite

the Hogem intrusive suite in the area. Garnett (1978) obtained a K-Ar biotite age of 183±5 Ma (converted to new decay constants) from in or adjacent to the Chuchi syenite. The sample site is in a complicated contact area with older monzonite; however it is probable that the biotite has been completely reset by, and records the cooling age of the syenite.

Potassium-argon ages for the older parts of the Hogem intrusive suite range from 206 to 171 Ma (Garnett, 1978; R.L. Armstrong, unpublished data, converted to new decay constants), corresponding to Sinemurian to early Bajocian faunal zones (Harland *et al.*, 1990). The older age is perhaps coeval with early Chuchi Lake volcanism, while the younger age postdates the onset of arc-continent collision, when Quesnellia overrode the margin of ancestral North America. Although the regional metamorphic grade is quite low, the existence of several ages of plutonism and the complex tectonic history of the area make resetting of K-Ar systems likely: systematic dating of the Hogem intrusive suite by more robust geochronologic techniques is desirable.

The Cretaceous(?) quartz-rich Hogem suite is represented by two discrete granite plutons, one west of Valleau Creek that intrudes the Valleau Creek intrusive suite, and one at the headwaters of Twin Creek. This suite is grouped with older bodies such as the Chuchi syenite in unit 9 (leucocratic granite, quartz syenite, alaskite) on Garnett's (1978) map. Yet texturally, and in terms of abundant modal quartz, it is quite distinct, closely resembling the Cretaceous Germansen batholith and the Klawli pluton. Orthoclase megacrysts in a coarse grained matrix of plagioclase, quartz and lesser biotite and hornblende are characteristic of these plutons. Related orthoclase-megacrystic, medium-grained granite dikes intrude the Takla Group in and north of the Twin Creek valley. A K-Ar biotite age of 114±4 Ma (Garnett, 1978, converted to new decay constants, R.L.Armstrong, unpublished data) was obtained from Garnett's unit 9, ten kilometres west of Valleau Creek.

The linear northwesterly trend of the Hogem batholith, sub-parallel with the Pinchi fault except where it turns eastward at its southern end, suggests deep structural control over its emplacement. Individual phases within the batholith also have pronounced linear trends (Garnett, 1978; Figure 3). The Valleau Creek body, that splays from the eastern margin of the batholith, is remarkable for the narrowness and sinuousity of its outcrop pattern.

Local zones with well-developed fabrics along the eastern margin of the Hogem batholith further substantiate the structurally controlled emplacement of its plutons. A vertical mylonite zone, 250 metres wide with steep lineations, is exposed along the its eastern edge, 1 kilometre southwest of Goat Ridge, and strongly flattened diorite/gabbro is exposed in the pass between the Kwanika and Valleau Creek watersheds.

THE MOUNT MILLIGAN PLUTON

Mount Milligan, a low prominence 7 kilometres north of the Mt. Milligan copper-gold deposit at Heidi Lake, is underlain by a composite monzonite-diorite-granite pluton that varies gradationally in composition, mineralogy and fabric. Most of it is monzonite, with variable percentages and types of mafic minerals. Gabbro-diorite and hornblende quartz monzonite and granite also occur. Major mineral phases include plagioclase, clinopyroxene, hornblende and biotite with interstitial orthoclase and minor quartz (<10%). Hornblende and biotite are in some cases poikilitic to skeletal. Hornblende commonly forms mantles on early crystallizing clinopyroxene. Also noteworthy in thin section are the relatively large (0.2-0.4 millimetre), abundant accessory sphene, magnetite and apatite. Fabrics in the body vary from massive to foliated. The planar fabric is due in part to igneous plagioclase alignment, and also to subsolidus recrystallization. Compositions and textures in this pluton strongly resemble the main Early Jurassic phases of the Hogem intrusive suite. It is on trend with the southern tail of the batholith, which turns eastward under Chuchi Lake. Continuity between them is further indicated by the magnetic trends, which perhaps are the response of a buried continuation of the Hogem batholith.

The youngest phase of the Mount Milligan intrusion is a coarse-grained plagioclase porphyritic granite. It cuts the earlier phases on the mountain's southern ridge, but itself shows strong fabrics - biotite alignment and recrystallization and quartz wisps - due to subsolidus deformation. A sample of this granite was submitted for uranium-lead dating.Four titanite analyses intersect concordia between about 165 and 169 Ma, and the preferred age for the intrusion is 168.6±.6 Ma (Table 3, Appendix 7). Data from analysed zircon fractions are discordant and show strong inheritance.

A rhyodacite dike occurs along the fault zone that bounds the Mount Milligan pluton to the west. It is creamy white and porphyritic, with phenocrysts of clear, round to embayed quartz, plagioclase and biotite. It is strongly deformed to protomylonitized, with dextral microscopic fabrics (see below, Chapter 4). Uranium-lead dating of titanites from this dike yielded an age of 169.3±5 Ma. Zircons are strongly discordant, with an average inheritance age of 1.21± 03 Ga. (Table 3, Appendix 7).

This Middle Jurassic age for the quartz-bearing late phases of the Mount Milligan intrusion is roughly coeval with the Nelson plutonic suite in southeastern British Columbia. Like the Nelson suite, these intrusions show evidence of syntectonic emplacement. They crosscut fabrics and, in the case of the dike, follow faults; but they themselves are deformed. The strong inheritance is also indicative that they were emplaced through Precambrian, probably structurally subadjacent North American crust. R.C. Delong (personal communication, 1991) has obtained late Early to mid-Jurassic K-Ar biotite (cooling) ages from several localities in the Mount Milligan pluton, suggesting that resetting occurred widely within it at that time. It is interesting to note that the 168 million year old clast from Uslika Formation conglomerate reported by Parrish and Tipper (1992) could well have come from the Mount Milligan pluton or a correlative.

GERMANSEN BATHOLITH

The Germansen batholith is a large, roughly equant granite body that outcrops in the highlands southwest of Manson Creek (Armstrong, 1948). Parts of its western and southern margin lie within the project area (unit EKG, Figure 3). Unlike the Hogem intrusive suite, the Germansen batholith is monotonously uniform in composition and texture. It is coarse grained, with 25 to 35% plagioclase, 25 to 40% orthoclase, 20 to 30% quartz and 7 to 15% biotite and hornblende. Orthoclase forms megacrysts in about half of the outcrops visited. Magmatic crystal-alignment fabrics are not present. Near Moly Lakes, the batholith has intruded and metamorphosed black shales and slates of the Slate Creek succession to biotite schist and strongly hornfelsed phyllite. The contact is sheared and folded; kinematic indicators in the metasediments show southwest-side-down shear sense on moderate to steeply dipping foliation planes. This is consistent with the upward emplacement of the western margin of the Germansen batholith along a southwest-dipping contact zone.In a few areas near its southern margin, a subsolidus foliation characterized by wispy quartz stringers is evident. Unlike the Hogem monzonite, the Germansen batholith is only weakly magnetic. Minor amounts of molybdenite occur on fractures near its margin in two localities, at the head of Valleau Creek and near Moly Lakes. An Early Cretaceous, 106.4±4 Ma K-Ar age for the Germansen batholith has been obtained from a biotite sample (Ferri and Melville, 1994). Garnett (1978) reports a discordant age, 106±3 Ma, K/Ar on hornblende and 85.8±2.7 Ma, K/Ar on biotite from the batholith. Concordance of the Ferri and Melville biotite date with the hornblende supports a late Early Cretaceous crystallization age.

KLAWLI PLUTON

The Klawli pluton is texturally and compositionally identical to the Germansen batholith. It intrudes the southern tail of the Valleau Creek suite near Klawli Lake. The pluton is composed of unvarying coarse-grained granite with 20 % pink orthoclase megacrysts 1.5 to 2 centimetres in length and 5-10 % mafics (hornblende±biotite). We concur with Armstrong (1949) that the Germansen batholith and the Klawli pluton belong to the same intrusive suite and are probably both mid-Cretaceous in age.

CRETACEOUS-EARLY TERTIARY SMALL INTRUSIONS AND DIKES

Small bodies of granite/rhyolite and granodiorite/(rhyo-)dacite are concentrated in two areas: at the Mt. Milligan deposit north to the western slope of Mount Milligan peak, around Dem Lake, and in the Twin Creek area. They generally occur as dikes, except for one large body east of Dem Lake. They are white, tan and grey in colour. Those near Mt. Milligan are fine grained and sparsely porphyritic, most with clear, round to embayed quartz phenocrysts. Plagioclase phenocrysts range from millimetre size to megacrystic, and biotite and hornblende form small phenocrysts. The dikes near Twin Creek and north along the eastern margin of the Hogem batholith are more granitic in texture and appear to be slightly finer grained, more porphyritic equivalents of the nearby granitic Hogem phase. A small syenite to quartz syenite body in this area is also assigned to the granite suite. This group of intrusions is considered to be partly or wholly of Late Cretaceous to Early Tertiary age. A strong thermal resetting event at the Mt. Milligan deposit is indicated by anomalously young whole rock K/Ar dates of 109±4 Ma and 66.3±2.3 Ma (Faulkner *et al.*, 1990). The quartz-phyric dikes may be implicated in this event.

CHAPTER 3 PETROCHEMISTRY OF IGNEOUS ROCKS

Major and trace element analyses were performed on a suite of igneous rock samples. This suite represents the range of volcanic compostions within the Takla Group and Early Jurassic successions, Early Mesozoic intrusions, the Lay Range assemblage, the 12 Mile basalts, Cretaceous-Tertiary felsic intrusions, and the Lower(?) Mississippian volcanic-sedimentary unit along the Omineca River. The resulting data are presented in Appendix 6. In this chapter, lithogeochemical data are discussed in terms of the following objectives: 1) to verify rock nomenclature and affiliations based on petrography, 2) to aid in establishing tectonic affinities of the various suites, and 3) to compare the lithogeochemical signature of the Early Mesozoic Quesnel arc with those from selected modern oceanic arc suites with alkalic to shoshonitic character, in order to evaluate them as possible tectonic analogues.

Samples for lithogeochemical analysis were screened for lack of alteration in the field and in stained thin section. Those with any trace of secondary potassium feldspar - on fractures, in amygdules, in patches or within other phenocrysts - were rejected. In addition, a few samples with high secondary calcite, high loss on ignition values (5%), or anomalous ratios of the elements potassium, sodium, rubidium, barium and strontium were not used in the discrimination plots. For instance, a ratio of K_2O x 100 / Sr greater than unity has been used as an index of alteration for igneous rocks in the Nation Lakes area (Barrie, 1993). On Figure 6a, the volcanic rocks that have been included on discrimination plots in this report are shown to have ratios of less than one. This lends confidence that observed trends, such as increase in K_2O at constant silica in the Mesozoic arc rocks, are of primary igneous origin and not the result of alteration.

The sample suite as a whole, including those of the Lay Range assemblage, lies on a calcalkaline trend on an AFM diagram (Figure 6b). The samples at the far right of the trend are hornblendites and clinopyroxenites from Early Mesozoic intrusions, which are of probable cumulate origin and thus lithogeochemically suspect, and the 12 Mile basalts, which may be tholeiitic. Ti-V and Ti-Zr diagrams (Figures 7 and 8) distinguish arc from ocean-floor basalts. Trends for Nation Lakes basalt samples show that the Takla Group, Early Jurassic successions and the Lay Range assemblage represent volcanic arc, rather than ocean floor, tectonic settings, with no distinction between the Paleozoic and Mesozoic suites. The 12 Mile basalts show oceanic affinities on both diagrams, particularily in terms of Ti-Zr.

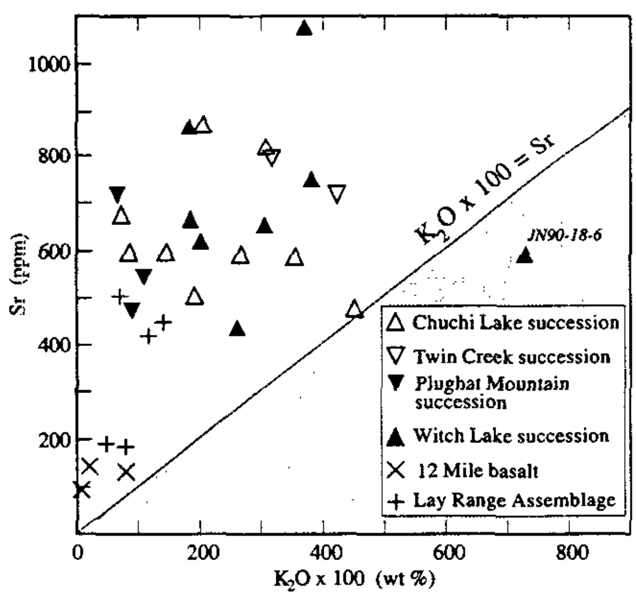

Figure 6a. K_2O x 100 vs. Sr, Nation Lakes basalts.

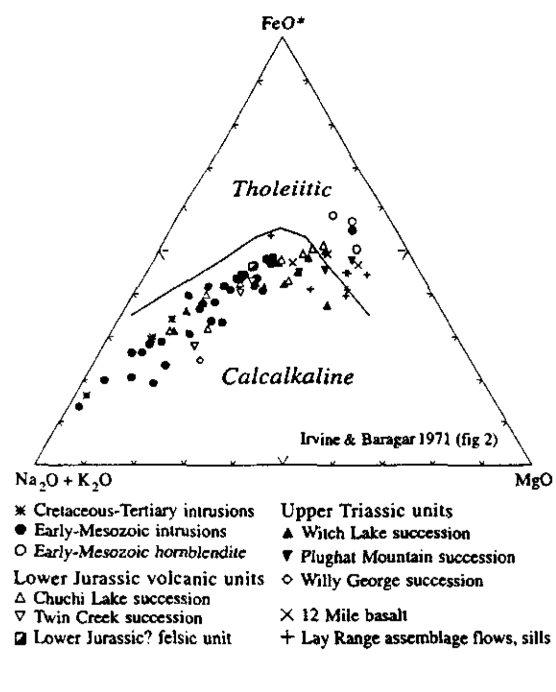

Figure 6b. AFM diagram for Nation Lakes igneous rocks.

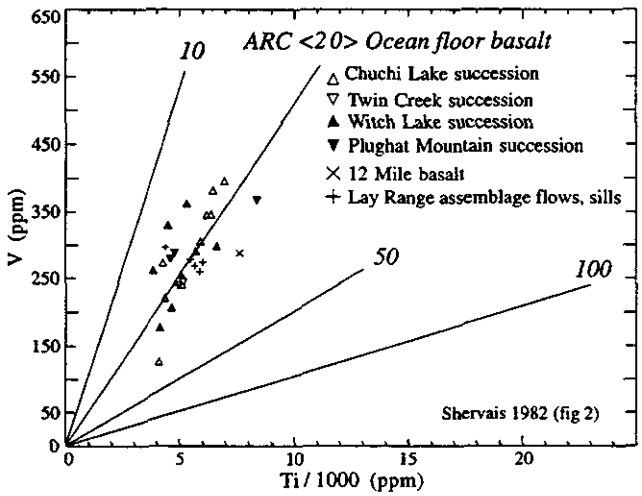

Figure 7. Ti-V, Nation Lakes basalts

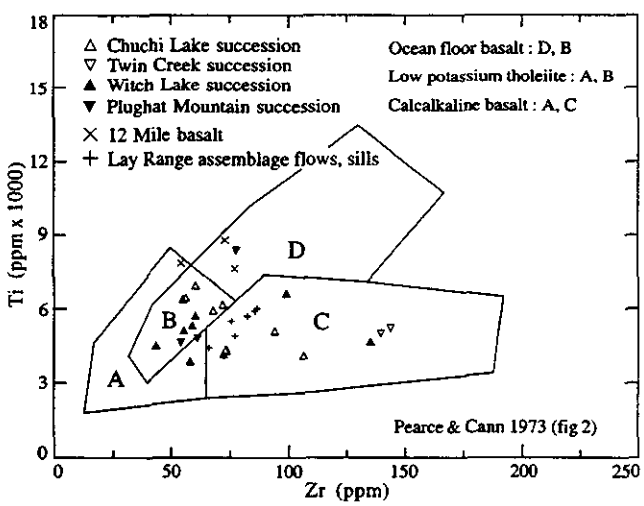

Figure 8. Ti-Zr, Nation Lakes basalts. OFB = ocean-floor basalt; LKT = low-potassium tholeiite; CAB = calcalkaline basalt.

Igneous rock nomenclature derived from major element geochemistry for volcanic samples is shown on Figure 9, and for intrusive samples on Figure 10. The mildly alkalic nature of the Takla Group igneous suite emerges clearly. Takla volcanic rocks range from subalkaline through alkali olivine basalts, trachybasalts and trachyandesites, except for subalkaline dacite and rhyolite-dacite in the upper part of the Jurassic Twin Creek unit and clasts in an Upper Triassic debris flow on Willy George Ridge, respectively. Takla intrusive rocks are mostly monzodiorites and monzonites. The more felsic lithologies plot as mildly alkalic granites and quartz syenites to strongly alkalic syenites. These lithologic designations based on chemical composition agree well, in general, with field and petrographic rock names of the samples. The few conflicts are apparent in Appendix 6.

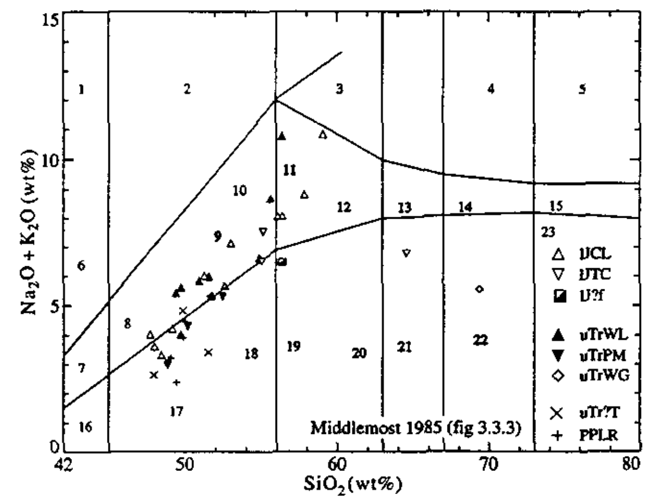

Figure 9. Silica-alkalis plot for Nation Lakes extrusive rocks, with fields for lithologic names. Unit designations as on Figure 3. Field names: 1 - Nephelinite 2 - Phonolite 3 - Alkali trachyte 4 - Pantellerite 5 - Comendite 6 - Basanite7 - Alkali picrite 8 - Alkali olivine basalt 9 - Trachybasalt 10 - Trachyandesite.- basalt 11 - Trachyandesite 12 - Trachyte 13 - Trachydacite 14 - Trachyrhyolite 15 - Alkali rhyolite 16 - Picrite 17 - Tholeiite basalt 18 - Andesite basalt 19 - Andesite 20 - Andesite dacite 21 - Dacite 22 - Rhyolite dacite 23 - Rhyolite

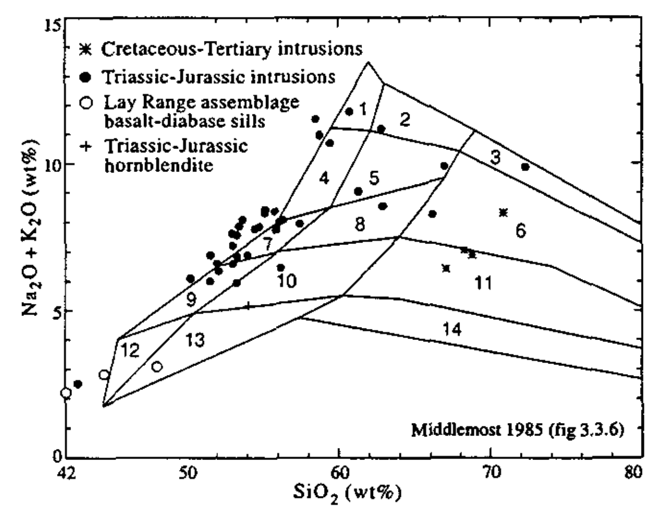

Figure 10. Silica-alkalis plot for Nation Lakes intrusive rocks, with fields for lithologic names. Field names: 1 - Alkali feldspar syenite 2 - Alkali feldspar quartz syenite 3 - Alkali feldspar granite 4 - syenite 5 - Quartz syenite 6 - Granite 7 - Monzonite 8 - Quartz monzonite 9 - Monzodiorite 10 - Quartz monzodiorite 11 - Granodiorite 12 - Diorite and gabbro 13 - Quartz diorite 14 - Tonalite

All of the other rock suites depicted on Figure 9 are subalkaline: basalts of the Lay Range assemblage and the 12 Mile basalt, and andesite from the Lower Mississippian unit. On Figure 10, the Cretaceous-Tertiary felsic intrusions, identified as rhyolite and granite in hand specimen and thin section, form a distinct cluster in the granite-granodiorite field. Thus the tendency to alkalic compositions of the Early Mesozoic arc volcanic suites and their consanguineous intrusions distinguish them from both older and younger igneous suites in the area.

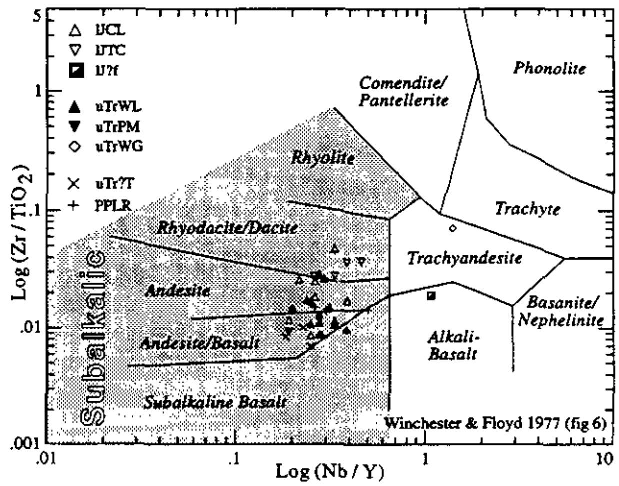

Figure 11. Log(Zr/TiO_2) *vs.* Log (Nb/Y) for Nation Lakes extrusive rocks. Unit designations as on Figure 3.

This tendency to alkalic, particularily potassium-rich compositions has been noted throughout the early Mesozoic volcanic/intrusive suites of Quesnellia. The Takla, Nicola and Rossland groups have been shown to include suites of shoshonitic affinity (Spence, 1985, Mortimer, 1987, Panteleyev *et al.*, 1996). The term shoshonite was first used by Iddings (1895) for orthoclase-bearing basalts from Yellowstone Park. Subsequent work by Joplin (1964, 1965, 1968) defined a shoshonite rock association. Morrison (1980) reviewed and re-evaluated the shoshonite association, reassigned some suites that Joplin had included within it to other associations, summarized the chemical criteria that distinguish shoshonites from other alkalic suites, and offered some generalizations about their tectonic setting. Gill and Whelan (1989a) defined additional chemical characteristics of shoshonites based on their work in Fiji.

Shoshonites are, worldwide, an uncommon variant of arc magmatism. They are mildly alkalic, with minor or no normative quartz or nepheline. They are characterized by calcalkalic trends on the AFM diagram, high Al_2O_3 (14-19%) and low concentrations of TiO_2 (<1.3%) and other high field-strength elements: features that they share with calc-alkalic arc rocks. Their alkalic nature is due to high potassium contents (>1.8% at 50% SiO_2, >2.5% at 53% SiO_2; Gill and Whelan, 1989a), with consequently high K_2O/Na_2O ratios (>0.6 at 50% SiO_2, >1.0 at 55% SiO_2; Morrison, 1980). They are distinguished from more common high-potassium calcalkalic suites by their even higher content of potassium, rubidium (Rb/Zr >0.6; Gill and Whelan, 1989a), barium, strontium, P_2O_5 and in some cases, light rare earths. Shoshonite suites occur in island arcs and along active continental margins. Other than their extreme large-ion lithophile and light rare earth enrichment they are, as a group, chemically indistinguishable from other arc rocks. That enrichment can be viewed as simply an exaggeration of ordinary calcalkalic trends.

The shoshonite suite is economically important, as it exhibits a recurrent association with gold and copper mineralization. In addition to the alkalic-suite copper-gold porphyry deposits of Quesnellia and Stikinia (Barr *et al.*, 1976, McMillan *et al.*, 1995), the shoshonite suite has been highlighted in a recent paper by Müller and Groves (1993), who point out the world class deposits hosted by it, such as the Emperor gold mine in Fiji, and Porgera and the Ladolam gold deposit on Lihir Island, Papua New Guinea.

The shoshonitic character of the Early Mesozoic volcanic suites in the Nation Lakes area is borne out on a number of discriminant diagrams. Figure 11 shows how these, like all other shoshonites, differ chemically from other alkalic suites. Although these rocks are apparently alkalic in their petrography and on silica-alkali diagrams (Figures 9, 10 and 12), on a plot of log (Zr/TiO_2) *vs.* log (Nb/Y) they plot in subalkalic fields because of the uniformly low, flat trend of their high field-strength element concentrations - particularily niobium, which is enriched in intraplate and continental alkalic suites. In the Nation Lakes volcanic suite, TiO_2 total is also low, ranging up to 1.34% and generally less than 1%, a further indication of arc affinity.

The unique chemical signature of the shoshonite suite is indicative of both a distinct tectonic setting and in the physical-chemical conditions of magma genesis in the mantle wedge. Understanding of the tectonic evolution of the ancient Quesnel arc may be aided by comparing it to those modern magmatic arcs in which the shoshonite suite occurs. In Table 4, diagnostic characteristics of young shoshonitic and other arc alkalic suites, drawn from the literature, are presented together with those of the Quesnel arc. The object of this comparison is to identify which of the modern suites most closely resemble it, and thus are its most appropriate neotectonic analogues. Suites with obviously different tectonic settings or isotope geochemistry are considered to be of lesser relevance.

The first filter is lack of continental basement. The Triassic-Jurassic arcs of Quesnellia are primitive, as shown by their low initial strontium ratios and epsilon neodymium values (Preto *et al.*, 1979; Beddoe-Stevens and Lambert, 1981; Smith Lang *et al.*, 1995; *et al.*, 1995), as well as by the extensive geologic evidence for an intraoceanic origin with only minor pericratonic underpinnings. By contrast, the extensive shoshonite suite of the western United States (Rowell and Edgar, 1983) lies on old continental crust, and limited isotopic data (McDonald *et al.*, 1992) suggest the involvement of old enriched mantle in its generation. High initial strontium and low radiogenic neodymium similarly disqualify the Sunda-Banda arc (Varne, 1985), the Roman region (Ellam *et al.*, 1989) and Greece (Pe-Piper and Piper, 1989). The first studies of shoshonites included such examples in their broad tectonic syntheses (Morrison, 1980, Spence, 1985): this resulted in a bias towards collisional settings and reversed arc polarity. In fact, shoshonites with

TABLE 4
LATE TERTIARY TO RECENT WORLD SHOSHONITE AND OTHER ISLAND ARC ALKALIC SUITES: COMPARISON WITH THE LATE TRIASSIC - EARLY JURASSIC QUESNEL ARC

	Quesnel arc	**Fiji**	**Marianas**	**Lihir-Tabar-Feni**	**Eastern Sunda arc**	**Grenada**	**New Hebrides**	**Western U.S.**
Tectonic setting	Intraoceanic arc: shoshonitic suites form arc front, except in Nicola Group, where east of calcalkaline belt. Elsewhere intermixed with subalkaline volcanics. No shoshonites north of the Omineca River? Shoshonitic volcanism spans entire history of the Quesnel arc, both Triassic and Jurassic.	Intraoceanic arc, with shoshonitic volcanism late in arc history, during fragmentation and rifting subsequent to a reversal of subduction polarity. Shoshonites on linears; contemporary calcalkaline and tholeiitic centres are located between the linears.	Intraoceanic arc. Mildly alkalic centres at the arc front in northern part of arc, from 23° N to Iwo Jima. Considered to be the earliest volcanic phase. These pass south into low- and medium-K subalkaline suites.	Shoshonitic and sodic alkalic centres lie along extension and/or transform faults in the old forearc region of an *extinct oceanic arc* that underwent a reversal of subduction polarity approximately 24 to 11 Ma ago.	Along the Sunda arc front from Sumbawa to Flores.This arc is presently colliding with the Australian continent, *the fringes of which have* entered the subduction zone.	Single volcanic island at southern end of the Lesser Antilles arc front; located near the southern terminus of this arc and *of the Caribbean plate,* which are bounded to the south by a dextral fault . zone.	In Central Chain, an arc rift that splits the pre-Pliocene arc in two.It arose after subduction polarity *reversed in middle* Miocene. Ambrym alkalic rocks are sodic to barely shoshonitic; Aoba alkalic rocks are sodic.	Scattered centres in Montana, Wyoming, Arizona, Nevada, Utah, California, New Mexico, Idaho. *In continental* interior east of main magmatic arcs. Extends into B.C. as Kamloops Group.
Strike length	>500 km: known shoshonites extend from U.S. border (Rossland Group) to Nation Lakes area (Takla Group and Chuchi Lake formation); may be others farther north.	~225 km; interspersed with calcalkaline and tholeiitic centres.	~200 km	~300 km	~700 km	< 50 km	<100 km	2000 X 1000 km
Duration	late Carnian to late Norian (~20 Ma); Sinemurian; Pleinsbachian *(~16 Ma)*	from 5.5-3.0 ma, "incipient rifting stage". During subsequent spreading, *OIB basalts erupted.*	not known, based on dredge samples of very young volcanic centres *(.5 - 1.0 Ma?).*	Pliocene-Quaternary (< 5 Ma)	Quaternary-Recent Varne (1985) infers after beginning of collision *(superimposed on Miocene* calcalkalic - Lombok-Sumbawa)	Miocene - Recent; also Lower Tertiary?	Late Pliocene -Recent < .5 Ma.	Eocene-Pliocene
K_2O @ 50% SiO_2 (approximate)	1 - 4.7% (this study) 1.6 - 5.2 (Mortimer, 1987)	1.8 - 4.7% (>1.8% defines shoshonites)	most <1.8%; only 3 analyses above 1.8%	Lihir: average ~2.0% Ambittle: 1.8 - 3.8%	1.8 - 3.0%	average ~.9%	1 - 1.8%	~4% (Yellowstone absarokites). 2.19-3.38 (Kamloops Gp.)
K_2O/Na_2O @50% SiO_2	.25 - 2.1 (this study) .88 - 1.7 (Mortimer, 1987)	.5 - 1.4	.32 - 1.26	Lihir: .15 - 1.03 Ambittle: .56 - .8	*.49 - 2.87*	*.19 - .55*	*Ambrym: .30 - .78* Other islands: .18-.55	*~1.7 (Yellowstone)* .7-1.4 (Kamloops Gp)
$^{87}Sr/^{86}Sr_{+A88}$	.7030 - .7047 (Preto *et al*., 1979) .70367+/-2 (Smith *et al*., 1995)	.7037-.7039		.7038 - .7042	.7038 - .707	.7039 - .7058		Bearpaw Mtns: .707 - .710 Kamloops Group .7038 - .7077

	Quesnel arc	Fiji	Marianas	Lihir-Tabar-Feni (includes Ambitle)	Eastern Sunda arc	Grenada	New Hebrides	Western U.S.
$^{143}Nd/^{144}Nd$	εNd intrusions +2.7 - +7.9 (Lang *et al*., 1995) Nicola Group: .512612-.512725; εNd(222 Ma)+5.0 to +7.9 (Smith *et al*., 1995)			.51297 - .51304	.512571 - .512830	.51282 - .51308		
La/Yb	2.1 - 13.5 (shoshonites are more LREE-enriched than subalkaline suites) Nicola Group (Mortimer, 1987).	4.4 - 10 (shoshonites are more LREE-enriched than subalkaline suites)	averages 16 in shoshonites; 2.4 - 2.6 in others (Lin *et al*., 1989).	Lihir: 5 - 11	16.0 - 42.3 (in calcalkaline rocks 4.79 - 6)	4.7 - 19.5	Ambrym: 2.9 - 7.9 Others: 2.5 - 9.25	
Nb ppm	< 6 ppm (near detection)	1.0 - 7.1 except Vatulele 18, 20	no data available	Lihir: .51 - 2.7 Ambittle: 13 - 38	15-Apr	3.5 - 15.8 (Thirlwall and Graham) 2 - 25 (Arculus)	Ambrym: 1.48-2.59 Others: .46 - 5.06	
Comments/ Comparisons	Low Sri suggests intra-oceanic; low Nb and fairly strong LREE enrichment.	Close analogue in intraoceanic setting and chemistry, intermixing with other arc magma suites.	Close analogue in intraoceanic setting, long strike length. Not as high K/Na.	Intraoceanic. Lihir chemistry like Quesnel; Ambittle more sodic and strictly alkalic, high Nb.	Trend to high Sri and low radiogenic Nd show input of old continental crust: poor analogue.	Very small: one island. Sodic, trends to high Nb. Poor analogue.	Only Ambrym shows K-rich, shoshonitic chemistry. Perhaps more like Stikinia?	Continental arc with trends to high Sri and low radiogenic Nb. Poor analogue.
References	Preto *et al*. (1979) Mortimer (1987) Bailey (1988) Hoy and Andrew (1989)	Gill and Whelan (1989a,b)	Stern *et al*. (1988) Bloomer *et al*. (1989) Lin *et al*. (1989)	Heming (1979) Kennedy *et al*. (1990)	Varne (1985) Varne and Foden (1986)	Arculus (1976) Thirlwall and Graham (1984); Hawkesworth *et al*. (1979).	Colley and Warden (1974);Gorton (1977) Carney and MacFarlane (1982).	Joplin (1968) Ewing (1981) McDonald *et al*., 1992

	Roman region, Italy	Aeolian arc	Hellenic arc, Greece	Aleutians	Papua New Guinea Mainland	South America
Tectonic setting	In complex zone of collision between Africa and Europe: related to eastward subduction of Tyrrenian Sea; or to curved or bifurcating Benioff zone related to Aeolian arc. On continental crust, but Hawkesworth and Vollmer (1979) show not crustal melts, rather from enriched subcontinental mantle.	In complex zone of collision between Africa and Europe. Clear NW-dipping Benioff zone, but both arc itself and present subducting plate are continental; may be a recently closed suture.	Shoshonites occur together with other magma suites in an extensional back arc region behind the south Aegean arc, founded on thinned continental crust. The Hellenic arc and the Aegean sea, its back arc, are located on a rotating microplate between Africa and Europe.	Alkalic centres occur at several locations along the arc front: Kanaga, Bogoslav, Bering Is. Hypothesised as forming above cross-arc fractures or transforms. All of these suites are sodic, not potassic, and thus not shoshonitic.	In collision zone between Australian continent and Bismark Sea arc; Highlands are founded on 40 km thick sialic crust; shoshonitic and calcalkalic volcanism coexist and are intergradational. In eastern Papua, shoshonites lie south of calcalkaline centres.	Belt located east of the main calcalkaline volcanic front and probably over the deepest part of the Benioff zone. These shoshonites fit the model of increasing potassium with increasing depth to the subducting slab. They are located on continental crust.
Strike length	~300 km	<100 km	scattered localities over 400 km	isolated islands in overall calcalkaline chain.	800 km	350 km
Duration	Pliocene-Recent (<8 Ma)	1 Ma	late Miocene-Quaternary 11.9-.5 Ma	Quaternary-Recent	Pliocene-Recent	Pliocene-Quaternary

	Roman region, Italy	Aeolian arc	Hellenic arc, Greece	Aleutians	Papua New Guinea Mainland	South America
K_2O @ 50% SiO_2 (approximate)	High-K series: typically 6-10% ("Ultrapotassic") Low-K series: ~3%	1 - 4%	2.64 - 2.99%, @SiO_2 53%	1.32% (Kanaga) 2.47, 1.60% (Bogoslav)	1.8 - 3%	>3% @ 51 -53% SiO_2 (no analysed rocks less than 51%).
K_2O/Na_2O @50% SiO_2		.9 - 1.5	.67 - .88 @ 53%	.36 (Kanaga) .58 - .61 (Bogoslav)	.25 - 2.0	1 - 1.3 @ 53% SiO_2
$^{87}Sr/^{86}Sr_{initial}$	Low-K series: .7064-.7075 High-K series: .7084-.7100	.7041 - .7074	.7049 - .7098	~.7030 (Bogoslav)	not available	not available
$^{143}Nd/^{144}Nd$	(Roccomonfina) .5122 - .51275	.512509 - .512817				
La/Yb	Ce/Yb = 31 - 120 (La not available)		25.3 - 56.5	5.13; 11.85 (Bogoslav)	not available	not available
Nb ppm			13-51 in interspersed sodic centres up to 107	data unavailable; Pearce (1982) shows somewhat enriched	Highlands: average 6.6 (calcalkaline ave. 9.8)	Not available; Ta content markedly higher than calc alkaline rocks to west (2-3 ppm)
Comments/ Comparisons	Continental arc with evidence of ancient enrichment event (high Sri, low radiogenic Nd). Poor analogue.	Involvement of ancient enriched mantle or subducted sediments makes poor analogue.	Trends to high Sr_i suggest ancient enrichment event. Also high Nb: poor analogue.	Limited extent: single islands. High Nb. Poor analogues.	Highlands: poor analogue because of setting on thick continental crust. Eastern Papua may be good match.	Poor analogue, because in back arc region of continental arc. Show truly alkalic character, at least in part (Pearce 1982).
References	Ninkovich and Hays (1972) Ellam *et al*. (1989) Hawkesworth and Vollmer (1979)	Barberi *et al*. (1974) Ellam *et al.* (1989)	Pe-Piper and Piper (1989)	Delong *et al*.. (1975) Arculus *et al*. (1977) Pearce (1982)	Johnson *et al*. (1971) MacKenzie and Chappell (1972)	Deruelle (1981)

strongly evolved isotopic signatures may not be the product of their immediate tectonic environment so much as of the partial melting of mantle that was metasomatised during the distant past.

Müller and Groves (1993) divide shoshonite-suite tectonic settings into four separate categories: early oceanic arcs, late oceanic arcs, continental arcs and post-collisional arcs. The criterion of primitive chemistry suggests that, of these, the preferred analogues of the Quesnel arc are early and late intra-oceanic arcs, as opposed to the continental and post-collisional settings. Specific cases on Table 4 include arcs of the western Pacific region - Fiji, Lihir and Ambittle of the Tabar-Feni chain, the Marianas - and also Grenada, in the Lesser Antilles. Representative chemical analyses of basalts from these areas are presented on a series of diagrams paired with the Nation Lakes basalts in order to show and characteristics of the shoshonite suite, and to compare/contrast the sample sets and test their degree of geochemical similarity. In the following diagrams, except for Figures 12 and 13, only samples of basaltic composition are plotted in order to facilitate comparisons between suites.

The silica-alkalis plots on Figures 12a and 13a show the transitional to mildly alkalic character of the Nation Lakes volcanic suites and their affiliated intrusions. Of the modern arcs, Fiji, Lihir and Ambittle contain the most alkalic rocks. Fiji shows the greatest range, both in total alkalis and in K_2O. The Marianas and Grenada are mainly subalkalic. In terms of K_2O versus SiO_2, Nation Lakes rocks range well into the very to extremely high potassium range, as do basalts of Fiji, Ambittle and Lihir. The Marianas show a less pronounced potassium enrichment trend, and Grenada basalts are, for the most part, not potassium-rich enough to be truly shoshonitic. Figures 14a and b plot two indices of shoshonitic character, K_2O/Na_2O and Rb/Zr ratios. Nations Lakes basalts trend towards fairly high values of both, well in the shoshonitic range. There is also a linear relationship between the two parameters. Fijian basalts, and to a lesser extent, those from Lihir, show a similar trend. Marianas samples, except for three, plot in the low, sub-shoshonitic range. Ambittle and Grenada, although they are somewhat alkalic and potassic, do not qualify as shoshonitic suites on these criteria, because of relatively high Na_2O and Zr contents compared with with the large-ion lithophiles K_2O and

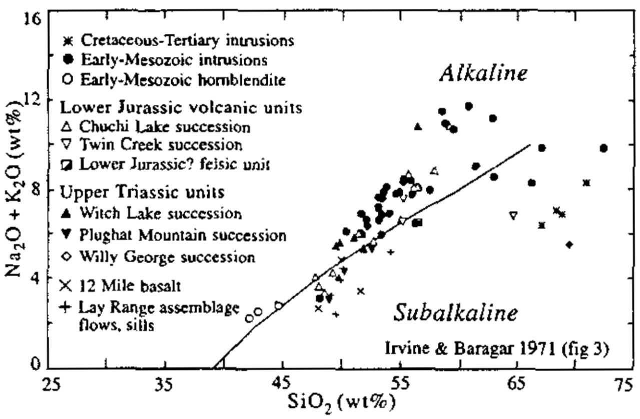

Figure 12a. Silica-alkalis plot for Nation Lakes igneous rocks.

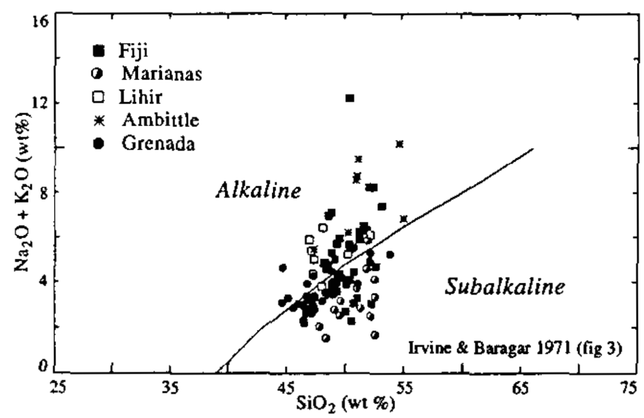

Figure 12b. Silica-alkalis plot for selected Late Tertiary/Recent alkalic arc basalts.

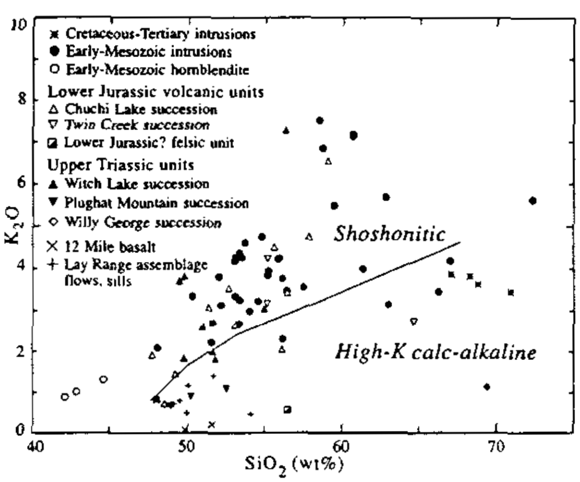

Figure 13a. K_2O-SiO_2 for Nation Lakes igneous rocks.

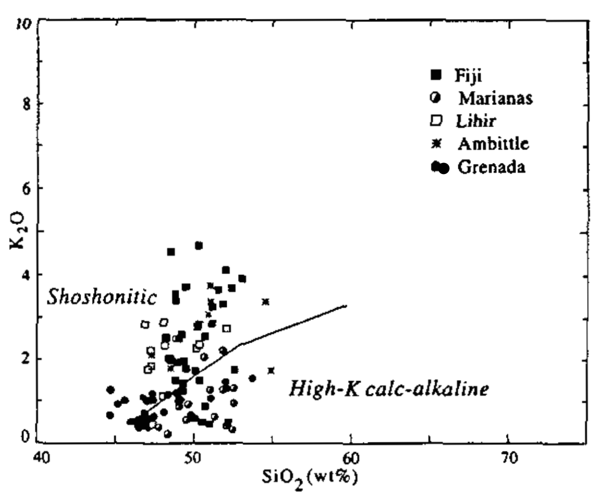

Figure 13b. K_2O-Si_2O for selected Late Tertiary/ Recent alkalic arc basalts

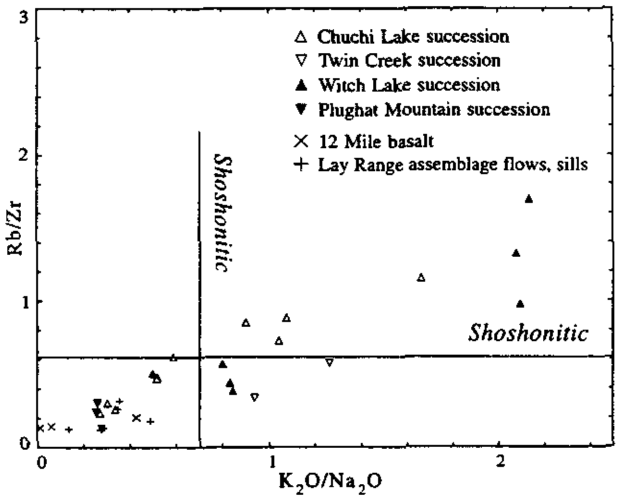

Figure 14a. Rb/Zr vs. K_2O/Na_2O, Nation Lakes basalts.

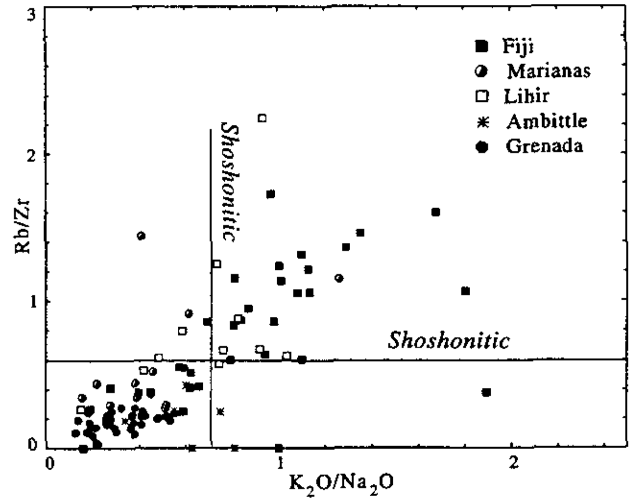

Figure 14b. Rb/Zr vs. K_2O/Na_2O, selected Late Tertiary/Recent alkalic arc basalts.

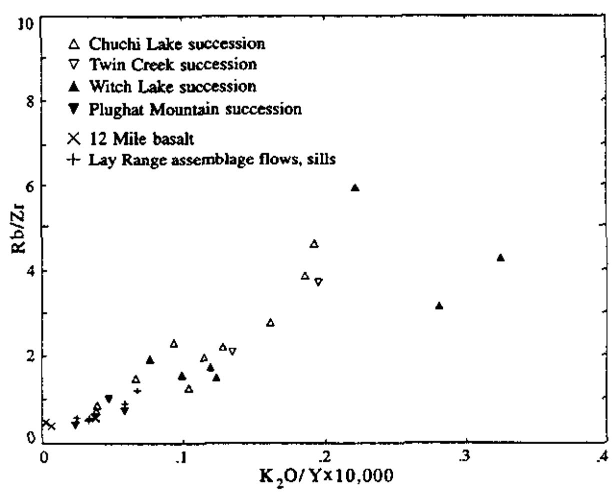

Figure 15a. Rb/Y *vs.* K_2O/Y, Nation Lakes basalts.

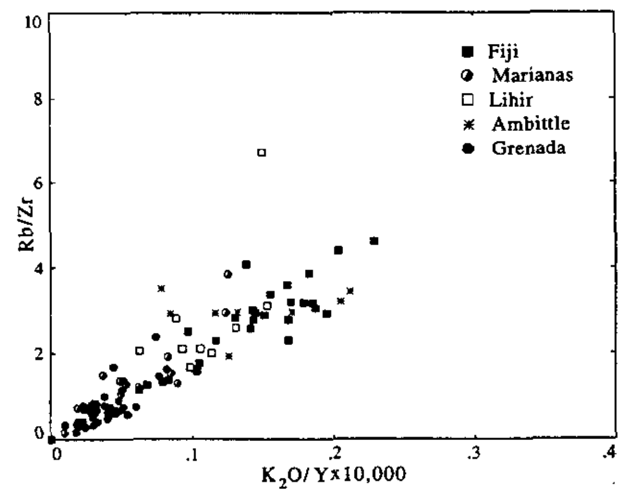

Figure 15b. Rb/Y vs. K_2O/Y, selected Late Tertiary/Recent alkalic arc basalts.

Rb. These diagrams show that the Early Mesozoic volcanic suites in the Nation Lakes area are well characterized as of mixed calcalkaline and shoshonitic affinity, with high enrichments in the large-ion lithophile elements and otherwise arc-like chemical compositions. Of the five modern arc suites used for comparison, Fiji and Lihir are the most shoshonitic and correspond most closely to the Nation Lakes suite; the Marianas suite somewhat less so. Grenada and Ambittle, although alkalic suites located within island arcs, are the least similar and are not shoshonitic.

The shoshonite suite is characterized by unusually high values of all of the large ion lithophile elements. The parallel increases to high values of K_2O, Rb, Ba and P_2O_5 with respect to yttrium, a compatible, high field strength element, are shown in Figures 15, 16 and 17. Rubidium/potassium ratios are similar in all of the suites, shoshonites and non-shoshonites alike. Lihir is distinctive in its low barium values.

Pearce (1982) contrasts island arc basalts with those from intraplate settings. Arc basalts, particularily calcalkaline to shoshonitic basalts, show large, variable enrichments in the large-ion lithophile elements and P_2O_5, whereas intraplate basalts are enriched in these and also in the more incompatible of the high field strength elements such as zirconium and niobium over more compatible yttrium. Figures 18a and b show the variation of niobium and zirconium with respect to yttrium. (There are no niobium data available for the Marianas suite.) In the Quesnel arc, ratios are low and uniform, typical of a calc-alkalic arc setting: Nb/Y is less than .5 and Zr/Y is less than 7. Lihir and Fiji, except for two samples, have the same signature. Grenada and Ambittle, on the other hand, show pronounced, parallel increases in zirconium and niobium. This pattern implies an intraplate-like enriched mantle source, even though they occur within island arcs.

Potassium, rubidium, barium and strontium are mobile in aqueous fluids (Tatsumi *et al.*, 1986). These elements and

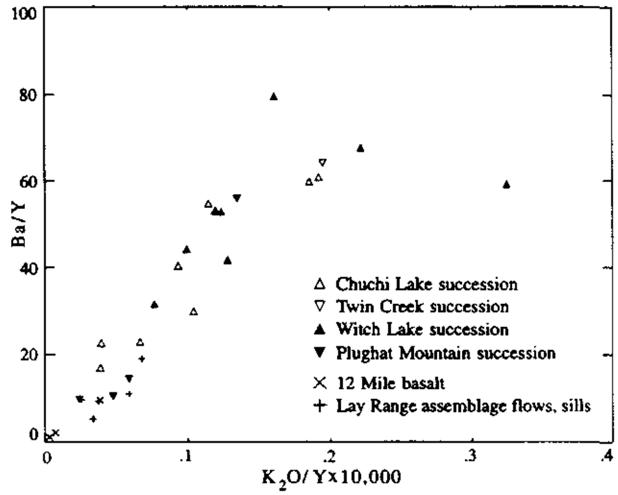

Figure 16a. Ba/Y vs. K_2O/Y, Nation Lakes basalts

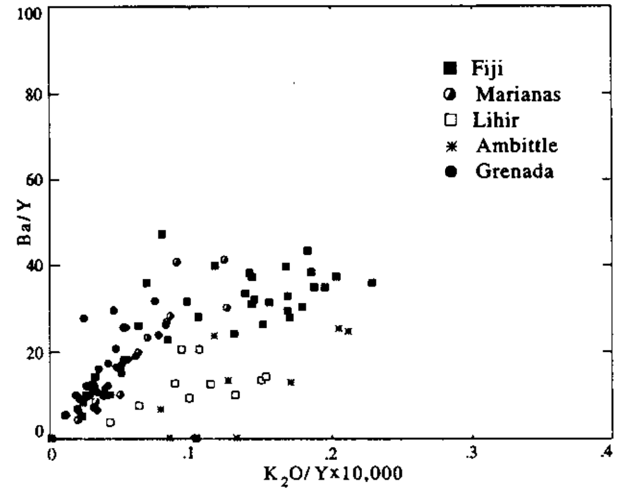

Figure 16b. Ba/Y vs. K_2O/Y, selected Late Tertiary/Recent alkalic arc basalts.

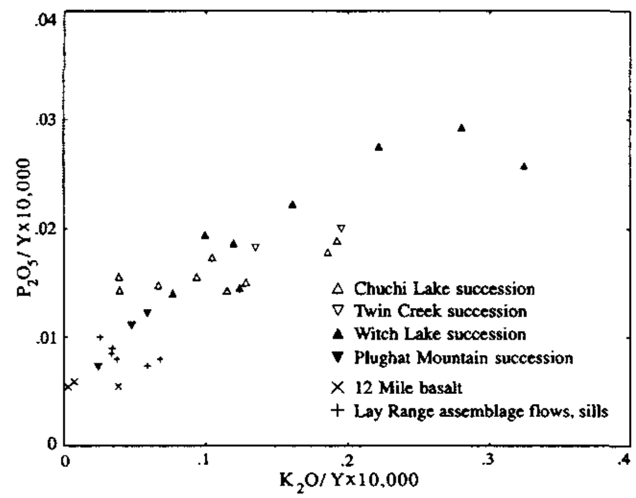

Figure 17a. P_2O_5 *vs.* K_2O/Y, Nation Lakes basalts.

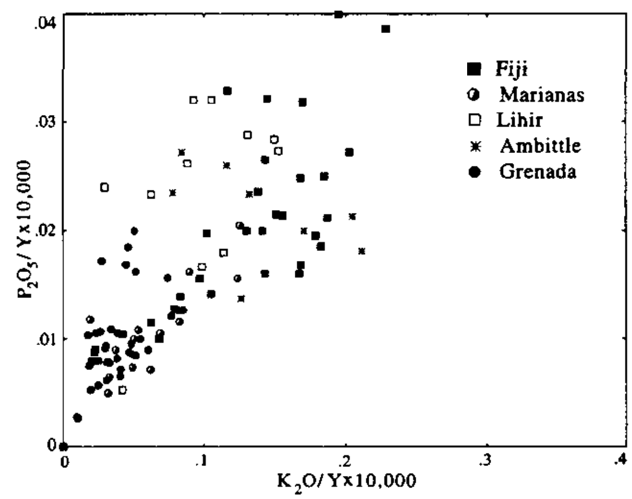

Figure 17b. P_2O_5 *vs.* K_2O/Y, selected Late Tertiary/Recent alkalic arc basalts.

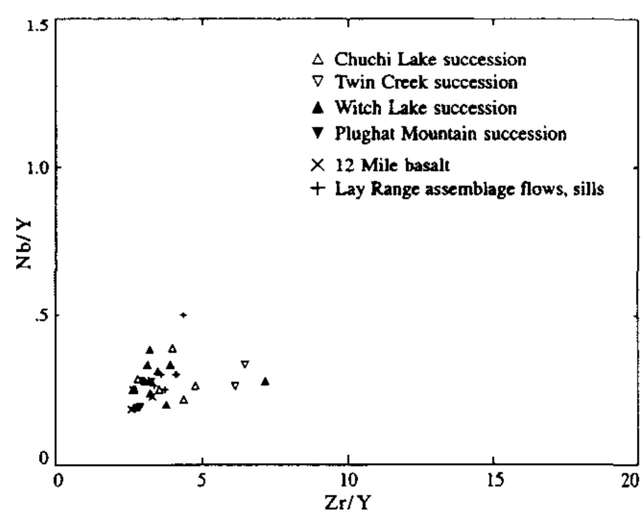

Figure 18a. Nb/Y *vs.* Zr/Y, Nation Lakes basalts.

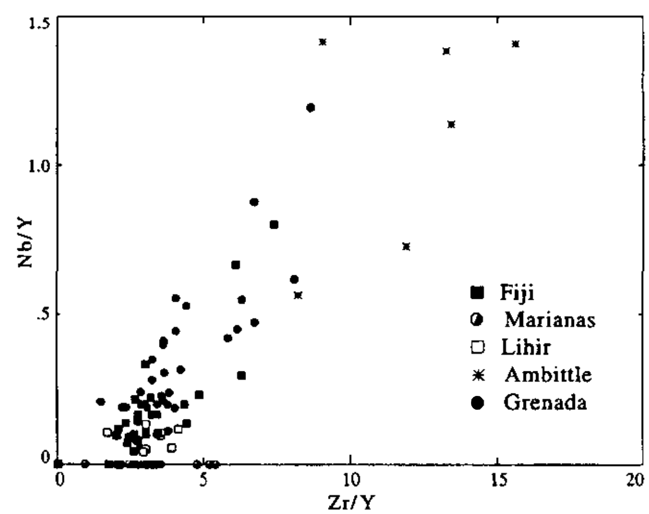

Figure 18b. Nb/Y *vs.* Zr/Y, selected Late Tertiary/Recent alkalic arc basalts.

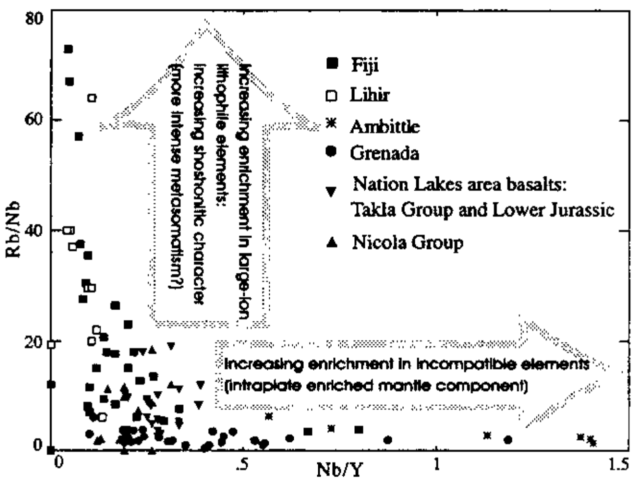

Figure 19. Rb/Nb *vs.* Nb/Y, Quesnel arc and Late Tertiary/ Recent alkalic arc basalts.

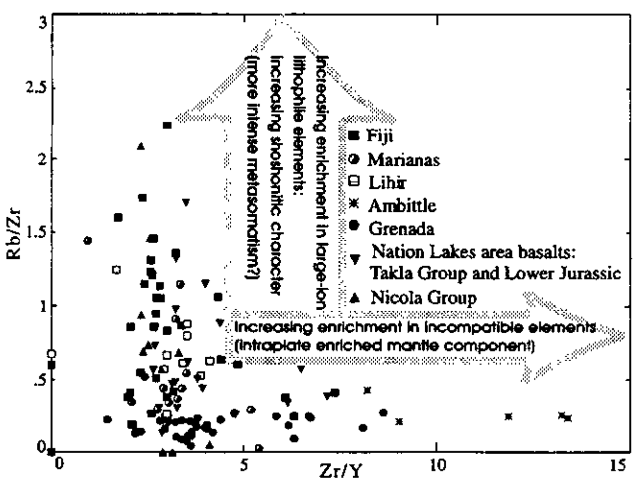

Figure 20. Rb/Zr *vs.* Zr/Y, Quesnel arc and Late Tertiary/Recent alkalic arc basalts.

also niobium and zirconium are incompatible in mantle lithologies. They partition strongly into partial melts. The difference between typical arc and intraplate mantle evolution may thus be simply a difference in the amount of water involved. Shoshonite suites such as the Early Mesozoic Quesnel arc may reflect melting of a depleted, sub-arc mantle that was repeatedly metasomatized by fluids and very hydrous melts over a long period of time.

Figures 19 and 20 give another view of this source. On them, Rb/Nb is plotted against Nb/Y and Zr/Y respectively, for modern arcs as well as the Nation Lakes Early Mesozoic basalts and the Nicola Group (Mortimer, 1987). High values of Nb/Y and Zr/Y indicate a within-plate alkalic source (Pearce, 1982). High rubidium with low niobium and zirconium characterize normal arc-volcanic suites. Figures 19 and 20 show concave trends that may be interpreted as a mixing range between these two discrete end members. Fiji, Lihir and the Marianas represent the arc phase, Ambittle and Grenada (with two samples from Vatulele in Fiji) the intraplate. Quesnel basalts plot with Fiji, although Rb/Nb ratios do not range as high. This may be partly due to the higher detection limits for niobium (3 ppm, Mortimer, 1987; 5 ppm, this study) than in the other data sets.

The Early Mesozoic igneous suites of Quesnellia include classical shoshonites in the sense that their chemistry departs from that of ordinary calcalkaline arc suites only in extreme abundances of potassium, rubidium, barium and P_2O_5. They contrast with some other arc alkalic suites, such as those of Ambittle Island in the Tabar Feni chain and Grenada in the Lesser Antilles, in which K_2O/Na_2O ratios are relatively low and niobium and zirconium show parallel enrichments. Their chemical similarity with particularly Fiji and Lihir, and also the Marianas, suggest that common processes were involved at the sites of magma genesis. Implications of this comparison for the tectonic setting of the Quesnel arc are taken up in the concluding chapter.

CHAPTER 4 STRUCTURAL GEOLOGY AND METAMORPHISM

STRUCTURAL GEOLOGY

Northern Quesnellia as a whole has undergone several important episodes of deformation since late Paleozoic time, each with a characteristic structural style. First, the Slide Mountain Terrane and Lay Range assemblage were deformed during Late Permian to Early Triassic time, in a somewhat cryptic amalgamation event that preceded deposition of the Takla Group (Monger *et al.*, 1990). In the project area, structures and metamorphic assemblages within the late Paleozoic assemblages are indistinguishable from those in the Mesozoic rocks, so evidence for this earliest phase is lacking.

Igneous activity in the Late Triassic to Early Jurassic Quesnel arc was probably structurally controlled, at least in part. The highly elongate shape of the Hogem batholith, for instance, points at fundamental structural control. Following cessation of arc volcanism, Quesnellia was emplaced eastward onto the western edge of Ancestral North America in late Early Jurassic time. This episode, at 186 to 181 ma (Murphy *et al.*, 1995; Nixon, 1993), was coeval with the youngest intrusions of the Quesnel arc, probably because it involved the demise of the long-lived subduction zone between Quesnellia and the Cache Creek Terrane. Because of this Toarcian tectonic event, North American miogeoclinal rocks structurally underlie Quesnellia, as shown by the S-type post-accretionary granites, such as the Germansen batholith, and by exposures of metamorphosed miogeoclinal strata in core complexes within Quesnellia (Deville and Struik, 1990; Struik, 1993).

Dextral transcurrent faulting affected the amalgamated terranes from Cretaceous through Oligocene time (Ferri and Melville,1994; Struik, 1989; 1993). Major faults include the Manson-McLeod system on the east side of Quesnellia, which connects through a complex transfer zone near the Omineca River with the Discovery Creek system and northward into the Finlay-Ingenika system west of Quesnellia; and the Pinchi fault, which separates Quesnellia from the Cache Creek Terrane (Figure 2). A network of second-order, northwesterly striking transcurrent faults and normal faults have divided Quesnellia into structural blocks (Figure 3). Early Tertiary and older (?) sedimentary sequences filled grabens that developed during this event.

STRUCTURES DEVELOPED WITHIN THE ACTIVE QUESNEL ARC

The tabular nature of the Triassic-Jurassic Valleau Creek intrusive body (Figure 3) and the associated linear magnetic signature suggest a strong structural control for its emplacement. This mafic-ultramafic body is similar to the earliest identified phases of the Hogem intrusive suite and is probably synchronous with Early Mesozoic volcanism. Long-lived synvolcanic structures are key to the generation of alkaline porphyry copper-gold systems (Nelson *et al.*, 1991a). The Valleau Creek fault may be one of the best examples of an Early Mesozoic, synvolcanic structure in the project area. The presence of Jurassic Chuchi Lake succession west of the complex and Triassic Inzana Lake formation to the east suggests that the fault was active until at least the Jurassic and had an overall displacement of roughly a kilometre, west side down. The lack of crowded porphyry intrusions and porphyry mineralization and alteration may be a function of a deep level of erosion. Minor disseminated malachite was noted south of Wudtsi Lake.

A marked structural break coincides with the southern tail of the Hogem batholith under Chuchi Lake (Figure 3). South of the lake, interfingering Witch Lake and Inzana Lake successions strike northeast and dip gently to moderately northwest, in the hinge of a very gentle northwest trending regional anticline. This fold is not present north of Chuchi Lake; instead, an approximately homoclinal panel of Chuchi Lake formation dips gently to the south. A fault is therefore inferred under Chuchi Lake. The preferred interpretation for the disappearance of the anticline north of Chuchi Lake, is that the fault may have formed at a point of structural weakness along the plunge depression of the anticline. The open nature of the fold, and the gentle dips of bedding on both sides of Chuchi Lake, suggest that the fold opens further to the north and loses its identity. Movement on the Chuchi Lake fault probably predated emplacement of the Hogem intrusive complex, since it does not offset the strong magnetic anomaly associated with the monzonite. Instead, the fault may have acted as a guide, deflecting the southern end of the batholith to the east. The east-trending magnetic signature of the batholith continues far past its most eastern exposures. Probably the roof of the batholith continues eastward in the subsurface. In this view, the two satellite bodies of coarse-grained monzonite on the south side of Chuchi Lake, located on trend with Hogem salients, represent two culminations on the undulating top of the buried batholith.

Other possibly early faults include an east-northeasterly trending fault along Klawdetelle Creek and a northerly striking fault on the BP-Chuchi property that terminates against the Klawdetelle fault. Both of these structures offset the sedimentary marker unit in the Chuchi Lake succession. On the BP Chuchi property the sedimentary marker is comparatively thick and contains lapilli and crystal tuffs, full of intrusive material, derived from a local source. This local anomalous facies may reflect fault control. The Klawdetelle fault seems also to have exerted control over the northwestern margin of the Chuchi syenite, a late phase of the Early Jurassic Hogem intrusive suite. Therefore this fault, like the Chuchi Lake fault, was probably active between deposition of the Chuchi Lake succession and the latest Early Jurassic intrusions.

On a more local scale, but important to the Mt. Milligan story, a northeasterly-striking shear zone may have controlled intrusion of the Heidi Lake suite. A small shear zone on the cliff south of Heidi Lake contains secondary potassium feldspar, showing that motion on it predated the alteration event.

STRUCTURES ASSOCIATED WITH THE DOCKING OF QUESNELLIA

GENERAL STRUCTURAL STYLE

Regionally, Quesnellia is cut by foreland-style thrust faults into the uppermost panels of the regional thrust system that places it structurally on top of a similarly deformed North American miogeoclinal section. None of these thrust faults are exposed in the project area. The massive volcanic units are weakly deformed, at most into open warps. The thin-bedded, incompetent Slate Creek and Inzana Lake successions, on the other hand, exhibit tight polyphase folding and well-developed penetrative cleavages. In part, this may simply be the result of disharmonic folding; but the eastward fold vergences around Inzana Lake, and the intense shortening seen in the lower Takla Group units in general suggest that décollements (thrust flats) run through them. One oriented thin section of a phyllite in the Slate Creek succession near Rainbow Creek shows a top-to-the-east, synmetamorphic shear sense.

The gentle attitudes of regional bedding, where not disturbed by later high-angle faults, are displayed clearly in areas such as west of Kwanika Creek, north of Chuchi Lake, and east of Valleau Creek. Overall, bedding west of Kwanika Creek is nearly horizontal, as is the attitude of the unconformity below the Twin Creek succession. Excellent exposures on, and east of, 'Adade Yus Mountain provide good control on the attitudes of regional bedding and the often strongly discordant orientations of individual beds within them. The Chuchi Lake succession, as a whole, is only gently warped in these exposures and dips at about 15° to the south, whereas steep dips and tight folds are observed in thin-bedded sandstone and shale of the sedimentary marker. East of Valleau Creek, the basal contact of the Witch Lake succession is nearly horizontal, but bedding and foliation in the Inzana Lake tuffs and slates are very steep to vertical. The only major fold in the area involves the Chuchi Lake, Witch Lake and Inzana Lake successions south of Chuchi Lake. They are folded into a gently northwest-plunging, upright open anticline with Inzana Lake sediments in its core and on the west limb, where they interfinger with Witch Lake basalts.

FABRICS AND MINOR FOLDS

Detailed structural analyses of the Inzana Lake succession was only successful in its southern exposures, where sufficient facing directions and minor fold measurements could be obtained. Even there, facing directions and bed orientations may vary in single outcrops, due to the small scale of the folds. This, together with soft-sediment deformation, inverse grading, and later block faulting with accompanying rotations, hampered structural interpretation. Nonetheless, two separate and coaxial phases of folding can be discerned. The best evidence for polyphase folding is the presence of overturned beds in the hinges of large-scale F2 upright folds, which indicate tight, recumbant refolded F1 hinges. An excellent example of this occurs in the regional anticlinal hinge zone near Mudzenchoot Lake, where a facing and dip reversal occurs in northeast-striking strata. Other examples of F1 folds defined by changes in facing directions in F2 fold closures occur near Inzana Creek, north of Benoit Lake and north of Inzana Lake. Although F1 and F2 folds are readily distinguishable in the closures of F2 folds, the two are not easily discernible on the limbs of F2 folds, due to their coaxial orientations.

Mesoscopic F1 folds were only observed in a single outcrop north of Hat Lake (Figure 21a). Tight F1 folds with

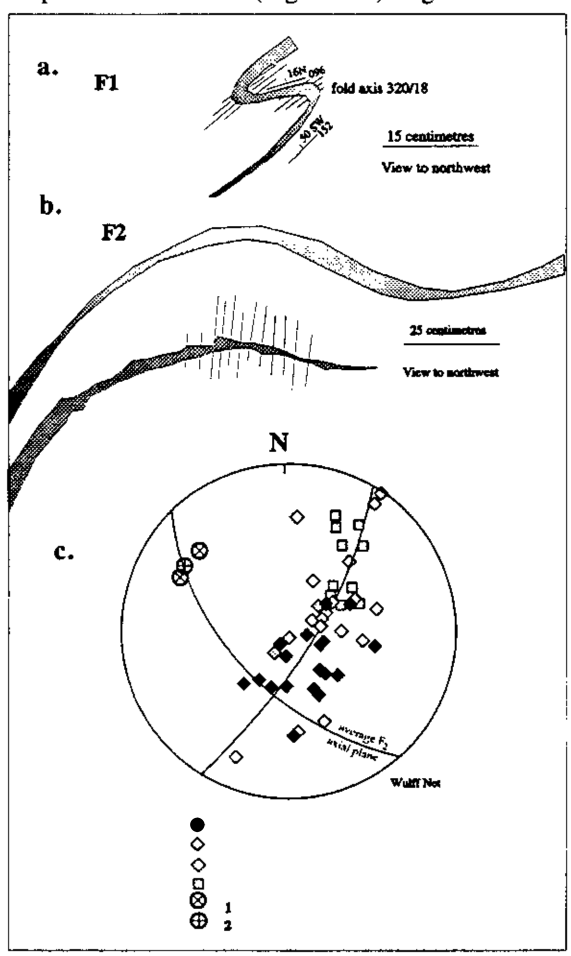

Figure 21. Minor folds in the Inzana Lake succession. (a) Field sketch of F1 fold. (b) Field sketch of F2 fold. (c) Stereonet plot of bedding, foliations and fold axes.

gently northwest-plunging axes are overturned and show a northeast-directed asymmetry. These folds are located on the southwest-dipping limb of a large-scale F2 fold that has a well-developed axial planar cleavage. At the Hat Lake locality, the axial planes of the two phases are parallel due to their location on the limb of an F2 fold. Several examples of outcrop-scale F2 folds were seen in the field (Figure 21b). They have gently northwest-plunging fold axes parallel to F1 and are characteristically open and upright. These folds appear to be parasitic on the regional anticlinal structure.

A stereonet plot shows a great circle distribution of bedding around the F1 and F2 fold axes (Figure 21c). Poles to overturned bedding measurements cluster with the poles to upright bedding, attesting to the tightness of F1 folds. As a group, bedding measurements are less steep than foliations. The poles to foliation, although scattered, define an average northwest-striking, southwest-dipping F2 axial plane.

The two phases of folding apparent in the Inzana Lake succession represent two separate events in the accretion history of Quesnellia. First and second phase folds are coaxial but not coplanar; their axial planes are approximately perpendicular to each other. First phase minor folds are tight and recumbent. A regional northeast transport direction is suggested by their symmetry. They were formed by tectonic transport of the overlying Mesozoic volcanic rocks in a single coherent panel, eastward with respect to the lower part of Quesnellia. The opposing vergences of F2 minor folds are geometrically related to the map-scale upright anticlinal structure. They represent later mild shortening.

FABRICS ASSOCIATED WITH THE INTRUSIONS ON MOUNT MILLIGAN

Ductile fabrics on Mount Milligan also record the accretion of Quesnellia. Two intrusive phases are present: an older, Hogem-like sphene-bearing monzonite with gabbro and hornblende granite end-members; and late, quartz-rich porphyritic granite, which has yielded a Middle Jurassic U-Pb zircon age with strong Precambrian inheritance (Chapter 2). The wallrocks and numerous pendants include strongly foliated amphibolites and augite gneisses as well as contact hornfelses. The transition from the plutonic and high-grade metamorphic core of the complex into low-grade metamorphic Witch Lake rocks occurs variously across both contact metamorphic zones and strain gradients. In one area south of the main peak, amphibolites (Photo 30) occur less than 300 metres from texturally unaffected augite porphyries. Near its southern margin the Hogem-like body is cut by a wide-spaced biotite or chlorite schistosity. This same strong but widely spaced schistosity is seen sporadically in the country rocks. The Middle Jurassic granite body crosscuts the amphibolite foliation but is itself foliated in places. Some of its most felsic apophyses are postkinematic. Therefore, granite was emplaced during the waning stages of penetrative deformation in its wall rocks.

Photo 30. Witch Lake basalt agglomerate, amphibolitized at southern margin of Mount Milligan suite intrusion. In thin section this is a coarse grained, strongly foliated amphibolite.

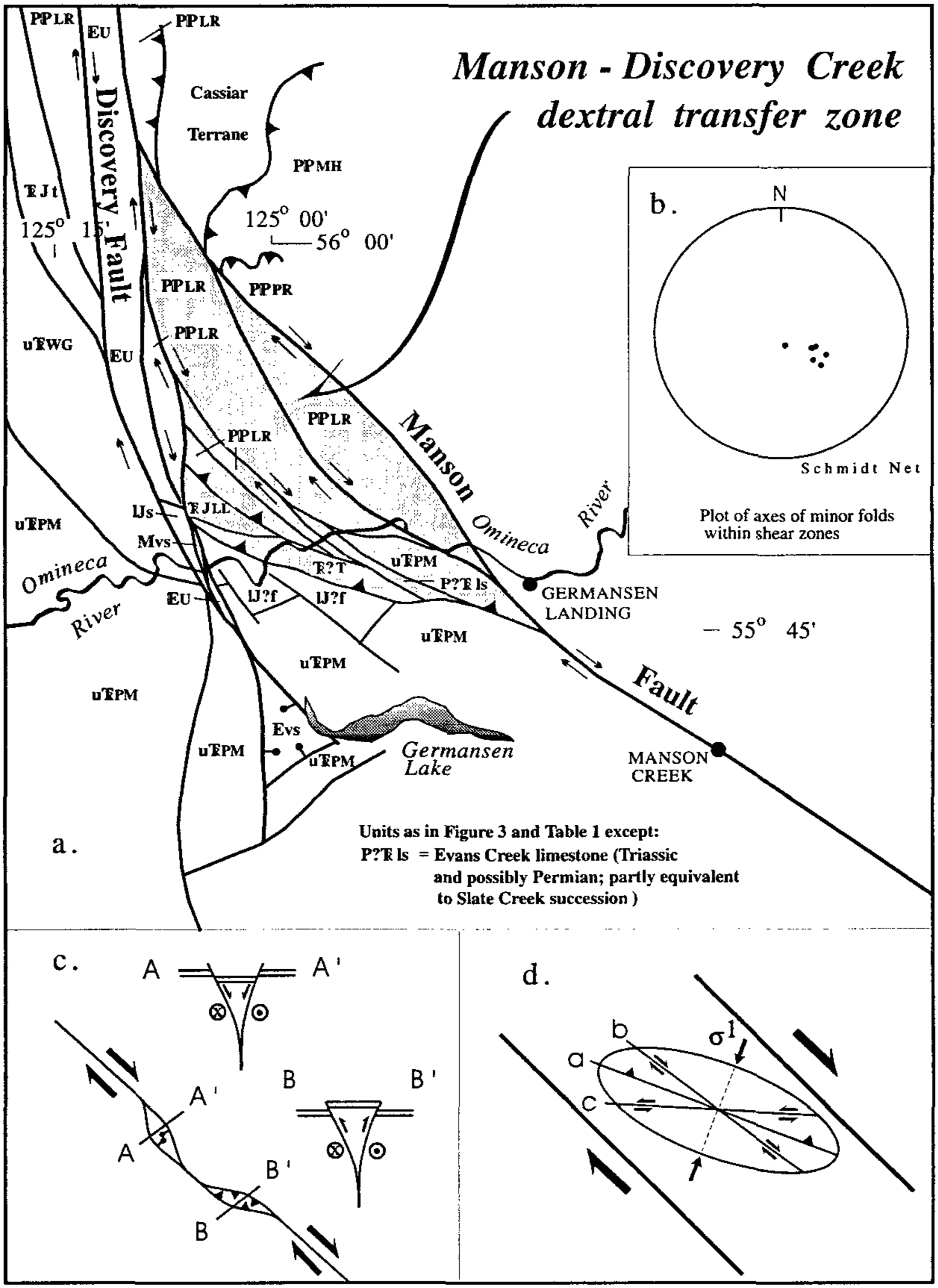

Figure 22. The Manson-Discovery Creek dextral transfer zone. (a) Regional map of the zone. (b) Stereonet plot of axes of northwesterly-verging minor folds in the Discovery Creek fault zone and along fault bounding Evans Creek limestone to the northeast. (c) Diagram of releasing (extensional) and restraining (contractional) bends in a dextral shear system. (d) Strain ellipse for dextral shear system.

The prevalence of strong fabrics in metamorphosed Takla rocks, and the evidence of deformation in intrusive units mark this as a synkinematic intrusive suite, in strong contrast to the Hogem intrusive suite, which according to the ubiquitous isotropic textures in its surrounding hornfelses was not emplaced during deformation. We originally interpreted the Mount Milligan suite as a core complex (Nelson *et al.*, 1991a); however the Middle Jurassic age of the youngest synkinematic granite and the Jurassic cooling ages obtained by Delong (personal communication 1992) suggest that instead, the ductile fabrics resulted from crustal shortening accompanied locally by plutonic heating.

THE CRETACEOUS - TERTIARY DEXTRAL TRANSCURRENT FAULT SYSTEM: LOCAL EXPRESSIONS

A system of dextral transcurrent faults, including the Tintina, Pinchi, Kutcho, Teslin and Manson faults, is a major element of tectonic architecture in the central Cordillera. Individual offsets of tens to hundreds of kilometres are thought to have occurred principally in mid-Cretaceous through Early Tertiary time (Gabrielse, 1985). Several splays of this Cordilleran-wide transcurrent fault system transect the Nation Lakes area: the western edge of the Manson-McLeod system south of the Nation River and west to the main road; the Discovery Creek fault system and the zone of faults that links it to the northern end of the Manson fault near the Omineca River, and the fault that separates Slate Creek from Inzana Lake strata near Dem Lake (Figure 3), which is a splay of the Pinchi fault west of the map area. Outside these areas, faults are less common, displacements on them are minor, and regional dips are slight. For example, high-angle faults near Groundhog Creek and north of Twin Creek, well constrained by the offset of the maroon basalt marker bed (uTrPMb), have stratigraphic throws in the order of 100 metres or less. The zones of transcurrent faulting, by contrast, are characterized by significant to profound stratigraphic throws and steeply tilted panels.

THE MANSON - DISCOVERY CREEK DEXTRAL TRANSFER ZONE

The Discovery Creek area is transected by two major strike-slip fault systems; the Manson and Discovery Creek fault zones. The northwest-trending Manson fault zone is a vertical dextral strike-slip fault with an overall strike length of 150 kilometres. It continues southwards into the McLeod and Rocky Mountain Trench fault systems (Figure 2), which may in part truncate it (Deville and Struik, 1990; Struik, 1993). Ferri and Melville (1994) suggest a Cretaceous age for some of the motion on this system, since some of its strands are cut by the mid-Cretaceous Germansen batholith. Early Tertiary motion is also likely. This regional fault becomes undefined north of Wasi Lake, a few kilometres north of the northeastern corner of the present project area (Figure 22a). There, its apparent offset is insignificant (Ferri *et al.*, 1992c), and it may either merge with or be cut off by the Discovery Creek fault. Strands of it may also follow the contact between the Lay Range Assemblage and the Cassiar Terrane. The amount of Cretaceous-Tertiary motion on this projection is limited, however: twenty kilometres to the north the basal Lay Range fault is a strictly Early Jurassic, ductile structure (Nixon, 1993), that does not seem to have undergone later movement (F. Ferri, personal communication, 1996).

The Discovery Creek fault zone is a north-northwest-trending strike-slip system, approximately 5 kilometres wide in the map area, composed of anastomosing strands. Its southern extent is the west Germansen Lake graben where Eocene rhyolites and sedimentary rocks outcrop in a triangular pattern. (Figure 3; 22a), a feature that geometrically resembles a releasing bend in a theoretical dextral system (Figure 22c). Some splays of the Discovery Creek system run into the valley of Twentymile Creek, but south of Germansen Lake the displacement on them becomes slight (Figures 3, 22a). North of the Omineca River, fault strands define grabens containing three units younger than the Takla Group: the Toarcian (Lower Jurassic) sedimentary succession, the Eocene Uslika Formation and the red rhyolite tuff (unit KTvs). Lensoid slivers of Lay Range assemblage and the Mississippian volcanic-sedimentary unit are also caught up in the fault zone. This fault system continues northward into the Uslika Lake map area, where Ferri *et al.* (1992a) have suggested that a northeast shift in the dextral fault has produced an extensional flower structure, with Cretaceous and Early Tertiary sedimentary strata in grabens along fault strands. Farther north, the fault swings slightly more northwesterly and joins the Lay Range fault system (Ferri *et al.*, 1993a) and then the Finlay-Ingenika-Pinchi fault system (Wheeler and McFeely, 1991).

Tight northwest-verging folds with steep southeast-plunging axes occur along the main Discovery Creek fault zone and the splay along Cook Creek (Figure 22b). As kinematic indicators, they are consistent with dextral shear, as is shown by the strain ellipse in Figure 22d. Antithetic, east-west sinistral shear is suggested by a fault zone 5 metres wide in Discovery Creek, as well as by numerous offset beds including a 1-centimetre layer of anthracite in the late Toarcian sedimentary unit. A carbonate alteration zone 20 metres wide, and smaller carbonate veins, also follow prominent east-west trends.

The area between the Manson and Discovery Creek fault systems is occupied by a set of west-northwest-trending faults along the Omineca River (Figure 22a). Faults in this zone divide the stratigraphy into predominantly southwest-facing, steeply dipping, homoclinal packages.The panels form a general younging trend from northeast to southwest. Paleozoic Lay Range rocks form the hanging wall of the whole system, thrust on the undated Lounge Lizard intrusive suite and 12 Mile basalt. The footwall south of the Omineca River consists of Plughat Mountain succession and the felsic volcanic/sedimentary unit of possible Jurassic age. There are, however, clear age reversals within the fault zone, for instance in the valley of Cook Creek where limestone of the Middle to Upper Triassic Slate Creek succession is interleaved with Pennsylvanian to Permian Lay Range Assemblage. Most of the fault-bounded panels face southwest (Figure 3). Slickensides on the steep fault that separates the Lounge Lizard intrusion from the Lay Range show that the northeast block moved up; therefore it is a reverse or steep thrust fault. The location and configuration of the

Omineca River fault zone are consistent with the westward stepping of motion from the Manson fault zone to the Discovery fault zone through a zone of compression or positive flower structure (Figure 22). Woodcock and Fischer (1986) describe such strike-slip duplexes, which develop at restraining bends in transcurrent systems - in the case of a northwesterly trending dextral fault, a step to the west. The transfer zone develops by sequential outward propagation of dextral and reverse faults. Here, the lithologic makeup of the fault slivers suggests that the imbrication occurred in the southwesterly block. West-northwesterly and northwesterly faults within it show either reverse or dextral displacements, consistent with the predictions of the strain ellipse (Figure 22d).

Two anomalous rock units are restricted to this fault zone: the Lounge Lizard intrusive suite that intrudes the tholeiitic 12 Mile basalt, and the apparently long-lived Permian(?) to Middle-Upper Triassic Evans Creek limestone (Ferri and Melville, 1994). In addition, it demarcates the southern extent of Lay Range assemblage exposures. Perhaps this Cretaceous-Tertiary fault zone masks earlier profound faulting that juxtaposed dissimilar rock units.

The probable Eocene age of the Uslika Formation provides an older limit to the last movement on the Discovery Creek system. This motion is considerably younger than that inferred for some of the more southwesterly strands of the Manson fault (Ferri and Melville, 1994); however other strands of the Manson join the Tertiary Wolverine fault zone and run south into the McLeod system, where Eocene-Oligocene motion is indicated (Deville and Struik, 1990; Struik, 1993). Early Tertiary motion on the Manson and Discovery faults is thus likely. This simultaneous Early Tertiary movement on both faults suggests that the Manson fault was not simply truncated/offset by a later Discovery Creek system. The position of the Omineca River fault zone where the Manson fault dies northward and the Discovery Creek fault dies to the south further suggests that it acted as a left-stepping, compressional transfer zone between the two, a link that connected the Pinchi through the Discovery fault into the Manson-McLeod fault system.

FAULTS SOUTH OF THE NATION RIVER

The structural style of the area between the Nation River, the Fort St. James - Manson road, and the Germansen-Cripple logging road is characterized by tilted fault blocks of contrasting stratigraphic levels. Long, but ultimately discontinuous, northwest-trending faults are linked by shorter, second-order northeast-trending faults, which separate horsts and grabens (Figure 3). The latter, like the graben west of Germansen Lake (Figure 22a), are triangular with apices pointing north. This map pattern is consistent with a zone of extension, in which motion is transferred from southwest to northeast between two northwest-trending dextral faults (Figure 22c). At the eastern edge of the Mt. Milligan deposit, Takla stratigraphy is truncated by the Great Eastern fault, a broad zone of milling and brittle shear zones seen only in drill core. The Great Eastern fault juxtaposes a moderately east-dipping panel of Witch Lake volcanics against Early Tertiary continental clastics, basalt and coal. It is crosscut by quartz and plagioclase-porphyritic dikes, which show only minor shearing (R.C. DeLong, personal communication, 1990). These dikes are texturally unique but still part of the rhyodacite-dacite suite. One dike is an amygdaloidal plagioclase porphyry; the other contains white plagioclase and pink orthoclase megacrysts and smaller, rounded quartz phenocrysts.

West of Mount Milligan peak, the intrusion is in faulted contact with slightly metamorphosed Takla rocks. Quartz-plagioclase-biotite rhyodacite porphyry dikes occur within and strike parallel to this fault zone. They are strongly deformed and have steep, northwesterly striking foliations parallel to the inferred fault trace. Subhorizontal lineations and asymmetric pressure shadows in outcrop, and poorly developed C-S structures in thin section indicate dextral strike-slip motion on the fault. These plastically deformed rocks are in contact with foliated, green clay gouge, which shows later, post-uplift, brittle deformation. The rhyodacite has yielded a U-Pb titanite age of 169.3 ± 5 Ma. The dikes are interpreted as synkinematic. Their overall control by the fault zone indicates that it was in existence before they were emplaced; on the other hand their high degree of deformation shows continued motion after they cooled. This fault was thus in existence by the Middle Jurassic, but underwent subsequent dextral motion.

Other fault zones outcrop on the northeast shore of Dem Lake, in the valley of Rainbow Creek, on the ridge due east of Kalder Lake, on the southeast spur of the ridge on the Max claims, and a kilometre east of the map area on the Germansen-Cripple road. The fault at Dem Lake is probably a major splay of the Pinchi Lake fault. It has a very pronounced signature on regional magnetic maps. This magnetic trend diverges from the main Pinchi Lake fault at latitude 55° and cuts across Quesnellia towards Prince George, with a total strike length of 100 kilometres.

Except at Dem Lake, where deformation is purely brittle, all of these zones show strong penetrative fabrics. At the Germansen-Cripple locality, large-augite porphyry agglomerate has been smeared into a northeasterly trending tectonite with moderately plunging stretching lineations. Slightly assymetric pressure shadows seen in thin sections from this zone are compatible with sinistral offset.

FABRICS ASSOCIATED WITH THE GERMANSEN BATHOLITH

Sporadic zones of strong northwesterly trending foliation, separated by areas with weaker fabrics, occur in the Inzana Lake succession in a broad area between Valleau Creek and the Germansen batholith. In thin section, the foliation consists of strongly oriented actinolite needles and, less commonly, biotite trains that wrap around relict augite phenocrysts. Within this zone of foliation, a discrete fault near the headwaters of Valleau Creek is represented by an iron carbonate, quartz and sericite alteration zone, 1.5 to 2 kilometres wide, with minor pyrite and carbonate-mariposite rock (listwanite). Within a kilometre of the Germansen batholith, inside its thermal aureole, the foliation is overprinted by randomly oriented actinolite and biotite, and the matrix has a finely granular texture. The sporadic development of foliation resembles the structural style seen near fault strands in the Mount Milligan area. Such a fault, perhaps an older, pre-mid-Cretaceous strand of the Discovery Creek system may have controlled the southwestern margin of the Germansen batholith and later been truncated by it (Figure 3). In addition, parts of the batholith margin, for example north of Moosmoos Creek, show post-solidus deformation and foliation. Microscopically, the foliation is due to recrystallization of igneous biotite to finer grained trains, accompanied by subgrain formation in feldspars and neoblastic recrystallization along grain boundaries. Thus, strain in this area both predated and postdated intrusion of the Cretaceous Germansen batholith.

METAMORPHISM

Most of the pre-Cretaceous rocks in the project area have undergone prehnite-pumpellyite facies metamorphism, including all of the Lay Range assemblage and the Slide Mountain Terrane, as well as the Takla Group. Lower greenschist facies metamorphism, accompanied by penetrative cleavage development, has affected the faulted panels east of the Fort St. James road and south of the Nation River; and the Inzana Lake and Slate Creek successions between Valleau Creek and the Germansen batholith (Figure 23).

Prehnite-pumpellyite facies rocks contain secondary chlorite, carbonate, albite, epidote and rare pumpellyite and prehnite. Pumpellyite is best seen in amygdules in Lay Range basalts. Albite in amygdules, common in the Chuchi Lake succession, may be a replacement of pre-existing zeolites. In general clinopyroxenes are fresh, plagioclases are fresh to albitized and sericitized, and olivines are completely converted to serpentine or chlorite.

Greenschist-facies basalts of the Witch Lake succession between the Nation River and Cripple Lake contain abundant clear to pale green metamorphic actinolite. Actinolite occurs as mats of tiny acicular crystals and also as overgrowths on, and replacements of, clinopyroxene phenocrysts (Photo 31). Albite is stable in these rocks. Deformed slate-siltstone from the Slate Creek succession near Rainbow Creek contain synkinematic, blobby cordierite porphyroblasts.

In the project area, unlike the Quesnel area farther south in Quesnellia (Rees, 1987), metamorphic isograds are clearly not related to stratigraphic or structural depth. Instead, the two lower greenschist zones seem to be related to discrete metamorphic culminations. The zone south of the Nation River is associated with Cretaceous-Tertiary transcurrent and normal faulting. It presently lies 20 to 40 kilometres north of the southern Wolverine Complex (Figure 2 and 23). If Struik's detachment model is correct (Deville and Struik, 1990; Struik, 1993), prior to tectonic denudation of the complex, these Takla rocks lay much closer to it; they perhaps even formed part of its roof. In this case, it is reasonable that they were affected by elevated

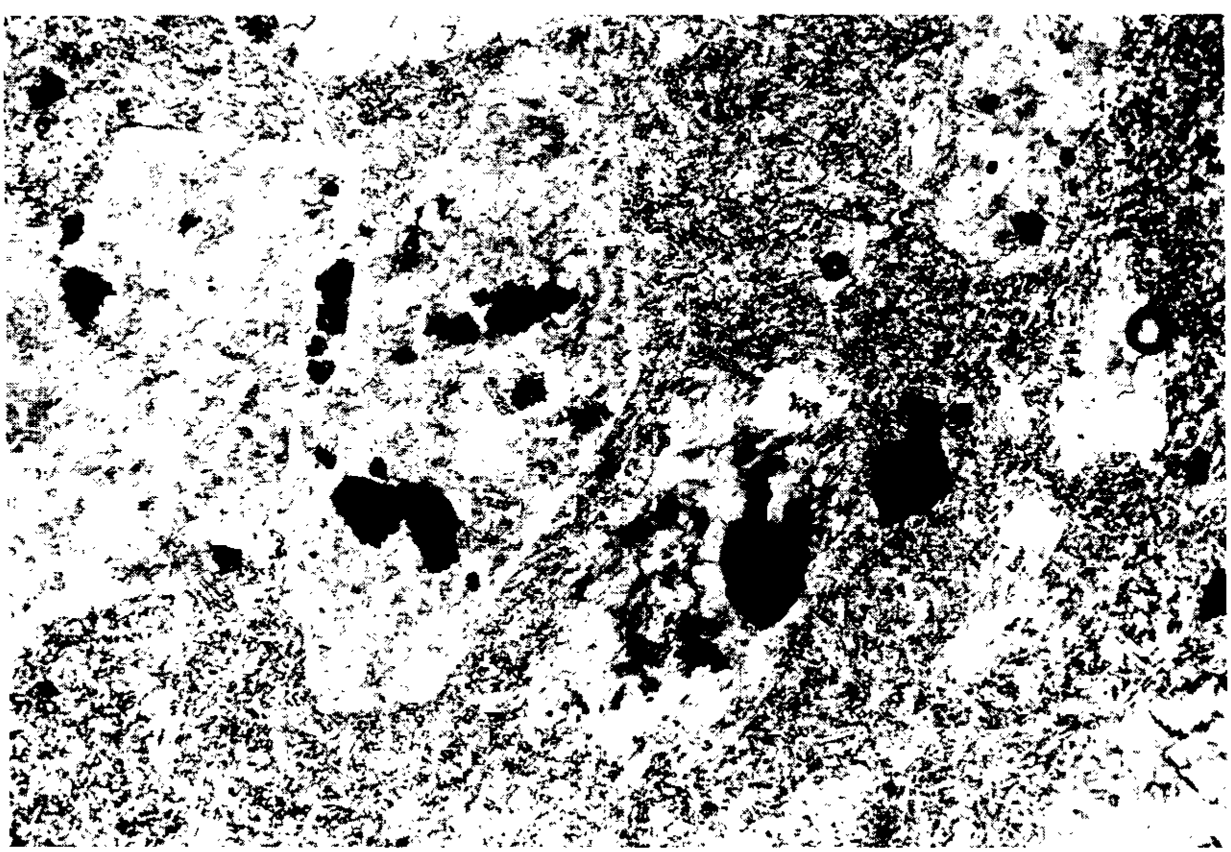

Photo 31. Regional greenschist facies metamorphism of Witch Lake succession near Mitzi Lake: augite phenocrysts replaced by mattes of green actinolite with clear rims in photomicrograph. Chlorite-actinolite clumps in amygdules. Field of view (short dimension) 1 millimetre.

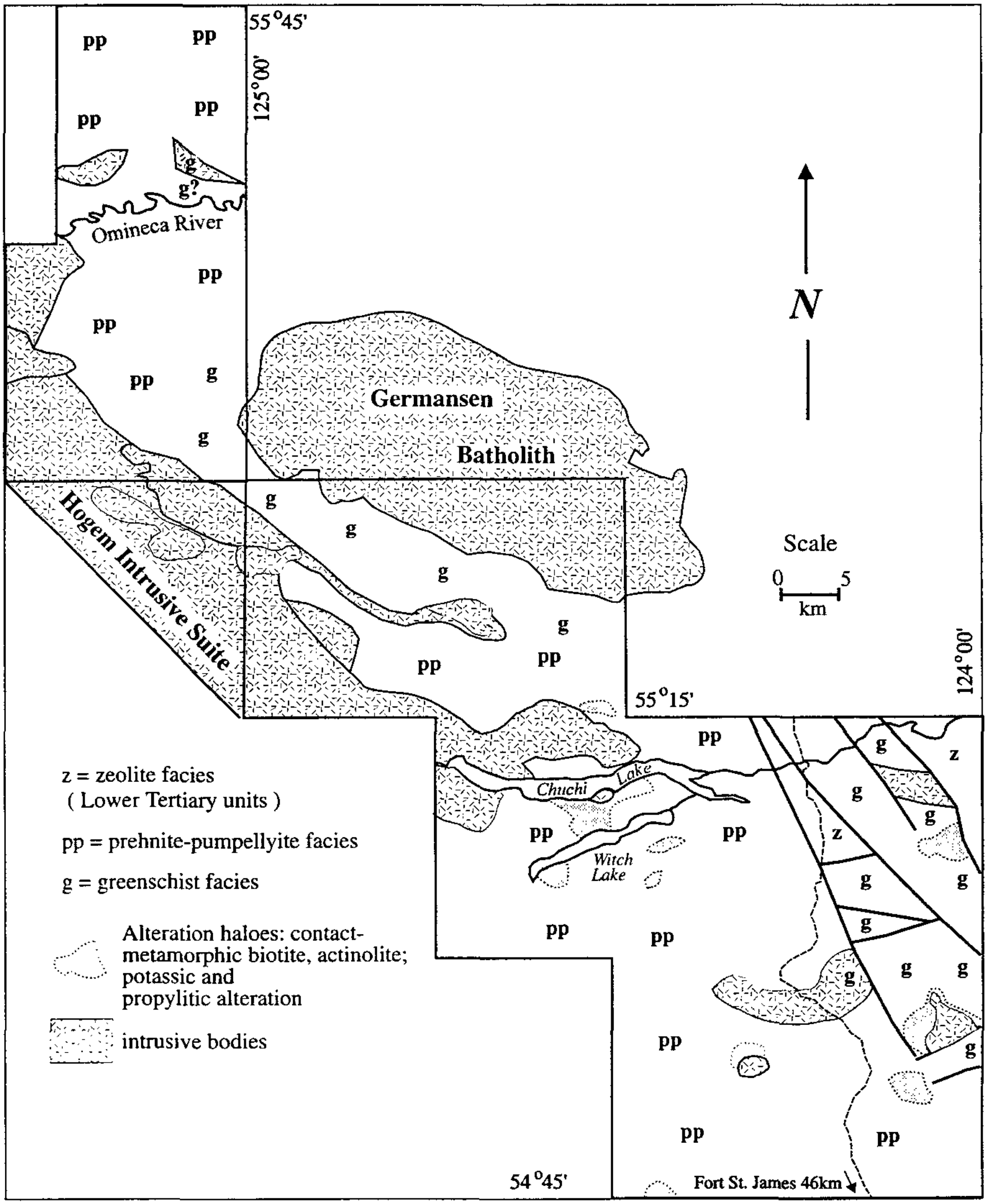

Figure 23. Metamorphic facies map of the project area.

regional temperatures in Cretaceous-Early Tertiary time. The more northerly metamorphic culmination lies between the Hogem and Germansen batholiths. While not contact metamorphism *sensu strictu*, because of its broad extent and pervasive fabrics, this zone may be the result of magmatic heating.

Contact metamorphic textures are of two types. Very fine grained, flinty hornfelses with lavender shades are due to submacroscopic biotite concentrations and occur in the aureoles of the small Early Mesozoic intrusions, where they are intimately associated with secondary, alteration biotite and potassium feldspar. Near the larger intrusive bodies, the Hogem, Germansen, Klawli and Mount Milligan bodies, coarse-grained hornfelses are developed with macroscopic actinolite and biotite, and patches, segregations and vesicle fillings of epidote, in some areas with garnet. The garnet probably formed at the expense of epidote as a result of the reaction: epidote + quartz = grossular-andradite + anorthite + magnetite + water. The width of contact aureoles varies greatly. For the Hogem batholith, it is generally less than 500 metres. The aureole is best defined on the north shore of Chuchi Lake, where hornfelses pass outward into texturally pristine prehnite-pumpellyite facies rocks. Between the Hogem and Germansen batholiths, contact metamorphism merges indistinctly with regional greenschist effects. Planar fabrics are associated with the thermal peak in the inner contact aureole of the Klawli intrusion. They result from crystallographic alignment of biotite. The overall texture is granoblastic. These fabrics encircle the intrusion, and are consistent with its forceful emplacement. Around the Germansen batholith and Mount Milligan intrusions, textures in thin sections variously indicate that the peak of metamorphism was before or after the strongest deformation. As described above in the section on structure, the deformational history around these bodies was complex, and reflects pre-intrusive shearing and forceful intrusion, followed by further strain.

CHAPTER 5 ECONOMIC GEOLOGY

THE NATION LAKES PORPHYRY COPPER-GOLD CAMP

Quesnellia and Stikinia host a suite of Early Jurassic, alkalic, typically gold-rich porphyry deposits, spread from the American border to the Stikine country. These include Similco (Copper Mountain), Katie, Afton, Mt. Polley and other deposits near Quesnel, and the Nation Lakes camp, including Mt. Milligan and Lorraine (Figure 24). Within Stikinia, Stikine Copper (Galore Creek) is a strongly alkalic, gold-enriched porphyry deposit (Allen *et al.*, 1976; Panteleyev, 1976); Red Chris, hosted by subvolcanic monzonite but characterized by quartz stockworks, is borderline calcalkaline to alkaline (Newell and Peatfield, 1995). These deposits are coeval and interspersed with porphyry systems of calc-alkalic affinities such as Highland Valley, Kerr, Kemess and Schaft Creek. All of the alkalic-suite deposits are essentially copper-gold resources with very low molybdenum contents (McMillan *et al.*, 1995, Figure 4). By contrast, many of the calc-alkalic suite are copper-molybdenum with very low gold; although Kemess and Kerr are copper-gold and Schaft Creek is copper-molybdenum-gold.

All of the alkalic-suite deposits are associated with shoshonite-suite, mildly alkalic volcanic sequences of Late Triassic to Early Jurassic age and, more specifically, with coeval and cogenetic alkaline intrusions (Barr *et al.*, 1976; Preto, 1979; Bailey, 1988; Pantaleyev *et al.*, 1996; Cathro *et al.*, 1993; Lang *et al.*, 1994). Many of the alkalic porphyry copper-gold deposits of Quesnellia, including Copper Mountain, Iron Mask, Mt. Polley and Mt. Milligan, occur in and around typically small, high level to subvolcanic intrusions. These crowded porphyritic diorites to monzonites consist of densely crowded, blocky plagioclase phenocrysts about 2 millimetres in diameter, and less abundant biotite, augite, hornblende, or orthoclase, in a dense very fine grained feldspar groundmass (Photos 22, 23). Intrusive breccias and diatremes are also an important aspect of alkaline porphyry systems (Barr *et al.*, 1976; Sillitoe, 1990). In the porphyry systems, contact metamorphism, most commonly expressed by flinty biotite hornfels, is extensive, compared to the small size of the intrusions that core the aureoles. Propylitic and potassic alteration assemblages are superimposed on contact-metamorphosed country rocks (Photo 32) and also occur in the monzonite. Abundant sec-

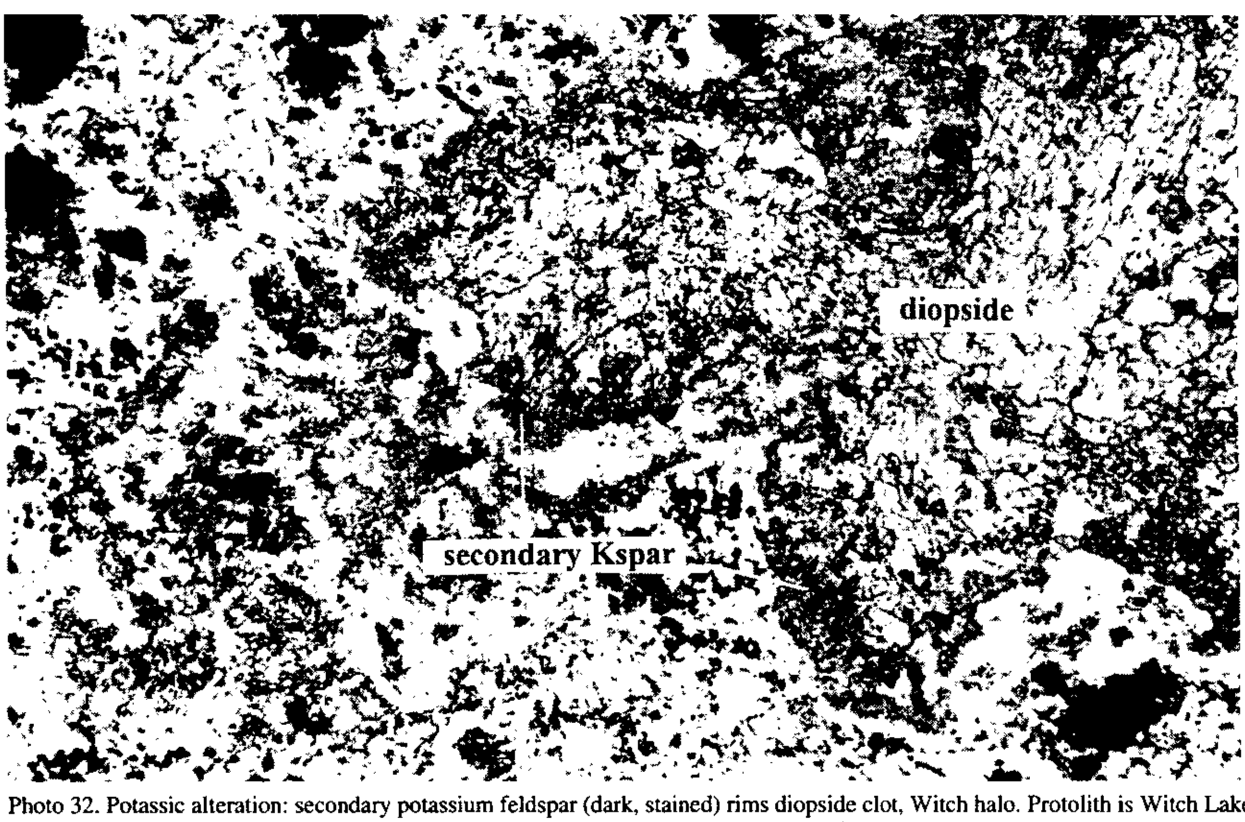

Photo 32. Potassic alteration: secondary potassium feldspar (dark, stained) rims diopside clot, Witch halo. Protolith is Witch Lake basalt lapilli tuff. Field of view (short dimension) 3 millimetres.

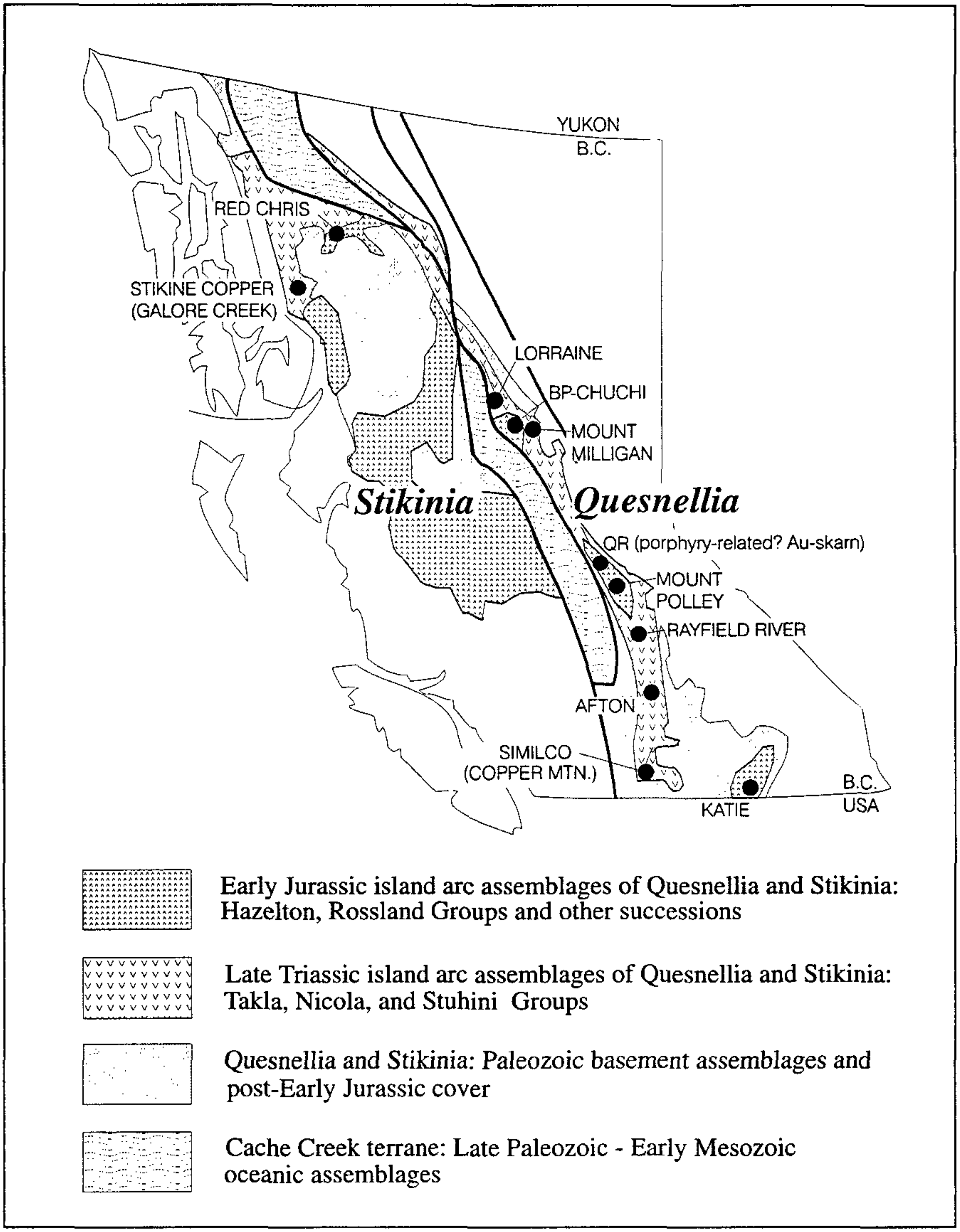

Figure 24. Early Mesozoic alkalic-suite porphyry deposits of British Columbia.

ondary magnetite, part of the potassic alteration assemblage, makes airborne and ground magnetic surveys an important exploration tool. Extensive pyrite haloes outline the porphyry systems. Small, high-grade veins such as the Esker veins at Mt. Milligan (Rebagliati, 1990), veins on the Tas property and the gold-magnetite veins and magnetite-matrix breccias at the Cat property (Ferri *et al.*, 1992a) may signal the presence of nearby large-tonnage, lower grade zones. Barrie (1993) demonstrates that lithogeochemical studies can aid in defining alteration zones, in which the ratio K_2Ox100/Sr increases due to simultaneous addition of potassium, plagioclase breakdown and leaching of strontium by hydrothermal fluids. Some alkalic porphyry systems contain zones of secondary albite (notably at the Ajax deposit in the Iron Mask botholith) and garnet (Galore Creek).

A major concentration of alkalic porphyry copper-gold deposits and related potassic and propylitic alteration zones lies within the southern part of the Nation Lakes project area, from Klawdatelle Creek east to Mt. Milligan and south to the Dem alteration halo, near Tezzeron Lake. This porphyry camp extends in two directions from the southern end of the Hogem batholith. One trend runs south from the BP-Chuchi property, through the Skook, Witch and Camp alteration haloes (Figures 3, 25). The Tas property and the Dem halo lie on a southward projection of this trend, the northerly-striking veins at the Tas also parallel it. A second trend is delineated by strong regional magnetic highs that run east-southeastward from the eastern limit of the Hogem intrusive suite to Mount Milligan, including the Mitzi-Taylor halo (Figure 25). The Mt. Milligan deposit lies at the southeastern end of this magnetic trend, where it is presumably truncated by the Great Eastern fault.

The two trends of shallow monzonite intrusions, bifurcating from an origin near the southern end of the Hogem intrusive suite, with which the monzonites are coeval and cogenetic, suggests control by basement structures. The south-trending group of porphyries lies on the southern extension of the structure defined by the mafic Valleau Creek intrusion and its strong magnetic expression. On the Tas property, near the southern end of the porphyry trend, coarse-grained hornblendite inclusions in crowded porphyritic monzonite and diorite link the high-level systems to underlying magma chambers where mafic cumulates, such as are found in the Valleau Creek body, were formed. Perhaps the Valleau Creek intrusive suite represents the deeper levels of such a magma chamber, one of a number that were localized by a deep set of north-south fractures. The easterly turn of the Hogem intrusive suite seems to be guided by faults under Chuchi Lake and in the valley of Klawdatelle Creek. It was argued above (Chapter 2) that the eastern end of the Hogem suite plunges rather than terminates. Its magnetic expression continues eastward, seemingly uninterrupted by early Tertiary grabens. The coarse-grained monzonites on Mount Milligan are interpreted as a final culmination of the Hogem batholith. The Mt. Milligan deposit centres on two small crowded porphyritic monzonites that may be offshoots of a buried extension. In this model, both bifurcating limbs of the porphyry camp have formed above subjacent, structurally controlled magma chambers.

Within the Nation Lakes porphyry camp, two deposits have significant resources, Mt. Milligan with 300 million tonnes of 0.5 grams per tonne gold and 0.2 to 0.3% copper, and BP-Chuchi with about 50 million tonnes of 0.21 to 0.40% copper and 0.21 to 0.44 grams per tonne gold. Other analogous systems, large alteration haloes with showings or prospects of copper-gold mineralization, include the Witch alteration halo between Witch and Chuchi Lake, the Taylor-Mitzi halo south of the eastern end of Witch Lake, the Tas halo near Hatdudatehl Creek, and the Skook, Camp, Max/Lynx and Dem haloes. The Aplite Creek prospect shows some affinity with alkalic porphyry deposits, in that chalcopyrite and gold occur in veins close to an intrusive breccia. The Wit prospect north of Chuchi Lake is an epithermal vein, possibly a near-surface expression of an underlying porphyry system. In the Nation Lakes area, porphyry-style mineralization within the Hogem intrusive suite is best represented by the Col occurrence, between Chuchi Lake and Lhole Tse Mountain. The Takla-Rainbow prospect on Twin Creek has a significant, but poorly defined gold resource (Bailey, 1991). Its main economically important zone is a set of gold-bearing quartz veins in a shear zone that also hosts Cretaceous(?) megacrystic granite dikes; it is unrelated to the early Mesozoic alkalic porphyry deposits (Figure 24). West of this zone, chalcopyrite occurs in a quartz-tourmaline stockwork in a mafic phase of the Hogem intrusive suite.

DEPOSIT DESCRIPTIONS

NATION LAKES PORPHYRY CAMP

MT. MILLIGAN (MINFILE 093N194, 191)

The Mt. Milligan deposit, with published reserves of 299 million tonnes of .45 grams per tonne gold and .22% copper (Sketchley *et al.*, 1995), was one of the most significant mineral deposit discoveries of the 1980s (Faulkner *et al.*, 1990; DeLong *et al.*, 1991). The Mt. Milligan story began in 1937, when prospector George Snell collected a sample of altered andesite on the southwest flank of Mount Milligan while cutting a pack trail into his placer claims. An assay result of 0.12 ounces of gold per ton prompted him to return in 1945. He then found four more samples, which contained from a trace to 4.38 ounces per ton gold. None of these samples were of bedrock. Consolidated Mining and Smelting Company geologists examined the property that year and thoroughly sampled the bedrock in Snell's trenches. Their sampling yielded negative results. The very high gold assay that Snell obtained in 1945 became a piece of local exploration folklore, a lost gold mine tale. Pechiney Development drilled near Heidi Lake, about 2 kilometres south of Snell's discovery in 1973, but encountered nothing of economic interest. No prospector has ever been able to duplicate the discovery. During this project we relocated the old trenches, but found no significant mineralization in either bedrock or float. It is likely that Snell picked up clasts from the glaciofluvial deposits that blanket the area. However, as can often happen in the history of mineral discovery, Snell "with assays of bias, by indirections, [found] directions out" (Shakespeare, 1604). The area remained suffi-

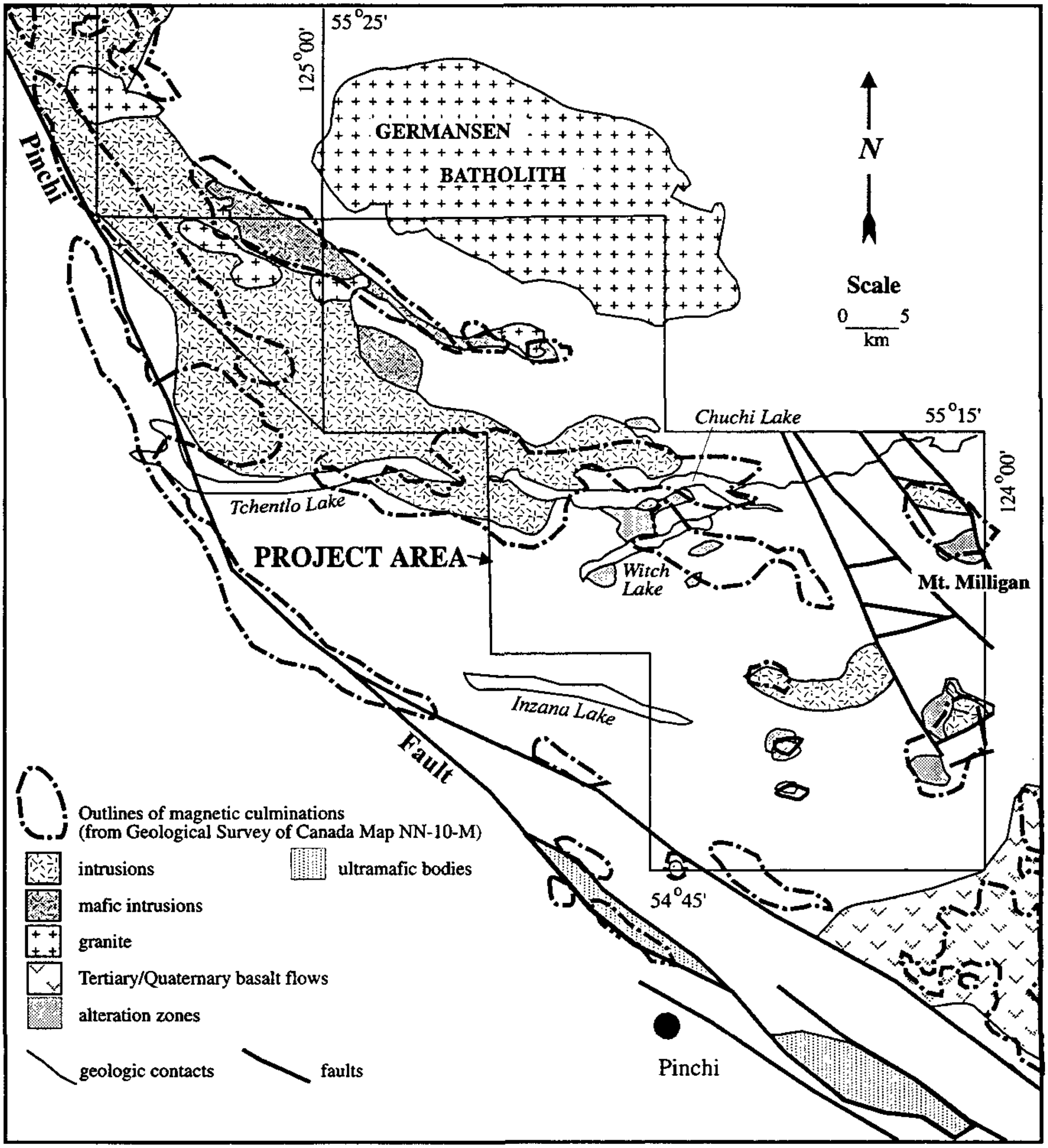

Figure 25. Location of the Nation Lakes porphyry camp, relationship to the Hogem intrusive suite, simplified aeromagnetic topography and major faults.

ciently attractive for Selco, Inc. (later to become the Selco Division of B.P. Resources Canada) to restake a much larger claim block in 1983-4, targeting alkalic copper-gold porphyries. In the course of the program, Selco geologists retreived some Pechiney core from porcupine-ravaged bags, which showed propylitic alteration and anomalous gold and arsenic values.

In August, 1983, Richard Haslinger, a Fort St. James resident who combined prospecting with his guide-outfitting business, discovered copper-gold mineralization in bedrock exposed in a creek bank a few hundred metres east of the BP claims, what would later be called the Creek zone. News of winter staking in 1983 prompted him to stake the Heidi claims over his discovery in early 1984. BP-Selco optioned these claims. The BP-Selco program under the direction of Mark Rebagliati and Randy Farmer outlined broad zones of elevated copper and gold in association with magnetic and IP anomalies around a lake 4 kilometres south of Snell's trenches, named Heidi Lake by Haslinger after his younger daughter who had accompanied him on the original prospecting foray. BP-Selco trenched high-grade veins near Heidi Lake in 1984 and 1985, but did not identify a significant porphyry system and by 1986 they were downsizing and had lost interest in the property. However, Mark Rebagliati, at that point an ex-BP geologist, remained keenly interested. He gained an agreement with BP to market several of their claims. He approached 23 companies before Dave Copeland of Lincoln Resources Ltd. signed an option agreement with BP to explore the Heidi Lake claims. A drill program in the spring and summer of 1987 tested several targets, first the high grade Esker zone and the Creek zone, which had been exposed by trenching of copper-gold soil anomalies. In September 1987, under Rebagliati's direction, the drill program stepped out into an outwash-covered area on Haslinger's claims that showed strong coincident magnetic, geochemical and IP anomalies - a bold move for a junior exploration company, particularily since the geochemical anomalies in outwash could easily be explained away as transported from the known anomalies near Heidi Lake. But on September 25, Rebagliati's hunch paid off when Hole 87-12 intersected the Magnetite Breccia zone or MBX zone, and Mt. Milligan began its rise to prominence.

There are two separate potential orebodies on the property (Figure 26). The Mt. Milligan Main deposit, including the MBX, WBX, and DWBX zones, is associated with the MBX stock. It grades into the peripheral, gold-rich 66 zone. The Southern Star zone is associated with the Southern Star stock. These two small, biotite-and quartz-bearing crowded porphyritic monzonite bodies are later phases within the Heidi Lake intrusive suite, which also includes hornblende-sphene-bearing, quartz- and biotite-free monzonites. Orthoclase-megacrystic monzonites to syenites are post-ore. The monzonites form an east-west elongate cluster from Heidi Lake east to the Great Eastern fault. Subsurface data show that the MBX and Southern Star stocks both plunge moderately west (Faulkner *et al.* 1990; Rebagliati 1990). They intrude a moderately northeast-dipping and facing panel of Witch Lake pyroclastic and epiclastic strata, all of augite-phyric basalt derivation except for an amygdaloidal trachyte/dacite flow unit accompanied by fine grained sedimentary strata, that occurs stratigraphically below the two deposits. Outside the alteration halo, on the ridge between Mitzi Lake and Rainbow Creek, the augite basalts and their epiclastic equivalents generally contain no primary potassium feldspar. Where they do, the potassium feldspar is clearly of primary origin, forming an even, very fine grained groundmass around unaltered macro- and microphenocrysts. Within the deposit area the Witch Lake basalts are described as latites and trachytes. The potassium feldspar in them is of secondary origin, as is shown clearly in stained thin sections: it fills fractures and amygdules and occurs in tiny patches in primary augite (now actinolite) and plagioclase phenocrysts (Photo 33). In the laminated epiclastic siltstone and greywacke, it forms clumps and lenses along bedding planes, accompanied by pyrite and epidote (Photo 34). In one thin section from the North Slope, north of Heidi Lake, these alteration textures are accompanied by stylolitic growth on bedding planes.

Gold-copper mineralization correlates with intense potassic alteration, except for gold-pyrite with propylitic and minor albitic alteration in the 66 zone (Sketchley *et al.*, 1995). The copper-to-gold ratio is highest in the Southern Star stock. Mineral assemblages are simple: chalcopyrite, pyrite, magnetite and minor bornite. The gold-rich 66 zone developed by bedding-parallel infiltration and replacement of volcanic sediments and andesites of the Witch Lake succession above and spreading away from the MBX stock. Sporadic supergene alteration is also recognized in the MBX and WBX zones.

The present geometry of the Heidi Lake intrusive suite and the Mt. Milligan alteration system is probably the result of tilting during Tertiary faulting. The original configuration can be seen by rotating the northeasterly dipping and facing Witch Lake stratigraphy to horizontal (Figure 27). This restoration shows the MBX and Southern Star stocks as vertical widening-upwards pipes with laccolithic offshoots along bedding. These two relatively differentiated bodies lie above the more mafic phases on the North Slope north of Heidi Lake. The MBX stock is a vertical feeder to the laccolithic, sill-like Rainbow dike. Dilation along bedding planes, particularily along fine grained epiclastic horizons, may have controlled the emplacement of the Rainbow dike and also provided increased permeability, which later channelled ore fluids to create the 66 zone.

BP-CHUCHI/RIO-KLAW HALO (MINFILE 093N 159)

The BP Chuchi/Rio Klaw system is an extensive intrusive complex and alteration halo that lies in an incised north-south pass, south of Klawdetelle Creek. The centre of the system is on the Phil claim block, which was bought by Digger Resources Inc. from Mark Rebagliati in 1986. BP Resources Canada Limited acquired an option from Digger Resources and drilled in 1989 to 1991 (Wong, 1990; Wong and Barrie, 1991; unpublished data). The northern extension on the Klaw claims was drilled by Rio Algom Exploration Inc. in 1990 and 1991 (Campbell, 1990a, 1991a, b). The alteration system is bounded to the east by a north-trending fault, and to the north by the fault along Klawdetelle Creek. Within it, biotite-bearing crowded plagioclase phyric mon-

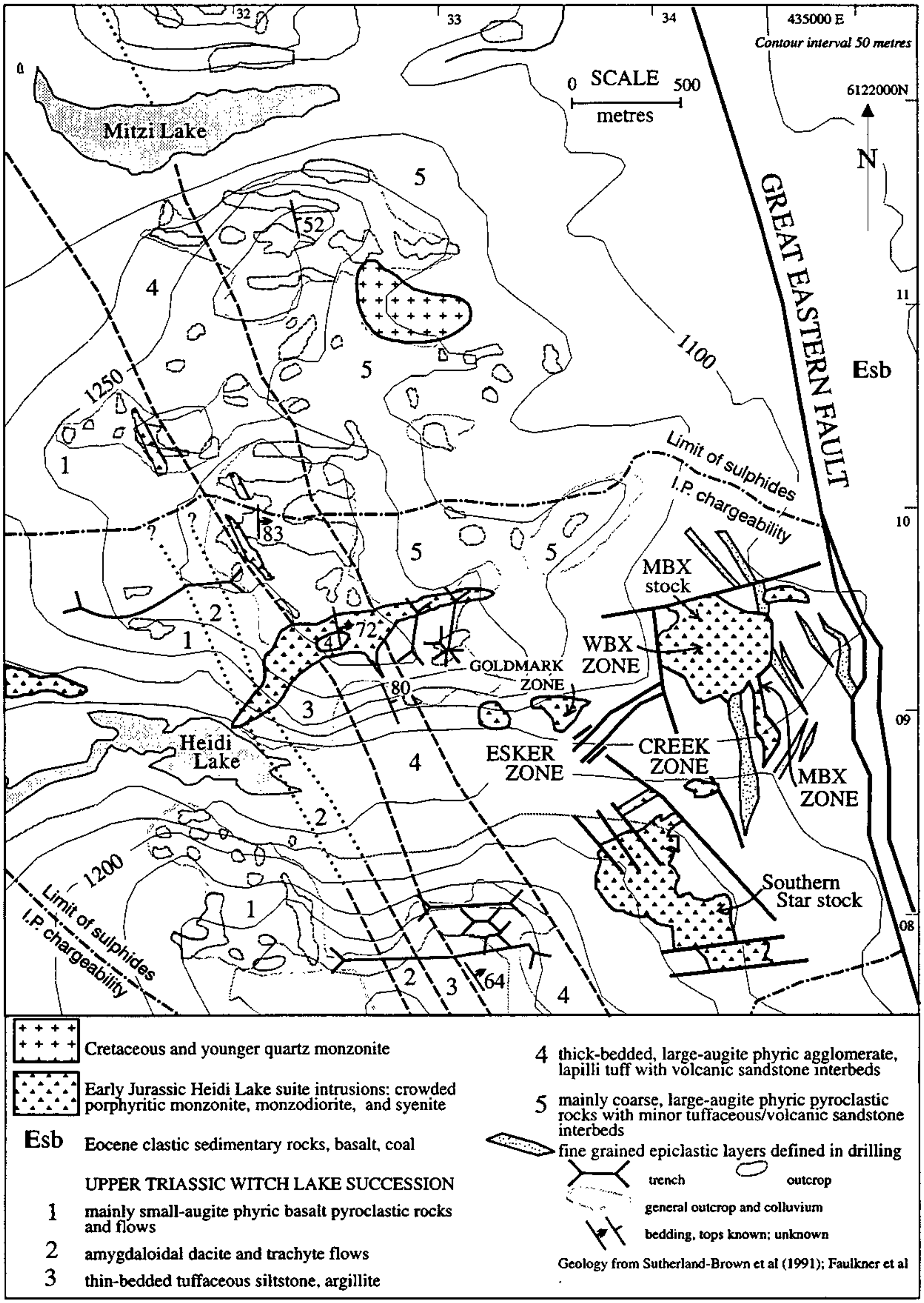

Figure 26. Geological map of the Mt. Milligan deposit area.

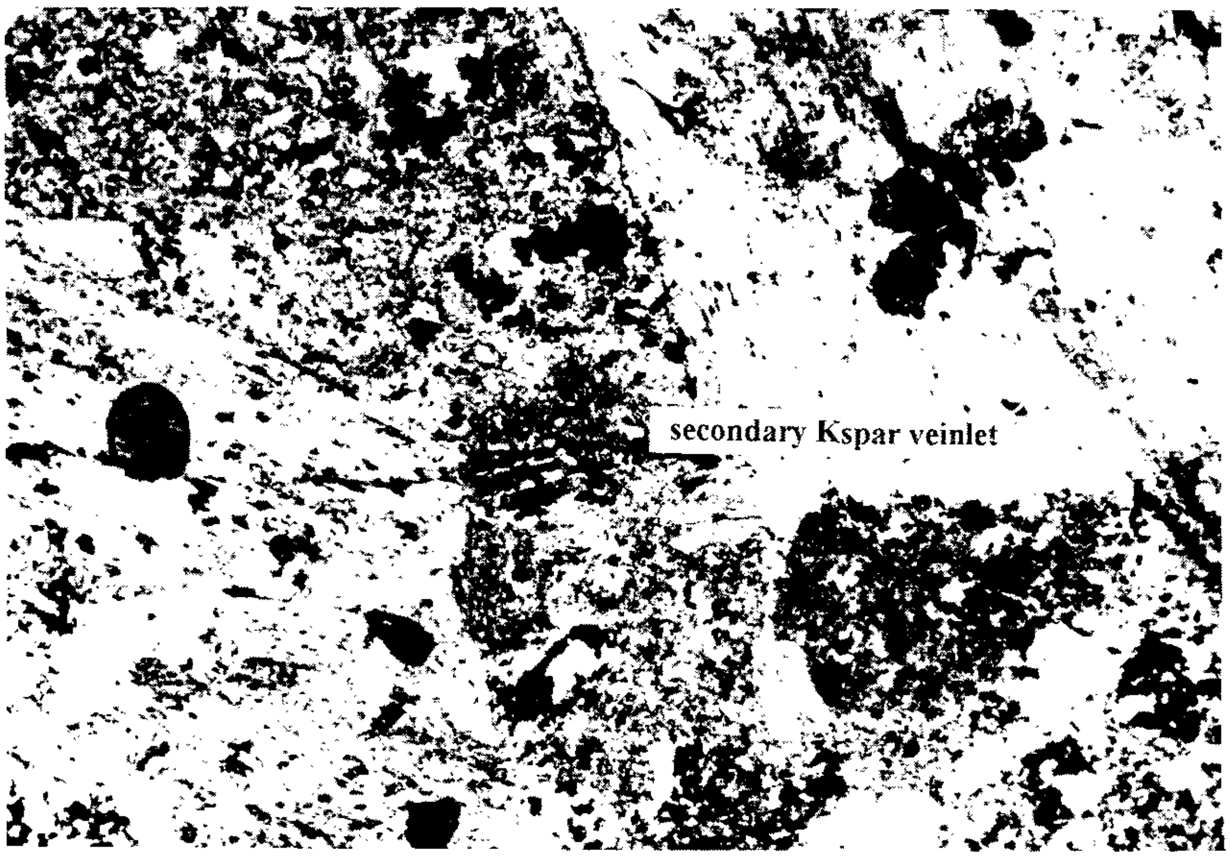

Photo 33. Potassic alteration: potassium feldspar veinlet cuts across actinolized augite phenocryst, North Slope, Mt. Milligan deposit. Field of view (short dimension) 3 millimetres.

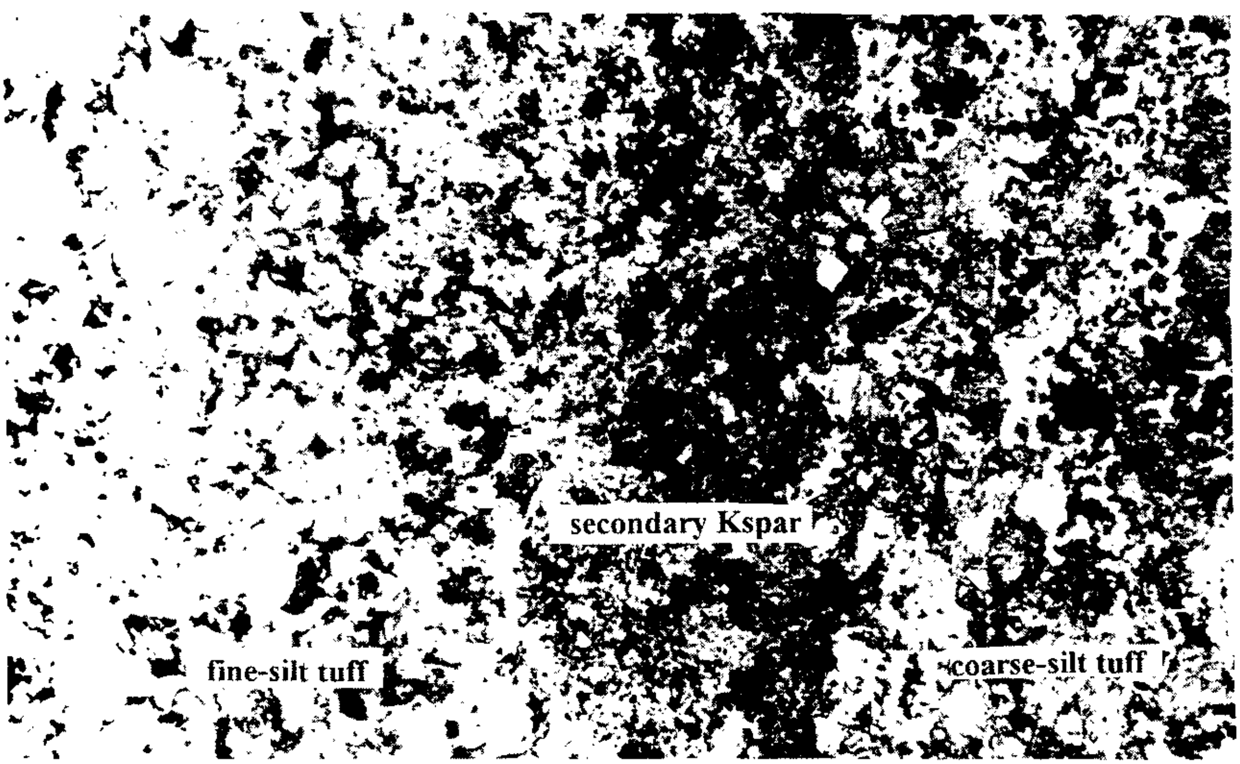

Photo 34. Potassic alteration: secondary potassium feldspar infiltrates a bedding contact in volcanic siltstone/greywacke, North Slope, Mt. Milligan deposit. Field of view (short dimension) 3 millimetres.

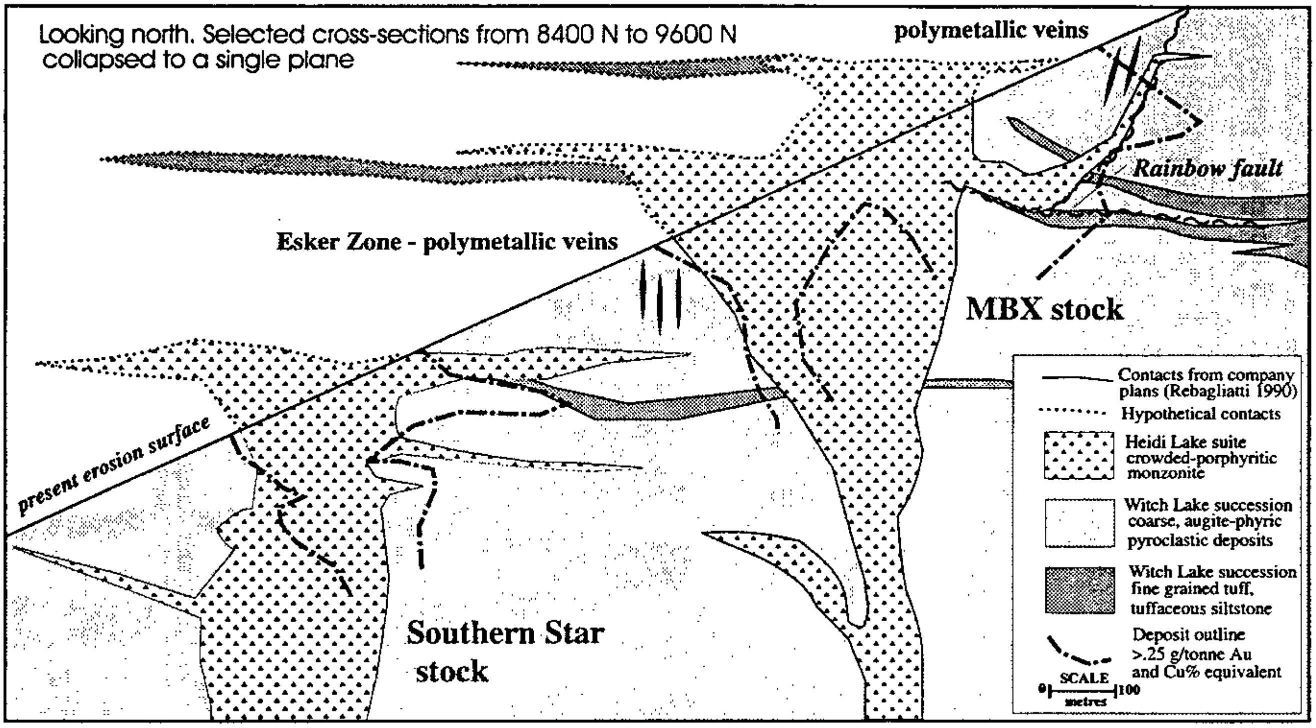

Figure 27. Cartoon restoration of the Mt. Milligan system, by rotation of bedding to horizontal.

zonite stocks intrude the sedimentary horizon in the Chuchi Lake succession (lJCL(D)) and blossom out into sill swarms (Wong and Barrie, 1991). This monzonite porphyry is 188.5± 2.5 Ma by uranium-lead methods on titanites (Table 3, Appendix 7).

In many instances in drill core, hornfelsed sedimentary rocks show soft-sediment deformation, and are intimately intercalated with monzonite: this association is considered to indicate intrusion of the monzonites while the sediments were still unlithified (Wong and Barrie, 1991; Barrie, 1993). The fine-grained, well-bedded sandstones, siltstones and tuffs grade downwards into massive, coarse lapilli tuffs and agglomerates. Intrusive clasts form a large percentage of the fragmental material, from agglomerates to crystal tuffs. Crowded plagioclase porphyry clasts, with small blocky plagioclase crystals less than 2 millimetres across, are common and identical to the later porphyries that intrude the sediments. Clasts with pink secondary potassium feldspar, magnetite and epidote are also present. Sulphide-bearing porhyritic monzonite clasts occur clustered in a heterolithic lapilli tuff in the Chuchi Lake succession north of Klawdatelle Creek (*see* Hannah showing, MINFILE 093N 211). Grab samples from an area rich in rusty fragments yielded results up to 840 ppb gold and 224 pm copper. These clasts may be distal to the BP-Chuchi system, as they lie at about the same stratigraphic level; or they may reflect other, unknown sources.

Abrupt changes in the relative percentage of sedimentary rocks and fragmental material are observed between closely spaced drill holes (B. Augsten, personal communication, 1991). Possible interpretations of this include rapid facies changes or local faulting. In the valley of Klawdetelle Creek, drill intersections of monotonous black argillites contain virtually no coarse components (Campbell, 1991). The marked difference between these sections and the fragmental-rich sedimentary sections farther south and west may constitute evidence for facies changes over less than 2 kilometres.

On the ridge 1 kilometre south of the main mineralized area, the sedimentary section is overlain by a suite of plagioclase-augite and augite-plagioclase-phyric flows and minor, thin crystal tuffs of identical composition. These flows contain plagioclase laths 0.6 to 1 centimetre long, commonly synneused into bundles of two or three crystals. This habit of sticking together of different-sized crystals on their flat faces gives a distinctive ragged appearance to their terminations. They are accompanied by blocky augite crystals up to 0.8 centimetre in diameter. A partly brecciated plagioclaseaugite porphyry dike with this distinct appearance cuts the crowded porphyry monzonite in BP diamond-drill hole 1991-53.

The geological relationships described here point to an intimate relationship between the hypabyssal intrusions and sedimentation. Some intrusions predate the sedimentary unit, as clasts of them occur in and are also interbedded with the underlying fragmental units. Other intrusions cut the sediments but not the overlying flows. A possible feeder dike to the flows cuts one of the monzonites. The predominance of sills over dikes suggests that they were intruded before lithification was complete, as is observed with synsedimentary igneous activity in, for example, the Guaymas Basin. It is also possible, albeit not proven, that the sills plastically deformed the sediments around them. The abundance of intrusive material in the surface fragmentals probably resulted from surface venting of intrusive breccias into the sedimentary basin.

In light of the geological evidence that sedimentation, intrusion and porphyry-style copper-gold mineralization were roughly coeval, it can be inferred that the the B.P.-Chuchi porphyry system formed contemporaneously with the Pliensbachian sedimentary horizon. Like the other porphyry systems of Quesnellia (Lang *et al.*, 1995), it formed during a volcanic lull. Although this gap in volcanism was much less profound than either the Triassic/Jurassic break or the final termination of Quesnel arc volcanism at the end of the Pleinsbachian, this example accords with the ideas developed by Lang *et al.* that the major porphyry events occurred in the waning stages of volcanic episodes, when declining magma supply led to more thorough differentiation.

As at Mt. Milligan (D. Sketchley, personal communication, 1991; Figure 27), the presence of sediments in this system may have enhanced the size and intensity of the altered area, by providing a permeable zone for lateral expansion of the intrusions and the hydrothermal cells. Bailey (1988) cites alteration of Pliensbachian sedimentary strata by the Bullion Pit stock near the Quesnel River, dated as 193 Ma by K-Ar on biotite. This porphyry system may have been approximately coeval with the B.P.-Chuchi system.

Both the monzonite and the sedimentary rocks at B.P.-Chuchi are extensively altered. Secondary potassium feldspar occurs in pink veinlets in the monzonite with magnetite, pyrite and chalcopyrite. The sedimentary rocks show a strong biotite hornfels overprint, with subsequent mottling by potassic and propylitic alteration. Hairline veinlets with bleached alteration envelopes and magnetite veinlets and disseminations are also characteristic of alteration.

Rough estimates of geological reserves for this system are about 50 million tonnes with grades between 0.21 and 0.40% copper and 0.21 and 0.44 grams per tonne gold (Digger Resources Inc. news release, October 17, 1991).

APLITE CREEK, AHDATAY (MINFILE 093N 085)

The Aplite Creek mineral prospect is situated 4.75 kilometres east-southeast of the southern end of Ahdatay Lake, along Aplite Creek. The area has received considerable exploration sporadically since the 1970s for porphyry copper-molybdenum and most recently for porphyry copper-gold deposits. The prospect is within the Aplite Creek intrusive suite, which is cut by fracture zones that trend northwest (345°) or northeast (060°). Deeply incised gullies with good outcrop exposures are coincident with these subvertical fracture zones and form prominent topographic linears. Moderate to intense propylitic and potassic alteration envelopes up to 20 to 25 metres thick occur around the fractures (Paterson and Barrie, 1991).

Mineralization consists of disseminated pyrite, pyrrhotite and chalcopyrite in anastomozing quartz-carbonate veins up to 4 centimetres thick. Sulphides are also present in the groundmass of the country rocks, locally up to 100 metres away from the fractures (Paterson and Barrie, 1991). Variable amounts of malachite, azurite, limonite and hematite are associated with the sulphide minerals. The locality (Figure 3) is placed on a prominent vein along Aplite Creek. Polymictic intrusive breccia outcrops a few hundred metres northwest of this vein.

WITCH HALO (MINFILE 093N 084 Moss; MINFILE 093 164 Witch)

The broad Witch alteration halo, located between Chuchi and Witch lakes, covers an area of 3 by 5 kilometres (Figure 3). It was explored most recently by Rio Algom Exploration Inc. (Campbell, 1990b; Campbell and Donaldson, 1991). Volcanic rocks of the Witch Lake succession, including augite phyric flows and fragmentals, aphanitic volcanics and minor tuffs, host the alteration system. Biotite hornfelsing is widespread, overprinted by patchy potassic and propylitic alteration (Photo 32). Pyrrhotite, pyrite and minor chalcopyrite occur throughout the halo. Secondary magnetite is locally abundant. Skarn occurs in several areas at the expense of limy tuffaceous sediments. Skarn minerals include epidote, garnet and diopside. In one thin section, diopside skarn is overprinted by secondary potassium feldspar.

In comparison to the B.P.-Chuchi/Rio-Klaw halo, the volume of exposed hypabyssal intrusive rock is very small. Crowded plagioclase porphyritic monzonite forms tiny scattered stocks and dikes with associated, more widespread intrusive breccias. The breccias are easily confused with surface fragmentals, except that they are more disorderly and the clasts are entirely intrusive. Their matrix is composed of fine fragmental material and alteration minerals. They compare with the intrusive breccias on the BP-Chuchi/Rio-Klaw properties.

This region is also intruded by several phases of the Hogem intrusive suite including coarse-grained equigranular monzonite, sericite-bearing potassium feldspar pegmatite and coarse-grained syenite. The best-developed surface mineralization on the property is at the Moss showing. It consists of minor fracture coatings and blebs of chalcopyrite associated with abundant pyrite and pyrrhotite in a gossanous host (Campbell and Donaldson, 1991). Propylitic, potassic and carbonate alteration are so intense within this zone that original lithologies are not distinguishable in outcrop or thin section.

CAMP HALO (MINFILE 093N 081 Camp)

The Camp alteration halo is developed in fine-grained dust tuffs and siltstones of the Inzana Lake succession where it interfingers with augite porphyry agglomerates of the Witch Lake succession. A swarm of coarse hornblende-phyric dikes cuts the sediments. Pyrrhotite and pyrite are abundant in altered biotite hornfels and minor chalcopyrite and malachite occur as disseminations and along fracture surfaces. The main altered outcrops that constitute the Camp showing were trenched and drilled in the winter of 1990-1991 by Noranda Exploration Company, Limited. The area south of them is covered by extensive Quaternary alluvium. A Regional Geochemical Survey stream-sediment sample from a glacial gully 2 kilometres south of the showing returned 309 ppm copper, 1100 ppb mercury and 1.5 ppm silver. The sample location is in an obscure drainage plugged by numerous beaver dams. The only surficial materials are organic muck and glaciofluvial gravels exposed in stream banks, and the significance of this sample is in doubt. Five kilometres farther southeast, large-hornblende-phyric dikes identical to those at the showing are accompanied by crowded plagioclase porphyritic monzonite stocks and one body of intrusive breccia. It is possible that the Camp showing is part of a much more extensive halo that lies under thick Quaternary cover.

SKOOK HALO (MINFILE 093 140, Skook, MINFILE 093N 208, Rig Breccia, MINFILE 093N 208, GG, MINFILE 093N 209)

The Skook alteration system contains several small showings and occurs primarily within the sedimentary unit of the Chuchi Lake succession near its contact with the Hogem intrusive suite. The CL11 zone is the area of most intense alteration and highest density of crowded porphyritic monzonite intrusions. It is exposed in an east-trending gully in a logging cut. The sediments are bleached and hornfelsed; alteration minerals include potassium feldspar, chlorite, pyrite, sericite, epidote, biotite, calcite and minor tourmaline (Campbell, 1988). These rocks contain disseminated pyrite, pyrrhotite, and minor chalcopyrite and bornite. White-weathering siliceous tuffs with limy nodules are baked and have developed weak skarn alteration minerals such as garnet and chlorite. A polymetallic quartz vein contains sphalerite, galena and chalcopyrite. The best assay results on grab samples from this locality are 13.4 grams per tonne gold, 16.6 grams per tonne silver and 2.3% zinc (Campbell, 1988). The South zone lies 250 metres south of this vein and consists of a silicified zone in volcanics that contains quartz, calcite, pyrite and chalcopyrite. The GG polymetallic vein and the Rig breccia zone are also hosted by the overlying flows and are probably part of an epithermal vein system near the Takla-Hogem contact.

COL HALO (MINFILE 093N 101, Col)

The Col property (Col and Kael claims) of Kookaburra Gold Corporation is located 5 kilometres north of the west end of Chuchi Lake. The main copper-gold showings are situated within the southern end of the Hogem intrusive suite (Figure 3). They are hosted by coarse-grained alkaline intrusive rocks near the contact with volcanic flows of the Chuchi Lake succession. Medium to coarse-grained hornblende monzonite, fine to medium-grained pink syenite, aplite and pegmatite are the main intrusive phases. Copper mineralization, including chalcopyrite, bornite and malachite, is concentrated along steep, 140°-trending parallel fractures, surrounded by envelopes of salmon pink potassium feldspar rich alteration 1 to 4 centimtres thick. These zones may also contain quartz, minor magnetite, and hairline seams of tremolite/actinolite and chlorite. Some outcrops are so heavily striped with alteration zones that they take on a gneissic appearance. Although some of the zones appear to be late magmatic syenitic dikes, most appear to be the result of metasomatic alteration of the monzonite. A later crosscutting set of steep fractures strikes 050°, but contains only minor mineralization. A trench on the Col showings averaged 2.2 ppm gold and 0.16% copper over a 4-metre interval (Nebocat and Rotherham, 1988).

Garnett (1978) reports a potassium-argon biotite age of 179±5 Ma from medium grained monzonite sampled from drill core on the Col property (new decay constants, R.L. Armstrong, unpublished data). This comparatively young age may reflect resetting by the late-stage Chuchi syenite, of which the syenite dikes are likely offshoots.

CHUCHI HALO (MINFILE 093N 104, SRM)

The eastern tail of the Hogem intrusive suite contains sparse, fracture-controlled chalcopyrite with pink orthoclase, epidote and magnetite, as well as barren orthoclase veins and zones of disseminated iron sulphides. Scattered blebs of chalcopyrite are also present in flows of the Chuchi Lake succession near the margin of the intrusive suite, and chalcedonic quartz breccia veins and small swarms of quartz veinlets contain minor pyrite. These sparse showings are grouped into the Chuchi alteration halo, a weak system with some resemblance to the Col, which similarly lies near the contact between the Hogem intrusive suite and the Takla Group volcanics.

WIT (MINFILE 093N141)

The WIT showing was initially covered by the Wit and Wag claim groups, but due to restaking in the 1980s is now (1993) covered by the Skook claim group. The showing is located on the north shore of Chuchi Lake and is reached by a forest road that joins the Fort St. James - Germansen logging road 5 kilometres north of the Nation River crossing. The main showing is an irregular epithermal vein (5 metres wide by 20 metres vertical extent) of banded white and grey quartz and chalcedony that is exposed in and around a trench. The vein contains small pods and disseminations of galena and sphalerite with possible argentite and tetrahedrite. Gangue minerals include barite and siderite. Banded chalcedony and quartz with calcite, pyrite and trace galena occurs 150 metres east of the main vein outcrop. The host-rocks are maroon and green matrix-supported polymictic breccias and lahars of the Chuchi Lake succession.

Exploration work on the property (Holcapek, 1981; Campbell, 1988) has delineated as estimated geological reserve of 20 000 tonnes grading 7% combined lead-zinc. The surface showing seems to be the top of a larger epithermal system. The best assays that we obtained from the trenched area on the surface contain up to 10.5% zinc, 1.87% lead and 148 grams per tonne silver. Barite lenses and stockworks as well as strongly oxidized and limonitic zones have also been documented by previous workers on the property.

CHIC (MINFILE 093N202)

The Chic showing is located on the Goldfinger claim group approximately 3 kilometres north of the outlet of the Nation River on Chuchi Lake, 2.5 kilometres east of the Wit prospect. The showing is a poddy epithermal vein that cuts a megacrystic feldspar porphyry intrusion, the intrusive equivalent of a nearby megacrystic feldspar porphyry flow of the Chuchi Lake succession. The vein contains light green kaolinite and quartz with abundant blebs of disseminated pyrite and traces of chalcopyrite. It is barely anomalous, geochemically; its significance is to show epithermal potential in addition to the Wit.

TAYLOR-MITZI HALO (TAYLOR, MINFILE 093N 096)

The Taylor-Mitzi alteration halo, located south of Witch Lake, includes the Taylor showing (Figure 3). Disseminated pyrite and pyrrhotite, and silicification, are abundant throughout. The eastern side of the halo disappears under cover. Most of the associated magnetic anomaly is in an area covered by glacial overburden, which was drilled by Noranda Exploration Company, Limited in 1991-1992 (Walker, 1992). This program documented widespread skarn-type and propylitic alteration. The regional airborne scintillometer survey of Shives and Holman (1991) shows a strong potassium response over and east of the Taylor-Mitzi alteration halo. The Taylor showing outcrops in a northeast-flowing tributary of Wittsichica Creek, 3 kilometres south of the outlet of Witch Lake. Diverse alteration assemblages including secondary biotite, chlorite, secondary amphibole, black tourmaline, garnet skarn and white bleaching are intermixed in an outcrop less than 20 metres long. Up to 10% pyrrhotite occurs with fine-grained pyrite and chalcopyrite. Values of 1.59% copper and 4.93 grammes per tonne gold have been obtained from grab samples (Roney and Maxwell, 1989).

TAS HALO (Tas East Zone, MINFILE 093K 080; FREE GOLD ZONE (MINFILE 093K 091)

The Tas alteration halo is developed in fine-grained, hornfelsed Inzana Lake sedimentary rocks near the northern contact of a large, poorly exposed, composite, coarse grained intrusive body, the Tas pluton. Country rocks were intruded by large-hornblende phyric andesite dikes, followed by crowded porphyritic monzonite and diorite, dated at 204.2 ±9 Ma by U-Pb zircon method (Appendix 7). The Tas (East zone) is located on a small hill just north of the Germansen-Inzana forest road, approximately 10 kilometres from its junction with the Fort St. James - Germansen logging road (Photo 35). Semi-massive sulphide pods occur in steeply dipping, north-trending shear zones 10 to 20 centimetres wide. On surface these zones contain up to 70% sulphides: mainly pyrite and pyrrhotite with minor chalcopyrite and marcasite(?). The Free Gold zone is located on the Tas claims on the main Germansen-Inzana forest road, 2 kilometres southwest of the East zone. A small zone of intense quartz-carbonate alteration is exposed in a quarry. Up to 10% pyrite with traces of magnetite and malachite and rare native gold occur in the rock. Propylitized coarse-grained hornblende diorite with sporadic potassium feldspar veins and traces of malachite on fractures outcrop near the showing. Elsewhere, mineralization consists of minor amounts (<2%) of disseminated pyrite and pyrrhotite. The hornblende porphyry forms intrusive breccias with xenoliths of sediments and hornblendite. At one locality on the ridge west of the East zone, a diatreme containing milled fragments of tuffs, hornblende porphyry and monzodiorite appears to grade into a hydrothermal breccia containing matrix quartz and fine-grained massive actinolite.

Photo 35. Tas property, East zone.

If the age of the crowded porphyritic monzonite/diorite is the age of this system, then it is coeval with many of the major porphyry systems of Quesnellia and Stikinia, which concentrate at about the Triassic/Jurassic boundary (Mortensen *et al.*, 1995).

MAX HALO (MAX, MINFILE 093K 020, LYNX, MINFILE 093K 083, K-2 MINFILE 093K 086)

The Max claims are located east of the Fort St. James - Germansen logging road near Cripple Lake; approximately 14 kilometres east of the Tas property and 22 kilometres south of the Mt. Milligan deposit . The property covers an extensive area of propylitic alteration and sporadic mineralization that is associated with a complex polyphase intrusive body. The location of the Max prospect recorded in MINFILE is in the approximate centre of the alteration zone. The Lynx showing south of Cripple Creek is a large area (approximately 2 by 1 km) of bleached, silicified and mineralized rocks. This alteration zone, although separated by overburden from the main system, may also form part of it.

The intrusive suite includes texturally variable monzonite, diorites and monzodiorites. Hornblendite and aplite dikes have also been mapped on the property. In one locality hornblendite apparently grades into amygdaloidal extrusive equivalents. Similar hornblendite dikes have been documented on the Tas property. Propylitic alteration is extensive in the intrusive rocks, and secondary epidote and chlorite are abundant. Minor potassic alteration also occurs. The intrusions contain up to 20% pyrite in places, but average sulphide contents are closer to 3%.

The intrusions cut heterolithic augite±plagioclase porphyry flows and agglomerates, black siliceous argillite and volcanic siltstones and sandstones of the Witch Lake succession. The sediments are intensely hornfelsed with abundant secondary biotite; the volcanic rocks are strongly epidotized. Up to 30% pyrite occurs in these hostrocks. Minor disseminated pyrrhotite is found with chlorite in veinlets. Chalcopyrite and magnetite have also been identified.

The main part of the Lynx showing is in a trench adjacent to the Germansen-Cripple logging road. A 3-metre square sulphide-rich oxidized zone occurs within light green, silicified and brecciated ash and dust tuffs of the Inzana Lake succession. The zone contains up to 30% massive and crystalline pyrite, up to 5% chalcopyrite and minor malachite. The rocks have a well-developed network of hairline fractures with alteration envelopes along them. Both propylitic and potassic alteration are present. The rocks are strongly hornfelsed and contain abundant secondary biotite; however, no intrusive rocks have been identified on the property. Adjacent to the gossan a northwest-trending, steeply dipping fault contains a 30-centimetre gouge zone that hosts quartz but no sulphides.

Stratigraphically above the main showing (approximately 1.25 kilometres to the west-northwest), tuffaceous siltstones and minor lapilli tuffs are sporadically altered to skarn. Biotite and diopside hornfelsing are widespread for several hundred metres. One zoned garnet-epidote-diopside-biotite skarn contains concentrations of massive pyrrhotite (50-70%) with minor flecks of chalcopyrite and possibly covellite. The metatuffs are interbedded with intermediate plagioclase±augite±hornblende porphyry flows and/or sills. They contain disseminated pyrite and abundant epidote in streaky veins.

The K-2 showing is located near the western boundary of the Max claims, approximately 3 kilometres north-northeast of Cripple Lake. The showing is a hydrothermally brecciated quartz-carbonate vein exposed over a width of two metres as a subcrop zone. The vein trends south-southeast over 50 metres and is hosted by clinopyroxene-rich flows and agglomerates of the Witch Lake succession. It contains up to 30% chalcopyrite with minor malachite and specular hematite, and fragments of bleached and milled wallrock.

DEM HALO (MINFILE 093K 077)

The Dem halo is characterized by hornfelsing, abundant disseminated pyrite, hairline magnetite veinlets and local strong alteration of the Slate Creek sequence near Dem Lake. Well-laminated sandstones and siltstones are intruded, hornfelsed and altered by syenomonzonite dikes. Areally extensive alteration ranges from local massive epidote - tremolite skarning to biotite-diopside hornfelsing. Small sulphide-bearing veins and pods occur within the halo. The main showing is a pod-shaped subcrop exposure (20 centimetres by 1 metre) of brecciated quartz vein. The vein contains between 5 and 10% arsenopyrite that forms in clumps with epidote and tremolite. A grab sample of this vein assayed 361 ppb gold, 2.11% arsenic and 66 ppm antimony. Approximately 500 metres south of the arsenopyrite quartz breccia vein, another massive skarn pod (0.5 metre wide) occurs within the sediments close to syenomonzonite dikes. Skarn mineralization consists of pyrite and pyrrhotite with secondary biotite and actinolite veinlets. A grab sample assayed 204 ppb gold and 41 ppm copper.

KBE (MINFILE 093N 203)

The small, isolated KBE showing is located approximately 10 kilometres north-northeast of the east end of Inzana Lake and 5 kilometres southeast of Mudzenchoot Lake. Less than 1% disseminated malachite occurs in a bleached and slightly gossanous hornblende granite or granodiorite intrusion in the Inzana Lake succession. No visible pyrite or other sulphides are associated with the malachite. A grab sample from this showing returned an analysis of 196 ppb gold and 0.2% copper. Minor amounts of epidote and magnetite occur in the granite within 100 metres of the showing.

HA1 (MINFILE 093K 004)

The HA1 showing is located on the HA1 claim near Taslinchecko Creek, approximately 5.5 kilometres south of the Tas property. The showing consists of 5% pyrite and less than 1% chalcopyrite disseminated in siliceous black argillite of the Inzana Lake succession. Quartz±carbonate stringers are abundant, some containing minor pyrite. Heavily hematite-coated fractures cut in silicified sediments in a trench exposure.

Drilling on the property has shown the presence of subsurface diorite and gabbro intrusions on the HA1 claim. Fine to coarse-grained gabbro with 20 to 25% hornblende phenocrysts contains 2 to 3% pyrite and pyrrhotite. Fine to medium-grained, equigranular to weakly porphyritic diorite contains less than 1% pyrite. Hornfelsed sediments contain 2 to 5% disseminated pyrite and quartz-carbonate altered zones contain 5 to 10% (Maxwell, 1987).

HAT LAKE (MINFILE 093K 084)

The Hat Lake showing is located on the Hat Lake claim group 1.5 kilometres south of Hat Lake on the Germansen - Hat logging road. Bedrock is best exposed along road cuts and in trenches. Silicified, hornfelsed and fractured black argillite, cherty tuffs and green sandstone of the Inzana Lake succession contain disseminated pyrite. The sediments are cut by texturally highly variable gabbro and diorite intrusions, gabbro pegmatite and intrusion breccias. These mafic intrusive phases appear very similar to those that form xenoliths in crowded porphyritic diorite on the Tas property. A trench exposes a plagioclase-augite-hornblende diorite dike that contains 10% pyrrhotite. Pale quartz carbonate alteration and a shear zone were also noted at the showing. Several gold and silver soil geochemical anomalies have been outlined on the property. One coincides with a 1 metre wide quartz-carbonate stockwork that contains minor sulphides - up to 5% pyrite and pyrrhotite with traces of chalcopyrite (Schmidt, 1987).

OTHER MINERAL OCCURRENCES

TAKLA-RAINBOW (MINFILE 093N 082)

The Takla-Rainbow prospect lies at the headwaters of Twin Creek, west of the headwaters of Kwanika Creek. This area was explored by various companies in the early 1970s. The Twin claims were staked in 1981 by L. Warren and N. Scarfe. Imperial Metals Corporation optioned the claims in 1985 and explored them until 1989, identifying a significant zone of gold mineralization with associated copper and zinc on the West grid, referred to here as the Main zone. This zone is centred on the west-northwest trending Twin Creek fault (Figure 3). The presence of abundant orthoclase-megacrystic granite dikes within the fault zone, many of them sheared, suggests synplutonic, probably Cretaceous, motion. Sulphides occur as disseminations in silicified, chloritized Takla Group and dikes within anastomosing shears of the Twin Creek fault zone. There are two other zones of alteration. The Red zone lies 1.2 kilometres northwest of the Main zone. It is an area of bleached tourmaline-matrix breccia developed in diorite of the Hogem intrusive suite. Eastfield Resources Limited drilled this zone in 1990. Bailey (1991) reports low gold and copper values, propylitic alteration and disseminated sulphides that are suggestive of a porphyry-style system. The ridge south of the Twin Creek fault is underlain by a strong quartz-kaolinite-pyrite alteration zone, capped by a discontinuous horizontal sericite-quartz zone up to 5 metres thick that extends over 500 metres. It offers an as-yet unexplored epithermal target.

GROUNDHOG (MINFILE 093N 212)

The Groundhog MINFILE locality is situated on a creek cut by the Tsayta - Germansen Lake road at Groundhog Pass, approximately 2 kilometres south of the confluence of Groundhog Creek and Twin Creek. A multi-element stream sediment anomaly was identified at the mouth of this creek during a Regional Geochemical Survey (RGS) in 1983. Follow-up assessment work by B.P. Resources Canada Limited in 1984 failed to locate the source of the anomaly (Humphreys, 1984). Fresh, maroon, amygdaloidal, plagioclase-porphyritic basaltic andesites in the Groundhog Pass area belong to the lower part of the Jurassic Twin Creek succession. Amygdules up to 1 centimetre in diameter are filled with massive magnetite. A grab sample from an amygdaloidal flow assayed 890 ppm copper, 100 ppm zinc and 12 ppm lead. The magnetite amygdules are the probable source of the RGS anomaly. Minor malachite was noted on a fracture surface.

VALL (MINFILE 093N 213)

The Vall showing is exposed along the northeast bank of Valleau Creek approximately 5.5 kilometres from its confluence with the Klawli River. It is a skarn 20 centimetres wide with an attitude 000/78E, associated with a small, irregular carbonate vein system. A grab sample from the showing assayed 130 ppb gold and 176 ppm copper. The occurrence is hosted by hornfelsed coarse augite and minor plagioclase porphyritic basalts of the Jurassic Chuchi Lake succession adjacent to the Valleau Creek intrusive suite.

TSAY (MINFILE 093N 214)

The Tsay occurrence is hosted by a northwest-trending fault structure that extends 10 kilometres from the west end of Tsaydaychi Lake to the headwaters of Valleau Creek. The fault zone, 1.5 to 2 kilometres wide, lies entirely within the Inzana Lake succession and is characterized by iron carbonate and quartz-sericite alteration. Disseminated green mica (mariposite?) and pyrite occur in intensely altered, pale buff coloured, foliated sediments. A grab sample returned 135 ppm arsenic and 98 ppm copper. The presence of anomalous arsenic values with carbonate-quartz-sericite alteration and mariposite suggests a listwanite association. The fault structure has potential for hosting gold-bearing quartz veins, and is thus an interesting regional exploration target.

WUDTSI (MINFILE 093N 215)

At the headwaters of Valleau Creek, approximately 5 kilometres north of the south end of Wudtsi Lake, a small, hybrid stock intrudes the Inzana Lake succession. The intrusive is a varitextured diorite-gabbro body. A hornfelsed mesocratic hornblende diorite phase contains pyrrhotite-bearing quartz stringers that yielded analyses of 190 ppm copper. Epiclastic sandstone and siltstone hosts are hornfelsed and altered (potassic?) and contain disseminated pyrite.

KLAWLI (MINFILE 093N 032)

The Klawli showing, located east of the Klawli River, is hosted by plagioclase±hornblende porphyritic volcanics of the Chuchi Lake succession. In creek bank trenches near old adits the volcanics are bleached and altered with zones containing pyrite, chalcopyrite, malachite and azurite. Although the rocks appear sheared and fractured, discrete shear zones and fabrics were not recognized. Three grab samples assayed greater than 2% copper, 102.8 grams per tonne silver and 2.6 grams per tonne gold (Shaede, 1984).

GERTIE (MINFILE 093N 210)

The Gertie copper showings, located approximately 5 kilometres south of Klawli Lake, are hosted by volcanic flows of the Lower Jurassic Chuchi Lake succession. The showings consist of two large outcrops spaced roughly 1 kilometre apart. The eastern outcrop is of brecciated green, grey and maroon crystal-lapilli tuff, which contains disseminated malachite, chalcocite and tetrahedrite. A grab sample from this outcrop yielded 1.08% copper and 17.5 grams per tonne silver. In the western outcrop, 1.2 kilometres southwest, an amygdaloidal, maroon and grey, plagioclase-phyric latite flow hosts disseminated and fracture controlled malachite and minor azurite. Native copper blebs, 1 by 2 centimetres in size, are associated with carbonate and jasper in open-space fillings and occur within a highly amygdaloidal part of the same flow package. An assay on a single grab sample from this locality returned 0.2% copper. A brecciated zone in a more greenish and aphanitic area of the outcrop contains minor chalcopyrite and has areas of bleaching and hairline fractures with chlorite envelopes. Multidirectional vuggy quartz veinlets with sporadic malachite are also present. An altered and bleached intrusive body outcrops 150 metres to the south. It contains a crackle breccia that grades into a matrix-supported breccia with milled fragments of intrusive floating in a hematite-rich matrix; no sulphides are visible at this locality. Two zones of strong propylitic alteration (epidote, chlorite) 1-metre wide cut the outcrop and contain disseminated malachite. Stratigraphically, the Gertie showing is located near the top of a maroon flow package that is overlain by massive and monotonous green-grey heterolithic agglomerates. The beds strike 070° and dip gently to the south. The regional attitude of bedding suggests that the two outcrops are roughly along strike. The open-space nature of the mineralization is consistent with a flow-top hosted copper occurrence. This showing resembles several other native copper occurrences in the Takla Group such as the Sustut Copper deposit in north-central British Columbia and showings in the Hydraulic map area near Quesnel(Church, 1975; Monger, 1977; Bailey, 1987). Similar copper-silver-bearing pods occur in amygdaloidal and brecciated flow tops in the Telkwa Formation (MacIntyre and Desjardins, 1988; D.G. MacIntyre, personal communication, 1991).

MITZI (MINFILE 093N204)

The Mitzi showing is located on the Phil claim group 1 kilometre north-northeast of the east end on Mitzi Lake and 4.5 kilometres northwest of the Mt. Milligan deposit. The showing is a tetrahedrite-chalcopyrite-bearing quartz-ankerite breccia vein hosted by hornfelsed augite porphyry agglomerate of the Witch Lake succession. The 20-centimetre, northwest-striking vein contains up to 5% tetrahedrite with minor chalcopyrite. Alteration in the metavolcanics includes massive garnet and biotite. Prominent red-weathering zones occur within 500 metres of the vein, but contain no visible sulphides.

RAINBOW CREEK (MINFILE 093N205)

The Rainbow Creek showing is located on the Rain claims along a north flowing tributary of Rainbow Creek, about 15 kilometres south of the Mt. Milligan deposit. A strong base metal geochemical anomaly occurs at the creek confluence. The following values have been identified by Regional Geochemical Survey (RGS) stream sediment sample collected near the mouth of the tributary: 21.5 ppm arsenic, 9.4 ppm antimony and 128 ppm zinc .

A grey to black fault breccia with quartz and carbonate veining and up to 20 % pyrite outcrops on the banks of the tributary. The fault zone cuts through augite porphyry agglomerates and white-weathering tuffaceous black siltstone and mudstone of the Witch Lake succession. Gossanous zones contain 3% disseminated pyrite with magnesite and traces of fuchsite. A few discontinuous chalcedony veins cut the pyritic breccia. The fault breccia itself is geochemically flat escept for one sample that contains 140 ppm copper, but a grab sample of one of the veins returned an anomalous analysis of 1400 ppb gold and 180 ppm arsenic.

CHAPTER 6
SUMMARY AND CONCLUSIONS

CONTRIBUTIONS OF THIS STUDY TO THE HISTORY OF QUESNELLIA

The Lay Range assemblage contains the oldest rocks in Quesnellia. Although regionally the Lay Range assemblage is considered to form the basement of the Quesnel arc (Monger *et al.*, 1990), throughout central Quesnellia it is separated from the Takla Group by major strike-slip faults. This study has made two contributions to the stratigraphy of the Lay Range assemblage. An early Mississippian (Visean?) conodont identification by M.J. Orchard from a mixed package of plagioclase-phyric lapilli tuffs, andesite flows and clastic sedimentary rocks exposed near the Omineca River makes it the oldest known lithostratigraphic element in the assemblage. These rocks attest to volcanic arc activity nearly as old as the oldest known basaltic volcanism in the Slide Mountain Terrane, at the Devonian-Mississippian boundary (Harms, 1986; Nelson and Bradford, 1993). The Slide Mountain Terrane has been modelled by several authors as a marginal basin that opened behind the developing Lay Range - Harper Ranch arc (Rees, 1988; Nelson, 1993; Roback, and Walker, 1995). This evidence for approximate coeval initiation supports that model. At the younger end of Lay Range history, an upper Pennsylvanian-Lower Permian radiolarian collection in chert (identified by F. Cordey) dates the top of an epiclastic sequence of mixed mafic to intermediate derivation, which is succeeded gradationally by a thick sequence of augite±olivine±plagioclase-phyric, primitive arc basalts. The basalts, which outcrop extensively north of the Omineca River and east of Discovery Creek, were previously included in the Takla Group. Their reassignment to the Lay Range assemblage shows that it represents arc-axis, as well as epiclastic, off-arc environments (*c.f.* Monger *et al.*, 1990).

The main contribution of this project has been to meaningfully subdivide the the Takla Group, which previously was undifferentiated in the Nation Lakes area (see Armstrong, 1948). Some of the new units are adapted from the concomitant, adjoining work of Ferri and his colleagues; others are apparently restricted to the Nation Lakes project area. Overall, they depict initial basinal sedimentation that evolved in late Carnian time into dominantly augite-phyric basaltic, explosive volcanism in the Norian. Coarse, vent-proximal deposits occur as discrete units, surrounded by finer pyroclastic and epiclastic deposits. The oldest basinal sedimentation corresponds to the lower part of the Slate Creek succession. Basaltic centres are preserved in the Plughat Mountain and Witch Lake successions. Dominantly epiclastic units, in part older than the basalts, are the upper part of the Slate Creek succession, the Inzana Lake succession and the Willy George succession.

The presence of Early Jurassic, pre-early and post-late Pliensbachian volcanism was established in the course of this study, based on ammonite identifications by Howard Tipper. The ammonites were collected from a clastic horizon within a highly varied sequence of intermediate and mafic, plagioclase and augite-phyric pyroclastic rocks and flows, designated the Chuchi Lake succession. The Chuchi Lake succession is excluded from the Takla Group in the interest of restricting that name to Upper Triassic rocks, as in the well-known McConnell Creek area (Monger and Church, 1977). The Twin Creek succession consists of similar but slightly older - Sinemurian - rocks, which are separated in outcrop from the Chuchi Lake succession by a 10-kilometre intrusive interval. The Twin Creek succession has a well-defined basal unconformity on Upper Triassic basalt at the top of the Plughat Mountain succession, first observed by Dave Bailey in 1990, and documented during this project (Bailey *et al.*, 1993). The plagioclase-phyric Lower Jurassic volcanic rocks show close textural and compositional affinity to the hypabyssal porphyritic monzonites that core the Mt. Milligan and BP-Chuchi porphyry deposits. The main episode of porphyry-style mineralization was related to the Early Jurassic, post-Takla arc, although the earliest Jurassic (*circa* 205 Ma) ages of porphyry stocks, such as Tas, suggests that some late-stage Takla magmas may have been involved as well. By this time the crust had been thickened enough that terrestrial environments could develop; and a sufficient crustal density filter created large, long-lived magma chambers in which extensive differentiation and consequent evolution of volatiles could occur.

Fossil and radiometric ages from units younger than the Quesnel arc constrain the later structural history of the terrane. Latest Toarcian ammonites, identified by Giselle Jacobs (Appendix 3b), occur in greywackes that contain immature debris from syenite or monzonite of the Hogem intrusive suite. These sediments record rapid initial uplift and erosion of the Early Jurassic intrusions: K-Ar hornblende ages as young as 171 Ma show cooling of Hogem intrusions into Bajocian time. On the time scale of Harland *et al.* (1990), the latest Toarcian greywackes are 180 to 178 Ma old. Although the errors for both individual K-Ar ages and picks for the absolute ages of faunal zone boundaries are too broad to permit a definitive conclusion, it appears that the late Toarcian greywackes were eroded from the batholith while other phases were still cooling. Nixon's (1993) new U-Pb zircon data on synplutonic fabrics in the Polaris ultramafite supports the beginning of eastward tectonic transport of Quesnellia at 186 Ma (equivalent to late Pliensbachian; G. Johannsen, personal communication, 1993). Uplift of the Hogem batholith may be a direct consequence of that event.

The timing, sense and amount of displacement on Cordilleran transcurrent faults are key issues in tectonic reconstruction. In the Nation Lakes area, coarse to fine-grained clastic sedimentary rocks, in some cases accompanied by rhyolite or basalt, form distinct packages in isolated grabens associated with strike-slip faults, including the Discovery Creek and Great Eastern faults as well as an unnamed fault west of Mount Milligan. Two early Tertiary fossil ages and one Eocene K-Ar biotite age (48.2 Ma) from these units provide older limits on major motion on the graben-bounding faults, and by inference on the fault system as a whole. These ages agree with determinations by Ferri (Ferri and Melville, 1994) and Struik (1989; 1993) for other faults in the Manson-McLeod system. Dextral slip indicators were observed within the Discovery Creek fault system and west of Mount Milligan.

TECTONIC IMPLICATIONS OF THE SHOSHONITE ASSOCIATION FOR THE EARLY MESOZOIC QUESNEL ARC

New petrologic and geochemical data show that the Takla Group and overlying Chuchi Lake succession and associated intrusive bodies in the Nation Lakes area are of calc-alkaline to mildly alkaline, shoshonitic affinity. This tendency to unusually high concentrations of potassium group elements characterizes Triassic and Jurassic volcanic suites in much of the Quesnel arc. Shoshonite associations have been noted for the Nicola Group by Mortimer (1987), the Rossland Group by Beddoe-Stephens and Lambert (1981) and in the Quesnel area by Panteleyev *et al.* (1996). The spatial extent of this atypical arc volcanic suite in Quesnellia is remarkable, spanning over 500 kilometres of strike length.

The unique chemical signature of shoshonites, and their rarity in island arcs, are the result of unusual magmatic processes and/or unusual chemical composition in the magmatic source regions. These may also be linked to tectonic peculiarities in the subduction regime. In common with other alkalic suites, for instance the continental ultrapotassic suite, the genesis of shoshonites has been ascribed to the melting of mantle that has been enriched in selected elements by metasomatism (Roden and Murthy, 1985; Foley *et al.*, 1987; Box and Flower, 1989). Metasomatism has also been implicated in island arc magmatism generally. Fluids and small partial melts from the down-going slab are thought to modify the overlying mantle wedge, before it melts to produce arc basalts and andesites (Ringwood, 1977, Wyllie, 1982, Saunders *et al.*, 1980, Tatsumi, 1989, 1990). Shoshonites may be the product of an unusual variant or degree of arc metasomatism, possibly enhanced by anomalous tectonic processes. Their prevalence in the Quesnel arc may thus provide a clue that can be used to infer its tectonic setting, by analogy with appropriate examples in young arc igneous suites.

Such comparisons must be done with a careful view of the important characteristics of the Quesnel shoshonite suite. The following points should be recalled:

1. Potassium-enriched rocks occur among the oldest and also the youngest Quesnel arc volcanic sequences, ranging in age from late Carnian to late Pliensbachian, a time span of some 36 million years. Shoshonitic magmatism thus spanned the entire history of the Quesnel arc; it was not "late" in arc evolution, unless the Lay Range arc is also considered as part of the arc cycle.

2. Although potassium-enriched rocks are restricted to a belt east of calc-alkaline rocks in southern Quesnellia (Mortimer, 1987), in central Quesnellia they occur throughout the width of the terrane, as far west as the Pinchi fault (Panteleyev *et al.*, 1996; and this study). It is thus likely that they were erupted at the Early Mesozoic arc front. The suggestion of Mortimer (1987) that the easterly increase of potassium in the Nicola Group corresponds to increasing depth to the paleo-Benioff zone does not obviously apply north of 51° north, about the latitude of Kamloops (Figures 24, 28).

3. Strontium isotopic data from the Nicola and Rossland Groups (Preto *et al.*, 1979; Beddoe-Stephens and Lambert, 1981) show that the elevation in potassium group elements is not accompanied by an increase in initial radiogenic strontium, which at .7030-.7047 is within the normal intraoceanic arc field. Similarily, εNd values of +5.0 to +7.9 from the Nicola Group (Smith *et al.*, 1995) and +2.7 to +7.9 from associated alkalic intrusive suites of Quesnellia and Stikinia (Lang *et al.*, 1995) show no evidence of continental influence (Table 4). The Quesnel arc was a primitive, intraoceanic magmatic arc. It was built on the Lay Range arc, which is also primitive in its chemistry. Scraps of attenuated continental basement are inferred to underlie the Lay Range assemblage, based on quartzite clasts in Pennsylvanian-Permian lapilli tuffs and Precambrian inheritance in some Early Mesozoic igneous zircon populations. However these had little effect on the overall chemistry of Early Mesozoic magmas.

Some modern shoshonite suites, because of their very radiogenic initial strontium and unradiogenic neodymium, are probably melts of subcontinental lithosphere, which has undergone an ancient metasomatic event (Varne, 1985; Ellam *et al.*, 1989). In these cases, eruption of shoshonites may well be incidental to arc tectonics, and only reflect anomalous mantle below the arc. Shoshonite suites within continental settings are suspect for the same reason, even if isotopic data are not available. This criterion disqualifies the Sunda-Banda arc, the Roman region, Greece, the Papua New Guinea Highlands, and the western United States as appropriate analogues to the Quesnel arc.

Some alkalic suites in intra-oceanic, isotopically primitive arcs are nonetheless not shoshonitic. They are characterised by K_2O: Na_2O ratios less than 0.6 and K_2O less than 1.8% at 50% SiO_2; while enhancements of high field-strength elements such as niobium and zirconium show a departure from pure arc character. Pearce (1982) infers an alkaline, intraplate contribution in the genesis of these sodic-alkalic arc basalts. They typically occur in small areas surrounding cross-arc fractures or hinge faults (Delong *et al.*, 1975), unlike the widespread shoshonites of Quesnellia. In Chapter 3, basalts from Grenada and Ambittle Island in the Tabar-Feni chain were shown to be chemically very dissimilar to the Nation Lakes suite and other Takla and Nicola basalts, particularily in their high Nb/Y and Zr/Y ratios.

Application of the these two filters to the list of Late Tertiary to Recent shoshonitic suites in Table 6 leaves an extremely short list of close analogues: Fiji (Gill and Whelan, 1989); Lihir (Kennedy *et al.*, 1989) the Marianas (Bloomer *et al.*, 1989, Lin *et al.*, 1989), and possibly Ambrym on the New Hebrides. The shoshonites on Fiji and Lihir are associated with deep fracture zones in older arc crust. In both cases, arc polarity has reversed and the remnant arc region is being dismembered. Lihir lies within the Tabar-Feni chain, controlled by a profound linear in the back-arc region of the New Britain arc, an earlier fore-arc (Kennedy *et al.*, 1989). Ambittle, with its sodic, strongly alkalic basalts is situated in this same chain. Fiji provides an interesting analogue in that the shoshonites there occur along well-defined linears with strong magnetic expressions, while contemporary calc-alkaline and tholeiitic centres are scattered randomly between the linears (Gill and Whelan, 1989). The common coexistence of subalkalic and alkalic volcanic rocks in the Quesnel arc may be the expression of such an eruptive pattern. Indeed coeval and cospatial alkalic and subalkalic intrusions occur at, for instance, Mt. Polley, showing that magmas from different sources even rose through the same conduits.

In contrast to Fiji and the Tabar-Feni chain, shoshonites in the northern Marianas form the arc front (Bloomer *et al.*, 1989). They occur immediately north of where the Mariana trough, an inferred locus of backarc spreading, impinges on the arc front (Stern *et al.*, 1988). Müller and Groves (1993) discount initial oceanic arcs such as the Marianas as hosts of gold-copper mineralization, based on the lack of known occurrences. This assessment may be correct, although it may be partly an artifact of the preponderance of seamounts - intractable exploration targets - in the shoshonite-dominated northern Mariana chain.

Some of the obvious plate-tectonic attributes of Fiji and Tabar-Feni create confusion if applied literally to the Quesnel arc. Morrison (1980) generalized the shoshonite association as late in arc history and located over the deepest part of subducting slabs, particularly over failing and flipping subduction zones. Spence (1985) used these ideas to relate Quesnel arc volcanism to terrane collision and accretion. This interpretation was made prior to the accumulation of precise data on the relative timing of arc volcanism and terrane amalgamation. Shoshonitic volcanism occurred in Quesnellia over a long period of time when it was a consistently west-facing volcanic arc, long prior to late Early Jurassic accretionary events (Nixon, 1993, Murphy *et al.*, in press; Ricketts, *et al.*, 1992). In north-central Quesnellia, shoshonitic volcanism extended to the Late Triassic magmatic front, as in the Marianas, and began when the arc began. Moreover, there is absolutely no geologic evidence for westerly subduction under Quesnellia within the Late Triassic to Early Jurassic interval during which the Quesnel arc formed, and thus no independant support for a polarity reversal.

The modern analogues nevertheless do offer insights into the Quesnel arc. Shoshonitic suites on Fiji and Lihir are the result of structurally controlled magma genesis, within mantle that was previously modified by supra-subduction zone processes. The Quesnel arc developed, at least partially, on top of the older, subalkaline Lay Range arc. Perhaps the crucial "ground preparation" of repeated metasomatic events occurred during the late Paleozoic, as the Harper-Ranch-Lay Range arc developed. In the Late Permian to Early Triassic, the older arc and its underlying mantle were tectonically disturbed, and a new subduction zone was initiated, near but not identical to the previous one.

Further tectonism occurred between Norian and Sinemurian time, as shown by the Triassic-Jurassic unconformity. The eastern Cache Creek Terrane between Quesnel and Takla Landing includes blueschists with Late Triassic cooling ages, and Upper Triassic, arc derived sedimentary rocks (Paterson, 1977). It is intruded by the 217 Ma Granite Mountain pluton (Bysouth *et al.*, 1995), which hosts the Gibraltar porphyry copper deposit. These relationships suggest that the eastern part of the Cache Creek Terrane may have been accreted to the Quesnel fore-arc near the Triassic-Jurassic boundary, while open ocean persisted to the west until mid-Jurassic time, as shown by the continued deposition of cherts and hemipelagic sediments in more westerly parts of the Cache Creek Terrane.

Strong structural control, analogous to the Fiji linears, is supported locally by the tabular shapes of intrusions like the Hogem and Valleau Creek intrusive suites, and throughout Quesnellia by the remarkable linear arrays of alkalic porphyry intrusions in the central Nicola belt (Preto, 1979) and near Quesnel (Bailey 1987; Pantaleyev *et al.*1996); (Figure 28). In both Quesnellia and Stikinia, long-lived Early Mesozoic arcs are superimposed on Paleozoic arcs. They should be regarded, not as "late" arcs, but as second or even third-cycle arcs. However the same favorability for copper-gold mineralization that Müller and Groves (1993) note for "late" arcs also applies. The generation of shoshonitic magmas in them is due, as in "late" arcs, to a long prior history of mantle metasomatism. Like crustal metasomatism, it is likely that this process would be more thorough along deeply-penetrating sub-arc structures. Thus the repeated correlation in Quesnellia and Stikinia of productive alkalic porphyry deposits with faults and linears may have a partly petrologic basis, in addition to the advantage that deep structures offer for channelling small, differentiating melts.

MINERAL POTENTIAL OF NORTHERN QUESNELLIA

The Nation Lakes area is the locus of a major porphyry copper-gold camp, including one large, although presently subeconomic deposit, Mt. Milligan, and one other deposit with significant reserves, BP-Chuchi. Numerous large alteration zones have been outlined in the course of this project, that expand the size and potential of the Nation Lakes porphyry camp. Given favourable gold and copper prices, further discoveries are likely, both inside the known alteration zones and outside of them, of new, overburden-covered systems. The extent of glacial cover will require the use of careful surficial geology and geochemical studies, geophys-

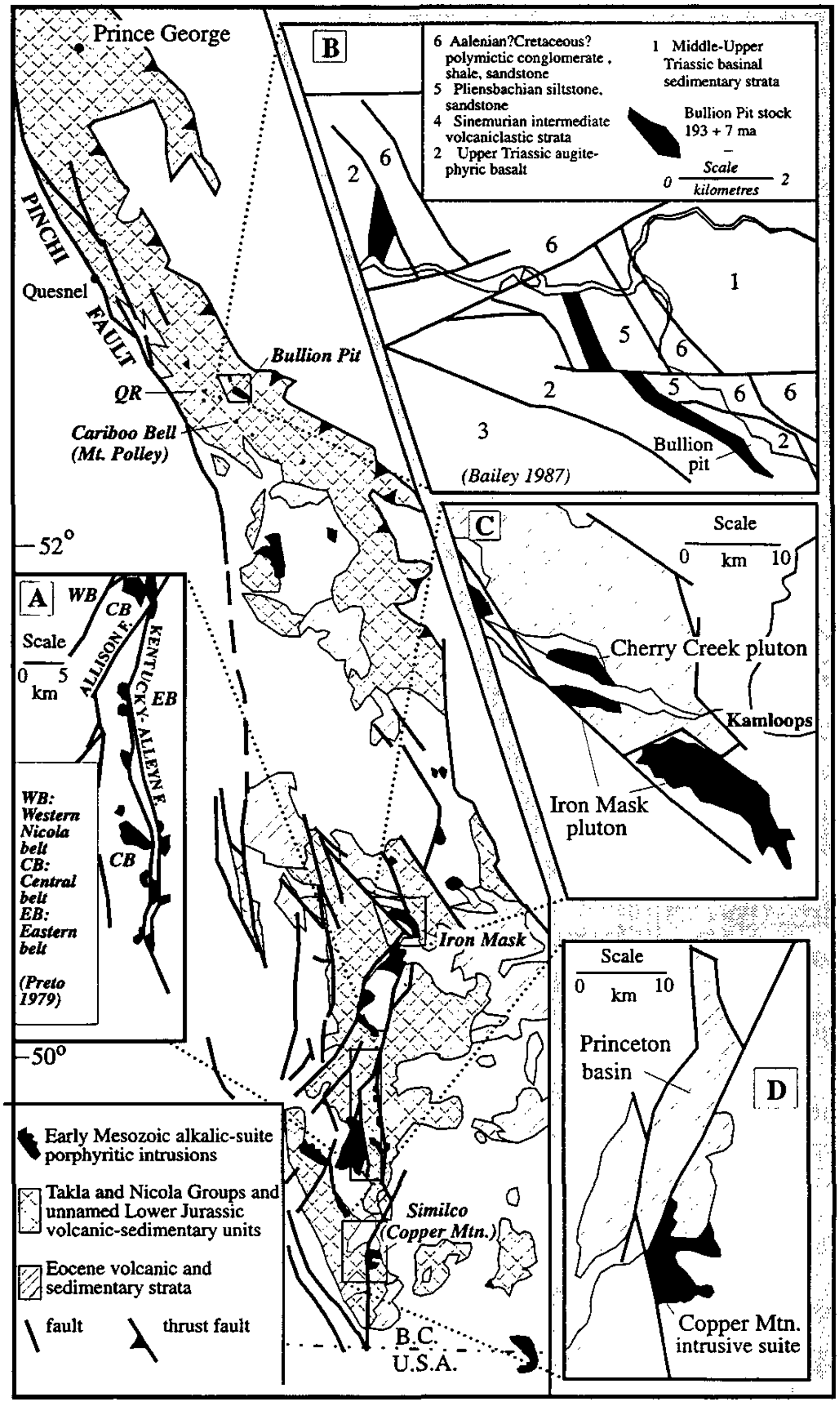

Figure 28. Relationship of alkalic suite porphyry deposits of Quesnellia to major structures.

ics and, in the end, faith to find them. The very recent progression of Mt. Milligan from new showing to new prospect to major resource demonstrates that such opportunities are still there to be found.

The Nation Lakes porphyry camp is a coherent cluster of alteration haloes, radiating south and east from the southeastern tail of the Hogem intrusive suite. Outside of this cluster, the characteristic features of porphyry systems, i.e. crowded porphyritic monzonite, diorite or syenite, spotty brown and green biotite hornfels with disseminated pyrite and magnetite, propylitic and potassic alteration, are rare and minute in extent. The first typical alkalic, high-level porphyry system north of Aplite Creek is the Cat property (MINFILE 094C 069), located 7 kilometres north of the Nation Lakes project area in the Osilinka River watershed. The southern limit of the Nation Lakes porphyry camp was not encountered, and new discoveries could be made in the outcrop-poor areas south of Dem Lake and southeast of the Max. The alkalic porphyry copper-gold deposits of Quesnellia, however, are not spotted randomly throughout the terrane, but rather concentrate in major camps. The trend from Copper Mountain to the Iron Mask batholith (Preto, 1979), the Quesnel porphyry belt, including Mt. Polley and QR, and the Nation Lakes camp are examples of this clustered distribution (Figure 28).

What focuses these deposits? Perhaps the general answer is outlined in the previous section, that discrete, deep structures controlled the volcanic centres. This strong structural control is seen best in the distribution of alkalic-suite porphyritic intrusions of Quesnellia. Like the Nation Lakes porphyry camp described above and shown in Figures 3 and 25, the Copper Mountain-Iron Mask and Quesnel porphyry camps consist of linear arrays of alkalic intrusions, trending north-south in the central Nicola belt and northwesterly near Quesnel (Figure 28). In the central Nicola belt, the intrusions lie along a narrow belt associated with the Allison, Kentucky-Alleyne and Quilchena faults. Near Quesnel, most small intrusions occur at roughly 11 kilometre intervals along the central axis of Quesnellia, associated with Sinemurian volcanic rocks (Pantaleyev *et al.*,1996). The sole exception is the Bullion Pit stock, a northwesterly-elongate body that intrudes both Upper Triassic basalts and Pliensbachian clastic sedimentary strata, which occupy a northwesterly-trending fault-bounded basin (Inset B on Figure 28). The coincidence and parallelism of the stock and local structures suggest they were interlinked. The western contact of the Pliensbachian unit is now a thrust fault (Pantaleyev *et al.* 1996). However it may have been a reactivated arc-parallel normal fault. Structural control on a local scale is also important in southern Quesnellia. Both Copper Mountain and Iron Mask intrusions (Insets C and D on Figure 28) occur next to faults that bound Tertiary grabens - faults that may be reactivated Early Mesozoic features (V. Preto, personal communication 1990). These local settings are similar to that of the Mt. Milligan deposit, which is fault-bounded to the east along the Great Eastern fault against Early Tertiary strata. One could equally speculate that the Great Eastern fault is a reactivated Early Mesozoic structure.

Deep structural trends, with strong magnetic signatures as well as geologic expressions, are useful guide for regional porphyry exploration. The common coincidence of Mesozoic alkalic porphyry deposits and important younger faults should also be taken into account. Integration of the bedrock data from this project with the multiparameter airborne geophysical data of Shives and Holman (1992), shows an excellent correlation of high calculated potassium with the Mt. Milligan, Taylor and BP-Chuchi alteration haloes. Other intriguing potassium peaks occur in mainly overburden-covered areas. Field follow-up to this airborne study and its extensions (Shives *et al.* 1994; Shives and Carson 1994) may generate new porphyry targets.

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APPENDICES

APPENDIX 1
RADIOLARIAN IDENTIFICATIONS

Report No. FC93-1; F. Cordey, Geological Survey of Canada, January 25, 1993

Report on radiolarians, submitted in 1992 by JoAnne Nelson, map area 93N/14

GSC Location Number: C-189658 **NTS: 93N/14**

Collector: Mary Maclean Field Number: 92-MM-13-10

GEOGRAPHY: UTM Zone 10; 374675E, 6207200N; NE corner of 93N/14

STRATIGRAPHY: Nina Creek Group, chert

PALEONTOLOGY:

Radiolarian taxa:

silica ghosts: very poorly preserved shells

AGE: undetermined

GSC Location Number: C-189659 **NTS: 93N/14**

Collector: Mary Maclean Field Number: 92MM-13-9(a)

GEOGRAPHY: UTM Zone 10; 374675E, 6207000N; NE corner 93N/14

STRATIGRAPHY: Nina Creek Group, red chert

PALEONTOLOGY:

Radiolarian taxa:

?Albailella sp.

Scharfenbergia sp.

rare poorly preserved spumellarians

AGE: Late Paleozoic (Devonian-Permian)

GSC Location Number: C-189659 **NTS: 93N/14**

Collector: Mary Maclean Field Number: 92MM-13-9(b)

GEOGRAPHY: UTM Zone 10; 374675E, 6207000N; NE corner 93N/14

STRATIGRAPHY: Nina Creek Group, grey/red chert

PALEONTOLOGY:

Radiolarian taxa:

very poorly preserved silica shells and fragments

AGE: none can be suggested

GSC Location Number: C-189660 **NTS: 93N/14**

Collector: JoAnne Nelson Field Number: 92-JN29-1

GEOGRAPHY: UTM Zone 10; 373750E, 6193475N; east of Discovery Creek

STRATIGRAPHY: Lay Range assemblage, chert

PALEONTOLOGY:

Radiolarian taxa:

none observed

AGE: undetermined

GSC Location Number: C-189661 **NTS: 93N/14**

Collector: Keith Mountjoy Field Number: 92KM26-6(a)

GEOGRAPHY: UTM Zone 10; 369500E, 6204400N; northeast of Discovery Creek

STRATIGRAPHY: Lay Range assemblage, red chert

PALEONTOLOGY:

Radiolarian taxa:

Albailella sp.

Pseudoalbailella bulbosa Ishiga

Pseudoalbailella U-forma Holdsworth and Jones

rare sponge spicules

AGE: Late Pennsylvanian to Early Permian; Missourian-Wolfcampian

GSC Location Number: C-189661 **NTS: 93N/14**

Collector: Keith Mountjoy Field Number: 92KM-26-6(b)

GEOGRAPHY: UTM Zone 10; 369500E, 6204400N; northeast of Discovery Creek

STRATIGRAPHY: Lay Range assemblage, red chert

PALEONTOLOGY:

Radiolarian taxa:

Pseudoalbailella sp.

AGE: Middle Pennsylvanian-Permian

APPENDIX 2
CONODONT IDENTIFICATIONS

Report No. OF-1991-17; M.J. Orchard, December 20, 1991
Report on conodonts and other microfossils, Fort Fraser (93K), 3 collections made by JoAnne Nelson/K. Green 1990

GSC Location Number: C-153846 **NTS: 93K/16**
Collector: J. Nelson Field Number: 90-JN32-10
GEOGRAPHY: UTM: Zone 10; 407575E, 6070000N
Description: NE shore of Dem Lake
STRATIGRAPHY: Rock Unit: Slate Creek succession, Takla Group
Description: carbonate, isolated outcrop
PALEONTOLOGY: Fossils: conodonts
Conodont taxa: CAI: 4±
Metapolygnathus ex gr. *nodosus (Hayashi 1968) (1)*
AGE: Late Triassic, probably Late Carnian
Remarks: Probable age specified by collector as Triassic-Jurassic. Processed at University of Victoria.

GSC Location Number: C-159248 **NTS: 93K/16**
Collector: J. Nelson Field Number: 90 JN26-5
GEOGRAPHY: UTM: Zone 10; 412000E, 6070500N
Description: Hat claims south of Hatdudatl Creek
STRATIGRAPHY:Rock Unit: Inzana Lake succession
Description: carbonate, limy pod in black argillite and grey sandstone
PALEONTOLOGY:Fossils: conodonts
Conodont taxa: CAI: 5
Metapolygnathus lindae Orchard 1991 (1)
Metapolygnathus nodosus (Hayashi 1968) (5)
ramiform elements (1)
AGE: Late Triassic, Late Carnian, nodosus zone
Remarks: probable age specified by collector as Triassic-Jurassic. Processed at University of Victoria.

GSC Location Number: C-168237 **NTS: 93K/16**
Collector: Kim Green Field Number: 90-KG-20-5
GEOGRAPHY:UTM: Zone 10; 408000E, 6072825N
Description: NE of Dem Lake
STRATIGRAPHY: Rock Unit: Inzana Lake succession
Description: carbonate, isolated outcrop
PALEONTOLOGY: Fossils: conodonts, ichthyoliths
Conodont taxa: CAI: 5
Epigondolella carinata Orchard 1991 (1)
Epigondolella elongata Orchard 1991 (4)
Epigondolella spiculata Orchard 1991 (3)
Epigondolella sp. indet. (3)
AGE: Late Triassic, Middle Norian, elongata zone
Remarks: probable age specified by collector as Triassic-Jurassic. Processed at University of Victoria.

Report OF-1993-38; M.J. Orchard, September 24, 1993
Report on conodonts and other microfossils, Manson River (93N) 8 collections made by JoAnne Nelson and Kim Bellefontaine, 1992 with new data added from a collection by JoAnne Nelson, 1995.

GSC Location Number: C-189651 **NTS: 93N/14**
Collector: J. Nelson Field Number: 92-JN-26-4
GEOGRAPHY: UTM: Zone 10; 360125E, 6198775N
Description: Willy George Ridge, west of Discovery Creek
STRATIGRAPHY: Rock Unit: Willy George succession
Description: carbonate
PALEONTOLOGY: Fossils: conodonts, ichthyoliths, sponge spicules
Conodont taxa: CAI: 4.5
platform fragments (1)
AGE: Ordovician-Triassic
Remarks:

GSC Location Number: C-189652 **NTS: 93N/14**
Collector: K. Bellefontaine Field Number: 92-KB-24-1
GEOGRAPHY: UTM: Zone 10; 359450E, 6197625N
Description: Willy George Ridge, west of Discovery Creek
STRATIGRAPHY: Rock Unit: Willy George succession
Description: limestone clast in polymictic breccia
PALEONTOLOGY: Fossils: conodonts, ichthyolith
Conodont taxa: CAI: 4.5-5
Epigondolella sp. cf. *E. multidentata* Mosher 1970 (1)
Metapolygnathus sp. aff. *M. communisti* Hayashi 1968 (3)
Metapolygnathus sp. cf. *M. pseudoechinatus* (Kozur 1989) (1)
Metapolygnathus nodosus (Hayashi 1968) (15)

AGE: Late Triassic, Late Carnian-Middle Norian
Remarks: elements are predominantly Late Carnian, but single epigondalellid is suggestive of Middle Norian: ?mixed fauna

GSC Location Number: C-189727 **NTS: 93N/11**
Collector: K. Bellefontaine Field Number: 92-KB-14-4
GEOGRAPHY: UTM: Zone 10; 360875E, 6179100N
Description: Eaglenest Ridge south of Omineca River
STRATIGRAPHY: Rock Unit: Plughat Mountain succession
Description: limestone
PALEONTOLOGY: Fossils: conodonts, ichthyoliths, shell fragments
Conodont taxa: CAI: 6.5
Neogondolella sp. (1)

AGE: Triassic

GSC Location Number: C-189728 **NTS: 93N/11**
Collector: J. Nelson Field Number: 92-JN-13-2
GEOGRAPHY: UTM: Zone 10; 360825E, 6179525N.
Description: Eaglenest Ridge, south of Omineca River
STRATIGRAPHY: Rock Unit: Plughat Mountain succession
Description: limestone
PALEONTOLOGY: Fossils: conodonts, ichthyoliths, tubes
Conodont taxa: CAI: 4-6
Neogondolella sp. indet. (1)
AGE: Triassic

GSC Location Number: C-189729 **NTS: 93N/11**
Collector: K. Bellefontaine Field Number: 92-KB-14-7
GEOGRAPHY: UTM: Zone 10; 361300E, 6177725N
Description: Eaglenest Ridge, south of Omineca River
STRATIGRAPHY: Rock Unit: Plughat Mountain succession
Description: limestone
PALEONTOLOGY: Fossils: conodonts, ichthyoliths
Conodont taxa: CAI: 4-4.5
Neogondolella aff. steinbergensis (Mosher 1968) (17)
CAI:4.5
AGE: Late Triassic, Middle-Late-Norian

GSC Location Number: C-189738 **NTS: 93N/14**
Collector: K. Bellefontaine Field Number: 92-KB-21-7
GEOGRAPHY: UTM: Zone 10; 372025E, 6200450N
Description: east of Discovery Creek
STRATIGRAPHY: Rock Unit: Lay Range assemblage
Description: carbonate
PALEONTOLOGY: Fossils: conodonts
Conodont taxa: CAI: 4
Idiognathodus sp. (1)
Neogondolella sp. cf. *N. clarki* (Koike 1967) (2)
AGE: Late Carboniferous, ?Bashkirian-Moscovian

GSC Location Number: C-189739 **NTS: 93N/14**
Collector: J. Nelson Field Number: 92-JN-22-1
GEOGRAPHY: UTM: Zone 10; 370000E, 6186926N
Description: ridge north of Omineca River, east of Discovery Creek
STRATIGRAPHY: Rock Unit: Mississippian volcanic -sedimentary unit (Lay Range assemblage)
Description: limestone clast in lapilli tuff
PALEONTOLOGY: Fossils: conodonts, ichthyoliths
Conodont taxa: CAI: 3-4
ramiform elements (8)
Gnathodus cuneiformis Mehl & Thomas 1947 (3)
Gnathodus homopunctatus Ziegler 1960 (3)
AGE: Early Carboniferous, Visean

GSC Location Number: C-189745 **NTS: 93N/15**
Collector: K. Bellefontaine Field Number: 92-KB-28-4
GEOGRAPHY: UTM: Zone 10; 379850E, 6180925N
Description: west of Evans Creek, south of Omineca River
STRATIGRAPHY: Rock Unit: Lower Jurassic? felsic unit
Description: carbonate
PALEONTOLOGY: Fossils: conodonts
Conodont taxa: CAI:
coniform elements (10)
AGE: Cambrian-Ordovician
Remarks: The unadulterated sample was barren. A second vial marked "KB-28-4 contaminated? with MM-18-2" produced the listed conodonts, some of which were included with a slide sent from Victoria.

J. Nelson's note: Sample 92-MM-18-2 is from the same map unit as KB-28-4. An early Paleozoic age is considered highly unlikely; perhaps the contamination is from the University of Victoria laboratory.

GSC Location Number: C-189666 **NTS: 93N/11**
Collector: J. Nelson Field Number: 95-JN-EN27-1
GEOGRAPHY: UTM: Zone 10; 360958E, 6178882N
Description: Manson River near 20 Mile Creek
STRATIGRAPHY: Rock Unit: Eaglenest limestone reef, within Takla Group
Description: limestone slump breccia
PALEONTOLOGY: Fossils: conodonts, ichthyoliths
Conodont taxa: CAI: 4.5-5
Neogondolella cf. steinbergensis (Mosher 1968) (1)
Neogondolella cf navicula (Huckriede 1958) (1)
AGE: Late Triassic, Middle? Norian

APPENDIX 3A
AMMONITE IDENTIFICATIONS

Report J7-1991-HWT; Howard W. Tipper, Geological Survey of Canada, 15 November, 1991

Report on three collections of Jurassic fossils, collected in 1991, *from the Manson Creek map area (93N)*, British Columbia, submitted by JoAnne Nelson, BCMEMPR.

Field No.: 91JN-19-4 **GSC Loc. No: C-189721**

Collector: JoAnne Nelson

Locality: North of Chuchi Lake, Skook claims. In an east-west gully .5 km north of main logging road. UTM 403200E 6l1700N; 93N/2.

Fossils: ammonites

Identifications:

Leptaleoceras aff. *accuratum* (Fucini)
Leptaleoceras sp.
Fuciniceras? sp.
Arieticeras cf. *algovianum* (Oppel)

Age and comments: Late Pliensbachian. Lower part of the Kunae zone. This is a first occurrence of the Late Pliensbachian in the Fort St. James area. Important new information for Quesnellia Terrane.

Field No.: 91JN-93N8W **GSC Loc. No.: C-189719**

Collector: JoAnne Nelson

Locality: Clearcut north of Chuchi Lake, GR claim Group. UTM 410550E 6123275N; 93N/8W

Fossils: ammonites

Identifications:

Amaltheus sp.
Fanninoceras? sp.
Leptaleoceras aff. *accuratum* (Fucini)
Arieticeras? sp.

Age and comments: Late Pliensbachian. Lower part of the Kunae zone. Almost certainly equivalent to collection C-189721.

Field No.: 91CRE-7-3 **GSC Loc. No. C-189720**

Collector: Chris Rees

Locality: 'Adade Yus Mountain north of Chuchi Lake. UTM 392875E, 6128050N; 93N/7E

Fossils: ammonites, bivalves

Identifications:

Tropidoceras sp.
Acanthopleuroceras? sp.
Metaderoceras evolutum (Fucini)
Gemmellaroceras?? sp.
Phricodoceras??? sp.
bivalves

Age and comments: Early Pliensbachian. Whiteavesi zone. Material is compressed but the assemblage is clearly Early Pliensbachian in age and almost certainly Whiteavesi zone; i.e. mid-Early Pleinsbachian.

Report J1-1992-GKJ; Giselle K. Jacobs, Visiting Fellow, Geological Survey of Canada, 29 September, 1992

Report on Jurassic fossils from the Manson River map area (93N14), submitted by J. Nelson (BCGS) in September 1992.

Field No.:92-JN-24-1 **G.S.C. Loc. N. C-189742**

Locality: Discovery Creek, Takla Group. UTM 368600E 6187000N.

Identifications: ammonites
Pleydellia n.sp.
Lytoceras sp.
Phymatoceratidae n.gen. et n.sp.
ammonite aptychi
bivalves

Age & Comments: late Late Toarcian

Field No.: 92-JN-21-4 **G.S.C. Loc. No.: C-189663**

Locality: Discovery Creek, approximately 2.25 km from road crossing. UTM 367600E 6187975N. Takla Group.

Identifications: pelecypods
rhynchonellid brachiopods
belemnite

Age & Comments: The presence of a belemnite with an internal radiating structure suggests an age younger than Middle Toarcian.

Field No.:92-JN-21-5 **G.S.C. Loc. No.: C-189664**

Locality: Discovery Creek, approximately 2.25 km from road crossing. UTM 367525E 6188050N. Takla Group.

Identifications: ammonites
Dumortieria n.sp.
Phymatoceratidae n.gen. et n.sp.

Age & Comments: late Late Toarcian

Field No.:92-JN-22-1 **G.S.C. Loc. No.: C-189665**

Locality: 750 m northeast of Ron Repko's house. UTM 370000E 6186825N. Lay Range Assemblage.

Identifications: crinoid columnals

Age & Comments: not diagnostic

APPENDIX 3B
PLANT MACROFOSSIL IDENTIFICATIONS

Report on plant macrofossil specimens by Elizabeth McIver, Visiting Fellow, Geological Survey of Canada, Calgary, Alberta, 16 October 1990

For JoAnne Nelson, Geological Survey Branch; submitted on October 2, 1990.

Field Number: 90-JN-34-1 **GSC Locality: C-168233**

Geography: Assunta claims, near Gidegingla Lake, 93N/1; UTM Zone 10, 422600E, 6107925N

Description: shale/mudstone in drill core from DD11NR89-2, @ 270-288.5 metres

Identifications:

SUBDIVISION:Gymnospermophytina
CLASS: Gymnospermopsida
FAMILY: Taxodiaceae
Metasequioa occidentalis - leafy twigs

FAMILY Pinaceae
Pinus - seeds, and probably leaves; but without fascicles, identification of the leaves as *Pinus* is impossible.
Picea - seeds

SUBDIVISION: Angiospermophytina
CLASS: Magnoliospsida

FAMILY:Betulaceae
cf. *Betula* - leaves betulaceous and could be *Betula* but, as the leaves are poorly preserved or only fragments, they should not be assigned to the genus.

FAMILY: Protaceae
Lomatia lineata (Lesquereux) MacGinitie - leaves and probably seeds (seeds are incomplete but resemble those of the taxon).

FAMILY: Myricaceae
Comptonia hesperia Berry - leaves

AGE: Eocene or Oligocene

APPENDIX 4
POLLEN IDENTIFICATION

Report AS-93-01, A.R. Sweet, Paleontology Division, Geological Survey of Canada, Calgary, Alberta

Applied Research Report on one Tertiary sample from north central British Columbia (NTS 93N/14; Zone 10, 6190525N, 367325E) as requested by collector JoAnne Nelson.

Field Number: 92-JN-24-6 GSC Location Number: C-189662
ISPG Number: P3776-1

Selected flora:

- *Alnipollenites verus* Potonié ex Potonié, 1931 (rare)
- Betulaceae
- *Ericipites compactipolliniatus* (Traverse) Norris, 1986 (abundant)
- *Sphagnum* sp. (abundant - dominant polymorph)
- *Paraalnipollenites alterniporus* (Simpson) Srivistava, 1975
- *Ulmipollenites undulosus* Wolff, 1934 (abundant)
- tricolpate pollen

Comments: Recovery and preservation good. Residue dominated by coaly debris and pollen and spores.

GENERAL COMMENTS: The age of this sample is probably within the Eocene. *Paraalnipollenites alterniporus* is not known to range above the Eocene (Ioannides and MacIntyre, 1980), although it is also abundant in the Paleocene. This provides an upper limit to the probable age range for this sample. The oldest age given to *Ericipites compactipolliniatus* (Traverse) Potonié (1960) by Norris (1986) is upper Eocene although *Ericipites* has otherwise been reported from earlier in the Eocene (Rouse and Mathews, 1988). Its abundant presence provides the lower, Eocene age limit. The good preservation of the palynomorph assemblage indicates that a narrower age range would be possible if samples from lithofacies other than coal (coaly shales and mudstones) were sampled for palynological analysis.

APPENDIX 5
SOURCES OF IGNEOUS ROCK NOMENCLATURE

Classification of intrusive and extrusive rocks follows the nomenclature of Streckeisen (1967; IUGS, 1973). Rocks with grain sizes entirely greater than 1 millimetre are assigned plutonic names. Those with grain sizes in whole or partly less than 1 millimetre, for instance in the groundmass of porphyritic rocks, are assigned volcanic names, whether their mode of occurrence is extrusive or intrusive. A sole exception is made for the crowded porphyritic rocks. In hand sample they appear to consist entirely of crowded phenocrysts, but in thin section the larger crystals partly touch and are partly separated from each other by a groundmass that forms thin, fine-grained selvages. In accordance with their macroscopic appearance, they are assigned plutonic names, *e.g.* monzonite.

In accordance with Streckeisen's (1967) modal QAP classification, intermediate volcanic rocks with no or minimal quartz and plagioclase/potassium feldspar ratios of 1.8 to 0.5 are termed latites in this publication. These rocks are referred to as trachyandesites in many industry reports.

We have also followed IUGS usage for textural description of pyroclastic rocks (Schmid, 1981). In this system, the terms agglomerate or pyroclastic breccia, lapilli tuff and tuff refer to pyroclastic deposits in which the volumetrically dominant clasts are, respectively, greater than 64 millimetres, between 2 and 64 millimetres, and less than 2 millimetres. The term agglomerate is applied to deposits in which round clasts predominate, whereas in breccias, most clasts are angular. Thus, for instance, most of the coarse pyroclastic, andesitic to basaltic deposits in the Witch Lake and Plughat Mountain successions are classified as agglomerates because most of the clasts in them are round. Concavo-convex outlines of these clasts and their weakly altered, glassy (?) rims suggest that they may be bombs or poorly formed pillows, rather than angular clasts that were mechanically rounded. By contrast, agglomerates in the Chuchi Lake and Twin Creek successions contain regularly rounded clasts that probably were mechanically abraded. Such agglomerates are interpreted as lahars, for this and other reasons elaborated in the text.

Appendix 6 Whole Rock and Trace Element Lithogeochemistry
BC Ministry of Energy, Mines and Petroleum Resources Bulletin 99

SAMPLE	UNIT	DESCRIPTION	UTM E	UTM N	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	SUM	CO_2	S	FeO	Au	Cu	Zn	Ni	Cr	Sr	Rb	Zr	Y	Nb	V	Ba
					%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
90JN5-5	EJI	monzodiorite	430250	6115775	52.39	0.77	15.17	10.26	0.18	3.95	7.55	3.16	4.28	0.45	0.93	99.09	0.14	0.01	4.79		144				1199	90	71	17	5	266	1101
90JN5-5A	EJI	monzodiorite	430250	6115775	53.07	0.75	14.88	10.05	0.19	3.9	7.51	3.44	4.54	0.43	0.32	99.08	0.14	0.01	4.97		182				1024	116	109	20	7	258	944
90JN5-8	EJI	monzodiorite	430500	6115700	52.6	0.78	14.86	10.2	0.19	4.05	7.64	3.55	4.18	0.45	0.74	99.03	0.28	0.01	5.21		100				963	96	79	18	6	278	997
90JN5-7	EJI	monzodiorite	430625	6115600	52.25	0.81	14.69	10.54	0.2	4.25	7.73	3.32	4.19	0.46	0.49	98.93	0.21	0.01	5.69		92				953	106	102	20	5	276	957
90JN7-5	EKi	deformed rhyolite dike	428175	6115750	66.24	0.42	16.15	4.33	0.07	1.22	3.85	2.51	3.82	0.18	1.13	99.92	0.14	0.01	2.36		8				772	112	175	14	18	51	911
90JN8-16	uTrWL	large- amygdaloidal trachyte	430600	6119350	52.79	0.65	15.98	6.23	0.14	2.24	4.96	3.28	6.82	0.54	5.17	96.6	3.1	0.01	3.14	3	119	92	5	24	557	90	68	21	5	166	1242
90JN9-5	IJCL	trachyte	408000	6118300	56.89	0.45	17.61	6.36	0.28	2.12	1.94	4.13	6.31	0.19	3.49	99.77	1.42	0.36	3.43	19	35	89	2	13	199	107	128	24	8	76	1703
90JN10-2	IJCL	plag-augite phyric volcanic	406500	6120000	51.12	0.7	18.17	8.72	0.16	3.71	6.5	4.33	2.56	0.3	3.06	99.33	0.18	0.01	4.39	1	98	73	5	16	572	44	71	20	5	213	832
90JN17-8	uTrWL	sparse augite latite-trachyte	431250	6104660	48.38	0.81	17.14	9.16	0.14	5.66	7.75	3.07	2.47	0.29	4.16	99.03	0.5	0.06	6.99		117				416	30	53	20	5	243	1055
90JN19-2	Eji	plag-augite phyric kltrusion	422830	6090650	53.57	0.76	16.08	8.76	0.18	3.65	6.56	3.04	4.63	0.46	1.34	99.03	0.14	0.02	5.36		163				675	88	109	21	5	232	1676
90JN20-9	Eji	hornblende phyric dike	428950	6081010	57.75	0.3	17.7	4.34	0.11	2.44	3.93	5.03	5.34	0.19	1.63	98.76	0.39	0.01	2.2		23				2660	77	131	15	5	105	943
90JN24-4	Eji	hornblende diorite	433350	6112750	49.28	0.99	14.98	11.63	0.21	5.1	9.31	2.69	3.28	0.52	0.86	98.85	0.14	0.01	6.36		135				1306	57	46	21	5	339	1272
90JN26-4A	Eji	coarse hornblende phyric gabbro	411325	6070425	41.36	1.59	11.42	16.91	0.2	10.19	12.17	1.45	0.98	0.23	2.03	98.53	0.32	0.24	12.33		459				564	10	44	20	5	653	381
90JN32-7	KTI	rhyolite dike	407060	6069125	68.17	0.33	15.74	1.77	0.02	0.23	1.79	4.67	3.32	0.1	3.08	99.22	1.47	0.01	0.23		2				918	53	165	10	5	26	1916
90KB1-5	uTrWL	augite phyric flow	432940	6107750	47.42	0.62	13.08	9.76	0.19	9.41	9.78	1.66	3.55	0.44	3.15	99.06	0.65	0.01	5.5	4	130	95	147	365	1034	95	56	16	5	251	1082
90KB2-5	EJi	plag-hbl phyric monzonite	432200	6109400	54.75	0.7	17.55	7.49	0.09	3.05	5.27	4.46	3.37	0.34	2.09	99.16	0.14	0.13	2.76	17	87	30	5	24	647	60	82	21	8	243	1220
90KB2-6	EJi	large kspar phyric dike	432430	6109480	56.46	0.45	19.79	5.55	0.11	1.59	1.24	3.84	7.27	0.24	3	99.54	0.8	0.03	2.09	3	159	107	2	6	474	182	183	28	11	38	1187
90KB2-6A	EJi	monzonite	432430	6109480	58.93	0.5	18.14	5.56	0.04	2.59	1.29	4.85	3.84	0.34	2.55	98.63	0.22	0.45	2.62	41	0	26	6	18	567	77	88	18	6	178	1789
90KB2-7	EJi	monzonite	432700	8109350	61.32	0.47	17.39	3.47	0.05	2.35	1.46	5.35	5.56	0.22	1.51	99.15	0.14	0.09	1.81	11	350	17	6	22	290	65	76	18	5	211	1338
90KB3-1	uTrWL	large augite phyric volcanic	433560	8107900	49.47	1.06	15.76	10.85	0.17	5.07	7.3	3.82	1.92	0.35	3.32	99.09	0.8	0.52	7.25	80	89	89	30	86	596	48	95	25	5	286	791
90KB3-4	EJi	hbi-plag phyrlc Intrusion	432700	6107680	50.85	0.83	17.05	8.26	0.19	3.91	8.24	3.13	2.55	0.39	3.79	99.19	1.63	0.21	5.74	11	146	62	12	40	805	56	88	21	10	258	953
90KB5-2	EJi	hbl-plag phyric Intrusion	431425	6106425	56.35	0.6	16.24	6.38	0.13	3.62	6.69	4.31	3.48	0.23	1.03	99.06	0.14	0.03	4.29	2	17	55	16	73	622	40	86	21	5	202	1255
90KB6-9	EKi	megacrystic quariz monzonite	431770	6113750	67.8	0.37	15.4	3.58	0.05	0.97	3.45	3.22	3.57	0.16	0.64	99.21	0.14	0.01	1.74	3	17	42	2	10	1025	75	182	17	23	47	1053
90KB10-10	IJCL	maroon plagkldase phyric flow	408250	6115250	52.84	0.82	20.32	7.67	0.1	0.92	6	4.48	2.55	0.45	2.68	98.83	0.25	0.01	1.14		40				856	40	106	24	7	117	826
90KB10-10	IJCL	maroon plag phyrlc flow(dup)	408250	6115250	53.01	0.83	20.29	7.74	0.1	0.94	6.06	4.53	2.58	0.45	2.61	99.14	0.39	0.01	1.07		44				854	47	102	22	5	117	828
90KB20-4E	EJi	diorite	415720	6064730	61.18	0.43	17.86	3.74	0.06	1.08	4.39	5.26	3.06	0.13	1.55	98.74	0.28	0.53	2.33		97				925	68	131	20	5	63	1690
90KB20-4F	EJi	hornblende diorite	415720	6064730	54.13	0.65	18.11	6.86	0.14	2.53	6.05	4.03	4.09	0.31	2.16	99.06	0.14	0.45	4.33		67				918	91	104	25	5	142	1987
90KB20-5	EJi	monzodiorite	415550	6064840	52.43	0.64	19.14	6.73	0.08	1.72	7.53	4.38	3.1	0.37	3.13	99.25	1.36	0.34	5.2		52				1054	92	102	28	5	135	1318
90KB20-5B	EJi	homblendite xenolith In volcanic	415550	6064840	43.41	1.23	11.17	15.47	0.31	10.94	11.91	1.51	1.26	0.13	1.86	99.2	0.35	0.01	11.24		10				321	17	35	11	5	431	329
90KB20-7	EJi	homblendite xenolith In volcanic	415950	6064800	40.59	1.9	12.22	17.27	0.23	9.77	12.15	1.29	0.85	0.17	2.39	98.83	0.14	0.11	11.43		117				267	11	36	18	6	830	216
90KB25-1B	EJi	kspar phyric hb monzonite	430725	6066600	59.58	0.31	18.08	3.73	0.11	1.52	3.06	4.5	7.05	0.19	1.09	99.22	0.44	0.01	1.77		18				3005	112	98	15	5	107	1540

SAMPLE	UNIT	DESCRIPTION	UTM E	UTM N	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	SUM	CO2	S	FeO	Au	Cu	Zn	Ni	Cr	Sr	Rb	Zr	Y	Nb	V	Ba
90KB25-1B	EJi	kspar phyric hb monzonite (dup)	430725	6086600	59.59	0.31	18.13	3.73	0.11	1.52	3.08	4.51	7	0.19	1.09	99.26	0.6	0.01	1.91		19				3001	110	98	15	5	109	1536
90KB26-8	EJi	hornblende-biotite diorite	408650	6094150	54.7	0.67	18.78	6.64	0.11	2.01	7.85	4.03	2.25	0.32	2.01	99.37	0.32	0.04	4.07		24				906	70	92	23	5	131	738
90KB28-3A	EJi	monzonite	430900	6115125	51.06	0.89	14.71	11.39	0.2	4.8	8.21	3.15	3.07	0.47	1.31	99.26	0.14	0.01	5.35		145				1015	90	57	21	5	298	903
90KB28-3B	EJi	hornblendite	430900	6115125	47.18	1.11	5.97	17.9	0.35	8.61	13.17	0.98	2.05	0.79	0.68	98.77	0.14	0.01	9.26		6				261	50	110	41	15	479	453
90KB28-4	EJi	monzodiorite	431050	6115225	55.14	0.72	16.08	8.77	0.18	3.21	6.43	3.46	4.18	0.38	0.9	99.45	0.18	0.01	4.23		59				1117	99	121	23	5	205	1006
90KG1-8	EJi	intrusive breccia	409175	6122775	54.55	0.49	17.46	6.16	0.1	3.07	7.39	4.11	3.66	0.21	2.69	99.89	0.14	0.01	2.46		52				139	50	68	12	7	166	735
90KG3-2	uTrWL	augite-plag-olivine volcanic	407000	6115850	48.42	0.93	16.4	10.24	0.18	5.87	11.03	2.14	1.79	0.28	1.67	98.95	0.14	0.01	5.73		134				650	26	59	15	5	283	795
90KG7-9	uTrWL	large augite phyric flow	408200	6107325	52.32	0.74	14.4	8.9	0.17	4.87	7.1	3.42	2.9	0.4	3.68	98.9	2.09	0.01	6.65		90				626	50	129	18	5	197	1431
90KG14-1	EJi	augite phyric Intrusion	432580	6089560	50.22	1.15	15.51	10.62	0.18	4.87	8.68	3.67	2.18	0.29	1.63	99	0.14	0.01	6.49		64				718	42	85	25	5	305	766
90KG15-9	EJi	augite-plag phyric Intrusk>n	432190	6090400	52.99	0.83	15.39	9.13	0.18	5.16	7.45	3.83	2.93	0.24	0.98	99.11	0.14	0.08	6.24		72				700	65	64	18	5	286	1536
90KG18-5	uTrlL	augite phyric hyaloctastite	433160	6073800	46.65	0.74	15.84	10.38	0.19	6.17	9.66	3.21	1.2	0.44	4.31	98.79	0.14	0.12	7.14		174				691	19	51	16	5	306	452
90KG19-1	EJI	hbl-plag phyrlc monzonite	405430	6070150	63.2	0.55	16.15	3.43	0.06	0.78	3.17	4.6	3.3	0.26	3.48	98.96	1.72	0.05	1.07		2				1185	66	166	13	8	66	3621
90MM2-1	EKI	quartz monzonite	431750	6113850	67.36	0.39	15.46	3.78	0.06	1.02	3.48	3.19	3.77	0.16	0.54	99.21	0.14	0.01	1.9		2				1038	102	179	15	31	45	1078
90MM2-3	EJI	hornblende monzonite	431600	6114600	52.06	0.9	15.6	10.41	0.2	4.16	7.83	3.19	3.28	0.47	0.85	98.95	0.14	0.01	5.53	5	73	101	10	45	1167	76	94	21	5	274	1166
90MM3-1A	IJCL	dacite	407200	6118725	52.68	0.65	18.83	6.42	0.17	2.03	5.27	3.96	4.27	0.41	4.67	99.36	2.21	0.01	3.53	2	45	75	3	13	453	89	101	23	5	120	1375
90MM3-5B	EJI	plag-hbl-kspar porphyry	409275	6120725	53.27	0.7	17.8	7.21	0.17	2.57	6.41	4.34	3.7	0.36	2.45	98.98	0.14	0.01	2.47	2	114	73	3	20	434	62	78	20	5	245	940
90MM3-5B	EJI	plag-hbl-kspar porphyry	409275	6120725	53.56	0.7	17.8	7.22	0.18	2.59	6.37	4.37	3.82	0.36	2.45	99.42	0.14	0.01	2.36	2	113	71	3	19	441	71	82	23	7	245	936
90MM3-8C	IJCL	plag-augite phyric volcanic	410125	6120425	56.03	0.55	16.71	6.19	0.15	3.31	5.08	3.95	4.6	0.22	2.75	99.54	0.97	0.01	2.43	9	65	51	14	79	560	81	88	17	5	170	1314
90MM5-1	IJCL	plag phyric andesite	414200	6119990	54.53	0.62	17.74	7.66	0.14	2.54	5.29	4.49	3.32	0.3	2.66	99.29	0.71	0.01	3.34		73				1087	53	94	19	5	191	1173
90MM6-3A	Hic	fine grained monzo-diorite	405200	6121325	51.08	0.77	16.33	9.19	0.18	3.7	7.62	2.93	4.01	0.45	2.45	98.71	0.39	0.01	4.19		162				674	86	100	21	5	248	1323
90MM6-3B	IJCL	plagioclase phyric volcanic	405200	6121325	54.1	0.82	18.49	7.01	0.12	2.49	5.24	5.81	1.98	0.33	2.7	99.09	0.57	0.01	3.01		14				842	24	91	19	5	232	570
90MM7 -1	uTrWL	augite-plag phyric flow	420375	6121475	47.72	0.72	13.76	11.09	0.18	6.68	9.96	1.74	3.65	0.38	3.38	99.24	2.21	0.07	7.79	4	146	91	30	115	719	41	42	13	5	317	1330
90MM16-6	uTrWL	augite phyric flow	432170	6092350	50.67	0.87	15.62	10.11	0.19	4.89	9.9	3.43	1.79	0.35	0.97	96.79	0.14	0.02	6		155				850	28	58	18	5	355	794
90MM17-2	uTrlL	sparse plag phyric dacite	431350	6078930	47.68	0.56	10.63	10.83	0.2	12.08	10.03	1.79	3	0.41	1.89	99.1	0.14	0.01	6.53		106				710	100	37	15	5	252	1011
90MM21-5	EJI	aplite	432225	6086650	66.4	0.37	16.88	2.85	0.07	0.54	2.13	5.66	4.15	0.07	0.65	99.77	0.14	0.01	0.86		3				340	56	212	25	15	21	809
MM21-12	EJI	coarse grained monzodiorite	432200	6084250	50.11	0.77	18.59	9.17	0.22	3.6	7.48	4.05	2.63	0.5	2.36	99.48	0.14	0.01	3.67		122				1302	59	64	22	5	231	1135
91CR1-3	EJI	hypabyssal monzodiorite	404400	6121550	50.24	0.92	16.89	9.29	0.12	4.33	7.98	2.72	3.67	0.41	2.63	99.2					146			10	576	74	85	22	5	270	1389
92JN2-6	uTrPM	maroon basalt	365425	6185975	51.01	0.75	13.5	10.72	0.18	6.54	9.06	4.1	1.06	0.22	2.43	99.57					118			0	530	13	53	18	5	271	261
92JN13-4	uTrPM	maroon basalt	361225	6179800	46.89	1.34	12.51	12.54	0.19	9.38	9.95	2.23	0.63	0.19	3.64	99.49					104			0	686	10	75	26	5	353	253
92JN16-8	UTC	maroon plag.qtz porphyry	358100	6167525	60.71	0.4	16.13	3.68	0.09	2.18	4.25	3.82	2.55	0.17	5.53	99.51					11			0	416	54	88	13	5	90	2641
92JN16-8	UTC	maroon plag-qlz porphyry (dup)	358100	6167525	60.64	0.4	16.03	3.67	0.09	2.17	4.28	3.82	2.57	0.17	5.53	99.37					11			0	417	57	90	13	6	84	2647
92JN22-3	uTrPM	basalt?	370975	6187900	46.43	1.27	14.97	11.57	0.19	9.27	10.37	1.78	0.77	0.11	2.72	99.45					39			353	129	11	53	20	5	345	190
92JN23-3	Eji	very fine grained diorite	367250	6205350	52.26	1.25	15.48	11.5	0.21	4.08	6.63	4.55	0.45	0.25	3.23	99.87					150			28	132	10	105	28	7	348	212
92JN26-2	uTrWG	dacite fragments	359575	6198450	67.83	0.25	15.83	2.74	0.05	2.1	3.26	4.31	1.12	0.25	2	99.74					18			0	593	14	107	10	14	30	596
91JN26-6	Eji	chilled margin, kspar porphyry	399350	6123475	71.61	0.11	14.64	1.75	0.02	0.25	0.84	4.2	5.57	0.03	0.41	99.43					25			10	224	150	220	23	17	9	697

91JN26-10	EJi	BP-Chuchl: hbl phylic monzonite	400850	6124550	51.89	0.66	16.31	8.93	0.21	4.47	7.8	3.49	3.16	0.35	1.72	98.99					201			26	994	63	71	22	5	247	1693
91JN27-1	lJCl h	hbl-plag-olivine basalt	401000	6123800	51.43	0.7	14.2	9.73	0.19	6	9.56	2.08	3.46	0.34	1.33	99.02					131			147	576	83	72	18	7	267	1095
SAMPLE	**UNIT**	**DESCRIPTION**	**UTM E**	**UTM N**	**SiO2**	**TiO2**	**Al2O3**	**Fe2O3**	**MnO**	**MgO**	**CaO**	**Na2O**	**K2O**	**P2O5**	**LOI**	**SUM**	**CO2**	**S**	**FeO**	**Au**	**Cu**	**Zn**	**Ni**	**Cr**	**Sr**	**Rb**	**Zr**	**Y**	**Nb**	**V**	**Ba**
91JN27-4	EJH	c.g. weakly porph monzonite	401580	6123350	57.94	0.78	17.4	5.76	0.09	2.01	3.32	4.05	6.75	0.51	0.79	99.4					168			30	384	187	139	18	9	168	1126
91KB1-4	lJCL	f.g green aug-plag porphyry	399870	6116010	47.69	0.96	17.78	10.54	0.16	5.62	9.74	2.69	1.4	0.31	2.35	99.24					27			10	580	31	66	21	7	296	482
92KB2-1	lJCL	plag-aug porphyry	380450	6184350	53.62	0.81	16.32	8.61	0.18	4.11	5.75	3.24	4.1	0.42	2.5	99.66					71			0	697	78	136	21	7	233	1348
92KB2-8	lJCL	plag-aug porphyry	360685	6184225	53.97	0.85	16.59	8.81	0.16	4.07	6.64	3.29	3.1	0.42	1.77	99.67					265			0	779	48	141	23	6	239	1284
91KB19-1A	lJCL	maroon aug-plag porphyry	396950	6116500	46.78	1.13	15.46	11.98	0.2	7.19	10.81	2.7	0.83	0.3	1.67	99.05					197			10	583	18	59	21	6	386	476
91KB19-1B	lJCL	maroon aug-plag porphyry	395950	6116500	46.62	1.04	17.02	11.67	0.21	6.38	10.44	2.07	1.87	0.31	1.44	99.07					155			50	494	46	54	20	5	338	807
91KB19-1C	lJCL	green aug-plag porphyry	396950	6116500	47.28	1.05	15.86	11.35	0.22	6.47	11.71	2.55	0.7	0.28	1.6	99.07					161			57	660	13	55	18	5	373	306
91KB19-5	lJCL	maroon flow with green blebs	400970	6116750	55.45	0.65	19.86	6.22	0.13	1.88	3.68	3.62	4.99	0.44	2.99	99.91					22			10	498	87	126	22	10	81	1629
91KB26-1	lJCL	maroon + green augite porphyry	412500	6123600	49.75	1	13.98	11.87	0.19	5.72	8.17	2.85	2.98	0.37	2.36	99.24					76			108	797	51	70	26	5	335	1421
92KB26-8	PPLR	augite-olivlne basalt	369775	6201775	49.13	1.12	17.28	11.39	0.17	5.99	5.33	3.51	2.45	0.28	2.84	99.49					116			51	740	47	93	25	5	317	1061
92KB28-1	Uf ma	maroon andesite with qtz eyes	380875	6180900	54.41	1.83	14.47	9.85	0.15	3.94	5.03	5.71	0.54	0.45	2.61	98.99					208			11	399	10	209	27	29	274	215
92KM2-3	uTrPM	maroon basalt	363500	6167400	46.43	0.64	13.21	9.25	0.21	4.28	9.66	3.56	4.27	0.36	7.75	99.62					85			0	371	64	63	16	5	234	937
92KM14.3	uTrPM	pillow In aug-plag phylic flow	365575	6173650	48.15	0.77	12.7	11.22	0.19	7.81	10.73	3.26	0.86	0.2	3.49	99.38					108			0	455	18	59	18	5	276	188
92KM28-11	PPLR	augite-olivine basalt	374700	6193250	47.78	0.91	13.59	10.43	0.19	9.67	9.2	3.29	0.46	0.18	3.49	99.19					105			414	184	10	79	18	9	257	173
92KM28-4	PPLR	augite-olivine basalt	374675	6192575	50.02	0.79	15.31	9.88	0.17	7.59	7.74	3.79	1.36	0.16	2.9	99.71					57			236	435	24	75	20	5	232	382
92KM28-8	PPLR	augite-olivine basalt	373600	6193100	48.27	0.71	14.15	10.84	0.17	10.59	7.26	3.19	1.12	0.14	3.38	99.82					47			353	405	17	64	19	5	286	210
92KM28-13	PPLR	augite-olivine basalt	374000	6193875	46.96	0.87	13.94	10.36	0.18	9.31	10.83	1.52	0.75	0.16	4.94	99.82					85			328	176	13	72	20	6	264	186
92MM14-7	PPLR	augite-olivine basalt	369475	6203550	46.74	0.94	15	10.44	0.17	8.46	10.53	2.33	0.68	0.18	3.82	99.29					102			266	483	11	82	20	6	248	104
92MM14-7	PPLR	augite-olivine basalt (dup)	369475	6203550	46.93	0.96	14.99	10.46	0.16	8.35	10.46	2.42	0.87	0.17	3.86	99.43					101			266	482	10	83	20	6	262	104
92SD30-1	uTr?T	pillow basalt	373650	8186250	49.21	1.4	13.22	10.99	0.19	6.87	10.07	3.07	0.2	0.16	4.21	99.59					38			266	138	10	70	27	5	277	57
92SD30-1B	uTr?T	pillow basalt	373650	6186250	46.94	1.2	15.52	9.84	0.21	5.29	10.43	4.48	0.07	0.12	4.98	99.08					35			221	89	10	73	22	5	271	25

APPENDIX 7
URANIUM-LEAD ZIRCON, TITANITE AND RUTILE ANALYTICAL DATA

GEOCHRONOLOGY LABORATORY,
DEPARTMENT OF GEOLOGICAL SCIENCES,
THE UNIVERSITY OF BRITISH COLUMBIA

Analysis and Interpretation
By Janet Gabites and Richard Friedman

MM-90-2-1 Mount Milligan granite

Abundant zircon and primary igneous titanite were recovered from this well-foliated porphyritic granite body, a late phase of the Mount Milligan pluton. The zircon consists of clear, pale pink high quality grains with morphologies ranging from equant multifaceted (commonly tear-drop shaped) to less commonly prismatic elongate and acicular grains. The titanite occurs as honey brown broken euhedral grains.

Six of seven analysed zircon fractions (fractions A-F) are discordant with $^{206}Pb/^{238}U$ ages greater than about 220 Ma, and contain demonstrable inheritance (Figure 29a). Cores were not observed in these fractions. A single fraction of fine grained, acicular zircon (G) slightly intersects concordia at about 176 Ma, which is considered as a maximum crystallization age for this rock. It is likely that there is also minor inheritance in this analysis. Four analyses of titanite intersect concordia between about 165 and 169 Ma (Figure 29b). Fractions T1 and T3, which are concordant at 168.5 Ma, are interpreted to record the crystallization and cooling of this small, high-level intrusion. It is probable that slightly younger fractions T2 and T4 lost minor amounts of Pb. An age of 168.6± 0.6 Ma is based on the $^{206}Pb/^{238}U$ ages for fractions T1 and T3.

JN-90-7-3 Rhyodacite porphyry

This rock is a quartz-plagioclase-biotite phyric rhyodacite which is mapped as younger than the Takla Intrusions. It forms a dike which has been mylonitized by a fault bounding the west side of the Mount Milligan horst. The zircons are clear, colourless euhedral doubly terminated prisms with aspect ratios around 1: 4. Cloudy cores were visible in some crystals. The titanite is clear, colourless to pale yellow, and occurs as anhedral fragments.

The best estimate of the age of the rock, 169.3±5 Ma, is given by the weighted mean of the $^{207}Pb/^{206}Pb$ ages of the three titanite fractions (Figure 30). The three titanite analyses all overlap concordia and each other. The zircon fractions all contain variable inherited components, with an average age of 1.210±3 Ga.

JN-91-17-2 Monzonite, BP-Chuchi property

This rock is a crowded porphyritic monzonite mapped as a Takla intrusion. It is the host for mineralization on the B.P. Chuchi copper-gold property. The zircons are clear, colourless to very pale tan coloured euhedral doubly terminated prisms with aspect ratios around 1:1-2. Cloudy cores were visible in some crystals. Many crystals are fractured. The titanite is clear, pale yellow and resinous, and occurs as angular fragments.

The best estimate of the age of the rock, 188.5±2.5 Ma, is given by the weighted mean of the $^{207}Pb/^{206}Pb$ ages of the three titanite fractions, two of which are concordant and overlap (Figure 31). The zircon fractions all contain variable inherited components, with an average age of 1.12±0.24 Ga. Fraction B has lost lead, causing it to plot below the titanites.

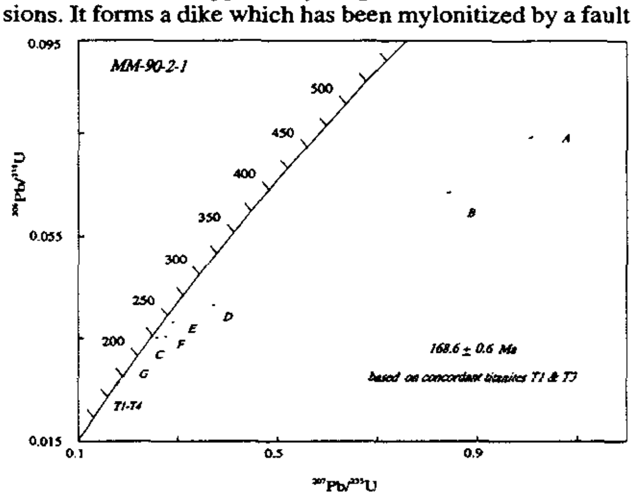


Figure 29a. 206Pb/^{238}U v. $^{207}Pb/^{235}U$ concordia diagram for sample MM-90-2-1, Mount Milligan granite. Fractions are labelled as in Table 1.

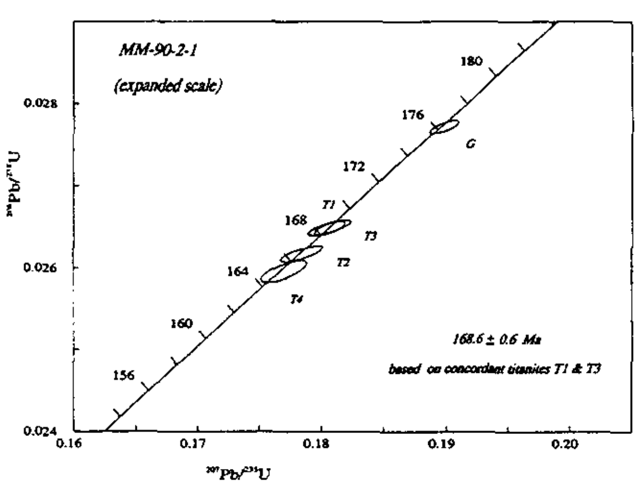


Figure 29b. Figure 29a with expanded scale to show titanite fractions.

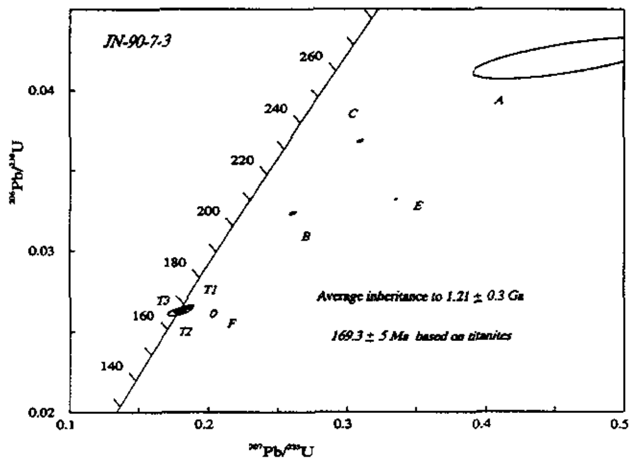


Figure 30. $^{206}Pb/^{238}U$ *v.* $^{207}Pb/^{235}U$ concordia diagram for sample JN-90-7-3, rhyodacite dike west of Mount Milligan. Fractions are labelled as in Table 5.

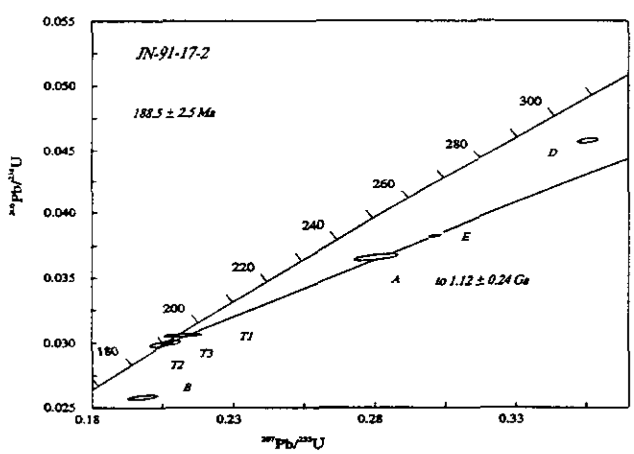


Figure 31. $^{206}Pb/^{238}U$ *v.* $^{207}Pb/^{235}U$ concordia diagram for sample JN-91-17-2, monzonite from BP-Chuchi property. Fractions are labelled as in Table 5.

JN-90-2-3, Rainbow Dike, Mt. Milligan property

This rock is a mineralized monzonite dike from the Mt. Milligan porphyry copper-gold deposit. The Rainbow dike is an apophyse of the MBX stock. Zircon is very sparse, and of two morphologies. A minor proportion is clear and colourless, slightly rounded doubly terminated prisms containing fluid inclusions. The rest are opaque grey tabular prisms. Fractions C, D, and E are from the latter population. The rutile is deep red, clear, and occurs as fragments of elongate striated prisms.

The best estimate of the age of the rock, 191.0±12.8 Ma, is given by the upper intercept of a least squares regression through fractions C, D, and E (Figure 32). Fractions A and F (clear zircons) both contain inherited zircon. The rutile recovered from the sample is presumably a hydrothermal alteration phase, and thus provides a constraint of the minimum age of intrusion. The weighted mean of the $^{206}Pb/^{238}U$ ages of the two rutiles is 182.5±4 Ma, which is interpreted to represent the time of alteration of the dike.

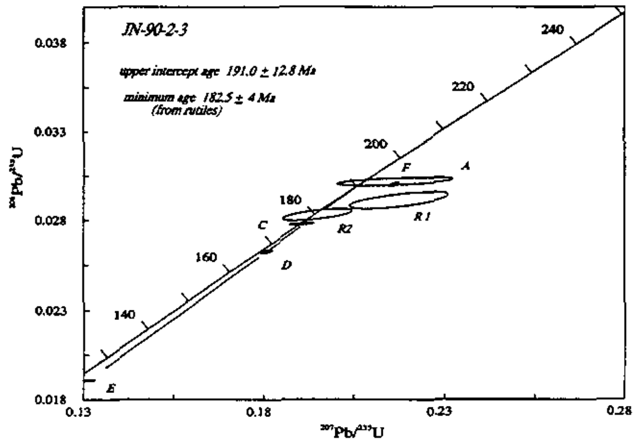


Figure 32. $^{206}Pb/^{238}U$ v. $^{207}Pb/^{235}U$ concordia diagram for sample JN-90-2-3, Rainbow dike. Fractions are labelled as in Table 5.

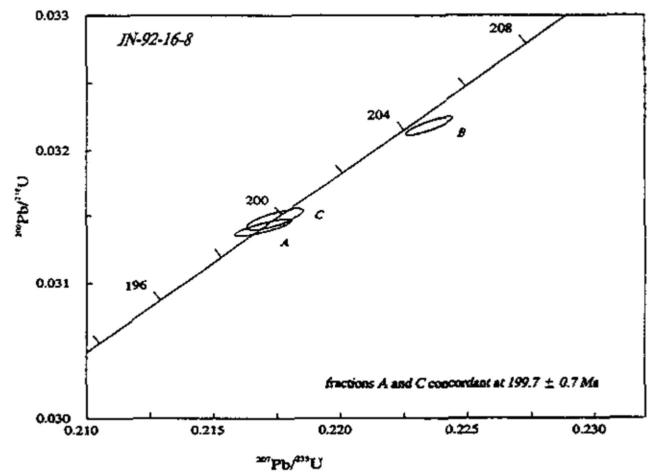


Figure 33. $^{206}Pb/^{238}U$ v. $^{207}Pb/^{235}U$ concordia diagram for sample JN-92-16-8, dacite from upper Twin Creek succession. Fractions are labelled as in Table 5.

JN-92-16-8 Quartz-phyric dacite, upper Twin Creek succession

This is an undeformed quartz-bearing felsic flow from the ridge south of Twin Creek. Two fractions of strongly abraded, relatively coarse grained zircon, and one fraction of slightly finer, unabraded zircon were analysed. One abraded fraction and the unabraded fraction give overlapping concordant analyses (Figure 33). The total range of $^{206}Pb/^{238}U$ ages for these two fractions is 199.7±0.7 Ma, which is taken as the crystallization age of the rock. The second abraded fraction gives somewhat older Pb/U and Pb/Pb ages, indicating the presence of a minor inherited zircon component.

KB-90-20-4, Crowded porphyry monzodiorite, Tas property

This rock is a mineralized monzo-diorite intrusion collected from the Tas property. It is mapped as a Takla Intrusion. Zircon was sparse in this sample, and was not split magnetically. Fraction A was picked from the very finest

TABLE 5
URANIUM-LEAD ANALYTICAL DATA

Fraction[1]	Wt	U	Pb*[2]	$^{206}Pb^{3}$ / ^{204}Pb	Pb[4]	$^{208}Pb^{5}$	Isotopic ratios (±1s,%) 6			Apparent ages (±2s,Ma) [6]	
	mg	ppm	ppm		pg	%	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{206}Pb$
MM-90-2-1: Granite, Mount Milligan											
A c,N2/2a,eq	0.077	239	18	6085	14	9.3	0.07423 (0.11)	1.0067 (0.19)	0.09836 (0.10)	461.6 (1.0)	1593.3 (3.6)
B m,N2/2a,eq	0.068	306	21	5208	15	11.2	0.06350 (0.09)	0.8443 (0.18)	0.09643 (0.10)	396.9 (0.7)	1556.1 (3.6)
C m,N2/2a,p,e	0.039	366	12	2320	13	6.4	0.03521 (0.10)	0.2571 (0.23)	0.05296 (0.16)	223.1 (0.4)	327.1 (7.1)
D m,N2/2a,p,s	0.098	300	12	4702	16	7.2	0.04159 (0.11)	0.3716 (0.20)	0.06481 (0.11)	262.7 (0.6)	768.1 (4.7)
E m,N5/2a,p,e	0.032	379	14	3789	8	8.1	0.03824 (0.10)	0.2901 (0.20)	0.05502 (0.12)	241.9 (0.5)	412.9 (5.4)
F m,N5/2a,p,e	0.037	392	14	4672	7	7.8	0.03542 (0.11)	0.2754 (0.20)	0.05640 (0.12)	224.4 (0.5)	468.1 (5.4)
G f,N5/2a,e,n	0.023	447	12	1670	11	5.4	0.02771 (0.14)	0.1898 (0.30)	0.04967 (0.21)	176.2 (0.5)	179 (10)
T1 cc,N20/2a,b	0.985	425	14	524	1382	28.2	0.02649 (0.17)	0.1806 (0.48)	0.04944 (0.36)	168.6 (0.6)	169 (17)
T2 cc,N20/2a,b	1.300	445	15	514	1929	28.5	0.02618 (0.18)	0.1784 (0.47)	0.04944 (0.35)	166.6 (0.6)	169 (16)
T3 cc,N20/2a,b	0.730	435	14	555	990	27.6	0.02649 (0.16)	0.1807 (0.34)	0.04946 (0.25)	168.6 (0.5)	170 (12)
T4 cc,N20/2a,b	0.808	418	14	483	1192	27.8	0.02596 (0.27)	0.1770 (0.52)	0.04946 (0.36)	165.2 (0.9)	170 (17)
JN-90-7-3: Rhyodacite, Mount Milligan											
A m,N1/2a,p	0.100	320	15	39	3495	14.5	0.04198 (1.6)	0.4592 (7.4)	0.07935 (6.4)	265.1 (8.6)	1181 (270)
B f,N1/2a,p	0.500	407	12	428	996	3.9	0.03233 (0.14)	0.2610 (0.43)	0.05855 (0.35)	205.1 (0.5)	550 (15)
C f,M1/2a,p	0.150	596	21	465	454	5.2	0.03682 (0.12)	0.3092 (0.38)	0.06092 (0.30)	233.1 (0.5)	636 (13)
E f,N1/2a,p,e	0.010	1757	142	407	52	78.4	0.01909 (0.65)	0.1317 (0.65)	0.05003 (0.61)	121.9 (0.2)	196 (29
F f,N1/2a,p,e,ti	0.016	400	10	1434	7	4.2	0.02615 (0.42)	0.2036 (0.54)	0.05648 (0.52)	166.4 (1.4)	471 (23)
T1 c,N20/2a,b	0.645	115	3	170	800	17.6	0.02655 (0.23)	0.1855 (1.1)	0.05066 (1.0)	168.9 (0.8)	225 (46)
T2 c,N20/2a,b	0.322	95	3	162	349	12.3	0.02630 (0.21)	0.1795 (1.2)	0.04951 (1.0)	167.3 (0.7)	172 (49)
T3 c,N20/2a,b	0.287	85	2	76	688	14	0.02630 (0.57)	0.1798 (2.5)	0.04959 (2.1)	167.3 (1.9)	176 (99)
JN-91-17-2: BP-Chuchi monzonite											
A N3/1.5a	0.033	595	34	138	372	42	0.03659 (0.37)	0.2804 (1.4)	0.05558 (1.2)	231.7 (7.1)	436 (51)
B N3/1.5a	0.055	466	19	138	343	42	0.02584 (0.36)	0.1981 (1.4)	0.05561 (1.2)	164.4 (1.8)	437 (51)
D N3/1.5a,p	0.014	363	23	671	22	35.5	0.04578 (0.20)	0.3558 (0.53)	0.05636 (0.45)	288.6 (1.1)	467 (20)
E N3/1.5a,p	0.017	659	44	818	33	47.4	0.03826 (0.13)	0.3014 (0.35)	0.05713 (0.26)	242.1 (0.6)	497 (11)
T1 N20/2a	0.485	72	5	150	496	61.5	0.03057 (0.19)	0.2124 (1.6)	0.05038 (1.5)	194.1 (0.7)	212 (68)
T2 N20/2a	0.310	100	6	365	170	54.1	0.02990 (0.17)	0.2067 (0.50)	0.05014 (0.40)	189.9 (0.6)	201 (19)
T3 N20/2a	0.3	53	4	133	261	66.9	0.02995 (0.38)	0.2062 (1.3)	0.04993 (1.1)	190.2 (1.4)	192 (52)
JN-90-2-3: Rainbow Dike											
A N1/2a	0.064	231	7	77	455	13.4	0.03020 (0.38)	0.2164 (3.7)	0.05197 (3.5)	191.8 (1.4)	284 (160)
C M3/1.5a,t	0.013	1257	124	397	72	74.5	0.02781 (0.13)	0.1905 (0.91)	0.04969 (0.83)	176.8 (0.4)	180 (39)
D M3/1.5a,t	0.026	1643	193	601	122	79.6	0.02628 (0.19)	0.1809 (0.45)	0.04992 (0.34)	167.2 (0.6)	191 (16)
E M3/1.5a,t	0.010	1757	141	407	53	78.4	0.01909 (0.09)	0.1317 (0.65)	0.05003 (0.61)	121.9 (0.3)	196 (29)
F M3/1.5a,t,p	0.028	417	13	2190	10	14.4	0.03005 (0.20)	0.2161 (0.33)	0.05214 (0.21)	190.9 (0.7)	291.8 (9.4)
R1 m	0.311	46	1	62	588	2.2	0.02914 (0.81)	0.2174 (3.1)	0.05413 (2.7)	185.1 (3.0)	376 (120)
R2 m	0.400	42	1	79	489	0.7	0.02832 (0.59)	0.1949 (2.5)	0.04991 (2.1)	180.0 (2.1)	191 (99)
JN-92-16-8: Upper Twin Creek succession											
A c,N5/2a,p	0.117	155	5	1498	24	8.7	0.03141 (0.10)	0.2170 (0.26)	0.05010 (0.18)	199.4 (0.4)	199.5 (8.5)
B c,N5/2a,p	0.075	235	8	4163	9	10.8	0.03218 (0.11)	0.2235 (0.21)	0.05037 (0.13)	204.2 (0.4)	212.1 (5.9)
C m,N5/2a,p	0.072	222	7	1929	16	10.5	0.03147 (0.13)	0.2174 (0.26)	0.05010 (0.18)	199.8 (0.5)	199.6 (8.3)
KB-90-20-4: Tas monzodiorite											
A f,bulk	0.036	552	31	1376	32	44.3	0.03490 (0.54)	0.2529 (0.42)	0.05254 (0.39)	221.2 (2.3)	309 (18)
B m, bulk	0.151	168	6	1732	35	11	0.03714 (0.13)	0.2682 (0.26)	0.05238 (0.16)	235.1 (0.6)	302.1 (7.3)
C f,bulk,bulk,eq	0.045	274	11	1376	22	12.3	0.03888 (0.21)	0.2840 (0.32)	0.05297 (0.19)	245.9 (1.0)	327.6 (8.8)
D f,p	0.076	366	14	2597	24	14.7	0.03615 (0.12)	0.2590 (0.23)	0.05196 (0.14)	229.0 (0.5)	283.9 (6.2)

TABLE 5 (continued)

[1]*All zircon fractions, except those listed as T1, and R1, etc. which are titanite and rutile, respectively. Most zircon fractions are air abraded (exceptions noted in text). Grain size, intermediate dimension: cc = >180 µm, c= <180 µm and 134µm, m=<134µm and >74µm, f=<74µm; Magnetic codes:Franz magnetic separator sideslope (in degrees) and field strength (in amperes) at which grains are nonmagnetic (N) or magnetic (M); e.g., N1/2a=nonmagnetic at 1° and 2 amperes; Front slope for all fractions=20°; Grain character codes: b= broken pieces e=elongate, eq=equant, n= needles, p=prismatic, s=stubby, t=tabular, ti=tips*

[2]*Radiogenic Pb*

[3]*Measured ratio corrected for spike and Pb fractionation of 0.0043/amu±20% (Daly collector) and 0.0012/amu±7% (Faraday collector).*

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

[5]*Radiogenic Pb*

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

crystals, and was not abraded. The zircon is clear, colourless and euhedral, with aspect ratios varying from 1:1 to 1:3. Fraction C was picked from the equant crystals, fraction D from the longer prisms.

The best estimate of the age of the rock, 204.2±9 Ma, is given by the lower intercept of a York least squares regression through the three abraded fractions (Figure 34). The non-abraded fraction plots away from both concordia and the regression line, presumably as a result of a combination of lead loss and inherited old zircon. The average age of the inherited components in the zircons is 660±100 Ma. Although the age of this sample is not well constrained, it is consistent with an age obtained from the CAT intrusion (Mortensen *et al.*, 1995).

U-Pb Geochronology: Analytical Techniques and Data Interpretation

Zircon and titanite were separated from ~25 kg samples using conventional crushing, grinding, and Wilfley table

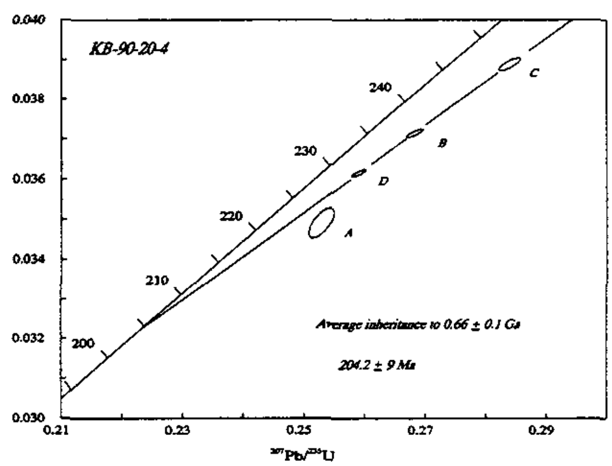
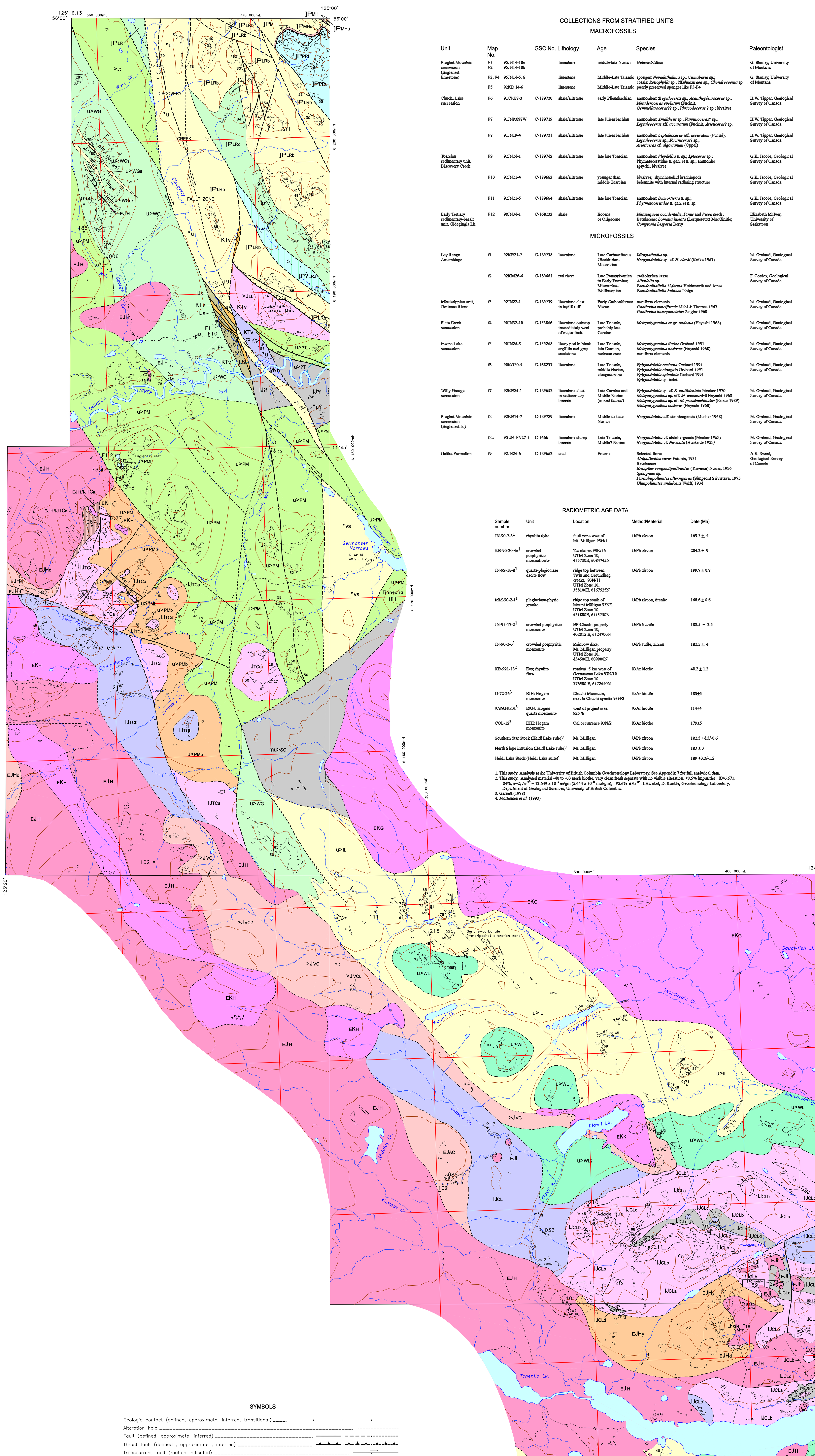
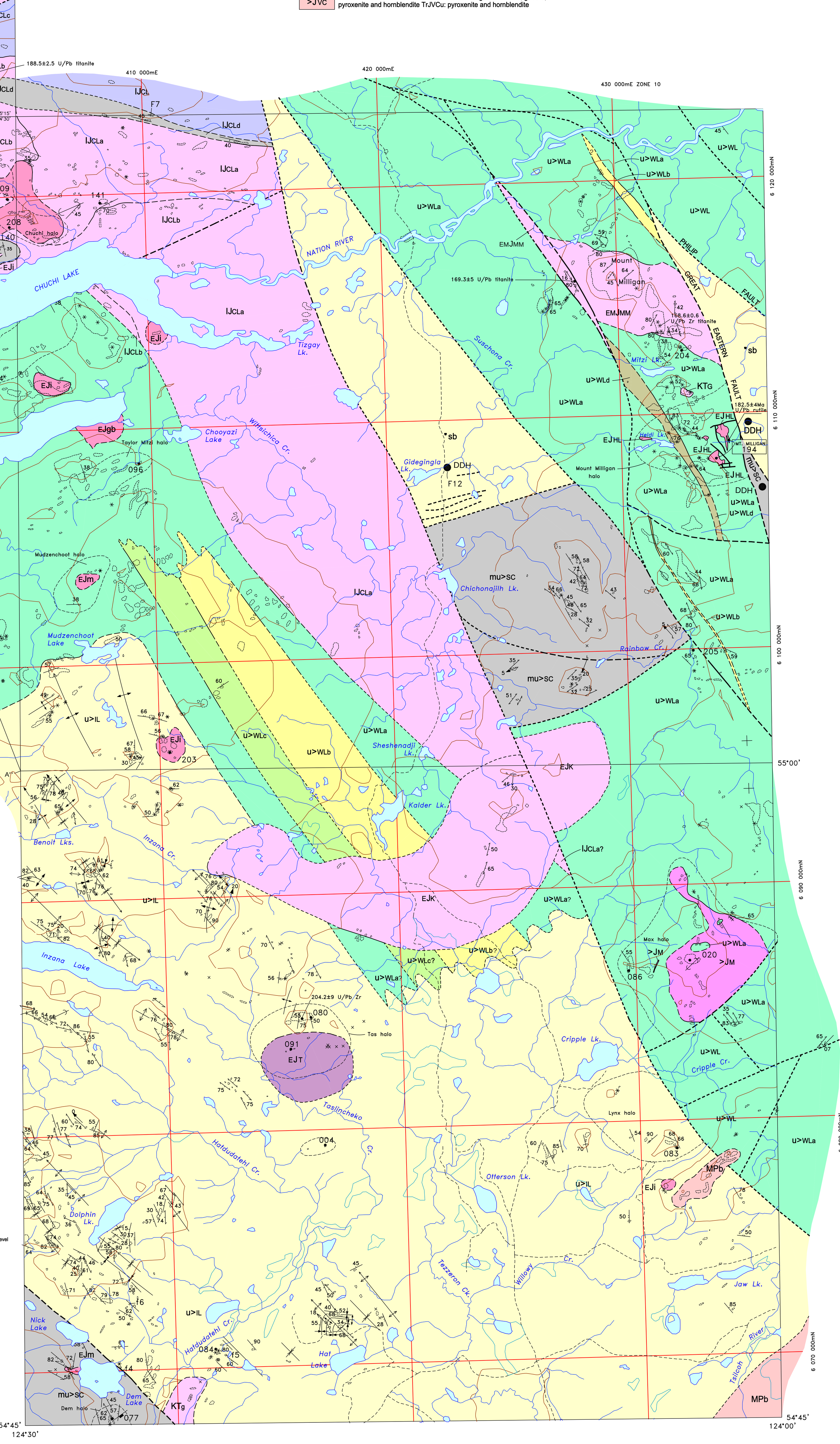


Figure 34. $^{206}Pb/^{238}U$ *v.* $^{207}Pb/^{235}U$ concordia diagram for sample KB-90-20-4, crowded porphyry monzodiorite, Tas property. Fractions are labelled as in Table 5.

techniques, followed by final concentration using heavy liquids and magnetic separations. Mineral fractions for analysis were selected based on grain morphology, quality, size and magnetic susceptibility. All zircon fractions were abraded prior to dissolution to minimize the effects of post-crystallization Pb-loss, using the technique of Krogh (1982). All geochemical separations and mass spectrometry were done in the Geochronology Laboratory at the University of British Columbia. Samples were dissolved in concentrated HF and HNO_3 in the presence of a mixed $^{233-235}U$-^{205}Pb tracer. Separation and purification of Pb and U employed ion exchange column techniques modified slightly from those described by Parrish *et al.* (1987). Pb and U were eluted separately and loaded together on a single Re filament using a phosphoric acid-silica gel emitter. Isotopic ratios were measured using a modified single collector VG-54R thermal ionization mass spectrometer equipped with a Daly photomultiplier. Most measurements were done in peak-switching mode on the Daly detector. U and Pb analytical blanks were in the range of 1-3 pg and 7-15 pg, respectively, during the course of this study. U fractionation was determined directly on individual runs using the $^{233-235}U$ tracer, and Pb isotopic ratios were corrected for a fractionation of 0.12%/amu and 0.43%/amu for Faraday and Daly runs, respectively, based on replicate analyses of the NBS-981 Pb standard and the values recommended by Todt *et al.* (1984). All analytical errors were numerically propagated through the entire age calculation using the technique of Roddick (1987). Analytical data are reported in Tables 1 and 2. Concordia intercept ages and associated errors were calculated using a modified version of the York-II regression model (wherein the York-II errors are multiplied by the MSWD) and the algorithm of Ludwig (1980). All errors are quoted at the 2 level. Age assignments follow the time scale of Harland *et al.* (1990).





British Columbia
Ministry of Employment and Investment
Energy and Minerals Division
Geological Survey Branch

Geological Survey Branch

BULLETIN NO. 99

GEOLOGY OF NORTH-CENTRAL QUESNELLIA TEZZERON LAKE TO DISCOVERY CREEK CENTRAL BRITISH COLUMBIA

NTS 93N, 93K

Compiled by J.L. Nelson, 1993, 1994

Geology by J.L. Nelson, K.A. Bellefontaine, K.G. Green
M.E. McLean, C.J. Rees, K.J. Mountjoy, 1990-1992; J.A. Garnett, 1978;
J.E. Armstrong, 1948; A. Sutherland Brown, 1991; D.G. Bailey, F. Ferri, 1992

Scale 1:100 000

0 2 4 6 8 10 KILOMETRES

COLLECTIONS FROM STRATIFIED UNITS

MACROFOSSILS

Unit	Map No.		GSC No.	Lithology	Age	Species	Paleontologist
Plughat Mountain succession (Eaglenest limestone)	F1 F2	95JN14-10a 95JN14-10b		limestone	middle-late Norian	*Heterastridium*	G. Stanley, University of Montana
	F3, F4	95JN14-5, 6		limestone	Middle-Late Triassic	sponges: *Nevadathalmia* sp., *Cinnabaria* sp.; corals: *Retiophylla* sp., ?*Kuhnastraea* sp., *Chondrocoenia* sp	G. Stanley, University of Montana
	F5	92KB 14-6		limestone	Middle-Late Triassic	poorly preserved sponges like F3-F4	
Chuchi Lake succession	F6	91CRE7-3	C-189720	shale/siltstone	early Pliensbachian	ammonites: *Tropidoceras* sp., *Acanthopleuroceras* sp., *Metaderoceras evolutum* (Fucini), *Gemmellaroceras*?? sp., *Phricodoceras* ? sp.; bivalves	H.W. Tipper, Geological Survey of Canada
	F7	91JN93N8W	C-189719	shale/siltstone	late Pliensbachian	ammonites: *Amaltheus* sp., *Fanninoceras*? sp., *Leptaleoceras* aff. *accuratum* (Fucini), *Arieticeras*? sp.	H.W. Tipper, Geological Survey of Canada
	F8	91JN19-4	C-189721	shale/siltstone	late Pliensbachian	ammonites: *Leptaleoceras* aff. *accuratum* (Fucini), *Leptaleoceras* sp., *Fuciniceras*? sp., *Arieticeras* cf. *algovianum* (Oppel)	H.W. Tipper, Geological Survey of Canada
Toarcian sedimentary unit, Discovery Creek	F9	92JN24-1	C-189742	shale/siltstone	late late Toarcian	ammonites: *Pleydellia* n. sp.; *Lytoceras* sp.; Phymatoceratidae n. gen. et n. sp.; ammonite aptychi; bivalves	G.K. Jacobs, Geological Survey of Canada
	F10	92JN21-4	C-189663	shale/siltstone	younger than middle Toarcian	bivalves; rhynchonellid brachiopods belemnite with internal radiating structure	G.K. Jacobs, Geological Survey of Canada
	F11	92JN21-5	C-189664	shale/siltstone	late late Toarcian	ammonites: *Dumortieria* n. sp.; *Phytmatoceritidae* n. gen. et n. sp.	G.K. Jacobs, Geological Survey of Canada
Early Tertiary sedimentary-basalt unit, Gidegingla Lk	F12	90JN34-1	C-168233	shale	Eocene or Oligocene	*Metasequoia occidentalis*; *Pinus* and *Picea* seeds; Betulaceae; *Lomatia lineata* (Lesquereux) MacGinitie; *Comptonia hesperia* Berry	Elizabeth McIver, University of Saskatoon

MICROFOSSILS

Unit	Map No.		GSC No.	Lithology	Age	Species	Paleontologist
Lay Range Assemblage	f1	92KB21-7	C-189738	limestone	Late Carboniferous ?Bashkirian-Moscovian	*Idiognathodus* sp. *Neogondolella* sp. cf. *N. clarki* (Koike 1967)	M. Orchard, Geological Survey of Canada
	f2	92KM26-6	C-189661	red chert	Late Pennsylvanian to Early Permian; Missourian-Wolfcampian	radiolarian taxa: *Albailella* sp. *Pseudoalbailella U-forma* Holdsworth and Jones *Pseudoalbailella bulbosa* Ishiga	F. Cordey, Geological Survey of Canada
Mississippian unit, Omineca River	f3	92JN22-1	C-189739	limestone clast in lapilli tuff	Early Carboniferous Visean	ramiform elements *Gnathodus cuneiformis* Mehl & Thomas 1947 *Gnathodus homopunctatus* Zeigler 1960	M. Orchard, Geological Survey of Canada
Slate Creek succession	f4	90JN32-10	C-153846	limestone outcrop immediately west of major fault	Late Triassic, probably late Carnian	*Metapolygnathus ex gr. nodosus* (Hayashi 1968)	M. Orchard, Geological Survey of Canada
Inzana Lake succession	f5	90JN26-5	C-159248	limey pod in black argillite and grey sandstone	Late Triassic, late Carnian, nodosus zone	*Metapolygnathus lindae* Orchard 1991 *Metapolygnathus nodosus* (Hayashi 1968) ramiform elements	M. Orchard, Geological Survey of Canada
	f6	90KG20-5	C-168237	limestone	Late Triassic, middle Norian, elongata zone	*Epigondolella carinata* Orchard 1991 *Epigondolella elongata* Orchard 1991 *Epigondolella spiculata* Orchard 1991 *Epigondolella* sp. indet.	M. Orchard, Geological Survey of Canada
Willy George succession	f7	92KB24-1	C-189652	limestone clast in sedimentary breccia	Late Carnian and Middle Norian (mixed fauna?)	*Epigondolella* sp. cf. *E. multidentata* Mosher 1970 *Metapolygnathus* sp. aff. *M. communisti* Hayashi 1968 *Metapolygnathus* sp. cf. *M. pseudoechinatus* (Kozur 1989) *Metapolygnathus nodosus* (Hayashi 1968)	M. Orchard, Geological Survey of Canada
Plughat Mountain succession (Eaglenest ls.)	f8	92KB14-7	C-189729	limestone	Middle to Late Norian	*Neogondolella* aff. steinbergensis (Mosher 1968)	M. Orchard, Geological Survey of Canada
	f8a	95-JN-EN27-1	C-1666	limestone slump breccia	Late Triassic, Middle? Norian	*Neogondolella* cf. steinbergensis (Mosher 1968) *Neogondolella* cf. *Navicula* (Huckride 1958)	M. Orchard, Geological Survey of Canada
Uslika Formation	f9	92JN24-6	C-189662	coal	Eocene	Selected flora: *Alnipollenites verus* Potonié, 1931 Betulaceae *Ericipites compactipolliniatus* (Traverse) Norris, 1986 *Sphagnum* sp. *Paraalnipollenites alterniporus* (Simpson) Srivistava, 1975 *Ulmipollenites undulosus* Wolff, 1934	A.R. Sweet, Geological Survey of Canada

RADIOMETRIC AGE DATA

Sample number	Unit	Location	Method/Material	Date (Ma)
JN-90-7-3[1]	rhyolite dyke	fault zone west of Mt. Milligan 93N/1	U/Pb zircon	169.3 ± 5
KB-90-20-4e[1]	crowded porphyritic monzodiorite	Tas claims 93K/16 UTM Zone 10, 415730E, 6084745N	U/Pb zircon	204.2 ± 9
JN-92-16-8[1]	quartz-plagioclase dacite flow	ridge top between Twin and Groundhog creeks, 93N/11 UTM Zone 10, 358100E, 6167525N	U/Pb zircon	199.7 ± 0.7
MM-90-2-1[1]	plagioclase-phyric granite	ridge top south of Mount Milligan 93N/1 UTM Zone 10, 431800E, 6113750N	U/Pb zircon, titanite	168.6 ± 0.6
JN-91-17-2[1]	crowded porphyritic monzonite	BP-Chuchi property UTM Zone 10, 402015 E, 6124700N	U/Pb titanite	188.5 ± 2.5
JN-90-2-3[1]	crowded porphyritic monzonite	Rainbow dike, Mt. Milligan property UTM Zone 10, 434500E, 609000N	U/Pb rutile, zircon	182.5 ± 4
KB-921-13[2]	Evs; rhyolite flow	roadcut .5 km west of Germansen Lake 93N/10 UTM Zone 10, 376900 E, 6172450N	K/Ar biotite	48.2 ± 1.2
G-72-36[3]	EJH: Hogem monzonite	Chuchi Mountain, next to Chuchi syenite 93N/2	K/Ar biotite	183±5
KWANIKA[3]	EKH: Hogem quartz monzonite	west of project area 93N/6	K/Ar biotite	114±4
COL-12[3]	EJH: Hogem monzonite	Col occurrence 93N/2	K/Ar biotite	179±5
Southern Star Stock (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	182.5 +4.3/-0.6
North Slope intrusion (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	183 ± 3
Heidi Lake Stock (Heidi Lake suite)[4]		Mt. Milligan	U/Pb zircon	189 +3.3/-1.5

1. This study. Analysis at the University of British Columbia Geochronology Laboratory. See Appendix 7 for full analytical data.
2. This study.. Analysed material -40 to -60 mesh biotite, very clean fresh separate with no visible alteration, <0.5% impurities. K=6.67± 04%, n=2; Ar^{40*} = 12.649 x 10^{-6} cc/gm (5.644 x 10^{-10} mol/gm); 92.6% Ar^{40*}. J.Harakal, D. Runkle, Geochronology Laboratory, Department of Geological Sciences, University of British Columbia.
3. Garnett (1978)
4. Mortensen *et al.* (1993)

LEGEND

LAYERED ROCKS

Miocene to Pleistocene

- MPb — Olivine-bearing basalt

Eocene (-Oligocene?)

- sb — Volcanic wacke; plant-bearing, volcanic ash-rich mudstone; basalt

Eocene

- u — USLIKA FORMATION: conglomerate, sandstone, siltstone, mudstone, minor coal
- vs — Quartz-eye rhyolite tuffs and flows; minor mafic lapilli tuff; siltstone, sandstone, quartzo-feldspathic conglomerate

Cretaceous or Tertiary

- KTv — Maroon, orthoclase and quartz-bearing tuff with plagioclase-porphyritic volcanic fragments

Toarcian

- lJs — Arkose, greywacke, sandstone, siltstone, minor conglomerate

Lower Jurassic

- lJCL — Sinemurian?-Pliensbachian CHUCHI LAKE succession: plagioclase±augite porphyry flows and fragmental volcanics
  - lJCLa — Heterolithic agglomerate
  - lJCLb — Plagioclase±augite and augite±plagioclase porphyry andesite, latite and dacite flows
  - lJCLc — Augite-olivine±hornblende±plagioclase basalt flows
  - lJCLd — Intravolcanic sedimentary sequence: sandstone, siltstone, shale, cherty tuff
  - lJCLe — Heterolithic conglomerate

Sinemurian
TWIN CREEK succession: heterolithic lapilli tuff, plagioclase±quartz porphyritic flows and agglomerate/tuff breccia

  - lJTCb — Plagioclase±quartz porphyritic flows, lapilli and crystal tuff; plagioclase-augite phyric flows
  - lJTCa — Plagioclase, augite, hornblende phyric lapilli tuff, agglomerate

- lJ?f — Jurassic? felsic unit: heterolithic lapilli tuff, agglomerate, conglomerate, amygdaloidal augite porphyry flows, crystal ash tuffs (plagioclase>augite); clasts of plagioclase-rich volcanics, monzonite intrusives, maroon augite porphyry and cherty tuffaceous sediments

Triassic or Jurassic

- >Jt — VEGA CREEK succession: maroon-brown to grey-brown plagioclase and augite-phyric lapilli tuff, agglomerate, basalt.

Upper Triassic

Takla Group

- u>PM — PLUGHAT MOUNTAIN succession: predominantly green augite±plagioclase-porphyritic basalt flows and fragmentals, maroon basalt, pillow basalt, amygdaloidal olivine porphyritic basalt, heterolithic lapilli tuff, volcanic sandstone and siltstone, limestone
  - u>PMl — Limestone (Eaglenest reef)
  - u>PMb — Maroon augite±olivine basalt flows, flow breccia, minor red sandstone
- u>WL — WITCH LAKE succession: mainly green and minor maroon, augite±plagioclase and hornblende±plagioclase porphyritic volcaniclastics and flows
  - u>WLa — Augite (±plagioclase±olivine±hornblende) porphyry agglomerate, lapilli tuff and epiclastic sediments
  - u>WLb — Trachyte and tuff-breccia
  - u>WLc — Plagioclase porphyry latite flows and agglomerate
  - u>WLd — Epiclastic sediments (sandstone, siltstone); minor amygdaloidal trachyte and dacite flows.
- u>WG — WILLY GEORGE succession: augite-plagioclase lapilli tuff, crystal tuff, sedimentary breccia, arkose/wacke, argillite, siltstone
  - u>WGs — Arkose/wacke, argillite, siltstone
  - u>WGdx — Breccia with large dacite clasts
- u>IL — INZANA LAKE succession: volcanic sandstone, green tuff, lapilli tuff, grey sandstone, argillite, slate, sedimentary breccia
- u>?T — TWELVE MILE basalt: pillow basalt, minor lapilli tuff

Middle to Upper Triassic

- mu>SC — SLATE CREEK succession: grey slate and siltstone; tuff, lapilli tuff, minor amygdaloidal andesite and basalt flows

Pennsylvanian to Permian

Nina Creek Group

PILLOW RIDGE succession

  -]PPRu — Pillow basalt ± variolites
  -]PPRl — Diabase-gabbro sill complex with minor chert-argillite screens

MOUNT HOWELL succession

  -]PMHu — Green and red ribbon chert, diabase sills
  -]PMHl — Grey to black argillite

Pennsylvanian to Permian

Lay Range Assemblage

-]PLRc — MAIN sequence: green and maroon augite± plagioclase and augite-olivine porphyritic basalt
-]PLRb — MAIN sequence: crystal and lapilli tuff, volcanic sandstone, siltstone, siliceous argillite, chert and quartz-bearing grit
-]P?LRa — COOK CREEK panel: thin-bedded siliceous siltstone and argillite, sandstone, siliceous tuff and bedded chert
-]PLR — Undivided Lay Range Assemblage

Mississippian

Lay Range Assemblage

- Mvs — Plagioclase porphyry lapilli tuff with limestone clasts; crystal tuff.

INTRUSIVE ROCKS

Cretaceous or Early Tertiary

- KTg — Quartz-eye porphyritic granite

Early Cretaceous

- EKG — GERMANSEN batholith: coarse-grained hornblende-biotite granite, equigranular to orthoclase megacrystic
- EKK — KLAWLI pluton: orthoclase-megacrystic, hornblende-biotite granite
- EKH — HOGEM intrusive suite: orthoclase-megacrystic granite, minor syenite

Early to Middle Jurassic

- EMJMM — MOUNT MILLIGAN intrusive suite: monzonite, granodiorite, diorite, gabbro (youngest phase 168.6±0.6 U/Pb titanite)

Early Jurassic

- EJH — HOGEM intrusive suite: monzonite, granodiorite, and diorite
  - EJHd — Diorite, gabbro
  - EJHy — CHUCHI syenite: syenite, quartz syenite
  - EJH/lJTCa — Border zone of Hogem suite, intrusive rocks intimately mixed with screens of metamorphosed lower Twin Creek volcanics
- EJHL — HEIDI LAKE intrusive suite: crowded porphryritic, hypabyssal monzonite, diorite, syenite (189+3.3/-1.5 to 182.5±5 U/Pb Zr)
- EJAC — APLITE CREEK intrusive suite: equigranular to porphyritic, fine to medium grained diorite and gabbro, intrusive breccia, porphyritic monzonite
- EJK — KALDER pluton: plagioclase megacrystic fine grained diorite, plagioclase phyric diorite
- EJT — TAS pluton: coarse grained diorite, granodiorite (204.2±9 U/Pb Zr on satellite ? dike)
- EJi — Coarse grained or porphyritic monzonite, diorite, syenite, granodiorite and gabbro
  - EJgb — Gabbro
  - EJm — Monzonite
  - EJd — Diorite

Late Triassic or Early Jurassic

- >JLL — LOUNGE LIZARD intrusive suite: variably-textured diorite and gabbro, minor large plagioclase porphyritic diorite dikes
- >JM — MAX Pluton: monzonite, diorite, monzodiorite, hornblendite, aplite
- >JVC — VALLEAU CREEK intrusive suite: fine to coarse-grained diorite, gabbro, pyroxenite and hornblendite TrJVCu: pyroxenite and hornblendite

SYMBOLS

- Geologic contact (defined, approximate, inferred, transitional)
- Alteration halo
- Fault (defined, approximate, inferred)
- Thrust fault (defined , approximate , inferred)
- Transcurrent fault (motion indicated)
- Bedding (tops known, unknown, overturned)
- Foliation
- Minor fold axis — 12
- Lineation — 12
- Fold axial trace — F1 F2
- Mineral occurrence & MINFILE number (Note: south of 55° N, prefixed by 093K; north of 55° N, prefixed by 093N) — 150
- Macrofossil locality — F1
- Microfossil locality — f1
- Radiometric date (U/Pb=uranium-lead, K/Ar=potassium-argon, bi=biotite, zr=zircon, ti=titanite) — 48.1±2.0 K/Ar bi
- Outcrop
- Small intrusion
- Diamond Drill Hole (only selected holes referred to in accompanying report are shown) — DDH
- Cross-section line — A A' A''
- Glacial striae