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# REGIONAL GEOLOGICAL MAPPING NEAR THE MOUNT MILLIGAN COPPER-GOLD DEPOSIT (93K/16, 93N/1)

**By JoAnne Nelson, Kim Bellefontaine, Kim Green and Mary MacLean**

*KEYWORDS*: Regional geology, Mount Milligan, porphyry Cu-Au, alkaline intrusions, Takla Group, Rainbow Creek formation, Inzana Lake formation, Witch Lake formation, Chuchi Lake formation, Tertiary basins, Takla intrusions, structural geology, Mount Milligan horst, metamorphism, alteration, mineralization.

## INTRODUCTION

The Nation Lakes area of central British Columbia is located approximately 75 kilometres north of Fort St. James and is accessed by well-maintained logging roads from Fort St. James and MacKenzie (Figure 1-10-1). Its current exploration importance is due to the 1987 discovery of the Mount Milligan porphyry copper-gold deposit by Lincoln Resources Inc. At present, the Mount Milligan deposit is nearing feasibility stage with geological reserves, currently under revision, of approximately 400 million tonnes grading 0.48 grams per tonne gold and 0.2 per cent copper (Rebagliatti, 1990, DeLong *et al.*, 1991, this volume). Exploration for other copper-gold porphyry deposits is very active in the area; by August 1990 approximately 90 per cent of the Wittsichica Creek (93N/1) and Tezzeron Creek (93K/16) map areas was staked.

The Nation Lakes regional mapping project was started in 1990 to assist exploration efforts by providing a geological database in this virtually unmapped area. Two 1:50 000 map sheets were covered in the summer of 1990. They are available as Open File 1991-3 (Nelson *et al.*, 1991). This high productivity was made possible due to the sparseness of outcrop, less than 5 per cent, and the excellent access to much of the area by logging roads. Goals of the project are as follows:

- To outline stratigraphic subdivisions of the Takla Group, which is undivided on previous reconnaissance-scale geological maps (Armstrong, 1949; Garnett, 1978).
- To locate intrusions and alteration zones as an aid to mineral exploration.
- To accurately locate previously documented mineral occurrences and add new showings.
- To provide lithogeochemical and stream-sediment data.
- To evaluate the potential of the area for new discoveries of porphyry-style mineralization and other types of mineral deposits.

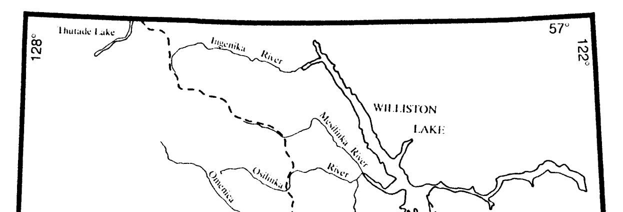



Figure 1-10-1. Location of Wittsichica Creek and Tezzeron Creek map areas (93N/1, 93K/16).

## REGIONAL GEOLOGIC SETTING

### THE TAKLA ARC

The Nation Lakes area is predominantly underlain by Early Mesozoic Takla Group rocks of island-arc affinity. The Takla Group and its southern equivalent, the Nicola Group, define the Quesnel Terrane or Quesnellia (Monger *et al.*, 1990). The northwest-elongate Hogem batholith is intruded into this terrane. The southern tip of this intrusion lies within the map area on the north shore of Chuchi Lake (Figure 1-10-2). The main phase of the Hogem batholith is dated by K-Ar methods as 176 to 212 Ma, and is considered to be an intrusive equivalent of at least part of the Takla Group (Garnett, 1978).

At the latitude of the map area the western border of Quesnellia is the Pinchi fault. Here the Takla Group lies in tectonic contact with oceanic rocks of the Cache Creek Terrane (Figure 1-10-2). The presence of Triassic blueschists along the Pinchi fault (Paterson, 1977) suggests that a subduction zone lay west of the Takla arc. The eastern border of Quesnellia is a complex zone of faults that place lower Takla rocks against the Late Paleozoic Slide Mountain Terrane (Ferri and Melville, in preparation) and metamorphic rocks of autochthonous North America, notably the southern Wolverine complex near Carp Lake (Struik, 1990).

Regionally, the Takla Group comprises a lower Late Triassic sedimentary unit which interfingers with and is overlain by voluminous volcanic, pyroclastic and epiclastic rocks. These rocks are intruded by coeval plutons which range up to Early Jurassic in age. Augite-phyric rocks predominate, although plagioclase and hornblende are present

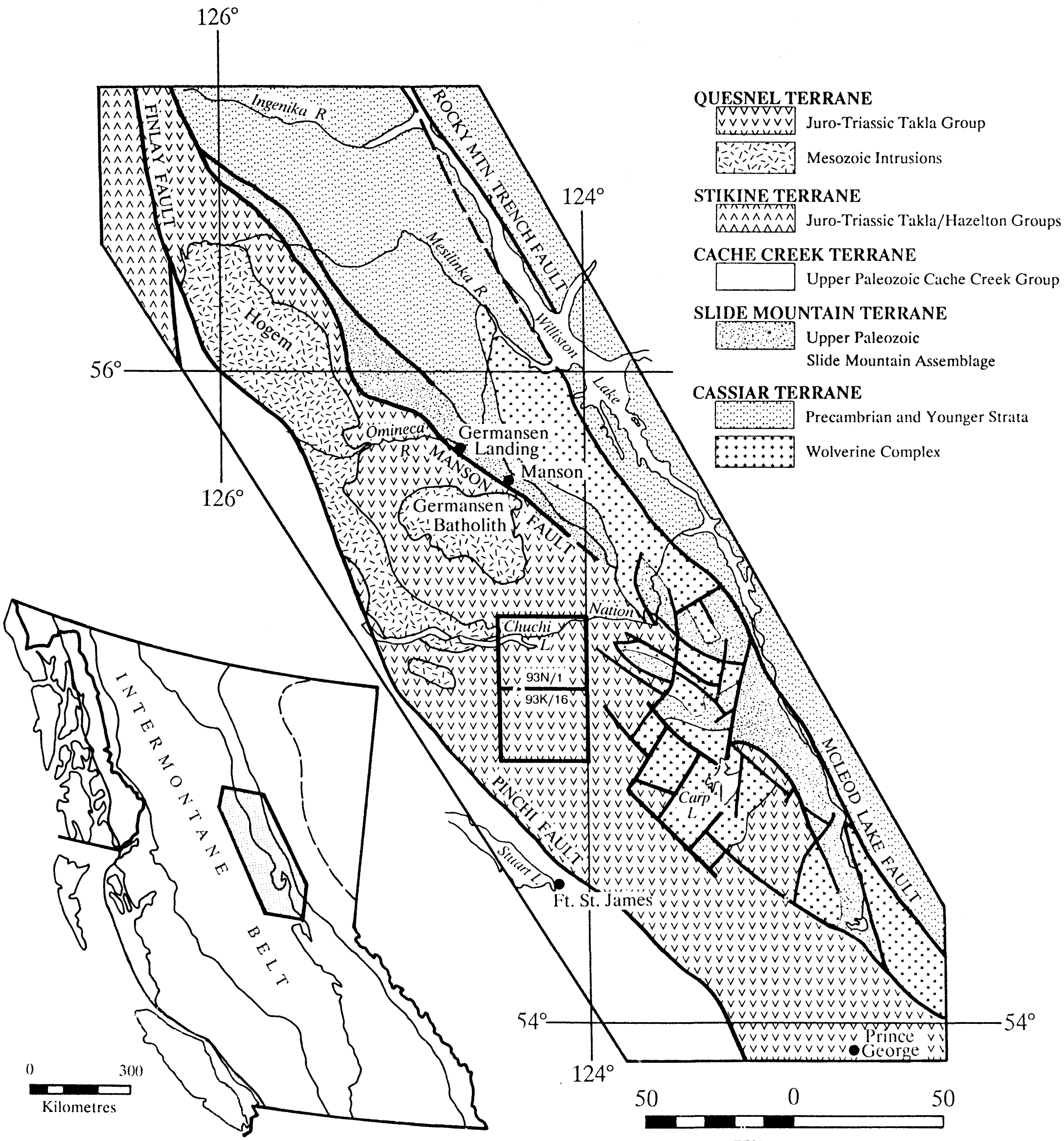



Figure 1-10-1. Location of Wittsichica Creek and Tezzeron Creek map areas (93N/1, 93K/16).

and can be abundant. Takla volcanics tend to be unusually potassium rich and are transitional to alkalic in their major-element chemistry (Rebagliati, 1990; Ferri and Melville, in preparation). They share this characteristic with contemporaneous arc-volcanic rocks of the Nicola Group in the Quesnel Terrane (Mortimer, 1987) and the Stuhini Group in the Stikine Terrane near Galore Creek (Logan and Koyanagi, 1989). The Stikine Terrane is separated from

Quesnellia either by major faults or by the strongly allochthonous Cache Creek Terrane (Monger *et al.*, 1990). These petrologic and petrochemical parallels between Quesnellia and Stikinia, two apparently disparate tectonic entities, pose an interesting question in Cordilleran geology. Stratigraphies of the two Early Mesozoic arcs show further similarities as discussed later.

## The Alkaline Porphyry Copper-Gold Association

The potassium-rich volcanics of the Takla and Nicola groups have been classified as shoshonites by Mortimer (1987) and de Rosen-Spence (1985). Shoshonites are thought to arise from unusual conditions within magmatic arcs. A variety of tectonic mechanisms have been called upon to explain the strongly alkalic nature of these rocks, including the breaking off and foundering of the downgoing slab (de Rosen-Spence, 1985), mantle metasomatism (Foden and Varne, 1980) and the melting of subcontinental lithosphere during subduction (Varne, 1985). Whatever the ultimate origin of shoshonites, their coeval and cogenetic alkaline intrusions tend to host or nucleate porphyry-style deposits that are enriched in both copper and gold. There are many excellent examples of alkalic porphyry copper-gold deposits in British Columbia, most of them associated with Late Triassic to Early Jurassic intrusive bodies in Quesnellia and Stikinia (Barr *et al.*, 1976). Operating mines include Similco (Copper Mountain) and Afton; mine prospects include Mount Milligan, Mount Polley and Stikine Copper (Figure 1-10-3).

Barr *et al.* (1976) outlined exploration parameters for alkalic porphyry copper-gold deposits. These are summarized here to provide a context for the following discussion of local geology. One of the most important characteristics of alkaline porphyry deposits is that they tend to be spatially related to long-lived faults. Faults that control early intrusive activity are later reactivated and also control much younger features such as Eocene extensional basins. Both Copper Mountain and Afton/Ajax lie near important Eocene basin-bounding faults, which are interpreted as reactivated Triassic-Jurassic structures (V.A. Preto, personal communication, 1990).

The alkalic intrusive bodies associated with porphyry copper-gold deposits are typically small and high level to subvolcanic. Their textures strongly resemble those of volcanic flows. These intrusions consist of densely crowded, blocky plagioclase phenocrysts about 2 millimetres in diameter, and perhaps less abundant biotite, augite, hornblende, or orthoclase, in a dense very fine grained feldspar matrix. They are distinguished from surrounding flows by their limited areal extent, lack of volcanic features such as amygdules and pyroclastic facies, extremely crowded phenocrysts and a relatively more felsic composition. Intrusive breccias and diatremes are also an important aspect of alkaline porphyry systems (Barr *et al.*, 1976; Sillitoe, 1990).

Alkalic porphyries often have associated propylitic and potassic alteration. Abundant magnetite, part of the potassic suite, makes airborne and ground magnetic surveys an important exploration tool. Extensive pyrite haloes outline the porphyry systems and can aid the prospector who does

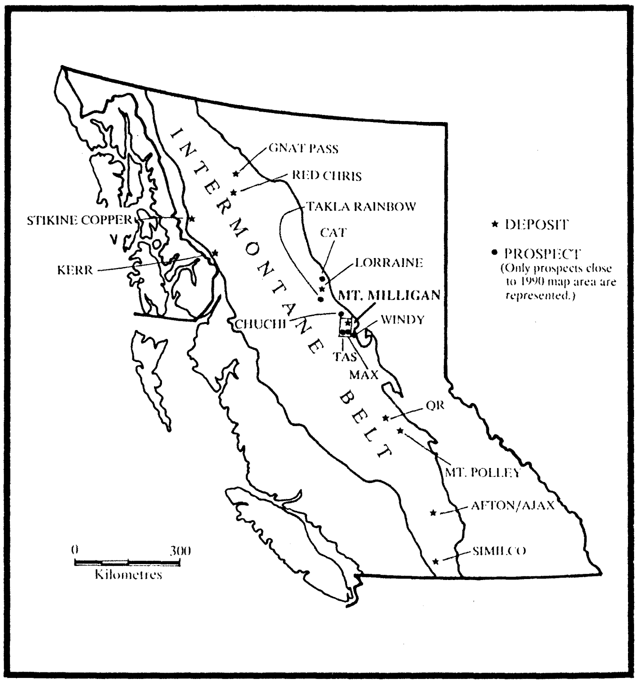



Figure 1-10-3. Distribution of porphyry copper-gold deposits associated with alkaline intrusions within the Intermontane Belt of British Columbia. Modified after Legun *et al.* (1990).

not have access to a petrographic microscope or feldspar-staining apparatus. Small, high-grade veins such as the Esker veins at Mount Milligan (Rebagliati, 1990) and the gold-magnetite veins and magnetite-matrix breccias at the Cat property, may signal the presence of nearby large-tonnage, lower grade zones.

## Regional Structural Setting

The Nation Lakes area lies between two regional-scale northwest-trending fault systems that probably had significant dextral offsets in Late Mesozoic to Eocene time; the Pinchi fault to the west and the Manson, McLeod and Northern Rocky Mountain Trench faults to the east. Struik (1990) has shown how transcurrent motion in this area was transferred from one fault system to the other through sets of subsidiary faults in the block between. The southern Wolverine complex, centred on Carp Lake 20 kilometres southeast of the present map area (Figure 1-10-2), is an uplifted horst of basement gneisses. it is bounded by a series of steep, northwest-trending dextral faults and northeast-trending low-angle normal faults (Struik, 1989, 1990). Several of the northwest-trending bounding faults project into the Nation Lakes map area (Figure 1-10-2).

# CAPSULE EXPLORATION HISTORY

Figure 1-10-3 shows the distribution of significant copper-gold deposits associated with alkaline porphyry systems in Quesnellia and Stikinia. The Nation Lakes region has seen two phases of intense exploration activity in the last two decades. The first pulse, dating roughly from 1970 to 1975, concentrated on deposits in and near the Hogem

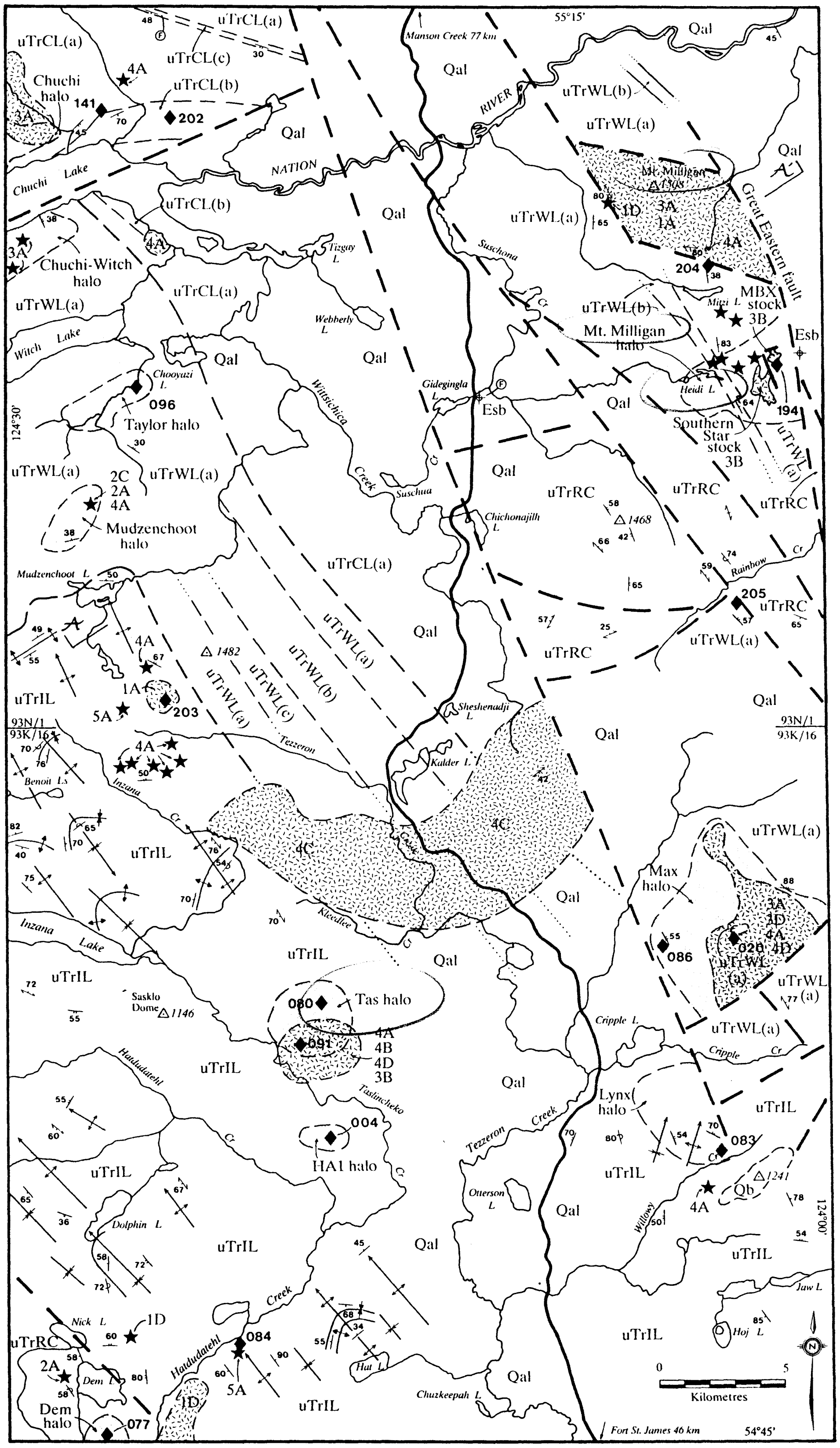



Figure 1-10-4a. Generalized geology and mineral occurrences in the Nation Lakes map area (Wittsichica Creek 93N/1 and Tezzeron Creek 93K/16 map areas). Refer to MINFILE descriptions in text.

## LEGEND

### LAYERED ROCKS

**QUATERNARY**

| | |
|---|---|
| Qal | *UNCONSOLIDATED GLACIAL TILL AND ALLUVIUM* |

**QUATERNARY?**

| | |
|---|---|
| Qb | *OLIVINE-BEARING BASALT* |

**EOCENE - OLIGOCENE**

| | |
|---|---|
| Esb | *BASALT, VOLCANIC WACKE AND FOSSILIFEROUS VOLCANIC ASH-RICH MUDSTONE* |

**UPPER TRIASSIC(-JURASSIC?)**

**TAKLA GROUP**

| | |
|---|---|
| uTrCL | **CHUCHI LAKE FORMATION: (A)** *GREEN AND MAROON HETEROLITHIC AGGLOMERATE;* **(B)** *PLAGIOCLASE-PORPHYRY TRACHYTE FLOWS AND BRECCIAS;* **(C)** *INTERVOLCANIC SEDIMENTS* |
| uTrWL | **WITCH LAKE FORMATION: (A)** *AUGITE (± PLAGIOCLASE ± HORNBLENDE) PORPHYRY AGGLOMERATE, VOLCANIC BRECCIA, LAPILLI TUFF AND EPICLASTIC SEDIMENTS;* **(B)** *TRACHYTE FLOWS AND TUFF-BRECCIAS;* **(C)** *PLAGIOCLASE (± AUGITE) PORPHYRY LATITE FLOWS AND AGGLOMERATES* |
| uTrIL | **INZANA LAKE FORMATION:** *VOLCANIC SANDSTONE, SILTSTONE, MUDSTONE, ARGILLITE, LAPILLI TUFF AND SEDIMENTARY BRECCIA* |
| uTrRC | **RAINBOW CREEK FORMATION:** *GREY SLATE, THIN-BEDDED SILTSTONE, MINOR VOLCANICLASTIC SEDIMENTS* |

### INTRUSIVE ROCKS

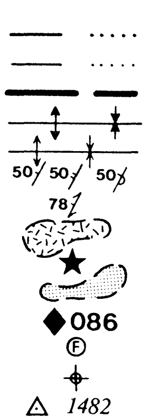
**LATE CRETACEOUS-EARLY TERTIARY?**

| | |
|---|---|
| 1 | **GRANITE SUITE: (1A)** *EQUIGRANULAR, COARSE GRAINED GRANITE;* **(1D)** *RHYODACITE/DACITE* |

**LATE TRIASSIC-EARLY JURASSIC**

| | |
|---|---|
| 2 | **SYENITE SUITE: (2A)** *COARSE GRAINED, EQUIGRANULAR SYENITE;* **(2C)** *MEGACRYSTIC SYENITE* |
| 3 | **MONZONITE SUITE: (3A)** *EQUIGRANULAR, COARSE GRAINED MONZONITE;* **(3B)** *CROWDED PLAGIOCLASE PORPHYRITIC MONZONITE;* **(3D)** *SPARSELY PORPHYRITIC LATITE* |
| 4 | **DIORITE/MONZODIORITE SUITE: (4A)** *COARSE GRAINED, EQUIGRANULAR DIORITE/MONZODIORITE;* **(4B)** *CROWDED PLAGIOCLASE PORPHYRITIC DIORITE;* **(4C)** *MEGACRYSTIC PLAGIOCLASE (± AUGITE) PORPHYRITIC DIORITE;* **(4D)** *SPARSELY PORPHYRITIC ANDESITE* |
| 5 | **GABBRO/MONZOGABBRO SUITE: (5A)** *COARSE GRAINED, EQUIGRANULAR GABBRO/MONZOGABBRO* |

### SYMBOLS



geologic contact (approximate, inferred).....
lithologic contact (approximate, inferred)....
fault (defined, inferred)..............................
$F_1$ axial trace (anticlinal, synclinal)..............
$F_2$ axial trace (antiformal, synformal)...........
bedding (tops known, tops unknown, overturned) 50 50 50
foliation........................................................ 78
large intrusion ............................................
small intrusion ............................................
area of alteration .........................................
mineral occurrence and MINFILE number... 086
fossil locality ...............................................
diamond drill hole .......................................
elevation in metres ..................................... 1482

batholith. This led to the discovery of the Lorraine deposit by Granby Mining Corporation (Wilkinson *et al.*, 1976) and the Takla Rainbow prospect. Porphyry systems were also identified south of Chuchi Lake (reported in Campbell, 1990). Interest in porphyry systems declined until the mid-1980s when strong market prices for both copper and gold made alkaline porphyry deposits desirable exploration targets. Recent exploration efforts have extended outside the Hogem batholith to the entire Intermontane Belt. The most important result so far of this resumed interest in the Nation Lakes area was the 1987 discovery of the Mount Milligan deposit and its subsequent development to feasibility stage. Major drilling programs were conducted in the summer of 1990 on the Cat property owned by BP Resources Canada Limited and Lysander Gold Corporation, on Cathedral Gold Corporation's Takla Rainbow property, on Rio Algom Exploration Inc.'s Klawli property, and on the BP-Digger Resources Limited Chuchi property north of Chuchi Lake. The Lorraine is being investigated by Kennco Explorations (Canada) Limited. In addition, large alteration systems with anomalous copper and gold values are under investigation south of Chuchi Lake by Rio Algom, Westmin Resources Limited, and Noranda Exploration Company, Limited, on the Max claims by Rio Algom, on Grand America Minerals Ltd. Webb claims, and on Placer Dome Inc.'s Windy property. Noranda's promising Tas property has been inactive since 1989, its potential still unclear. Most other properties and projects are in the early stages of exploration.

# LOCAL GEOLOGY

## STRATIGRAPHY OF THE TAKLA GROUP

Mapping in the Nation Lakes area in 1990 resulted in a provisional subdivision of the Takla Group into four informal formations, the Rainbow Creek, Inzana Lake, Witch Lake and Chuchi Lake formations. A nearly complete stratigraphic succession can be seen in the broad anticline that outcrops from south of Chuchi Lake to the southern limit of mapping near Dem Lake (Figure 1-10-4A). Epiclastic sediments of the Inzana Lake formation are overlain by augite and other porphyritic volcanics and pyroclastics of the Witch Lake formation. These in turn pass upward into polymictic lahars and subaerial flows of the Chuchi Lake formation. Elsewhere, Takla units occur in incomplete, fault-bounded panels (Figures 1-10-4A, 4B and 5.)

### RAINBOW CREEK FORMATION (uTrRC)

The Rainbow Creek formation is a basinal package of dark grey slate with lesser siltstone and, in some exposures, epiclastic interbeds. It occurs in three fault-bounded structural blocks in the Nation Lakes map area – one north of Rainbow Creek, one near Dem Lake in the far southwest corner of the map area, and one intersected in a drillhole southeast of the Mount Milligan deposit.

The exposures north of Rainbow Creek are divided into two sub-blocks based on different trending schistosities and distinctive lithologic suites (Figures 1-10-4 and 5). The northern block consists mostly of monotonous grey slate with sparse, thin siltstone interbeds and minor quartz sand-

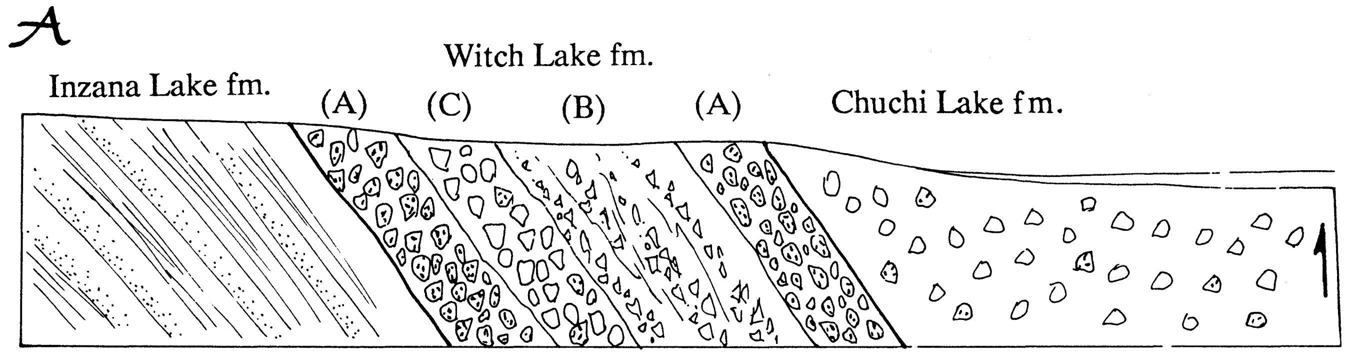



Figure 1-10-4b. Cross-section of Wittsichica Creek map area.

stones. The southern block, next to Rainbow Creek, is also dominated by slate, but contains some volcanic and volcaniclastic components. Near Dem Lake, the grey slate contains very common siltstone interbeds and also sedimentary breccias composed of slate interclasts. The black slate intersected in drill hole DDH-274, southeast of the Mount Milligan deposit, is limy, graphitic and soot-black.

All of these exposures are completely fault-bounded. Their original relationships to the rest of the Takla Group are not known. 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. Near Quesnel this unit is termed the "Triassic black phyllite" (Struik, 1988, Bloodgood, 1987, 1988). More locally, Ferri and Melville (in preparation) recognize dark grey slates, limy slates, siliciclastics and limestones of Late Triassic age in the Manson Creek area, which they propose to include in the lower part of the Slate Creek formation. The Rainbow Creek formation is correlated to these on lithologic grounds.

### INZANA LAKE FORMATION (uTrIL)

Extensive sedimentary, epiclastic and lesser pyroclastic rocks outcrop in the map area from north of Inzana Lake to the southern map border. Due to the lithologic monotony shown by this package over large areas, and to the tight folding within it, no subdivisions were made. It 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 Rainbow Creek formation. 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 occur mostly along the western margin of the map area. Fragments in the lapilli tuffs are characteristically sparse, less than 10 per cent 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.

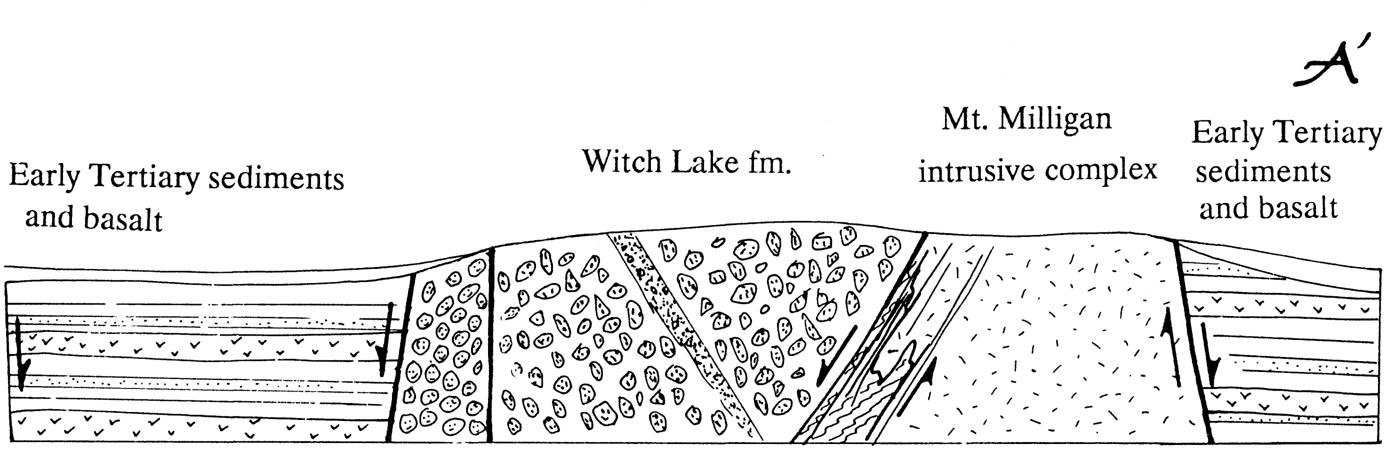
The sedimentary breccias contain mostly intrabasinal clasts of argillite, sandstone and fine-grained, green siliceous tuff. Volcanic and high-level plutonic clasts are also present, including plagioclase and pyroxene porphyry. At one exposure 300 metres east of the Fort St. James–Germansen road and 200 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 formation is transitionally overlain by augite porphyry agglomerates of the Witch Lake formation on the low ridge north of Mudzenchoot Lake. Its low stratigraphic position in the Takla Group and its character as facies equivalent of distant volcanic centres suggests that the Inzana Lake formation correlates with Unit 7 of the Takla Group near Quesnel (Bloodgood, 1988) and with the upper part of the Slate Creek formation of the Takla Group near Germansen Lake (Ferri and Melville, in preparation).

### WITCH LAKE FORMATION (uTrWL)

The best-known lithologies of the Takla Group are augite porphyry flows and pyroclastics. In the Nation Lakes area they are included in the Witch Lake formation, named for the thick, well-exposed sequences around Witch Lake. The Witch Lake formation has two main areas of exposure, one between Mudzenchoot and Chuchi lakes, where it is in stratigraphic continuity with the underlying Inzana Lake and overlying Chuchi Lake formations; and a fault-bounded structural panel on the eastern side of the Wittsichica Creek map sheet, which hosts the Mount Milligan deposit.

In addition to augite porphyry, a thick section dominated by plagioclase-porphyritic latites occurs in the Witch Lake formation south of Witch Lake. Acicular hornblende-plagioclase porphyries are locally abundant, particularly



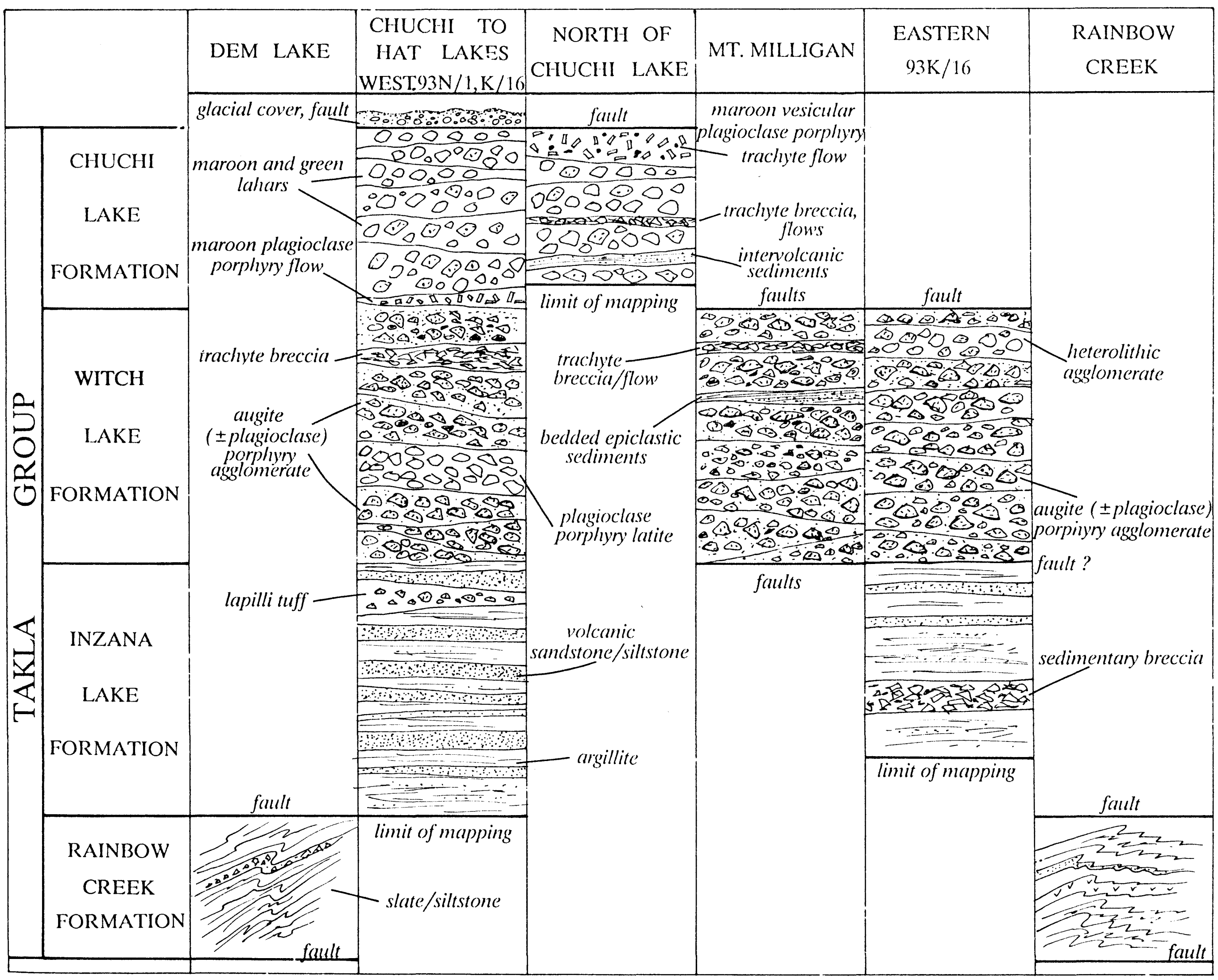




Figure 1-10-5. Composite stratigraphy of the Takla Group in the Nation Lakes area.

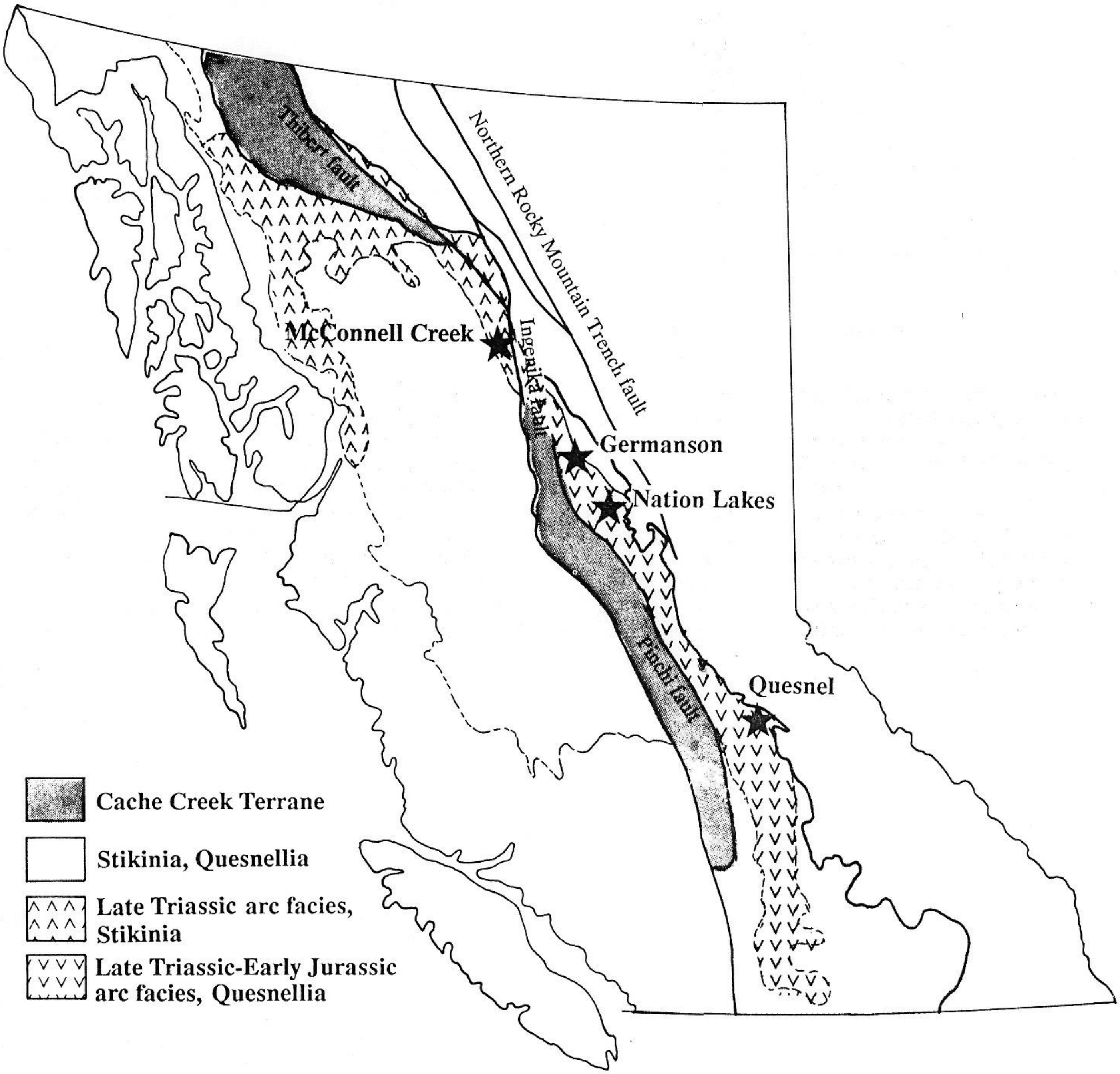



Figure 1-10-6a. Regional comparisons of Takla Group stratigraphy. Locations of stratigraphic sections and their terrane context.

south of Rainbow Creek and extending southward into the northeastern corner of the Tezzeron Creek map sheet. Here hornblende porphyries are the dominant lithology in agglomerates and in heterolithic aggregates that also contain the more common augite porphyries. At one locality south of Rainbow Creek, hornblendite and amphibolite clasts occur within the hornblende porphyries. One clast consists of clinopyroxenite in contact with amphibolite, reminiscent of Polaris-type ultramafic bodies (Nixon *et al.*, 1990).

Trachyte breccia occurs near the top of the western Witch Lake formation 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 augite porphyry suite that dominates the Witch Lake formation 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. Both small-augite por-

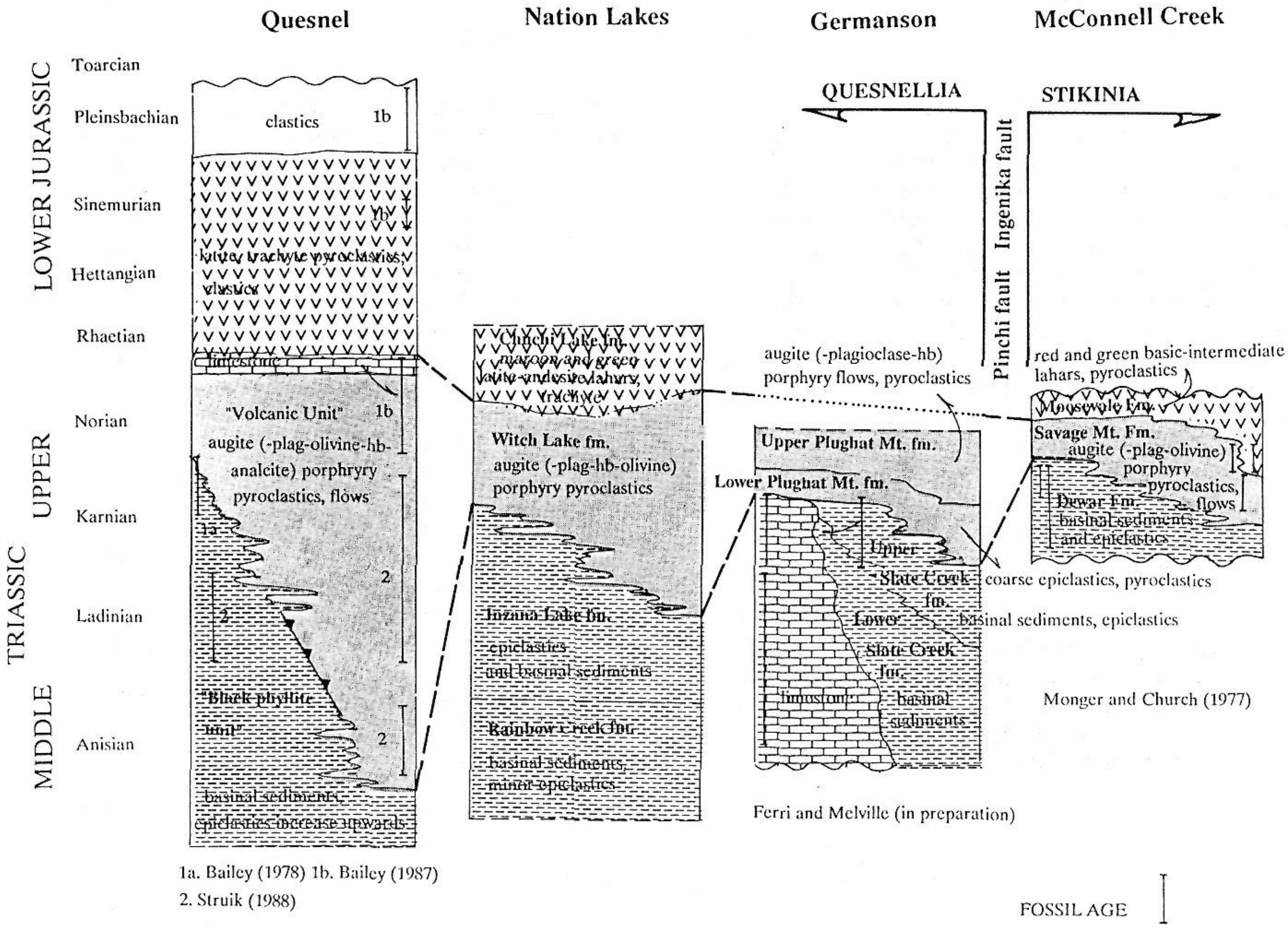



Figure 1-10-6b. Stratigraphic sections.

phyry and large-augite porphyry variations are present. Plagioclase and hornblende phenocrysts are subordinate and olivines rare. In terms of composition, the augite porphyries contain between 20 and 80 per cent matrix and phenocrystic plagioclase and in rare examples, primary potassium feldspar as a matrix phase. They are classified as andesites and basaltic andesites. The abundance of potassium feldspar in the volcanic rocks at and near the Mount Milligan deposit, has led past 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 plagioclase phenocrysts, and as fine-grained aggregates along bedding planes in the sediments. Such replacement distal to the deposit suggests that the highly potassic nature of the rocks within the deposit is due to wholesale replacement, converting andesites to "latites" and bedded andesitic sediments to "trachytes".

### CHUCHI LAKE FORMATION (uTrCL)

The intermediate to felsic Chuchi Lake formation transitionally overlies the Witch Lake formation along a northwest-trending contact that can be traced for 25 kilometres south of Chuchi Lake. The best exposures are seen north of Chuchi Lake; however, in this area the basal contact with the Witch Lake formation lies north of the Wittsichica Creek map sheet. In contrast with the marine Witch Lake formation, the Chuchi Lake formation shows evidence of deposition in a partly subaerial environment. It is dominated by polymictic plagioclase porphyry agglomerates and breccias. They are typically matrix supported and grey-green to pale maroon in colour. One of these lahars is in contact with a thin volcanic sandstone bed containing abundant wood fragments on bedding planes. Wood fragments caught up in the hot lahar are evidenced by black cores of remnant carbonaceous material with reaction rims.

The plagioclase($\pm$augite$\pm$hornblende) porphyries contain from 70 to 80 per cent plagioclase and from zero to 15 per cent matrix potassium feldspar. They are andesites and latitic-andesites.

Another characteristic lithology of the Chuchi Lake formation is dark maroon, felsic latite to trachyte flows with large, irregular, partly filled amygdules. Microscopically, the flows consist of potassium feldspar and plagioclase in varying proportions. Some are plagioclase phyric. The amygdules are 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, 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 is cut by the Hogem batholith.

Hornblende porphyry with acicular phenocrysts occurs as clasts in polymictic breccias at the base of the Chuchi Lake formation 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 contain small inclusions of hornblendite and amphibolite.

The basal contact of the Chuchi Lake formation is gradational; it lies within a zone where mainly augite porphyry agglomerates of the Witch Lake formation pass upwards into polymictic agglomerates with small, abundant plagioclase phenocrysts in the clasts. As well, the dark green colours of the Witch Lake formation change to maroon, reddish and green shades. The top contact of the Chuchi Lake formation is not observed in the map area.

**TABLE 1-10-I**
**FOSSIL IDENTIFICATIONS**

Macrofossils identified by Elisabeth McIver of the Institute of Sedimentary and Petroleum Geology.

C-168233

Sample Number: JN-90-34-1

From thinly bedded, dark grey-black, volcanic-ash-rich mudstones and siltstones in drill hole DDH-89-2 located on the Assunta claims near Gidegingla Lake. Sample taken from drill-hole interval 270-288.5 metres.

NTS 93N/1

UTM ZONE 10; N6107925 E422600

Identifications:

SUBDIVISION: Gymnospermophytina
CLASS: Gymnospermopsida
FAMILY: Taxodiaceae

*Metasequoia 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: Proteacaea

*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

## Comparison with Other Takla Group Localities

In the Nation Lakes area dark grey to black siliciclastic and limy strata of the Rainbow Creek formation are inferred to pass upward into the mixed epiclastic/basinal Inzana Lake formation, which in turn is succeeded by the predominantly augite-phyric porphyritic volcanics of the Witch Lake formation, and finally by somewhat more felsic and polymictic subaerial pyroclastics and flows of the Chuchi Lake formation (Figure 1-10-5). As shown on Figure 1-10-6, this stratigraphy is closely analogous to the Takla Group near Quesnel (Struik, 1988; Bailey, 1988; Bloodgood, 1987; 1988) and in the Manson Creek area (Ferri and Melville, 1989 and in preparation). It also strongly resembles the Takla stratigraphy outlined by Monger (1977) and Monger and Church (1977) in the McConnell Creek map area (Figure 1-10-6). The Rainbow Creek and Inzana formations are equivalent to the Dewar Formation; the Witch Lake to the Savage Mountain Formation; and the Chuchi Lake to the Moosevale Formation. In both the McConnell Creek and Nation Lakes map areas Late Triassic marine sedimentation is succeeded by voluminous volcanism that becomes increasingly intermediate in composition and subaerial through time. The McConnell Creek map area lies within Stikinia (Figure 1-10-6A), therefore these stratigraphic parallels are present across a major terrane boundary.

## Post-Takla Stratigraphic Units

### EARLY TERTIARY SEDIMENTARY ROCKS AND BASALTS (Esb)

Recessive Early Tertiary strata may underlie fairly extensive regions of the map area. Evidence for this comes from a few drill holes east of the Mount 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 Mount 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 (*see* discussion on faults).

Near Gidegingla Lake, sandstone, siltstone and 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 Institute of Sedimentary and Petroleum Geology, Geological Survey of Canada, includes *Metasequoia occidentalis, Pinus* and *Picea* seeds, Betulaceae (birch) family, *Lomatia lineata*, and *Comptonia hesperia* Berry (Table 1-10-1). This flora is of Early Tertiary age (E. McIver, personal communication, 1990). Samples of this material have been submitted for pollen analysis. The basalts 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 materials include chalcedony, crystalline calcite, celadonite and zeolites such as mordenite. These basalts strongly resemble Early Tertiary basalts in the Gang Ranch area as well as basalts of the Endako Group.

These subsurface data point to the existence of previously unrecognized Early Tertiary basins within the map area, probably controlled by penecontemporaneous block faults. This point is further developed in the discussion of structures following.

#### QUATERNARY(?) BASALT (Qb)

Fresh olivine-bearing basalt is exposed on an east-trending ridge near Willowy Creek in the southeastern corner of the Tezzeron Creek map area (Figure 1-10-4A). It uncomformably overlies the Inzana Lake formation on a bevelled surface. It may be a separate outlier of the young basalt mapped by Armstrong (1949, Unit 15A) on Hunitlin Mountain 15 kilometres to the south, although he assigned it to the older Endako Group. 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.

#### QUATERNARY GLACIAL OVERBURDEN (Qal)

A large north-trending belt of glacial and glaciofluvial deposits, approximately 100 kilometres long and 10 to 20 kilometres wide, extends from Fort St. James to north of the Nation River (Armstrong, 1949). Glacial drift in the Nation Lakes area can reach thicknesses exceeding 200 metres (Ronning, 1989) and can make geological, geophysical and geochemical interpretation extremely difficult. Recent surficial studies by Gravel *et al.* (1991, this volume) and Kerr and Bobrowsky (in preparation) at and near the Mount Milligan deposit have helped to explain its surficial geochemical signature.

Geological interpretation in the heavily glaciated regions of the map area is based on small isolated outcrops that poke through the Quaternary cover and, on several key drill holes on the Mount Milligan (DDH-426, DDH-433, DDH-440, DDH-445, DDH-446, DDH-449) and Assunta (DDH NR-89-2) properties. These drill holes show that significant thicknesses of glacial material overlie down-dropped Tertiary basins. Thick glacial deposits may have an application as a regional-scale exploration tool for Tertiary basins in this part of the Intermontane Belt.

## INTRUSIVE ROCKS

### CLASSIFICATION: COMPOSITIONS AND TEXTURES

Prior to this project, two intrusive bodies appeared on published regional maps of the Nation Lakes area; the Hogem batholith and the Mount Milligan intrusion. Several other small intrusions had been located by exploration work. Presently, six bodies mappable at 1:50 000 scale have been located in the area, in addition to many small ones. The large intrusions are: the southern end of the Hogem batholith north of Chuchi Lake, the Mount Milligan complex situated 10 kilometres north of the deposit, the MBX and Southern Star intrusions at the Mount Milligan deposit, a complex monzonite-diorite intrusion on the Max claims northeast of Cripple Lake, the extensive plagioclase-megacrystic diorite south of Kalder Lake, and the Tas intrusive complex. Most are multiphase, complex intrusive bodies. The highly variable nature of the intrusions is shown by the following classification scheme, in which we attempt to logically subdivide the range of textures and compositions that are present. This classification emphasizes hand-sample character, because we believe this to be most useful to the field geologist. The rock names and modal compositions were confirmed microscopically. All but those noted below are considered to be part of the Triassic-Jurassic Takla intrusive suite.

Using the classification scheme of Streckeisen (1967) the following compositions are represented in the area: (1) granite, (2) syenite, (3) monzonite/monzodiorite, (4) diorite, and (5) gabbro/monzogabbro. This numbering scheme is used on the map (Figure 1-10-4A), however it does not imply relative ages for the intrusions. The variations in potassium feldspar content between and within individual intrusions makes sodium cobaltinitrate staining necessary for correct identification. Texturally, the intrusions may be (A) coarse-grained equigranular to somewhat porphyritic; (B) crowded-porphyritic; (C) porphyritic with megacrysts; or (D) porphyritic with sparse phenocrysts in a very fine grained matrix. Because of the abundance of fine-grained matrix material in the sparsely porphyritic intrusions, they are named using volcanic terminology: (1) rhyodacite/dacite, (2)trachyte, (3) latite/latitic andesite and (4) andesite.

#### THE GRANITE SUITE (1)

##### COARSE-GRAINED EQUIGRANULAR GRANITE (1A)

Two phases of this lithology are seen on Mount Milligan peak. The first is a sphene-bearing hornblende granite, which is probably a quartz-rich differentiate of the main Mount Milligan monzonites (3A). The second phase forms discrete bodies near the southern end of the Mount Milligan ridge. Large plagioclase phenocrysts and smaller quartz and biotite crystals are spaced in a foliated, medium-grained (2 mm) equigranular matrix of quartz, orthoclase and plagioclase. This texture is indicative of subsolidus recrystallization.

##### SPARSELY PORPHYRITIC RHYODACITE/DACITE (1D)

These bodies may be partly or wholly of Late Cretaceous to Early Tertiary age. They are concentrated in two areas; at the Mount Milligan deposit north to the western flank of Mount Milligan peak, and around Dem Lake in the southwestern corner of the map area. They generally occur as dikes, except for one large body east of Dem Lake. They are white, tan and grey in colour. Most contain clear, round to embayed quartz phenocrysts. Plagioclase phenocrysts range from millimetre size to megacrystic. Biotite and hornblende form small phenocrysts. The rhyodacites and dacites may be fine-grained textural variants of the porphyritic granite on Mount Milligan (1A).

### THE SYENITE SUITE (2)

#### Coarse Grained, Equigranular Syenite (2A)

These coarse-grained intrusive rocks contain sparse to fairly abundant 5 to 8-millmetre plagioclase phenocrysts in ioclase. They form small intrusions west of Dem Lake and 6 kilometres south of Witch Lake, They are also found as cognate inclusions in a welded trachyte tuff/brecccia of the Chuchi Lake formation.

#### Megacrystic Syenite (2C)

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.

### THE MONZONITE SUITE (3)

This is the most important intrusive suite in the map area. It dominates the Mount Milligan intrusion and the southern end of the Hogem batholith. The MBX and Southern Star stocks are monzonite porphyries.

#### Coarse-Grained Equigranular Monzonite (3A)

Coarse-grained monzonite is seen most prominently on Mount Milligan. It also occurs in the southern end of the Hogem batholith, as small intrusions immediately south of Chuchi Lake, and on the central ridge on the Max Claims. The large Mount Milligan body varies gradationally in mineralogy and fabric. Constituents include plagioclase, clinopyroxene, hornblende and biotite with interstitial orthoclase and minor quartz (less than 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. The Mount Milligan body also contains less abundant phases ranging from diorite to granite. Fabrics in the body vary from massive to foliated. The planar fabric is due to igneous plagioclase alignment and/or subsolidus recrystallization.

The Chuchi monzonite is unfoliated and varies in texture from coarse-grained to medium-grained "salt-and-pepper"

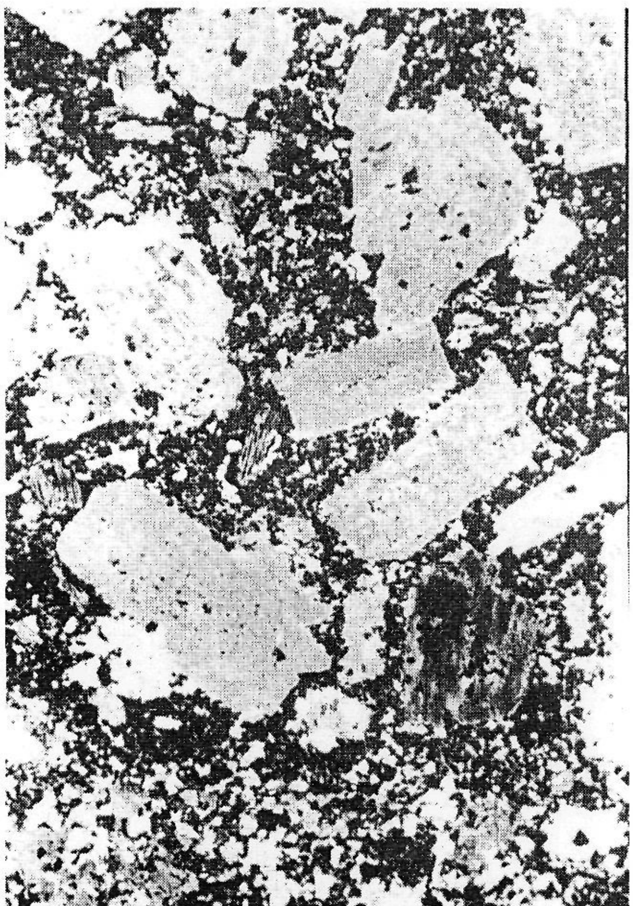


Plate 1-10-1. Creek zone crowded monzonite porphyry, near 66 zone. Plagioclase and minor chlorite-sericite-altered biotite phenocrysts in dark-stained K-spar-rich matrix. Station 90-JN2-4.

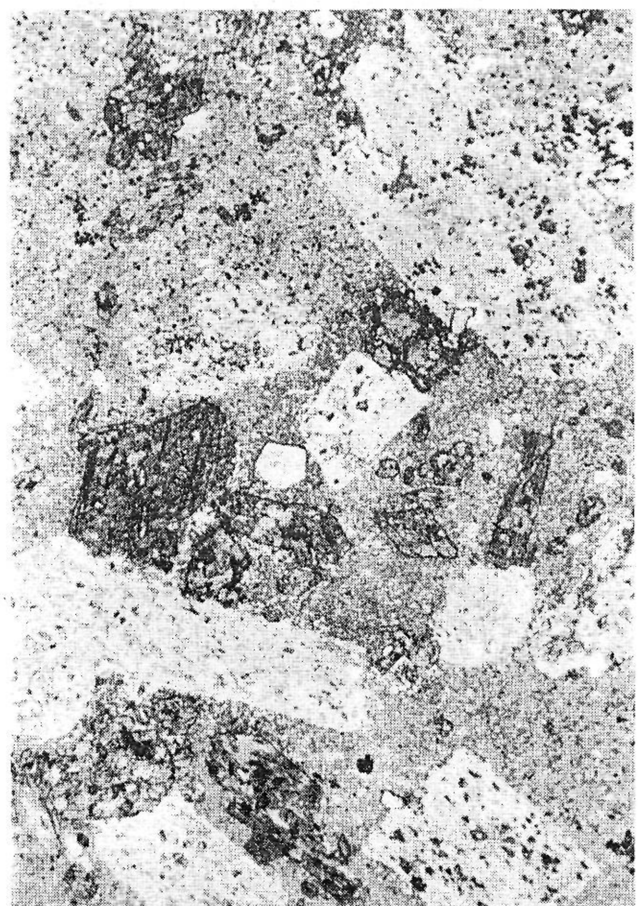


Plate 1-10-2. Somewhat crowded plagioclase-hornblende porphyry monzonite, West zone north of Heidi Lake. Station 90JN1-1.

textured to porphyritic. Diorite is also present in this body. The main mafic minerals are clinopyroxene and biotite.

### Crowded Plagioclase-Porphyritic Monzonite (3B)

This lithology is key to porphyry copper-gold deposits in the Nation Lakes area, as it is throughout the Quesnel trough. It makes up the MBX and Southern Star stocks at the Mount Milligan deposit and is also seen north of Heidi Lake, on the hill immediately south of Cripple Lake, and on the ridge at the centre of the Max claims. In general these rocks are quite felsic and mafic poor. Plagioclase phenocrysts 2 millimetres in size predominate, and hornblende, clinopyroxene and biotite may also be present (Plates 1-10-1 and 1-10-2). The MBX and Southern Star stocks are plagioclase biotite porphyries, the only occurrence of phenocrystic biotite in crowded porphyritic monzonites. The matrix is mostly plagioclase and potassium feldspar. Because of their low potassium contents, textural equivalents of the crowded monzonite porphyries on the Tas claims are classified here as diorites.

### Sparsely Porphyritic Latite (3D)

#### Plagioclase±Hornblende, Clinopyroxene Porphyritic Latite

This lithology occurs mainly as dikes. Small, elongate plagioclase phenocrysts with subordinate hornblende and/or clinopyroxene are sparse in a very fine grained, pale greenish matrix that consists of plagioclase, potassium feldspar and mafic minerals. Many dikes of these lithologic types occur south of Heidi Lake on the western fringes of the Mount 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 complexes. 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 formations: they may be feeders to the more evolved volcanic flows.

#### Acicular Hornblende±Plagioclase Porphyritic Latite

This highly distinctive intrusive type contains abundant needle-like hornblende crystals between 5 millimetres and 1 centimetre long. More irregular or blocky hornblendes may also be present, as well as xenoliths of hornblendite and amphibolite. The matrix consists of plagioclase, orthoclase, and smaller hornblende and augite crystals. Dikes of this lithology occur immediately west of the Mount Milligan deposit, near Mitzi Lake, south of Chuchi Lake, near Rainbow Creek, and in the southwestern corner of the Witsichica 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 exhibit an identical field character to these hornblende latites; they can only be distinguished by staining.

## THE DIORITE/MONZODIORITE SUITE (4)

### Coarse-Grained Equigranular Diorite/ Monzodiorite (4A)

A few examples of coarse-grained diorite were distinguished by potassium feldspar staining and thin-section examination. They are texturally similar to the orthoclase-rich monzonites and form in association with them. They occur on Mount Milligan, in the southern "tail" of the Hogem batholith, north of Benoit Lakes, and on the Max and Tas claims. Tas seems to be exceptional in that many of the intrusive phases are orthoclase poor. A large, multiphase pluton is shown in poor subcrop exposures east from the Free Gold zone. It is mostly diorite, although syenite with large orthoclase phenocrysts is also present.

### Crowded Plagioclase-Porphyritic Diorite (4B)

This lithology is seen 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 formation. On the Tas, plagioclase hornblende porphyry intrudes earlier, blocky hornblende porphyry andesite dikes. South of Chuchi Lake, the crowded porphyritic diorite shows intrusive-breccia and shattered textures in thin section.

### Megacrystic Plagioclase (±Augite) Porphyritic Diorite (4C)

This lithology is restricted to one large body south of Kalder Lake. Large, pale greenish plagioclase phenocrysts over a centimetre in size, and much smaller blocky augites, occur in a fairly dark green, very fine grained matrix. The matrix contains plagioclase and secondary actinolite needles. An accompanying phase contains smaller plagioclases.

### Sparsely Porphyritic Andesite (4D)

#### Hornblende-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 matrix of plagioclase and hornblende. Scattered examples of these "Tas" dikes are seen as far west as Inzana Lake. One acicular hornblende porphyritic andesite dike was mapped south of the Mount Milligan deposit.

#### Clinopyroxene-porphyritic Andesite

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 complex on the Max claims, and at the Lynx showing.

## THE GABBRO AND MONZOGABBRO SUITE (5)

### Coarse-grained, Equigranular Gabbro/ Monzogabbro (5A)

Hornblende-rich gabbros form a small part of the intrusive suite on Mount Milligan.

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.

A small coarse-grained augite-biotite-magnetite gabbro body is exposed near the northwestern corner of the map area.

### 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 gives stratigraphic constraint to the development of magma chambers. In the present map area, plutonic clasts other than hornblendites and gabbros occur only within the Chuchi Lake Formation. Many of the plagioclase-phyric clasts in the lahars could be equally 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 breccias. The two localities north of Chuchi Lake contain coarse, equigranular, felsic clasts that are hosted in plagioclase-phyric agglomerate and a partly welded trachytic tuff-breccia. Although clasts precisely equivalent in texture to the MBX stock were not seen, it is likely that the intermediate to felsic magma chambers that produced it were probably not active until after the transition to Chuchi Lake subaerial volcanism had occurred. The coincidence of elevation above wave base – and its implication of crustal thickening – with the development of evolved magma chambers carries a pleasing symmetry, which may be substantiated by zircon dates!

## METAMORPHISM

Three distinct metamorphic facies are seen in volcanic and plutonic rocks of the Takla Group. The lowest grade is subgreenschist, developed in the western and southern part of the map area. Metamorphic minerals include chlorite, carbonate, albite and rare pumpellyite. In general clinopyroxenes are fresh, and plagioclases are fresh to albitized and sericitized.

In the eastern part of the map area, including the vicinity of the Mount Milligan deposit and south to Cripple Lake, abundant clear to pale green actinolite indicates lower greenschist facies conditions. Actinolite occurs as mats of tiny acicular crystals and also as overgrowths on, and replacements of, clinopyroxene phenocrysts. This facies is developed in the megacrystic diorite south of Kalder Lake, and thus is not a contact metamorphic effect of Takla intrusions.

Near the peak of Mount Milligan, the lower greenschist passes into texturally destructive upper greenschist facies. Actinolites are more intense green. In many samples biotite and actinolite form well-oriented trains that wrap around phenocrysts and lithic fragments, and appear to develop at the expense of randomly oriented clusters. Hornfelses without visible fabric are also present. Within the Mount Milligan complex itself, there are screens of well-foliated hornblende-clinopyroxene-biotite-plagioclase-orthoclase granulites. The transition outwards from the Mount Milligan plutonic complex seems to be in part a thermal, and in part, a strain gradient.

## STRUCTURAL GEOLOGY

A strong northwesterly structural grain manifests itself in the Nation Lakes map area. It is defined by formation contacts, faults and several generations of folds. Each structural element is discussed separately below.

### FOLDS

The Takla Group in the western part of the map area occupies a regional-scale, gently northwest-plunging, upright anticline that extends from the south shore of Chuchi Lake to the southern limit of mapping. The trace of the fold is outlined by formational contacts between the Inzana Lake, Witch Lake and Chuchi Lake formations. They define a kilometre-scale fold closure near Mudzenchoot Lake and a northeastern limb that trends southeasterly to around Kalder Lake (Figure 1-10-2). Relatively incompetent sediments of the Inzana Lake formation are exposed in the core of the anticline and are strongly deformed. Although the Inzana Lake formation is well bed-

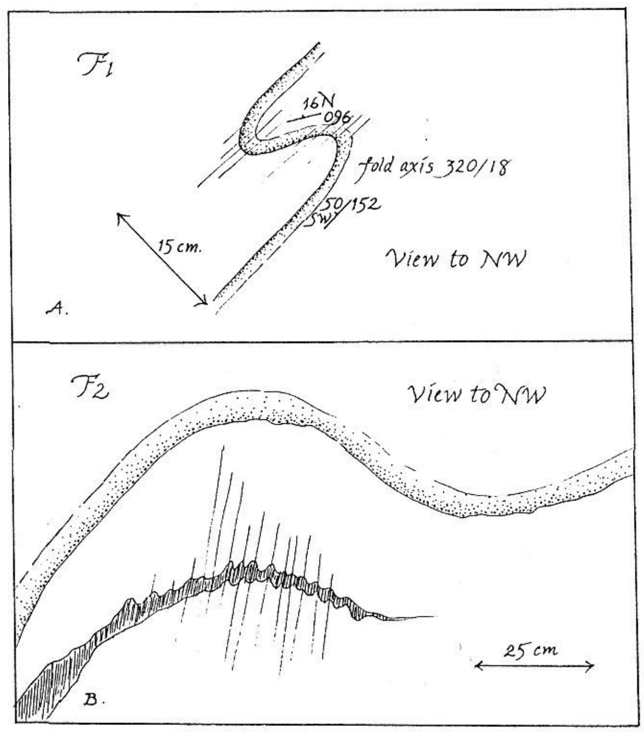



Figure 1-10-7. Sketches of $F_1$ and $F_2$ mesoscopic folds from the Inzana Lake formation. A) Overturned $F_1$ minor fold located on western limb of the major $F_2$ antiform. B) $F_2$ upright fold on the western limb of the major antiform.

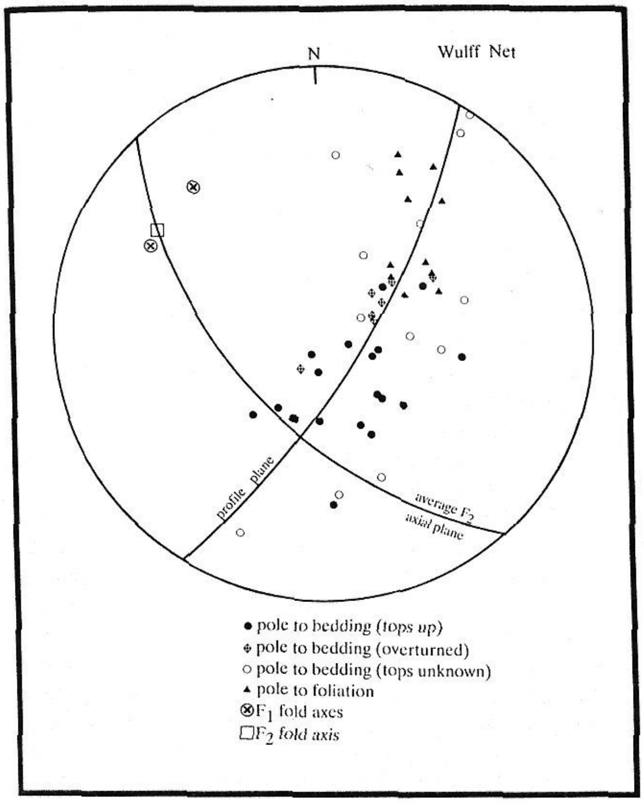



Figure 1-10-8. Stereonet plot of $F_1$ and $F_2$ structural data from north of Hat Lake.

ded, it lacks marker units. Thus structural interpretation of the region relies on rare minor folds and folds inferred on the basis of dip direction changes and facing reversals. Facing directions and bed orientations can change many times in a single outcrop due to the small scale of the folds. This, together with soft-sediment deformation, inverse grading, block faulting and rotation can make structures difficult to interpret. None the less, two coaxial phases of folding are clearly evident in the Inzana Lake formation.

The major evidence for two discrete phases of folding is the presence of overturned beds in the hinges of large scale $F_2$ upright folds, which indicate tight, recumbant refolded $F_1$ hinges. An excellent example of this occurs in the regional anticlinal hinge zone near Mudzenchoot Lake. An earlier phase of tight folding is clearly apparent where a facing/dip reversal occurs in northeast-striking strata. Other examples of $F_1$ folds defined by changes in facing directions in $F_2$ fold closures occur near Inzana Creek, north of Benoit Lake and north of Chuchi Lake. Although $F_1$ and $F_2$ folds are readily distinguishable in the closures of $F_2$ folds, the two are not easily discernible on the limbs of $F_2$ folds due to their apparently coaxial orientations.

Mesoscopic $F_1$ folds were only observed in a single outcrop north of Hat Lake (Figure 1-10-7a). Tight $F_1$ folds with gently northwest-plunging axes are overturned and show a northeast-directed asymmetry. These folds are superimposed on the southwest-dipping limb of a large-scale $F_2$ 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 $F_2$ fold. A stereonet plot for the outcrop shows a great circle distribution of bedding around both $F_1$ and $F_2$ fold axes (Figure 1-10-8). A small circle distribution of poles to bedding may be expected due to refolding, however, the lack of structural data from the hinge zone and northeast limb of the $F_2$ fold limits stereonet interpretation. An overturned bed that occurs close to the hinge of the $F_2$ fold also supports the existence of two phases of folding north of Hat Lake. The pole to this bed plots in the axial region of the $F_2$ fold on Figure 1-10-7.

Several examples of outcrop-scale $F_2$ folds were seen in the field (Figure 1-10-7b). They have gently northwest-plunging fold axes similar to $F_1$ and are characteristically open and upright. These folds appear to be parasitic to the regional anticlinal structure.

The large-scale fold closures shown on the map probably represent an oversimplified structural interpretation, as they are based on minor structures with dimensions that are too small to be accurately represented at 1:50 000 scale. The map pattern is still useful in that it shows the types of structures that are probably present in the map area.

Plate 1-10-3. *Shear band defined by actinolite needles in* megacrystic diorite, southeast of Kalder Lake. Station 90JN19-2.

The two phases of folding apparent in the Inzana Lake formation are probably part of a progressive deformation. $F_1$ and $F_2$ folds are coaxial but not coplanar; their axial planes are approximately perpendicular to each other. $F_1$ folds are tight and recumbent. A regional northeast transport direction is suggested by their symmetry. The vergences of $F_2$ minor folds are geometrically related to the map-scale upright anticlinal structure, rather than to regional tectonic transport. Folding is probably late Triassic to early Jurassic in age and is most likely related to docking of the Quesnel Terrane (Rees, 1987).

**FAULTS**

Faults play an important role in the interpreted map pattern of the area. Most of them are conjectural. Their basis is in small exposures of strongly deformed rocks, and in offsets of stratigraphy and abrupt changes of structural grain. Fault zones outcrop on the northeast shore of Dem Lake, west of Mount Milligan, in the valley of Rainbow Creek, on the ridge due east of Kalder Lake (Plate 1-10-3), on the southeast spur of the ridge on the Max claims, and a kilometre east of the map area on the Germansen-Cripple road. 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. West of Mount Milligan peak, the intrusive complex is in faulted contact with slightly metamorphosed Takla rocks. Quartz-plagioclase-biotite porphyry dikes within this fault zone are strongly deformed to mylonitized and have steep, northwesterly-striking foliations parallel to the inferred fault trace. Subhorizontal lineations and asymmetric pressure shadows in the outcrop indicate a dextral strike-slip motion for the fault. These plastically deformed rocks lie in contact with foliated, green clay gouge, which shows later, post-uplift, brittle deformation.

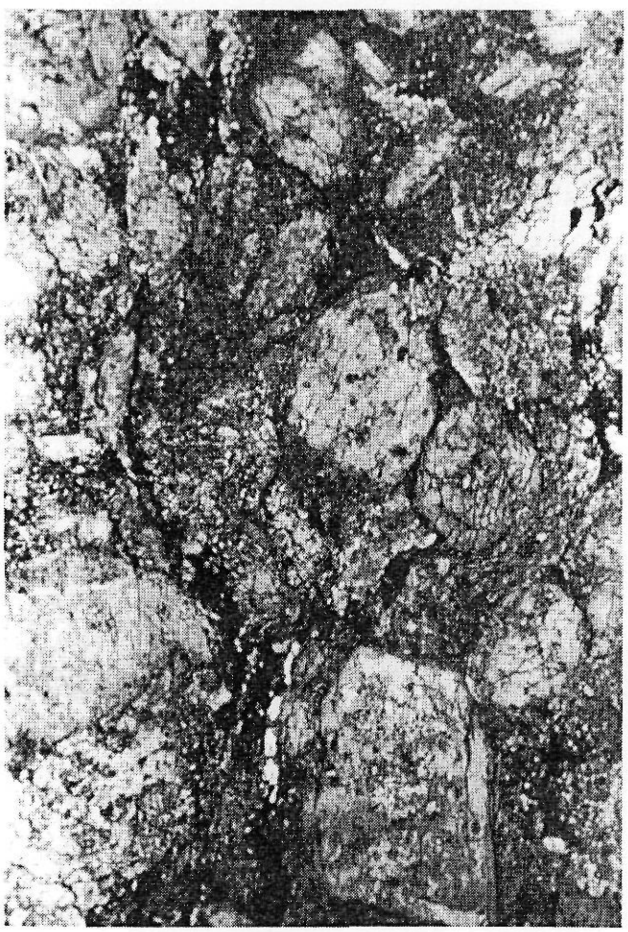


Plate 1-10-4. Biotite trains in deformed, schistose augite porphyry lapilli tuff northeast of Mount Milligan peak. Station 90JN8-11.

At the eastern edge of the Mount 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 Takla rocks against Early Tertiary continental clastics, basalt and coal. It is crosscut by quartz and plagioclase-porphyritic dikes, which show only minor shearing (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.

Other faults are inferred in order to explain map patterns. A northeasterly trending fault under Chuchi Lake is needed to separate the south-facing Chuchi Lake formation to the north from the east-facing Witch Lake formation to the south. The Early Tertiary sediments and basalts near Gidegingla Lake occupy a fault-bounded basin. The north-westerly trending bounding faults are necessary, in any event, to separate eastward-younging Chuchi Lake formation to the west from Witch Lake formation near Mount Milligan to the east, while the inferred northeasterly-trending faults are strong VLF linears (Ronning, 1989).

The overall map pattern shows a series of long, but ultimately discontinuous northwest-trending faults, linked by shorter, second-order northeast-trending faults (Figure 1-10-4A). This pattern is exactly that predicted for an area in which motion is transferred between two different northwest-trending dextral faults. The map pattern implies the same stress regime as Struik (1990) envisages for the contiguous McLeod Lake area.

**THE MOUNT MILLIGAN HORST**

The Mount Milligan intrusive complex is far from an ordinary plutonic body. It consists of at least two separate intrusive phases: sphene-bearing monzonite with gabbro and hornblende granite end-members; and porphyritic granite. Its wallrocks and numerous pendants include regionally metamorphosed amphibolites and granulites as well as contact hornfelses. The transition from the plutonic/high-grade metamorphic core of the complex into low-grade metamorphic, ordinary Witch Lake rocks occurs variously across both contact metamorphic zones and strain gradients (Plate 1-10-4). The western contact of the complex is a major transcurrent fault.

The earlier of the two plutonic bodies on Mount Milligan is an equigranular, massive to foliated quartz-deficient monzonite. Near its southern margin this 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 later plutonic body is a porphyritic, medium-grained granite with peripheral pegmatite and aplite stringers. This much smaller body crosscuts the amphibolite foliation but is itself foliated in places. Some of its most felsic apophyses are postkinematic. Therefore, this intrusion was emplaced during the waning stages of deformation.

The equigranular monzonite phase on Mount Milligan is probably a Takla intrusion. Perhaps it is a deep-level equivalent of the MBX and Southern Star monzonites. The presence of amphibolites among its wallrocks suggests that it was emplaced at a considerably deeper crustal level than anything else now exposed in the map area. The juxtaposition of these amphibolites against texturally unaffected augite porphyries – outcropping in one case less than 300 metres apart – requires significant uplift of the central Mount Milligan block. On the other hand, some Takla Group rocks south of the complex are strongly hornfelsed. The late-kinematic granite is a likely culprit. Although its exposed extent is small, it may be an offshoot of a larger body. Rhyodacite/dacite porphyry dikes of inferred Cretaceous to Early Tertiary age concentrate in the Mount Milligan area. All of them are recrystallized and many of them are strongly deformed. Plagioclase and quartz phenocrysts are subgrained and partly recrystallized to aggregates of tiny neoblasts; the matrix shows an incipient to well-developed biotite schistosity.

Uplift of the Mount Milligan complex as a horst, accompanied by Late Cretaceous to Early Tertiary felsic intrusions, fits well with the overall fault pattern of the Nation Lakes area. It also suggests an explanation for the anomalously young K-Ar dates (1094 Ma and 66.32.3 Ma) that have been obtained from the Mount Milligan deposit (Faulkner *et al.*, 1990). They were probably thermally updated by the quartz-bearing intrusions and by rapid uplift as well.

Like other large alkalic porphyry copper-gold deposits, the Mount Milligan deposit has had a complex later structural history. Its present structural setting near Early Tertiary downdropped sedimentary basins and an uplifted basement complex, is very like that of Copper Mountain and Afton. Speculatively, these later faults such as the Great Eastern fault may have had antecedents in early Mesozoic intrabasinal faults.

## Alteration And Mineralization

### ALTERATION HALOES

Broad alteration haloes occur throughout the mapped area. Most of them contain intrusive bodies and all coincide with magnetic anomalies. The alteration haloes are interesting as exploration targets on their own. Many of them contain known or newly discovered mineral occurrences, so they provide a context for discussing mineralization. They are given names for ease of reference.

The Mount Milligan halo extends at least 3 kilometres from the deposit to the skarn occurrence west of Heidi Lake, and north along the ridge towards Mitzi Lake. It includes a complex suite of small monzonitic intrusive bodies. Very strong potassic alteration occurs in the core of the halo. Secondary biotite clumps and pervasive fine-grained interlocking secondary potassium feldspar are abundant. Near the periphery, secondary potassium feldspar forms veinlets and clumps, as well as fine seams in plagioclase and augite phenocrysts. It also penetrates along the bedding planes of epiclastic sediments.

The Chuchi halo, north of Chuchi Lake, extends westward onto Noranda's Chuchi property. It occurs mostly within monzonites of the Hogem batholith. Disseminated pyrrhotite and pyrite and secondary potassium feldspar veins and veinlets are locally abundant.

The Chuchi-Witch halo lies between the two lakes it is named for and continues west onto Rio Algom's Witch claim group. The halo contains several small, crowded porphyry diorite and coarse-grained monzonite bodies. Intense alteration is extensive. Actinolite-diopside hornfels is overprinted by secondary biotite, potassium feldspar and epidote. Copper and gold showings occur within the halo off the western edge of the map area (Campbell, 1990).

The Taylor halo south of Witch Lake, includes the Taylor showing. Disseminated pyrite, pyrrhotite and silicification are abundant. The eastern side of the halo disappears under cover; most of the associated magnetic anomaly is in an area covered by glacial overburden.

The Mudzenchoot halo north of Mudzenchoot Lake contains several small outcrops of fine-grained diorite and orthoclase-megacrystic syenite. The surrounding fine-grained volcanic rocks are silicified and strongly hornfelsed. Stringers and disseminations of pryite are abundant.

The Max halo, which lies on and near the Max claims northeast of Cripple Lake, includes the Max, Lynx and K-2 mineral showings. A complex intrusive system with local intrusion breccia has areas of epidote flooding and associated pervasive potassic and propylitic alteration. Abundant disseminated pyrite and pyrrhotite also occur.

The Lynx halo south of Cripple Creek covers an area of bleached, silicified and hornfelsed sediments that host the Lynx showing. Pyrite, chalcopyrite, pyrrhotite, malachite and skarn mineralization are present in the halo.

The Tas halo, on and near the Tas claims, shows a strong, pervasive alteration in the vicinity of the East and West zones, where hornblende porphyry dikes and crowded porphyry diorites are most abundant. To the south, a large body of coarse-grained diorite to syenite is mostly propylitically altered but also has scattered potassium feldspar veins.

The HA1 halo south of the Tas property consists of silicified sediments with minor pyrite and chalcopyrite.

The Dem halo affects Rainbow Creek sediments south of Dem Lake. It hosts the Dem showing. It is characterized by hornfelsing, abundant disseminated pyrite, hairline magnetite veinlets and local strong alteration with associated syenite dikes.

The most common feature of these alteration haloes is the abundance of disseminated pyrite and/or pyrrhotite. Second most common is propylitic alteration, expressed generally as epidote flooding. Secondary potassium feldspar is widespread but generally detectable only by chemical staining or in thin section as hairline veinlets and scattered patches. Pervasive, texture-destructive alteration occurs only in the centres of the haloes, where it succeeds early purple-brown biotite hornfels.

The potential for undiscovered alteration haloes is still present in the map area due to extensive glacial overburden.

## MINERAL OCCURRENCES

### Mount Milligan (MINFILE 093N 194)

The Mount Milligan deposit, with published reserves of 400 million tonnes of 0.48 gram per tonne gold and 0.2 per cent copper (DeLong *et al.*, 1991), is one of the most exciting finds of the 1980s. More complete descriptions of the deposit can be found in Faulkner *et al.* (1990) and DeLong *et al.* (1991, this volume). At present, two potential orebodies have been identified on the property: the MBX zone associated with the MBX stock, which grades into the peripheral, gold-rich 66 zone; and the Southern Star zone, associated with the Southern Star stock. Gold and copper mineralization correlate with intense potassic alteration. The copper-to-gold ratio is highest in the Southern Star stock. The gold-rich 66 zone developed by bedding-parallel infiltration and replacement of volcanic sediments and andesites of the Witch Lake formation above, and spreading away from, the MBX stock. Rotation of northeasterly dipping and facing stratigraphy to horizontal shows the MBX stock as a vertical feeder to the laccolithic, sill-like Rainbow dike. Dilation along bedding planes may have controlled the emplacement of the Rainbow dike and also provided increased permeability, which channelled ore fluids to create the 66 zone.

### Tas (MINFILE 093K 080)

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. Hornfelsed and bleached siliceous argillites of the Inzana Lake formation are intruded by texturally variable hornblende±biotite±plagioclase porphyry. The hornblende porphyry often forms intrusive breccia with xenoliths of sediments and hornblendite. It is weakly propylitized. Later, more felsic diorite intrudes this package.

Mineralization in the sedimentary and intrusive rocks is confined to minor amounts ($<2\%$) of disseminated pyrite and pyrrhotite. Semimassive sulphide pods are found in steeply dipping, north-trending shear zones, 10 to 20 centimetres wide. On surface these zones contain up to 70 per cent sulphides: mainly pyrite and pyrrhotite with minor chalcopyrite and marcasite(?).

An unmineralized diatreme containing milled fragments of tuffs, hornblende porphyry and monzodiorite appears to grade into a hydrothermal breccia containing quartz and fine-grained massive actinolite. No sulphides were noted.

### Free Gold Zone (MINFILE 093K 091)

The Free Gold zone is located on the Tas claims on the Germansen–Inzana forest road. A small zone of intense quartz-carbonate alteration is exposed in a quarry. Up to 10 per cent pyrite with traces of magnetite and malachite and rare native gold occur in the rock. Propylitized hornblende diorite with sporadic potassium feldspar veins and traces of malachite on fractures outcrop near the showing. The diorite and the Free Gold zone are hosted by the Inzana Lake formation.

### Max (MINFILE 093K 020)

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 Mount Milligan deposit. The property covers an extensive area of propylitic alteration and sporadic mineralization that is associated with a complex polyphase intrusive body. The occurrence location recorded in MINFILE is at the highest elevation on the Max claims (1370 metres), the approximate centre of the alteration zone. The Max prospect includes several small showings in and around the main intrusive body.

The complex 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; epidote and secondary chlorite are abundant. Minor potassic alteration also occurs. The intrusions contain up to 20 per cent pyrite in places, but average sulphide contents are closer to 3 per cent.

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

### Lynx (MINFILE 093K 083)

The Lynx showing is located on the southern portion of the Max claims south of Cripple Creek. It occurs within a large area (approximately 2 km by 1 km) of bleached, silicified and mineralized rocks. This alteration zone may be part of a larger propylitic alteration halo associated with the intrusive body on the Max claims to the north.

The main part of the Lynx showing occurs in a trench adjacent to the Germansen–Cripple logging road. A three-metre square sulphide-rich oxidized zone occurs within light green, silicified and brecciated ash and dust tuffs of the Inzana Lake formation. The zone contains up to 30 per cent massive and crystalline pyrite, up to 5 per cent 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 and approximately 1.25 kilometres to the west-northwest, tuffaceous siltstones and minor lapilli tuffs are sporadically converted 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 to 70%) with minor flecks of chalcopyrite and possibly covellite. The meta-tuffs are interbedded with intermediate plagioclase+augite±hornblende porphyry flows or sills. They contain disseminated pyrite and abundant epidote in streaky veins.

## K-2 (MINFILE 093K 086)

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 which is exposed in a subcrop zone approximately 2 metres wide that trends south-southeast over 50 metres. The vein contains bleached and milled wallrock and is strongly hematite stained. Up to 30 per cent chalcopyrite with minor malachite and an unidentified grey-silver-coloured sulphide occur in the rock. The vein is hosted by clinopyroxene-rich flows and agglomerates of the Witch Lake formation. Secondary biotite and epidote are locally abundant in the rocks around the showing. These alteration minerals are probably part of the large propylitic alteration halo around the multiphase intrusion on the Max claims to the east.

## Dem (MINFILE 093K 077)

The Dem showings are hosted by metasomatically altered sediments of the Inzana Lake formation, within the Dem halo described above. Well-laminated sandstones and siltstones are intruded, hornfelsed and altered by syenomonzonite dikes. Areally extensive alteration in the sediments ranges from local massive epidote-tremolite skarning to biotite-diopside hornfelsing. Samples contain up to 137 ppm copper.

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 per cent arsenopyrite that forms in clumps with epidote and tremolite. A grab sample of this vein contains 361 ppb gold, 2.11 per cent 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 contains 204 ppb gold and 41 ppm copper.

## Mitzi (MINFILE 093N 204)

The Mitzi showing is located on the Phil claim group, 1 kilometre north-northeast of the east end of Mitzi Lake and 4.5 kilometres northwest of the Mount Milligan deposit. The showing is a tetrahedrite-chalcopyrite-bearing quartz-ankerite breccia vein hosted in hornfelsed augite porphyry agglomerate of the Witch Lake formation. The 20-centimetre vein trending 045°/65°NW contains up to 5 per cent 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.

Outcrops around the showing include strongly foliated biotite-rich mafic schists that are intruded by and occur as pods in coarse-grained equigranular diorite/syenodiorite. These regionally metamorphosed amphibolitic schists are part of the Mount Milligan horst.

## Chic (MINFILE 093N 202)

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 vein contains light green kaolinite and quartz with abundant blebs of disseminated pyrite and traces of chalcopyrite.

The feldspar porphyry is probably the intrusive equivalent of nearby potassium feldspar porphyritic andesites and purple amygdaloidal dacitic flows of the Chuchi Lake formation.

## Kbe (MINFILE 093N 203)

This small, isolated showing is located approximately 10 kilometres north-northeast of the east end of Inzana Lake and 5 kilometres southeast of Mudzenchoot Lake. The showing consists of less than 1 per cent disseminated malachite in a bleached and slightly gossanous hornblende granite or granodiorite intrusion. No visible pyrite or other sulphides are associated with the malachite. A grab sample from this showing contains 196 ppb gold and 0.2 per cent copper. Minor amounts of epidote and magnetite occur in the granite within 100 metres of the showing. The granite intrudes epiclastic sediments of the Inzana Lake formation.

## 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 on the property. Silicified, hornfelsed and fractured black argillite, cherty tuffs and green sandstone of the Inzana Lake formation 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 porphyry diorite on the Tas property. A trench exposes a plagioclase-augite-hornblende diorite dike that contains 10 per cent pyrrhotite. Pale quartz carbonate alteration and a shear zone were also noted at the showing.

Several gold and silver geochemical anomalies are present in soils on the property; one coincides with a quartz-carbonate stockwork 1 metre wide containing minor sulphides. Sulphides at the showing include up to 5 per cent pyrite and pyrrhotite with traces of chalcopyrite (Schmidt, 1987).

## 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 per cent pyrite and less than 1 per cent chalcopyrite disseminated in siliceous black argillite of the Inzana Lake formation. Quartz-carbonate stringers are abundant in the rocks; some of them contain minor pyrite. Abundant hematite-coated fractures occur in silicified sediments in a trench exposure.

Previous 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 per cent hornblende phenocrysts contains 2 to 3 per cent pyrite and pyrrhotite. Fine to medium-grained, equigranular to weakly porphyritic diorite contain less than 1 per cent pyrite. Hornfelsed sediments contain 2 to 5 per cent disseminated pyrite and quartz-carbonate altered zones contain 5 to 10 per cent (Maxwell, 1987).

## Rainbow Creek (MINFILE 093N 205)

The Rainbow Creek showing is located on the Rain claims along a north-flowing tributary of Rainbow Creek, about 15 kilometres south of the Mount Milligan deposit. There is a strong base metal geochemical anomaly in silts at the creek junction. The following values have been identified in a 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-zone breccia with quartz and carbonate veining and up to 20 per cent 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 formation. Gossanous zones contain 3 per cent disseminated pyrite with magnesite and traces of fuchsite. A few discontinuous chalcedony veins cut the pyritic breccia. The fault breccia itself is geochemically flat except 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.

## Taylor (MINFILE 093N 096)

The Taylor showing lies on the Mitzi claim group, within the Taylor halo. It 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 skarning and white bleaching are intermixed in an outcrop less than 20 metres long. Up to 10 per cent pyrrhotite occurs with fine-grained pyrite and chalcopyrite. Assays of 1.59 per cent copper and 4.93 grams per tonne gold have been obtained from grab samples (Roney and Maxwell, 1989).

The showing is hosted in trachytic plagioclase-augite-porphyritic latites of the Witch Lake formation. Intrusive rocks on the Mitzi claims include diorite and gabbro dikes (Roney and Maxwell, 1989).

## Wit (MINFILE 093N 141)

The Wit showing was initially covered by the Wit and Wag claim groups, but due to restaking in the 1980s is now on 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 hosts small pods and disseminations of galena and sphalerite with possible argentite and tetrahedrite. Banded chalcedony and quartz with calcite, pyrite and trace galena occur 150 metres east of the main vein outcrop.

Exploration work on the property (Holcapek, 1981; Campbell, 1988) has delineated an estimated geological reserve of 20 000 tonnes grading 7 per cent combined lead-zinc. The surface showing seems to be the top of a larger epithermal system. Barite lenses and stockworks as well as strongly oxidized and limonitic zones have also been documented by previous workers on the property.

The hostrocks are maroon and green matrix-supported polymictic breccias and lahars of the Chuchi Lake formation. The volcanics are in places scoriaceous and amygdaloidal and have calcite, albite and celadonite vesicle infillings. Sulphides are also disseminated in the hostrocks and in fracture fillings.

# CONCLUSIONS AND SUMMARY OF MINERAL POTENTIAL

Regional mapping in the Nation Lakes area has documented the potential for alkaline porphyry copper-gold deposits throughout the entire area where the Takla Group is exposed. No firm stratigraphic or structural constraints on the Mount Milligan deposit are shown in the regional geology. Instead, small intrusions associated with strong potassic-propylitic-pyritic alteration haloes and coincident magnetic anomalies occur scattered throughout the Takla Group. Recognition of these alteration zones, both through field tracing of sulphide-rich areas and through petrographic determination of potassic assemblages, is an important aspect of porphyry exploration efforts.

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