Regional Geology and Setting of the Cariboo, Bell, Springer and Northeast Porphyry Cu-Au Zones at Mount Polley, South-Central British Columbia

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INTRODUCTION

Porphyry deposits and prospects containing copper, molybdenum, gold and tungsten are the most important historic contributors to the metallic mining industry in British Columbia. Elevated metal prices and recent exploration successes have rekindled interest in British Columbia's copper-gold porphyry deposits. In particular, the alkalic Cu-Au porphyry class of deposits, such as Galore Creek, Mount Polley and Afton-Ajax, are key exploration targets. These and co-spatial calcalkaline Cu-Mo, Cu-Mo-Au porphyry deposits formed outboard of ancestral North America in island-arc settings in Late Triassic to Early Jurassic time. Two major components of this arc, the Stikine and Quesnel terranes, were the locus of a discrete alkaline magmatic event that gave rise to alkalic Cu-Au deposits at the end of the Triassic period (210 to 200 Ma).

In order to better understand the controls on mineralization and maximize exploration efficiencies, a partnership was struck between the British Columbia Ministry of Energy and Mines and exploration companies with a direct interest in refining the alkaline Cu-Au porphyry exploration model (Abacus Mining and Exploration Corporation, Imperial Metals Corporation, NovaGold Resources) as it applies to the Iron Mask, Mount Polley and Galore Creek magmatic complexes. The new information provided by these studies will update the provincial database and mineral deposit models, and promote Cu-Au porphyry exploration that will ultimately lead to new discoveries and resources in the province.

The Mount Polley Cu-Au porphyry deposit is located 56 km northeast of Williams Lake on the west side of Quesnel Lake (Fig. 1), approximately 8 km southwest of Likely (MINFILE 093A/008, 093A/164). It is currently owned and operated by Imperial Metals Corporation.

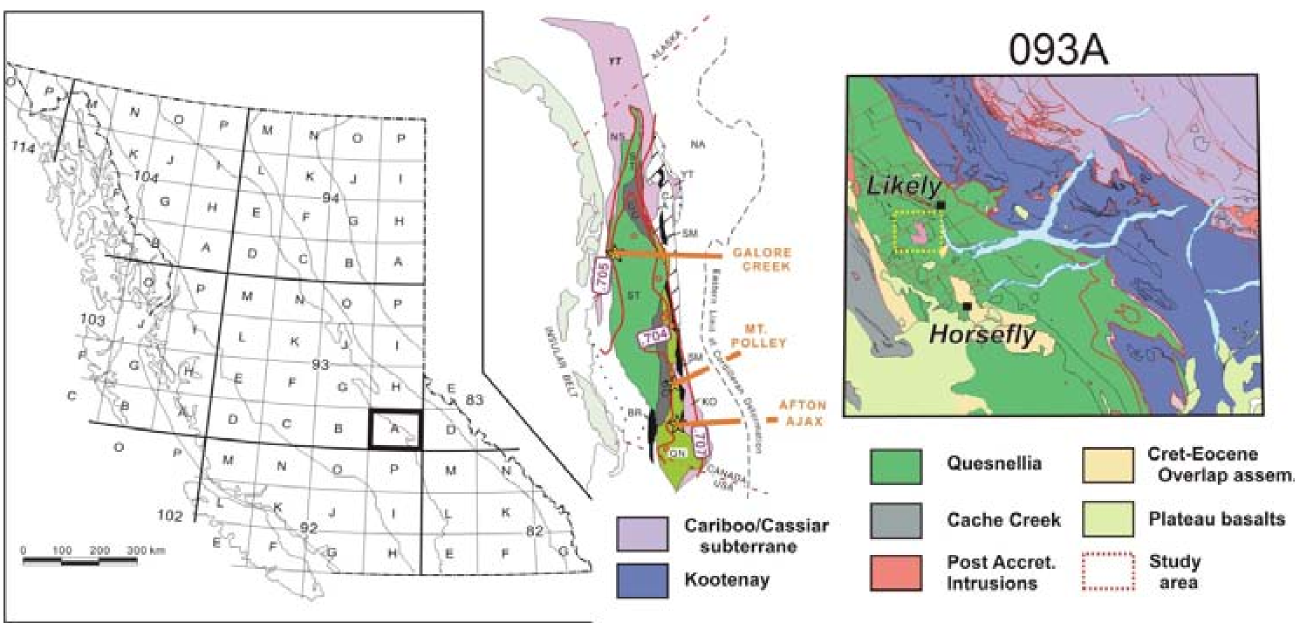

Figure 1. Location of the Mount Polley component of the Cu-Au Porphyry Project in south-central British Columbia (NTS 092I). Inset is terrane map of the northern Cordillera (modified from Wheeler and McFeely, 1991), showing the tectonostratigraphic setting of the three study areas. Mesozoic initial Sr isopleths are from Armstrong (1988). Box on right shows detailed terrane relationships for NTS 093A and the project area.

Production at Mount Polley began in October 1997 (Cariboo-Bell) and continued until 2001, with an overall production of 60 735 000 kg of copper; 11 517 000 g of gold and 2 347 000 g of silver from a total of 35.5 million tonnes mined and 27.6 million tonnes of material milled (BC Ministry of Energy and Mines, MINFILE). In 2003, discovery of a new zone of high-grade Cu-Au mineralization, the 'Northeast zone', spurred re-evaluation of the Mount Polley property and a resurgence in porphyry exploration east of Williams Lake.

Ongoing assessment of the previously produced (Springer and Bell zones) and newly identified (Northeast zone) resources on the property indicates the total proven and probable reserves to be: 24 733 044 t of 0.362% Cu and 0.31 g/t Au for the Springer zone; 9 784 689 t of 0.264% Cu and 0.297 g/t Au for the Bell; and 6 202 814 t of 0.9782% Cu, 0.324 g/t Au and 6.978 g/t Ag for the Northeast zone (Imperial Metals Corporation, press release, August 3, 2004). In anticipation of restarting operations at Mount Polley, Imperial Metals has applied, and been approved, for a mine permit amendment to allow mining of the Northeast zone. The Northeast zone has been renamed the 'Wright pit' after the late George Wight, mine manager at Cariboo-Bell from 1996–2003.

The Mount Polley field component of the Cu-Au porphyry study comprised reconnaissance geological mapping and sampling of the 200 km^2 area centred on the Cariboo pit. Key objectives of the project are to elucidate the stratigraphic and petrochemical relationships between the volcanic, subvolcanic and plutonic rocks that constitute the alkaline complex and to evaluate relationships between the newly discovered Northeast zone mineralization and the main hydrothermal system responsible for the Central zone (Cariboo and Bell) and West zone (Springer) mineralization. Uranium-lead dates for intrusive phases in the Mount Polley complex show Late Triassic crystallization ages (204.7 ± 3 Ma; Mortensen *et al*., 1995) using the time scale of Palfy (2000). However, previously defined stratigraphy based on regional correlations, fossil determinations and imprecise radiometric-dating techniques, which gave cooling rather than crystallization ages, are Early Jurassic for the country rocks. Mapping around Mount Polley and additional alkaline magmatic centres (Shiko Lake, Bullion Pit and Bootjack West) was conducted to help reconcile this inconsistency.

PREVIOUS WORK

Regional geological studies in the Quesnel River area by the Geological Survey of Canada were carried out in the 1950s and 1960s (Tipper, 1959, 1978; Campbell, 1961, 1963; Campbell and Campbell, 1970), but it was not until the work by Fox (1975) that the alkaline composition of the volcanic rocks was recognized in the Quesnel area. Detailed mapping and mineral deposit studies in the Horsefly area by Morton (1976) and by Bailey (1978) in the area around Morehead Lake provided the first stratigraphic subdivisions and descriptions of the geology encompassing Mount Polley.

Regional studies of the contact relationships between the Intermontane-Omineca belts have been the focus of numerous university thesis studies (e.g., Rees, 1987; Ross *et al*., 1985, 1989; McMullin *et al*., 1990 and references therein; Struik, 1986, 1987, 1988a, b). Bailey (1988, 1989, 1990), Panteleyev (1987, 1988), and Panteleyev and Hancock (1989) carried out regional-scale geological mapping and mineral evaluation in the area located between Quesnel and the Horsefly River as part of the 1985–1990 Canada-British Columbia Mineral Development Agreement. The focus of their studies was to remap and re-interpret the central Quesnel volcanic belt and test the economic potential for gold and copper deposits along its volcanic-intrusive axis (Panteleyev *et al*., 1996). Deposit studies at Mount Polley by Fraser (1994, 1995) and Fraser *et al*. (1995) recognized three stages of breccia emplacement (pre, syn and post-mineralization) and distinct alteration assemblages that separate the deposit into two distinctive zones.

REGIONAL GEOLOGY

The study area lies along the eastern margin of the Intermontane Belt, close to its tectonic boundary with the Omineca Belt, in south-central British Columbia. At this latitude, the Intermontane Belt is underlain mainly by Upper Paleozoic to Lower Paleozoic arc-volcanic, plutonic and sedimentary rocks of the Quesnel Terrane. Farther west are coeval rocks of the oceanic Cache Creek Terrane (Fig. 1). The Quesnel Terrane consists of a Late Triassic to Early Jurassic magmatic-arc complex that formed above an east-dipping subduction zone (Mortimer, 1987). The Cache Creek Terrane, with its Late Triassic to Middle Jurassic blueschist-facies rocks, represents the remnants of this subduction-accretionary complex (Travers, 1977; Mihalynuk *et al*., 2004). Quesnellia is fault bounded, juxtaposed on the west with Paleozoic and Mesozoic rocks of the Cache Creek complex and on the east with Mesozoic to Paleozoic and older metasedimentary, metavolcanic and metaplutonic rocks of the pericratonic Kootenay Terrane. The Barkerville and Cariboo Subterranes of the Kootenay Terrane separated Quesnellia from North America until the Middle Jurassic, at which time they were imbricated and thrust eastward onto the North American craton . The tectonic boundary between the Kootenay and Quesnel terranes is intruded by the Jura-Cretaceous Raft Batholith to the south. Tertiary volcanic rocks and feeder dikes of the Chilcotin Group are the youngest rocks in the region

Mount Polley is one of a chain of alkalic intrusion–related Cu-Au deposits that developed in the Upper Triassic to Lower Jurassic volcanic-plutonic arc rocks of the Quesnel Terrane (Barr *et al*., 1976). It is hosted by a high-level alkalic intrusive complex within the Central Quesnel Belt that is of latest Triassic age (202 Ma; Mortensen *et al*., 1995). A chain of similar deposits extends the length of the Intermontane Belt (Fig. 1). In the south, they are associated with the Iron Mask batholith (Afton, Ajax, and Crescent) and Copper Mountain intrusives (Copper Mountain, Ingerbelle) and, to the north, with the Hogem batholith (Lorraine) and, in the Stikine Terrane, with Galore Creek intrusives (Galore Creek).

Triassic Nicola Group

In the vicinity of Quesnel Lake, the Nicola Group consists of a lower, dominantly metasedimentary unit and an upper, dominantly volcanic-arc assemblage (Fig. 2). The older Middle to Late Triassic (Ansian to Norian) sedimentary unit forms a northwest-trending belt exposed east of Quesnel Lake. It has been estimated to comprise at least 2500 m (Rees, 1987) to locally 4000 m (Bloodgood, 1990) of fine-grained sedimentary rocks that grade upward into (Carnian to Norian) basal units of the upper volcanic unit. The overlying volcanic rocks define a parallel northwest-trending belt up, to 20 km wide, of subaqueous and subordinate subaerial volcanic rocks with an estimated thickness on the order of 5 to 6.5 km (Rees, 1987; Panteleyev *et al.*, 1996). Thickest accumulations of volcanic rocks and coeval subvolcanic intrusions define the magmatic axis of the Quesnel arc.

Panteleyev *et al*. (1996) adopted the stratigraphy of Bailey (1978) and recognized three volcanic units in the study area: a subaqueous pyroxene-phyric basalt unit of predominantly flows and breccias; pyroclastic and laharic deposits of more evolved ‘felsic compositions; and an upper subaerial analcime-bearing olivine basalt unit. Ages of these three units were interpreted to span the Upper Triassic to Early Jurassic boundary. The main basaltic unit was reported as Carnian to Norian in age, the felsic more differentiated volcaniclastic unit, Sinemurian, and the upper analcime-bearing basalt reported as Sinemurian to pre-Pliensbachian (Panteleyev *et al*., 1996 and references therein). Subsequent U-Pb isotopic dating of the various intrusive phases of the Polley and Bootjack stocks indicates that these intrusives are Upper Triassic in age (Palfy, 2000) and therefore can not be intruding rocks younger than 200 Ma.

The stratigraphy presented below summarizes the results of 3 weeks of mapping; it does not benefit from any new radiometric or fossil constraints and is therefore preliminary in scope and intent (Fig. 3). A detailed multisensor airborne survey (Shives *et al*., 2004) aided stratigraphic and structural analysis (Fig. 4).

AUGITE±OLIVINE BRECCIA FLOWS AND TUFFACEOUS ROCKS.

Green, grey and dark maroon pyroxene-phyric alkali olivine basalt flows, breccias and minor pillow basalt crop out near Jacobie Lake, west of Morehead Lake and south of Mount Polley. The flows are commonly massive with amygdaloidal brecciated tops. Massive coherent flows are interlayered with block and lapilli-flow breccias. Textures vary and include aphyric and trachytic varieties, but most commonly are coarsely porphyritic. Phenocrysts of pyroxene and plagioclase (up to 10 mm) and olivine (5 mm) constitute from 30 to 75% of the rock. The groundmass consists of very fine grained plagioclase (microlites), clinopyroxene, olivine, magnetite and alteration minerals, including iddingsite, calcite, chlorite, pyrite and epidote. Vesicles are rimmed by analcime and filled by calcite.

Copper mineralization occurs within interlayered maroon and green, pyroxene-olivine–phyric flow breccias near Jacobie Lake (Fig. 2). Here, 2 cm wide veins of chalcocite, malachite and azurite are localized at the contact zone between the base of one flow and the top of another. Zeolites commonly replace the matrix or fill voids within the volcanic units.

PYROXENE PORPHYRY BRECCIAS AND CRYSTAL-RICH SEDIMENTS

Pyroxene-phyric basalt flows, breccias and tuffaceous rocks display volcanic textures and depositional forms similar to those of the augite-olivine basalts, differing only by the absence of olivine and the greater abundance of plagioclase. Pyroxene basalts are more extensive, although they are locally interdigitated with augite-olivine basalt.

These rocks are maroon, green and grey in colour. Thick flows have massive centres and brecciated tops and/or bottoms. Breccias are clast supported to matrix rich. Lapilli to block tuff flows and fluidal ejecta are interlayered with juvenile pyroxene and plagioclase crystal-rich sandstones and finer grained green and grey siltstones. Well-preserved, thin-bedded, waterlain crystal and ash tuffs crop out along the Ditch road, west of Quesnel Lake and southeast of Jacobie Lake (Fig. 5). West of Quesnel Lake, submarine debris flows disrupt the strata and incorporate poorly preserved horn corals. Near Jacobie Lake, a complete (?) eruptive cycle is preserved in outcrop, beginning with coarse breccia blocks of purple vesicular pyroxene-plagioclase–phyric basalt that fine upward through lapilli and ash to crystal-rich horizons of pyroxene and plagioclase (Fig. 3). Normal graded bedding, crossbedding and load features are common in the sediments; all indicate upright facing beds and a subaqueous environment of deposition.

ANALCIME-BEARING PYROXENE BASALT BRECCIAS

Analcime-bearing mafic flows crop out near Trio Lake, Mount Polley and west of Morehead Lake (Fig. 2). However, easily accessible and excellent exposures are found along the highway north of Prior Lake within an ~260 m thick volcanic section dominated by dark grey-green to maroon, vesicular augite-porphyry flows. Analcime content varies from one flow to the next, as do pyroxene and olivine contents. Typical flows comprise 30% medium to coarse-grained euhedral pyroxene (up to 60%); 20–50% fine to coarse plagioclase, locally including coarse trachytically aligned, bladed phenocrysts; 2–10% medium-grained olivine, commonly replaced by bright red iddingsite (Fig. 6); up to 10% amygdules, mostly filled with calcite and chlorite; and 0–20% euhedral, salmon pink analcime up to 3 cm in diameter (Fig. 7). The volcanic section extends along strike to the north and, at Sister Mountain, is intruded by a <1 km^2 subvolcanic hornblende-plagioclase–phyric monzonite body. Other parts of the section include well-bedded tuffite and debris flows, including metre-size blocks of limestone. These features point to a submarine depositional environment.

Correlative maroon olivine-pyroxene–phyric basalt flows, breccias and poorly bedded ash and crystal tuff, located west of Morehead Lake, also contain conspicuous

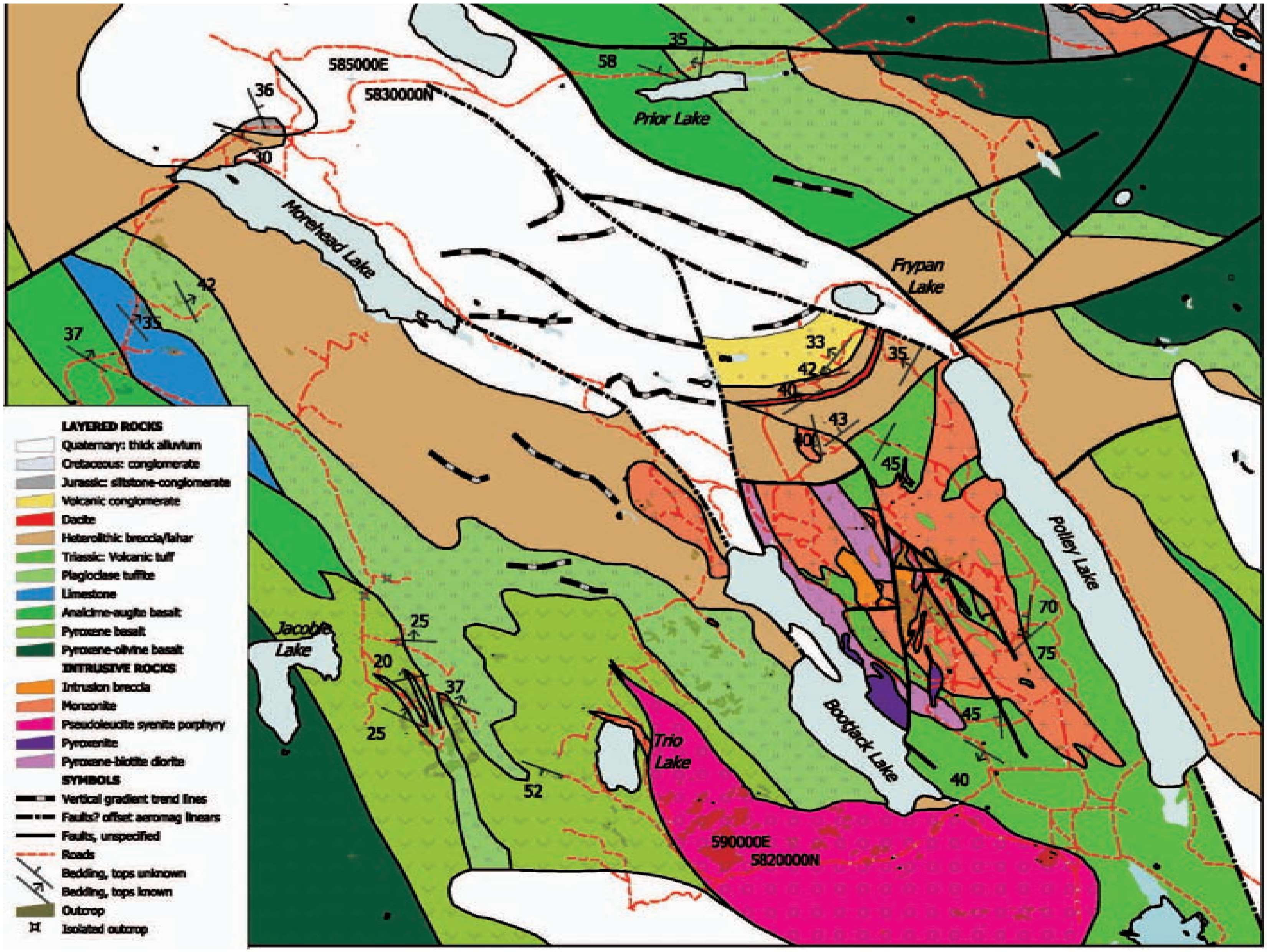

Figure 2. Compilation map of the Mount Polley area. Incorporates unpublished assessment work and published work by Bailey (1990), Hodgson *et al.* (1976), Panteleyev *et al.* (1996), Shives *et al.*(2004) and Wild (1999).

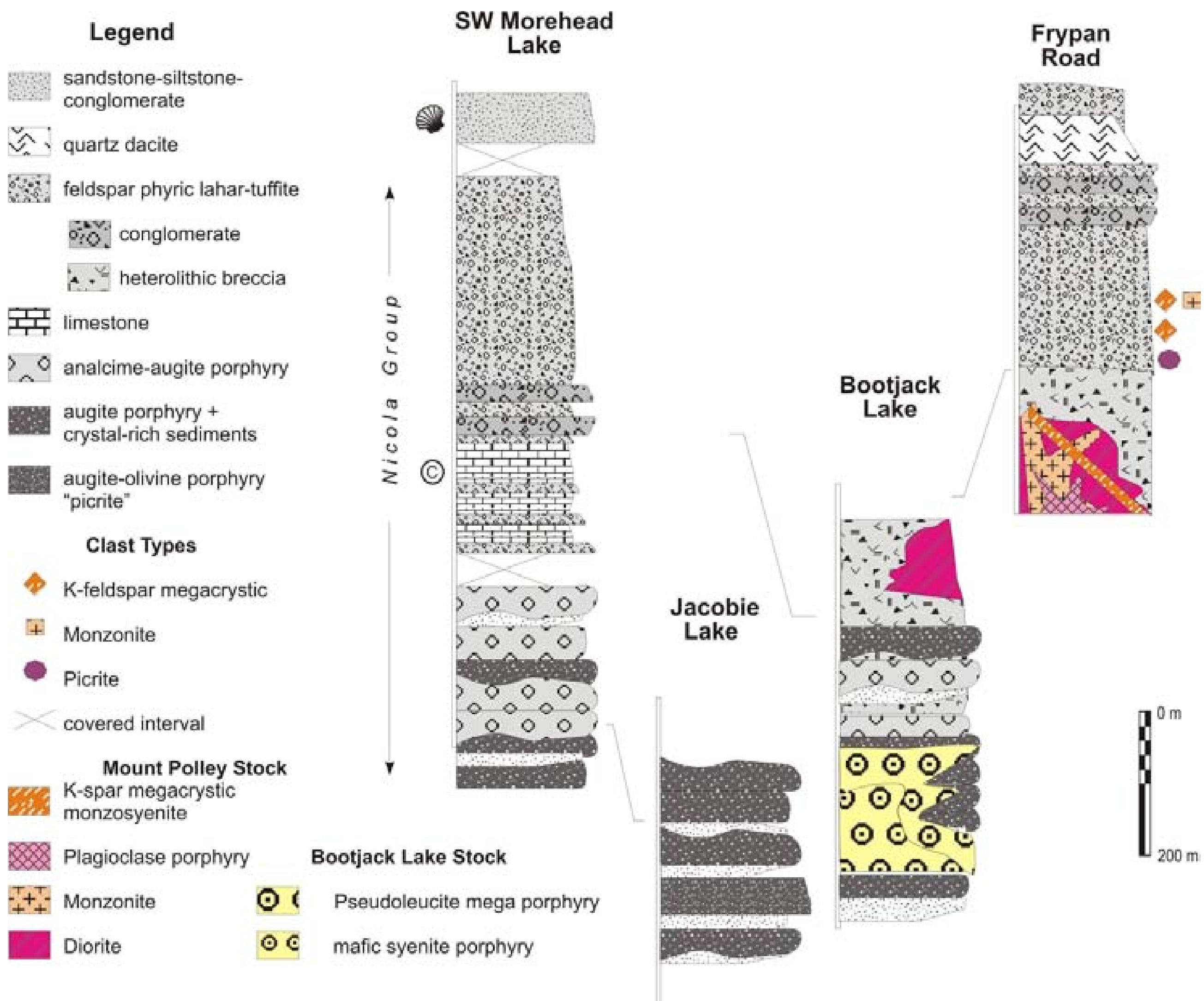

Figure 3. Stratigraphic sections for Nicola Group volcanic and sedimentary rocks in the Morehead Lake, Jacobie Lake, Bootjack Lake and Fryingpan Road areas.

analcime (Fig. 3). Flow rock comprises coarse tabular crystals of pyroxene; subrounded olivine (3–5 mm, altered to iddingsite); plagioclase laths; and pink or brownish, rounded to euhedral analcime crystals (2–5mm, 10–20 %). Some of the flow tops contain amygdules of analcime, calcite, chlorite and minor epidote. In thin-section, euhedral to subhedral analcime crystals (0.25 mm) and plagioclase laths are interstitial to larger euhedral (2–3 mm) zoned clinopyroxene crystals and altered olivine grains (<1 mm).

Massive, dark green to black, analcime-bearing pyroxene±olivine–phyric flows and breccias south and east of Trio Lake are intruded and hornfelsed by pseudoleucite porphyritic syenite of the Bootjack stock. In addition to pyroxene, plagioclase and olivine phenocrysts, the basalt contains up to about 20% euhedral to rounded, white analcime crystals. The basalt is interlayered with thick heterolithic volcaniclastic breccias dominated by pyroxene-plagioclase– and pyroxene-olivine–phyric fragments. Similar, coarsely porphyritic grey-green analcime-bearing olivine-pyroxene basalts are exposed in the containment ditch south of the mine, and on the Polley Lake road, west of the mine.

NORIAN – LIMESTONE AND INTERBEDDED MAROON EPICLASTICS

Light to medium-grey, recrystallized micritic limestone is exposed on two hillsides south of the highway, west of Morehead Lake (Fig. 2). The unit is no more than a few hundred metres thick and is discontinuous along strike. It dips moderately northeast and is interbedded with maroon epiclastic and conglomeratic units. Deposition of limestone and reworked clastic rocks probably mark a hiatus in volcanic activity.

The lower sections of the limestone are interbedded with 0.5 to 1.5 m thick maroon and limonitic weathering lapilli and fine, ash-rich tuff beds that overlie (across a 100 m covered section), pink analcime-bearing, pyroxene-olivine–phyric volcanic breccias and massive basalt flows.

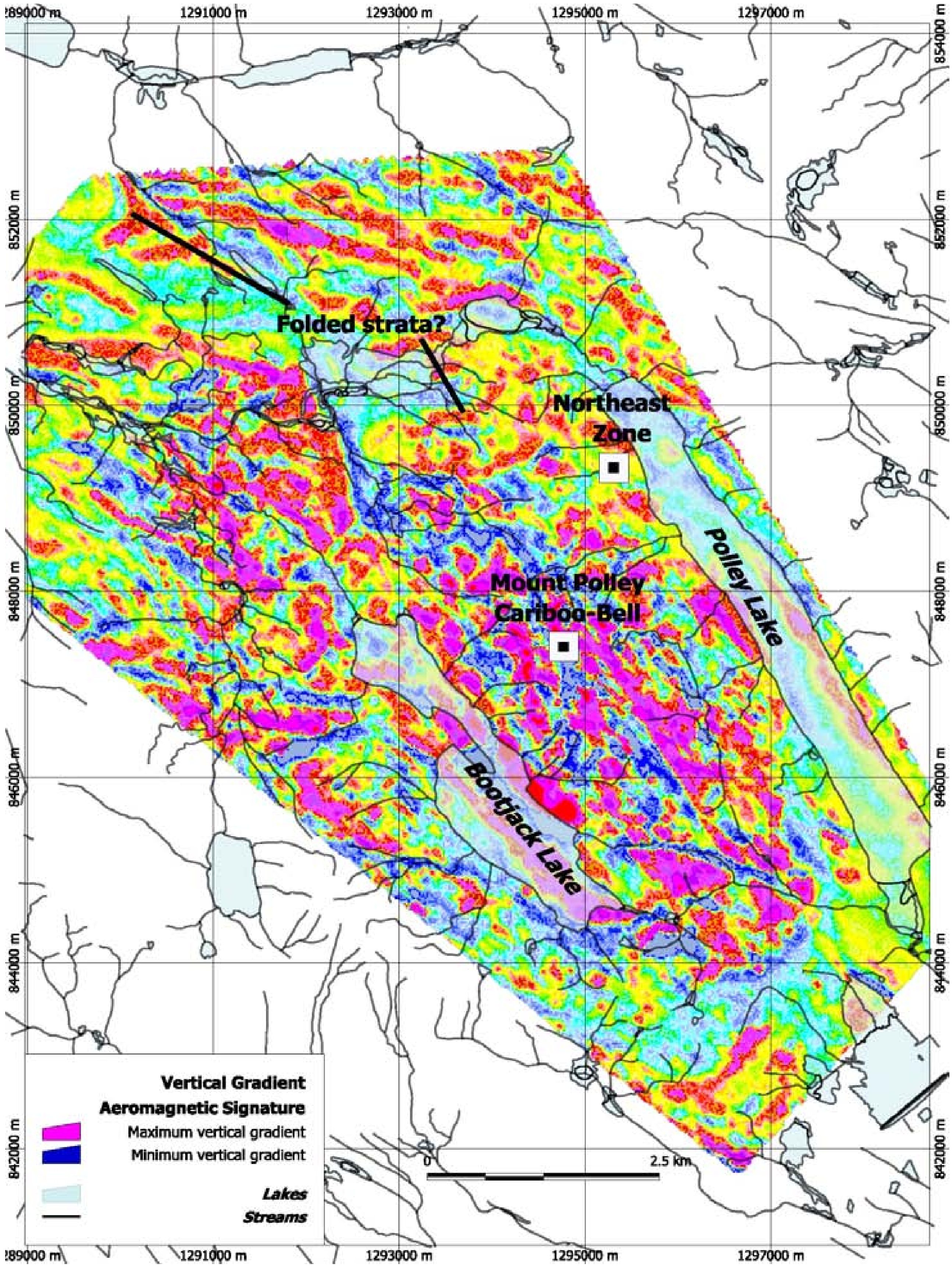

Figure 4. Vertical-gradient magnetic lineaments adapted from Shives *et al*. (2004).

Figure 5. Picritic basalt breccia interbedded with volcaniclastic units of the Nicola Group, southeast of Jacko Lake

Figure 6. Typical flow, comprising euhedral pyroxene, plagioclase and olivine replaced by bright red iddingsite.

Up section, the limestone is characterized by 5 to 10 cm thick beds of medium-grey micrite. The limestone is brecciated, recrystallized and cut by white calcite and limonitic iron carbonate veinlets; traces of pyrite and malachite occur locally where the limestone crops out along highway (Fig. 3).

At this locality, the limestone is reported to contain fossils of uncertain Lower Jurassic age (GSC- 93216, Sinemurian?; *in* Panteleyev *et al*., 1996); however, it is correlated with other discontinuous lenses of grey limestone unequivocally dated as Norian based upon conodont fauna (H.W. Tipper *in* Panteleyev *et al*., 1996). This limestone datum marks the top of the Triassic volcanic-volcaniclastic section on the west side of the central axis of the Quesnel belt (Bailey, 1988; Panteleyev *et al*., 1996).

LAHAR AND TUFFITE

A red to brown-weathering, tuffaceous lahar is exposed along the Frypan road (between Bootjack and northern Polley Lake) and around the northern end of Morehead Lake (Fig. 2). It is characterized by a dark hematitic ash matrix and conspicuous, locally abundant white and pink zeolites (laumontite) that replace the matrix and coat fractures. Clasts are polylithic and primarily angular lapilli with rare rounded boulders that show a complete lack of sorting. Clast compositions are dominated by green and maroon, crowded tabular feldspar porphyry basalts. The lahar is chaotic and massive; rarely are bedding attitudes observed.

Near Morehead Lake, the unit is heterolithic (Fig. 8). Common clast types include: maroon, fine tabular feldspar porphyry; aphanitic dark green basalt, locally with sparse coarse pyroxene crystals; olivine-magnetite (±chromite) dunite; fine to medium-grained, holocrystalline pink syenite (?) or K-metasomatized monzonite; polygenetic tuff and/or tuffite. At apparently deeper stratigraphic levels (assuming no fault displacements across numerous covered intervals), the lahar gives way to well-bedded maroon sandstone with sparse conglomerate lenses less than 10 cm thick. Clasts are tabular feldspar porphyry, lesser feldspar-hornblende porphyry, and sparse but conspicuous pyroxene clasts. Still farther down section, these become more tuffaceous in character and end abruptly at a covered contact with limestone (Fig. 3). Correlative units to the tuffaceous rocks are reported to contain Late Triassic fossils (GSC- 117609, 10 and 117621, Norian, probably upper Norian; *in* Panteleyev *et al*., 1996).

Clasts from an isolated outcrop of polylithic block to lapilli tuff located southwest of Morehead Lake consist of 90% crowded feldspar porphyries with equal abundances of trachytic and felted textures. Aphanitic mafic clasts and rare pyroxene-phyric clasts constitute the remaining 10%.

Exposures of the unit along the Frypan road are also heterolithic. Clasts include maroon, fine tabular feldspar porphyry; aphanitic green basalt; grey plagioclase-pyroxene–phyric basalt; and subvolcanic pyroxene microdiorite and monzonite. It is matrix supported with angular clasts, some of which display thin reaction rims. In one locality, the lahar is incised by a channel containing polylithic volcanic conglomerate (Fig. 3).

EARLY JURASSIC SEDIMENTARY UNIT

East of Morehead Lake, shallowly dipping dirty brown sandstone, black siltstone and lesser calcareous granule conglomerate contain abundant fossil fauna that all point to an Early Jurassic age (GSC- 93215b, Lower Sinemurian, Canadensis Zone; *in* Panteleyev *et al*., 1996). These strata may have been deposited atop the maroon lahar unit. Although contacts are covered, bedding orientations suggest a simple stratigraphic succession. If this is correct, the con-

Figure 7. Atypically coarse analcime-bearing pyroxene±olivine–phyric flow, highway north of Prior Lake.

glomerate is between Norian and Sinemurian in age, deposited near the Jurassic-Triassic boundary (Fig. 3).

CONGLOMERATES AND TUFFITE

Conglomerate and tuffite are apparently most extensive where they crop out near Morehead Lake and east of Polley Lake (Fig. 2). At these localities, a clear separation of this unit from the lahar-tuffite unit may not be possible. Lithologically similar units can be observed at other localities, such as the highway cutbanks north of Prior Lake, near Jakobie Lake, and along the eastern cliffs of northern Quesnel Lake; however, at these localities, the volcanic sandstone and volumetrically subordinate conglomerate tend to be intercalated with coarse tuffaceous or flow units and are clearly part of the arc construction phase.

The conglomerate unit is a variegated polymictic cobble to boulder conglomerate, best exposed on low glaciated outcrops and small knobs on both sides of the Frypan road. The unit apparently rests atop the tuffaceous lahar exposed in the Frypan roadcuts and around the northern end of Morehead Lake (see above). Polymictic conglomerate is massive to locally well bedded (Fig. 9). It contains subangular to well-rounded clasts up to large boulder size (70 cm).

Clast composition is variable, including monzonite (Fig. 3), possibly derived from the 'Polley volcanic succession' and a variety of plagioclase porphyries that contain hornblende or pyroxene. Pyroxene porphyry clasts are

Figure 8. Hematitic, maroon weathering tuffaceous lahar, comprised dominately of angular to subrounded clasts of crowded tabular feldspar porphyry basalt in a crystal-rich ash matrix. Exposure on highway southwest Morehead Lake.

probably derived from the more deeply incised part of the arc. These conglomerate units could mark a significant hiatus in volcanic deposition, although unit thickness is a poor proxy for elapsed time in dynamic volcanic environments. Note that heterolithic volcanic breccia and lahar-conglomeratic units are intruded by monzonite in the area between the Cariboo pit and Polley Lake, near the Au zone and possibly also west of Bootjack Lake. These are older volcaniclastic rocks that lie stratigraphically lower in the pile.

QUARTZ-PHYRIC MAUVE DACITE.

Dense, quartz-phyric, white to mauve-weathering lapilli tuff is exposed in two outcrops between Bootjack Lake and northern Polley Lake (Fig. 2). We have used the field term 'mauve dacite' for this unit even though the SiO_2 content is not quite high enough to place it squarely within the dacite field. Based upon bedding in enclosing strata, the thickness of this unit can be estimated as at least 70 m

Figure 9. Jurassic (?) conglomerate south of Frypan Road and north of Mount Polley.

(Fig. 3). It is crystal rich, composed of tabular and broken plagioclase laths (40%, <3 mm), hornblende (3% altered 2–3 mm prisms), light grey quartz eyes (up to 1%, 5 mm in diameter) and biotite (<1%, altered 2–3 mm booklets). A vague compaction fabric is preserved locally, but clear evidence of collapsed pumice fragments or welding is absent.

Bedding orientations of enclosing strata are parallel to the trend of the mauve dacite unit. A poorly exposed, probable gradational southern contact with the maroon laharic conglomerate suggests that this unit is part of the volcanic stratigraphy and not a hypabyssal intrusion, although a tuff dike or sill origin cannot be ruled out. Areas south of the unit have been penetrated by diamond-drilling. No unit like the mauve dacite is described in drillcore logs (Tennant, 1997, 1998, 2000). A sample of mauve dacite was collected for U-Pb geochronology; results are pending.

Mount Polley Intrusive Complex

The Mount Polley stock is a north to northwest-trending, high-level, composite alkalic intrusive complex (Fig. 2). The stock is 5.5 by 4 km in size and comprises primarily fine-grained porphyritic diorite and monzonite, plagioclase porphyry and syenite dikes with abundant screens of metavolcanic rocks and hydrothermal breccias, features characteristic of a subvolcanic environment. Bordering it to the southwest is an ~1 km thick panel of volcanic strata that separates it from the 2.3 by 7 km, northwest-elongated Bootjack stock, which is also a composite intrusive body and includes an unusual orbicular pseudoleucite syenite. Subvolcanic textures are lacking in the Bootjack stock.

A hornblende ^{40}Ar-^{39}Ar plateau age from the coarse-grained syenite phase of the Bootjack stock yielded a well-defined age of 203.1 ± 2.0 Ma (Bailey and Archibald, 1990). Uranium-lead ages (Mortensen *et al*., 1995) from the Polley stock (201.7 ± 4 Ma; zircon, diorite and 204.7 ± 3 Ma; zircon, plagioclase porphyry) are similar to ages from the Bootjack stock (202.7 ± 7.1 Ma; zircon orbicular syenite and 200.7 ± 2.8 Ma; Pb-Pb, titanite, pseudoleucite syenite). However, Fraser (1995) inferred that the Bootjack stock is younger on the basis of diorite xenoliths present within the nepheline pseudoleucite and orbicular syenite units.

PYROXENITE

Hornblende pyroxenite and biotite gabbro have been intersected in drillholes collared near the east shore of Bootjack Lake (Hodgson *et al*., 1976) and recognized as zenoliths within diorite, and clasts within intrusive breccia in the Bell pit (Fraser, 1995). Foliated hornblendite xenoliths and accidental clasts are common within volcanic units east of the Cariboo pit.

DIORITE

In the mine area, diorite is the earliest phase and comprises the majority of the Mount Polley stock. It is a homogeneous, medium to fine-grained equigranular rock that weathers pale grey. A large body of weakly altered, fine to medium-grained diorite is exposed north of the Cariboo pit and in the west wall of the Bell pit (Fig. 2). At this locale, it is cut by tight epidote-lined fractures that have albite-epidote±K-feldspar alteration envelopes. Unaltered, equigranular, medium-grained biotite-pyroxene diorite crops out along the Bootjack Lake road, west of the mine. Mafic minerals consist of medium-grained (3–6 mm) altered pyroxene (30%) and an additional 15% large poikilitic biotite crystal. In thin section, the diorite consists of euhedral (1–2 mm) plagioclase laths (40–50%), green clinopyroxene (1 mm) crystals (15–20%) and poikilitic biotite (10–15%) that encloses plagioclase, pyroxene and magnetite grains. Accessory minerals include magnetite, sphene and apatite.

MONZONITE

Monzonite, where unaltered, is grey to pink, fine to medium grained, porphyritic or rarely seriate. It is composed of roughly equal amounts of plagioclase (3–5 mm tabular laths) and K-feldspars (subhedral 2–3 mm grains and matrix material) and 10–15% mafic minerals (pyroxene and/or hornblende and less biotite). Accessory minerals include magnetite, sphene and apatite. In outcrop, the monzonite resembles a potassium enriched, medium-grained diorite. Its distribution, particularly around the mine, has been overestimated in part due to the pervasive potassium alteration in this area but also because monzonite was used as a field term or catch-all for pink to orange-altered rocks that could not be designated as diorite, plagioclase porphyry or potassium megacrystic monzo-syenite.

Small (<1 km^2), high-level, stocks of hornblende monzonite crop out north of Prior Lake and northwest of Bootjack Lake. These intrusions consist of holocrystalline plagioclase-hornblende–phyric subvolcanic monzodiorite and pink equigranular monzonite. Both stocks contain abundant rounded zenoliths of pyroxene porphyry and diorite. The stock northwest of Bootjack Lake consists of a crackle or autobrecciated, fine-grained monzonite. At its southern margin, it is a pink breccia with clasts defined by a tight, anastomosing network of chlorite fractures; however, toward its centre, the stock is dominated by a potassic-albite–altered breccia resembling the hydrothermal breccias at the Springer zone and on Mount Polley.

PLAGIOCLASE PORPHYRY

Plagioclase porphyry is a grey to green, fine to medium-grained, seriate-textured subvolcanic intrusion. It is characterized by 1–4 mm, white, stubby plagioclase phenocrysts (up to 70%), subhedral 2–3 mm mafic minerals including biotite, hornblende and less abundant pyroxene set in a groundmass that is commonly potassic altered. Accessory minerals include magnetite, sphene and apatite. Plagioclase porphyry are pre, syn and post-mineral intrusions. They appear to be associated with a pervasive potassium metasomatic event. A common occurrence of plagioclase porphyry (and monzonite) is as matrix to brecciated diorite in the intrusive breccias, which are common within mineralized zones

In drillcore from beneath (?) the Bell pit (BD-04-26), 2–3 m wide dikes of crowded plagioclase porphyry with

Figure 10. Plagioclase porphyry dike, chilled margin against pervasive potassium metasomatized monzodiorite. Drillcore from beneath Bell pit.

chilled sharp contacts and internal trachytic textures intrude equigranular potassium-altered diorite or monzonite (Fig. 10). Plagioclase porphyry containing xenoliths of biotite diorite is exposed halfway down the main haulage ramp in the Cariboo pit. The plagioclase porphyry (dyke?) is chilled against mineralized and altered medium-grained monzonite, clearly postdating potassic-albite fractures and patchy chalcopyrite mineralization.

POTASSIUM FELDSPAR PORPHYRITIC SYENITE

Potassium feldspar porphyritic monzonite-syenite occurs as dikes within the core of the Central zone, as a stock on the top of Mount Polley (Fraser, 1994) and as fragments in mineralized breccias at the Northeast zone (Fig. 11) and Lloyd-Nordic zone (Fig. 2). It is characterized by the presence of salmon pink coloured tabular K-feldspar (orthoclase) phenocrysts. An inverse relationship between the proportion of feldspar phenocrysts and their size results in crowded trachytic varieties that contain 20–25% phenocrysts averaging less than 7 mm in size, and those monzosyenites that contain fewer phenocrysts (2–10%), but which can be greater than 2 cm in length. The groundmass consists of weakly aligned plagioclase crystals with interstitial clinopyroxene, biotite and lesser magnetite, sphene and apatite. Plagioclase crystal inclusions within the potassium megacrysts indicate that the two crystallized simultaneously. Late deuteric alteration has sericitized the feldspars and replaced mafic minerals with a mixture of chlorite, white mica and carbonate.

In the high wall between the Bell and Cariboo pits is a set of east-southeast-trending, south-dipping dikes of K-feldspar porphyritic syenite. The dikes are 0.25–5 m thick, have chilled margins and a weak trachytic fabric, and are overprinted by weak chlorite-pyrite alteration. A sample was collected for radiometric dating; results are pending.

A southeast-trending intrusive breccia characterized by pervasive potassic alteration and frothy albite replacement along clast margins defines the western contact of the Mount Polley monzosyenite stock. Lithology closely resembles that of the dikes described above. The stock contains about 5% large equant potassium megacrysts in a plagioclase-rich groundmass containing pyroxene altering to hornblende, biotite, and magnetite. It is overprinted by discrete alteration zones containing one or more of albite, epidote, magnetite, chlorite and pyrite and locally chalcopyrite. A grab sample of chalcopyrite mineralization returned low Cu (~0.2%) and Au (207 ppb) values (JLO04-25-127; see Table 1).

BRECCIAS

Intrusion breccias and hydrothermal breccias are associated with a number of high-level alkalic intrusive centres

Figure 11. Mineralized fragments of K-feldspar porphyritic monzonite-syenite in breccias at the Northeast zone.

TABLE 1. ICP-ES AND INAA RESULTS FROM SELECTED MINERALIZED SAMPLES, MOUNT POLLEY AREA

		Element	Ag	Al	As	Au	Ba	Bi	Ca	Cd	Ce	Co	Cr	Cu	Eu	Fe	Hf	K	La	Li	Lu	Mg	Mn	Mo
		Units	ppm	%	ppm	ppb	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	%	ppm	ppm	ppm	%	ppm	ppm
		Method	TICP	TICP	INA	INA	INA	TICP	TICP	TICP	INA	TICP	INA	TICP	INA	TICP	TICP	TICP	TICP	TICP	INA	TICP	TICP	TICP
		Det'n Limit	2	0.01	0.5	2	50	0.02	0.01	0.01	3	0.1	5	0.01	0.2	0.01		0.01	0.5		0.05	0.01	1	0.01
Station Number	Easting	Northing																						
JLO04-21-90	605199	5812879	0.5	8.66	12.2	51	3900	0.1	4.5	0.5	23	15	11	2434.2	1	3.29	1	6.41	13.9	8.5	0.33	0.82	1052	0.9
JLO04-25-127	592419	5823830	1.3	7.87	28.9	207	1600	0.2	1.85	0.4	20	21	6	2021.5	0.8	5.26	1.7	5.66	15.4	25.2	0.33	0.83	1672	4.4
MMI04-16-7	593603	5822911	1.2	8.55	13.5	113	830	0.4	1.77	0.6	20	11	7	2872.4	0.7	2.85	1.7	3.62	12.1	15.2	0.35	0.73	1085	3.1
MMI04-20-12	589610	5823019	0.1	8.57	37.8	7	2000	0.2	4.96	0.1	12	20	10	135.1	0.7	7.96	1.1	2.51	6.5	18	0.24	2.21	1132	1.8
MMI04-21-7	591013	5825895	11.7	7.75	89.6	623	1070	3.3	0.87	1	37	32	b.d.	8240.4	1	11.81	1.5	2.75	31	51.7	0.24	1.4	2483	62.7
MMI04-22-1b	603335	5813020	0.6	7.8	2	149	b.d.	b.d.	3.28	0.1	7	2	12	1947.8	b.d.	0.71	1.3	0.03	3.8	2.3	0.19	0.29	561	15.2
MMI04-22-6	605772	5812844	1.5	6.8	18.9	558	310	0.1	13.67	0.4	21	41	238	2160.9	1.2	8.71	1.2	0.27	11.5	8.4	0.25	3.13	1982	2.4
MMI04-26-4	592870	5823600	0.3	8.84	8.7	74	1035	b.d.	1.67	0.2	41	26	8	1887.4	1.6	7.01	2.1	3.47	23.6	12.6	0.4	1.11	505	2.7
MMI04-26-6	592795	5823790	0.1	3.74	6.1	9	b.d.	b.d.	12.08	0.1	6	55	32	103.9	0.4	13.64	1	0.21	2.7	36.3	0.14	6.79	3450	1.2
MMI04-26-8	592473	5823702	2.1	7.9	17	511	1200	0.6	4.51	0.3	22	20	11	3026	0.9	6.85	1.5	4	12.5	35.5	0.34	1.56	2111	4.5
MMI04-26-9	592470	5823663	1.7	8.51	22.4	263	660	0.2	6.37	0.8	25	25	24	1757.3	1	8.46	1.6	1.98	17	44.1	0.33	2.05	2650	3.9
MMI04-27-1b	585709	5821580	29.1	7.04	2.5	19	645	b.d.	4.39	0.1	24	37	18	48010	0.9	8.84	1.4	2.16	14.3	18.7	0.18	2.99	1673	2
Std WPR-1/SY4			0.7	0.92	2.4	51	b.d.	0.1	1.68	0.4	5	180	3370	1689.4	0.3	10.86	0.4	0.09	2.2	5.6	b.d.	17.11	1420	0.4
MMI04-18-4	587880	5819740	0.1	11.09	5.4	5	1700	b.d.	2.92	0.1	17	13	6	170.2	0.5	3.56	1.4	5.57	11.3	62.9	0.19	0.78	1353	4.1
Std WPR-1/SY4			0.7	0.92	2.4	51	b.d.	0.1	1.68	0.4	5	180	3370	1689.4	0.3	10.86	0.4	0.09	2.2	5.6	b.d.	17.11	1420	0.4
Recommended			0.7	1.64	1.4	42	22	0.19	1.43	0.43	6	180	3300	1640	0.31	9.93	0.61	0.165	2.2	4.2	0.07	18.69	1549	0.9
% Difference			0.0	56.3	52.6	19.4		62.1	16.1	7.2	18.2	0.0	2.1	3.0	3.3	8.9	41.6	58.8	0.0	28.6		8.8	8.7	76.9

			Na	Nb	Nd	Ni	P	Pb	Rb	S	Sb	Sc	Sm	Sn	Sr	Th	Ti	U	V	W	Y	Yb	Zn	Zr
			%	ppm	ppm	ppm	%	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
			TICP	TICP	INA	TICP	TICP	TICP	TICP	TICP	TICP	INA	INA	TICP	TICP	INA	TICP	INA	TICP	INA	TICP	INA	TICP	TICP
Station Number	Easting	Northing	0.001		5	0.1	0.001	0.01		0.02	0.02	0.1	0.1		0.5	0.2	0.001	0.5	2	1		0.2	0.1	
JLO04-21-90	605199	5812879	1.283	2.5	19	17.9	0.107	8.6	140	0.2	3	3.5	2.6	0.8	588	2.6	0.303	1.3	116	2	18.4	1.9	117	28.2
JLO04-25-127	592419	5823830	1.78	2.3	16	3.2	0.092	9.3	203.4	b.d.	2.1	5.4	2	1.4	434	1.5	0.293	1.6	147	b.d.	16.4	2	192	50.4
MMI04-16-7	593603	5822911	4.414	3.3	21	2.9	0.07	21.2	98.6	0.2	2.1	3.5	2.2	1.3	625	2.2	0.311	2.7	116	b.d.	19.9	2.4	87	51.3
MMI04-20-12	589610	5823019	2.171	1.8	18	5	0.175	2.9	52.4	2.2	1.1	23.8	1.7	0.9	701	0.9	0.586	b.d.	364	b.d.	13.4	1.5	36	29
MMI04-21-7	591013	5825895	2.836	2.3	26	5	0.284	50.8	87	4.8	3.8	9.6	2	1.7	480	1.5	0.491	12	508	b.d.	15.9	1.4	248	48.6
MMI04-22-1b	603335	5813020	6.879	2.3	b.d.	1.4	0.029	0.9	0.6	0.1	0.4	4.6	0.7	0.4	103	2.6	0.083	2	33	5	6.7	1	12	31.5
MMI04-22-6	605772	5812844	0.256	1.5	22	55.3	0.15	108.8	7.8	0.3	4.8	15.6	2.4	0.8	984	1	0.323	2.2	283	b.d.	13.2	1.5	104	29.9
MMI04-26-4	592870	5823600	4.128	2.5	40	4.1	0.119	2.7	98.6	0.1	0.3	6.8	2.8	3.8	409	1.9	0.41	4.9	218	b.d.	25.4	2.7	41	65.4
MMI04-26-6	592795	5823790	0.579	0.5	b.d.	72	0.028	3.1	12	b.d.	0.3	79.8	1.2	1.2	178	b.d.	0.742	b.d.	482	b.d.	10.3	0.8	103	23.3
MMI04-26-8	592473	5823702	2.139	2.2	28	5	0.131	15.5	112.2	b.d.	0.8	13.8	2.3	2.1	738	0.8	0.508	1.9	236	b.d.	18.3	2	169	38.9
MMI04-26-9	592470	5823663	2.567	2	16	7	0.144	13.9	74	0.1	0.9	18.6	2.5	2	1015	0.8	0.568	3.5	295	b.d.	21.4	2.2	242	45.7
MMI04-27-1b	585709	5821580	1.706	2.7	26	11.7	0.257	6.2	54.5	0.2	0.1	21.3	2.5	1.1	1963	1.8	0.461	b.d.	385	b.d.	12.4	1.2	93	40.2
Std WPR-1/SY4			0.018	1.8	b.d.	3035	0.019	6.1	5	0.9	0.9	10.9	0.7	0.8	9	b.d.	0.173	b.d.	75	b.d.	4.2	0.5	105	14.2
MMI04-18-4	587880	5819740	4.961	3.4	10	1.2	0.12	12.9	139.4	0.1	0.5	3.8	1.4	0.6	2375	2.1	0.233	2	142	b.d.	9.7	1.1	90	48.1
Std WPR-1/SY4			0.018	1.8	b.d.	3035	0.019	6.1	5	0.9	0.9	10.9	0.7	0.8	9	b.d.	0.173	b.d.	75	b.d.	4.2	0.5	105	14.2
Recommended				2.4	3.5	2900	0.013	6	5	0.9	0.9	12	0.9	1.1	7	0.4	0.179	0.2	65			0.48	95	18
% Difference				28.6		4.6	37.5	1.7	0.0	0.0	0.0	9.6	25.0	31.6	25.0		3.4		14.3			4.1	10.0	23.6

in the study area (Mount Polley, all mineral zones; Shiko Lake and the small stock located northwest of Bootjack Lake). Intrusion breccias are matrix supported; plagioclase porphyry in the Cariboo pit (Fig. 12) or quartz syenite at Shiko Lake contain approximately 30% angular to rounded, rotated clasts of monzonite-diorite country rock in addition to more exotic xenoliths (pyroxene-olivine–phyric volcanic rock, mafic subvolcanic intrusive, foliated hornblende gabbro, or diorite clasts). Hydrothermal breccias are heterolithic, often with clasts of intrusion breccia, volcanic rocks, diorite and monzonite. These breccias contain either rounded (pebble dikes) or angular clasts that are partially replaced, and have their interstices filled, by alteration minerals (Springer zone, Fig. 13). Fraser (1994) divided the hydrothermal breccias at Mount Polley into four types, based on dominant matrix mineralogy: biotite, actinolite, albite and magnetite . The potassic-albite breccia west of Mount Polley and at the Springer zone are characterized by the presence of tabular albite and lesser biotite crystals filling vugs in the breccia matrix. Biotite breccia and actinolite breccia in the Cariboo and magnetite breccias occur northwest of the Northeast zone.

Bootjack Stock

The Bootjack stock is a silica undersaturated, layered syenite pluton (Hodgson *et al*., 1976; Fraser *et al*., 1993), located south of Bootjack Lake (Fig. 2). In contrast to the fine-grained porphyritic textures of the rocks that make up the Polley stock, the Bootjack phases exhibit coarse-grained plutonic textures. It has an easterly to northwesterly trend and is separated from the Mount Polley stock by a narrow belt of northwest-trending mafic metavolcanic flows, breccias and fine-grained bedded volcaniclastic units. To the south (and deeper), the stock intrudes stratigraphically lower analcime-bearing pyroxene-olivine–phyric basalt and volcaniclastic breccias. Compositional layering within the main body of the syenite strikes westerly and dips moderately north (consistent with the majority of regional bedding measurements), although, at the west end of the body (Trio Lake), the layering trends northwesterly with steep easterly dips (Hodgson *et al*., 1976). The stock comprises a mafic pseudoleucite syenite, a crowded orbicular syenite and a coarse-grained granophyric syenite (Fraser, 1994).

MAFIC PSEUDOLEUCITE SYENITE PORPHYRY

A melanocratic porphyritic syenite comprises ~40% of the stock and crops out primarily along the stock's western margin. It contains up to 20% 2 cm euhedral phenocrysts of pseudoleucite (mixture of nepheline, K-feldspar and sericite) in a medium to coarse-grained salt and pepper textured groundmass (Fig. 14) comprising K-feldspar, nepheline, albite, clinopyroxene, hornblende and magnetite. Mafic minerals constitute 15 to 25% of the rock. Narrow chilled

Figure 12. Intrusion breccia, plagioclase porphyry in the Cariboo pit

Figure 13. Intrusive breccia characterized by pervasive potassic alteration and frothy, albite replacement along clast margins. Breccia defines the western contact of the Mount Polley monzo-syenite stock located on Mount Polley.

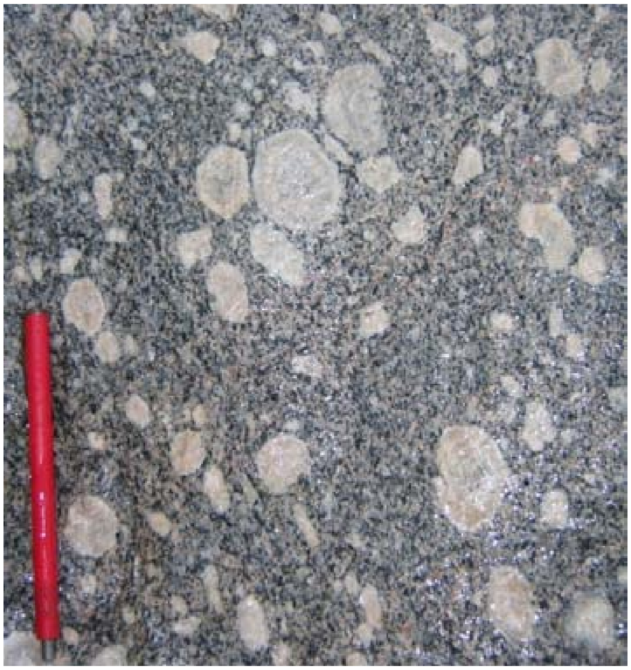

Figure 14. Porphyritic syenite, containing up to 20% 2 cm euhedral phenocrysts of pseudoleucite (mixture of nepheline, K-feldspar and sericite).

apophyses of the mafic syenite porphyry intrude mafic analcime-bearing basalt near Trio Lake.

A large (18 m wide), north-trending, east-dipping tabular block of pyroxene porphyritic metabasalt is exposed in the northeast wall of the borrow pit, approximately 2 km northwest of the tailings impoundments. The syenite is chilled adjacent to the xenolith and, to the west, the metabasalt is faulted against leucocratic orbicular nepheline syenite. In addition, the pyroxene porphyry is veined by pink potassic alteration (orthoclase flooding), epidote and minor pyrite. It is importance to note that, although this augite porphyry resembles some of the youngest crosscutting 'AP'dikes, observations indicate that it predates the syenite.

FELSIC ORBICULAR NEPHELINE SYENITE

The orbicular nepheline syenite is a leucocratic rock consisting of 30 to 90% orbicules of pseudoleucite up to 4 cm in diameter. Interstitial to the orbicules is a medium-grained equigranular matrix of nepheline, clinopyroxene, biotite, sphene and magnetite. The orbicules contain subhedral pseudoleucite cores and have concentric overgrowths of K-feldspar. This unit constitutes approximately 55% of the Bootjack stock.

The northeastern margin of the stock (southeast end of Bootjack Lake) has been overprinted by biotite and fluorite. (Fraser, 1995). In a structurally restored section, where regional dips have been removed by assuming that all parts of the crust were tilted equally, the northern part of the stock would be the roof zone (*see* 'Structure' section).

QUARTZ-PLAGIOCLASE PORPHYRITIC MONZOSYENITE

Coarse-grained quartz and feldspar-phyric monzonite and monzosyenite dikes intrude the pseudoleucite syenite southwest of Bootjack Lake. Panteleyev *et al*. (1996) included these as part of their Triassic-Jurassic suite of rocks (unit 7). Hodgson *et al*. (1976) correlated them with a younger suite of calcalkaline, quartz-bearing stocks of probable Cretaceous age. We follow Hodgson's correlation.

AUGITE PORPHYRY DIKES

Augite porphyry dikes are ubiquitous throughout the area. They are typically recessive, rubbly weathering, 10–100 cm thick and consist of 30–50% euhedral 1–5 mm clinopyroxene phenocrysts in a black to dark green aphyric groundmass of plagioclase laths, magnetite and interstitial K-feldspar (indicated by staining samples with sodium cobaltinitrate). The youngest intrusions occur as northerly striking, moderately east-dipping swarms of generally thin (centimetre to metre-scale) dikes that crosscut all of the igneous and breccia units at the deposit (Fraser, 1994).

They are compositionally like Nicola Group basalt flows and feeder dikes. They also cut mineralized monzonite intrusions that cut the Nicola Group basalts and are therefore younger. It is not uncommon to see augite porphyry clasts within intrusion-hydrothermal breccias themselves crosscut by augite porphyry dikes. These dikes probably represent feeders to Miocene or younger (Mathews 1989) alkaline plateau basalt flows known from west of the study area. However, these dikes bound mineralized zones (earning them the name 'Death Dikes') and are locally deformed (east wall of Cariboo pit ramp), suggesting that at least some of them are pre to syn-mineralization (unless they have intruded along post-mineral faults with significant offsets).

CHEMISTRY

Samples were steel milled at the British Columbia Geological Survey Branch Laboratory in Victoria. Splits were shipped for analysis to TeckCominco Laboratories, Vancouver for major element and trace element abundances (Ba, Rb, Sr, Nb, Zr and Y) by X-ray fluorescence (XRF); ACME Analytical, Vancouver for trace element analyses using inductively coupled plasma – emission spectrometry (ICP-ES); and Actlabs, Ancaster, Ontario for trace element analyses using instrumental neutron activation (INAA). A subset of these samples has also been sent to Memorial University, Newfoundland for trace element analyses using inductively coupled plasma – mass spectrometry (ICP-MS). Results are pending.

STRUCTURAL STYLE

Scattered exposures of well-bedded sediment and water-lain tuff are sources of reliable paleohorizontal orientation data that can be used to assess the effects of folding and faulting in the Polley area. Local excellent preservation of bedding tops indicators shows that, with the exception of a single outcrop that may have slumped, all beds are upright. Bedding orientation data are sparse and potentially unreliable in the volcanic-intrusive Mount Polley complex but, on its northern flank, orientation data form a low variance (0.018) unimodal population with minor dispersion on a Pi girdle (Fig. 15A). A lack of measurements from the fold limbs limits reliability of the calculated beta axis, 35°/300° (Fig. 15A). In a single-phase cylindrical fold, the beta axis is parallel with the fold axis. When combined with all reliable bedding determinations, the calculated Pi girdle is more robust, indicating a shallowly north-northwest-plunging fold, with a beta axis of 21°/353° (Fig. 15B). Effects of this plunge, if regionally applicable, could be substantial. For example, in the absence of block fault adjustments to compensate, the tilting of the Bootjack stock may have resulted in a differential exhumation of 2.6 km from northwest to southeast. That is to say, the exposed southern part of the stock was emplaced 2.6 km deeper than the currently exposed northern end. A south to north variation from megacrystic orbicular syenite to hydrothermally altered fine to coarse-grained syenite is consistent with this magnitude of regional tilting. However, an invariant regional metamorphic grade in Nicola Group strata does not permit differential uplifts of tens of kilometres, so extensional block faulting must have accompanied tilting of blocks that extend more than 20 or 30 km in a direction parallel to the regional fold axes. Major discontinuities in the fabric of the regional aeromagnetic total field data occur between the Bootjack stock and Shiko Lake stock, and between Morehead Lake and Quesnel River, possibly related to northeast-trending normal faults. Along the southern discontinuity are relicts of Miocene plateau basalt, perhaps fed from dikes that invaded these proposed faults.

Existence of north-northwest-trending faults is firmly established. Dominant structures in the mine area are the Polley Fault and the unnamed fault that truncates mineralization in the Northeast zone. The Polley fault is a steep easterly-dipping brittle structure that separates the deposit into the Central zone (Cariboo and Bell pits) and the West zone (Springer pit), each with distinctive mineralization, alteration and style of brecciation. In the southwest corner of the Cariboo pit, the structure comprises a 50 m wide zone of sheared and fractured rocks containing fault breccias and clay gouge, but the fault zone narrows to the north and south (Wild, 1999). The fault does result in apparent horizontal displacement of the northern contact of the Bootjack stock, and therefore any motion along the structure must either 1) have a displacement vector that is approximately parallel to the dip of the intrusive contact; 2) be a rotational fault with an axis of rotation located near the location of the Bootjack stock; 3) predates intrusion of the Bootjack stock (200 Ma); or 4) record a tremendous amount of motion but with no net displacement, and therefore be of little regional significance. Layered strata on the northern flank of Mount Polley are apparently not offset by the fault, and we show a deflection in the trace of the fault from ~350° to ~290° in order to continue the fault west of exposures of well-layered rocks. In this area, only two reliable well-bedded exposures lie west of the fault and they have an average orientation of 219°/42°, as compared to those east of the fault

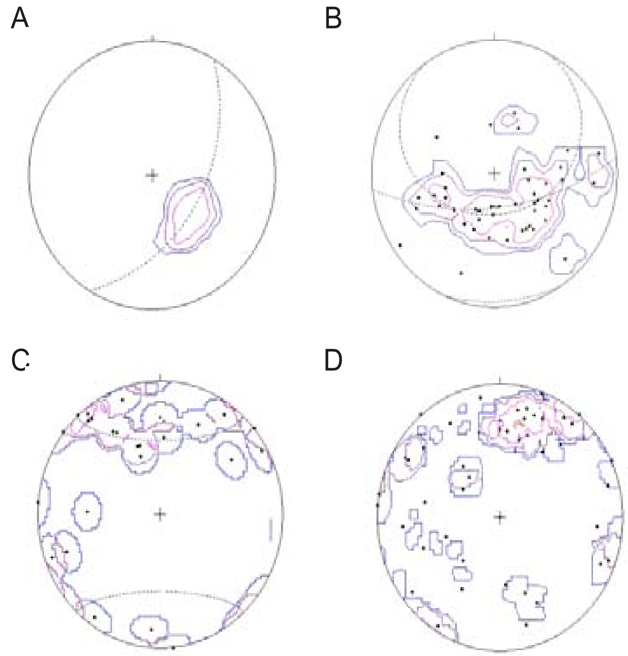

Figure 15. Equal area plots of **A)** reliable bedding measurements (N=14) from the northern flank of Mount Polley; contours are 8, 16, and 32% of data points per 1% of plot area; **B)** all reliable bedding measurements from the Polley area (N=51); contours are 2, 4, 8, and 16% of data points per 1% of plot area; **C)** all veins from the Polley area (N=25); contours are 4, 8, and 16% of data points per 1% area; and **D)** all dikes from the Polley area (N=51); contours are 2, 4, 8, and 16% of data points per 1% area.

(226°/35°; N=11). The averaged bedding orientation from east of the fault falls within the 20% contour (points per 1% area) of the eastern population (Fig. 15A) and is therefore not statistically different. Consistent bedding orientation rules out significant rotational variation across the Polley fault.

A second north-northwest-trending fault corridor has been intersected by drilling in the Northeast zone, where it marks the northwestern limit of mineralization. These structures may be related to a major fault that is obscured by cover within the Polley Lake valley. Possible continuation of this fault beneath cover northwest of Polley Lake is suggested by truncation of regional magnetic fabric shown on the Polley multiparameter dataset (BC MapPlace). In particular, apparently folded vertical-gradient magnetic lineaments (Fig. 4) that are consistent with the broad fold on the north flank of Mount Polley (Fig. 2) are truncated at the presumed fault extension (Fig. 4). If this is truly the same structure, its trend is deflected by about 60° from 350° to 290°, similar to the proposed deflection on the Polley fault. One highly speculative interpretation is that both faults are folded about a near-vertical axis. If this is so, the Northeast zone is located in the outer (dilatent) part of the hinge zone.

Most veins in the Polley area are steep (Fig. 15C) except for a small subset that dips moderately south-southeast. The mode represents a set of veins that dips steeply toward ~150º. Because paleohorizontal control is lacking for most of the Polley area, we have not attempted to unfold and rotate the data based upon the apparent regional folding.

Dike orientations display a mode of approximately 120º/65º (Fig. 15D); a smaller population is oriented about 310º/85º. Dikes may be useful indicators of the paleostress field, but relative ages and effects of later tilting and rotation must first be established.

MINERALIZATION AND ALTERATION

Alkalic intrusion–related mineralization defines the centre or axis of the Quesnel arc (Panteleyev *et al*., 1996, Fig. 8); fewer and more widely-spaced mineral occurrences associated with calcalkaline intrusions are located on the western margin of Quesnellia. In the area surrounding Mount Polley, there are a number of small, high-level composite intrusions with compositions ranging from diorite through monzonite to syenite. These are interpreted to have been emplaced into the upper levels of the arc and are often hosted by coarse extrusive facies equivalent volcanics that indicate individual eruptive centres (i.e., Mount Polley, Bailey and Hodgson, 1979; Shiko Lake, Panteleyev *et al*., 1996).

INTRUSIVE CENTRES

Mount Polley (MINFILE 093A/008 and 164)

Mineralization at Mount Polley is hosted by a variety of hydrothermal breccias that cut a high-level multiphase dioritic intrusion. Alteration and mineralization are interpreted to be related to a single hydrothermal centre modified by faulting (Fraser, 1994). However, they display sufficient zonal variation to warrant subdivision into West, Central and Northeast zones (Fig. 16).

Central and West Zones (Cariboo-Bell-Springer)

Alteration studies by Hodgson *et al*. (1976) and Bailey and Hodgson (1979) identified three roughly concentric alteration assemblages associated with the copper-gold mineralization at Mount Polley: a central potassic core, an intermediate garnet-epidote zone and an outer propylitic zone. Work by Fraser (1994, 1995) on the mineral zonation in the Central (Cariboo and Bell) and West (Springer) zones resulted in the subdivision of the potassic core into three subzones defined on the basis of the dominant alteration mineral: biotite, actinolite and K-feldspar–albite. The biotite and actinolite subzones occupy the Central zone, east of the Mount Polley fault, the K-feldspar–albite zone occurs west of the fault (West zone), and east of the actinolite zone in a northwest-trending belt west of Mount Polley (this study). Alteration mineral zonation appears to have been controlled by the distribution of hydrothermal breccias and reflects the evolving permeability, fluid composition and temperature of the hydrothermal system (Fig. 16).

The biotite subzone is characterized by coarse secondary biotite developed interstitial to hydrothermal breccias in the core of the Central zone. Extending north from the biotite subzone is the 600 by 200 m north-trending actinolite subzone (Fraser, 1995). It is characterized by abundant actinolite-chalcopyrite-pyroxene-magnetite veins that are enveloped by extensive K-feldspar alteration envelopes. Surrounding the actinolite and biotite subzones is a circular 0.8 km^2 zone of intense K-feldspar flooding. Where pervasive, potassic alteration has destroyed primary textures and fine-grained disseminated hematite imparts a salmon-pink colouration to the rocks. The eastern and western margins of the potassic core are marked by orange-weathering potassic hydrothermal breccias. In these zones, coarse granular white albite crystals fill veins and the spaces between the potassic-altered breccia fragments (West zone and west flank of Mount Polley).

Wild (1999) recognized that the relative abundance of main alteration minerals (K-feldspar, actinolite-biotite and magnetite) correlated well with copper grade. From this, an alteration scoring system was devised to estimate copper grades. Each of the constituents is scored from 0 to 5 based on intensity (low to high), with a total of 15. Grade or ~0.3% Cu corresponds to a 10–12 or higher score. From these criteria, it is necessary to have at least some of each of the main alteration constituents to reach grade. The alteration scoring system does not work at the Northeast zone (McAndless, personal communication, 2004).

The Mount Polley deposit (Cariboo-Bell-Springer) contains chalcopyrite, pyrite and bornite as primary sulphides that are associated with magnetite. Polished sections indicate rare tetrahedrite, galena, sphalerite and molybdenite. Oxide minerals include malachite, azurite, magnetite, hematite, and limonite. Native gold is present as 5 to 30 m inclusions in chalcopyrite (Wild, 1999). Mineralization is hosted primarily in hydrothermal and intrusion breccias, with lesser amounts in fractured country rocks.

Northeast Zone

The Cu-Au-Ag mineralization at the Northeast zone occupies a 150 by 500 m, northwest-trending, steeply dipping tabular zone located close to the northern margin of the Polley stock. Hostrocks are interpreted as hydrothermally brecciated monzodiorite, monzonite and porphyritic monzonite phases of the stock that are cut by premineral K-feldspar megacrystic syenite and plagioclase porphyry dikes. Post-mineral plagioclase porphyry and augite porphyry dikes also cut the Northeast zone.

A comprehensive petrographic study, augmented by scanning electron microscope (SEM) work on the mineralogy at the Northeast zone was completed by Ross (2004) for Imperial Metals. Quick logs of six drillholes along sections 14, 18 and 22, discussions with Pat McAndless, Lee Ferreira and Chris Rees during the ongoing drilling, and examination of select drillcore form the basis of the following description of the Northeast zone.

Alteration at the Northeast zone is not dissimilar to that present at the Central and West zones (1.5 km southwest). The Northeast zone consists of an early pervasive and texturally destructive potassium metasomatic event that predated or coincided with brecciation. Pink veinlets consist of cloudy brown secondary K-feldspar, which overprints the

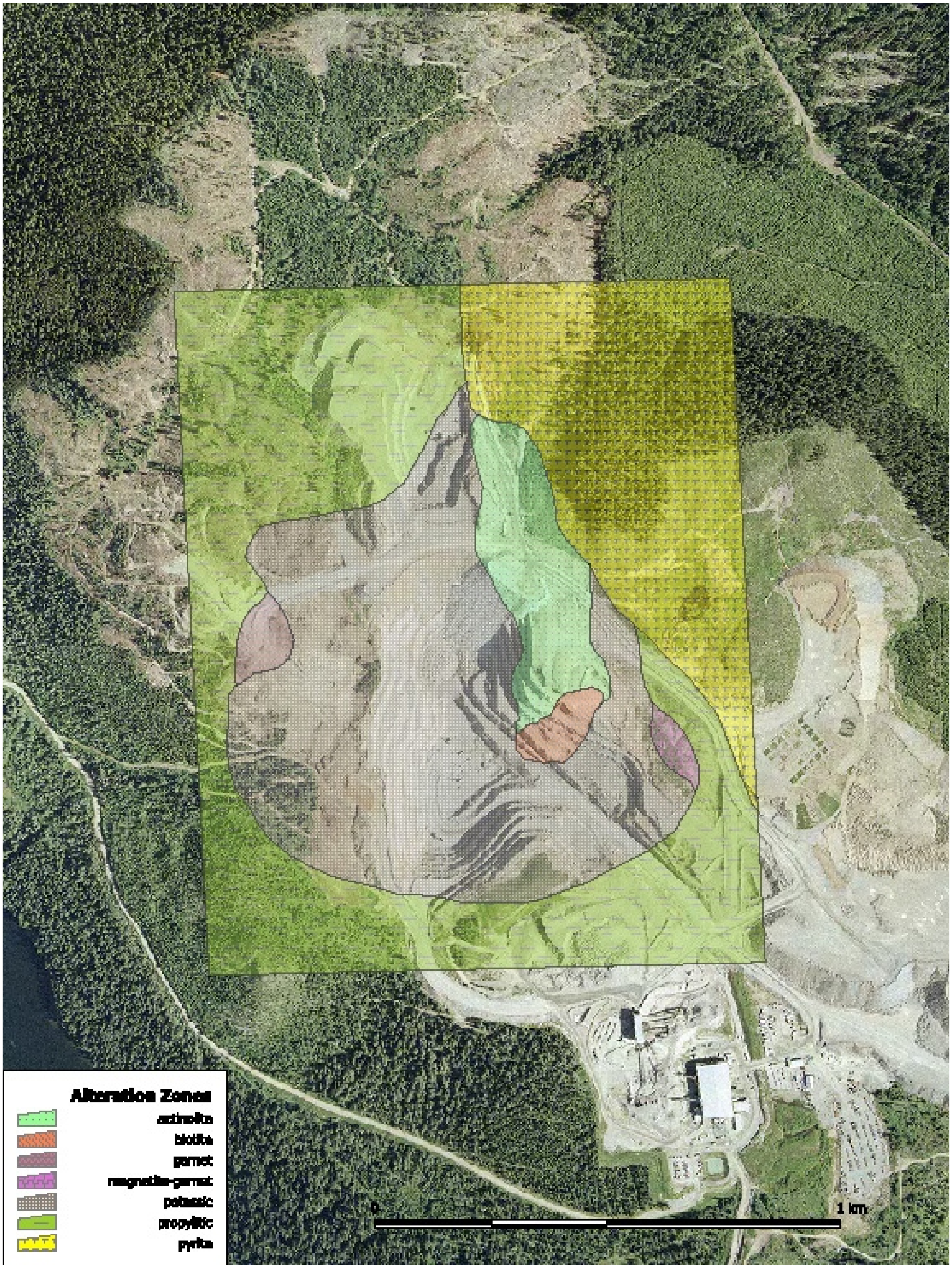

Figure 16. Distribution of alteration zones at Mount Polley (*from* Fraser, 1994). Biotite and actinolite subzones occupy the Central zone, east of the Mount Polley fault; the K-feldspar–albite zone occurs west of the fault (West zone) and east of the actinolite zone in a northwest-trending belt west of Mount Polley

groundmass plagioclase and locally destroys mafic minerals. Diffuse green veinlets consist of a very fine grained intergrowth of epidote-clinozoisite and calcite. (clinozoisite is an aluminum-rich epidote mineral). Fine-grained pyrite and chalcopyrite are associated with the green alteration. This was followed by a calcsilicate assemblage that Ross (2004) divided into two stages: an early magnetite-garnet-apatite stage; and a slightly younger clinozoisite-albite-calcite stage, which introduced most of the Cu sulphides. A late-stage, lower temperature alteration assemblage of calcite-albite-chlorite (retrograde continuum to the mineralizing stage; according to Ross, 2004) is separate from a propylitic assemblage of calcite-chlorite-pyrite that envelops the breccias but is more strongly developed in the volcanic rocks adjacent to the northeastern margin (Fig. 17). Late-stage calcite-gypsum veins occur deep in the section. They crosscut the peripheral propylitic zones as well as the intrusive breccias. Calcite and fibrous radiating zeolites are late and fill open spaces in the Central zone.

Garnet compositions from the Northeast zone are identical to those from Central and West zones (Ross, 2004; Fraser, 1994); both are nearly pure andradite with minor (10–15%) grossular (Ca) component in rims. Magnetite is inferred to be less important in the Northeast zone, although Ross (2004) reported that the highest grade mineralization is developed in magnetite-rich sections of the intrusive breccia. In drillhole WB-04-21, a post-mineral hydrothermal brecciation and albite-clinozoisite alteration overprints the mineralized breccia (Fig. 18). The zone is veined by coalescing white and pale green, banded or crustiform veinlets and a fine-grained sugary texture matrix containing tabular albite crystals. Breccia fragments of mineralization are surrounded by albite-altered matrix (Fig. 19).

The Northeast zone copper mineralization consists of chalcopyrite and bornite as primary sulphides that are sporadically intergrown with magnetite and lesser pyrite. Copper mineralization occurs as finely disseminated chalcopyrite and as coarse intergrown clots of chalcopyrite and bornite. Petrographic analysis shows bornite and chalcopyrite exsolution textures, one from the another. Copper mineralization appears to have pervaded the Northeast zone in two stages: first chalcopyrite, occurring within an interconnected network of fractures and veinlets; and later bornite, rimming and replacing chalcopyrite in veinlets (Fig. 19).

Gold and silver minerals occur with copper. Silver±selenium occur in tellurides, silver occurs in galena, and selenium occurs as inclusions in bornite and chalcopyrite (Ross, 2004). Mineralization at the Northeast zone is

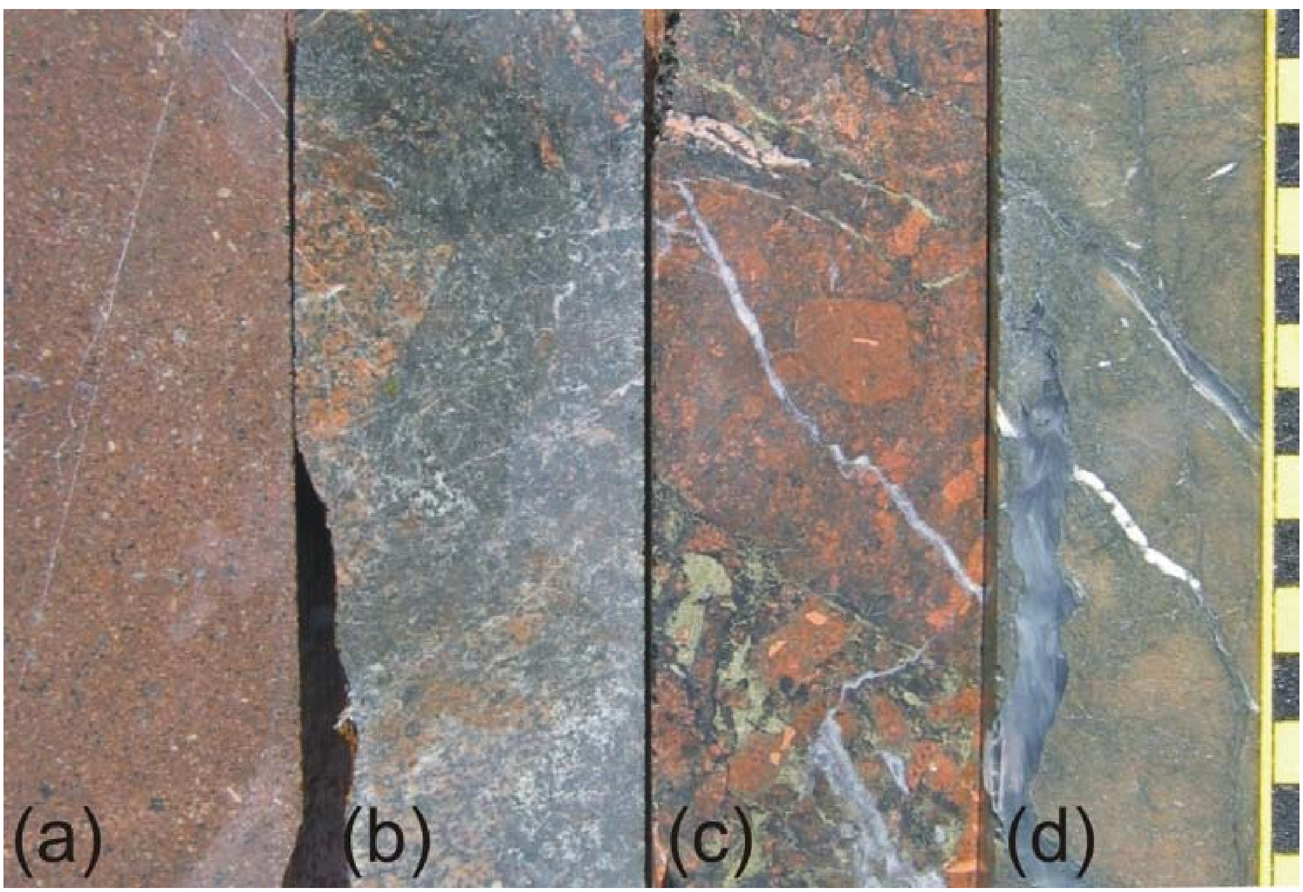

Figure 17. Four characteristic examples of Northeast zone lithology-alteration from DDH WB-03-27: **a)** postmineral plagioclase porphyry dike at 14.5 m; **b)** propylitic overprint weak potassic-altered monzonite in hanging wall at 19.0 m; **c)** potassic-altered, brecciated, brown calcsilicate overprint of matrix associated with chalcopyrite and magnetite at 202.2 m; and **d)** fine-grained, propylitic metavolcanic footwall rocks, disseminated pyrite cut by calcite and gypsum veinlets.

Figure 18. Post-mineral hydrothermal breccia with an albite-clinozoisite alteration overprint. Note clasts of mineralization within matrix.

Figure 19. Coarse intergrown clots of chalcopyrite and bornite in fractures cutting potassic altered monzonite breccia in the Northeast zone.

characterized higher copper grades, higher bornite content, higher copper:gold ratios, higher silver content, and lower magnetite content than other breccias in the camp. Copper grades are consistent and up to three times higher than the historical copper grades from the Cariboo and Bell pits. In addition, the Northeast zone contains silver, which is not recoverable elsewhere.

Abrupt termination of Northeast zone mineralization and decrease in the intensity of alteration on its northeastern side corresponds with a brittle fault zone invaded by numerous augite porphyry dikes. Southwest of the Northeast zone, the tenor of mineralization diminishes, except at the Leak and Boundary zones; which both have a mineralogy that differs slightly from that of the Northeast zone. The Leak zone more closely resembles alteration (actinolite–K-feldspar–magnetite) and metal grades (0.30% Cu) in the Cariboo pit; and the Boundary zone is an auriferous magnetite-rich breccia. The northwestern contact relationships of the Northeast zone are poorly exposed and pervasive potassic alteration makes it difficult to distinguish between intrusive breccias and the Upper Triassic volcanic breccias, lahar and conglomerate units known to crop out in the area. The mineralized breccia is heterolithic and clast supported. Clast compositions include equigranular monzonite, megacrystic K-feldspar porphyry syenite, and early plagioclase porphyry. The matrix is dark, fine grained and invariably altered and mineralized.

Bullion Lode (MINFILE 093A/041)

A north-trending body of equigranular, pink to grey monzodiorite is exposed in the placer workings at the Bullion pit, approximately 5 km northwest of Likely. The monzodiorite intrudes alkaline pyroxene-olivine–phyric basalt breccias and volcaniclastic rocks correlative with the basal volcanic ‘unit 2’ of Panteleyev *et al*. (1996).

The Bullion monzodiorite is a fine to medium-grained, melanocratic rock composed of plagioclase, orthoclase and clinopyroxene with coarse poikilitic biotite crystals and accessory minerals that include magnetite, apatite and sphene. The monzodiorite is cut by closely spaced fractures and stockworks, and veined by pegmatitic syenite segregations of orthoclase and albite that coalesce to form irregular intrusive breccias. In addition, narrow (<1 m), east-trending pink dikes of medium-grained, equigranular hornblende-biotite syenite intrude the monzodiorite. The syenite is composed of 3–5 mm equant salmon pink orthoclase and white plagioclase phenocrysts, 1–2 mm interstitial hornblende, biotite and magnetite.

The syenite contains disseminated clots of 1–2% chalcopyrite. Locally pyrite, chalcopyrite and molybdenum mineralization is developed along dike contacts or late fractures, which are crosscut by younger narrow veinlets of albite with sericite alteration envelopes.

Shiko Lake (Redgold; MINFILE 093A/058)

A high-level multiphase alkalic complex occurs northeast of Shiko Lake. At its western end, three separate intrusive phases are well exposed within a (ca. 1994) quarry that supplied syenite to colour the exterior of the Vancouver Public Library. From oldest to youngest, these include a melanocratic, medium-grained equigranular, biotite-pyroxene monzodiorite; a pink, trachytic, medium to coarse-grained, K-feldspar–phyric syenite; and a leucocratic alkali feldspar quartz syenite. The quartz syenite truncates a well-developed, west-striking, 30^o north-dipping trachytic fabric in the K-feldspar megacrystic syenite, which veins and engulfs the earlier diorite. All phases contain mafic xenoliths of olivine-pyroxene–phyric basalt, fine-grained metasedimentary rocks and subvolcanic dioritic to monzonitic compositions that increase in abundance as the contact is approached. Toward the centre of the stock, the dominant phase is a white, medium to coarse-grained, equigranular monzonite containing 0.7–1.0 mm grains of biotite and hornblende (biotite>hornblende) with trace amounts of magnetite, sphene and pyrite and abundant rounded, partially digested xenoliths of country rock. The monzonite is intruded by dikes and veins of fine-grained pink quartz syenite that coalesce to form zones of intrusive breccia. Rotation and incorporation of the monzonite blocks is evident from their random trachytic textures. Matrix to the breccia contains disseminated chalcopyrite and pyrite.

Country rock exposed adjacent to the stock includes fine-grained, hornfelsed metasedimentary and thin-bedded volcaniclastic rocks and a mixed volcanic package that includes stubby plagioclase, pyroxene-phyric massive basalt flows and crowded hornblende-plagioclase porphyritic dikes. Approximately 1 km southeast of the contact are coarse breccias and pillowed flows of olivine-pyroxene–phyric basalt with interclast limestone, fine-grained chert and limy lapilli tuff horizons. Heterolithic plagioclase, pyroxene-phyric breccias and chaotic volcaniclastic deposits are exposed in trenches on the Redgold mineral occurrence, located approximately 1.5 km east of the quarry.

Copper (chalcopyrite and bornite) and gold mineralization occurs as veins and disseminated clots within all three intrusive phases, but appears to be associated with the youngest quartz syenite phase. Vein assemblages cutting the intrusive rocks include intergrowths of actinolite, K-feldspar, sphene, magnetite, pyrite ± chalcopyrite. Potassic overgrowths on feldspars and replacement of hornblende by actinolite and biotite by chlorite are attributed to late deuteric alteration. The leucocratic quartz syenite hosts the majority of mineralization exposed in the quarry. It is characterized by quartz-filled miarolitic cavities and a low magnetic susceptibility response. A grab sample of the mineralized syenite (MMI04-22-1b; see Table 1) returned low copper and gold values. Additional mineralization-alteration has been recognized outside the stock in the volcanic cover rocks (Morton and Durfeld, 1998). Alteration and mineralization in the plagioclase-pyroxene–phyric volcaniclastic rocks is characterized by fracture-controlled, locally pervasive potassium flooding of the groundmass accompanied by epidote replacing either pyroxene±plagioclase or the matrix, and introduction of magnetite and disseminated chalcopyrite. Late-stage white calcite veinlets crosscut earlier alteration minerals. Grab samples of alteration-mineralization from the trenches returned low copper (~0.2%) and gold (51 and 558 ppb) values (JLO04-21-90 and MMI04-22-6; see Table 1).

Potassium-argon dating carried out by J.E. Harakal at the University of British Columbia on samples from the monzonitic core zone gave ages of 192 ± 10 Ma and 182 ± 6 Ma and a slightly older age of 196 ± 7 Ma for a hornblende porphyry dike cutting the stock (Panteleyev *et al*., 1996). A number of macrofossil identifications from the sedimentary rocks intruded by the Shiko stock are early Jurassic (GSC-C-118687, probable Sinemurian; GSC-C-118685, Lower Sinemurian or possibly Hettangian; GSC-C-118686, Lower Sinemurian, lower Pleinsbachian). Panteleyev *et al*. (1996) described volcanic and intrusive breccias along the southern contact of the stock that they interpreted to represent the vent zone of an intrusive centre. Field evidence could neither refute nor substantiate an age for the mineralization and emplacement of the Shiko stock or its enclosing rocks. A sample of leucocratic alkali feld-

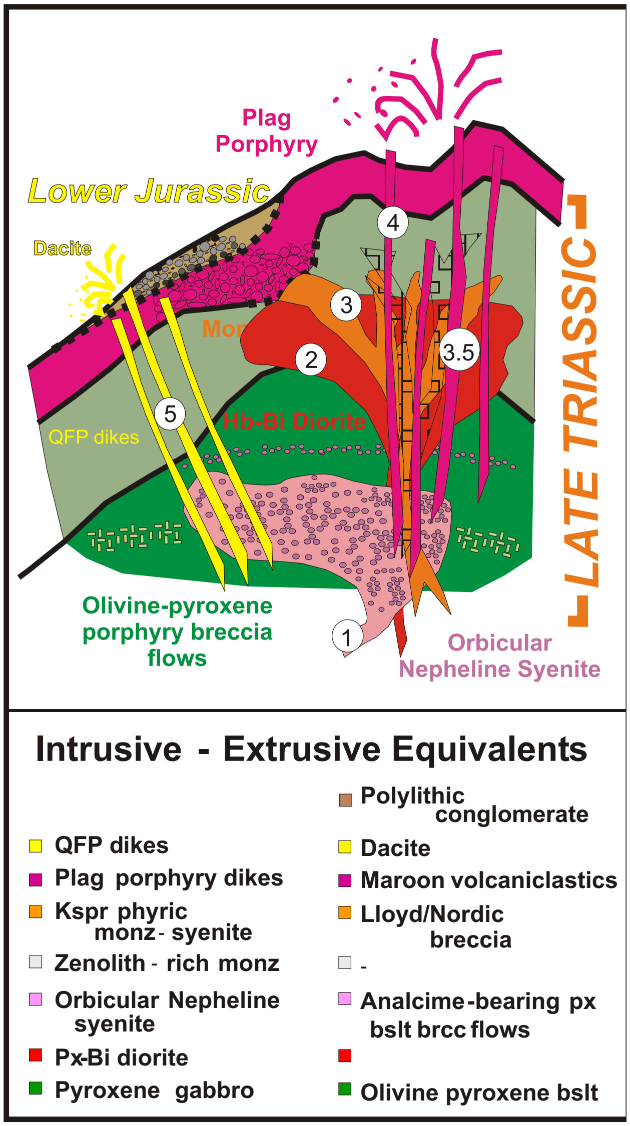

Figure 20. Schematic representation of Late Triassic volcanism and intrusion, showing relative age of events.

spar quartz syenite was collected for U-Pb geochronology; results are pending.

CONCLUSIONS

The spatial and temporal association of the Mount Polley intrusives with the thick pile of heterolithic, in part comagmatic volcanic breccias suggests that they were emplaced at shallow depths and proximal to a vent (Fig. 20; Bailey and Hodgson, 1979; Fraser, 1994;). Their northerly trend and position with respect to the Polley fault may also have exerted a structural control on emplacement, breccia development and hydrothermal flow of alteration and mineralizing fluids. The general evolution of the arc from early pyroxene-plagioclase-olivine to pyroxene-plagioclase± analcime and plagioclase-dominated basalt compositions is consistent with the successive emplacement of comagmatic pyroxene diorite, monzonite, plagioclase porphyry and potassium megacrystic monzosyenites.

According to Fraser (1994), alteration-mineralization paragenesis for the Central zone (Cariboo-Bell pits) progresses outward from a higher temperature core of biotite to an intermediate actinolite zone and an outer zone of K-feldspar and albite. The degree of mineralization is directly related to secondary permeability developed by fracture and brecciation, which in many examples affects intrusives that have been pervasively potassium metasomatized prior to brecciation. The potassium-albite breccia zones that flank the Cariboo pit (i.e., West zone and Mount Polley) exhibit this early pervasive, generally barren potassium metasomatism, brecciation and what appears to be open space deposition of albite±biotite±actinolite and sulphides. In places, coalescing albite fractures produce pseudobreccia textures, but hydrothermal breccia textures are recognized in the western zone. Alteration zonation is related to a migrating, cooling hydrothermal fluid, which evolved through a variety of fluid-wallrock interactions as it moved outward from the hydrothermal centre.

The relationship between the Polley and Bootjack stocks is equivocal.

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REFERENCES

Bailey, D.G. (1976): Geology of the Morehead Lake Area, central British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources,* Preliminary Map 20 with notes, scale 1:31 680.

Bailey, D.G. (1978): The geology of the Morehead Lake area; unpublished Ph.D. thesis, *Queen's University*, 198 pages.

Bailey, D.G. (1988a): Geology of the Central Quesnel Belt, Hydraulic, south-central British Columbia (93A/12); *in* Geological Fieldwork 1987, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1988-1, pages 147–153.

Bailey, D.G. (1988b): Geology of the Hydraulic map area, NTS 93A/12; *BC Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map 67, scale 1:50 000.

Bailey, D.G. (1989): Geology of the Central Quesnel Belt, Swift River, south-central British Columbia (93B/16, 93A/12, 93G/1); *in* Geological Fieldwork 1988, *BC Ministry of En-*

ergy, Mines and Petroleum Resources, Paper 1989-1, pages 167–172.

Bailey, D.G. (1990): Geology of the Central Quesnel Belt, British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources,* Open File 1990-31, 1:100 000-scale map with accompanying notes.

Bailey, D.G. and Archibald, D.A. (1990): Age of the Bootjack Stock, Quesnel Terrane, south-central British Columbia (93A); *in* Geological Fieldwork 1989, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1, pages 79–82.

Bailey, D.G. and Hodgson, C.J. (1979): Transported altered wall rock in laharic breccias at the Cariboo-Bell Cu-Au porphyry deposit, British Columbia; *Economic Geology*, Volume 74, pages 125–128.

Barr, D.A., Fox, P.E., Northcote, K.E. and Preto, V.A. (1976): The alkaline suite porphyry deposits: a summary; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 359–367.

Barrie, C.T. (1993): Petrochemistry of shoshonitic rocks associated with porphyry copper-gold deposits of central Quesnellia, British Columbia, Canada; *Journal of Geochemical Exploration*, Volume 48, pages 225–258.

Bloodgood, M.A. (1990): Geology of the Eureka Peak and Spanish Lake map area, British Columbia; *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-3, 36 pages.

Campbell, K.V. and Campbell, R.B. (1970): Quesnel Lake map-area, British Columbia (93A); *in* Report of Activities, Part A, *Geological Survey of Canada*, Paper 70-1A, pages 32–35.

Campbell, R.B. (1961): Geology of Quesnel Lake, Sheet 93A (West Half), British Columbia*; Geological Survey of Canada*, Map 3-1961.

Campbell, R.B. (1963): Geology of Quesnel Lake, sheet 93A (east half), British Columbia; *Geological Survey of Canada*, Map 1-1963.

Fox, P.E. (1975): Alkaline rocks and related mineral deposits of the Quesnel Trough, British Columbia (abstract); *Geological Association of Canada*, Symposium on Intrusive Rocks and Related Mineralization of the Canadian Cordillera, Program and Abstracts, page 12.

Fox, P.E. (1991): A model for alkaline copper-gold porphyry deposits; abstract; *Geological Association of Canada – Mineralogical Association of Canada*, Joint Annual Meeting, Program with Abstracts, page A39.

Fraser, T.M., (1993): Geology and alteration of the Mount Polley alkalic porphyry copper-gold deposit, British Columbia (93A/12); *in* Geological Fieldwork 1992, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 295–300.

Fraser, T.M. (1994): Hydrothermal breccias and associated alteration of the Mount Polley copper-gold deposit; *in* Geological Fieldwork 1993, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 259–267.

Fraser, T.M. (1995): Geology, alteration and the origin of hydrothermal breccias at the Mount Polley alkalic porphyry copper-gold deposit, south-central British Columbia; unpublished M.Sc. thesis, *University of British Columbia*, 259 pages.

Fraser, T.M., Stanley, C.R., Nikic, Z.T., Pesalj, R., and Gorc, D. (1995): The Mount Polley copper-gold alkalic porphyry deposit, south-central British Columbia; *in* Porphyry Deposits of the Northern Cordillera, Schroeter, T.G., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 46, pages 609–622.

Hodgson, C.J., Bailes, R.J. and Versoza, R.S. (1976): Cariboo-Bell; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 388–396.

Karlsson, H.R. and Clayton, R.N. (1991): Analcime phenocrysts in igneous rocks: primary or secondary? *American Mineralogist*, Volume 76, pages 189–199.

Mathews, W.H. (1989): Neogene Chilcotin basalts in south-central British Columbia: geology, ages, and geomorphic history; *Canadian Journal of Earth Sciences*, Volume 26, pages 969–982.

McMullin, D.W.A. (1990): Thermobarometry of pelitic rocks using equilibria between quartz-garnet-aluminosilicate-muscovite-biotite, with application to rocks of the Quesnel Lake area, British Columbia; unpublished Ph.D. thesis, *University of British Columbia*, 291 pages.

Mortensen, J.K., Ghosh, D.K. and Ferri, F. (1995): U-Pb geochronology of intrusive rocks associated with copper-gold porphyry deposits in the Canadian Cordillera; *in* Porphyry Deposits of the Northwestern Cordillera of North America, T. G. Schroeter, Editor, *Canadian Institute of Mining, Metallurgy and Petroleum*, Special Volume 46, pages 142–158.

Mortimer, N. (1987): The Nicola Group: Late Triassic and Early Jurassic subduction-related volcanism in British Columbia; *Canadian Journal of Earth Sciences*, Volume 24, pages 2521–2536.

Morton, J.W. and Durfeld, R.M. (1998): Summary report on the Redgold porphyry copper gold project; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 25 867.

Morton, R.L. (1976): Alkalic volcanism and copper deposits of the Horsefly area, central British Columbia; unpublished Ph.D. thesis, *Carleton University*, 196 pages.

Nelson, J.L. and Mihalynuk, M. (1993): Cache Creek Ocean: closure or enclosure? *Geology*, Volume 21, Number 2, pages 173–176.

Nixon, G.T., Archibald, D.A. and Heaman, L.M. (1993): ^{40}Ar-^{39}Ar and U-Pb geochronometry of the Polaris Alaskan-type complex, British Columbia; precise timing of Quesnellia – North America interaction; *Geological Association of Canada – Mineralogical Association of Canada – Canadian Geophysical Union*, Joint Annual Meeting, Program with Abstracts, page 76.

Palfy, J., Smith, P.L. and Mortensen, J.K. (2000): A U-Pb and ^{40}Ar-^{39}Ar time scale for the Jurassic; *Canadian Journal of Earth Sciences*, Volume 37, pages 923–944.

Panteleyev, A. (1987): Quesnel gold belt – alkalic volcanic terrane between Horsefly and Quesnel Lakes (93A/6); *in* Geological Fieldwork 1986, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1987-1, pages 125–133.

Panteleyev, A. (1988): Quesnel mineral belt – the central volcanic axis between Horsefly and Quesnel Lakes (93A/5E, 6W); *in* Geological Fieldwork 1987, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1988-1, pages 131–137.

Panteleyev, A. and Hancock, K.D. (1989): Quesnel mineral belt: summary of the geology of the Beaver Creek – Horsefly River map area; *in* Geological Fieldwork 1988, *BC Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-1, pages 159–166.

Panteleyev, A., Bailey, D.G., Bloodgood, M.A. and Hancock, K.D. (1996): Geology and mineral deposits of the Quesnel River – Horsefly map area, central Quesnel Trough, British Columbia (NTS 93A/5, 6, 7, 11, 12, 13; 93B/9, 16; 93G/1; 93H/4); *BC Ministry of Energy, Mines and Petroleum Resources*, Bulletin 97, 156 pages.

Preto, V.A. (1977): The Nicola Group: Mesozoic volcanism related to the rifting in southern British Columbia; *in* Volcanic Regimes in Canada, Baragar, W.R.A., Coleman, L.C. and

Hall, J.M., Editors, *Geological Association of Canada*, Special Paper 16, pages 39–57.

Preto, V.A., Osatenko, M.J., McMillan, W.J. and Armstrong, R.L. (1979): Isotopic dates and strontium isotopic ratios for plutonic and volcanic rocks in the Quesnel Trough and Nicola Belt, south-central British Columbia; *Canadian Journal of Earth Sciences*, Volume 16, pages 1658–1672.

Rees, C.J. (1987): The Intermontane – Omineca Belt boundary in the Quesnel Lake area, east-central British Columbia: tectonic implications based on geology, structure and paleomagnetism; unpublished Ph.D. thesis, *Carleton University*, 421 pages.

Ross, J.V., Fillipone, J.A., Montgomery, J.R., Elsby, D.C. and Bloodgood, M.A. (1985): Geometry of a convergent zone, central British Columbia, Canada; *Tectonophysics*, Volume 119, pages 285–297.

Ross, J.V., Garwin, S.L. and Lewis, P.D. (1989): Geology of the Quesnel Lake region, central British Columbia: geometry and implications; *in* Proceedings, 7th International Conference on Basement Tectonics, *D. Reidel*, Dordecht, Netherlands, pages 1–23.

Ross, K.V. (2004): Alteration study of the Northeast zone, Mount Polley Mine, British Columbia; unpublished report, *Imperial Metals Corporation*, 84 pages.

Schink, A.E. (1974): Geology of the Shiko Lake stock, near Quesnel Lake, British Columbia, unpublished B.Sc. thesis, *University of British Columbia*, 64 pages.

Shives, R.B.K., Carson, J.M., Ford, K.L., Holman, P.B. and Cathro, M. (2004): Imperial Metals Corp. Mt. Polley 2003 multisensor geophysical survey; *BC Ministry of Energy and Mines,* Open File 2004-10.

Souther, J.G. (1977): Volcanism and tectonic environments in the Canadian Cordillera – a second look; *in* Volcanic Regimes in Canada, Baragar, W.R.A., Coleman L.C. and Hall, J.M., Editors, *Geological Association of Canada*, Special Paper 16, pages 3–24.

Struik, L.C. (1986): Imbricated terranes of the Cariboo gold belt with correlations and implications for tectonics in southeastern British Columbia; *Canadian Journal of Earth Sciences*, Volume 23, pages 1047–1061.

Struik, L.C. (1987): The ancient western North American margin: an alpine rift model for the east-central Canadian Cordillera; *Geological Survey of Canada*, Paper 87-15, 19 pages.

Struik, L.C. (1988a): Regional imbrication within Quesnel Terrane, central British Columbia, as suggested by conodont ages; *Canadian Journal of Earth Sciences*, Volume 25, pages 1608–1617.

Struik, L.C. (1988b): Structural geology of the Cariboo gold mining district, east-central British Columbia; *Geological Survey of Canada*, Memoir 421, 100 pages.

Sutherland Brown, A. (1976): Morphology and classification; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 44–51.

Tennant, S.J. (1997): 1997 – diamond drilling assessment report on the Lloyd property; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 25 300.

Tennant, S.J. (1998): Diamond drilling report on the Lloyd and Nordik claim; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 25 651.

Tennant, S.J. (2000): 2000 drilling on the Lloyd property; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 26 495.

Tipper, H.W. (1959): Quesnel, British Columbia; *Geological Survey of Canada*, Map 12-1959.

Tipper, H.W. (1978): Northeastern part of Quesnel (93B) map-area, British Columbia; *in* Current Research, Part A, *Geological Survey of Canada*, Paper 78-1A, pages 67–68.

Travers, W.B. (1977): Overturned Nicola and Ashcroft strata and their relations to the Cache Creek Group, southwestern Intermontane Belt, British Columbia; *Canadian Journal of Earth Sciences*, Volume 15, pages 99–116.

Wheeler, J.O. and McFeely, P. (1991): Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; *Geological Survey of Canada*, Map 1712A, scale 1:2 000 000.

Wild, C. J. (1999): Diamond drilling report on the Mount Polley project; *BC Ministry of Energy, Mines and Petroleum Resources,* Assessment Report 25 906.