The Mount Polley alkalic porphyry copper-gold deposit, south-central British Columbia

T.M. FRASER, C.R. STANLEY
Mineral Deposit Research Unit, Department of Geological Sciences, The University of British Columbia, Vancouver, British Columbia

Z.T. NIKIC, R. PESALJ, D. GORC
Imperial Metals Corporation, Vancouver, British Columbia

ABSTRACT

Mount Polley is an alkalic porphyry copper-gold deposit of Lower Jurassic age within the Quesnel terrane in south-central British Columbia. The silica-saturated Mount Polley intrusive complex is assumed to be coeval with volcanic rocks of similar composition in the Nicola Group in which it was emplaced. Other intrusions and some of the volcanic rocks in the Mount Polley area are silica-undersaturated and contain feldspathoids.

The Mount Polley deposit is characterized by multiple intrusions that vary from diorite to crowded plagioclase porphyry to monzonite. Intrusion breccias are associated with some of the intrusive phases. Abundant hydrothermal breccias occur on the margins and above plagioclase porphyry intrusions. These breccias provide the main host for mineralization and are associated with the highest concentrations of copper and gold. The breccias are subdivided into four distinct types based on the dominant hydrothermal mineral in the matrix. Actinolite breccia is developed in an elongate zone within the core of the Central zone and grades laterally and vertically into biotite breccia to the southeast. Magnetite breccia is irregularly distributed and is relatively sparse throughout the deposit and albite breccia is dominant in the West zone. Pervasive and vein-related alteration correlates with the breccia types. The core of the hydrothermal system at Mount Polley is subdivided into three zones: actinolite, biotite and K-feldspar-albite. The margins of the core zone are overprinted by a discontinuous zone of calc-silicate minerals. This intermediate zone passes outward into propylitic alteration. Mineralization is most prominent within hydrothermal breccias and is generally present as disseminations, blebs within the matrix and abundant veins. Mineralization is associated with a chalcopyrite-magnetite-bornite assemblage in the core of the deposit passing out into magnetite-pyrite-chalcopyrite. Relatively constant copper to gold ratios suggest that both metals were precipitated under similar conditions.

Hydrothermal breccias are genetically related to the emplacement of the crowded plagioclase porphyry melt. Crystallization of the melt was probably accompanied by volatile/aqueous exsolution, forming a water saturated carapace. Decompression of the chamber in response to magma withdrawal, fracture propagation and possible fault movement allowed hydrothermal brecciation to occur at the apex and margins of the intrusion. Alteration and mineralization appears to have been controlled by fluids migrating away from the plagioclase porphyry.

Introduction

The Mount Polley alkalic copper-gold deposit is located 56 km northeast of Williams Lake and approximately 8 km southwest of the village of Likely, on the west side of Quesnel Lake in south-central British Columbia (Fig. 1). The deposit is on map sheet 93A/12E at 52°30′N latitude and 121°35′W longitude. Topography between Bootjack and Polley lakes consists of moderate hills with a maximum elevation of 1265 m above sea level at Mt. Polley. The property is accessible from Highway 97 at 150 Mile House via 76 km of paved road to Morehead Lake and then by 14 km of logging road.

Mount Polley is owned by Imperial Metals Corporation. Probable mineable reserves consist of 48.8 million tonnes grading 0.383% Cu and 0.556 g/t Au, using a Cu equivalent cut-off grade of 0.39% (Gorc et al., 1992). This estimation has been up-graded from previous indicated reserves of 25 million tonnes grading 0.49% Cu and 0.56 g/t Au (Hodgson et al., 1976).

Mount Polley is one of several alkaline deposits in British Columbia that form a continuous line from south to north, including the following deposits: Copper Mountain, Afton-Ajax, Rayfield River, Mount Polley, Mt. Milligan and Lorraine (Lang et al., 1994).

Exploration History and Economics

The first joint Federal-Provincial aeromagnetic map sheet published for the Mount Polley area was Hydraulic Sheet 93A/12, issued in 1963. An aeromagnetic anomaly over Mount Polley was noted and subsequent prospecting led to the discovery of copper mineralization. In the period between 1966 and 1987, Cariboo-Bell Copper Mines Limited, Highland Crow Resources, Teck Corporation, E & B Exploration Inc., Mascot Gold Mines and Corona Corporation conducted a series of exploration programs including trenching, mapping, geochemical and geophysical surveying and completed 290 diamond drill, rotary and percussion holes on a property-wide basis, totalling 33 736 m (Imperial Metals Corporation, 1989). Drilling outlined an extensive tonnage of low-grade copper-gold mineralization with dominant ore minerals consisting of chalcopyrite and minor bornite distributed in the matrix of breccias. Between 1988 and 1990, Imperial Metals Corporation completed an extensive exploration program of the Mount Polley deposit that included 238 NQ diamond drill holes totalling 27 566 m and six bulk samples (130 tonnes) from surface trenches for pilot plant metallurgical testing.

The Central and West zones were drilled at 50 m centres to an average depth of 120 m. The deepest holes in these zones are 150 m and 250 m, respectively. All pre-1988 sampling was done at a 3 m sampling interval, whereas core drilled in 1988 and 1989 was sampled at a 1.5 m interval.

The Au:Cu ratio (Au g/t per % Cu) averages 1.8 and 1.3 in the southern and northern parts of the Central zone, respectively; the ratio in the West zone is 0.9. No change in metal ratio with depth is apparent in the Central zone, possibly due to shallow drilling (Gorc et al., 1992). However, in the West zone, the ratio increases with depth. Frequency distributions for copper and gold assays for the entire sampled population, including the initial pit reserves, are presented in Figure 2.

Reserves were estimated by Wright Engineers in 1990 using various geostatistical, inverse distance and polygonal methods and the

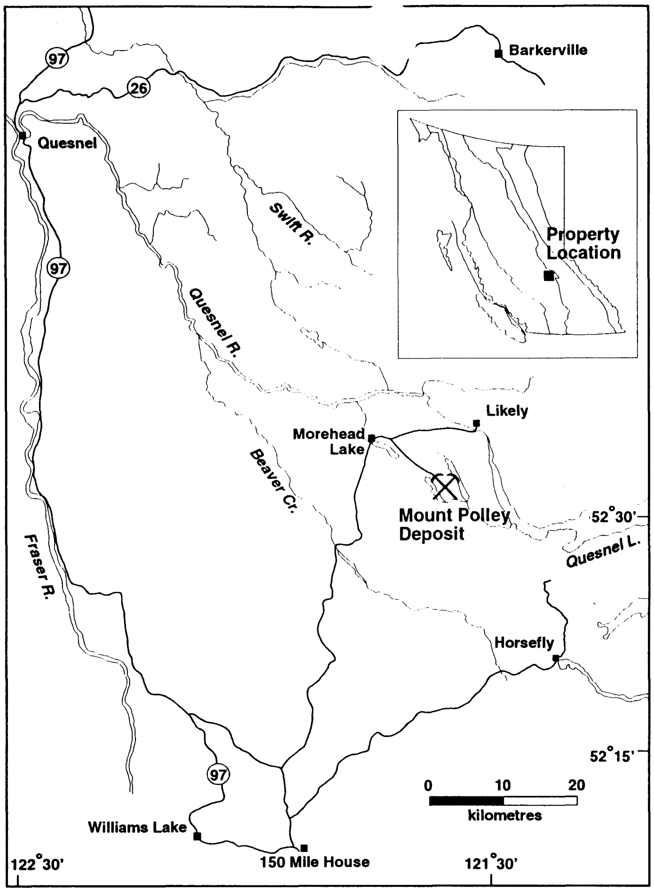

FIGURE 1. Location of the Mount Polley alkalic porphyry copper-gold deposit, south-central British Columbia.

results obtained are in general agreement. The ordinary kriging method returned higher tonnages and lower grades, whereas log-normal shortcut and polygonal methods yielded lower tonnages and higher grades. The total metal content estimated by all methods was almost identical. The copper equivalent cutoff grade is based on the equivalent recoverable copper grades, which were calculated from the sulphide copper, oxide copper and gold grades, and their corresponding recoveries. Prices were set at US$1.00/lb for copper and US$400/ounce for gold.

Geological reserves (inverse distance cubed method) at various cutoff grades are presented in Table 1. Favourable mineralization geometry and topography will facilitate a very high extraction rate of geological reserves. The ultimate pit could produce 77 750 kg of gold and 5.9 million tonnes of copper at a strip ratio of 0.7.

Mineable reserves calculated using a floating cone algorithm to determine the economics of mining each 20 m by 20 m by 10 m reserve block are presented in Table 2. Mining will be by conventional open pit methods with 10 m bench heights and an overall slope of 52°. The initial pit will be mined at an annual mill throughput of 5 million tonnes.

The occurrence of copper in both primary and secondary minerals coupled with the economically significant amounts of gold necessitated a comprehensive test program to develop a metallurgical process best suited for the Mount Polley ore. The testwork included investigations into cyanidation, flotation, acid leaching before and after flotation, and magnetic concentration of the flotation tails. Copper recovery is sensitive to the secondary copper mineral content, which has only a marginal effect on the recovery of gold. Metallurgical results show that over 90% of the gold is recovered with the primary copper minerals (Chong et al., 1991).

Preliminary processing plans indicate that primary crushing followed by a single line, two-stage semi-autogenous mill/ball mill

TABLE 1. Geolog' ' reserve data for various cutoff grades

Cu equivalent cutoff (%)	0.20	0.30	0.40
Million tonnes	293	174	100
Copper (%)	0.23	0.29	0.35
Gold (g/t)	0.30	0.38	0.48

TABLE 2. Ore reserve data for different mining stages

	Initial pit	**Ultimate pit**
Cu equivalent cutoff (%)	0.39	0.20
Million tonnes	49	243
Copper (%)	0.38	0.24
Gold (g/t)	0.56	0.32
Strip ratio	1.8	0.7

grinding circuit, followed by a sequential flotation will recover primary and secondary copper minerals and gold. Projected recoveries, based on extensive bench scale and pilot plant testing, will average 76% for copper and 80% for gold when 65% of the ore is less than 74 microns in size. Very clean, penalty-free copper concentrates would contain 25% copper and 30 to 75 g/t gold and silver.

In the feasibility study, Wright Engineers determined that the capital cost to bring Mount Polley into production is approximately $131.5 million. Operating costs are estimated at $6.52 per tonne based on a 13 700 tonnes of ore per day open pit operation.

Environmental impact assessment studies and reviews were conducted as a part of a forty-month long permitting process. The project is located in a region with a long history of mining and multiple land use. The studies revealed that, due to the deposits ecological environment, the selected mining and processing technologies, combined with proven mitigating measures, there would be no major impact on the environment by mine development. The acid-consuming properties of the ore, waste rock and tailings, and a water management plan that incorporates recycling of process water and surface runoff, make the Mount Polley project environmentally benign. On October 6, 1992, the Government of British Columbia issued a Mine Development Certificate for the Mount Polley project.

Applied Exploration Techniques

Effective exploration methods which readily helped to delineate mineralized zones on the property included soil geochemical surveys, ground magnetometer and induced polarization surveys, trenching, geological mapping and drilling. Two main zones of mineralization are located within the centre of a broad copper and gold soil anomaly which extends over 5 km. Peak values reach 3800 ppm for copper and 500 ppb for gold; values of 200 ppm for copper and 50 ppb for gold are considered anomalous. An excellent spatial correspondence exists between the magnetic and the gold and copper soil geochemical anomalies with copper-gold mineralization. The strongest geophysical and geochemical expressions occur above the two principal zones in areas where glacial overburden is thin or non-existent.

Regional Geology

Previous Work

The alkaline composition of volcanic rocks in the Central Quesnel belt was first documented by Fox (1975). The general geology of the Morehead Lake and Horsefly areas, which includes the Mount Polley property, was mapped and described by Bailey (1975, 1978) and Morton (1976). These authors subdivided the volcanic stratigraphy and used geochemistry to demonstrate that the volcanic and intrusive rocks are both nepheline and quartz normative.

The first detailed geology map of the region (Preliminary Map 20) was published by Bailey (1976). More recently, geological investigations in the Morehead Lake region by Bailey (1988, 1989), to the east by Bloodgood (1987, 1988) and in the Horsefly area

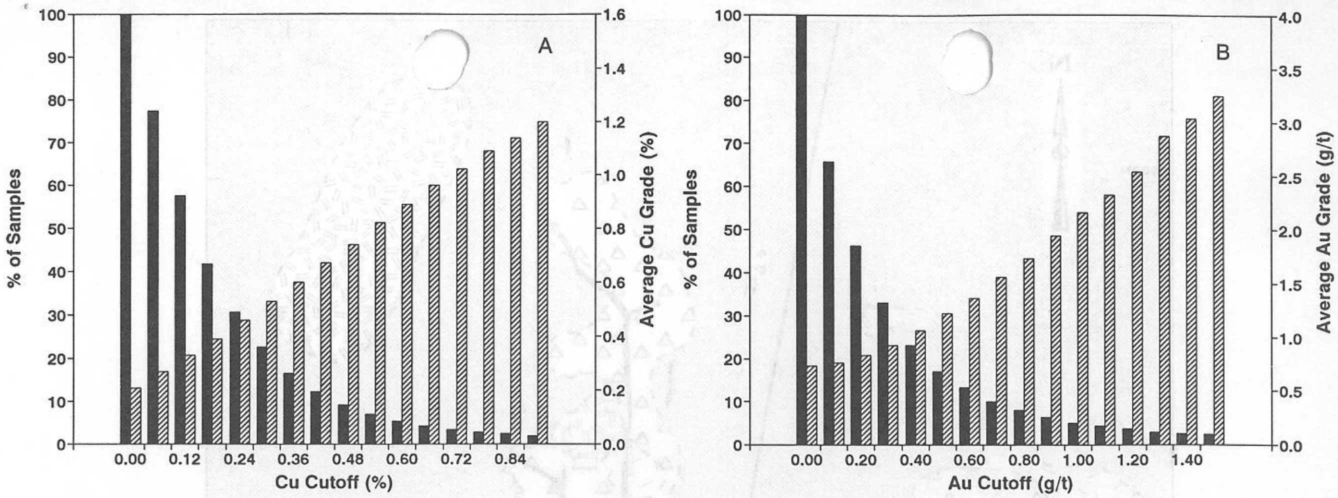

FIGURE 2. Grades and cumulative frequencies of all drill hole samples at Mount Polley for copper (A) and gold (B) at various cutoff grades.

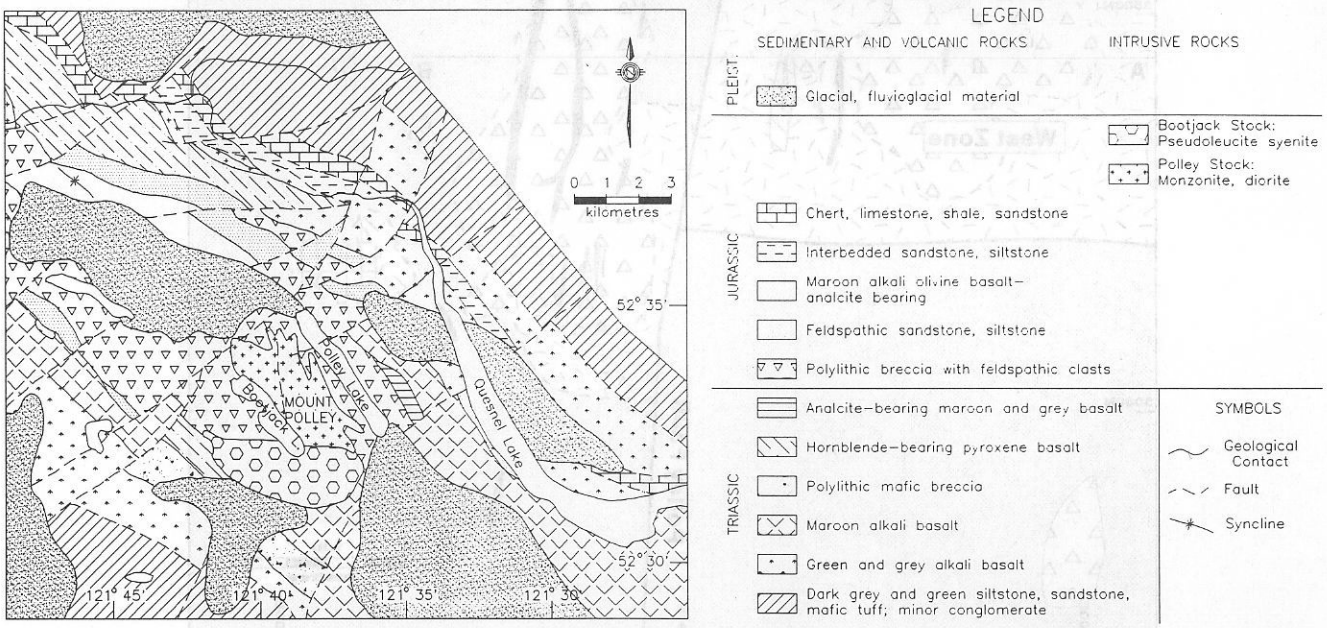

FIGURE 3. Geology of the Hydraulic map area. The Mount Polley deposit, located within the Polley stock, is intrusive into a series of Upper Triassic-Lower Jurassic volcanic rocks. The Nicola Group consists of dominantly submarine plagioclase and pyroxene phyric basalts grading upward into subaerial, maroon, analcite-bearing flows and breccias. Map modified from Bailey (1987, 1988).

by Panteleyev (1987, 1988, 1989) resulted in a re-interpretation of the stratigraphy. An up-dated map for NTS 93A/12 (Preliminary Map 67) was published by Bailey (1987).

Mineralization and alteration zonation patterns at the Mount Polley property were documented by Bailes (1977), Hodgson et al. (1976) and Bailey and Hodgson (1979). In general, porphyry copper mineralization was shown to be associated with a potassically-altered core, surrounded by an extensive propylitic alteration. Barr et al. (1976) and Morton (1976) argued that intrusive complexes are syn-volcanic, and alkalic volcanism and plutonism have a close temporal relationship with copper mineralization. This conclusion was supported by Hodgson et al. (1976) and Bailey and Hodgson (1979).

The rocks in the area of Mount Polley belong to the Nicola Group (Bailey, 1988) and comprise a basal, Upper Triassic assemblage of fine-grained sedimentary rocks overlain by a dominantly mafic to felsic volcanic package with abundant breccias. The stratigraphic units within the Hydraulic map area have a symmetric distribution, having been folded into a broad syncline (Fig. 3). The following summary of lithologies is based on work by Bailey (1975, 1988 and 1989).

Sedimentary and Volcanic Rocks

The lower-most member of the volcano-sedimentary assemblage consists of black phyllite grading up into siltstone, minor limestone, sandstone and greywacke. At the top of the unit, mafic volcanic debris within the sedimentary rocks is common, suggesting that early volcanism was contemporaneous with late sedimentation (Bailey, 1975, 1988). The age of this unit has been determined from conodonts and ranges from Middle Triassic to Late Triassic (Struik, 1986 and Bloodgood, 1988).

The dominantly sedimentary unit passes up into locally pillowed alkali olivine basalt, overlain by maroon to grey alkali basalt flows and breccias. Within this unit, hornblende-bearing pyroxene-phyric alkali basalt and porphyritic analcite-bearing pyroxene basalt occur locally. The unit is Late Triassic in age based on fossil evidence (Bailey, 1988 and Panteleyev, 1988). However, locally developed polylithic breccias, possibly representing slump deposits (Bailey, 1988), contain fossiliferous sedimentary lenses that indicate an Early Jurassic age (Bailey, 1978).

The central part of the Hydraulic map area consists of maroon alkali olivine basalt with pink analcite grains present as groundmass and phenocrystic phases. The unit is highly amygdaloidal and

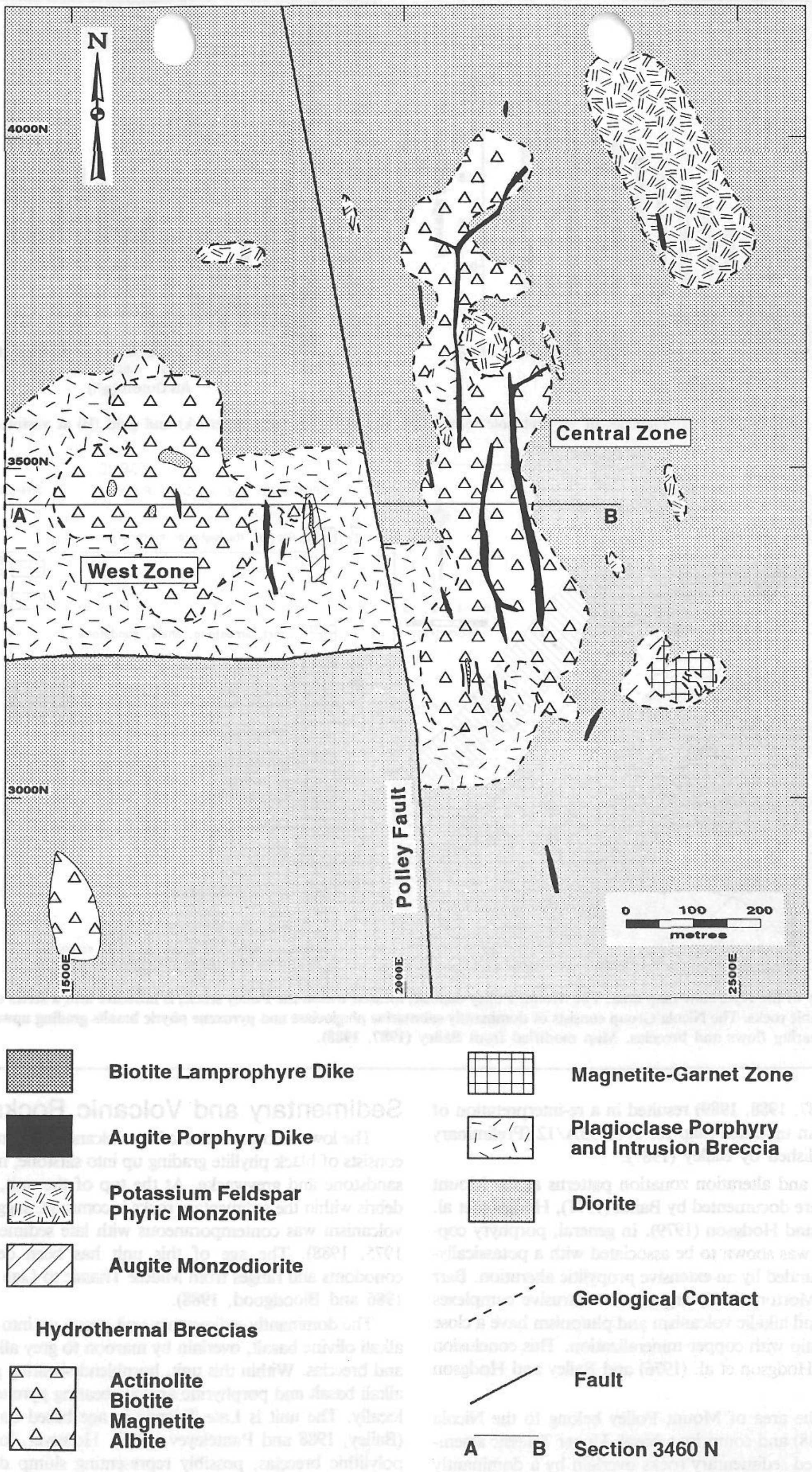

FIGURE 4. Surface geology at Mount Polley. The deposit is characterized by multiple intrusions elongated northerly and a series of hydrothermal breccias superimposed on diorite and plagioclase porphyry.

was probably erupted subaerially, represer' ·g the last stage of volcanism.

Intrusive Rocks

Jurassic-Triassic intrusive rocks comprise syenite, monzonite, diorite and monzodiorite of the Polley stock and several smaller plugs and dikes (Fig. 3). Almost all of these stocks have associated pyrite-chalcopyrite mineralization and are accompanied by propylitic alteration (Bailey, 1989). Radiometric dates from diorite-monzonite plutons intruding volcanic rocks range from 186 Ma to 204 Ma (Panteleyev, 1987 and 1988; and Mortensen, pers. comm., 1994).

A large silica undersaturated syenite pluton, the Bootjack stock (Fig. 3), intrudes the diorite phase of the Mount Polley stock and adjacent volcanic rocks (Hodgson et al., 1976; Stanley et al., 1993; and Fraser et al.,1993). The stock is layered on a gross scale, grading from pseudoleucite syenite porphyry in the west, to crowded orbicular syenite and coarse grained, equigranular granophyric syenite in the east. The pseudoleucite syenite contains up to 20% pseudoleucite phenocrysts, 2 cm in diameter, in a groundmass of K-feldspar, nepheline, albite, pyroxene, hornblende and magnetite. Mafic minerals form 15% to 25% by volume. Orbicular syenite has less than 5% mafics and contains 30% to 90% orbicules of pseudoleucite up to 4 cm in diameter. The orbicules contain pseudoleucite cores and have concentric overgrowths of K-feldspar. Orbicular syenite has been texturally destroyed and recrystallized into granophyric syenite by deuteric reaction with hydrothermal fluids and contains abundant biotite and fluorite. Two samples of the stock have been recently dated yielding ages of 202.7 ± 7.1 Ma (U-Pb, zircon) and 200.8 ± 1.8 Ma (Pb-Pb, titanite isochron) (Mortensen et al., this volume).

Deformation and Metamorphism

Metamorphic grade of the rocks in the area is of sub-greenschist facies and is characterized by the presence of zeolites in mafic volcanic rocks. East of Mount Polley, metamorphism is somewhat higher and is associated with thrusting and deformation during emplacement of Quesnellia (Bloodgood, 1987 and Bailey, 1989).

Folding is most prominent in the eastern-most sedimentary units and is especially strong at deeper structural levels (Bloodgood, 1987; and Bailey, 1988). Overlying volcanic rocks display little or no folding, occurring as thick, panels that have been extensively block faulted by a series of northeast-trending faults (Bailey, 1975, 1988; Panteleyev and Hancock, 1989; and see also Fig. 3). A broad northwest-trending open syncline of regional extent is mapped in the Mount Polley area.

Within the map areas of Bailey (1988; 1989) and Bloodgood (1987; 1988), there have been three recognized periods of faulting. The early faults are low-angle reverse faults that strike northwest, and are only found in the eastern part of the map area. These may be related to the collision of Quesnellia with the Omineca terrane (Bailey, 1988) and are Middle to Late Jurassic in age (Panteleyev and Hancock, 1989). The Eureka Thrust is a member of this fault set, is southwest-dipping and lies at the base of the Quesnel terrane (Bloodgood, 1988). Later faults strike dominantly to the northeast and have mainly sinistral displacement. A fault from this period is interpreted to cut the Polley stock (north-northwest trending). A third fault set, mainly dextral and north-striking, is probably related to the Pinchi Fault system to the west (Bailey, 1988).

Deposit Geology

The Mount Polley copper-gold deposit is hosted within a 5.5 km by 4 km diorite intrusion elongated in a northerly direction (Fig. 3). It has been cross-cut by a number of later intrusions and breccias of both intrusion and hydrothermal type. The majority of mineralization is contained within the matrix of hydrothermal breccias. The prominent north-northwest striking Polley Fault has been inferred by geophysical and topographical differences and divides the deposit into two zones, the West and Central (Fig. 4). Each zone is characterized by d' ent degrees of mineralization, alteration and distinct breccia ;. The West zone is a circular body composed dominantly of aıoıte breccia, cut on the south by an east-west striking fault. The Central zone is elongated in a north-south direction, east and parallel to the Polley Fault; it contains a high proportion of actinolite and biotite-rich breccias. The breccias are intruded by a variety of late to postmineral dikes, the most notable being potassium feldspar and augite phyric dikes. The major intrusive phases are described from oldest to youngest; relative ages are based on cross-cutting relationships:

Pyroxenite

Although pyroxenite does not crop out on the property its presence and aerial extent has been inferred by a ground magnetic survey to occur along the east side of Bootjack Lake (Hodgson et al., 1976). Pyroxenite occurs as angular clasts within the base of an intrusion breccia located on section 3460 N (drill hole 89-125) and as sparse xenoliths within diorite. The dark green, equigranular clasts have a composition of hornblende pyroxenite and are composed of approximately 75% rounded, subhedral green clinopyroxene grains, 15% subhedral magnetite grains with abundant ilmenite exsolution laths, and 7% to 10% interstitial hornblende. Minor biotite alteration is present along clast boundaries and occasionally rims hornblende.

Diorite

Diorite forms a large stock-like intrusion (Fig. 3), in contact with the Bootjack stock to the southwest. The intrusion lies between Bootjack and Polley lakes, is elongated in a northwesterly direction and has dimensions of approximately 5.5 km in length by 4 km in width (Fig. 3). Diorite is the dominant host for the mineralized breccia bodies and has been dated at 201.6 ± 0.5 Ma (Mortensen et al., this volume). In hand sample, diorite is fine-grained and equigranular but in thin section, it tends to have a weakly porphyritic texture with plagioclase and minor pyroxene phenocrysts. Colour of the fresh rock varies from medium to dark grey. Euhedral plagioclase laths form up to 60% to 70% of the rock by volume. Feldspars have moderately sericitized interiors exhibiting remnant albite and Carlsbad twinning. Several samples show evidence of weak alignment of plagioclase laths. The most prominent mafic minerals are disseminated, subhedral, pale green clinopyroxene (15%) with magnetite inclusions and brown, poikiolitic biotite (5% to 10%) which encloses plagioclase, pyroxene and magnetite grains. Accessory minerals include subhedral grains of magnetite, sphene and apatite. K-feldspar is present as a minor interstitial phase in some samples, but may have been introduced as a secondary alteration mineral.

Plagioclase Porphyry

Plagioclase porphyry intruded diorite and occupies the centre of the proposed pit area. Although dating of the plagioclase porphyry returned an age of 203.8 ± 0.6 Ma (Mortensen et al., this volume), slightly older than the diorite, cross-cutting relationships demonstrate that it is younger. Plagioclase porphyry locally forms the matrix to intrusion breccias. Breccia zones have gradational contacts into uniform plagioclase porphyry and the two textural types have been grouped together on Figures 4 and 5.

The plagioclase porphyry is seriate to crowded with fine plagioclase phenocrysts (up to 70%). Phenocrysts are euhedral, with remnant albite twinning visible in some grains. Almost all samples collected have undergone moderate to intense sericitization of feldspars. Some feldspar grains show a vague overgrowth or zonation, but compositional differences could not be resolved by optical means. Occasional tabular K-feldspar phenocrysts (3% to 5%), normally less than 1 cm and as much as 3 cm in length, occur in the plagioclase-rich matrix. Subhedral magnetite is finely disseminated in the matrix. Twinned hornblende with abundant magnetite inclusions is present in trace amounts and is usually rimmed with fine-

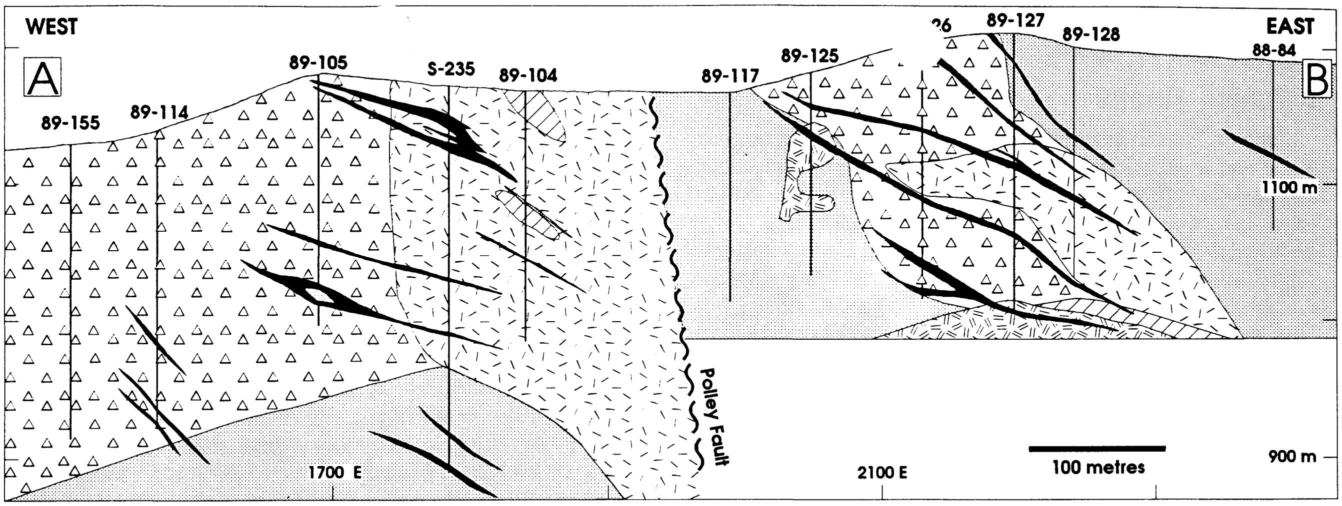

FIGURE 5. Detailed geology on cross-section 3460 N. Diorite is intruded by plagioclase porphyry and a number of east-dipping postmineral dikes. The apex and margins of the plagioclase porphyry are hydrothermally brecciated. Refer to Figure 4 for legend.

grained felted brown biotite. Primary brown biotite is quite common and is partially chloritized. Accessory phases include clinopyroxene and apatite disseminated in the groundmass. The groundmass, although showing varying intensities of K-feldspar alteration, appears to be largely composed of fine-grained plagioclase.

Intrusion breccias associated with plagioclase porphyry are dominated by subangular fragments of diorite. Clasts vary considerably in size, with the largest block being roughly 12 m in diameter and the average size being 3 cm. Fine-grained, dark coloured volcaniclastic fragments are rare, but a large volcanic block occurs on cross-section 3460 N (Fig. 5). The breccia is consistently matrix supported but locally contains areas having up to 35% clasts. The distribution of fragments within the breccia appears to be random and shows no concentration toward the margin of the intrusion.

Porphyritic Augite Monzodiorite

Porphyritic augite monzodiorite has only been mapped in the West zone, where it cuts plagioclase porphyry (Fig. 4). The unit is also present at depth on cross-section 3460 N (Fig. 5), cutting biotite breccia and truncated by potassium feldspar phyric monzonite. Generally this unit forms dike-like bodies with a northerly strike and a moderate to shallow easterly dip. Macroscopically, the unit is distinctive, having 10% prominent rounded green clinopyroxene phenocrysts. Petrography indicates that the phenocrysts occur as individual grains or aggregates and are sub- to euhedral, zoned and contain inclusions of magnetite. Tabular plagioclase grains form the majority of groundmass (75%) and are weakly to moderately aligned. Most feldspars are strongly sericitized. Subhedral magnetite is disseminated in the groundmass and contains exsolution lamellae of ilmenite. Accessory phases include apatite and biotite. Although no K-feldspar was visible microscopically, sodium cobaltinitrite staining indicates its presence, mostly as an interstitial phase. The dike-like bodies are unmineralized and do not exhibit the strong K-feldspar overprint characteristic of pre- to synmineral units present.

Potassium Feldspar Phyric Monzonite

Potassium feldspar phyric monzonite occurs in two locations, within the core of the deposit and at the summit of Mt. Polley (Fig. 4). The unit has been divided into two similar types, that differ in intrusive characteristics, alteration and possible timing.

Monzonite occurs as dikes and small pods in the centre of the deposit and extends to undefined vertical depths. Euhedral, zoned potassium feldspar phenocrysts (20%) form a trachytic texture, with individual phenocrysts up to 2 cm long. Most of the groundmass (70%) consists of weakly to moderately aligned plagioclase laths. Feldspars have both albite and Carlsbad twins. Plagioclase laths are incorporated into the margins of K-feldspar phenocrysts, indicating simultaneous crystallization. Subhedral to euhedral clinopyroxene is disseminated in the matrix and is weakly altered to hornblende. Accessory phases include sphene, apatite and magnetite with ilmenite exsolution. Minor alteration of the rock consists of a 'pinking' of the feldspars and may represent restricted deuteric alteration.

A second type of monzonite forms an extensive stock-like body that outcrops on the summit of Mt. Polley. This monzonite is differentiated by the presence (up to 5%) of large phenocrysts (2 cm by 1 cm) of K-feldspar. The megacrysts have altered margins and fresh interiors. Plagioclase laths have been incorporated into the margins. The unit also contains minor amounts of primary biotite, magnetite, altered pyroxene and subhedral apatite. The vertical and areal extent are poorly constrained, and it is possible that most of the topographic high of Mt. Polley is underlain by this unit. The monzonite is unmineralized but contains disseminated epidote, albite and fine grained pyrite. This suggests that it was emplaced late during hydrothermal alteration.

Augite Porphyry Dikes

Augite porphyry dikes occur as swarms throughout the deposit, cross-cutting all igneous and breccia units, striking northerly and dipping moderately to the east (Figs. 4 and 5). Dikes are continuous along strike for more than 100 m and have an average thickness of 4 m. Dark red-brown to grey aphanitic chilled margins have occasional plagioclase and pyroxene phenocrysts. Clinopyroxene (35% to 55%) forms optically zoned, euhedral phenocrysts while the bulk of the groundmass consists of euhedral plagioclase laths with remnant albite twinning. Feldspars are weakly sericitized. Sub- to euhedral magnetite with ülvospinel exsolution is disseminated in the groundmass and is included in clinopyroxene phenocrysts. The groundmass varies in grain size and submicroscopic K-feldspar may be present. These dikes are unaltered and are clearly postmineral.

Biotite Lamprophyre Dikes

Biotite lamprophyre dikes cross-cut all rock types and are possibly Tertiary in age. They have been mapped throughout the deposit, are oriented roughly north-south, similar to the other post-mineral dikes, and have a maximum thickness of 2 m. The dikes are fine-grained, friable and weather rapidly on surface to an olive-green sand. Euhedral biotite forms 40% of the unit, imparting a foliation, with moderately to weakly aligned plagioclase laths (50%) and sparse pyroxene phenocrysts. Most dikes are vesiculated and some contain amygdules filled with calcite. The lamprophyre

TABLE 3. Representative whole rock chemistry of Mount Polley intrusive rocks

Rock	Units	Method	D.L.	MTP92-047 AM	MTP92-061 KM	MTP93-076 KM7b	MTP92-058 PP	MTP92-033 DI	MTP92-049 AD
SiO_2	%	XRFF	0.01	48.50	59.10	52.7	59.10	48.90	48.20
Al_2O_3	%	XRFF	0.01	17.90	18.30	18	17.30	17.90	14.90
TiO_2	%	XRFF	0.01	0.858	0.488	0.671	0.530	0.820	0.660
FeO	%	Wet	0.1	3.3	1.6	2.2	1.6	4.4	4.1
Fe_2O_3	%	XRFF	0.01	10.20	4.71	8.25	5.57	10.70	10.90
MnO	%	XRFF	0.01	0.17	0.10	0.29	0.09	0.20	0.22
MgO	%	XRFF	0.01	3.92	1.47	2.3	1.77	4.34	5.37
CaO	%	XRFF	0.01	8.06	4.65	5.04	3.98	10.10	10.50
Na_2O	%	XRFF	0.01	3.08	5.25	3.04	5.71	2.96	2.34
K_2O	%	XRFF	0.01	3.49	4.67	6.04	4.25	2.67	4.68
P_2O_5	%	XRFF	0.01	0.31	0.20	0.34	0.19	0.33	0.46
Cr_2O_3	ppm	XRFF	0.01	17	48	—	45	40	89
H_2O^+	%	Grav	0.1	2.5	0.9	2.1	0.9	1.3	1.6
CO_2	%	Grav	0.01	0.18	0.09	0.02	0.03	0.02	0.06
SUM	%	Lab		99.6	100.4	99.2	99.9	100.3	100.1
LOI	%	Grav		2.80	1.05	2.1	1.00	1.15	1.55
Ba	ppm	XRFF	20	1760	2740	2410	2660	1200	1840
Rb	ppm	XRFF	2	97	89	141	90	68	90
Sr	ppm	XRFF	2	515	794	778	798	620	946
Nb	ppm	XRFP	2	6	7	4	6	6	5
Zr	ppm	XRFF	3	55	101	58	93	52	35
Y	ppm	XRFP	2	9	7	35	4	2	bd
As	ppm	INAA	2	18	4	35	8	2	3
Au	ppb	INAA	5	8	21	bd	12	bd	10
Cr	ppm	INAA	2	23	46	30	46	39	94
V	ppm	FusDCP	2	242	83	193	109	282	218
Sc	ppm	INAA	0.1	25.1	7.5	11.2	9.0	25.6	26.4
Th	ppm	INAA	0.5	0.7	2.0	1.4	1.3	0.8	1.4
U	ppm	INAA	0.5	0.9	1.1	2.1	0.5	0.9	0.6
Hf	ppm	INAA	0.5	1.6	2.7	1.8	2.8	1.9	1.5
Cl	ppm	XRFP	50	256	162	154	171	177	268
Co	ppm	INAA	1	28	10	21	11	31	37
F	ppm	Wet	20	817	450	661	573	264	445
Zn	ppm	XRFP	2	61	45	142	61	86	70
Cu	ppm	XRFP	2	199	67	−2	148	88	142
La	ppm	INAA	0.5	7.7	10.0	16.5	8.2	7.2	8.3
Ce	ppm	INAA	3	19	22	33	19	17	19
Nd	ppm	INAA	5	10	10	15	9	10	10
Sm	ppm	INAA	0.1	2.3	2.2	3.4	2.1	2.4	2.3
Eu	ppm	INAA	0.2	0.8	0.7	1.3	1.0	1.0	0.9
Yb	ppm	INAA	0.2	2.0	2.0	2.4	1.8	2.0	1.3
Lu	ppm	INAA	0.05	0.29	0.30	0.39	0.29	0.28	0.20

Abbreviations are as follows: AM = augite monzodiorite, KM = potassium feldspar phyric monzonite, PP = plagioclase porphyry, DI = diorite and AD = augite porphyry dike.

(minette) dikes are found regionally and therefore are most likely unrelated to the intrusive complex present at Mount Polley.

Whole-Rock Geochemistry

Thirty-six samples of fresh and weakly altered rocks representing major intrusive units at Mount Polley have been analyzed (Fraser, 1995). Table 3 contains representative whole rock analyses from various intrusive units at Mount Polley. More complete analyses are given in Fraser (1995).

Major element chemistry of least altered samples outlines the general petrologic character of individual units and relationships among units. Plots of major oxides against SiO_2 give a rough indication of differentiation among the intrusive and extrusive units sampled at Mount Polley (Fraser, 1995). The most highly differentiated units are represented by plagioclase porphyry and the potassium feldspar phyric monzonite, which tend to cluster together. The two units are chemically indistinguishable, having relatively high SiO_2 and low total Fe, MnO, MgO and P_2O_5. Plagioclase porphyry and potassium feldspar phyric monzonite generally contain higher Na_2O and lower CaO concentrations compared with the volcanic and other plutonic samples. The diorite, augite monzodiorite, augite porphyry and volcanic samples can be broadly grouped together. This group is separated from the more felsic rocks by a SiO_2 gap of approximately 5% to 8%, and contain the highest total Fe, MgO, MnO, CaO and P_2O_5 concentrations.

On an alkalis versus silica plot (Irvine and Baragar, 1971) for the plutonic rocks, all samples are alkaline in chemistry (Fig. 6). Generally, all intrusive samples have a higher silica content compared to regional volcanic rocks. Diorite, monzodiorite and augite porphyry samples cluster tightly together, with the more felsic units (monzonite and plagioclase porphyry) plotting in a separate group at higher silica and alkali contents.

The composition of the intrusive and volcanic rocks suggest formation in a volcanic arc setting. All units have nearly identical rare earth element signatures, with steep light rare earth element and flat heavy rare earth element patterns, and a slight to moderate negative anomaly in yttrium (Fraser, 1995). Rocks from the Mount Polley area are typical of subduction-related lavas with low normalized HFSE (high field strength elements: Ti, Zr, Hf, Nb, Ta) concentrations with troughs at Nb, Zr and high concentrations of LILE (peaks at K at Sr) (Fraser, 1995).

Hydrothermal Breccias

Hydrothermal breccias are important at Mount Polley and have been subdivided on the basis of the dominant mineral (or assemblage) present in the matrix. Features of each breccia type were

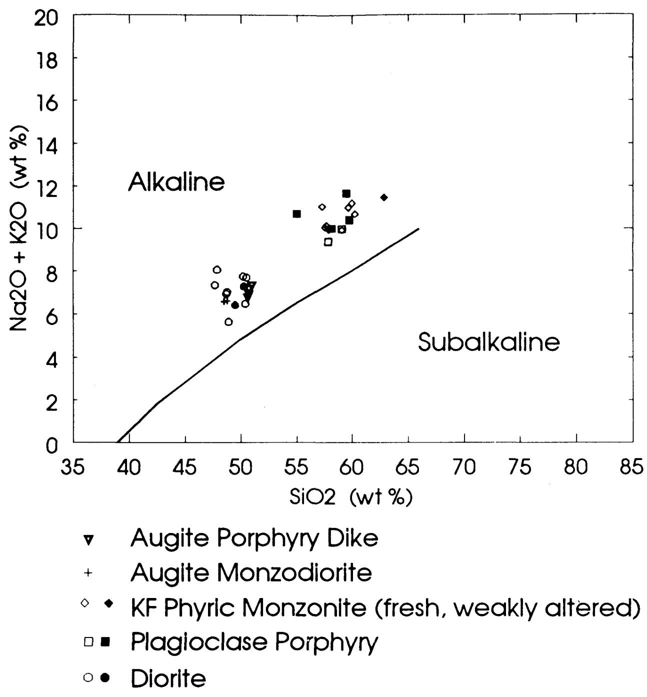

FIGURE 6. Classification of intrusive rocks from Mount Polley on an alkaline affinity diagram (Irvine and Baragar, 1971). Fresh samples (open symbols) and only weakly altered samples (filled symbols) are plotted. All units are strongly alkaline in nature.

recorded using the Geolog system (Blanchet and Godwin, 1972) to describe clast size, composition, matrix minerals, and proportion of matrix to fragments. Due to poor exposure and the lack of critical drill holes or preserved core, the relationships between each breccia type were difficult to ascertain. Breccias in outcrop are usually indicated by triangular vugs partially occluded by the growth of hydrothermal minerals. These indicate a minimum degree of clast rotation and the development of porosity during brecciation. Four hydrothermal breccias are recognized on the property and are separated from intrusion breccias which have an igneous matrix; the distribution of the hydrothermal breccias is shown in Figures 4 and 5.

Actinolite Breccia

The actinolite breccia is only present in the Central zone, where it crops out in a north-south elongate zone roughly 500 m by 200 m. Clasts consist of diorite and plagioclase porphyry. Fragments are subangular and 2 cm to 3 cm in diameter on average. The larger diorite blocks show some minor rotation, illustrated by small triangular vugs between blocks. Clasts commonly have unaltered interiors but are increasingly K-feldspar altered toward their margins, where primary texture is often destroyed. The matrix is readily distinguished by the high percentage of fibrous dark green actinolite. Accessory minerals in the matrix include pyroxene, magnetite, calcite and finely-disseminated chalcopyrite. The breccia is often cut by actinolite ± pyroxene-chalcopyrite veins with K-feldspar envelopes, which are common throughout the Central zone.

A gradational boundary appears to exist between the actinolite and biotite breccias. Small quantities of hydrothermal biotite were noticed at about grid line 3300 N and increased in abundance approaching the biotite breccia to the south, with a corresponding decrease in actinolite. To the north, the actinolite breccia is overprinted by albite breccia.

Biotite Breccia

The biotite breccia is exposed on surface in the southern part of the Central zone, where it is extensively oxidized. Clasts are pervasively altered to K-feldspar and the precursor rock type is difficult to identify; remnant [illegible]es suggest that the clasts are dominantly diorite and plagioclase porphyry. The majority of clasts are in the 2 cm range, but are locally up to 1 m across. The breccia is largely clast-supported but locally there are zones that are matrix-supported. Unweathered breccia is located at depth (Fig. 5) and has a matrix composed of coarse-grained hydrothermal black biotite flakes (up to 2 cm), disseminated sulphides and occasional pale albite crystals. The matrix assemblage of the breccia on surface has an average composition of 60% partially chloritized biotite, 25% chrysocolla (with trace malachite) and 15% white radiating zeolites. Secondary chrysocolla is intimately intergrown with biotite and also has impregnated clasts, suggesting extensive mobility during the oxidation of sulphides. Zeolites have been deposited considerably later in the formation of the breccia and have filled void space around biotite and chrysocolla.

Magnetite Breccia

Magnetite breccia is not abundant, but is locally developed throughout the Mount Polley deposit; it rarely forms areas large enough to illustrate at the scale of mapping. Diorite and plagioclase porphyry host zones of magnetite breccia. Clasts are predominantly 2 cm to 3 cm across and are pervasively altered to K-feldspar. The matrix consists of massive to euhedral grains of magnetite (2 mm to 3 mm) accompanied by accessory sulphides and pyroxene. This variety of breccia is always clast-supported, with an average of 10% matrix.

Albite Breccia

Albite breccia is a distinctive variety found predominantly in the West zone. It is typified by variably altered clasts with interiors that retain some primary texture, including albitic twinning in plagioclase, and margins that have remnant sericitized plagioclase and relict primary clinopyroxene. Fragment boundaries are irregular and undulating. Albite alteration has caused extensive recrystallization and replacement along margins of clasts, clouding the distinction between fragments and matrix. In many cases the matrix can be identified on the basis of secondary biotite in small vugs. The unit is largely clast-supported, containing small vugs partially filled with pristine, prismatic albite crystals or alternatively, the matrix may consist of fine-grained albite with accessory biotite, clinopyroxene, magnetite and disseminated sulphides.

Alteration Zones

Intrusive units at Mount Polley have undergone significant hydrothermal alteration. Previous authors, Hodgson et al. (1976) and Bailey and Hodgson (1979), identified three concentrically-zoned alteration assemblages: a potassic core surrounded by a garnet-epidote zone, and an outer propylitic rim. An extensive pyrite halo has been mapped on the eastern portion of the Mount Polley deposit. A combination of detailed mapping and core logging during 1992 and 1993 generally supports this interpretation. In addition, the core has been further divided into three distinct zones: biotite, actinolite and K-feldspar-albite. The intermediate and peripheral zones are defined by garnet-epidote-albite-K-feldspar and epidote-pyrite-albite-calcite assemblages, respectively. As in other alkaline porphyry systems, the argillic and phyllic alteration are absent from Mount Polley. The distribution of the following alteration zones is outlined in Figure 7.

Core Zone

A potassic core coincident with the hydrothermal and intrusion breccias and copper-gold mineralization is concentrated within the proposed pit area. It is characterized by pervasive K-feldspar, vein pyroxene, actinolite, chalcopyrite, magnetite and coarse, secondary biotite east of the Polley Fault. West of the fault there is a notable increase in albite and lack of actinolite. The potassic core can be subdivided into three major subtypes:

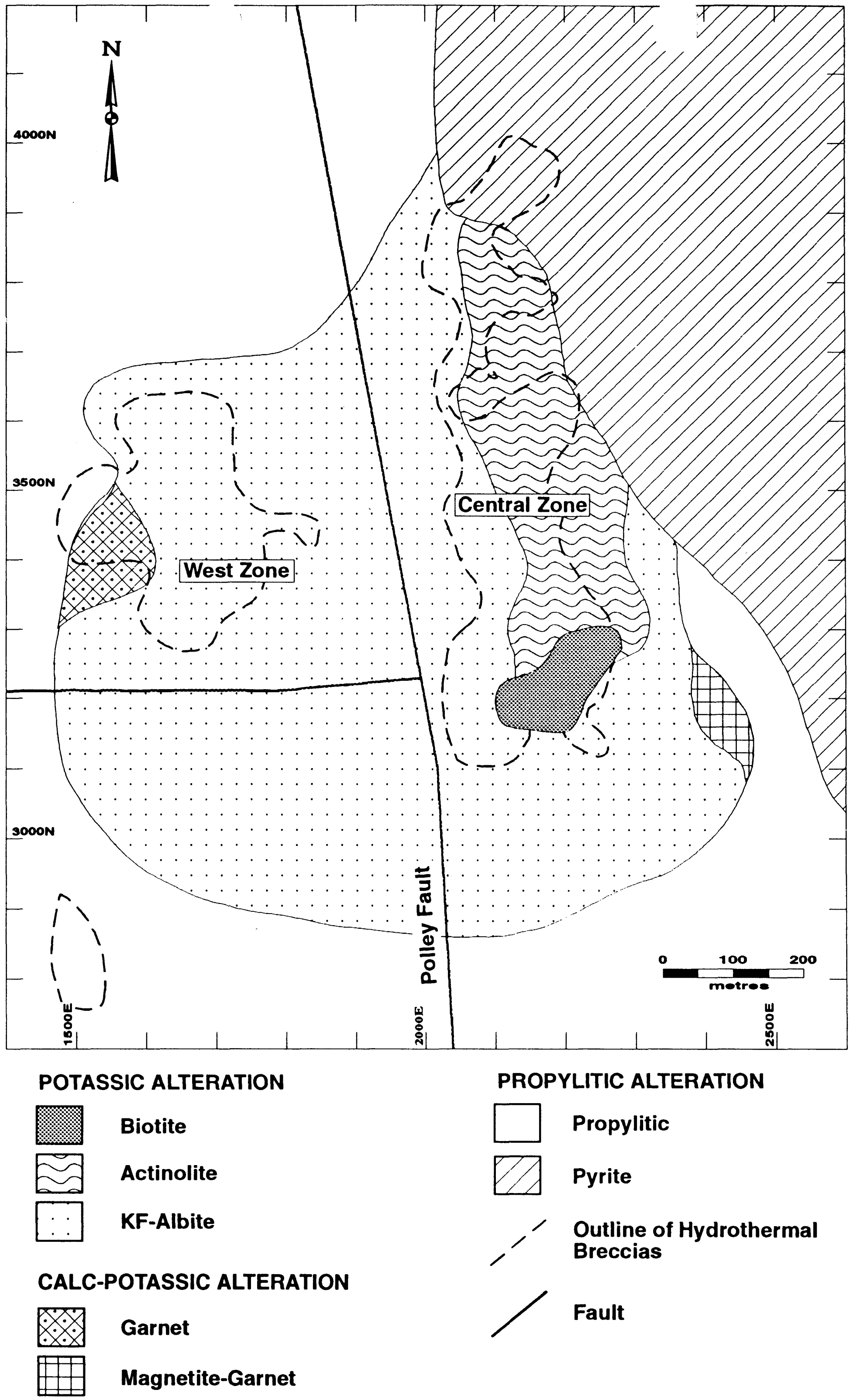

FIGURE 7. Alteration zones at Mount Polley. A core of actinolite and biotite alteration is surrounded by intensely potassic-altered material, grading out into calc-silicate and propylitic alteration.

Biotite Zone

A biotite zone is characterized by the development of coarse, secondary black biotite within vugs of the hydrothermal breccia in the Central zone. It averages 5% to 10% by volume, with flakes ranging from 1 mm to 1 cm in diameter. The zone of secondary biotite tends to be elongated in a north-south direction. Secondary, felted biotite has developed to a lesser degree within the plagioclase porphyry intrusion breccia. Hydrothermal biotite is also noted within the matrix of albite breccia, especially in the West zone; however, it is much less abundant. The highest biotite concentrations are found around the apex and margins of the plagioclase porphyry intrusion. The zone also contains pervasive K-feldspar-altered clasts and intrusive material (diorite). Min ed magnetite veins cut the biotite zone, along with blebs of cl pyrite within vugs of the breccia.

Actinolite Zone

An actinolite zone is characterized by abundant actinolite-chalcopyrite-pyroxene-magnetite veins that cut breccias, diorite and plagioclase porphyry. The zone is elongate in a north-south direction within the core of the system on the east side of the Polley Fault. Associated with the veins are extensive K-feldspar envelopes which tend to obliterate primary textures adjacent to veins. The zone is also typified by weak to moderate pervasive K-feldspar alteration of host rocks and cross-cutting chalcopyrite and magnetite veins.

Broad K-feldspar - Albite Zone

A broad K-feldspar-albite zone is arcuate around the biotite and actinolite zones. The majority of lithologies have suffered moderate to intense (15% to 70%) pervasive K-feldspar alteration, which has destroyed primary igneous textures and imparts a salmon-pink colouration. Stockworks of veinlets and fractures containing K-feldspar are abundant along with magnetite veins and fine-grained disseminations within breccias.

Intermediate Zone

Garnet alteration is restricted to two areas (Fig. 7), and does not have a uniformly concentric distribution as previously described (Hodgson et al., 1976). Its occurrence is confined to areas of intense albitic and potassic alteration. It is divided into two types that are also spatially distinct:

1. Western margin of the West zone: Zoned, euhedral to massive hydrothermal garnet occurs in veins or vugs within the albite breccia at the 150 m to 180 m level. Primary textures of the clasts have been overprinted by secondary K-feldspar and the matrix is partially or wholly filled with a complicated assemblage of dominantly albite with garnet, calcite, epidote, zeolites, magnetite, pyrite and chalcopyrite. Epidote and trace amounts of chlorite are strongly associated with garnet and are disseminated in the matrix and as diffuse vein envelopes. Calcite and fibrous, radiating zeolites appear to be paragenetically late, and are coarse grained, filling open spaces.
2. Southeast margin of the Central zone: A small magnetite-garnet replacement zone has been mapped in the southeastern portion of the Central zone (Fig. 4). Covering an aerial extent roughly 100 m by 100 m, the zone lies at the contact between diorite and plagioclase porphyry. The margin of the zone is poorly exposed but seems to interfinger and have sharp contacts with the plagioclase porphyry unit. The zone consists of a massive replacement of wallrock by early brown garnet (± magnetite and diopside) with cross-cutting veins and zones of magnetite. The amount of magnetite ranges from 40% to 70%. Garnet-rich areas form irregular elongate patches with diffuse margins. Microscopically, the garnet areas are fine-grained aggregates and individual grains have a uniform colour and exhibit no zoning. Incomplete replacement has resulted in textureless zones that are interpreted to be remains of the host rock although the original composition of these rocks is impossible to estimate. Abundant epidote and rare dark brown garnet veins cross-cut the magnetite-garnet rock. Actinolite forms fibrous masses along with trace amounts of pyroxene, chlorite and apatite. The distinct calc-silicate mineralogy of the rock and associated high magnetite content suggests a skarn affiliation. The timing of this replacement body is ambiguous.

Peripheral Zone

A peripheral propylitic zone is generally developed outside or on the margin of the deposit. On the whole, the rock units are weakly altered and commonly contain epidote-pyrite calcite veins and disseminated epidote that may replace mafic minerals and plagioclase. The hig epidote concentrations are located at the margins of the hyd mal system, especially to the northeast. Albite veining is diffuse and sinuous, cross-cutting all lithologies and is significantly different than the sodic metasomatism present in the K-feldspar-albite zone associated with mineralization. Calcite-zeolite veins are prominent but are postmineral.

A pyrite zone is present in the north-east section of the Mount Polley property cross-cutting the margin of the actinolite breccia and diorite. It is characterized by abundant fracture-controlled pyrite, up to 0.5 cm wide. Veins sometimes contain accessory magnetite and chalcopyrite and comprise 1% to 4% of the rock. Previous mapping has defined the pyrite-rich zone as a broad band extending 4.5 km by 1 km (Imperial Metals Corporation, 1989; and Hodgson et al., 1976).

Copper-gold Mineralization

Within the Mount Polley stock, copper-gold mineralization is concentrated in two main areas. The West zone of mineralization is roughly coincident with the hydrothermal breccia west of the Polley Fault. The region forms a circular, subvertical body 400 m in diameter. Mineralization extends to a drilled depth of at least 275 m. Copper and gold mineralization to the east of the Polley Fault, within the Central zone, is contained within an eastward dipping breccia body which has a northerly strike. The zone is approximately 200 m to 300 m in width by 1100 m north-south. The majority of mineralization has a close spatial relationship with hydrothermal breccias.

Hypogene ore minerals generally occur in fractures and veins, and as disseminations and blebs within the matrix of hydrothermal breccias. Typical sulphides are chalcopyrite, pyrite and lesser bornite. Bornite has an antithetic relationship with pyrite concentration. Similar to most other alkalic deposits, Mount Polley lacks significant molybdenite. Copper and gold assay values are closely correlated and are highest in the hydrothermal breccias. The highest grades occur in the southern part of the Central zone. Generally high magnetite concentrations correlate with high copper and gold assay values, and copper values are particularly high near the contact of the magnetite-garnet replacement zone and plagioclase porphyry. Gold is not macroscopically visible but is found as inclusions, 5 to 40 microns in diameter, of native gold in chalcopyrite.

The majority of the deposit is relatively unoxidized, having minor quantities of malachite and azurite on fractures at surface. The depth of oxidation is normally less than 100 m. Deep oxidation is restricted to the south-eastern region of the biotite breccia where primary sulphides in the matrix of the breccia have been replaced in-situ by chrysocolla and malachite. Trace azurite and native copper have been noted on fracture surfaces. The grade of the deposit in this area has not been significantly enhanced and no enrichment blanket has formed.

At Mount Polley, it was noted that the central region of the deposit has coincident copper and gold zones, similar to most alkalic porphyry systems in the Canadian Cordillera. The relatively constant Cu:Au ratio in these deposits suggests that chalcopyrite and gold are precipitating simultaneously (Stanley, 1993; Fraser, 1995).

Genetic Model of Breccia Development and Alteration

Previously the Mount Polley breccias have been described as a cross-cutting feeder pipe in the West zone and an east-dipping laccolithic structure in the Central zone, conformable with the regional volcanic strata (Hodgson et al., 1976; Simpson and Saleken, 1990; Gorc et al., 1992). A re-examination of the breccias at Mount Polley indicates that two genetically different types of breccias occur (Fraser, 1995): (1) intrusion breccias having an igneous matrix, and (2) hydrothermal breccias containing a variety of secondary minerals in triangular vugs. These breccias appear to be upwardly flaring, subvertical to vertical bodies cross-cutting wallrock with mineralization and alteration zoning closely associated with

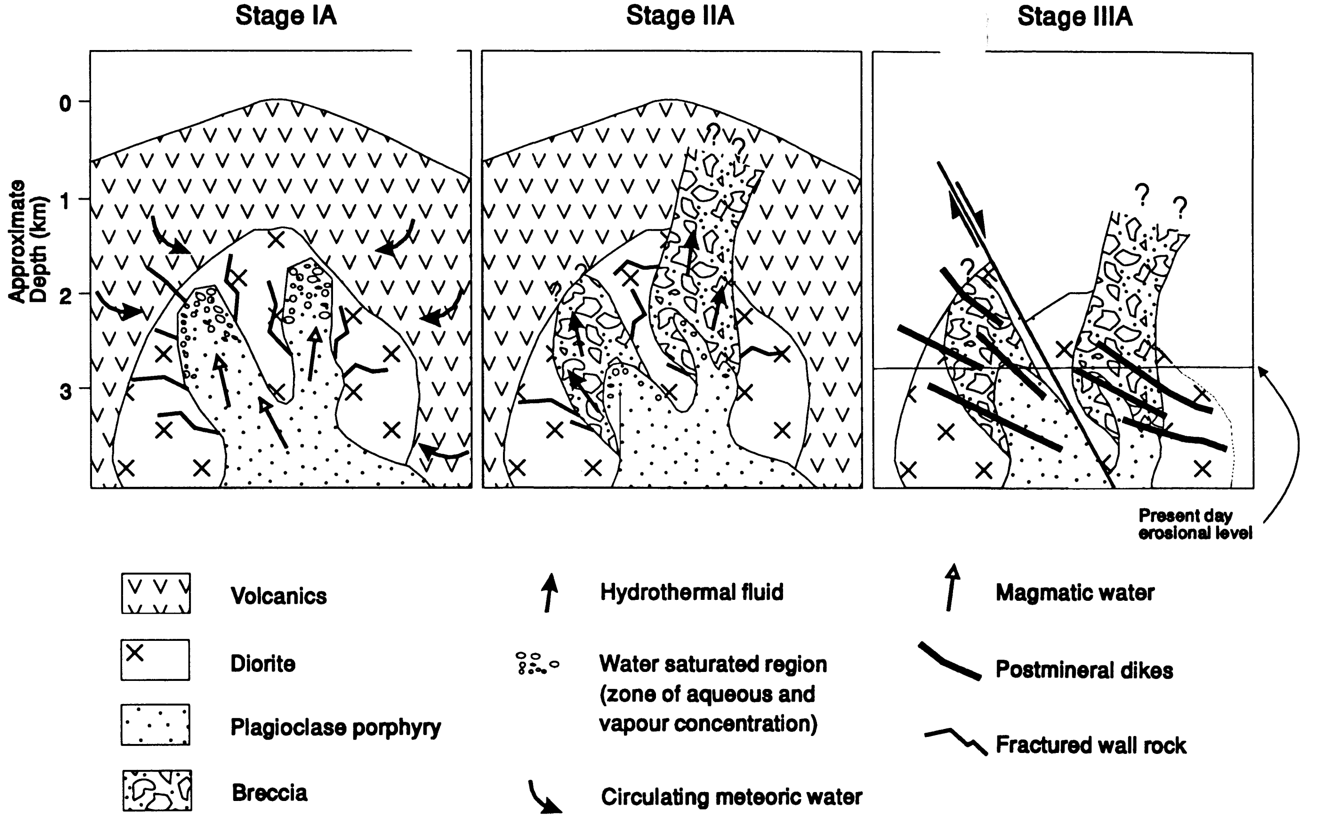

FIGURE 8. Deposit scale model of the intrusive history and development of hydrothermal breccias at Mount Polley. Intrusion of diorite and plagioclase porphyry into the volcanic pile is accompanied by intense wall rock fracturing. Separation of an aqueous phase begins while magma fluctuates (Stage IA). Diorite stoping and collapse into a low pressure cavity created by magma withdrawal is accompanied by vesiculation and brecciation due to explosive release of volatiles and mineralized fluid (Stage IIA). Postmineral dike intrusions and faulting take place (Stage IIIA).

hydrothermal brecciation. The four types of hydrothermal breccia (actinolite, biotite, magnetite and albite) are well mineralized and contain higher copper and gold values than intrusion breccia and diorite. Hydrothermal breccias are strongly altered and are distributed at the margins or apex of plagioclase porphyry intrusions. Secondary silicate mineral assemblages are also zoned outward from the plagioclase porphyry from K-feldspar-biotite-actinolite to propylitic alteration. It is postulated that the abundant hydrothermal breccias developed at Mount Polley are the result of magmatic-hydrothermal processes involving the release of hydrothermal fluids from a shallowly emplaced plagioclase porphyry magma during second boiling and subsequent decompression.

A complex sequence of brecciation, alteration and mineralization events have been proposed for Mount Polley (Fraser, 1995). These magmatic and magmatic-hydrothermal events are summarized as follows and are shown schematically in Figures 8 and 9.

Intrusion of Diorite

The Mount Polley complex appears to be shallowly emplaced within a thick wedge of volcanic strata including large volumes of breccias that are interpreted to be proximal to a vent (Bailey and Hodgson, 1979).

Intrusion of Plagioclase Porphyry and Formation of Intrusion Breccia (Stage IA, Fig. 8)

The Polley Fault may have provided the conduit for intrusion and brecciation as indicated by the elongation of intrusive units along strike. The abundance of undigested diorite xenoliths within the fine-grained porphyritic intrusion provides evidence of stoping and possibly syn-intrusion faulting, and supports a high level of emplacement into fractured diorite.

Volatile Saturation

Emplacement of the high-level plagioclase porphyry intrusion is accomplished by heat loss to the surrounding diorite as crystallization proceeds inward from the outer margin. Anhydrous crystallization (plagioclase and pyroxene) during cooling serves to enrich the residual melt in water and other volatile phases, eventually leading to volatile saturation. This mechanism of concentrating volatiles while a melt undergoes crystallization is called second boiling (Candela, 1989; Norton and Cathles, 1973; Burnham and Ohmoto, 1980; Burnham, 1967). Metals (Cu, Fe, Au and S) and aqueous chloride species partition into the volatile phase upon separation. During the formation of a volatile-rich carapace in the plagioclase porphyry intrusions, the core of the system undergoes potassic alteration causing pervasive K-feldspar alteration of diorite and plagioclase porphyry. Expansion and intensity of alteration is interpreted to occur during breccia formation. Interaction of magmatic-hydrothermal water with circulating meteoric fluids peripherally causes a thin outer propylitic alteration assemblage to develop and is characterized by low-temperature albite, epidote, pyrite and calcite.

Burnham and Ohmoto (1980) predicted that a melt of granodiorite composition having an initial water content of 2.7 wt.% would undergo 50% volume expansion at a depth of 2 km as a result of second boiling. Although Mount Polley rocks have slightly different chemistry and the depth of emplacement is unknown, it is clear that significant amounts of mechanical energy must have been available for fragmentation. Since melts containing <2 wt.% water are too dry to undergo second boiling and those containing $>>4$ wt.% solidify rapidly at depth, Burnham (1985) suggested that second boiling would take place at intermediate water contents. The presence of pyroxene rather than hornblende in the plagioclase porphyry suggests water contents in the lower part of this range. Although the depth of emplacement is not constrained. Brittle failure of wall rocks is more likely at depths of less thar 'm (Burnham, 1985). The abundance of magmatic-hydrother: ›reccias at Mount Polley generally supports a shallow level of emplacement for the complex.

Hydrothermal Brecciation

Brecciation may have been initiated by magma withdrawal, overpressuring of the magma chamber or movement on the Polley Fault. Overpressuring of the plagioclase porphyry magma chamber would cause fractures to propagate toward areas of lower pressure. As pressure decreases from lithostatic to hydrostatic, rapid decompression of the melt results in quenching while vesiculation and brecciation is promoted. At this stage, advanced second boiling would lead to a volume increase of the chamber, accommodated by either brittle failure at shallow crustal depths or magma withdrawal from below (Stage IIA, Fig. 8). The style of hydrothermal brecciation suggests that collapse due to magma withdrawal prior to volatile release may have been more important than explosive release. The morphology and shape of breccia bodies at Mount Polley does not conform to a typical diatreme-pipe and venting to surface may not have occurred. Plagioclase porphyry pulsations (Kents, 1964) could have provided a low pressure cavity into which wallrock collapse and fragmentation would have taken place, leaving relatively unfragmented cap rocks. This mechanism would account for the majority of clasts being derived from local country rock (diorite) with limited vertical movement and rotation.

Alteration and Mineralization

Release of hydrothermal fluid accompanied brecciation in response to decompression of the plagioclase porphyry chamber. Hydrothermal fluid migrated away from the plagioclase porphyry along microfractures, veins and through vugs created in the permeable breccias. Fluid flow away from the plagioclase porphyry is indicated by K-feldspar and actinolite-diopside stockworks in diorite wallrock immediately above the sub-surface roof of the breccia body in the Central zone. Elements partitioned into the magmatic-hydrothermal fluid would have included metal ions (Cu, Fe, Au), aqueous species (K, Na, Ca, Mg) and volatiles (Cl, F). Local ionic exchange with wallrocks and precipitation of minerals derived from the hydrothermal fluid results in deposition of actinolite and biotite in veins/vugs and the formation of K-feldspar envelopes. Cooling and changing fluid composition (increasing Ca relative to K activity) distally from plagioclase porphyry caused mineral zoning in breccias and veins from biotite to actinolite-dominant zones to outer propylitic mineral assemblages (Stage IIB, Fig. 9). The core of the hydrothermal system represents a higher temperature environment and is represented by biotite-actinolite-K-feldspar alteration. It is possible that during cooling of the hydrothermal system, the potassic alteration zone collapsed inward allowing a local overprint of propylitic alteration. These regions are indicated by the development of a complex calc-silicate assemblage including andradite garnet, epidote, potassium feldspar, albite, magnetite, sulphides, chlorite, zeolites and calcite.

Metals are also outwardly zoned from a high copper-gold core to a low copper-gold margin. Hypogene minerals are represented by magnetite, chalcopyrite, bornite and minor pyrite and were probably precipitated from the chloride-rich brine.

The albite breccia is located in the core of the hydrothermal system in the West zone. Albite fills open spaces in vugs as well as overprinting K-feldspar alteration of diorite clasts. Deposition of albite in the breccia, however, appears to be somewhat later than K-feldspar and is likely due to changing fluid composition (increasing Na activity relative to Ca and K). Albite-rich alteration has been interpreted to occur at deeper levels within some porphyry deposits (Einaudi, 1993; Ross, 1993), but there is no evidence at Mount Polley to suggest a markedly deeper origin for this alteration.

Postmineral Intrusions

Following brecciation, alteration and mineralization related to the plagioclase porph··· a variety of postmineral intrusions, largely dikes, were emplace› stmineral faulting dissected the deposit; although definitive evi...nce is lacking, it is proposed that the Polley Fault has normal east-side-down motion (Stage IIIB, Fig. 9). Finally, Mount Polley has undergone erosion to the present level and minor supergene alteration (Stages IIIA in Fig. 8 and Stage IIIB in Fig. 9).

Conclusions

The Mount Polley porphyry copper-gold deposit is one of a number of alkaline deposits within Quesnellia. Mount Polley is characterized by multiple intrusions emplaced into Nicola Group volcanic rocks. Volcanic rocks are petrologically diverse, and include silica-undersaturated and locally feldspathoid-bearing varieties. An undersaturated pseudoleucite-bearing syenite and orbicular syenite (Bootjack stock) located to the southwest of the deposit is temporally related to the emplacement of Mount Polley rocks, but is compositionally distinct.

Intrusions in the Mount Polley complex include premineral diorite and synmineral plagioclase porphyry that locally constitutes intrusion breccias. Postmineral dikes and pods include augite monzodiorite, potassium feldspar phyric monzonite and augite porphyry. A series of biotite lamprophyre dikes are noted regionally and are unrelated to the evolution of the Mount Polley complex.

Superimposed upon these lithologies are a wide range of hydrothermal breccias and lesser intrusion breccias. Hydrothermal breccias have been subdivided on the basis of matrix mineralogy. Four types are recognized: actinolite, biotite, magnetite and albite. Breccias are dominantly monolithic, clast-supported and have triangular vugs partially filled with secondary minerals. Biotite and actinolite breccias have a gradational relationship laterally and vertically in the Central zone. The albite breccia occurs to the west of the Polley Fault, and its relationship to the other breccia types is not well constrained.

Alteration is zonal, with the central part of the hydrothermal system represented by intense potassic and sodic alteration followed by an outer propylitic zone. The potassic zone is coincident with hydrothermal breccias and is divided into three sub-types:

1. actinolite alteration, elongate in a northerly direction, partly superimposed on actinolite breccia and characterized by abundant actinolite-pyroxene-magnetite-sulphide veins with K-feldspar envelopes. The mineralogy of the veins is identical to the assemblage present in the hydrothermal breccia open spaces, indicating that veining and hydrothermal brecciation is intimately related and probably deposited synchronously from a similar fluid.
2. biotite alteration, typified by coarse-grained secondary biotite deposited in open spaces in hydrothermal breccia.
3. potassium feldspar-albite alteration, arcuate around the other alteration facies. Alteration varies from locally intense pervasive K-feldspar to well-developed albitic alteration west of the Polley Fault.

Surrounding the potassic alteration zone is an intermediate zone characterized by the presence of minor amounts of andraditic garnet, disseminated epidote and variable amounts of chlorite, magnetite, albite, K-feldspar, calcite, zeolites and sulphides. An outer propylitic zone consists of an albite-epidote-pyrite-calcite-magnetite assemblage. The temporal relationship between these three alteration zones is not well constrained. Potassic alteration may be contemporaneous with the propylitic altered fringe.

Metals also show a zonation from core to margin. Central porphyry mineralization consists of fracture-controlled, disseminated and vug-fill chalcopyrite, magnetite and minor amounts of bornite. High gold concentrations correlate with high copper contents. The mineralogy grades outward into a more pyrite-dominated assemblage. Bornite has an antithetic relationship with pyrite. Metal zonation may reflect a temperature variation across the Mount Polley deposit.

Alteration and mineralization is directly related to intrusion of the plagioclase porphyry intrusion. Relatively shallow emplacement of the magma, combined with cooling, crystallization and release

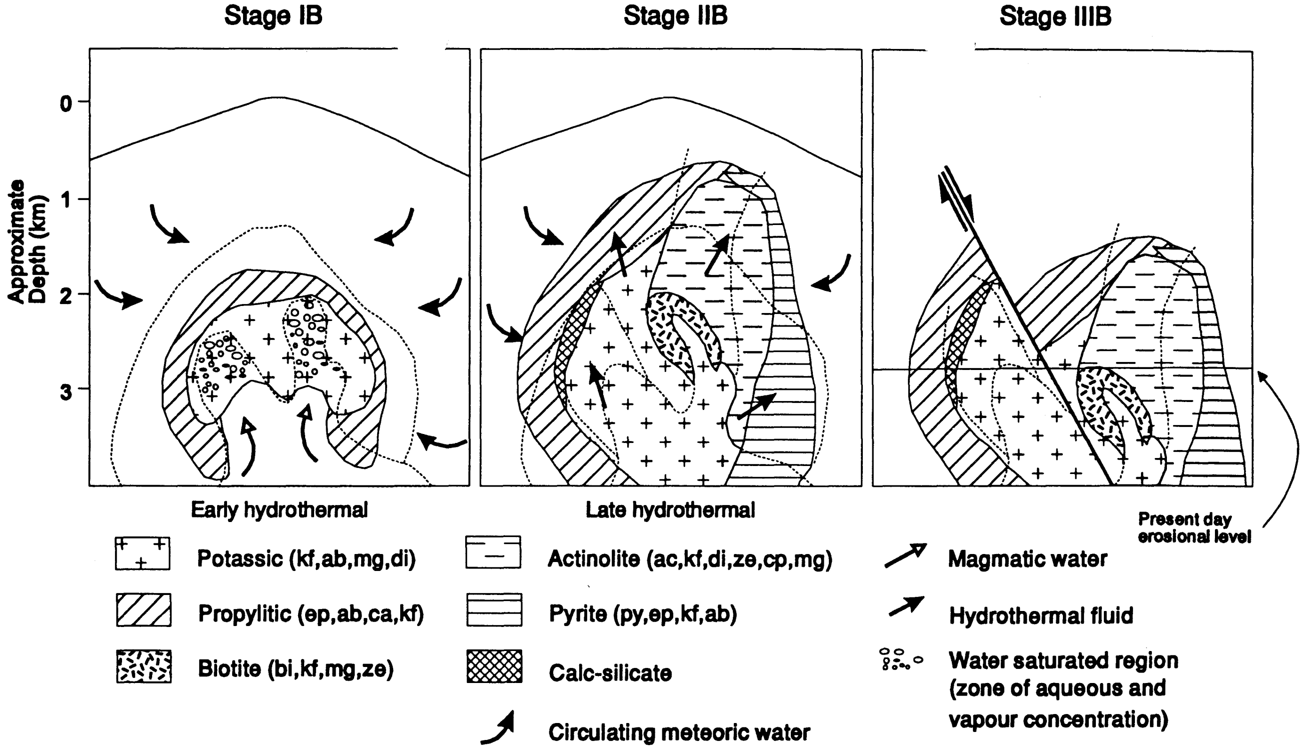

FIGURE 9. Deposit scale model of alteration zoning at Mount Polley. Plagioclase porphyry intrusion and water saturation is accompanied by development of K-feldspar altered core and thin propylitic margin (Stage IB). Expansion of hydrothermal system and release of magmatic-hydrothermal fluid during brecciation causes intense potassic alteration of core, along with biotite and actinolite alteration zones due to a differing fluid composition. A calc-silicate alteration zone develops between the potassic and propylitic zone. Intense sodic metasomatism is associated almost exclusively with breccias west of the Polley Fault (Stage IIB). Faulting and erosion have given rise to the alteration zoning observed (Stage IIIB).

of magmatic-hydrothermal fluids, gave rise to breccias located at the margins and apex of the plagioclase porphyry.

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