HYDROTHERMAL BRECCIAS AND ASSOCIATED ALTERATION OF THE MOUNT POLLEY COPPER-GOLD DEPOSIT (93 A/12)

Theresa M. Fraser
Mineral Deposit Research Unit, U.B.C.
(MDRU Contribution 039)

KEYWORDS: Economic geology, porphyry Cu-Au, Mount Polley, hydrothermal breccia, alteration, skarn, magnetite, albite, garnet, actinolite.

INTRODUCTION

The Mount Polley alkalic porphyry copper-gold deposit in south-central British Columbia (52°30'N, 121°35'W) is located 56 kilometres northeast of Williams Lake. The current owner of the property, Imperial Metals Corporation, has estimated geological reserves at 2.8 million ounces of gold and 1.5 billion pounds of copper, using a copper equivalent cut-off grade of 0.2%, and mineable reserves at 48.8 million tonnes grading 0.383% copper and 0.556 gram gold per tonne, using a copper equivalent cut-off grade of 0.39% (Gorc *et al.*, 1992).

The deposit is hosted by a diorite stock that intrudes compositionally similar volcanic rocks in the central part of the Quesnel Terrane.The diorite consists of several intrusive phases and a number of breccia bodies.

Fieldwork was undertaken in June, 1993, to map the area surrounding the proposed S19 open pit at a scale of 1:2000. The objective was to subdivide the breccias on the basis of mineralogy, textural differences, type of matrix, alteration of clasts, timing and distribution. Alteration minerals and their modes of occurrence were noted on surface and combined with drill-log information to outline the distribution of potassic (subdivided into biotite, actinolite and potassium feldspar), propylitic and pyritic assemblages. Nomenclature of the alteration zones has changed slightly from last season (Fraser *et al.*, 1993) in that the calc-potassic zone has been subdivided into areas corresponding to the dominant alteration mineral, for example, actinolite. Finally, vein assemblages that were recognized previously were mapped to determine the relative timing of vein-filling and brecciation.

DEPOSIT GEOLOGY

The Mount Polley deposit is hosted by a moderate sized diorite intrusion (Figure 1) that is crosscut by several breccia types, including intrusion and hydrothermal breccias (Fraser *et al.*, 1993). Most of the ore is contained within hydrothermal breccias. The deposit is dissected by a prominent north-trending fault. The type of breccia changes across the fault; an albite-rich breccia is present in the west zone while actinolite and biotite-rich breccias characterize the east zone (Figure 1). The breccias are intruded by a variety of late to post-mineral dikes, the most abundant of which are augite porphyry dike swarms.

Lithologies, including distinct types of breccia, are described from oldest to youngest:

Volcanics (unit 1) do not outcrop in the area mapped In the region, however, volcanic rocks consist of diverse maroon polymictic volcanic breccias, augite-phyric basalts, trachybasalts and tuffs. Volcanic xenoliths are commonly found in the diorite unit. Drill-hole logging on cross-section 3460 N identified a block of green crystal lapilli tuff contained within a plagioclase porphyry intrusion breccia.

Diorite (unit 2) forms a stock-like intrusion and is the dominant host for the mineralized breccia bodies at Mount Polley. Most commonly, the diorite is dark grey, fine grained, and equigranular to weakly porphyritic (plagioclase and clinopyroxene phenocrysts). Euhedral plagioclase laths are andesine in composition and are moderately sericitized. The most prominent mafics are biotite and clinopyroxene; the latter occasionally has altered rims of hornblende. The diorite is relatively fresh away from the breccias but the intensity of alteration increases towards the core of the system (where the unit is cut by several vein types, including magnetite, actinolite and potassium feldspar).

Plagioclase porphyry (unit 3) forms a massive intrusive unit and the matrix of locally extensive intrusion breccias. For mapping purposes, the two textural types have been grouped together and are identified on the map as unit 3a (plagioclase porphyry) and unit 3b (intrusion breccia) based on the predominant textural characteristic.

The plagioclase porphyry is crowded with plagioclase phenocrysts (up to 70%), and locally seriate in texture. The feldspars are euhedral and moderately sericitized. Accessory minerals include biotite, magnetite hornblende and trace apatite. Most of the unit has suffered moderate to intense potassium feldspar alteration.
Plagioclase porphyry forms the matrix of the intrusion breccia that is dominated by subangular fragments of diorite, normally more than 3 centimetres across. The

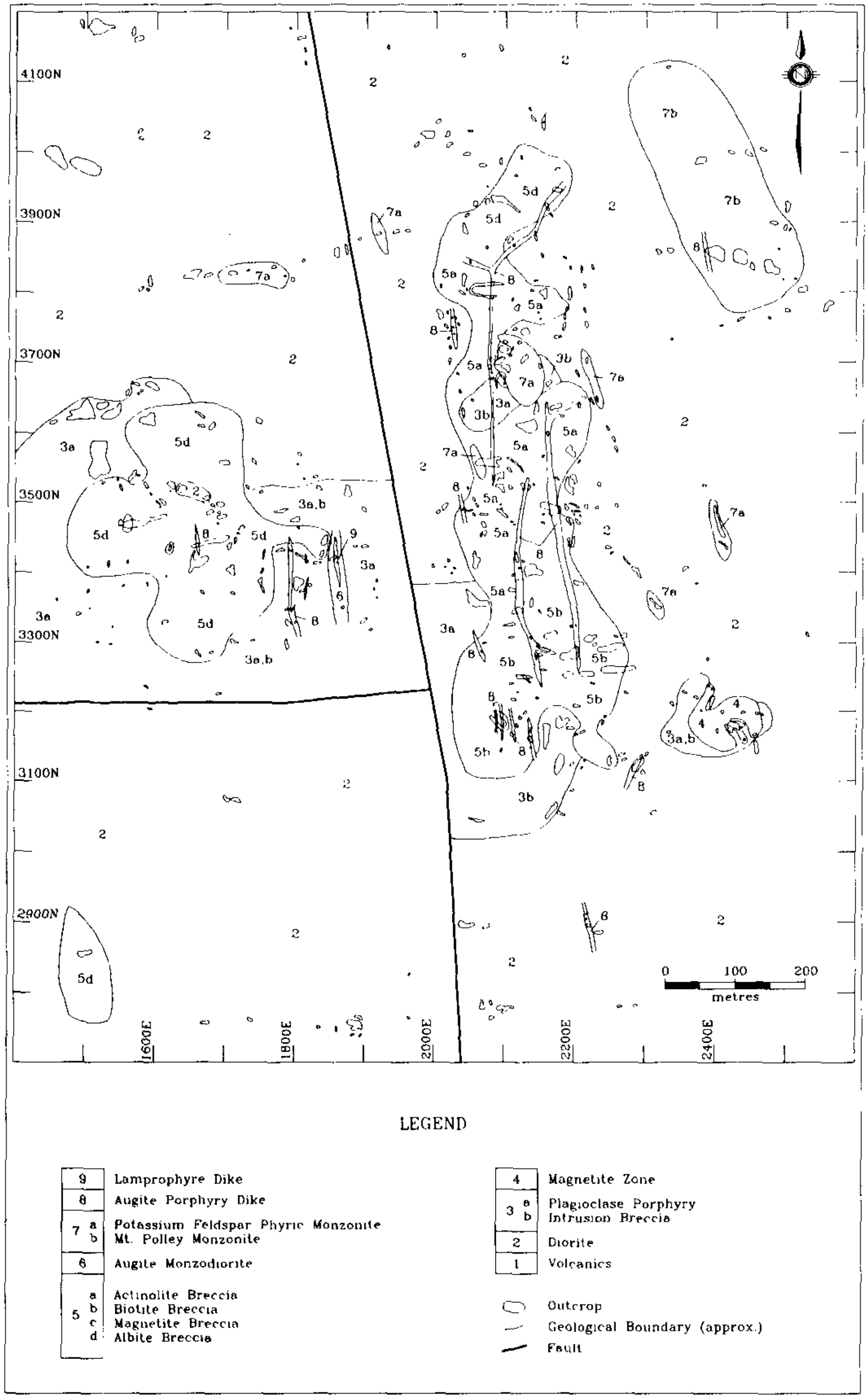

Figure 1. Surface geology map of the Mount Polley deposit using the Imperial Metals Corporation grid.

breccia is matrix supported and locally contains up to 35% clasts. The unit has undergone intense alteration, with strongly sericitized feldspar phenocrysts and the development of secondary potassium feldspar that has destroyed primary textures in many areas.

Magnetite-Garnet (unit 4) forms a "replacement zone" in an area roughly 100 by 100 metres in the southeastern portion of the proposed S19 open pit. The zone lies at the contact between diorite to the north and plagioclase porphyry to the south (Figure 1). The margin of the zone is not well exposed but appears to interfinger and have sharp contacts with the plagioclase porphyry unit. Plagioclase porphyry has a narrow, bleached alteration envelope adjacent to the contact and this is accompanied by the destruction of primary texture.

The magnetite zone consists of 40 to 70% magnetite; the remainder is strongly weathered brown garnet (Plate 1A). Garnet-rich areas form irregular elongate patches with diffuse margins that are crosscut by magnetite veins and microfractures along which garnet has been replaced by magnetite. Epidote veins cut the magnetite-garnet replacement zone and small voids within the unit have been partially filled with zeolites and calcite.

Hydrothermal breccias (unit 5) are prominent in the map area and have been subdivided on the basis of texture and mineralogy. Four breccia types have been identified, each with its own characteristic matrix mineralogy: actinolite breccia, biotite breccia, magnetite breccia and albite breccia. Clasts are dominated by the local country rock to the breccia, typically diorite and occasionally plagioclase porphyry. Crosscutting relationships between the various hydrothermal breccias are difficult to identify due to poor exposure on surface. A more detailed description of the breccia types will follow in a separate section entitled "Hydrothermal breccias and veins".

Porphyritic augite monzodiorite (unit 6) only outcrops in the western zone and is present at depth, for example on cross-section 3460 N. Generally it forms dike-like bodies with a northerly strike and moderate to shallow easterly dip. Macroscopically, this unit is very distinctive, having 10% prominent rounded green clinopyroxene phenocrysts in an intensely sericitized plagioclase groundmass. Accessory minerals include magnetite, apatite and biotite. This unit is unmineralized and unaltered.

Potassium feldspar phyric monzonite (unit 7) occurs in two distinct locations, the core of the deposit and the summit of Mount Polley (Figure 1).

The monzonite unit (unit 7a) occurs as dikes and pods in the centre of the deposit and extends to undefined depths. Euhedral, zoned potassium feldspar phenocrysts (20%) form a trachytic texture with individual phenocrysts up to 2 centimetres long. Most of the groundmass has weakly aligned tabular plagioclase grains. Accessory minerals include clinopyroxene, sphene, apatite and magnetite. Clasts of diorite occur in the monzonite intrusion. Diamond-drill hole MP89-125 cut a 15-metre interval of intrusion breccia in which 20 to 30% angular fragments of hornblende pyroxenite and diorite were identified. The pyroxenite may be derived from a larger body at depth.

The Mount Polley summit monzonite (unit 7b) was mapped in the 1993 field season. It has been previously described by Hodgson *et al.* (1976) as an intrusion breccia, but on surface no fragments were visible and drill core was unavailable. The rock resembles unit 7a, having a moderate alignment of feldspars and containing 5% large megacrysts of potassium feldspar. The extent of the unit is unknown and it may be much larger than shown on Figure 1; it is bounded on the south by diorite. The monzonite is unmineralized, but is partially altered to epidote, albite and minor pyrite.

Augite porphyry dikes (unit 8) occur as swarms throughout the deposit, striking northerly and dipping moderately to the east. Dikes are continuous along strike and have an average thickness of 4 metres. Most have an aphanitic chilled margin with occasional augite or plagioclase phenocrysts. Clinopyroxene (35-55%) forms optically zoned, euhedral phenocrysts and plagioclase forms the bulk of the groundmass, together with disseminated magnetite.

Biotite lamprophyre dikes (unit 9) crosscut all rock units and are possibly Tertiary in age. They have been mapped throughout the deposit, have a maximum thickness of 2 metres, and are oriented roughly north-south (similar to other post-mineral dikes). The dikes are fine grained, friable and weather rapidly on surface to a dark green sand. Euhedral biotite forms 40% of the unit, imparting a foliation, with lesser moderately to weakly aligned plagioclase laths and sparse pyroxene phenocrysts.

HYDROTHERMAL BRECCIAS AND VEINS

The features of each breccia type intersected in drill holes were systematically noted by using the Geolog system (Blanchet and Godwin, 1972) for porphyry deposits. Representative sections, corresponding to assay intervals, were logged. Where diamond-drill core was unavailable, surface material was described. Hydrothermal breccia characteristics are summarized in Table 1.

Actinolite breccia (unit 5a) is only present east of the fault; no actinolite has been identified in the west zone. This unit is hosted by diorite. Diorite blocks show minor rotation with small triangular vugs between blocks. The vugs are filled with fibrous dark green actinolite and are surrounded by envelopes of potassium feldspar. Diorite clasts are subangular and 2 to 3 centimetres across on average. The clasts commonly have unaltered interiors but

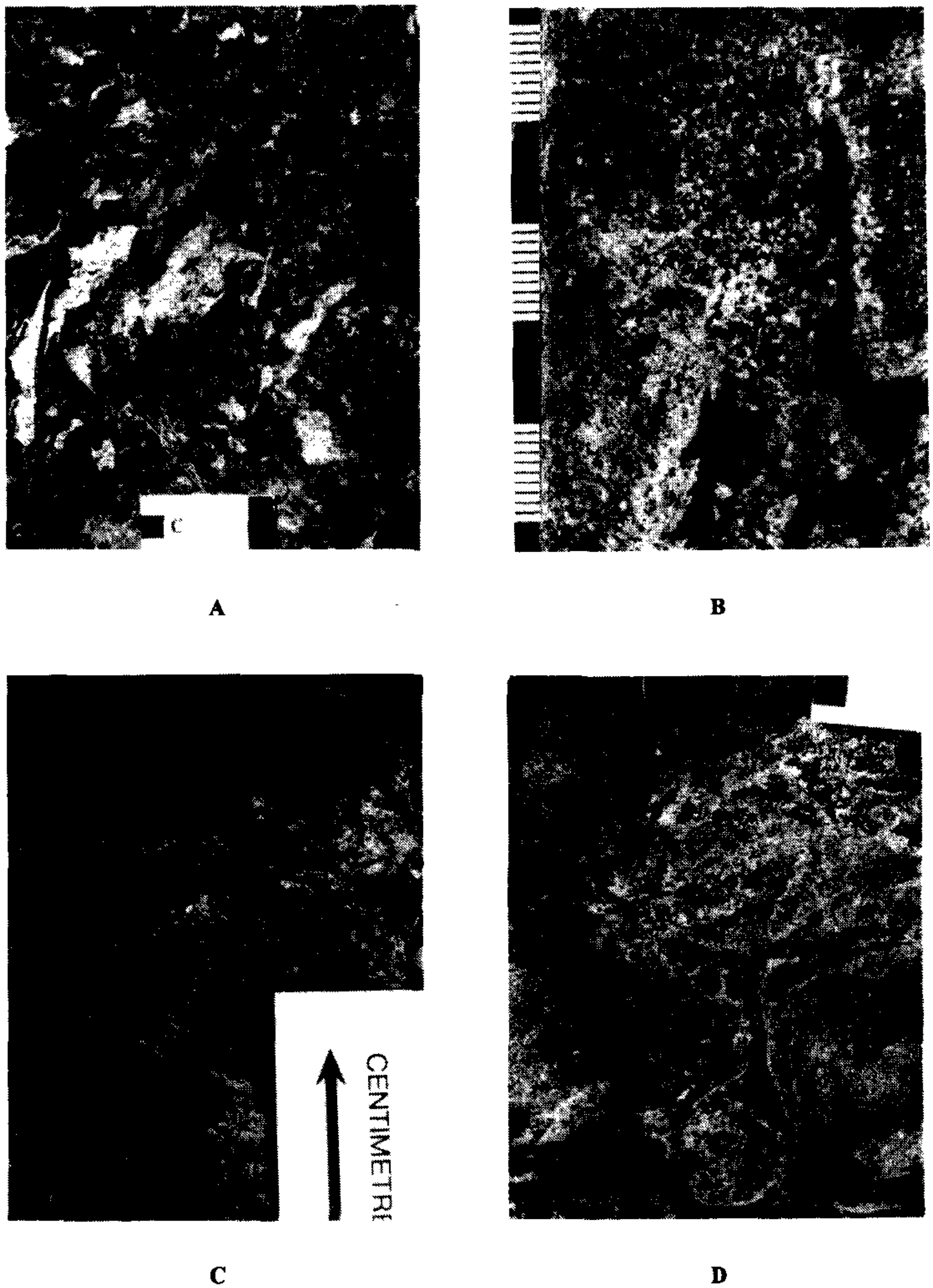

Plate 1. **A** An outcrop photograph of massive magnetite (black) and elongate garnet patches (white). **B** A cut slab of biotite breccia from the central zone of Mount Polley. The breccia has coarse hydrothermal biotite in the matrix (black) and *subangular diorite clasts.* **C** *Magnetite breccia from the west zone with strongly altered angular clasts and matrix of* magnetite, accessory sulphides and diopside. **D** Texture of weathered albite breccia from the west zone is evident. The albitic matrix is recessive (black) and clasts are strongly altered to potassium feldspar.

TYPICAL HYDROTHERMAL BRECCIA FEATURES

Breccia Type	Ave. Matrix Size (mm)	Ave. Clast Size (cm)	% Clasts	Max. Clast Size (cm)	Sorting	Clast Roundness	Clast Sphericity	Open vs. Closed
Actinolite	1.0	4.5	85	200	3	3	7	C
Biotite	6.0	3.0	85	100	2	5	9	C (O)
Magnetite	2.0	3.0	90	5	2	5	9	C
Albite	0.5	4.5	75	10	5	7	9	C

Table 1. Biotite, magnetite and albite breccias were estimated using representative drill holes over intervals up to 30 metres. Information about the actinolite breccia was accumulated on a large stripped outcrop in the central zone. Scales are as follows: Sorting - 2 = very poorly sorted and 5 = moderately sorted, Roundness - 3 = subangular and 7 = moderately rounded, Sphericity - 9 = most spherical (refer to Blanchet and Godwin's (1972) L-scale definitions). Open versus closed refers to matrix-supported and clast-supported breccias, respectively.

become increasingly altered by potassium feldspar toward their margins where primary texture has been destroyed. The matrix consists entirely of actinolite with traces of disseminated chalcopyrite. The breccia is generally cut by abundant actinolite (±chalcopyrite, diopside) veins with potassium feldspar envelopes. Similar veins occur throughout the central zone of the Mount Polley deposit. Actinolite breccia appears to grade into the biotite breccia to the south and into actinolite-albite breccia to the north. In the latter, 1 to 3-centimetre vugs have been partially filled by prismatic albitic crystals (3 x 3 x 10 mm). Their margins are albitically altered and locally overprint potassium feldspar alteration.

Biotite breccia (unit 5b, Plate 1B) is exposed on surface in the southern part of the central zone, where it is extensively oxidized and outcrops are weathered and friable. Clasts are pervasively altered to potassium feldspar and the original rock type is difficult to identify; remnant textures suggest that the clasts are dominantly diorite and plagioclase porphyry. The majority of clasts are in the 2-centimetre range, but locally are up to a metre across. The breccia is largely clast supported but locally there are zones of matrix-supported breccia.

The matrix contains coarse-grained hydrothermal biotite flakes up to 2 centimetres in diameter, with patchy development of secondary chlorite (Plate 1B). The matrix assemblage has an average composition of 60% biotite, 25% chrysocolla (with trace malachite) and 15% zeolites. Chyrsocolla is intimately intergrown with biotite and also has impregnated clasts, suggesting extensive mobility during the oxidation of sulphides. The zeolites are late in the formation of the breccia and have filled void space around biotite and chrysocolla.

Magnetite breccia (unit 5c, Plate 1C) is not abundant, but is developed locally 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 to 3 centimetres across and are pervasively altered to potassium feldspar. The matrix consists of massive to euhedral grains of magnetite (2 to 3 mm) locally accompanied by accessory sulphides and pyroxene. This variety of hydrothermal breccia is always clast supported, with an average of 10% matrix.

Albite breccia (unit 5d, Plate 1D) is a distinctive variety found 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 is only identified on the basis of secondary biotite in small vugs. The unit is largely clast supported, containing small vugs partially filled with pristine, zoned prismatic albite crystals or alternatively the matrix may consist of fine-grained albite with accessory biotite, magnetite and disseminated sulphides.

To constrain the timing of veins, crosscutting relationships among vein sets were identified. Most of the data were collected from split drill-core with lesser amounts from available outcrop. Veins are almost always weathered at surface to such an extent that positive identification of minerals is difficult and much ambiguity results. Vein assemblages and the location and relative timing of distinct veins are summarized in Table 2. Field relationships suggest the following:

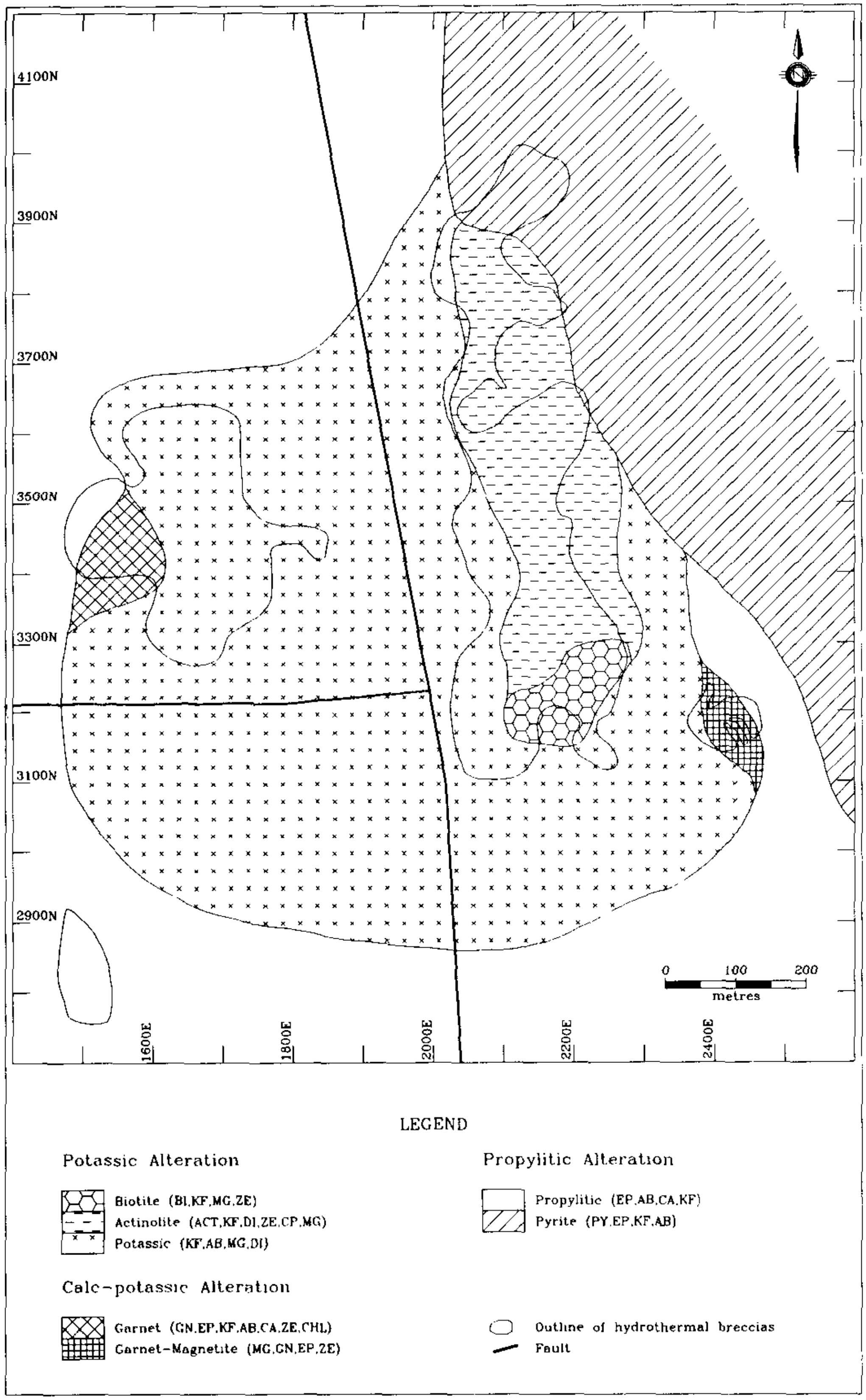

Figure 2. Alteration map of Mount Polley. Modes of occurrence of alteration minerals are: vein (actinolite, chalcopyrite, pyrite, epidote, magnetite, diopside, albite, potassium feldspar), pervasive (epidote, potassium feldspar) and vug-fill (biotite).

SUMMARY OF VEIN ASSEMBLAGES AT MOUNT POLLEY

Vein Type	Name	West Zone	Central Zone	Fringe	Relative Timing
1	actinolite		AC+DI+CP (KF)		early
2	magnetite	MG+DI+CP+PY (KF)	MG+DI+CP+PY (KF)		early
3a	chalcopyrite	CP+BO+MG	CP+BO+MG		intermediate
3b	pyrite			PY+MG+CP	intermediate
4	epidote			EP+PY+CC	intermediate
5	albite			AB	intermediate
6	quartz		QZ		late to post-mineral
7	calcite	CC+ZE	CC+ZE	CC+ZE	post-mineral

Table 2. The abbreviations are as follows: AC = actinolite, DI = diopside, CP = chalcopyrite, KF = potassium feldspar, MG = magnetite, PY = pyrite, BO = bornite, EP = epidote, CC = calcite, AB = albite, QZ = quartz and ZE = zeolites.

- Actinolite veins crosscut a variety of breccia units and intrusives east of the fault. The veins are present in a narrow zone elongated north-south and superimposed on the actinolite breccia zone. The veins are mineralized and have accessory diopside. Potassium feldspar envelopes occur around the veins and similar alteration envelopes are associated with microfractures that contain no vein-fill.
- Magnetite veins are widespread throughout the deposit. Most veins contain chalcopyrite, trace diopside and pyrite. Locally, narrow potassium feldspar envelopes are developed, similar to those around actinolite veins.
- Chalcopyrite-bornite-magnetite veins (3a) occur in the core of the system and grade outward to pyrite-magnetite-chalcopyrite veins (3b). Veins 3a and 3b may have been produced by the same hydrothermal fluid but at different temperatures or sulphur fugacities .
- Epidote veins are found on the fringe of the breccia complex and mark the propylitic zone. Most veins contain considerable coarse-grained euhedral pyrite and accessory calcite.
- Albite veins crosscut pre-existing potassium feldspar envelopes and actinolite veins. Almost all veins examined are strongly weathered and the presence of other minerals is obscured. The association of albite with hydrothermal breccias in the west zone may indicate that the veins are related to mineralization and the peripheral propylitic zone.
- Rare, late quartz veins cut the plagioclase porphyry unit in drill hole MP89-126 and on surface, east of the fault in the core of the system. These veins truncate actinolite and chalcopyrite-bearing veinlets. The unmineralized quartz veins may be unrelated to the Mount Polley system.
- Calcite and zeolite veins cut all lithologies and vein types. They are widespread throughout the deposit and occur in all alteration zones. These are post-mineral veins, and like quartz, may be unrelated to the main mineralizing event.

All of the distinct vein assemblages are summarized in Table 2. Distribution of assemblages is noted, as well as an estimate of the timing of vein formation. Both early and intermediate veins are mineralized, and are separated on the basis of mineralogy and suspected time of deposition. Intermediate veins were formed during the main hydrothermal event in the core of the system and are probably contemporaneous with epidote and pyrite on the fringe.

DISTRIBUTION OF 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 was mapped on the eastern portion of the Mount Polley deposit. A combination of detailed mapping and drill-hole logging during the past two field seasons generally supports this interpretation but, in addition, the potassic core is now divided into three distinct units based on the dominant mineral assemblage (Figure 2).

POTASSIC ALTERATION

A potassic core (Figure 2) coincident with the hydrothermal and intrusion breccias can be subdivided into three major subtypes:

- A biotite zone characterized by the development of coarse, secondary black biotite within vugs of the hydrothermal breccia (unit 5b), with pervasive secondary potassium feldspar in clasts.
- An actinolite zone characterized by abundant actinolite-chalcopyrite-diopside-magnetite veins that crosscut breccias, diorite and plagioclase porphyry and by the presence of actinolite in vugs within hydrothermal breccias. The zone is elongate in a north-south direction within the core of the system on the east side of the fault. Actinolite veins and breccias have not been noted in the west zone. Associated with the veins are quite extensive potassium feldspar envelopes which tend to obliterate primary textures adjacent to the vein.
- A potassium feldspar - albite zone is arcuate around the biotite and actinolite zones. Almost all of the rock units in this area have undergone varying degrees of pervasive potassium feldspar alteration or veining. In the western part of the deposit, albite occurs as envelopes around microfractures and vuggy regions of the breccias, in addition to or in place of potassium feldspar.

CALC-POTASSIC ALTERATION

Garnet alteration occurs in two areas (Figure 2), and does not have a uniformly concentric distribution as previously described (Hodgson *et al.*, 1976). Its occurrence is confined to the perimeter of the S19 pit, generally in areas of intense albitic and potassic alteration. In the western area, two drill holes contain brown, zoned, euhedral to massive garnet in hydrothermal veins or vugs within the albitic breccia at the 150 to 180-metre level. Primary textures of clasts have been overprinted by secondary potassium feldspar and vugs in the matrix are partially or wholly filled with an assemblage of albite, magnetite, garnet, calcite, epidote, zeolites, chlorite, pyrite and chalcopyrite.

The eastern area contains a body of massive brown garnet overprinted by magnetite and diopside, with abundant epidote veins and retrograde alteration minerals (unit 4). The timing of this replacement body is ambiguous and may not correspond with the garnet-epidote assemblage found elsewhere in the deposit.

PROPYLITIC ALTERATION

A peripheral propylitic zone is generally developed outside the proposed pit (Figure 2). The rock units are weakly altered and commonly contain epidote-pyrite veins and disseminated epidote which may replace mafic minerals. Albite veining is diffuse and crosscuts all lithologies. Calcite-zeolite veins are also prominent but are post-mineral.

A pyrite zone is present in the north-east section of the Mount Polley property. It is characterized by abundant pyrite veins crosscutting the breccias and diorite. Veins sometimes contain accessory magnetite and chalcopyrite. The zone has undefined lateral extents and reaches beyond the mapped area. It has a potential length of more than 1.4 kilometres and minimum width of 200 metres. Most of the lithologies are pervasively altered to potassium feldspar and are crosscut by pyrite, epidote and albite veins.

CONCLUSIONS

The Mount Polley alkalic porphyry deposit is part of a complex system involving a variety of intrusive bodies and hydrothermal breccias. It is further complicated by the overprinting of several alteration zones and related sets of veins.

Detailed mapping on a property-wide basis and extensive drill-core logging has yielded the following picture of Mount Polley summarized in Figure 3. The deposit is hosted by a diorite stock that contains volcanic xenoliths and screens. Plagioclase porphyry intrudes the diorite and forms the matrix to intrusion breccias. A series of four distinct hydrothermal breccias (actinolite, biotite, magnetite and albite) formed in the core of the system and provide the host to much of the mineralization. A zone of magnetite-garnet in the south-eastern part of the deposit may replace intrusive and/or volcanic rocks by skarn-type reactions, as suggested by Sutherland Brown (1967) and Simpson and Saleken (1990). Late to post-mineral dikes were intruded, following these main events.

During the main hydrothermal event, the core of the system was potassically altered. The most characteristic minerals of this zone are biotite, actinolite, diopside and magnetite. Numerous mineralized veins crosscut the breccias, with actinolite-diopside-chalcopyrite and chalcopyrite-magnetite-bornite veins being the most important. A discontinuous garnet-epidote zone, with lesser chlorite, zeolites and pyrite separates the potassic and propylitic zones. A propylitic assemblage of epidote, pyrite and albite fringes the entire deposit. A laterally extensive pyrite zone lies to the north-east.

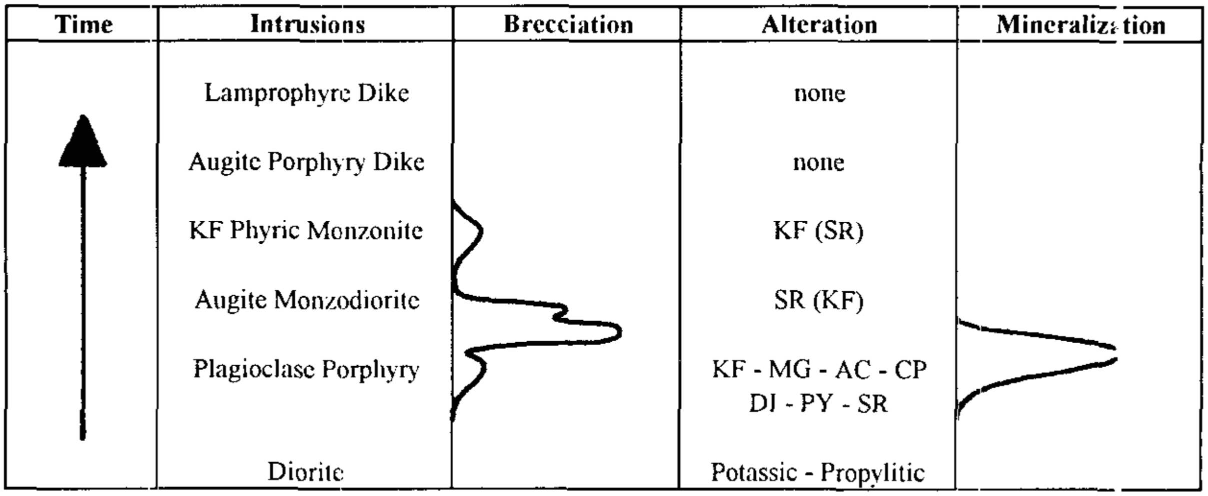

Figure 3. Summary diagram for the sequence of intrusive, breccia and alteration events at Mount Polley. The abbreviations are as follows: KF = potassium feldspar, SR = sericite, MG = magnetite, AC = actinolite, CP = chalcopyrite, DI = diopside and PY = pyrite.

ACKNOWLEDGMENTS

I wish to thank Imperial Metals Corporation for access to the Mount Polley property and invaluable drill-log information. John Thompson is thanked for comments in the field and insightful ideas on the genesis of albitic alteration and skarn processes. The company of my field assistants, Jennifer Garrett and Julie Kadar, and their hard work was greatly appreciated over the last two summers. The following colleagues at the Mineral Deposit Research Unit are gratefully acknowledged for their help using the AUTOCAD program: A. Toma, R. Bartsch, P. Metcalfe and P. Lewis.

Fieldwork for this study was supported financially by the Mineral Deposit Research Unit at the University of British Columbia and it forms part of the project "Porphyry Copper-Gold Systems of British Columbia".

REFERENCES

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.

Blanchet, P.H. and Godwin, C.I. (1972): Geolog System for Computer and Manual Analysis of Geologic Data from Porphyry and Other Deposits; *Economic Geology*, Volume 67, pages 796 - 813.

Fraser,T.M., Godwin, C.I., Thompson, J.F.H. and Stanley, C.R. (1993): Geology and Alteration of the Mount Polley Alkalic Porphyry Copper-Gold Deposit, British Columbia (93A/12); *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 295 - 300.

Gorc, D., Nikic, Z.T. and Pesalj, R. (1992): Mount Polley; *Imperial Metals Corporation*, unpublished report, 11 pages.

Hodgson, C.J., Bailes, R.J. and Verzosa, 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.

Simpson, R. and Saleken, L.W. (1990): Cariboo-Bell Deposit; *Geological Association of Canada - Mineralogical Association of Canada -- Canadian Geophysical Union*, Joint Annual Meeting, Volume 1, Trips 1 - 8, pages 13 - 21.

Sutherland Brown, A. (1967): Cariboo-Bell; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Annual Report 1966, pages 126 - 131.

NOTES