Hydrothermal Breccia in the Mount Polley Alkalic Porphyry Copper-Gold Deposit, British Columbia (NTS 093A/12)

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Introduction

Hydrothermal and magmatic-hydrothermal breccias are common in porphyry Cu deposits. Depending on their timing relative to mineralization and the nature and genesis of the breccias, they can provide either preferential sites for sulphide mineral deposition, leading to high-grade ore zones, or they can provide fluid barriers that retard fluid movement, causing the ponding of mineralizing fluids adjacent to low-grade or barren zones (Burnham, 1985; Sillitoe, 1985; Zweng and Clark, 1985; Bushnell, 1988; Serrano et al., 1996). Late breccia formation can also dilute ore by mixing fragments of variably mineralized rock, or by erupting, thereby venting potentially mineralizing fluids to the atmosphere and diluting the grade of the rock mass (e.g., Zweng and Clark, 1985; Cannell et al., 2005). Establishing those relations is therefore important, as breccias can have strong influences on distribution of metals and the economics of the deposit.

Lang et al. (1995b) noted that hydrothermal breccia is present in the silica-saturated and silica-undersaturated alkalic porphyry deposits of British Columbia. In the silica-saturated deposits, the breccia formed during the main-stage mineralization, whereas, in the silica undersaturated deposits, it is interpreted to have formed pre–, syn–, and post–main stage mineralization. At Mount Polley, the breccia is a major host to ore grade Cu and Au (Fraser et al., 1995; Lang et al., 1995b).

Mount Polley is one of a series of silica-undersaturated alkalic Cu-Au porphyry deposits in British Columbia that formed in the Triassic to Early Jurassic Quesnel and Stikine terranes (Figure 1; Barr et al., 1976; Lang et al., 1995a; Logan and Mihalynuk, 2005). The Mount Polley deposit, owned and operated by Imperial Metals Corporation, is composed of several porphyry Cu-Au(-Ag) centres (Figure 2), most of which are breccia hosted (Hodgson et al., 1976; Fraser, 1994a, b; Fraser et al., 1995; Rees et al., 2005, 2006; Logan and Mihalynuk, 2005). The Cariboo, Bell and Springer deposits (Core zone) are hosted in part by hydrothermally brecciated intrusive rocks, with veins extending into surrounding monzonite and diorite (Fraser, 1994a, b; Fraser et al., 1995; Imperial Metals Corporation, 2007). In contrast, the Northeast zone, currently being mined in the Wight pit, is predominantly hosted by a polylithic hydrothermal breccia body (Deyell, 2005; Deyell and Tosdal, 2005; Jackson et al., 2007; Pass et al., 2007; Imperial Metals Corporation, 2007).

Keywords: *alkalic, porphyry, hydrothermal breccia, Mount Polley*

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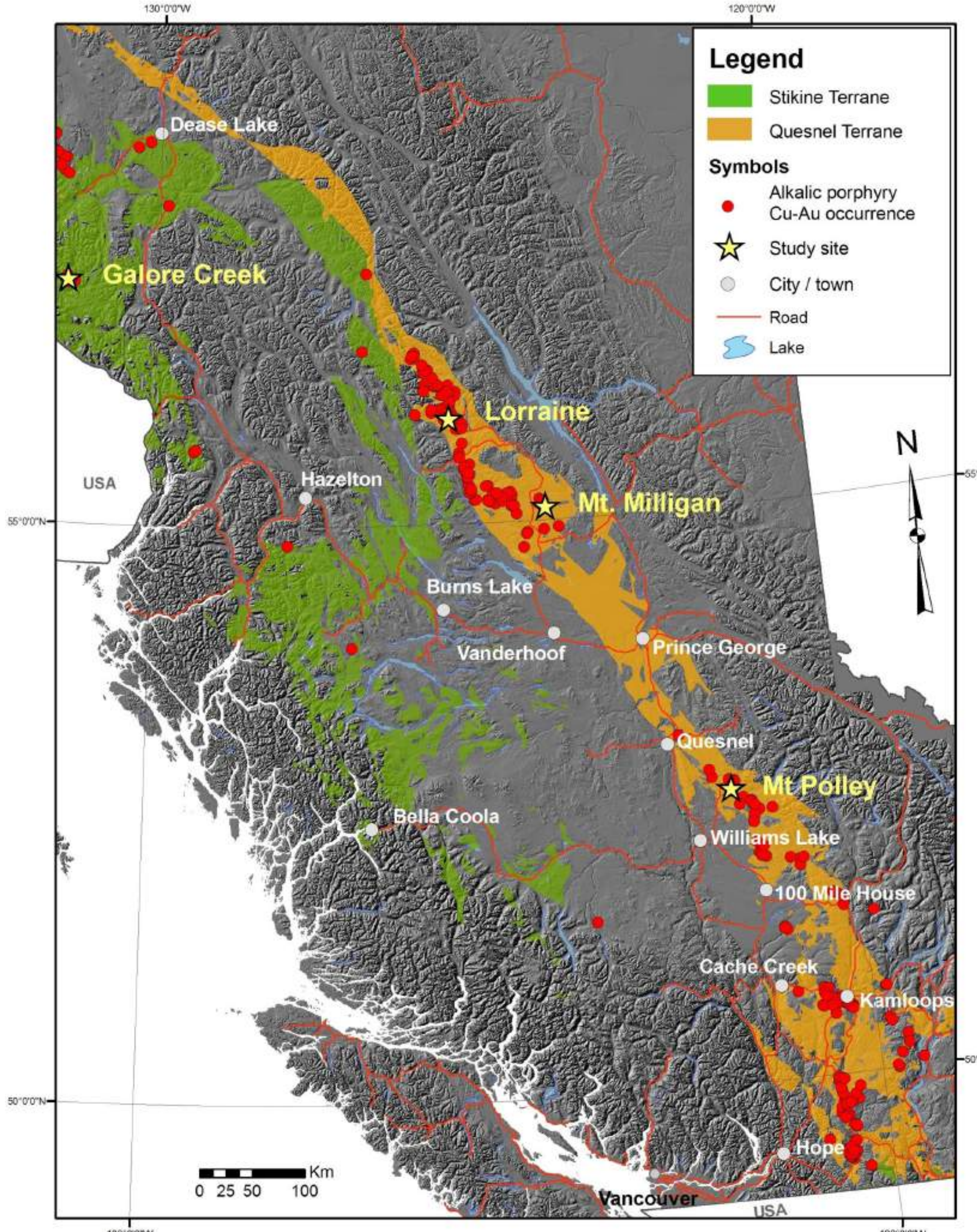

Figure 1. Location of alkalic porphyry Cu deposits in British Columbia, showing location of Mount Polley with respect to the other deposits and to the Triassic and Early Jurassic Quesnel and Stikine terranes.

Geological Framework of the Mount Polley District

The Mount Polley alkalic porphyry Cu-Au deposit lies along the eastern margin of the Intermontane Belt, close to the boundary with the Omineca Belt. Upper Paleozoic to Lower Mesozoic volcanic, plutonic and sedimentary rocks of the Quesnel Terrane are the principal rocks underlying the region (Panteleyev et al., 1996; Logan and Mihalynuk, 2005). The Quesnel Terrane consists primarily of Late Triassic to Early Jurassic magmatic-arc complexes formed above an east-dipping subduction zone (Mortimer, 1987). Mount Polley is one of a chain of alkalic intrusion–related porphyry Cu-Au deposits that developed at intervals along the arc (Barr et al., 1976; Lang et al., 1995a).

The Mount Polley deposit is hosted by a multiphase alkalic intrusive complex (Figure 2). The intrusive complex is a

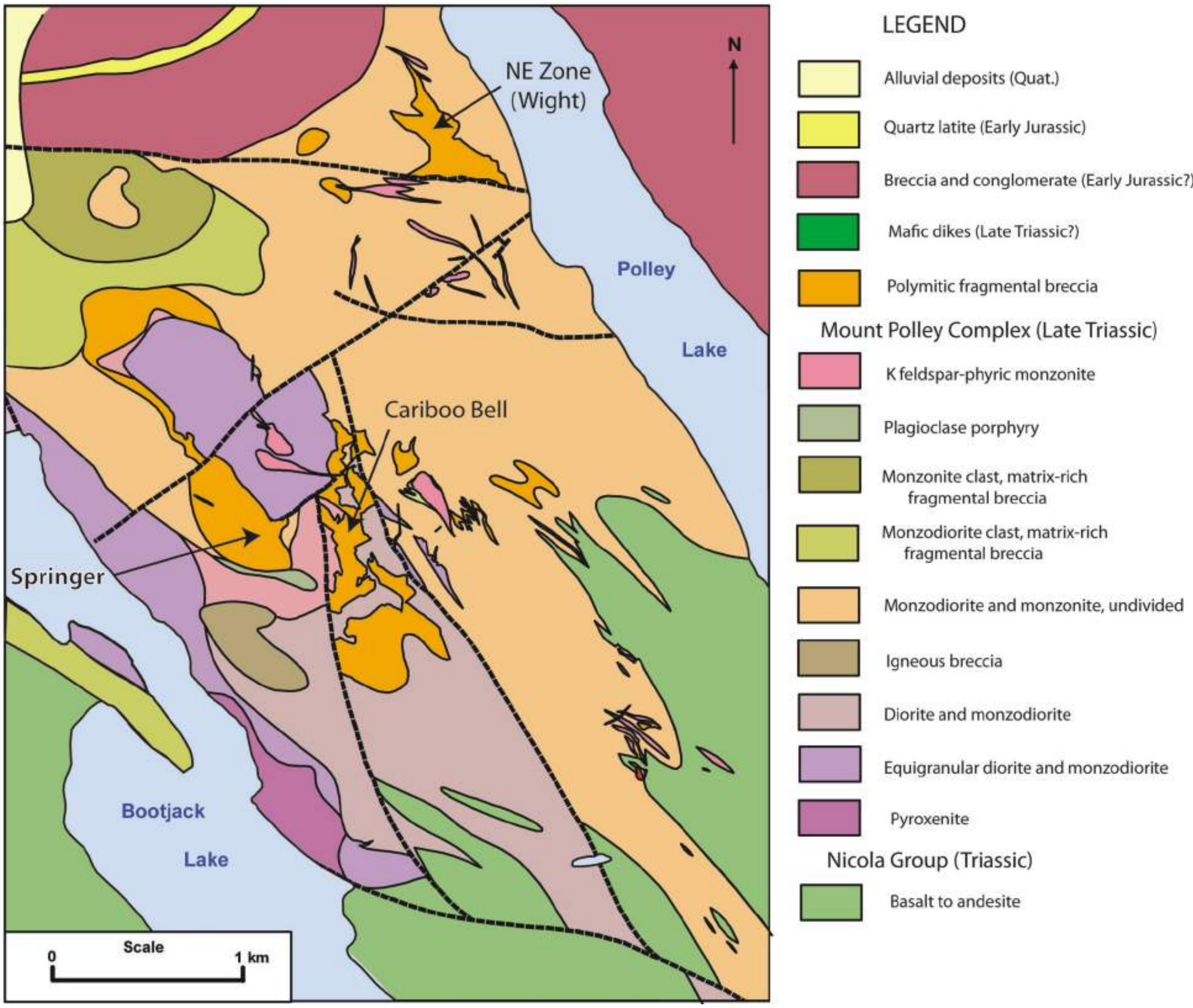

Figure 2. Generalized geology of the Mount Polley region, showing location of mineralized centres in the deposit (*adapted from* Logan and Mihalynuk, 2005; Rees et al., 2005).

north- to northwest-trending body composed primarily of equigranular to porphyritic diorite, monzodiorite and monzonite intruded by syenite dikes. Uranium-lead and ^{40}Ar-^{39}Ar ages from several of the intrusive phases in the complex give dates between 201 and 205 Ma, indicating a Late Triassic age (Bailey and Archibald, 1990; Mortensen et al., 1995; Logan et al., 2007).

Diorite and monzodiorite are the oldest intrusive rocks in the complex (Logan and Mihalynuk, 2005; Rees et al., 2005, 2006) and consist largely of augite and plagioclase with minor K-feldspar in the monzodiorite. Monzonite, the most abundant rock type, consists of augite and lesser biotite, and subequal amounts of plagioclase and K-feldspar. Monzonite can be equigranular or porphyritic and is commonly reddish due to pervasive fine-grained hematite along grain boundaries. The hematite forms a halo around the orebody, and is an alteration common to many alkalic porphyry systems (e.g., Wilson et al., 2003; Holliday and Cooke, 2007). Equigranular monzonite is the principal hostrock to breccia in the Northeast zone and is the most common clast type in that breccia. A distinctive, megacrystic, K-feldspar–phyric monzonite is present as clasts within breccia and also forms dikes or small elongate intrusive bodies outside the breccia bodies where they are spatially associated with most of the mineralized centres (Fraser, 1994b; Fraser et al., 1995; Logan and Mihalynuk, 2005; Logan et al., 2007). The megacrystic K-feldspar–phyric monzonite intrusions are thought to be associated with the hydrothermal system (Logan et al., 2007).

Core Zone (Springer-Bell-Cariboo Deposits)

The Mount Polley mine opened in 1997, with initial mining in the Cariboo and Bell orebodies (Fraser, 1994b; Fraser et al., 1995; Imperial Metals Corporation, 2007). Early work on these mineralized zones identified concentrically zoned alteration assemblages, a central potassic zone, surrounded successively by garnet-epidote and a distal propylitic fringe (Hodgson et al., 1976; Bailey and Hodgson, 1979). Fraser et al. (1995) subsequently showed that the garnet-epidote was spatially restricted and did not form a concentric zone. Within the potassic zone, Cu-Fe sulphides are hosted in hydrothermal breccia and lesser veins (Fraser, 1994a, b; Fraser et al., 1995). Diorite, monzodiorite, and monzonite of the Mount Polley complex are the country rock to the breccia (Figure 3). Megacrystic K-feldspar–porphyry dikes and small elliptical stocks are present in the area (Fraser et al., 1995; Rees et al., 2005).

The Cariboo deposit (Central zone *in* Fraser, 1994a, b) is developed in pink, potassically altered, fractured or brecciated diorite. Calcite, epidote, actinolite and microcline occur as breccia cement, within minor veins and as a replacement style of alteration. This alteration assemblage is more intense in more strongly mineralized rock. Magnetite as a breccia cement and veins is spatially highly variable (Fraser et al., 1995) but correlates with Cu and Au grade (Imperial Metals Corporation, 2007). Chalcopyrite is predominantly disseminated as a cement to the breccia, and less commonly as disseminations or in veinlets that cut the country rock and breccia.

The Bell deposit (Central zone *in* Fraser, 1994a, b), essentially a northward extension of the Cariboo deposit (Figures 2 and 3), is developed in K-feldspar–altered, brecciated monzodiorite and monzonite. Chalcopyrite is present as breccia cement, as well as disseminated and infill to veins. Hypogene bornite, chalcocite, covellite and digenite are also present, indicating that the hydrothermal fluid evolved toward high-sulphidization mineral assemblages (Einaudi et al., 2003). The Cariboo is characterized by a greater abundance of pyrite than the adjoining Cariboo (Imperial Metals Corporation, 2007).

The Springer deposit (West zone *in* Fraser, 1994a, b) is developed in strongly K-feldspar– and albite-altered breccias (Fraser et al., 1995; Imperial Metals Corporation, 2007). Rocks are frequently reddish due to the ubiquitous fine-grained hematite. Chalcopyrite is present as breccia cement, as well as disseminated and infill to veins. Minor bornite and trace quantities of covellite, chalcocite and digenite are also present. Albite veins present outside the breccia cut older K-feldspar and actinolite veins, indicating a late alteration stage.

Hydrothermal breccia in each zone is heterolithic, composed of clasts of diorite and monzonite with minor altered mafic rocks (Fraser, 1994a, b; Fraser et al., 1995). Using the terminology of Davies (2002; Davies et al., 2003), clast organization in the breccias ranges from jigsaw fit with angular clasts (indicative of *in situ* fragmentation and little to no transport) to a chaotic organization with rounded clasts (interpreted to indicate significant transport and milling of clasts). Clast margins locally are partially replaced by actinolite, biotite or albite. Silicate alteration minerals and Cu-Fe sulphide minerals cement the clasts. Actinolite with minor chalcopyrite veins cut the breccia (Fraser, 1994b).

Fraser (1994a, b; Fraser et al., 1995) divided the hydrothermal breccias in the Cariboo-Bell and Springer deposits into four types, based on dominant silicate cement mineralogy: biotite, actinolite, albite and magnetite. Albite-cemented breccia in the Springer is characterized by the presence of tabular albite and lesser biotite, magnetite and sulphides as breccia cement. Clast boundaries are diffuse and albite has extensively replaced the clasts. Biotite- and actinolite-cemented breccia characterize the Cariboo and Bell. The actinolite-cemented breccia dominates the Bell, whereas the biotite-cemented breccia dominates the Cariboo (Figure 3). Fraser et al. (1995) reported that the transition between the two breccia cements is gradational. Actinolite or biotite forms the dominant breccia cement and contains Cu-Fe sulphide minerals in varying amounts. In the actinolite breccia, K-feldspar replaces breccia clast margins and also forms alteration selvages around actinolite-sulphide veins that cut the country rock and breccia. In the biotite-cemented breccia, the clasts are moderately to completely replaced by K-feldspar (Fraser, 1994b). Albite-cemented breccia overprints actinolite-cemented breccia in the northern part of the Bell pit.

Magnetite-cemented breccias are uncommon (Fraser, 1994b). Where present, however, they are commonly associated with elevated Cu concentrations (Imperial Metals Corporation, 2007). Clasts in these breccias are also partially replaced by K-feldspar. Sulphide and sparse pyroxene are also present as breccia cement.

Northeast Zone (Wight Pit)

The Northeast zone (Wight pit) is distinctly higher grade than other Mount Polley deposits and consists of coarser grained Cu-Fe sulphides than the Cariboo, Bell or Springer ores. The average Cu grade in this zone is 0.8–1.0%, which is approximately three times higher than the other zones (Imperial Metals Corporation, 2007).

Copper-iron sulphides in the Wight pit are confined to a dominantly polylithic breccia body (Figure 4) hosted in a distinctly hematite-dusted monzonite (Jackson et al., 2007; Logan et al., 2007; Pass et al., 2007; Imperial Metals Corporation, 2007). The breccia body is irregular in shape and intruded by multiple generations of post-mineral, petrologically related dikes and cut by post-mineral faults. The breccia appears to be divisible into two segments (Figure 4). A northern segment appears to narrow with depth (Pass et al., 2007), where it is extensively intruded by post-breccia barren dikes. A southern segment is fault bounded, forming a discordant wedge between the Green Giant fault, the Brown Wall fault and potentially a fault that cuts the breccia obliquely, separating the southern from the northern end (Figure 4). The breccia consists of jigsaw-fit, rotated and chaotic facies, which reflect increasing degrees of transport during brecciation. Approximately 90% of breccia clasts are equigranular, augite-bearing, monzonite country rock. The breccia also contains clasts of mafic rock and strongly altered material.

Locally, a significant percentage (up to 10% overall but locally greater than 50%) of the breccia is composed of K-feldspar megacrystic monzonite porphyry clasts, many of which have fine-grained margins and globular shapes, im-

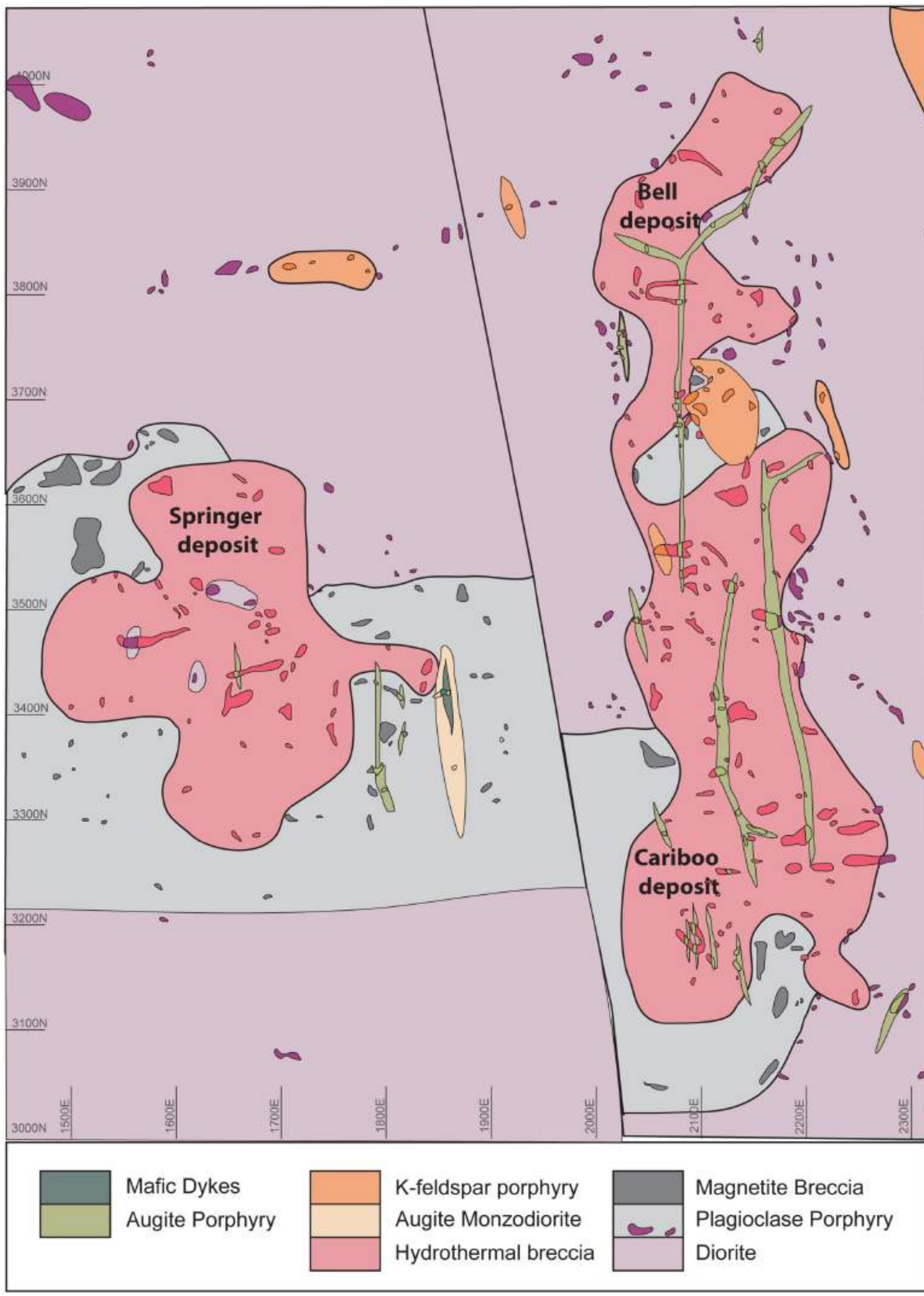

Figure 3. Pre-mining surface geological map of the 'Central and West' zones, now referred to as the Core zone (*modified from* Fraser et al., 1995).

plying they were still hot and able to plastically deform at the time of brecciation (Rees et al., 2006; Jackson et al., 2007). Equigranular to plagioclase-phyric monzonite is the most volumetrically significant intrusive phase of the Mount Polley complex, and is the dominant clast type in the breccia.

Alteration is characterized by reddish K-feldspar, calcite and a marginal zone marked by fine-grained andraditic garnet. Significant hydrothermal magnetite is not present, in contrast to the Cariboo-Bell and Springer zones (Imperial Metals Corporation, 2007). Chalcopyrite occurs as a cement in both jigsaw-fit breccia and in matrix-poor, clast-supported, polylithic chaotic breccia. Bornite accompanies chalcopyrite in the high-grade core of the orebody (Deyell, 2005; Deyell and Tosdal, 2005; Pass et al., 2007), where it commonly rims and locally replaces chalcopyrite, becoming the dominant Cu-Fe sulphide. Pyrite is sparse to absent in the high-grade core but increases towards the outer parts (Imperial Metals Corporation, 2007). A second generation of volumetrically minor Cu-Fe sulphide–bearing veinlets followed intrusion of post-breccia, equigranular, augite-bearing monzonite dikes.

The bulk of sulphide mineral deposition is accompanied by biotite cement and alteration of clasts, with the highest Cu grades found near the contact between biotite-dominant and K-feldspar–dominant assemblages (Jackson et al., 2007; Pass et al., 2007). Magnetite is present at depth beneath the Cu-Fe sulphide minerals but is not associated with higher Cu grades, in contrast to the situation in the Cariboo and Bell pits (Imperial Metals Corporation, 2007). The magnetite at depth is overprinted by a late albite-epidote assemblage. Hematite dusting and carbonate blebs are ubiquitous throughout and around the ore zone. Late quartz-sericite-pyrite and carbonate-pyrite assemblages are localized along fractures, faults and veins (Pass et al., 2007).

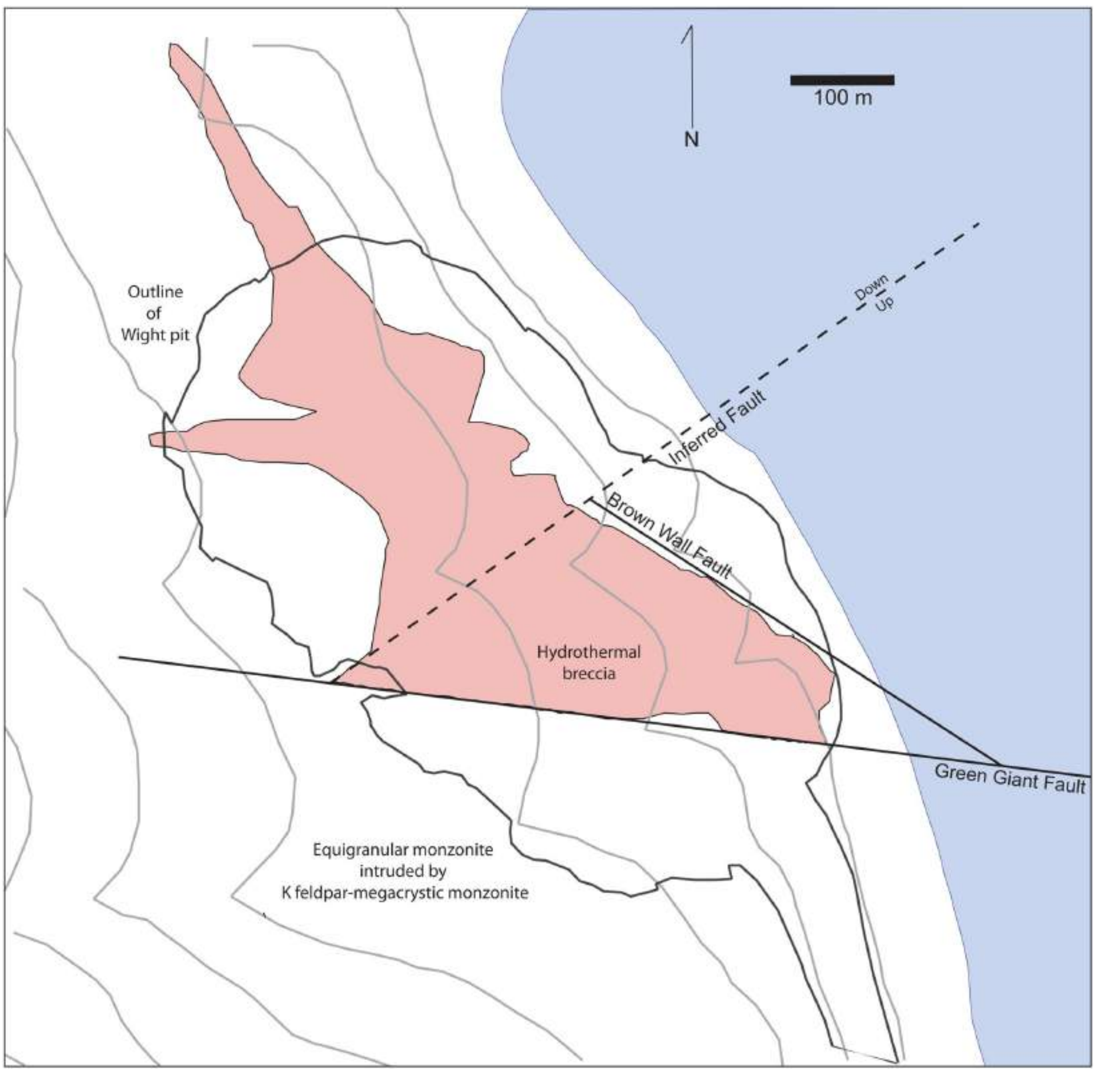

Figure 4. Surface map of Northeast Zone breccia being developed in the Wight pit.

Most of the breccia margins are truncated by post-breccia faults or are exploited by post-breccia dikes, leading to a highly irregular map pattern (Figure 4). Where breccia margins are preserved, there is a gradation from coherent country rock to jigsaw-fit breccia to rotated and chaotic breccias. Preserved breccia margins are rare, so the original volume and geometry of the breccia body is poorly constrained.

Hydrothermal Breccia in Alkalic Porphyry Systems

It is evident that, in the orebodies that have been mined or are being mined at Mount Polley, there is a close relationship between hydrothermal breccia and economic Cu-Fe sulphide minerals (Lang et al., 1995b; Imperial Metals Corporation, 2007). Furthermore, there is also an association between Cu grade and the apparent intensity of brecciation, as the Core zone (Cariboo-Bell-Springer) contains both breccia- and vein-hosted Cu, whereas the higher grade Northeast zone is entirely hosted in breccia (Fraser et al., 1995; Lang et al., 1995; Imperial Metals Corporation, 2007).

Despite the differences in grade and brecciation style, there are similarities between the orebodies at Mount Polley. They all have a high-temperature core consisting of potassic alteration minerals (K-feldspar and biotite) that are typical of most porphyry Cu deposits regardless of composition (Seedorff et al., 2005). Actinolite associated with Cu-Fe sulphide minerals is also common in all the Core zone deposits, although it is rare in the Northeast zone. The presence of actinolite indicates a calcpotassic assemblage in the high-temperature portions of the deposits, a characteristic found in most alkalic porphyry systems worldwide (Lang et al., 1995b; Wilson et al., 2003; Holliday and Cooke, 2007).

The widespread presence of hydrothermal breccia in the ore zones of Mount Polley distinguish this alkalic system from many of the other alkalic porphyry systems in British Columbia. Hydrothermal breccias are reported to be common at Galore Creek (Enns et al., 1995), where they in part host Cu-Au ore but can also lack any significant Cu and Au values (Lang et al., 1995b). Of the many deposits around the Iron Mask batholith, only the DM and Crescent deposits are hosted in significant hydrothermal breccia (Lang et al., 1995b). Hydrothermal breccias are present but reportedly insignificant at Copper Mountain and Mount Milligan (Lang et al., 1995b; Sketchley et al., 1995). It is interesting that, although the tonnage of the various deposits varies considerably, grade correlates with the presence of significant breccia, with Mount Polley and Galore Creek both having generally higher grades than do systems lacking significant breccia (*see* Table 1 *in* Lang et al., 1995b).

Hydrothermal breccia forms where the ambient fluid pressure exceeds the lithostatic load of the overlying rock column coupled with the tensile strength of the surrounding rock (Burnham, 1985). Thus, breccia should form more easily in shallow upper-crustal environments. As such, it is tempting to suggest that Mount Polley represents one of the shallower alkalic porphyry deposits in BC. As an analogy, Zweng and Clark (1995) used fluid inclusions from the breccia-hosted Toquepala porphyry Cu-Mo system (>800 million tonnes) in southern Peru to suggest that it formed at much shallower depths than the nearby vein-dominated Cuajone porphyry Cu-Mo deposit (>1200 million tonnes). Unfortunately, most alkalic porphyry systems in British Columbia lack the appropriate minerals from which depth of formation can be determined, and geological constraints on the scale of post-mineral erosion and deformation of the Triassic and Early Jurassic deposits are limited. These two factors have, to date, precluded the establishment of any independent constraints on the depth of formation of these systems (Lang et al., 1995b).

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