

Geology and supergene processes: Berg copper-molybdenum porphyry, west-central British Columbia

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ABSTRACT

The Berg porphyry Cu-Mo deposit is in the Taitsa Mountain Ranges approximately 84 km southwest of Houston, British Columbia. Mineralization is localized in and adjacent to one of several ca. 50 Ma quartz monzonite intrusions in the area. Two mineralized zones with a mineral resource of 250 million tonnes grading 0.40% Cu and 0.052% MoS₂ (at a 0.25% Cu cutoff) occur in a highly fractured zone superimposed on hornfelsed Hazelton Group volcanic rocks which occur adjacent to a quartz diorite intrusion.

Hydrothermal alteration zones are spatially related to the central quartz monzonite stock and extend up to 1000 m from the intrusive contact. Hypogene alteration types are divided into facies (potassic, phyllic, argillic and propylitic), zones and subzones based on diagnostic mineral assemblages. Copper and molybdenum mineralization occur primarily in potassically altered rocks; the best grades are developed in the altered and hornfelsed volcanic rocks close to the intrusive contact.

Hypogene mineralization is characterized by several generations of veining. Disseminated mineralization is only important in the central part of the stock and in the adjacent quartz diorite where fracture intensities are low. Earliest veins, designated as types 1 and 2, contain much of the copper and molybdenum mineralization. Associated alteration envelopes are either potassic or non existent, implying equilibrium with the potassically altered wall rocks. Later veins (types 3 and 4), are typically poor in sulphides and are associated with phyllic and propylitic alteration assemblages.

A well-developed supergene enrichment blanket is superimposed on hypogene mineralization. Three mineralogically distinct supergene zones are recognized: supergene sulphide (covellite, chalcocite and digenite), supergene oxide (malachite/azurite, cuprite, tenorite and native copper) and leached capping. The presence or absence of these zones is determined by several factors including, fracture intensity, abundance of hypogene sulphides and topography. Topography has the greatest effect on supergene profile development. Three different profiles corresponding to ridge top, slope and valley floor environments are recognized. In the ridge-top environment, the supergene profile is complex, consisting of a strong leached and oxidized zone underlain by a thick but poorly enriched supergene sulphide zone. In the valley floor environment, where the water table is at or close to the surface, leaching is minimal and fresh hypogene minerals occur at surface. The most complex profile is developed on steep slopes, where highly variable water table levels and a high rate of groundwater migration have coupled to produce a strongly enriched supergene sulphide zone overlain by a zone of supergene oxide.

Introduction

The Berg porphyry Cu-Mo deposit is an excellent example of a well-exposed, undeformed calc-alkaline porphyry copper system with many similarities to the classic model proposed by Lowell and

Guilbert (1970). Spatial relationships between rock units and mineralized and altered zones are well documented as a result of many years of exploration and two graduate theses at The University of British Columbia (Panteleyev, 1976; Heberlein, 1985). A PhD dissertation by Panteleyev in 1976 described the geological setting, mineralization and zonation of the porphyry system. This work was published in British Columbia Ministry of Energy, Mines and Petroleum Resources Bulletin 66 (Panteleyev, 1981). A condensed version of Panteleyev's study was also published in The Canadian Institute of Mining and Metallurgy Special Volume 15 titled: Porphyry Deposits of the Canadian Cordillera (Panteleyev, 1976). The reader is referred to these publications for background information about the deposit.

This paper is a summary of new information on the Berg deposit based on the author's M.Sc. thesis at The University of British Columbia (Heberlein, 1985). It focusses on hydrothermal alteration and mineral paragenesis and supergene zonation and genesis.

The Berg deposit is in the Taitsa Ranges of central British Columbia at latitude 53° 49' N and longitude 127° 22' W. It is approximately 84 km southwest of Houston and 585 km north of Vancouver (Fig. 1). Access to the mineralized area during active exploration was by way of a 42 km four-wheel drive road from Twinkle Lake on the Taitsa Lake Forest Service Road. The old access road crosses the north flank of Sibola Peak and follows Kid-price Creek south and west to a 1740 m high pass at its headwaters. Berg camp is located on a tributary to the north fork of Bergeland Creek, about 6 km northwest of the pass at an elevation of 1555 m. The route is free of snow between late June and October. At other times of the year, the property is reached by helicopter from Houston.

Mineralized zones at Berg underlie a cirque-like bowl on the east flank of a glaciated valley draining northwest into Bergeland Creek. The cirque is divided into two tertiary drainages, called Pump Creek and Red Creek, by a prominent southwest-trending ridge. The deposit is easily recognized by virtue of its large and prominent gossan.

History

The Taitsa Ranges were first prospected in the early 1900s after gold was discovered near Sibola Mountain. Prior to the late 1920s, several lead-zinc-silver, gold-tungsten and copper showings had been staked. In 1948, the Lead Empire Syndicate restaked claims originally located by Cominco Ltd. in 1929 over several lead-zinc occurrences. These are now recognized as part of the Berg porphyry system. The potential for porphyry copper style mineralization at Berg was first understood by Kennco Explorations (Western) Ltd. who recognized the prominent gossan and associated stream sediment anomaly (Stewart, 1967; Panteleyev, 1976, 1981). Kennco started an exploration program in 1968 that eventually discovered an

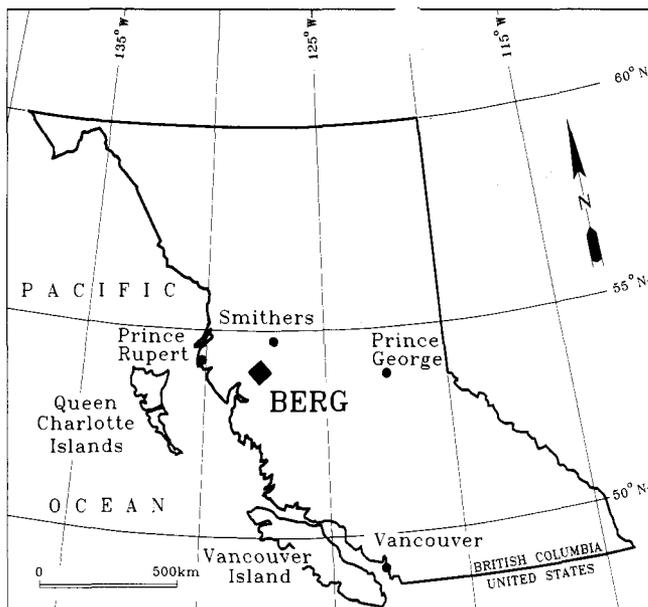


FIGURE 1. Location map.

extensive supergene enrichment blanket over hypogene chalcopyrite and molybdenite mineralization. Canex Placer Limited optioned the property in 1972 and by 1980 a total of 93 diamond drill holes totalling 16 907.8 m had been completed and a geological resource of 250 million tonnes of 0.40% Cu and 0.052% MoS₂ (at a 0.25% Cu cutoff) outlined. Since 1982, the only activity on the project was the computerization of the drilling data base by Placer Dome Inc. in 1992.

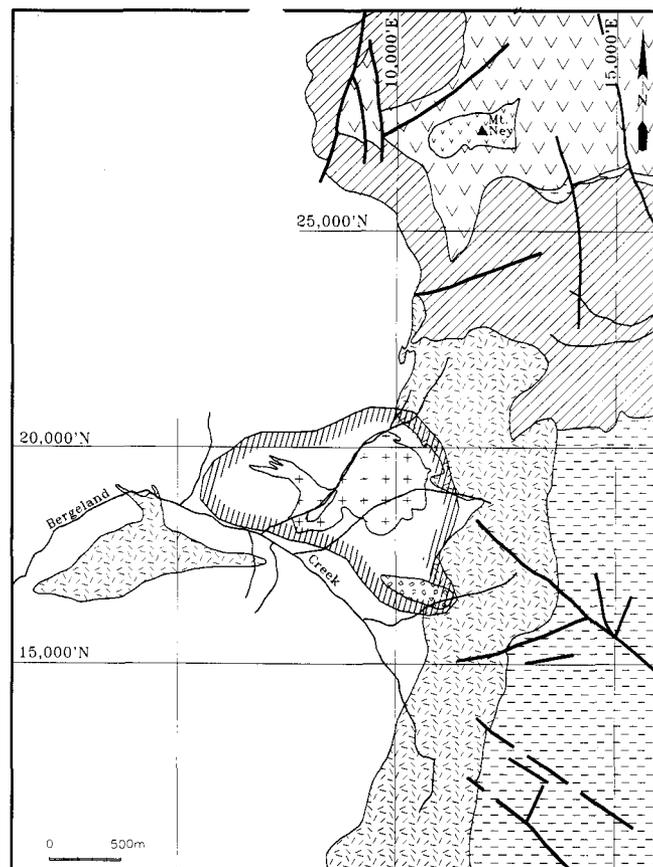
Regional Geology

Berg is centred on one of several Early to Middle Eocene (52 Ma to 47 Ma; Panteleyev, 1981) composite quartz monzonite stocks that intrude Middle Jurassic Hazelton Group and Lower Cretaceous Skeena Group rocks in the area (Carter, 1974, 1981; Woodsworth, 1979, 1980; Panteleyev, 1981). Hazelton Group rocks are well exposed west of the Berg stock (Fig. 2). They consist of a sequence of green, grey, red and maroon lithic tuffs, tuff breccias and flows of andesitic composition. Skeena Group rocks overlie the Hazelton Group and are exposed mainly east of the property. Amygdaloidal and vesicular andesites and basalts make up the lower part of the Skeena Group succession. Many of the flows exhibit trachytic textures that distinguish them from the underlying Hazelton Group. Sandstones, siltstones and conglomerates comprise the upper part of the succession.

The contact between the Skeena Group and the Hazelton Group is not exposed in the property area as it is everywhere intruded by quartz diorite. An exposure of the contact on a cliff face north of the property is strongly epidotized and rocks on both sides are hydrothermally altered (Panteleyev, 1981).

Kasalka Group (MacIntyre, 1978) rocks unconformably overlie the Skeena Group north of the property. Best exposures occur at Mount Ney, 6 km north of the Berg stock. Here the succession consists of a basal conglomerate member that has a distinctive red to maroon colour. Overlying the conglomerate is a predominantly volcanic sequence of white, grey and pale green rhyolite and dacite flows and flow breccias with interbedded crystal and crystal vitric tuff.

Structure of the region is simple. Poorly developed open folds with north to northeast axial trends cause local dips of 10° to 30°. Fractures and Miocene basalt dikes parallel this structural trend that may have also acted as the principal structural control for the emplacement of intrusions in the area. This relationship is supported by the pronounced elongation of the quartz diorite intrusion (Fig. 2).



LEGEND

EOCENE	
Intrusive Rocks	
	Berg stock - quartz monzonite porphyry
	Intrusive breccia
	Quartz diorite
MIDDLE TO UPPER CRETACEOUS	
Kasalka Group	
	Rhyolite, rhyodacite, rhyolite breccia
	Maroon andesite, latite, lahar and tuff
LOWER CRETACEOUS	
Skeena Group	
	Sandstone, siltstone, shale
	Purple to green basalt, andesite and breccia
MIDDLE JURASSIC	
Hazelton Group	
	Grey, green and maroon andesite flows and tuffs, minor dacite and sedimentary rock
	Limit of hydrothermal alteration
	Fault

FIGURE 2. Regional geology of the Berg area (modified from Panteleyev, 1981).

Property Geology

Two main intrusive bodies are exposed in the property area. The largest consists of a north-trending, elongate body of quartz diorite that intrudes the contact between Hazelton Group and Skeena Group east of the mineralized area. The intrusion extends from about 750 m north of the Berg stock to over 6.5 km to the south. It ranges in width from 600 m on the property area to over 2 km

Hornblende, biotite and opaque minerals also occur in the groundmass.

A breccia pipe intrudes quartz diorite and hornfelsed Hazelton Group volcanic rocks 750 m south of the Berg stock. The breccia body is elliptical in shape, with approximate dimensions of 580 m by 175 m and a northeast elongation. It consists of highly milled fragments of quartz monzonite, diorite, andesite and siltstone in a matrix of finely comminuted rock material. The presence of altered and mineralized clasts suggests that the breccia postdates at least one episode of mineralization.

Hydrothermal Alteration

There have been several articles describing the distribution of hydrothermal alteration zones at Berg. For additional information, the reader is referred to Panteleyev (1976, 1981), Heberlein and Godwin (1984) and Heberlein (1985).

Alteration facies at Berg are well described by the terms potassic, phyllic, argillic and propylitic, as used by Lowell and Guilbert (1970) and Rose (1970). At Berg these facies are further subdivided on the basis of consistent and mappable mineral assemblages, each named after its dominant mineral component.

Alteration can be identified up to 1 km from the Berg stock but it is best developed immediately adjacent to the intrusion. In plan view (Fig. 3), the zonal arrangement of alteration facies can be seen. Central zones are potassic and are subdivided into the Orthoclase zone (Zone I), the Orthoclase-Biotite zone (Zone II) and the Biotite zone (Zone III). Zones I and II occur principally in the intrusion, while Zone III is confined mainly to the hornfelsed Hazelton Group volcanic rocks and in the quartz diorite intrusion. Phyllic alteration (Zone IV) is restricted to an arcuate zone straddling the southern contact of the Berg stock. A broad halo of propylitic alteration (Zone V) extends about 500 m to 1000 m from the intrusive contact.

Argillic alteration overprints the potassic and phyllic alteration close to the intrusive contacts. It is characterized by pervasive replacement of primary feldspars by chalky kaolinite and montmorillonite. The close spatial association of argillization with strongly pyritic zones and areas of high fracture density suggest that much of it may be of supergene origin. As such, it will not be considered further in this paper. A brief petrographic description of each alteration zone is presented below. The alteration zones are summarized in Table 1 and shown in cross section in Figure 4.

Orthoclase Zone (I)

Pervasive orthoclase alteration in Zone I is restricted to the QMP phase of the Berg stock. It has a distinctive orange-pink colour resulting from the fine-grained replacement of groundmass minerals by a mosaic of secondary orthoclase, quartz and sericite. Secondary orthoclase also occurs as overgrowths on pre-existing feldspar and rarely biotite phenocrysts in envelopes marginal to quartz veinlets.

TABLE 1. Alteration facies, zones and subzones at the Berg deposit

Facies	Zone ⁽¹⁾	Subzone	Mineralogy ⁽²⁾
Potassic	Orthoclase (I) Orthoclase-Biotite (II) Biotite (III)	Biotite-Anhydrite Biotite	Orth, Qtz, Ser, Bio, Mag, Cpy, Py, Mo Orth, Qtz, Bio, Anh, Ser, Mag, Py, Cpy Bio, Qtz, Anh, Py, Cpy, Mo, Tpz, Fl Bio, Qtz, Ser, Cpy, Py, Mo
Phyllic	Quartz-Sericite (IV)		Ser, Qtz, Py, Hem, Kaol, Mm
Propylitic	Transition (V)	Biotite-Chlorite	Bio, Qtz, Chl, Py, Cpy, Calc
Propylitic	Chlorite-Epidote		Chl, Ep, Ab, Calc, Qtz, Py, Mag, Sph, Gln
Argillic ⁽³⁾	Kaolinite		Qtz, Kaol, Mm, Py

⁽¹⁾ Roman numerals refer to alteration zones in Figures 3 and 4.

⁽²⁾ Minerals are in order of abundance and are coded as follows: Ab=albite, Anh=anhydrite, Bio=biotite, Calc=calcite, Chl=chlorite, Cpy=Chalcopyrite, Ep=epidote, Fl=fluorite, Gln=Galena, Hem=Hematite, Kaol=Kaolinite, Mag=magnetite, Mm=montmorillonite, Ser=sericite, Mo=molybdenite, Orth=orthoclase, Py=pyrite, Qtz=quartz, Sph=sphalerite, Tz=topaz.

⁽³⁾ The argillic zone is interpreted to be supergene in origin.

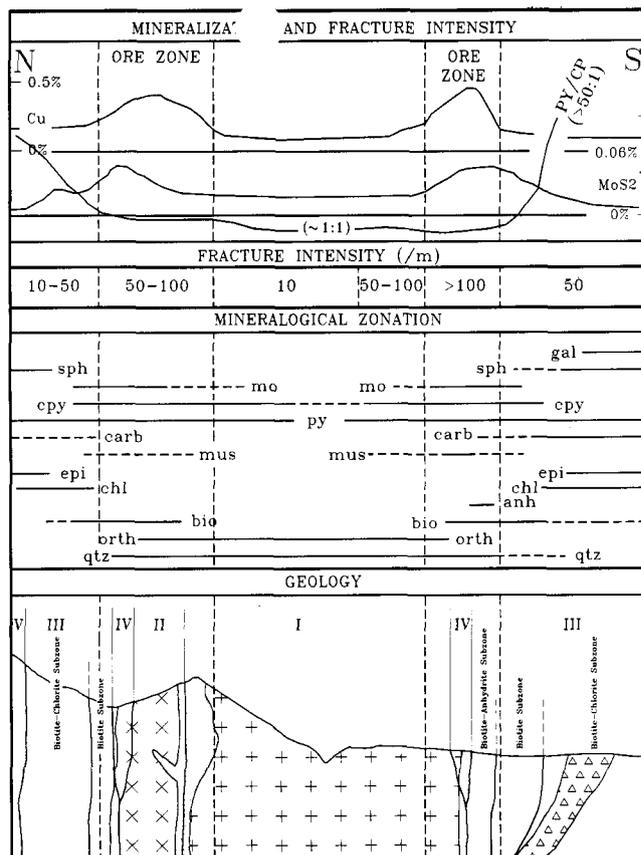


FIGURE 4. Cross section of Berg (Fig. 3; A-A') showing rock units, alteration zones, fracture intensity and mineral zoning.

Plagioclase crystals tend to be clouded by fine-grained sericite. Hornblende and primary biotite crystals are replaced by felted masses of secondary biotite. Anhydrite is common throughout Zone I. It occurs as pink to purple aggregates of euhedral crystals in the groundmass, as veinlets, and as vuggy cavity fillings in early quartz veins. Sulphides are scarce in this zone; they typically average about 1% with chalcopyrite the dominant type. Secondary magnetite, ilmenite and rutile occur as fine-grained opaque minerals throughout the groundmass.

Orthoclase-Biotite Zone (II)

This type of alteration is best developed in the PBQP phase of the Berg stock, although similar alteration is found very locally in the QMP. It is characterized by flooding of the groundmass with fine-grained secondary biotite resulting in an overall brown hue.

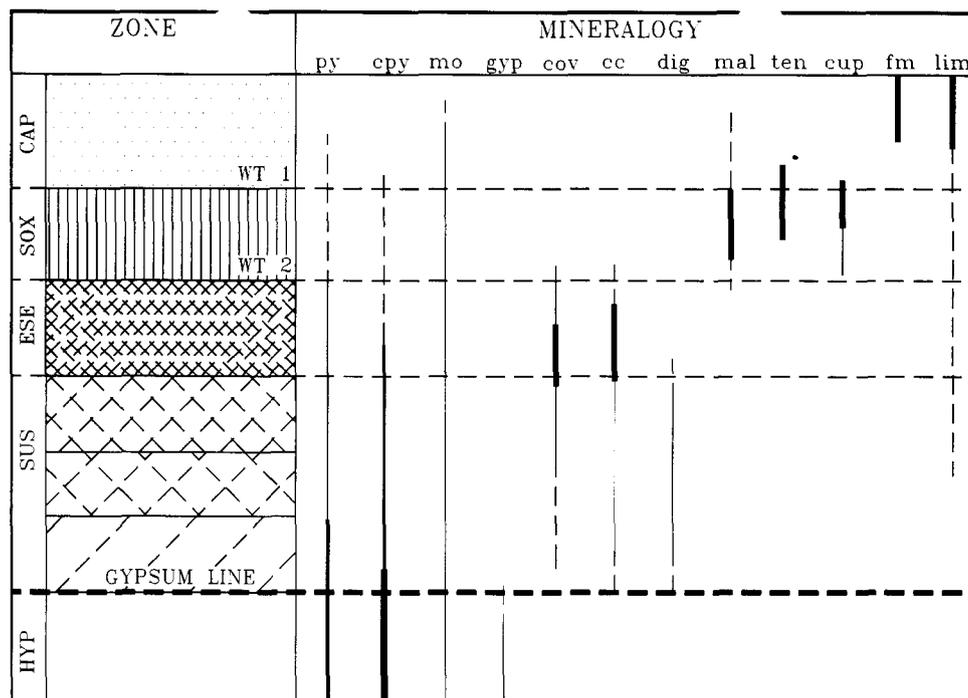


FIGURE 5. A schematic profile for the Berg deposit illustrating the vertical distribution of primary and secondary minerals. Abbreviations are as follows: CAP - leached cap; SOX - Supergene Oxide zone; ESE - Enhanced Supergene zone; WT - watertable; py - pyrite; cpy - chalcopyrite; mo - molybdenite; gyp - gypsum; cov - covellite; cc - chalcocite; dig - digenite; mal - malachite; ten - tenorite; cup - cuprite; fm - ferrimolybdate; lim - limonite.

tact. Alteration envelopes are generally absent or thin, but where present consist of sericite.

Type 3a veins are very different from types 1 and 2 in that chalcopyrite is rare and molybdenite absent. They consist of grey to white quartz and contain streaks and disseminations of pyrite. Pyrite is also abundant in wide sericitic envelopes that are typical of this vein type. Where densest, at the intrusive contacts, envelopes overlap and completely destroy pre-existing structures, textures and mineralogies. They decrease in density with depth and laterally from the intrusion.

Type 3b veins contain much chlorite and carbonate. These veins occur throughout the deposit but become more abundant away from the intrusion, in the biotite-chlorite subzone and propylitic zone. They are characterized by chlorite and carbonate (usually calcite) and varying combinations of pyrite, sphalerite and galena. In some instances, black sphalerite is a conspicuous component. Vein mineralogy is partly a function of wallrock composition; chlorite and carbonate occur where veins cut biotite-rich wallrocks. Sericitic occurs where intrusive rocks are the host.

Youngest veins are represented by gypsum filled fractures. They are post ore in origin and may reflect a supergene process. They are typically sub horizontal in attitude and rarely greater than 2 mm in width. Coarser grained, fibrous gypsum veins up to 30 mm in width are also common in the intrusion; these probably formed by reaction of hypogene anhydrite bearing veins with groundwater.

Supergene Enrichment

Berg is atypical of Canadian Cordilleran porphyry deposits in that it has a well-developed supergene enrichment blanket (Stewart, 1967; Panteleyev, 1981). The largest, most intensely developed or best preserved examples currently known in the Canadian Cordillera, including the Berg deposit, were described briefly in Ney et al. (1976). The supergene mineralization discovered recently at the Kemess deposit is described elsewhere in this volume. This sheet-like zone of secondary mineralization varies from 15 m to over 100 m in thickness and is covered by an extensive leached capping. Maximum depth of leaching recorded in drill holes is about 22 m. The thick-

TABLE 2. Vein and alteration envelope mineralogy

Vein type ⁽¹⁾	Mineralogy ⁽²⁾	Envelope mineralogy ⁽²⁾	Origin
1a	Qtz, Anh	Qtz, Ser, Orth, Bio	Magmatic
1b(1)	Qtz, Py, Cpy, Mo, (Anh)	Qtz, Bio, Ser, (Chl, Orth)	Magmatic
1b(2)	Qtz, Py, Cpy, Mo, Anh	None	Magmatic
2a(1)	Qtz, Mo	Ser	Magmatic
2a(2)	Anh, Mo	None	Magmatic
2a(3)	Mo	None	Magmatic
3a(1)	Qtz, Py, Mag, Calc, Chl	Qtz, Ser	Meteoric
3a(2)	Qtz, Py (Cpy)	(Ser)	Meteoric
3b(1)	Qtz, Chl, Calc, Sph (Ser, Gyp)	Ser	Meteoric
3b(2)	Qtz, Chl, Calc, Sph (Ser, Py)	None	Meteoric
3b(3)	Py, Chl, Calc, Sph, (Ser)	Chl	Meteoric
3b(4)	Qtz, Calc	Ser	Meteoric
4a	Gyp	None	Meteoric

⁽¹⁾ Vein types, defined in text, are in order of relative age (type 1 is the oldest). Numbers in parentheses define subdivisions of general vein types.

⁽²⁾ Minerals listed in order of abundance on a volume per cent basis, are coded: Anh = anhydrite, Calc = calcite, Chl = chlorite, Cpy = chalcopyrite, Gyp = gypsum, Mag = magnetite, Mo = molybdenite, Ser = sericite, Orth = orthoclase, Py = pyrite, Qtz = quartz, Sph = sphalerite.

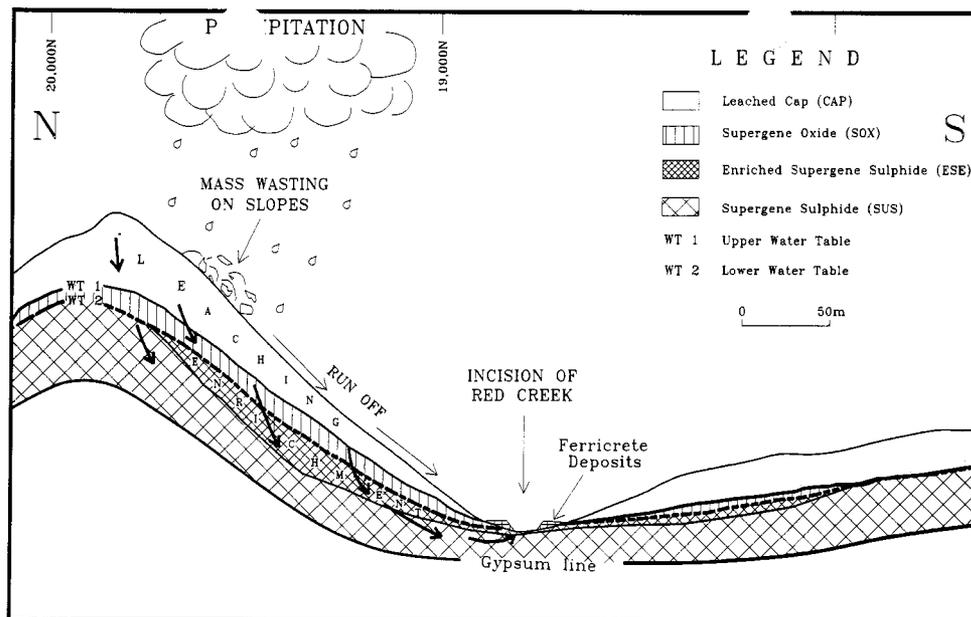


FIGURE 7. A schematic cross section illustrating the relationship between supergene zones, water table (WT), gypsum line and topography. Arrows indicate the probable path of migrating groundwater as it travels from hill top to valley floor.

of groundwater to react with hypogene sulphide minerals in the zone of oxidation is controlled by several key factors (Anderson, 1982; Emmons, 1917; Sato, 1960; Blanchard, 1968). Most important is fracture permeability, which controls the movement of air and surface water. The abundance of sulphide minerals, particularly along fractures, is also critical for the development of mineralization. Important too, is the rate of removal by flushing of oxidation products that otherwise would shield sulphide grains from further oxidation. Other factors that influence the rate of reaction are reactivity of the wall rocks, temperature, depth to water table and climate.

At Berg, three of these factors can be considered to be constant. Wall rock reactivity is low because the dominant gangue minerals are quartz and feldspar. Fracture intensity, although difficult to quantify in the near surface environment, is generally high (i.e. > 50 fractures per metre of drill core). Groundwater temperature (and hence reactivity) is assumed to remain constant throughout the summer season when leaching is active.

Bearing in mind the controls on leaching outlined above, conclusions about the oxidation and leaching potential of groundwaters for each topographic environment can be made. In the ridge-top environment, partial oxidation of primary sulphides in the leached capping can be explained by rapid migration of groundwaters (thick arrows, Fig. 7) away from the ridge crest. This leaves all but the smallest fractures air-filled for much of the time. Hypogene sulphides oxidize slowly under these conditions and build up a protective mantle of oxidation products that further retard reaction. Thick oxide mantles are observed on most sulphide grains at ridge top localities. Periodic recharge of the oxidation zone (by rain storms) accelerates oxidation by leaching the soluble oxidation products and exposing fresh surfaces for oxidation. Poor copper enrichment in the ridge-top environment is explained by downhill migration of copper in solution (solid arrows, Fig. 7).

Limonite fractures and intense leaching in the hillside environment suggest that the oxidizing zone is being continually flushed by acidic groundwaters derived from uphill. Here, fractures are wet much of the time and dilution of groundwaters by rainfall is minimal, since most is removed by surface runoff. The shallow depth to the water table observed in hole DH078 implies that mechanical erosion is keeping pace with the downward migration of the water table. Supergene oxide overprinting (vertical hatching), indicates that the water table level fluctuates (perhaps season-

ally). When low, the top of the supergene sulphide zone is re-exposed to oxidizing conditions and a transition from a sulphide to an oxide mineralogy occurs. This process causes more copper to be removed and transported downward to the water table where it is redeposited as secondary sulphide minerals in an "enhanced supergene sulphide" zone (dense cross hatching, Figs. 6 and 7).

Coexistence of supergene sulphide and hypogene minerals at the surface in the valley floor is the result of the water table lying close to surface. This is supported by the presence of seeps and springs, which actively precipitate oxide and sulphate minerals in the drainages. Below the surface (and water table), supergene sulphide minerals are deposited onto fresh hypogene sulphides. Development of a strongly enriched zone is prevented by the rapid removal of the supergene sulphide zone by mechanical erosion of the valley floor.

Discussion and Conclusions

A combination of hypogene and supergene processes have contributed to the formation of the mineralized zones at Berg. Prior to the emplacement of the Berg stock, a brittle biotite hornfels was developed at the contacts of the quartz diorite intrusion. Intrusion of the Berg stock into hornfelsed Hazelton Group volcanic rocks and differentiation of the crystallizing hydrous quartz monzonite magma (cf. Burnham, 1979) was accompanied by extensive fracturing above and peripheral to the solidus boundary of the magma body. Magmatic hydrothermal fluids, evolved from the crystallizing magma permeated the fractured wall rocks and reacted extensively with them as they migrated away from the heat source. Periodic sealing of fractures by precipitation of sulphides and gangue minerals caused internal pressure build-ups. These eventually resulted in failure and refracturing of the confining rocks. Sudden release of pressure during these events caused adiabatic cooling of the magma and rapid crystallization. Crystallization was accompanied by the differentiation of more magmatic fluid which was driven away from the intrusion through the newly formed fractures. Multiple episodes of veining close to the intrusive contact reflect this process.

Reaction of K-rich magmatic fluids with the wall rocks resulted in potassic alteration. Within the intrusion, secondary orthoclase was formed by K⁺ substitution for Na⁺ and Ca²⁺ in plagioclase