# GEOLOGY AND MINERALIZATION IN THE NORTHERN PART OF THE IRON MASK BATHOLITH, KAMLOOPS, BRITISH COLUMBIA (92I/9, 10)

**Clifford R. Stanley, James R. Lang and Lori D. Snyder,**
**Mineral Deposit Research Unit, U.B.C**

*(MDRU Contribution # 037)*

*KEYWORDS:* Economic geology, porphyry, copper, gold, alkalic, Nicola volcanics, Pothook diorite, Sugarloaf diorite, Cherry Creek monzonite, Iron Mask, Quesnellia, hydrothermal alteration.

## INTRODUCTION

The Iron Mask batholith is an earliest Jurassic (207±3 Ma; Ghosh 1993), composite alkalic intrusion located approximately 10 kilometres southwest of Kamloops, British Columbia (Figure 1). It lies in the southern part of the Quesnel Terrane, a volcanic arc that lay somewhere offshore of North America during the Late Triassic (Souther, 1992). The batholith is an elongate, northwest-trending body approximately 22 kilometres long and 5 kilometres wide, and intrudes volcanic and sedimentary rocks of the Upper Triassic Nicola Group (Preto, 1968). The batholith is exposed in the Iron Mask pluton to the southeast and in the smaller Cherry Creek pluton to the northwest which are separated by a graben of down-faulted Eocene Kamloops Group volcanic and sedimentary rocks (Kwong, 1987).

The Iron Mask batholith is host to a number of alkalic porphyry copper-gold deposits. These include the Afton, Crescent, Pothook, Ajax East, Ajax West and Iron Mask deposits, all of which have been mined, and the Galaxy, Big Onion, DM and Python zones, all of which have published reserve figures (Kwong, 1987). With the exception of the Iron Mask underground mine, production in the district occurred between 1977 through 1991.

Previous authors (Preto, 1968; Northcote, 1974, 1976, 1977) have identified five principal intrusive units that form the Iron Mask batholith. Their interpretation of age relationships among the units was, from oldest to youngest, Iron Mask hybrid, Pothook diorite, serpentinized picrite, Sugarloaf diorite, and Cherry Creek diorite-

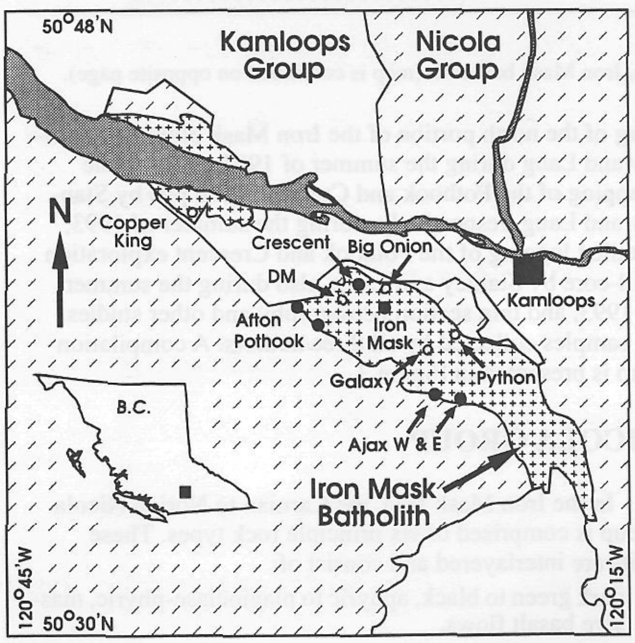



Figure 1. Generalized geological map of the Iron Mask batholith, showing locations of the principle mineral deposits (simplified from Kwong, 1977).

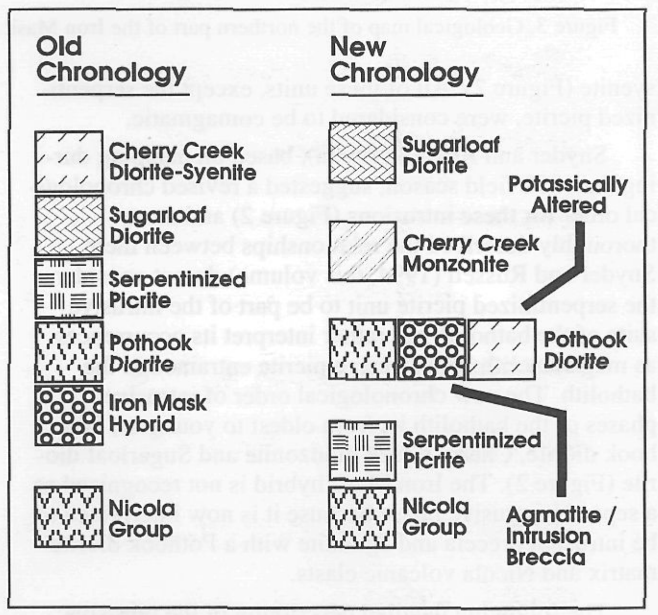



Figure 2. Chronology of the old and new interpretations of the volcanic and intrusive history of the Iron Mask batholith.

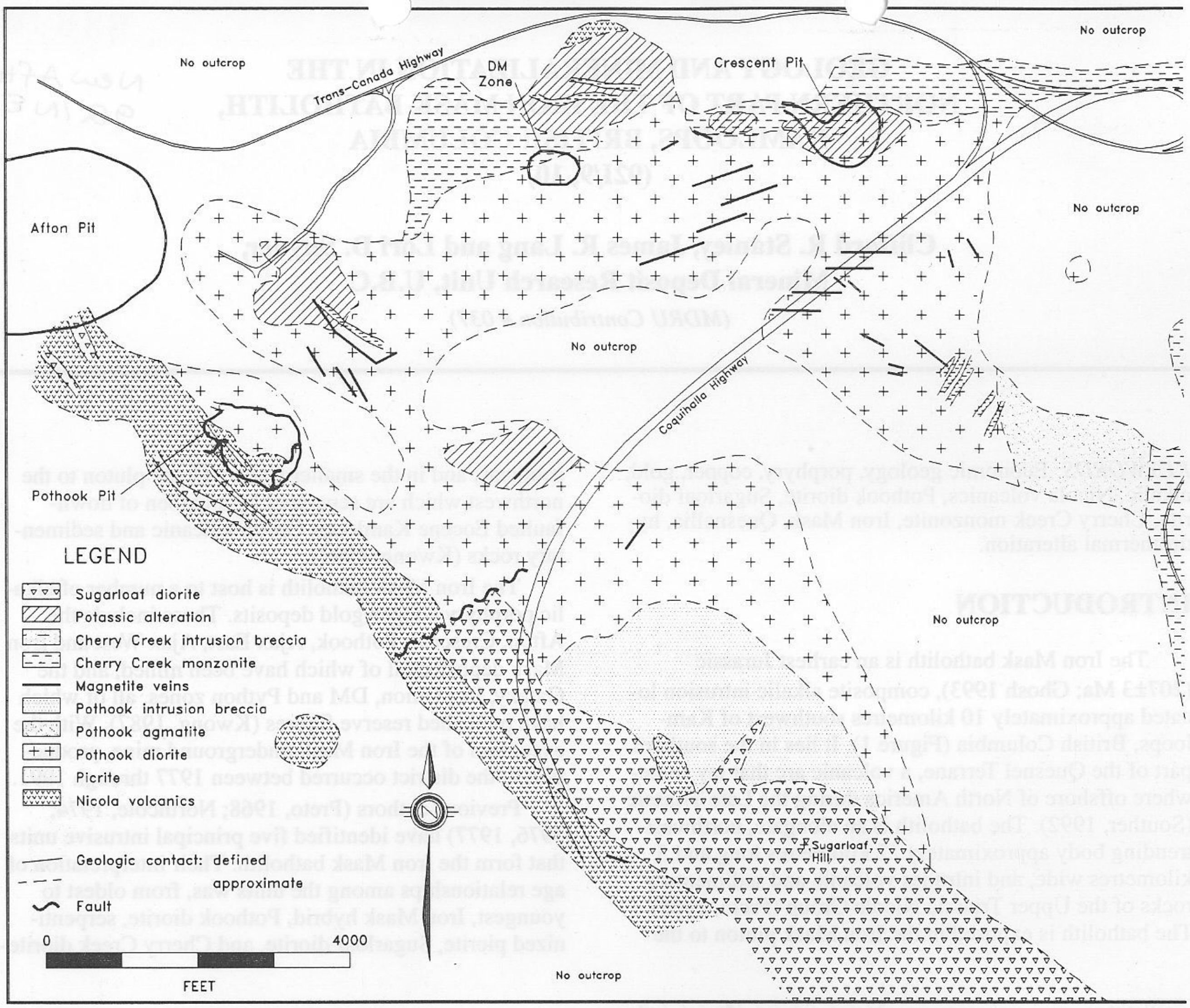



Figure 3. Geological map of the northern part of the Iron Mask pluton, Iron Mask batholith (map is continued on opposite page).

syenite (Figure 2). All of these units, except the serpentinized picrite, were considered to be comagmatic.

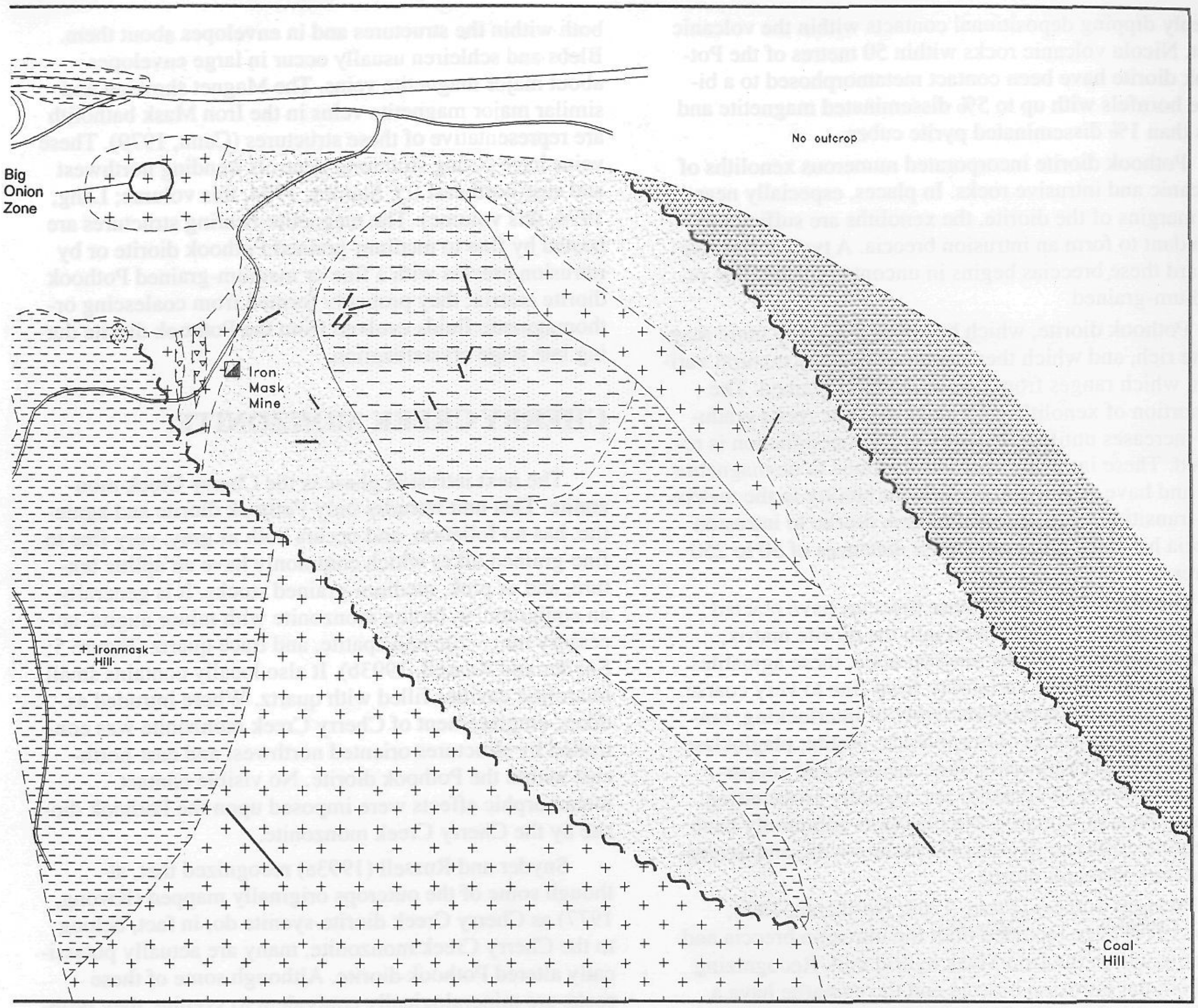
Snyder and Russell (1993a), based on mapping during the 1992 field season, suggested a revised chronological order for these intrusions (Figure 2) and more thoroughly described the relationships between them. Snyder and Russell (1994, this volume) do not consider the serpentinized picrite unit to be part of the intrusive suite of the batholith but rather interpret its occurrences as megaxenoliths of extrusive picrite entrained in the batholith. The new chronological order of intrusive phases of the batholith is, from oldest to youngest, Pothook diorite, Cherry Creek monzonite and Sugarloaf diorite (Figure 2). The Iron Mask hybrid is not recognized as a separate intrusive phase because it is now interpreted to be intrusion breccia and agmatite with a Pothook diorite matrix and Nicola volcanic clasts.

The following detailed description of the intrusive and volcanic units in and around the Iron Mask batholith is based on: 1:20 000-scale mapping of the batholith by Snyder during the summer of 1992, 1:2400-scale mapping of the north portion of the Iron Mask pluton by Stanley and Lang during the summer of 1993, 1:600-scale mapping of the Pothook and Crescent open pits by Stanley and Lang, respectively, during the summer of 1993, detailed logging of the Pothook and Crescent exploration drill-core by Stanley and Lang, also during the summer of 1993, and thin section petrography and other studies on samples collected by all three authors. A compilation map is presented in Figure 3.

## NICOLA GROUP

In the Iron Mask area, the Carnian to Norian Nicola group is comprised of six principle rock types. These units are interlayered and consist of:

- dark green to black, aphyric to plagioclase-phyric, massive basalt flows,
- maroon to dark grey, aphyric to sparsely plagioclase or augite-phyric, poorly bedded, ash to lapilli mafic tuffs and lesser blocky agglomerates,
- black, augite-phyric, massive basalt flows,



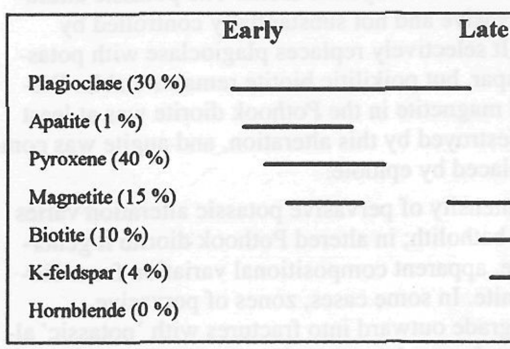




Figure 4. Igneous mineral paragenesis of the Pothook diorite.

- dark grey, crowded plagioclase-phyric andesite flows and feeder dikes,
- light green, well-bedded and sorted, ash to lapilli, andesite to dacite tuffs, and
- reddish, fine-grained, hematitic, poorly bedded to massive cherts up to 1 metre thick, and

Picritic basalts with olivine and clinopyroxene phenocrysts outcrop near the top of the Nicola succession (Snyder and Russell, 1993b). Outside the batholith picrites are relatively fresh, are not serpentinized, and have cumulate and fragmental textures. Within the batholith, picrite occurs as large serpentinized ultramafic screens. A more detailed description of this unit is presented in Snyder and Russell (1994, this volume).

## POTHOOK DIORITE

Snyder and Russell (1993a) consider the Pothook diorite to be the oldest intrusive phase of the Iron Mask batholith. It is predominantly an equigranular, slightly foliated, plagioclase augite diorite with late poikilitic biotite which encloses both plagioclase and augite inclusions. Up to 15% disseminated magnetite, accessory potassium feldspar, and minor disseminated apatite and titanite are also present (Figure 4). Toward the centre of the batholith, Pothook diorite is medium grained, near the margins of the intrusion it is fine to medium grained, and at intrusive contacts with Nicola Group it is chilled. Apophyses of Pothook diorite also intrude along faults and steeply dipping depositional contacts within the volcanic host. Nicola volcanic rocks within 50 metres of the Pothook diorite have been contact metamorphosed to a biotite hornfels with up to 5% disseminated magnetite and less than 1% disseminated pyrite cubes.

Pothook diorite incorporated numerous xenoliths of volcanic and intrusive rocks. In places, especially near the margins of the diorite, the xenoliths are sufficiently abundant to form an intrusion breccia. A typical traverse toward these breccias begins in uncontaminated, fine or medium-grained

Pothook diorite, which becomes gradually more magnetite rich, and which then acquires a patchy textural variation which ranges from fine to medium grained. The proportion of xenoliths of Nicola volcanic rocks gradually increases until an intrusion breccia designation is required. These intrusion breccias continue to be magnetite rich and have significant textural variability in the matrix. The transition from normal Pothook diorite to intrusion breccia has been observed across distances of 50 to 250 metres.

The clasts in some of these breccias have reacted with and partially assimilated into the diorite matrix, forming agmatite. On the outcrop scale, these agmatites exhibit great textural variability from fine to very coarse grained, and consist predominantly of interlocking, randomly oriented grains of hornblende, biotite, plagioclase and magnetite. Commonly, fine, medium and coarse-grained varieties of agmatite are mutually crosscutting. Within zones of agmatite, Nicola clasts commonly have undergone different degrees of reaction with, and assimilation into, Pothook diorite.

Previous authors (Preto, 1968; Northcote, 1974, 1976, 1977) have included both the intrusion breccia and agmatite within the Iron Mask hybrid unit. Recognizing that both the intrusion breccia and the agmatite have a matrix consisting of Pothook diorite, the Iron Mask hybrid and Pothook diorite units are now thought to be coeval, and are here considered two different facies of a single intrusive phase.

The Pothook diorite contains abundant magnetite-apatite-actinolite veins, blebs, schleiren and breccias. These structures occur at millimetre to metre scales and may contain epidote, chlorite, pyrite and chalcopyrite,

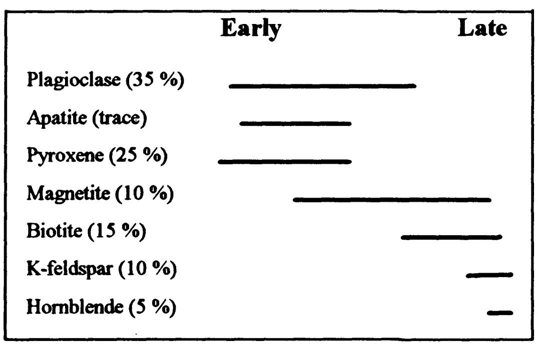



Figure 5. Igneous mineral paragenesis of the Cherry Creek monzonite.

both within the structures and in envelopes about them. Blebs and schleiren usually occur in large envelopes about major magnetite veins. The Magnet showing and similar major magnetite veins in the Iron Mask batholith are representative of these structures (Cann, 1979). These veins have strong structural controls trending northwest and east-northeast (*cf.* Stanley, 1994, this volume; Lang, 1994, this volume). The magnetite-bearing structures are hosted by fine to medium-grained Pothook diorite or by intrusion breccia with a fine or medium-grained Pothook diorite matrix; they probably formed from coalescing orthomagmatic fluids evolved from the Pothook diorite during late stage crystallization.

## CHERRY CREEK MONZONITE

The next intrusive phase is the Cherry Creek monzonite. This unit intrudes only Pothook diorite and agmatite, has no foliation, and occurs both as grey, very fine to fine-grained dikes which commonly have an aplitic texture, and as pink, medium-grained stocks. It is generally an equigranular, biotite monzonite with minor augite, accessory magnetite and apatite, and trace quartz (Figure 5; Snyder and Russell, 1993b). It also locally contains small miarolitic cavities filled with quartz. Where intruded as dikes, emplacement of Cherry Creek monzonite was controlled by structures oriented northwest and east-northeast within the Pothook diorite. No visible contact metamorphic effects were imposed upon the Pothook diorite by the Cherry Creek monzonite.

Snyder and Russell (1993a) recognized that, although some of the outcrops originally mapped (Kwong, 1977) as Cherry Creek diorite-syenite do, in fact, belong to the Cherry Creek monzonite, many are actually potassically altered Pothook diorite. Although some of these rocks are mineralogically equivalent to syenite, they probably never existed as syenite melts. The potassic alteration is pervasive and not substantially controlled by fractures. It selectively replaces plagioclase with potassium feldspar, but poikilitic biotite remains stable. Disseminated magnetite in the Pothook diorite was at least partially destroyed by this alteration, and augite was commonly replaced by epidote.

The intensity of pervasive potassic alteration varies across the batholith; in altered Pothook diorite it generates a wide, apparent compositional variation from diorite to syenite. In some cases, zones of pervasive alteration grade outward into fractures with 'potassic' alteration envelopes, demonstrating that locally the outer parts of these alteration zones formed from coalescing alteration envelopes. In other cases, fracture-controlled potassium metasomatism is a later, separate event (Lang, 1994, this volume).

Pervasive potassium metasomatism is spatially associated with the contacts between true Cherry Creek monzonite and Pothook diorite, and often obscures their precise locations. Whereas the margins of Cherry Creek monzonite intrusions tend to be strongly altered, the cores of the intrusions remain relatively fresh. Therefore, this pervasive alteration style is thought to result from deuteric reaction of orthomagmatic fluids emanating from the Cherry Creek monzonite during the later stages of crystallization. This redefinition of the Cherry Creek unit indicates that it is substantially over-represented in previous maps of the batholith; Pothook diorite affected by pervasive potassium metasomatism should be considered an alteration facies of the Pothook diorite unit.

## SUGARLOAF DIORITE

The youngest intrusive phase of the Iron Mask batholith is the Sugarloaf diorite unit. This diorite has a sparsely to strongly crowded porphyritic texture with a phenocryst population which includes stubby hornblende, smaller augite, and plagioclase that commonly displays trachytic alignment. Phenocrysts are set in an aphanitic groundmass of plagioclase, potassium feldspar and disseminated magnetite, with locally significant pyrite and chalcopyrite (Figure 6; Snyder and Russell, 1993a). The Sugarloaf diorite was emplaced predominantly as a set of northwest-trending, steeply dipping dikes along the southwestern edge of the batholith and as lenticular bodies along northwesterly striking structures within the central part of the batholith. These dikes intrude Nicola Group more commonly than Pothook diorite, do not intrude the Cherry Creek monzonite, and are widest, most abundant, and, in some cases radially oriented, around Sugarloaf Hill, which is thought to be a volcanic neck and intrusive centre (Snyder and Russell, 1993b). The intrusive form of the Sugarloaf diorite resembles the classic hypabyssal volcanic neck at Shiprock, New Mexico (Press and Siever, 1978).

Sugarloaf diorite produced contact metamorphism in adjacent volcanic country rocks. This involved the wholesale recrystallization of mafic volcanic rocks to actinolite and plagioclase with abundant disseminated magnetite; total destruction of textures commonly precludes recognition of the volcanic protolith immediately adjacent to the intrusion. Contact metamorphic effects were not observed in Pothook diorite where it is intruded by dikes of Sugarloaf diorite. The more extensive recrystallization of volcanic rocks associated with emplacement of the small Sugarloaf diorite dikes may suggest that these dikes were intruded at higher temperatures than the Pothook diorite.

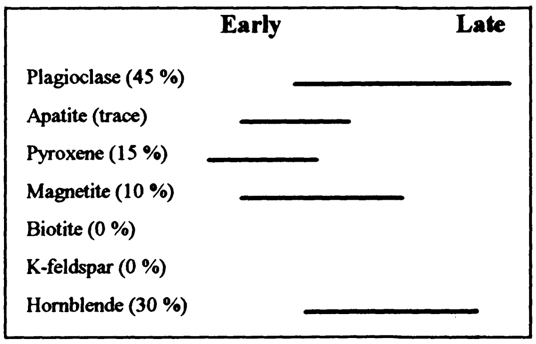



Figure 6. Igneous mineral paragenesis of the Sugarloaf diorite.

Alternatively, the probably higher volatile fugacity of the Sugarloaf phase, as indicated by its more porphyritic texture, may have more efficiently catalyzed recrystallization and metasomatism in texturally destructive hornfels.

After the Sugarloaf diorite was emplaced, another episode of hydrothermal alteration took place. This took the form of weakly to totally pervasive 'albitic' alteration. Albitization occurs only in intrusive rocks and, where less intense, fracture control was nominal. Where intense, alteration envelopes about fractures coalesce, producing a pervasive style of alteration. In the Pothook diorite, albite replaced plagioclase, augite and potassium feldspar, and chlorite replaced biotite. Where less intense, Pothook diorite is incompletely albitized in zones which are commonly restricted to fracture envelopes and in which plagioclase has suffered selective replacement by albite but biotite, augite and potassium feldspar remained stable. The Sugarloaf diorite has experienced only selective albitization. Albite replaced plagioclase and potassium feldspar, but hornblende generally remained stable. Sugarloaf diorite also contains blebs of epidote which may be related to this alteration event. Significant albitic alteration is restricted to the Pothook copper-gold deposit, the Big Onion zone, and to a few structurally controlled zones close to exposures of Sugarloaf diorite. Albitic alteration probably resulted from deuteric reaction of orthomagmatic fluid emanating from dikes of Sugarloaf diorite during their later stages of cooling.

## CONTRASTING STYLES OF COPPER-GOLD MINERALIZATION

The northern part of the Iron Mask pluton hosts the majority of porphyry copper-gold deposits in the Iron Mask batholith. Although the Afton and Iron Mask deposits were not physically accessible to study, two contrasting styles of mineralization have been recognized among the remaining deposits (Stanley, 1994, this volume; Lang, 1994, this volume).

The Pothook and Big Onion deposits occur near contacts between Nicola volcanic units (including picrite) and the Pothook diorite. Dikes of Sugarloaf diorite intrude along and adjacent to this contact, and were probably the cause of the pervasive albitic alteration associated with these deposits. The deposits themselves are hosted by zones of high fracture and fault density, possibly due to the brittle behaviour of albitically altered rocks. These fractures control a through-going, vein-related potassic alteration that crosscuts earlier albitic alteration. Mineralization is hosted by Pothook diorite, Sugarloaf diorite and Nicola Group. It is predominantly associated with planar, crosscutting chlorite-magnetite(specular) hematite veins without significant envelopes, and hydrothermal breccias with a variety of milled volcanic and intrusive fragment types. Mineralization consists of pyrite, chalcopyrite and bornite, in order of decreasing abundance. In the Pothook zone, copper/gold ratios vary considerably across the deposit. A more thorough description of the geology of the Pothook zone is presented in Stanley (1994, this volume).

The Crescent and DM deposits, and the smaller, intervening Audra zone, represent a different style of mineralization (Lang, 1994, this volume). These deposits are located near contacts between the Pothook diorite and Cherry Creek monzonite. Furthermore, the deposits have experienced pervasive potassic alteration and have high fracture and fault densities. Mineralization is hosted by biotite+potassium feldspar±quartz±epidote±magnetite veins, with chalcopyrite greater than pyrite. Biotite is commonly altered to chlorite. These sinuous veins occur in irregular stockworks and their biotite - potassium feldspar - magnetite envelopes form pseudobreccias of strongly altered and less altered Pothook diorite. Later quartz-calcite-matrix fault breccis and veins also host some mineralization, especially in the DM zone. In the Crescent zone copper/gold ratios are very constant. A more thorough description of the geology of the Crescent deposit is presented in Lang (1994, this volume).

## CONCLUDING STATEMENT

A revised intrusion history of the Iron Mask batholith, together with remapping of the northern part of the Iron Mask pluton, has provided significant new insight regarding the style of intrusion of the batholith, its cooling history, and its relationship to the country rocks. A more complete understanding of the styles and causes of mineralization in the field area has also been achieved. Improved insights into the nature of porphyry copper-gold deposits in the batholith have significant implications for both regional and local exploration.

## REFERENCES

Cann, R.M. (1979): Geochemistry of Magnetite and the Genesis of Magnetite-Apatite Lodes in the Iron Mask Batholith, British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, 196 pages.

Ghosh, D. (1993): Uranium-Lead Geochronology; *in* Porphyry Cu-Au Systems of British Columbia, Mineral Deposit Research Unit, T*he University of British Columbia,* Annual Technical Report, *pages 11.1-11.26.*

Kwong, Y.T.J. (1987): Evolution of the Iron Mask Batholith and Associated Copper Mineralization; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 77.

Lang, J.R. (1994): Geology of the Crescent Alkalic Porphyry Cu-Au Deposit, Afton Mining Camp, Kamloops, British Columbia (92 I/9, 10); *in* Geological Fieldwork 1993, Grant, B. and Newell J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Northcote, K.E. (1974): Geology of the Northwest Half of the Iron Mask Batholith; *in* Geological Fieldwork 1974, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1975-1, pages 22-26.

Northcote, K.E. (1976): Geology of the Southeast Half of the Iron Mask Batholith; *in* Geological Fieldwork 1976, B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1977-1, *pages 41-46.*

Northcote, K.E. (1977): Geological Map of the Iron Mask Batholith (92I/9W and 10E); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Preliminary Map No. 26 and accompanying notes, 8 pages.

Press, F. and Siever, R. (1978): Earth; *W.H. Freeman and Company*, San Francisco, 649 pages.

Preto, V.A.G. (1968): Geology of the Eastern Part of the Iron Mask Batholith, *B.C. Ministry of Mine and Petroleum Resources, Annual Report 1967, pages 137-147.*

Snyder, L.D. and Russell, J.K. (1993a): Field Constraints on Diverse Igneous Processes in the Iron Mask Batholith (92I9,10); *in* Geological Fieldwork 1992, Grant, B. and Newell J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 281-286.

Snyder, L.D. and Russell, J.K. (1993b): Petrology and Geochemical Aspects of Rocks in the Iron Mask Batholith; *in.* Porphyry Cu-Au Systems of British Columbia, *Mineral Deposit Research Unit, The University of British Columbia*, Annual Technical Report, pages 5.0.0-5.2.15.

Snyder, L.D. and Russell, J.K. (1994): Petrology and Stratigraphic Setting of the Kamloops Lake Picritic Basalts, Quesnellia Terrane, South-central B.C. ; *in* Geological Fieldwork 1993, Grant, B. and Newell J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Souther, J.G. (1992): Volcanic Regimes; *in* Geology of the Cordilleran Orogen in Canada. Gabrielse, H. and Yorath, C.J., Editors, *Geological Survey of Canada*, Decade of North American Geology Project, Paper No. 4, pages 457-490.

Stanley, C.R. (1994): Geology of the Pothook Alkalic Porphyry Cu-Au Deposit, Afton Mining Camp, British Columbia (92 I/9, 10); *in* Geological Fieldwork 1993, Grant, B. and Newell J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

# GEOLOGY OF THE POTHOOK ALKALIC COPPER-GOLD PORPHYRY DEPOSIT, AFTON MINING CAMP, BRITISH COLUMBIA (92I/9, 10)

**Clifford R. Stanley, Mineral Deposit Research Unit, U.B.C.**

*(MDRU Contribution # 035)*

*KEYWORDS:* Economic geology, porphyry, copper, gold, supergene, alkalic, Nicola, Pothook, Sugarloaf, Cherry Creek, diorite, monzonite, Iron Mask, Quesnellia.

## INTRODUCTION

The Pothook deposit is one of several alkalic porphyry copper-gold deposits (Afton, Crescent, Ajax East, Ajax West) developed in the Afton mining camp, located 10 kilometres west of Kamloops, British Columbia. These deposits are all hosted by the Iron Mask batholith, a large composite alkalic intrusion of earliest Jurassic age that intrudes latest Triassic Nicola volcanic rocks of the Quesnellia oceanic island arc terrain (Souther, 1992). The Pothook deposit is located on the southwestern edge of the Iron Mask batholith, approximately 750 metres southeast of the much larger Afton copper-gold deposit (Figure 1). It contained a geological reserve of 3.26 million tonnes grading 0.40% copper and 0.16 gram per tonne gold ($0.40 copper equivalent cut-off; Bond, 1985).

Between October 1986 and September 1988, Afton Operating Corporation, a division of Teck Corporation, mined 2.60 million tonnes of ore with an average grade of 0.35% copper and 0.21 gram of gold per tonne from an open-pit, with a stripping ratio of 1:1.9 (L. Tsang, personal communication, 1993).

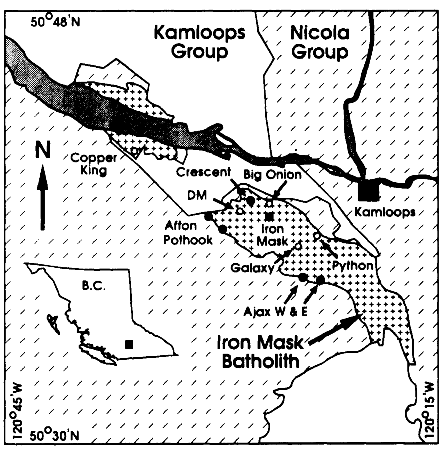



Figure 1. Generalized geological map of the Iron Mask batholith, showing locations of the principle mineral deposits (after Kwong, 1977).

Detailed open-pit mapping at 1:300 scale, more regional mapping of the area around the Pothook deposit at 1:2400 scale, and drill-core logging carried out during the summer of 1993 have documented the complicated geological history of the deposit. An open-pit map of the Pothook deposit is presented in Figure 2.

## GEOLOGICAL HISTORY

The geological history of the Pothook zone is summarized in Table 1 and a full description of the geological units and events is presented in chronological order below.

### *LATE TRIASSIC*

Several different volcanic lithologies act as host-rocks for the Iron Mask batholith in the deposit area. These consist of: dark green to black, aphyric to plagioclase-phyric, massive basalt flows; maroon to dark grey, aphyric to sparsely plagioclase or augite-phyric, poorly bedded, ash to lapilli mafic tuffs and lesser blocky agglomerates; black, crowded, augite-phyric, massive basalt flows; dark grey, crowded plagioclase-phyric andesite flows and feeder dikes; and dark green to black, crowded augite-phyric picrite flows (Snyder and Russell, 1993b). These units comprise the Carnian to Norian (latest Triassic) Nicola Group on the southwestern edge of the Iron Mask batholith (Preto, 1977).

### *EARLY JURASSIC*

The Nicola Group was intruded during the earliest Jurassic (at approximately 2073 Ma; Ghosh, 1993) by the Iron Mask batholith. Several intrusive bodies comprise the batholith; all are exposed in the Pothook open pit.

#### POTHOOK DIORITE

The first to intrude was the Pothook diorite phase, a predominantly fine to medium-grained, equigranular, plagioclase-augite diorite with late poikilitic biotite containing both plagioclase and augite inclusions (Snyder and Russell, 1993a). Disseminated magnetite in variable concentrations up to 10%, and accessory potassium feldspar and apatite also occur. The Pothook diorite incorporated

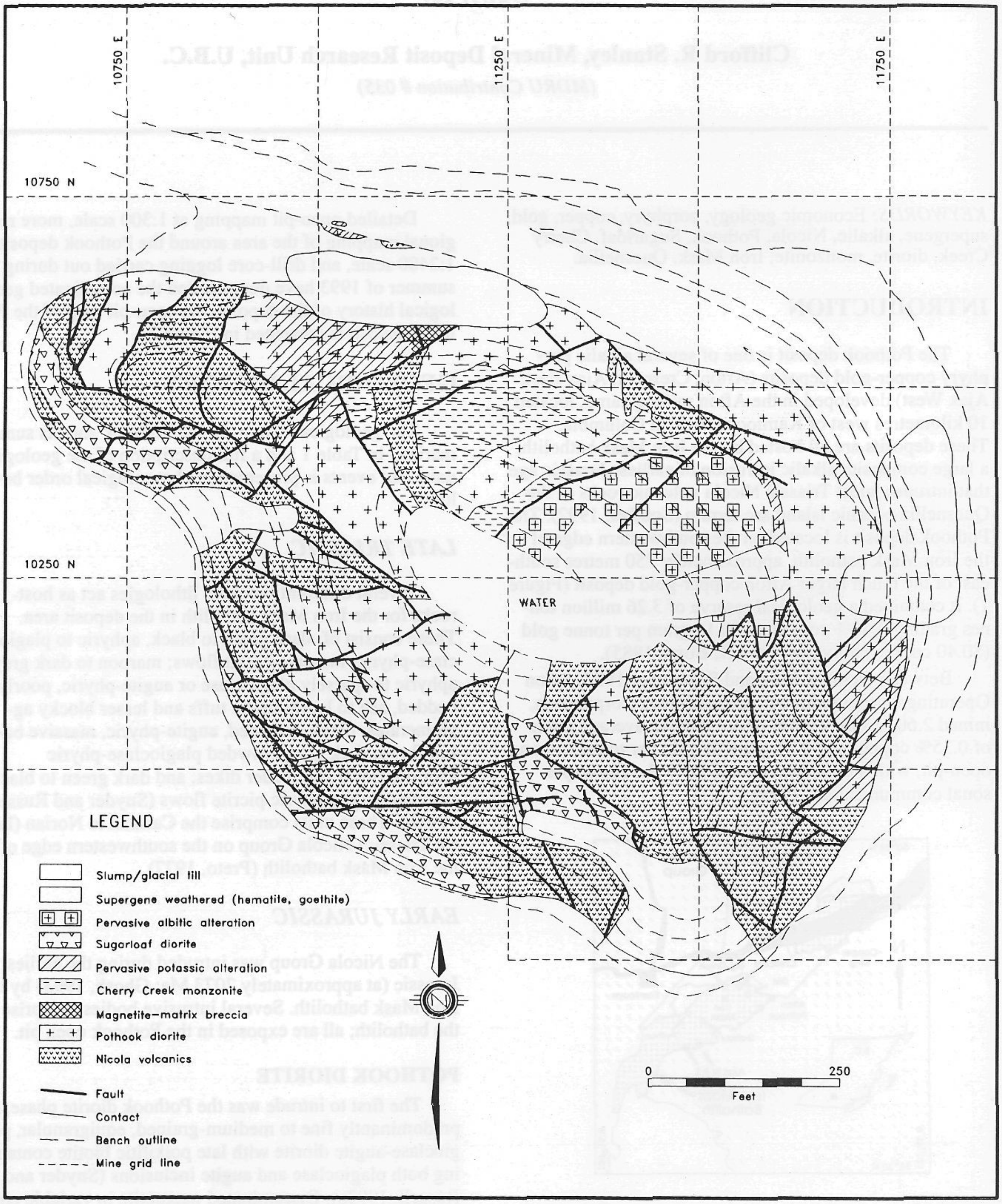



Figure 2. Geological map of the Pothook alkalic porphyry copper-gold deposit open pit.

TABLE 1
SUMMARY OF CHRONOLOGY OF INTRUSIVE, STRUCTURAL, ALTERATION/METAMORPHISM/WEATHERING EVENTS IN THE POTHOOK ALKALIC PORPHYRY COPPER-GOLD DEPOSIT

| Event | Age | Intrusion | Faulting | Alteration / Metamorphism / Weathering |
|---|---|---|---|---|
| 1 | earliest Jurassic | Fine to medium-grained Pothook diorite intrudes Nicola volcanics | | Hornfels in adjacent Nicola volcanics |
| 2 | earliest Jurassic | Medium-grained Pothook diorite intrudes fine to medium-grained Pothook diorite | | |
| 3 | earliest Jurassic | | Steep NNW and ENE faulting disrupts intrusive contacts | |
| 4 | earliest Jurassic | | | Magnetite-apatite-actinolite blebs, veins and breccias cut Pothook diorite |
| 5 | earliest Jurassic | Cherry Creek monzonite intrudes earlier Pothook diorite phase | | |
| 6 | earliest Jurassic | | | Pervasive potassic alteration - K-spar replacement / mag destruction in Pothook diorite |
| 7 | earliest Jurassic | | Steep NNW and ENE faulting disrupts intrusive contacts | |
| 8 | earliest Jurassic | Sugarloaf diorite dikes intrude volcanics and fine to medium-grained Pothook diorite | | act-plag hornfels contact metamorphic replacement of Nicola volcanics |
| 9 | earliest Jurassic | | | Pervasive albitic alteration - alb replacement of feldspar and aug, chl replacement of biot |
| 10 | earliest Jurassic | | | K-feldspar-epidote veins cut Pothook diorite and Cherry Creek monzonite |
| 11 | earliest Jurassic | | Steep NNW and ENE faulting disrupts intrusive contacts | |
| 12 | earliest Jurassic | | | Iron-oxide-**Cu-sulphide** (chlorite-epidote) veins and breccias cut all lithologies |
| 13 | earliest Jurassic | | | Chlorite / kaolinite veins fill joints and microfractures in all lithologies |
| 14 | earliest Jurassic | | | Calcite veins and crackle zones cut all lithologies |
| 15 | Eocene | | Shallow NW faulting throws tops to SW | |
| 16 | Eocene | Aphyric mafic dikes associated with Kamloops Group volcanics cut Pothook diorite | | |
| 17 | Eocene | | | Quartz veins cut all lithologies |
| 18 | Eocene to Pleistocene | | | Supergene weathering dissolves cpy, precipitates native Cu, chal and earthy hematite |
| 19 | Eocene to Pleistocene | | Steep NW reverse faulting down drops supergene-weathered zones into grabens | |
| 20 | Pleistocene | | | Glacial erosion produces current exposure level |

mag=magnetite; act= actinolite; plag-plagioclase; alb-albite; aug-augite; chl-chlorite; biot-biotite; cpy-chalcopyrite; chal=chalcocite numerous blocks of volcanic rocks as xenoliths within the intrusion. In places, especially near the margins of the diorite, these xenoliths are sufficiently abundant to comprise an intrusion breccia. Apophyses of Pothook diorite also intruded along faults and steeply dipping depositional contacts in the volcanic hostrocks. A fine-grained chilled margin of the diorite occurs at the intrusive contacts with these volcanics. Volcanic rocks adjacent to the diorite contact recrystallized to a biotite hornfels containing less than 1% disseminated pyrite cubes and disseminated magnetite.

A medium-grained variety of Pothook diorite was intersected at depth in exploration drill-holes. This later variety intrudes the fine to medium-grained Pothook diorite variety, but is otherwise petrologically similar. It is not observed to intrude, nor contain xenoliths of, Nicola volcanic rocks.

After the Pothook diorite intrusion had cooled sufficiently to allow brittle fracture, an episode of largely steep faulting disrupted the diorite-volcanic contact and juxtaposed volcanic rocks, without contact metamorphic recrystallization effects, and diorite. Displacements along these numerous, steeply dipping faults (most have dips >70) are probably vertical, appear to be generally less than 100 metres, and several sets of fault orientations were observed (NNW and ENE; Figure 3). This faulting appears to predate the pervasive potassic alteration described below.

After and probably during this steep faulting, magnetite-apatite-actinolite veins, blebs, schleiren and breccias formed along dilatant fractures. These fractures also occasionally contain epidote and chlorite, both within the structures and in alteration envelopes surrounding them.

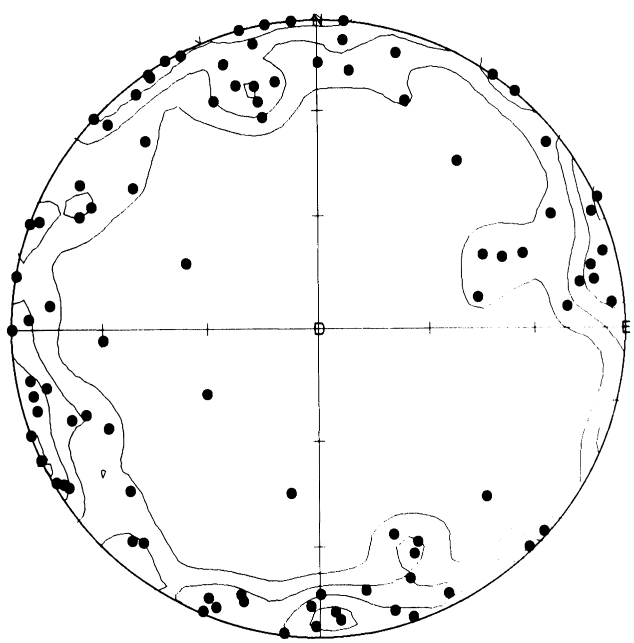



Figure 3. Stereonet of poles to steeply dipping faults cutting Pothook diorite and Nicola volcanics (n = 97).

Blebs and schleiren tend to occur in large envelopes about major magnetite veins. The Magnet showing, and probably other magnetite veins in the Iron Mask batholith, formed at this time (Cann, 1979). In the Pothook deposit area, all of these magnetite-bearing structures are hosted by the fine to medium-grained Pothook diorite or by intrusion breccia with a fine to medium-grained Pothook diorite matrix. These magnetite-bearing structures may have formed from coalescing orthomagmatic hydrothermal fluids evolved from other, still molten, parts of the Pothook diorite during late stage crystallization.

## CHERRY CREEK MONZONITE

The Cherry Creek monzonite phase of the Iron Mask batholith was next to intrude. In the Pothook area, it intruded only Pothook diorite (Stanley *et al.*, 1994, this volume). This intrusion is generally a very fine grained, equigranular, potassium feldspar-plagioclase-biotite-augite monzonite with accessory magnetite and apatite, and trace quartz (Snyder and Russell, 1993a). It also contains small miarolitic cavities filled with quartz, and locally exhibits an aplitic texture. Its emplacement was apparently controlled by pre-existing structures within the Pothook diorite; it does not intrude Nicola volcanic rocks in the Pothook area (Stanley *et al.*, 1994). No contact metamorphic effects were observed in Pothook diorite adjacent to the Cherry Creek monzonite.

A generally pervasive potassic alteration occurs within but near the margins of the Cherry Creek monzonite and in Pothook diorite adjacent to exposures of Cherry Creek monzonite in the open pit. This alteration involved the 'selective pervasive' replacement of plagioclase by potassium feldspar in both phases, and the partial destruction of disseminated magnetite in the Pothook diorite. Biotite remained stable, but augite was commonly replaced by epidote. At the margins, this 'selective pervasive' alteration grades outward into fractures with potassic alteration envelopes, indicating that at least the outer parts of these alteration zones formed from coalescing alteration envelopes. The close spatial association between this alteration and the monzonite suggests that the alteration is probably deuteric and was related to and occurred during the late stages of cooling of the monzonite. The widespread nature of this alteration, and the pink colour imparted by the potassium feldspar, have caused pervasive, potassically altered fine to medium-grained Pothook diorite to be confused with the fine-grained Cherry Creek monzonite in the past (Stanley *et al.*, 1994, this volume). In the Pothook open-pit, this early pervasive potassic alteration is restricted to the north wall, adjacent to and above the exposure of Cherry Creek monzonite.

After intrusion of the Cherry Creek monzonite, additional steep faulting took place. Displacements occurred largely along pre-existing structures, and this further disrupted intrusive contacts along the southwest edge of the batholith.

## SUGARLOAF DIORITE

The second period of faulting was followed by the intrusion of the Sugarloaf diorite into earlier phases of the Iron Mask batholith and surrounding rocks. This diorite contains large, sparse to crowded, stubby hornblende phenocrysts, generally smaller augite and commonly trachytically aligned plagioclase phenocrysts. These are set in an aphanitic groundmass of plagioclase and potassium feldspar with disseminated magnetite (Snyder and Russell, 1993a). The Sugarloaf diorite was emplaced as a set of northwest-trending, steeply dipping dikes along the southwestern edge of the batholith. These intrude Nicola volcanics more commonly than Pothook diorite, do not intrude the Cherry Creek monzonite, and are widest, most abundant, and, in some cases radially oriented, around Sugarloaf Hill, which is thought to be a volcanic neck and intrusive centre (Snyder and Russell, 1993b). As such, the intrusive form of the Sugarloaf diorite resembles the classic hypabyssal volcanic neck at Shiprock, New Mexico (Press and Siever, 1978).

Sugarloaf diorite produced contact metamorphism in adjacent volcanic rocks. This involved the complete recrystallization of mafic volcanic rocks to an actinolite-plagioclase hornfels with abundant disseminated magnetite. This contact metamorphism was texturally destructive so the protoliths of amphibolitized Nicola volcanic rocks cannot be ascertained. No contact metamorphic effects are apparent in Pothook diorite where it is intruded by the Sugarloaf diorite dikes, probably because of the low hydration state of the Pothook diorite and the stabilities of the minerals comprising it under those metamorphic conditions. The more extensive recrystallization of volcanic hostrocks associated with emplacement of the small Sugarloaf diorite dikes may suggest that these dikes were intruded at higher temperatures than the Pothook diorite. Alternatively, the probably higher volatile fugacity of the Sugarloaf phase, as indicated by its more porphyritic texture, may have more efficiently catalyzed recrystallization and metasomatism, forming the higher grade hornfels.

Another stage of hydrothermal alteration took place after intrusion of the Sugarloaf diorite. This took the form of partial to pervasive albitic alteration and was confined to the intrusive rocks. This alteration becomes pervasive where envelopes surrounding fractures coalesce. It probably occurred during cooling of the Sugarloaf diorite, and may also have been deuteric. In the Pothook diorite, albite replaced plagioclase, augite and potassium feldspar, and chlorite replaced biotite. Moderate but subequal amounts of chalcopyrite and pyrite precipitation accompanied this alteration. This albitic alteration is most intense (pervasive) on the southeast wall of the open pit, below the ramp, where the Pothook diorite consists almost completely of albite. Elsewhere, Pothook diorite is incompletely albitized, occasionally in fracture envelopes, where plagioclase is selectively but pervasively replaced by albite but chlorite has not replaced biotite, and augite and potassium feldspar remained stable. The Sugarloaf diorite is only 'selective pervasively' albitized. Albite replaced plagioclase and potassium feldspar, but hornblende generally remained stable. Sugarloaf diorite also contains blebs of epidote thought to be related to this alteration event.

The pervasive albitic alteration is overprinted by fracture-controlled potassic alteration represented by through-going potassium feldspar-biotite-epidote veins. These were strongly controlled by steeply dipping, north-northwest-striking fractures (Figure 4) and are restricted to the Pothook diorite and Cherry Creek monzonite intrusions. These veins are not significantly dilatant but are continuous across 20 vertical and 30 horizontal metres and in many places constitute 'sheeted' vein sets. During this hydrothermal alteration, different vein and envelope alteration mineral assemblages were produced in different lithologies. Specifically, in unaltered to moderately albitized Pothook diorite and Cherry Creek monzonite, the veins are primarily filled by potassium feldspar and biotite and have epidote envelopes. In pervasively albitized Pothook diorite, the veins are commonly filled by epidote and have potassium feldspar and biotite envelopes. In pervasive potassically altered Pothook diorite, the veins are generally filled only by epidote. All of these potassium feldspar - epidote veins contain small but subequal amounts of chalcopyrite and pyrite, and are well developed on the southeast wall of the open pit above the ramp, and along the north wall of the open-pit just above the ramp on the lower benches. This structurally controlled potassic alteration introduced a small amount of copper and gold mineralization, as chalcopyrite and bornite, in the veins.

Following the episode of fracture-controlled potassic alteration, further steep faulting dissected many of the Sugarloaf diorite dikes and through-going potassium feld-

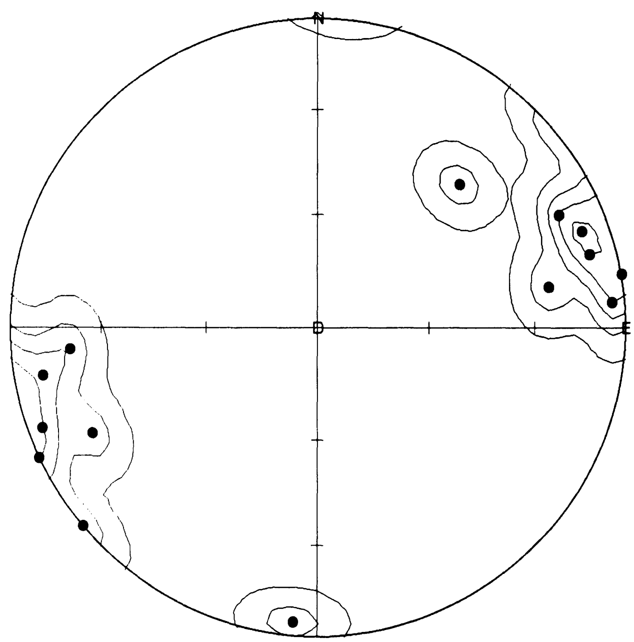



Figure 4. Stereonet of poles to structurally controlled potassium feldspar - epidote veins (n = 14).

spar-epidote veins, and further disrupted the margin of the Iron Mask batholith. Much of this movement took place along pre-existing structures.

## COPPER-GOLD MINERALIZATION

None of the previously described pervasive or fracture-controlled hydrothermal alteration events is characterized by the introduction of significant amounts of copper to the Pothook area. The copper ore-forming event is represented by iron oxide - sulphide veins. On the southwest side of the open-pit, these veins are characterized by a chlorite-pyrite-chalcopyrite-magnetite-(specular) hematite mineral assemblage, whereas on the northeast side they contain chalcopyrite, bornite and magnetite. These veins, like the potassium feldspar-epidote veins that they cut, were not significantly dilatant. Similarly, they also have a preferred orientation approximately perpendicular to the orientation of the potassium feldspar - epidote veins, ranging from west-southwest to northwest with dips generally greater than 45 (Figure 5). The density of these mineralized veins appears to control ore grade, and produced some very significant copper and gold concentrations (occasionally up to 2% Cu and 2 g/t Au in exploration drilling samples). Where these veins cut Nicola volcanic rocks or their metamorphosed equivalents, significant chlorite selvages and envelopes are developed. Where they cut intrusive rocks, epidote envelopes and selvages predominate on the vein margins. These veins are not through-going and tend to dissipate into micro-fractures with epidote or chlorite envelopes. Previously existing fault zones are also at least partially filled by these iron oxide - sulphide veins.

In the centre of the open pit, and seen only in drill core, there is a large body of hydrothermal breccia that contains rotated and clasts of Pothook diorite, Cherry Creek monzonite, Sugarloaf diorite, and Nicola volcanics in a matrix of rock flour, chlorite and pyrite, with subordinate amounts of magnetite, chalcopyrite and bornite. In places, especially toward the centre of the breccia, these clasts are well rounded due to milling, range in size from 5 to 100 millimetres, and are clast supported. Toward the margins of the breccia, fragments are larger and more angular, and the breccia grades into a crackle zone with unrotated fragments in a disrupted stockwork of iron oxide - sulphide veins. As such, the hydrothermal breccia and veins are interpreted to be genetically related.

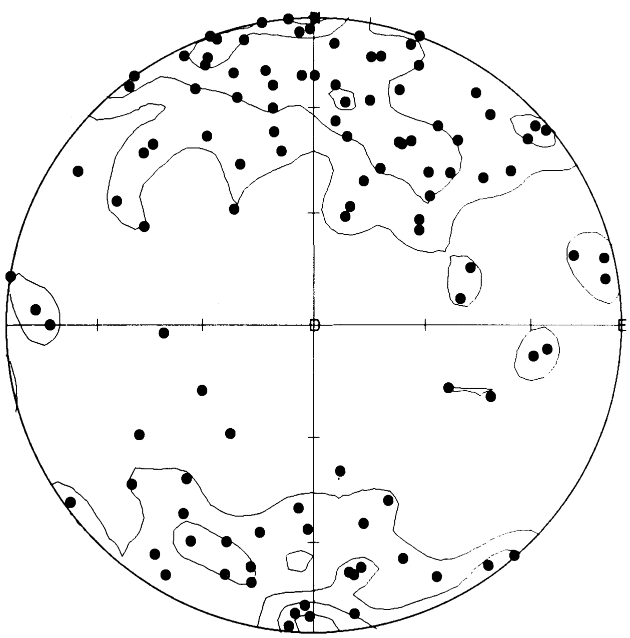



Figure 5. Stereonet of poles to iron oxide - sulphide veins (n = 112).

The mineralizing episode that produced the sulphide-bearing veins and breccia was followed by, or possibly evolved into, a propylitic episode of chlorite veining without significant amounts of associated copper or gold mineralization. Chlorite veinlets fill narrow fractures at all scales, from large through-going joints down to micro-fractures, in both volcanic and intrusive rocks. They are responsible for the predominantly dark colour of rock exposures in the open pit because blasting has broken the rocks along these veins, exposing dark green chlorite. This chlorite veining event involved no other alteration minerals, except for minor amounts of calcite and disseminated pyrite intergrown with the chlorite. Chlorite veins do not occur in pervasive albitically altered Pothook diorite. Rather, late kaolinite-calcite-filled microfractures are prevalent (Bond, 1985). These veins may be the equivalent to the chlorite veins, but contain no chlorite because of the lack of iron and magnesium in intensely albitized Pothook diorite.

Calcite veins crosscut the propylitic chlorite veins. In the intrusive units, these veins consist solely of calcite with no associated alteration envelopes. In the Nicola volcanic rocks, they are commonly associated with talc and serpentine, and have chlorite selvages. Calcite veins have no preferred orientation, and are not through-going. In general, wider calcite veins tend to be truncated by smaller, crosscutting calcite veins. Wider calcite veins are generally isolated from each other, and thus are rarely widespread and abundant enough to form crackle zones. Nevertheless, the overall distribution of these calcite veins suggest that the rocks have been intensively shattered, in spite of the relative absence of large crackle zones. The calcite veins postdate the sulphide-bearing veins and probably formed from lower temperature fluids. They also partially fill pre-existing fault zones.

## *EOCENE*

Another episode of faulting followed the mineralizing and alteration events. Unlike the earlier episodes of faulting, movement occurred along relatively shallow planes with southeasterly strikes and dips generally less than 30 to the southwest (Figure 6). Numerous faults with this orientation cut the upper southwest wall of the open pit, and display spoon-like, concave-upward (listric) forms. The displacement direction is generally to the southwest, and movements of up to 50 metres are indicated on individual fault planes. Given the number of these faults, the main mass of Pothook diorite and Sugar-

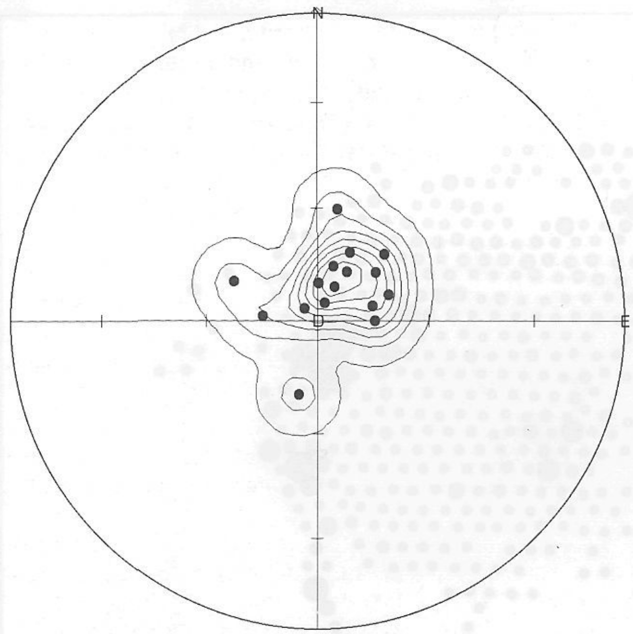



Figure 6. Stereonet of poles to shallow listric faults with southwesterly directed throw (n = 16).

loaf diorite dikes above these faults may have been displaced significant distances from the margin of the batholith (up to or exceeding 250 m) onto unmetamorphosed Nicola volcanics. This stage of faulting may reflect unroofing of the batholith, possibly during a period of extensional tectonics that affected the region during the Eocene (Souther, 1992).

Late, relatively rare mafic dikes intruded the Pothook area during the Eocene. These are aphyric to sparsely plagioclase phyric and are unaltered. They may be feeder dikes to the mafic volcanic rocks in the Eocene Kamloops Group, which fills grabens formed during extension (Souther, 1992).

Rare, late quartz-calcite-chlorite veins cut through all lithologies in the open pit. They partially fill all faults, including those with shallow dips, and previously formed veins with open spaces. They also fill shallow-dipping fractures oriented parallel to the shallow-dipping 'detachment' faults. These veins contain amethystine quartz and may be related to hydrothermal activity associated with Kamloops Group mafic volcanic feeder dikes.

During a period of late Tertiary supergene weathering, some of the chalcopyrite and bornite was destroyed and replaced by native copper, chalcocite and earthy hematite. Pyrite was also partially destroyed and replaced by earthy hematite and goethite during this supergene event. This weathering appears to have occurred without significant supergene enrichment, but local movements into adjacent fractures undoubtedly occurred. This relative lack of copper mobility was probably due to the high calcite and low pyrite abundances in the deposit. The relative absence of pyrite limited the amount of acid that could be produced during weathering, and the of calcite neutralized any acid that was produced. This prevented descending meteoric fluids becoming sufficiently acidic to transport copper downward to form a supergene enrichment blanket. Instead, the meteoric fluids caused the destruction of primary copper sulphide mineralization and the formation of secondary native copper and chalcocite. This produced a supergene blanket without copper enrichment (*cf.* Kwong, 1987). This weathering is predominantly fracture controlled, often occurring in open spaces thought to be originally filled by calcite, and penetrates to depths of up to 50 metres below the bedrock surface in unfractured rocks and to depths greater than 200 metres along faults.

Finally, further movement on pre-existing, northwest-striking faults down-dropped supergene weathered material into grabens where they were protected from subsequent Pleistocene glacial erosion.

## ORE DISTRIBUTION

Copper and gold grades in both exploration drill-holes and production blast-holes were examined to assess lithological and structural controls on mineralization. Scatterplots of copper and gold concentrations are presented in Figure 7. This demonstrates that copper and gold concentrations are not well correlated, and that, in general, high copper concentrations occur in samples with relatively low gold grades, and *vice versa.* This lack of correlation between copper and gold grade is different from most other alkalic porphyry copper-gold deposits, which commonly exhibit strongly correlated copper and gold concentrations, and relatively constant copper/gold ratios within individual deposits (average ratios in individual deposits range from 10 000 to 25 000; Stanley, 1993).

Figures 8 and 9 are bubble plots of copper and gold blast-hole assays from the 2340-foot bench in the Pothook open pit. Higher copper grades exhibit a strong structural control and define trends with variable strikes. Many of these trends can be traced directly into fault zones mapped on the 2340-foot bench (Figure 2). These

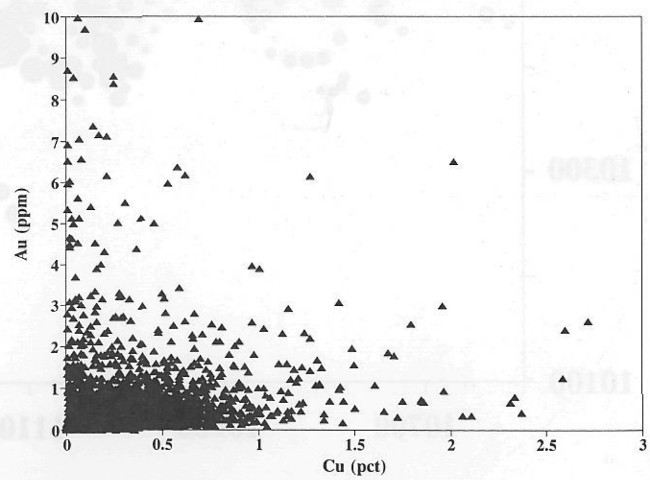



Figure 7. Scatterplot of exploration drill-hole and production blast-hole copper and gold assays from the 2100, 2160, 2220, 2280, 2340 and 2400-foot benches in the Pothook open pit (n = 3992).

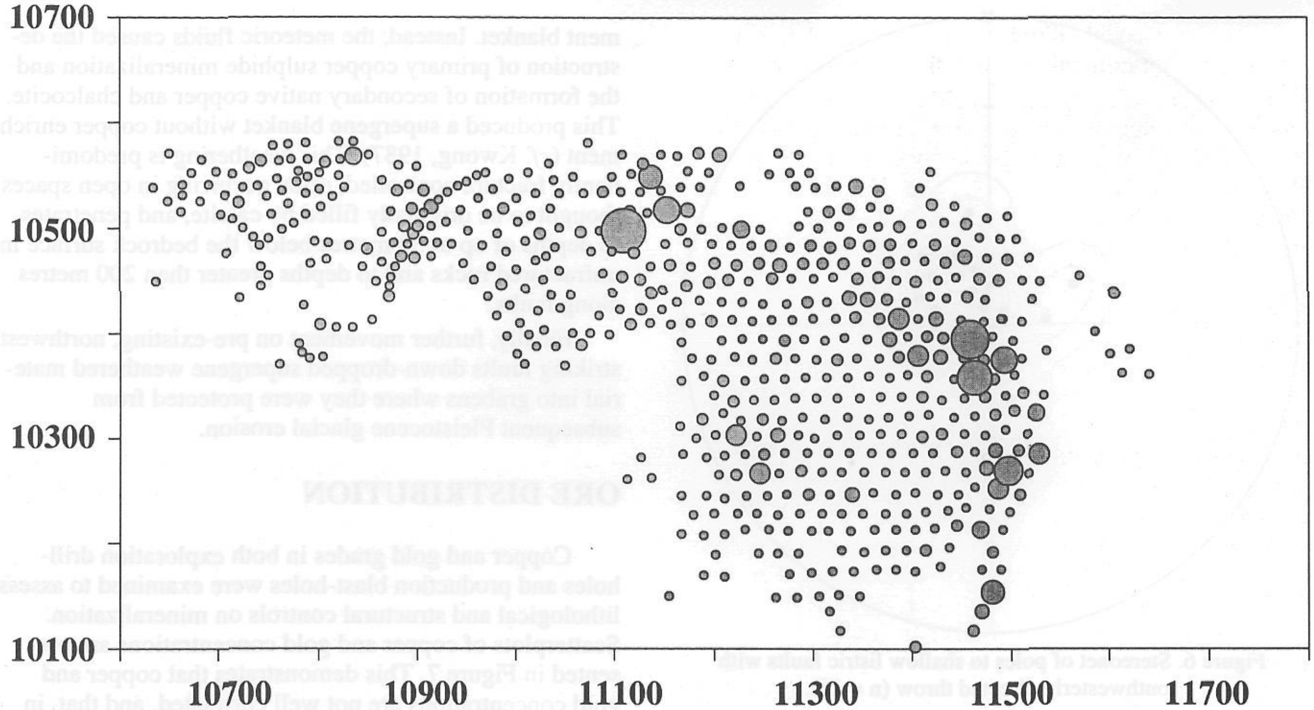



Figure 8. Bubble plot of production blast-hole copper assays from the 2340-foot bench of the Pothook open pit. Assays have been transformed and scaled to enhance geochemical contract. The smallest and largest bubbles corresponds to copper grades of 0.01% and 2.60%, respectively (n = 635).

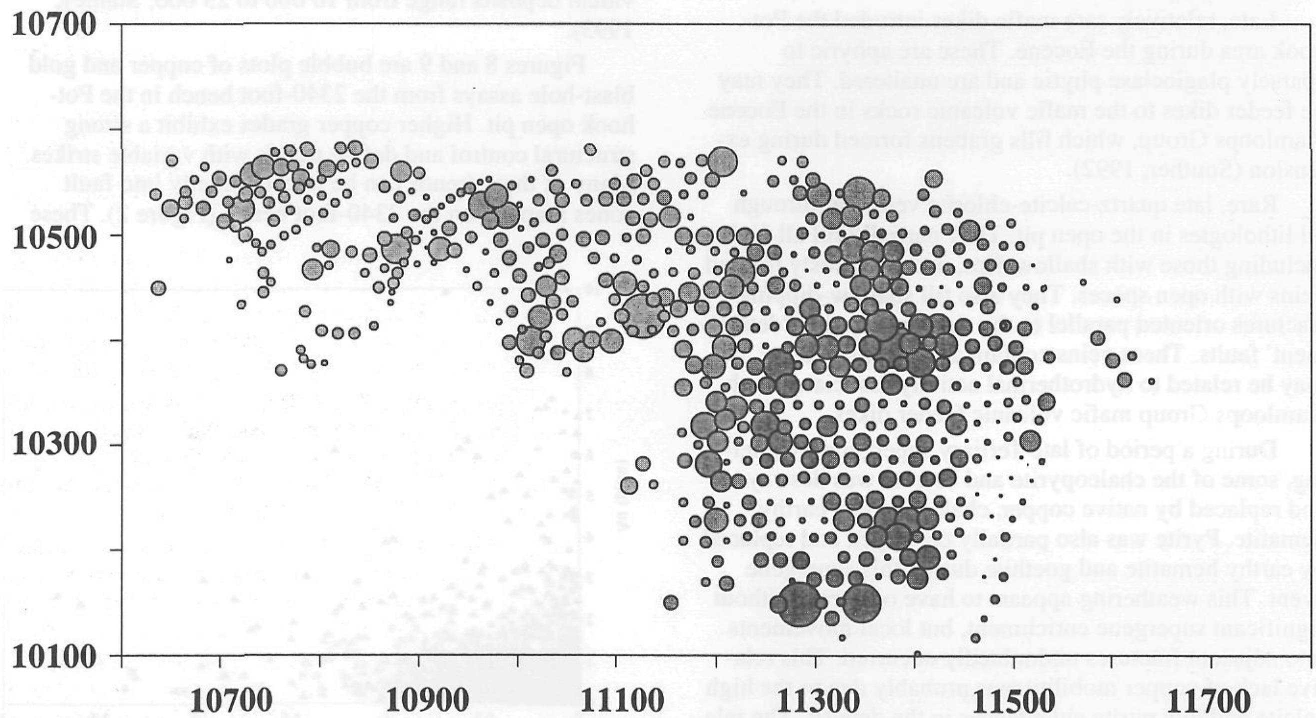



Figure 9. Bubble plot of production blast-hole gold assays from the 2340-foot bench of the Pothook open pit. Assays have been transformed and scaled to enchance geochemical contract. The smallest and largest bubbles correspond to gold grades of 0.034 and 28.972 grams per tonne, respectively (n = 635).

fault zones are steeply dipping and were active before, during and after mineralization in the Pothook deposit.

The distribution of higher gold concentrations, however, suggests that the gold and copper mineralization in the Pothook deposit is not identically controlled (Figure 9). In fact, there is little correspondence between the locations of high gold and high copper concentrations in blast holes. The lack of correlation between copper and gold, in terms of both magnitude and space, may be due in part to local mobility during supergene weathering, or to inaccuracies produced by nugget effects. However, given the relatively high density of blast-holes (approximately 20-foot spacing), the spacing of assays in exploration drill-core samples (continuous, immediately adjacent intervals), and the masses of these samples ( >2 kg), it is more likely that copper and gold do not share an identical mineral paragenesis. Whereas the timing of copper mineralization can be determined because the copper minerals are visible, the timing of gold mineralization remains unclear. Copper and gold may have been introduced at different times, or by the different means, during the hydrothermal history of the deposit.

## CONCLUSIONS

In the Pothook area, the Pothook diorite, Cherry Creek monzonite and Sugarloaf diorite all intruded latest Triassic Nicola volcanics during the earliest Jurassic. These intrusions and their host-rocks have been affected by several, largely pre-mineral, stages of hydrothermal alteration: magnetite veins and breccias controlled by fractures in the Pothook diorite; pervasive potassic alteration associated with the Cherry Creek monzonite; pervasive albitic alteration associated with the Sugarloaf diorite; and late, potassium feldspar - epidote veins.

Copper-gold mineralization in the Pothook area appears to be most closely related to Sugarloaf diorite dikes that cut Nicola volcanics along the southwest margin of the Iron Mask batholith. Mineralization occurs predominantly in hydrothermal breccia and steeply dipping, east-striking veins that cut all three phases of the batholith and the surrounding Nicola volcanics. The Pothook orebody is characterized by abundant pyrite, magnetite, chlorite and minor (specular) hematite gangue and chalcopyrite, bornite and native copper ore minerals.

Ore-stage mineral zoning is spatially consistent with both the predominant orientation of the veins and a hydrothermal fluid source in the Sugarloaf diorite dikes. The zoning of pyrite-chalcopyrite and chalcopyrite-bornite mineral assemblages across the deposit suggests that copper and gold mineralization may have precipitated under variable temperature and/or fluid sulphidation conditions (Einaudi, 1993) encountered as fluids migrated away from the Sugarloaf diorite dikes.

Precipitation of copper and gold occurred after the pervasive albitic alteration event that affected all intrusive rock types, and contact metamorphism of volcanics adjacent to Sugarloaf diorite dikes. The hostrocks to mineralization appear to have been made more competent by these pre-mineral alteration events such that they fractured more brittley and acted as ready hosts for mineralization.

Late, post-mineral chlorite veins cut un-albitized rocks, whereas kaolinite veinlets cut albitized rocks. Later calcite veins cut all lithologies.

During the Eocene, low-angle 'detachment' faulting, mafic dike emplacement and graben formation reflect the extensional tectonic episode that affected the Pothook area. Late quartz-bearing veins are associated with this tectonic and intrusive episode.

## REFERENCES


Bond, L. (1985): Geology and Mineralization of the Pothook Zone; *Afton Operating Corporation*, internal company report, 99 pages.

Cann, R.M. (1979): Geochemistry of Magnetite and the Genesis of Magnetite-Apatite Lodes in the Iron Mask Batholith, British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, 196 pages.

Einaudi, M.T. (1993): Anatomy of Porphyry Copper Systems, *in* Volcanoes and Ore Deposits, *Mineral Deposit Research Unit, The University of British Columbia*, Short Course No. 14, April.

Ghosh, D. (1993): Uranium-Lead Geochronology, in Porphyry Copper-Gold Systems of British Columbia; *Mineral Deposit Research Unit, The University of British Columbia*, Annual Technical Report, pages 11.1-11.26.

Kwong, Y.T.J. (1987): Evolution of the Iron Mask Batholith and its Associated Copper Mineralization; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 77.

Press, F. and Siever, R. (1978): Earth; *W.H. Freeman and Company*, San Francisco, 649 pages.

Preto, V.A. (1977): The Nicola Group: Mesozoic Volcanism Related to Rifting in Southern British Columbia; *in* Volcanic Regimes in Canada, Baragar, W.R.A., Coleman, L.C. and Hall, J.M., Editors, *Geological Association of Canada*, Special Paper No. 16, pages 39-57.

Snyder, L.D. and Russell, J.K. (1993a): Field Constraints on Diverse Igneous Processes in the Iron Mask Batholith (92I9,10); *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 281-286.

Snyder, L.D. and Russell, J.K. (1993b): Petrology and Geochemical Aspects of Rocks in the Iron Mask Batholith; *in* Porphyry Cu-Au Systems of British Columbia, *Mineral Deposit Research Unit, The University of British Columbia*, Annual Technical Report, pages 5.0.0-5.2.15.

Souther, J.G. (1992): Volcanic Regimes; *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Survey of Canada*, Decade of North American Geology Project, Paper No. 4, pages 457-490.

Stanley, C.R. (1993): A Thermodynamic Geochemical Model for the Co-precipitation of Gold and Chalcopyrite in Alkalic Porphyry Cu-Au Deposits; *in* Porphyry Cu-Au Systems of British Columbia', *Mineral Deposit Research Unit, The University of British Columbia*, Annual Technical Report, pages 12.1-12.17.

Stanley, C.R., Lang, J.R. and Snyder, L.D. (1994): Geology and Mineralization in the Northern Part of the Iron Mask Pluton, Kamloops British Columbia (92I/9, 10); *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1994-1, this volume.

# GEOLOGY OF THE CRESCENT ALKALIC PORPHYRY COPPER-GOLD DEPOSIT, AFTON MINING CAMP, BRITISH COLUMBIA (92I/9)

**By James R. Lang**
**Mineral Deposit Research Unit, University of British Columbia**

*(MDRU Contribution 036)*

*KEYWORDS:* Economic Geology, Porphyry, Copper, Gold, Iron Mask Batholith, Pothook Diorite, Cherry Creek Monzonite, Alkalic, Quesnellia

## INTRODUCTION

The Crescent deposit is one of several porphyry-style deposits located within the Iron Mask batholith. Other mined deposits in the district include the Afton, Ajax East and West, and Pothook deposits; the Big Onion, DM, and Python zones have published reserves but have had no production (Figure 1; Kwong, 1977). The Iron Mask is a composite intrusion of alkalic affinity which was emplaced at about 207±3 Ma (Ghosh, 1993) into coeval volcanic rocks of the Nicola Group which is part of the Quesnellia oceanic island-arc terrane (Souther, 1992). The copper-gold deposits within the batholith have been classified within the silica-saturated group of alkalic porphyry deposits (Lang *et al.*, 1992). The Crescent deposit is located 3 kilometres due east of the Afton deposit, the largest orebody in the district (Figure 1), and yielded 1.36 million tonnes of ore with an average grade of 0.46% copper and 0.2 gram per tonne gold during production in 1989 and 1990.

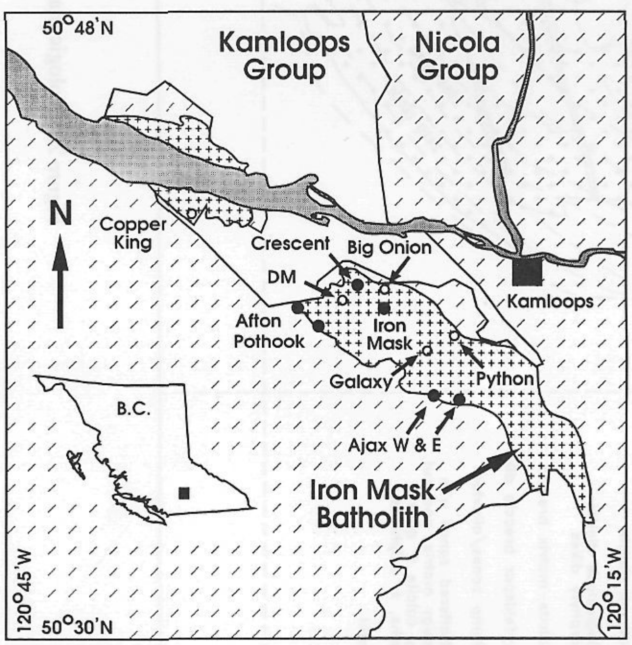



Figure 1. Location of the Iron Mask batholith and associated mineral deposits. Closed and open symbols respectively distinguish deposits with production from those that have not been mined. Dark grey is Kamloops Lake.

The work reported here is based on a map of the open pit prepared at a scale of 1:600 (Figure 2), an outcrop map at 1:2400 scale for areas outside the pit (see Stanley *et al.*, 1994), and examination of diamond drill core. Only preliminary thin section work has been conducted as of this writing, and geochemical data are not yet available. This report summarizes the geology within the open pit, the characteristics of hydrothermal alteration and mineralization, and the currently recognized controls on the distribution of mineralization.

## GEOLOGY

The geology of the open pit (Figure 2) is dominated by Pothook diorite and a finer grained, porphyritic monzodiorite to diorite which intrudes the Pothook and is tentatively assigned to the Cherry Creek phase of the Iron Mask batholith (Snyder and Russell, 1993). Minor rock types include andesite dikes and plagioclase diorite porphyry dikes. The contact zone between the diorite and monzodiorite is afforded special treatment because it is the locus for development of economic copper-gold mineralization.

## *POTHOOK DIORITE*

The Pothook diorite is the oldest unit and dominates the south and west portions of the pit (Figure 2). Least-altered samples of the diorite are greenish grey and equigranular, with a mineral assemblage comprising euhedral to subhedral plagioclase and pyroxene, poikilitic biotite, anhedral magnetite and potassium feldspar, and accessory euhedral apatite (Table 1); subhedral titanite was observed in one sample. Grain size is typically 1.5 to 3 millimetres, but more fine-grained areas have been recognized, particularly close to the contact with the Cherry Creek monzodiorite. Within the batholith as a whole, the Pothook diorite is notable for a magnetite

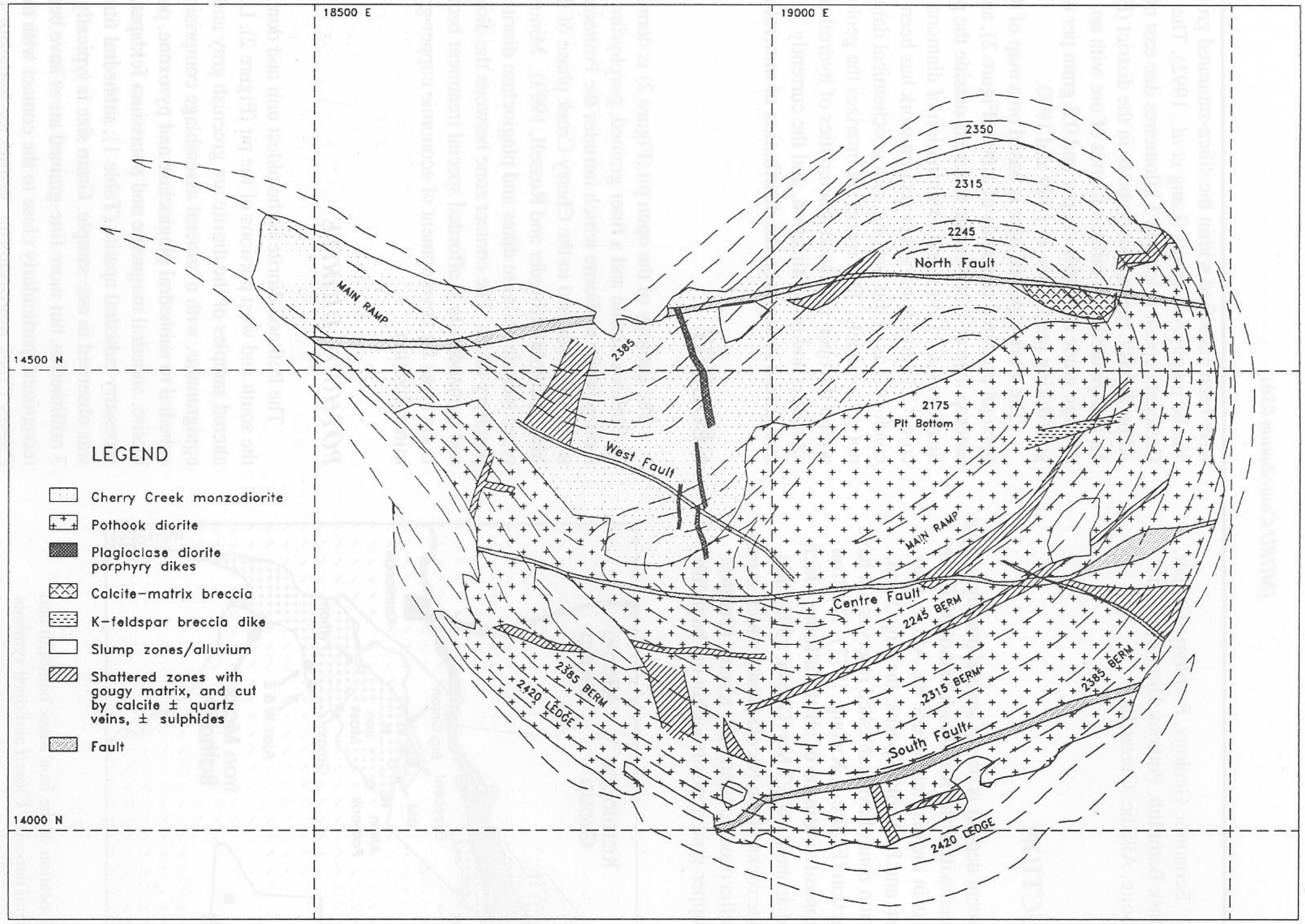



Figure 2. Geologic map of the Crescent open pit.

content which locally exceeds 15%, large poikilitic biotite grains which enclose plagioclase and augite (Snyder and Russell, 1993), and magnetite veins and segregations which may reach several metres in width (Stanley *et al.*, 1994; Cann, 1979); these features are also present in and adjacent to the Crescent deposit. Near its contact with the Cherry Creek monzodiorite, Pothook diorite has been affected by strong potassium metasomatism which has locally given it a pseudoporphyritic texture as a result of conversion of the margins of plagioclase grains to massive, pink potassium feldspar. Subangular to rounded xenoliths of an amphibolitized mafic rock, interpreted as a Nicola volcanic unit, are only rarely present.

## *CHERRY CREEK MONZODIORITE*

The northern part of the pit (Figure 2) is dominated by a monzodioritic to microdioritic intrusion that is assigned to the Cherry Creek phase of the batholith (Stanley *et al.*, 1994). Although it is treated as a single intrusive phase, substantial variation in texture, and possibly in mineralogy, do not preclude the presence of several discrete units. In general, Cherry Creek monzodiorite is more fine grained than Pothook diorite, is variably porphyritic, and ranges from light pinkish grey to greenish grey in colour. Phenocrysts include euhedral plagioclase laths and less abundant, more equant, subhedral to euhedral pyroxene. Strongly altered, subhedral amphibole was observed in trace to minor amounts in a few samples. The aphanitic to fine-grained groundmass comprises potassium feldspar, magnetite, biotite, plagioclase, and sporadic occurrences of apatite (Table 1). Locally, and particularly near intrusive contacts, the plagioclase phenocrysts have a trachytic texture. Strong to intense potassium metasomatism has locally obliterated the porphyritic texture and has converted the rock to a dense, maroon-coloured, nearly aphanitic rock with few visible grains.

**TABLE 1. PETROGRAPHIC CHARACTERISTICS OF THE POTHOOK DIORITE AND CHERRY CREEK MONZODIORITE.**

| | Pothook Diorite | Cherry Ck Monzodiorite |
|---|---|---|
| N | 8 | 5 |
| Pyroxene | 17 to 22 | 12 to 15* |
| Amphibole | | 0 to 5* |
| Biotite | 5 to 15 | 2 to 10* |
| Magnetite | 7 to 10 | 2.5 to 7 |
| Plagioclase | 50 to 55 | 55 to 65* |
| K-Feldspar | <5 to 10 | 7 to 15 |
| Apatite | trace to 0.5 | 0 to low 0.x |
| Quartz | | 15 in one spl |
| Grain Size | 1.25 to 3mm | Matrix: 20-40 microns; Phenos 0.2-1.5mm |
| Phenocryst % | 0 | 0 to 80 |
| Texture | equigranular to seriate | equigranular to porphyritic |

* Observed as a phenocryst phase

## *MINOR ROCK TYPES*

### ANDESITE DIKES

Andesite dikes are rare in the Crescent pit and are typically less than a metre wide, black to dark green in colour, aphanitic, and commonly discontinuous. Larger examples observed elsewhere in the northern part of the Iron Mask batholith have pyroxene phenocrysts to 3 millimetres and may also contain equant plagioclase phenocrysts less than 2 millimetres in size. The groundmass is always macroscopically aphanitic. These rocks have not been affected by alteration or mineralization events, and may be related to the Eocene mafic volcanism of the Kamloops Group. In the pit, andesite dikes are cut by flat fractures and faults but offsets in excess of 2 metres were not observed.

### PLAGIOCLASE DIORITE PORPHYRY DIKES

Plagioclase diorite porphyry dikes are common throughout the northern end of the batholith but are rare and of very minor volume in the Crescent pit. As a group, they are typically dark green in colour, and range from less than 1 metre to about 5 metres in width. Narrow examples are commonly aphyric or have only very small plagioclase phenocrysts. Wider dikes have cores characterized by subhedral plagioclase, and more rarely pyroxene phenocrysts, in a fine-grained to aphanitic, dark grey-green groundmass, and chilled, dark grey, aphanitic margins up to 1 metre in width. Contacts with the hostrock are typically sharp but are commonly irregular. Xenoliths, where present, are limited to the immediate wallrock and are volumetrically minor. These dikes intruded during the waning stages of the pervasive potassium metasomatism event described below; in the Crescent pit, however, they are cut by later mineralized veins.

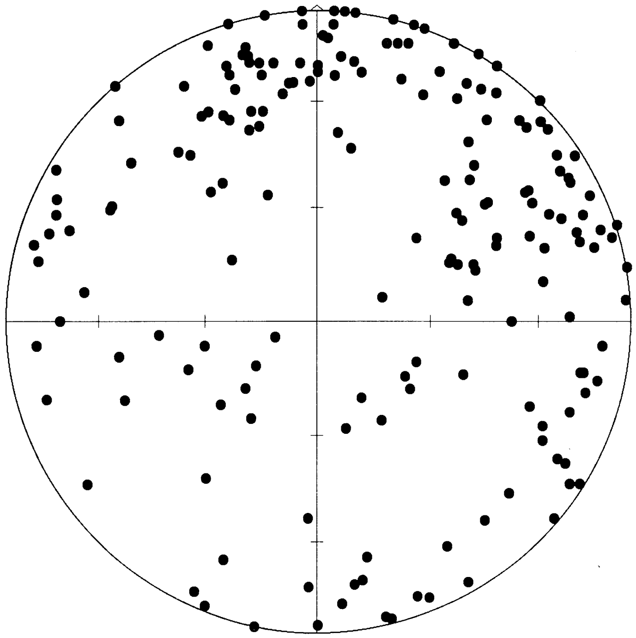


Figure 3. Lower hemisphere projection of poles to faults and fractures, Crescent deposit. Only those fractures continuous over at least one full bench face are included.

## *STRUCTURES*

Major faults which could be traced visually across the pit include the North, Centre, South and West faults (Figure 2). The absence of marker units has, however, severely limited assessment of offset. The North fault is the largest break and varies in width from 1 to about 5 metres along its easterly trace. It may be offset slightly by the West fault. The North fault cuts the plagioclase diorite porphyry dike but does so right at the bedrock surface on the 2385 bench (Figure 2) and offset cannot be determined. The Centre fault is parallel to the North fault but less prominent. On the southernmost margin of the pit, the South fault forms a major fracture zone of unknown offset with a trend of 070$^{o}$. The West fault is visible in the south wall of the pit as a major structure, but it disappears beneath the flooded pit bottom and projects beneath the main ramp; displacement of the plagioclase diorite porphyry dikes between benches 2245 and 2315 suggests a maximum offset of a few metres. The Centre fault may have effected left-lateral offset of the West fault by up to 35 metres. These major fault zones are dominated by gougy or strongly shattered material with abundant calcite and chlorite; locally they contain calcite-quartz±pyrite veins, very rarely with trace chalcopyrite.

All rocks exposed in the open pit are intensely fractured. Typically these fractures are planar and many can be traced over more than one bench. The fractures are filled with strongly shattered rock which is usually cut by veins and vein swarms comprising calcite-chlorite-quartz±pyrite±epidote±trace chalcopyrite. The width of the broken material is usually less than 10 centimetres, but may range up to several metres. Hydrothermal veins may be the dominant fill in narrower fractures but form only a small portion of the filling of larger structures. Most of the fractures dip more steeply than 60$^{o}$ and have orientation modes of roughly 350$^{o}$, 060$^{o}$ and 120$^{o}$ (Figure 3). Fractures with relatively shallow dip were also noted. Steeply dipping fractures almost invariably host hydrothermal veins but veins are largely absent from flatter fractures. The preferred orientations are roughly parallel to the major faults, the contact zone between the Pothook and Cherry Creek intrusions, and the zone of mineralization.

## CONTACT BETWEEN POTHOOK AND CHERRY CREEK INTRUSIONS

The contact zone between the two major intrusive phases provided the locus for hydrothermal alteration and mineralization in the Crescent deposit. Vein density and alteration are most intense immediately adjacent to the contact zone. The most important features along this contact are development of intrusion breccias, pervasive potassium metasomatism, and the formation of pseudobreccia textures as a consequence of hydrothermal veining. The intensity of the metasomatism commonly obscures the nature and exact location of the contact itself.

Near its contact with the Pothook diorite, the Cherry Creek monzodiorite contains exotic inclusions which increase in abundance as the contact zone is approached and which become sufficiently abundant locally for the rock to be called an intrusion breccia. The fragments are mostly angular, but range to subrounded. They are dominated by Pothook diorite which displays various degrees of development of potassium metasomatism. Less common xenoliths include fragments of amphibolitized Nicola volcanic units, and fragments of massive magnetite veins which are similar to the magnetite segregations common in the Pothook diorite. Even more rarely, fragments macroscopically similar to the Cherry Creek intrusion itself are present; these are either ripped up margins of the Cherry Creek intrusion or strongly metasomatized Pothook diorite which has assumed a pseudoporphyritic texture, as described above.

To the south of the contact lies what may be an intrusion breccia in the form of a dike (Figure 2). The matrix is similar to the Cherry Creek phase but is not macroscopically porphyritic. Fragments include Pothook diorite with various degrees of potassium metasomatism, finer grained porphyries similar to the Cherry Creek unit and, more rarely, fragments of a mafic rock now converted to amphibolite. The fragments are typically angular, but some are milled to a subrounded form. The dike has a constant thickness of about 2 metres in the single exposure on the main ramp. It is not mapped on the overlying bench, but may widen to the west where it is exposed in a narrow rill on the floor of the main ramp.

The main contact is typically obscured by intense potassium metasomatism. This alteration event was contemporaneous with intrusion of the Cherry Creek monzodiorite, and affects both the Pothook and Cherry Creek intrusions. Typically, primary igneous plagioclase and white potassium feldspar are selectively replaced by salmon-pink potassium feldspar. Magnetite is destroyed in strongly altered areas. The alteration is centred on the contact and strong effects extend up to 75 metres into the Pothook diorite, at which point the intensity of alteration decreases gradationally but rapidly, although local effects are visible well beyond the pit boundary to the southeast. In many places near the contact the Pothook diorite acquires a 'spotted' texture resulting from formation of ovoid clots up to 7 millimetres across, comprising chlorite with lesser calcite; this texture reliably indicates proximity to the contact both within the Crescent deposit and elsewhere in the northern end of the batholith. Nearly identical occurrences of potassium metasomatism are present in many exposures of Pothook diorite in the northern end of the batholith and these have commonly been mapped as Cherry Creek monzonite and syenite. This alteration is best described as deuteric. It preceded the introduction of sulphides into the Crescent deposit; later mineralizing fluids overprinted the early deuteric alteration but apparently followed similar flow paths.

## ALTERATION AND MINERALIZATION

### *SEQUENCE OF VEIN TYPES*

Six vein types have been recognized in the pit. Crosscutting relationships are well defined and permit a paragenetic sequence to be established (Table 2).

#### MAGNETITE VEINLETS

Magnetite veinlets have irregular forms and are most common near the main intrusive contact. They are usually less than 1 millimetre wide but may exceed 1 centimetre. They have narrow, distinct alteration envelopes of pink potassium feldspar. Although minor chalcopyrite has been observed, these veins are not abundant and did not carry significant copper.

#### POTASSIUM FELDSPAR VEINS/DIKELETS

Throughout the deposit, veins of pink potassium feldspar with minor biotite have the appearance of syenite dikelets. In the pit, most of these veins formed as replacements of wallrock along tight fractures, but an intrusive origin cannot be ruled out for larger examples with very sharp contacts with their host. An intrusive origin is not inconsistent with observations in other parts of the northern end of the batholith where similar dikelets have been noted near the contact between Pothook diorite and Cherry Creek intrusions. Sulphide is rare in these veins and they did not contribute substantially to ore grade.

#### CHLORITE-SULPHIDE VEINS

Chlorite-sulphide veining is best developed within the tabular ore zone and its hangingwall in the Pothook diorite. The altered and mineralized rocks have a distinct mottled colour in shades of pink, black and green. Individual veinlets are narrow and discontinuous and may impart a brecciated appearance to the rock. The dominant minerals are chlorite and magnetite. Chlorite may be a replacement of biotite, which has been observed locally. Magnetite either coexists with or is replaced by hematite. Calcite is common, potassium feldspar is usually present as a trace mineral, and epidote was observed in one case. Quartz is minor and sporadically present and pyrite is absent to minor. Several percent chalcopyrite may be present within veinlets of calcite, chlorite and minor quartz, or in their alteration envelopes. Hostrock between the veinlets is usually altered by potassium feldspar, chlorite, magnetite/hematite and calcite. In the most intensely veined rocks, magnetite is often destroyed, but may be preserved only millimetres away from veins. This alteration type is largely coincident with the ore zone, and the high abundance of chalcopyrite in these veins suggests that they carry most of the copper.

#### EPIDOTE VEINS

Epidote veins are abundant and widespread but are most common peripheral to the tabular ore zone. They vary from planar structures to more irregular, diffuse veins and, more rarely, they form the matrix to small breccia zones. They range from less than a millimetre to several centimetres in width. Epidote and calcite are the major minerals but pyrite and chalcopyrite locally constitute up to 10%. Minor potassium feldspar and albite(?) were observed, together with rare quartz. Distinct alteration envelopes were not observed, but the veins are often associated with clots of alteration minerals similar to those found in the veins themselves. Chlorite is common in the alteration clots and in the wallrocks to the veins, and is associated with

**TABLE 2. PETROGRAPHIC CHARACTERISTICS AND SEQUENCE OF HYDROTHERMAL VEINS.**

| Vein/Alteration Stage | Major Minerals | Minor Minerals | Envelopes | Morphology |
|---|---|---|---|---|
| ***Early*** | | | | |
| Magnetite | mag | cpy | K-spar | sinuous |
| K-spar-dominated | K-spar | bio-cpy-mag-hem | K-spar | irregular |
| Chlorite-Sulfide | chl-mag-hem-calc-cpy | K-spar-ep-qtz-py | mag? | irregular |
| Calcite-Quartz | calc-qtz | hem-py-cpy-K-spar-ep | K-spar-mag-cpy | planar |
| Epidote-dominated | ep-cac-py-cpy | K-spar-qtz | K-spar-chl | planar |
| Calcite Only | calc | py-chl | none | planar |
| ***Late*** | | | | |

Abbreviations: chl, chlorite; calc, calcite; ep, epidote; qtz, quartz; py, pyrite; cpy, chalcopyrite; mag, magnetite; hem, hematite; K-spar, potassium feldspar

disseminated chalcopyrite. Beyond the pit boundary these veins carry magnetite, hematite, epidote and minor calcite, in some cases with alteration envelopes of albite and/or epidote.

### CALCITE-QUARTZ VEINS

Calcite-quartz veins are broadly distributed through the deposit. They range from 2 millimetres to several centimetres in width, have sharp contacts with their host, and are usually planar. Calcite usually, but not always, exceeds quartz in abundance. Hematite, pyrite, chalcopyrite, and potassium feldspar are present, and epidote was observed in one sample. Envelopes of pink potassium feldspar similar in width to the veins themselves are almost always developed. In one sample an alteration envelope grades from an inner zone comprising potassium feldspar with minor magnetite and chalcopyrite to an outer zone of magnetite with minor chalcopyrite. Commonly, the grain size of calcite and the abundance of quartz increase toward the core of these veins; the reverse is rare.

### CALCITE VEINS

Veins dominated by calcite, with common but minor chlorite and very rare pyrite, occur throughout the deposit. They range from fracture coatings to dilatant veins many centimetres wide, are continuous and planar, have sharp contacts with their hosts, and lack alteration envelopes. Similar veins have been recognized throughout the northern end of the batholith; they have been observed to cut Eocene dikes and are unrelated to mineralization in the Crescent deposit.

### OPEN SPACE BRECCIAS

True open-space hydrothermal breccias are common. Fragments are typically angular and have not been milled. The matrix of breccias is usually dominated by calcite with lesser quartz and, less commonly, chalcedony. Typically the matrix contains little or no sulphide although rare, small examples with up to 10% chalcopyrite have been observed. Most sulphide contained in hydrothermal breccias occurs in the fragments. One sample shows two stages of brecciation. The later stage has an unmineralized calcite matrix. Fragments within this matrix are themselves an earlier breccia with a matrix of calcite and minor hematite, chalcopyrite and pyrite; the fragments in this earlier breccia are altered by potassium feldspar and chlorite, and contain over 5% sulphide with a high chalcopyrite to pyrite ratio. The sulphides are in part disseminated and in part contained within calcite-quartz veins that are restricted to the fragments. Larger examples of these breccias are spatially related to major faults.

## *DISTRIBUTION OF ALTERATION MINERALS*

A visual estimate of the percentage of epidote, magnetite, potassium feldspar, chlorite, albite, calcite, pyrite, chalcopyrite, quartz and hematite was made for the bench face at stations spaced 15 metres apart. The

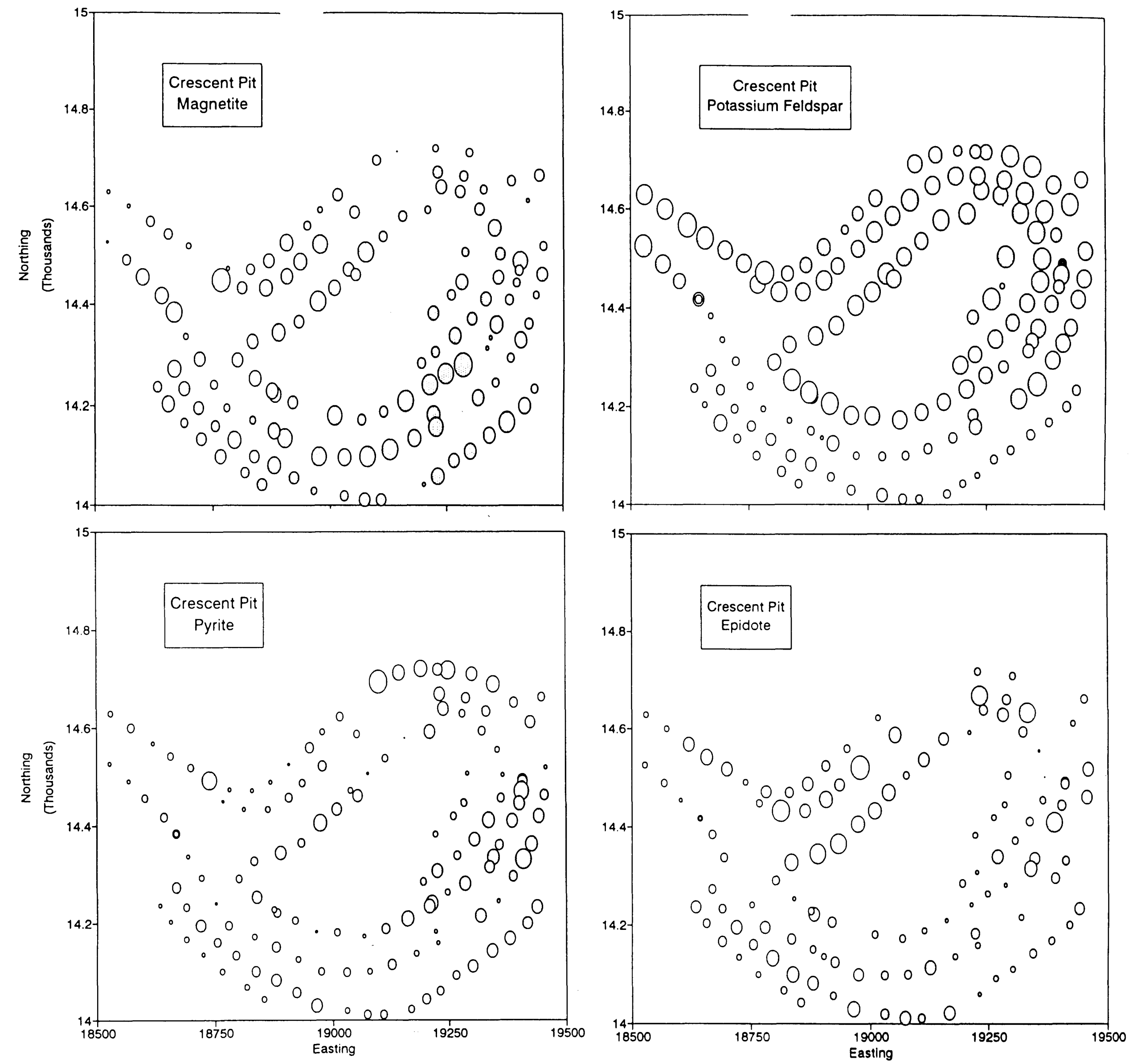
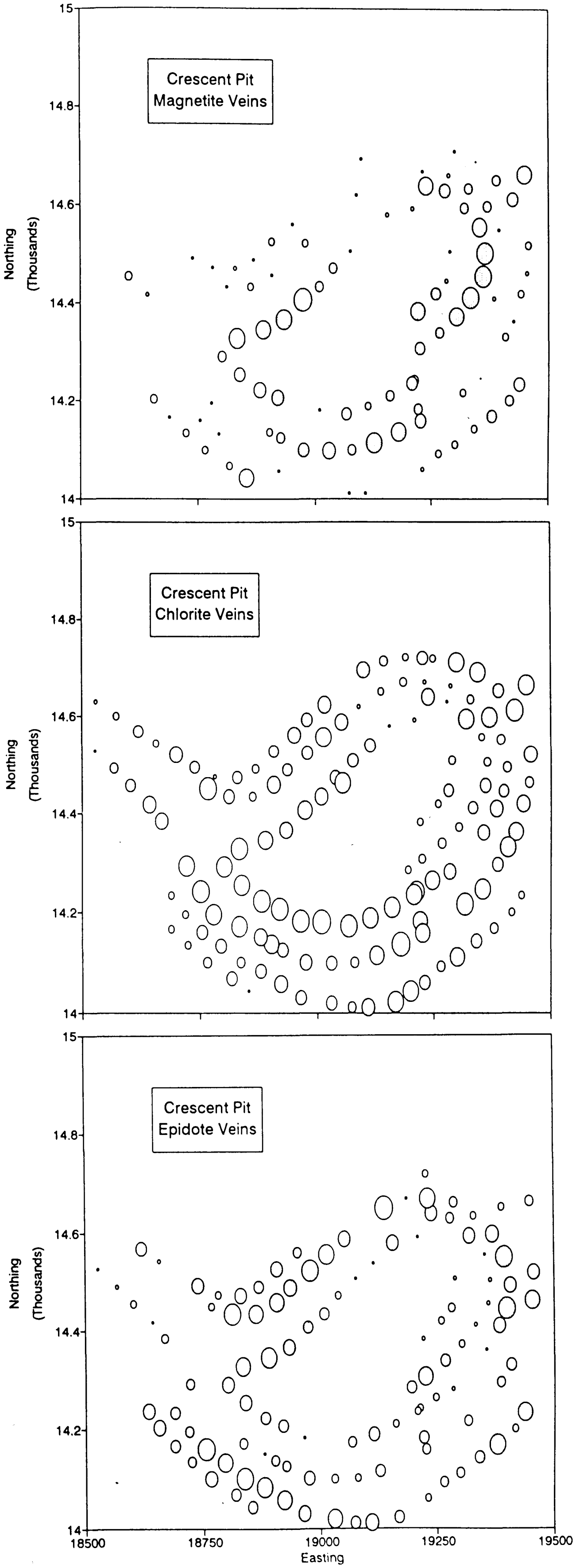



Figure 4. Bubble plots of alteration mineral distribution. Data are visual estimates at 15-metre stations along each accessible bench. Bubble diameter is proportional to value. Maximum values for potassium feldspar, magnetite, pyrite, and epidote are 65%, 15%, 7%, and 20%, respectively.

data were analyzed on bubble plots (Figure 4). Among the minerals not shown on Figure 4, calcite and chlorite are very evenly distributed, and quartz, hematite and albite are erratically distributed with no apparent pattern. A reconnaissance examination of thin sections has shown that visual estimates of chalcopyrite have unacceptably large errors because of its finely disseminated occurrence. Magnetite, potassium feldspar, pyrite and epidote are shown on Figure 4. Magnetite is largely disseminated and is consistently abundant throughout the deposit, even though the Pothook diorite contains nearly twice as much primary magnetite as the Cherry Creek monzodiorite; this reflects the partial destruction of magnetite during potassium metasomatism of the Pothook diorite.

Potassium feldspar is more abundant in the Cherry Creek monzodiorite and in the areas of Pothook diorite affected by strong potassium metasomatism; a sharp decrease is apparent on the south and west sides of the pit. The abrupt decrease on the west occurs at an atypically sharp contact between the Pothook and Cherry Creek units that is not characterized by the usual intrusion or hydrothermal brecciation present elsewhere; the 'tightness' of the contact may have limited fluid flow at this point. Pyrite and epidote abundance is highest on the margins of the deposit and reflects a propylitic, pyritic halo surrounding the ore zone.

At each alteration station (Figure 5), the relative abundance of each vein type was assigned a value from 0



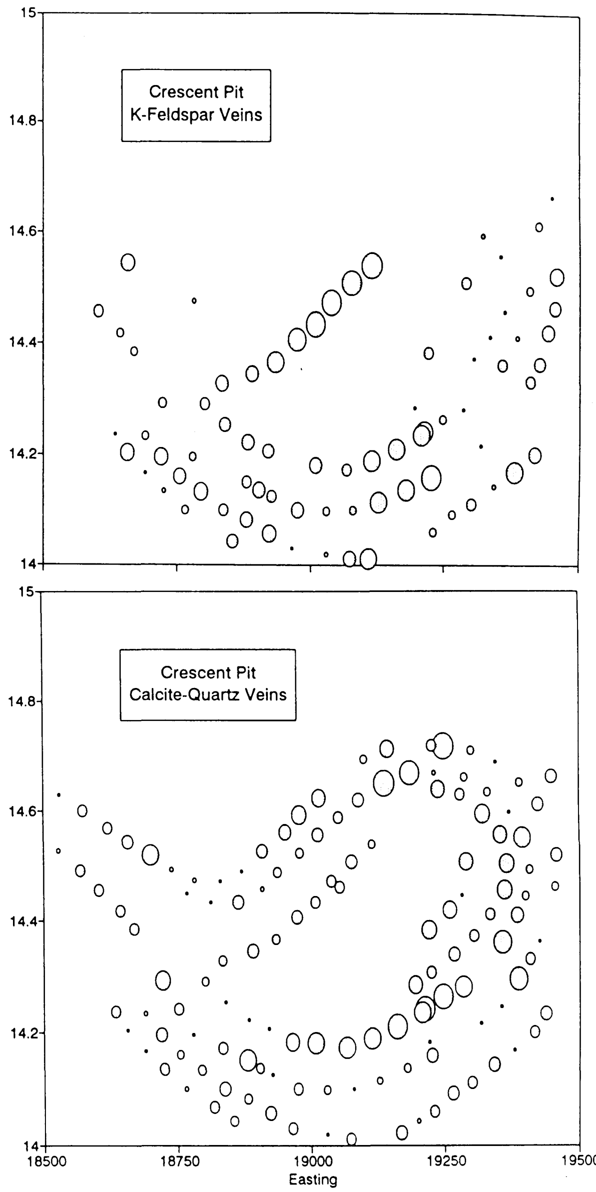




Figure 5. Distribution of veins. The points are based on visual estimates of the density of a given vein on a scale of 0 (absent) to 5 (greatest observed density of that vein type). Bubble diameter is proportional to value.

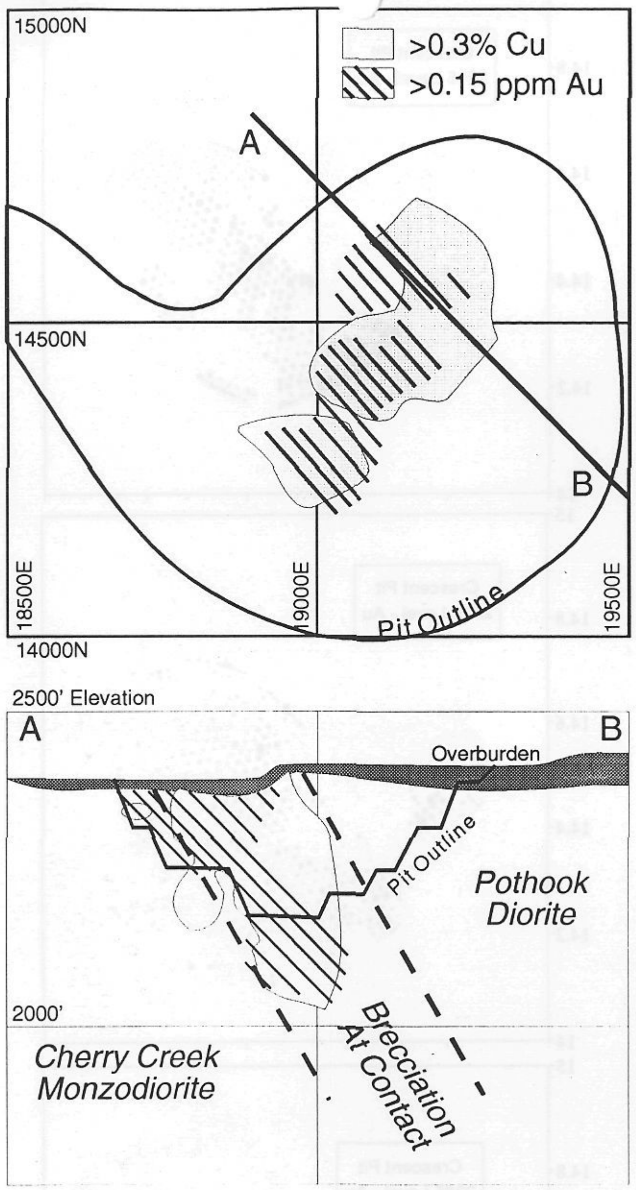



Figure 6. Plan and cross-section distribution of mineralization in the Crescent deposit. Simplified from Bond and Tsang (1988).

(absent) to 5 (greatest number of that particular vein type observed). Magnetite veins occur in both the Pothook diorite and the Cherry Creek monzodiorite but are most abundant near the contact zone. Potassium feldspar veins are more commonly developed in the Pothook diorite, but their greatest and most consistent abundance is on the 2245 level, near the contact zone. Chlorite-sulphide veins are more abundant in the hangingwall of the contact, roughly coincident with the ore zone. Calcite-quartz veins show no distinct distribution pattern. Epidote veins are most abundant on the margins of the pit. The only vein type that is well developed outside the confines of the pit is epidote-magnetite veins which occur sporadically in many exposures of the Pothook diorite throughout the northern end of the Iron Mask batholith; these veins are indigenous to the Pothook diorite itself and are not directly related to the formation of the copper-gold deposits.

## *DISTRIBUTION OF MINERALIZATION*

The ore reserve in the Crescent pit formed a tabular zone oriented about $050^{o}$ with a southerly dip of $60^{o}$ (Figure 6; Bond and Tsang, 1988). Mineralization continues downward to at least the 300-metre limit of drilling (L.H.C Tsang, personal communication, 1993). Chalcopyrite was the dominant ore mineral, and insignificant amounts of bornite and molybdenite are also reported (Bond and Tsang, 1988). Figure 7 illustrates the distribution of copper and gold as determined from blast-hole assays. A comparison with Figure 2 shows that the higher grades were present along the contact zone and its immediate hangingwall but that sporadic high values were present throughout the deposit. Gold has a more erratic distribution, but Figure 8 shows a good correlation between copper and gold at a nearly constant ratio of about 25,000. This ratio is consistent with values observed at other alkalic porphyry copper-gold deposits and is apparently a fundamental feature of this deposit type (Stanley, 1993). The absence of samples with lower Cu/Au ratios indicates that a late stage episode of gold enrichment, similar to that which has affected some deposits of this class such as the nearby Pothook deposit (Stanley, 1994) and the 66 zone at Mount Milligan (Stanley and DeLong, 1993), has not affected the Crescent deposit. In the Crescent deposit, gold was deposited with chalcopyrite in a single hydrothermal event.

## SUMMARY

The Crescent deposit formed in the earliest Jurassic in response to the intrusion of alkalic igneous rocks of the Iron Mask batholith. A proposed sequence of events is presented in Table 3. Mineralization, alteration, and vein formation were localized at the brecciated contact between the older Pothook diorite and the younger Cherry Creek monzodiorite. Relatively more permeable intrusion breccias may have focussed fluid flow. Early deuteric alteration related to intrusion of the Cherry Creek monzodiorite effected intense potassium metasomatism but did not deposit sulphide minerals in the system. This event was closely followed in sequence by magnetite, potassium feldspar, chlorite-sulphide, calcite-quartz, and epidote veins. Ore grade mineralization is associated with chlorite (after biotite?) veining and alteration, and forms a tabular zone along the contact that extends southward into Pothook diorite in the hangingwall. Epidote and pyrite extend beyond the deposit and form a weak halo surrounding the ore zone.

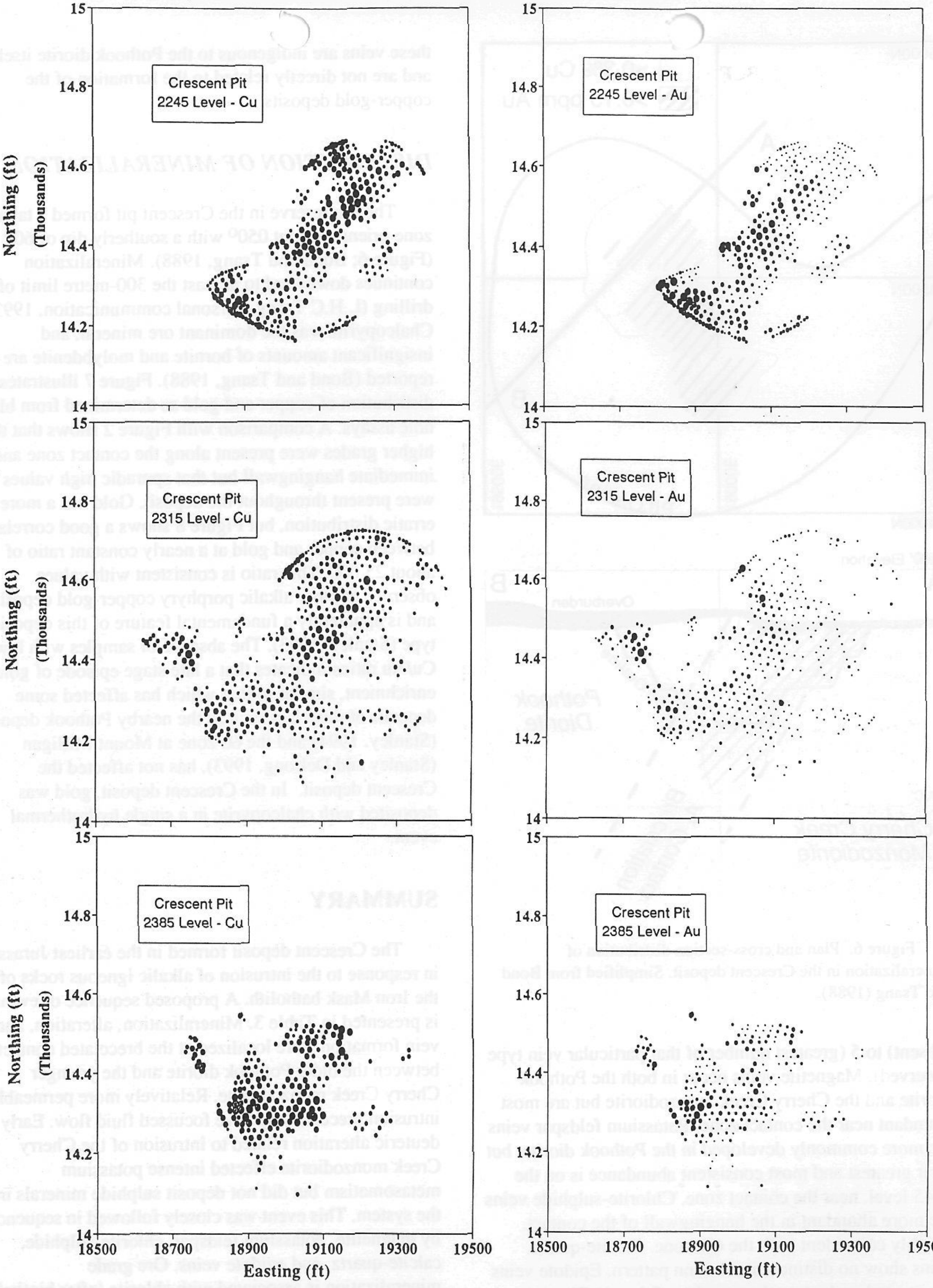



Figure 7. Bubble plots of copper and gold blast-hole assays. Data are shown for each of the four main benches. Bubble diameter is proportional to value. For each respective level N, the number of data points, maximum and minimum copper grade (wt. %), and maximum and minimum gold grade (g/t) are: 2175 level, 258, 2.09, 0.09, 0.82, 0.035; 2245 level, 349, 1.41, 0.06, 0.86, 0.00; 2315 level, 511, 1.83, 0.11, 1.82, 0.00; 2385 level, 236, 1.25, 0.13, 1.41, 0.035.

**TABLE 3. SEQUENCE OF EVENTS AFFECTING THE CRESCENT DEPOSIT.**

| Timing | Geologic Event |
|---|---|
| 1 | Intrusion of Pothook diorite |
| 2 | Intrusion of Cherry Creek monzodiorite |
| 3A | Formation of intrusion breccias at contact |
| 3B | Potassium metasomatism at contact |
| 3C | Formation of pseudobreccias by K-feldpsar veining (Cu-Au mineralization) |
| 4 | Intrusion of plagioclase diorite porphyry dikes |
| 5A | Formation of hydrothermal veins (Cu-Au mineralization) |
| 5B | Movement along major faults; formation of major fractures |
| 5C | Formation of barren calcite-quartz+/-pyrite veins |
| 6 | Intrusion of andesite dikes |
| 7 | Minor additional fault movement; formation of barren calcite veins |

Hydrothermal breccias closely related to faults are common but generally postdate main-stage copper mineralization. A constant Cu/Au ratio of 25000 is similar to other alkalic suite porphyry deposits and indicates that copper-gold introduction was related to a single hydrothermal event.

## REFERENCES


Bond, L.A. and Tsang, L.H.C. (1988): Diamond Drilling on the CID1, CID2, and Winty C. G. Mineral Claims; Afton Operating Corporation, Private Report, 53 pages.

Cann, R.M. (1979): Geochemistry of Magnetite and the Genesis of Magnetite-Apatite Lodes in the Iron Mask Batholith, British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, 196 pages.

Ghosh, D.K. (1993): Uranium-Lead Geochronology; *Mineral Deposit Research Unit - The University of British Columbia*, Copper-Gold Porphyry Systems of British Columbia, Annual Technical Report - Year 2, pages 11.1-11.26.

Kwong, Y.T.J. (1987): Evolution of the Iron Mask Batholith and its Associated Copper Mineralization; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 77.

Lang, J.R., Stanley, C.R. and Thompson, J.F.H. (1992): Quartz-Alkalic and Nepheline-Alkalic: Two Distinct Subtypes of Porphyry Deposits Related to Alkalic Igneous Rocks; *Geological Society of America,* Abstracts With Programs, Volume 24, page A143.

Snyder, L.D. and Russell, J.K. (1993): Field Constraints on Diverse Igneous Processes in the Iron Mask Bathjolith (92I9,10); *in* Geological Fieldwork 1992, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1993-1, pages 281-286.

Souther, J.G. (1992): Volcanic Regimes; *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Society of America*, The Geology of North America Decade of North American Geology Series, Volume G-2, pages 457-490.

Stanley, C.R. (1993): A Thermodynamic Geochemical Model for the Co-precipitation of Gold and Chalcopyrite in Alkalic Porphyry Copper-Gold Deposits; *Mineral Deposit Research Unit-The University of British Columbia*, Copper-Gold Porphyry Systems of British

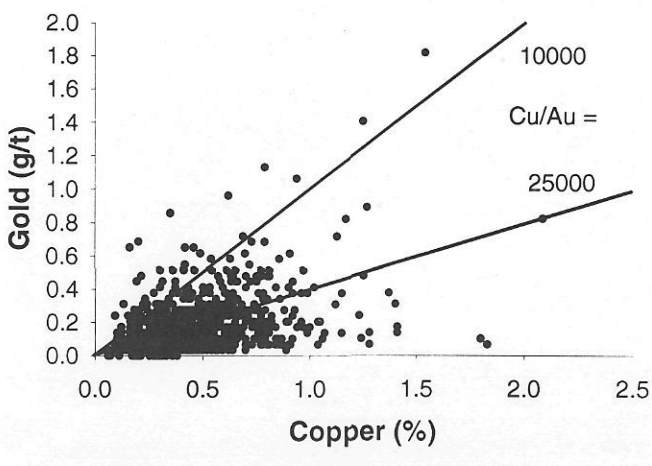




Figure 8. Copper and gold blast-hole assay data, Crescent deposit.

Columbia, Annual Technical Report - Year 2, pages 12.1-12.17.

Stanley, C.R. (1994): Geology of the Pothook Alkalic Porphyry Copper-Gold Deposit, Afton Mining Camp, British Columbia (92I/9,10); *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.

Stanley, C.R. and DeLong, C. (1993): A Crystal Chemical Analysis of Hydrothermal Biotite From the MBX and 66 Zones, Mt. Milligan Cu-Au Porphyry Deposit; *Mineral Deposit Research Unit - The University of British Columbia*, Copper-Gold Porphyry Systems of British Columbia, Annual Technical Report - Year 2, pages 9.1-9.12.

Stanley, C.R., Lang, J.R. and Snyder, L.D. (1994): Geology and Mineralization in the Northern Part of the Iron Mask Pluton, Iron Mask Batholith, British Columbia (92I/9,10); *in* Geological Fieldwork 1993, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, this volume.