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Porphyry Cu-Au Deposits of the Iron Mask Batholith, Southeastern British Columbia

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INTRODUCTION

The Iron Mask batholith is located 10 km southwest of Kamloops (Fig. 1). It is the source of Cu-Au-Ag produced from porphyry deposits such as Afton, Crescent, Pothook, Ajax West and Ajax East, as well as structurally controlled Cu-magnetite veins (Iron Mask, Makaoo, Grey Mask). Currently, it is the target of exploration for Cu-Au-Ag-Pd mineralization by DRC Resources at the Afton mine property and by Abacus Mining and Exploration Corp. at the Rainbow-Coquihalla East and DM-Audra occurrences.

The Iron Mask component of the Cu-Au Porphyry Project is a regional mapping and compilation study designed to produce an up-to-date geological map of the Cu-Au–enriched Iron Mask batholith. The study incorporates information from the MDRU-Porphyry Cu-Au study (ca. 1991) and company reports to update the last published regional map of Kwong (1987). The compilation has utilized the detailed, low-level, airborne geophysical survey carried out over the Iron Mask batholith by the Geological Survey of Canada (Shives, 1994) to better define structures and the distribution of individual intrusive phases, alteration and mineralization in areas of little or no outcrop. Results of the study arise from collaborative partnerships between the British Columbia Ministry of Energy and Mines, Abacus Mining and Exploration Corporation, Imperial Metals Corporation and NovaGold Resources Inc.

PREVIOUS WORK

The geology of the Iron Mask batholith and its ore deposits have been described by Cockfield (1948), Carr (1957), Carr and Reed (1976), Preto (1967, 1972), Northcote (1974, 1976, 1977), Hoiles (1978), Kwong (1982, 1987) and Kwong *et al.* (1982). Recent work on porphyry Cu-Au deposits by the Mineral Deposit Research Unit of the University of British Columbia include studies by Ross (1993), Snyder and Russell (1993, 1995), Snyder (1994), Lang and Stanley (1995) and Ross et. al. (1995). Nixon

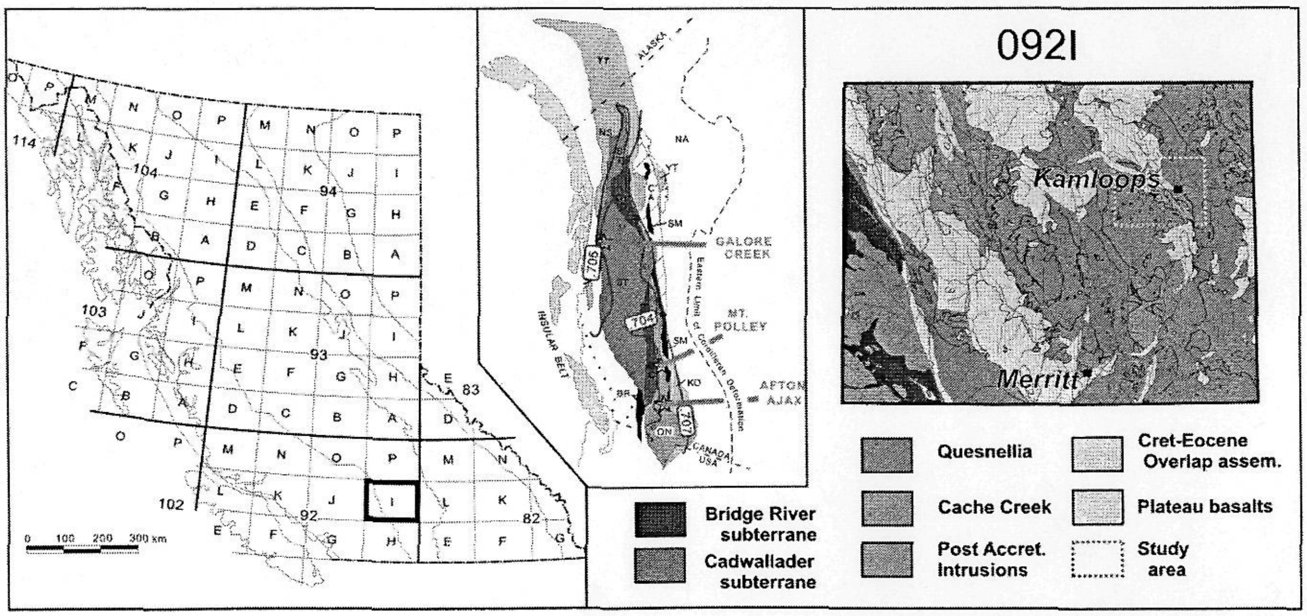


Figure 1. Location of the Iron Mask component of the Cu-Au Porphyry Project in south-central British Columbia (NTS 092I). Inset is terrane map of northern Cordillera (modified from Wheeler and McFeely, 1991), showing the tectonostratigraphic setting of the three study areas. Mesozoic initial strontium isopleths are from Armstrong (1988). Box on right shows detailed terrane relationships for NTS 092I and the project area.

(2004) conducted petrographic and geochemical studies of the PGE distribution in the Afton deposit as part of a larger provincial study.

REGIONAL GEOLOGY

The study area lies along the eastern margin of the Intermontane Belt close to its tectonic boundary with the Omineca Belt, in south-central British Columbia. At this latitude, the Intermontane Belt is underlain mainly by unmetamorphosed Upper Paleozoic to Lower Paleozoic arc-volcanic, plutonic and sedimentary rocks of the Quesnel Terrane. Farther west are coeval rocks of the oceanic Cache Creek Terrane (Fig. 1). The Quesnel Terrane consists of a Late Triassic to Early Jurassic magmatic-arc complex that formed above an east-dipping subduction zone (Mortimer, 1987). The Cache Creek Terrane, with its blueschist-facies rocks, represents the remnants of this subduction-accretionary complex (Travers, 1977), which was active until the Middle Jurassic. To the east of the Quesnel Terrane are rocks of the Omineca Belt, which include Upper Paleozoic oceanic rocks of the Slide Mountain Terrane and Paleozoic and older metasedimentary, metavolcanic and metaplutonic rocks of the pericratonic Kootenay Terrane. The Slide Mountain Terrane consists of basalt, chert and gabbro, but also clastic units that can be correlated with rocks of the Kootenay Terrane and has been interpreted to represent a marginal or back-arc basin that developed directly outboard of North America (Klepaki and Wheeler, 1985; Schiarizza, 1989; Ferri, 1997). Amalgamation of the Intermontane Belt (Cache Creek, Quesnel, Stikine and Slide Mountain terranes) began in the Late Paleozoic with initial closure of the Slide Mountain ocean basin and was complete by the Middle Jurassic. In the Early Jurassic (186 Ma), Quesnellia rocks were thrust eastward over the North American miogeocline . By the Middle Jurassic, Stikinia had collided with Quesnellia, resulting in the demise of the Cache Creek subduction zone (173 Ma) and stitching of the boundary by ~172 Ma plutons . The tectonic boundary between the Kootenay and Quesnel terranes is intruded by the Jura-Cretaceous Raft batholith north of Kamloops. Middle Eocene volcanic and sedimentary rocks of the Kamloops Group unconformably overlie the Nicola Group and Iron Mask rocks, and Miocene alkaline flood basalts are the youngest rocks in the region (Fig. 2).

MAP COMPILATION

Figure 2 is a compilation map of the Iron Mask batholith. Contact configuration is based upon seven weeks of fieldwork by the authors, with heavy reliance on previously published mapping. Principal compilation sources are Carr (1957), Northcote (1977) and compilations by Kwong (1987), and Stanley *et al.* (1994). Company reports and maps, as well as topical studies, contain many excellent observations, normally on a detailed scale, that have been incorporated into the works cited. Many of the compilation sources lack indication of outcrop distribution or other data sources that constrain the geological contacts shown, such as drillholes, trenches, or underground workings. Carr (1957) is one exception, and we have applied a high weighting to this compilation source. In many instances, workings that were open to Carr, have now collapsed, or have been overgrown. We show the outcrops, workings and drillholes that helped to constrain his interpretations in areas where we lacked field data. Field stations shown by Northcote (1977), presumably indicating the presence of outcrop, are also given a high weighting. Where the near-subsurface geology is constrained by underground workings, we have shown the data projected to surface as if the geological relationships were visible in outcrop. In areas of no exposure or subsurface information, we have relied upon the aeromagnetic response of the buried bedrock to guide the interpretation of contacts shown in Figure 2.

AEROMAGNETIC LINEAMENTS

In 1993, a multiparameter airborne geophysical survey of the Iron Mask batholith area was flown by Sander Geophysics Limited, under contract to the Geological Survey of Canada. The survey collected quantitative gamma-ray spectrometric (K, U, Th), VLF-EM and aeromagnetic data. The data were processed and results presented on 1:150 000-scale colour maps and stacked profiles (Shives, 1994). Distinctive airborne geophysical signatures are apparent for all 20 of the known deposits (low eTh/K ratio with strong, flanking, high magnetic signature). Carmel Lowe of the Geological Survey of Canada, Sidney Subdivision reprocessed components of the 1993 data and converted them into image formats that could be registered with our current geological compilation.

A structural discontinuity that marks an abrupt transition from nonfoliated to strongly foliated rocks, situated southwest of the batholith, corresponds with an equally abrupt drop in the aeromagnetic response of the well-exposed rocks. This is presumably due to magnetite destruction during fabric development. A strong vertical gradient results, which roughly corresponds with the mapped trace of the Cherry Creek Fault (Fig. 3). Flexures within the trend of the vertical gradient anomaly (4 km due west of Jacko Lake), might be due to a folded deformation front.

Aeromagnetic response does not in all instances reflect the bedrock lithology. The Iron Mask Hybrid phase contains abundant coarse interstitial grains of magnetite and typically displays magnetic susceptibility an order of magnitude higher than most other rock types. However, extensive brittle faulting can destroy magnetite in the hybrid unit (such as the eastern contact near the Makaoo, or at the Galaxy deposit) and undeformed pegmatitic hybrid phases may also lack a high magnetic susceptibility. Intrusive units with a typically low magnetic susceptibility may show elevated values, particularly where adjacent to the hybrid unit. Such anomalies appear to have a strong association with copper mineralization (e.g., Joker).

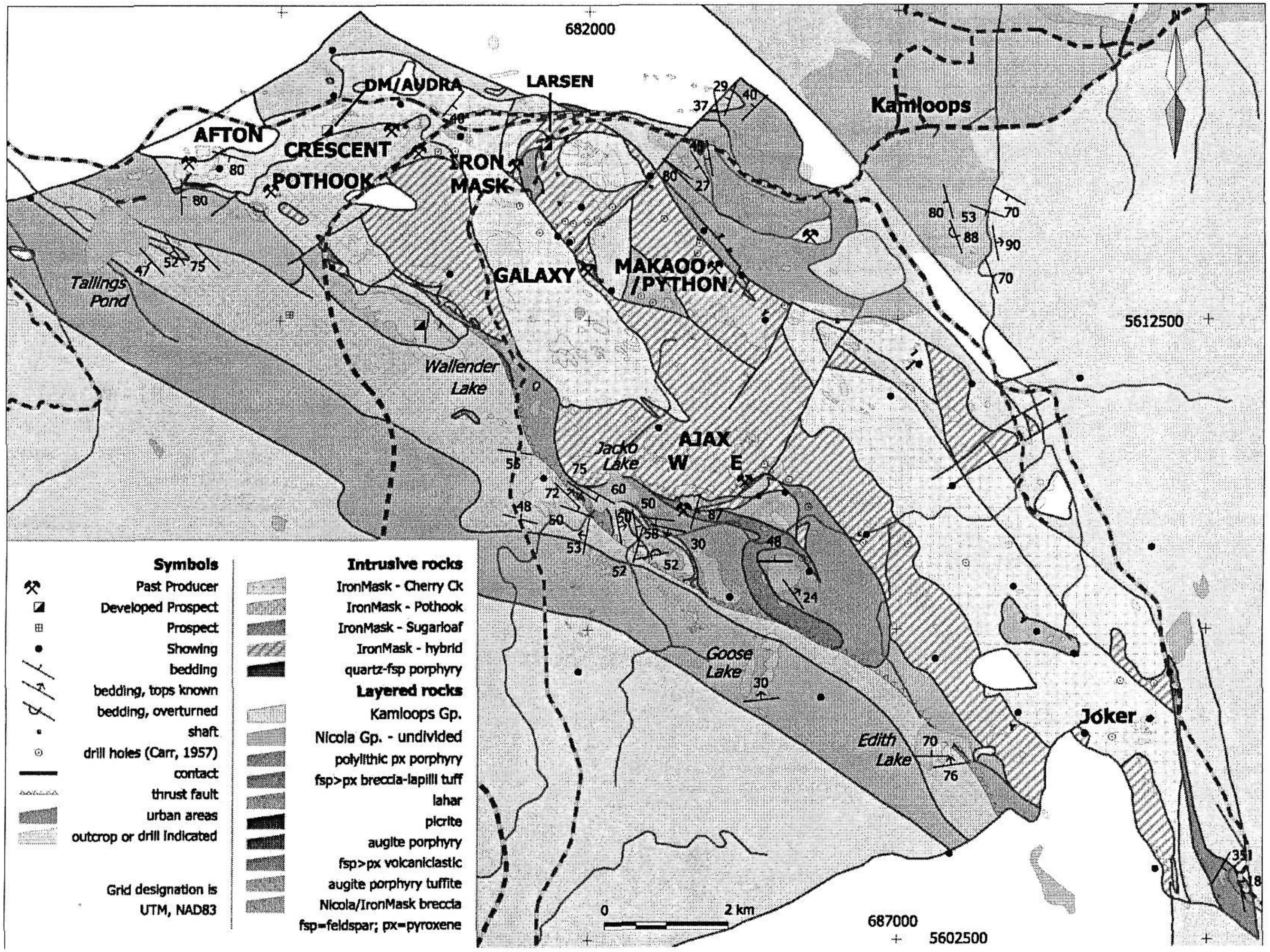
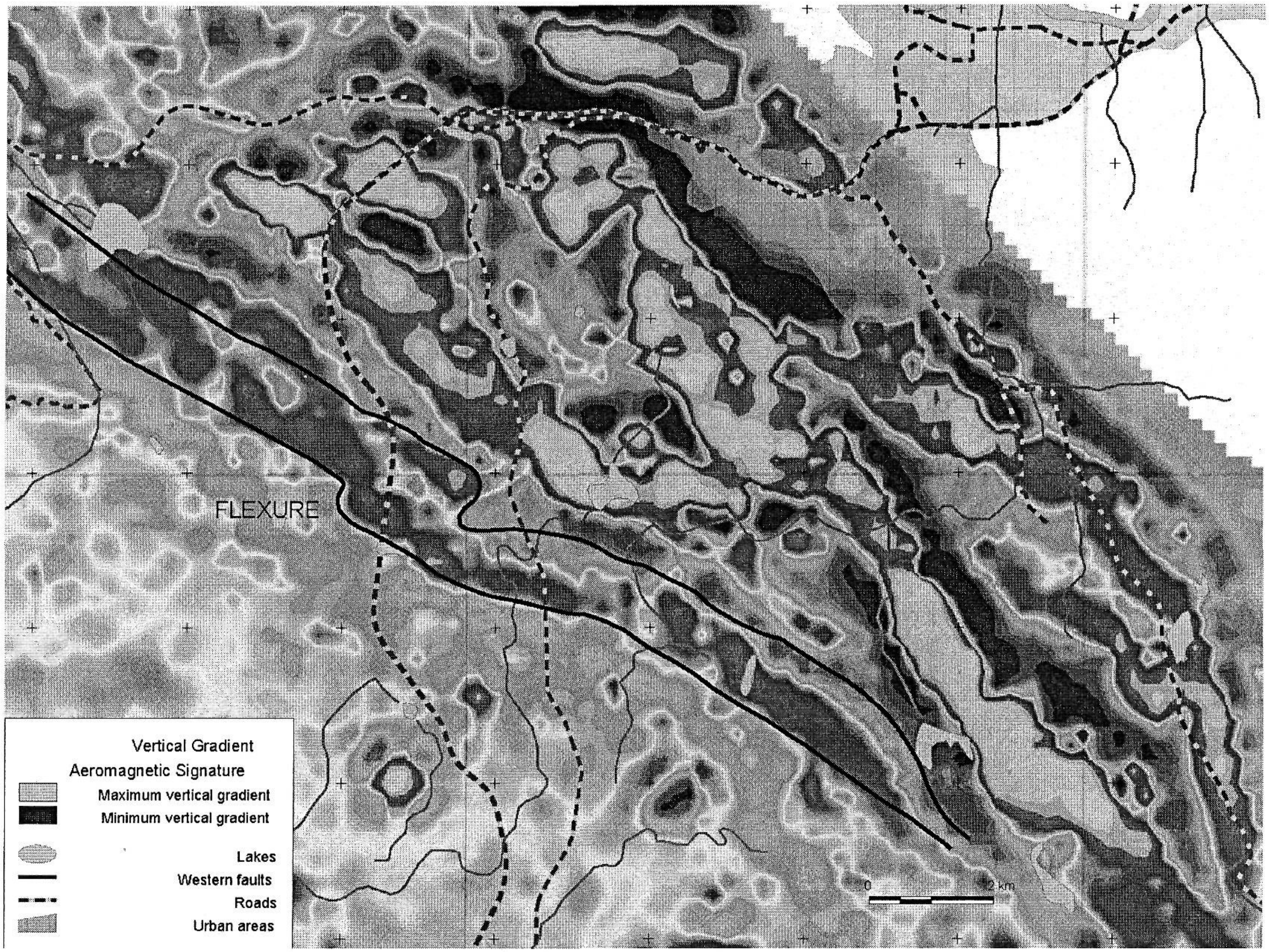


Figure 2. Compilation map of the Iron Mask batholith, incorporating unpublished assessment work and published work by Carr (1957), Kwong (1987), Preto (1967), Northcote (1976, 1977), Snyder and Russell (1994, 1995), Stanley et al. (1994) and Ross et al. (1995).

Figure 3. Vertical gradient aeromegnetic map of the Iron Mask batholith. See text for discussion.



NICOLA GROUP ROCKS

The Late Triassic Nicola Group of south-central British Columbia comprises Carnian to Norian, subaerial and submarine assemblages that include pyroxene and plagioclase-phyric basaltic and andesitic flows, breccias, lahars and conglomerate that have been intruded by Late Triassic to Early Jurassic alkalic and calcalkalic plutons and batholiths (Preto, 1977, 1979). They have been subdivided into three north-trending fault-bounded belts. The Iron Mask batholith intrudes volcanic and sedimentary rocks of the eastern belt of the Nicola Group (Preto, 1979; Mortimer, 1987).

Within the study area, the Nicola Group rocks situated southwest of the batholith can be divided into three main units: 1) picrite and pyroxene porphyritic breccias; 2) heterolithic pyroxene-dominant tuffs and volcanic wacke, siltstone and tuffite; and 3) tabular feldspar porphyry breccias and tuffs. North of the batholith in the Dufferin Hill area, the Nicola Group rocks comprise three main rock types: 1) heterolithic tuff, 2) monolithic monzonitic-latite breccias, and 3) a mixed volcaniclastic and epiclastic lahar unit (Fig. 4).

The Nicola Group rocks are metamorphosed to a lower greenschist facies mineral assemblage that includes chlorite, epidote, actinolite and calcite. Adjacent to the batholith the Nicola rocks are hornfelsed.

Stratigraphy Southwest of the Batholith

PICRITE UNIT

Coarse olivine-augite–bearing porphyritic (picritic) basalt and augite porphyritic (absarokitic ankaramite) breccia is a common hostrock to the Iron Mask batholith. Excellent, bright blue-green exposures are seen at Jacko Lake, northwest of Shumway Lake, south of the Afton pit and north of Goose Lake. Unit thickness is difficult to assess, but distribution of outcrops suggests a thickness in excess of 200 m. It is clearly volcanosedimentary in nature, as indicated by sedimentary interbeds and lobes of picritic basalt breccia within tuffite (Fig. 2, 5). In all exposures, it displays a good breccia texture on clean, weathered surfaces. Weathering may reduce the unit to rubble, which can be disaggregated by hand except for dense clast interiors. In no location is it possible to demonstrate unequivocal intrusive relationships, although feeder dikes must exist locally. In hand specimen, picrite is characterized by serpentinized rounded olivine phenocrysts, prismatic relict clinopyroxene, and magnetite grains in a fine-grained groundmass of serpentine-tremolite. Where sheared, fractures are coated with serpentine.

Pyroxene-olivine breccia forms the lowest unit below well-indurated angular pyroxene lapilli tuff. The relationship of the picrite breccia to the main augite porphyry unit is not certain. Near the Iron Mask mine, a large xenolith of serpentinized picrite marks the contact zone between Iron Mask hybrid diorite and Cherry Creek monzonite. The picrite is hornfelsed/recrystallized by the intrusions and

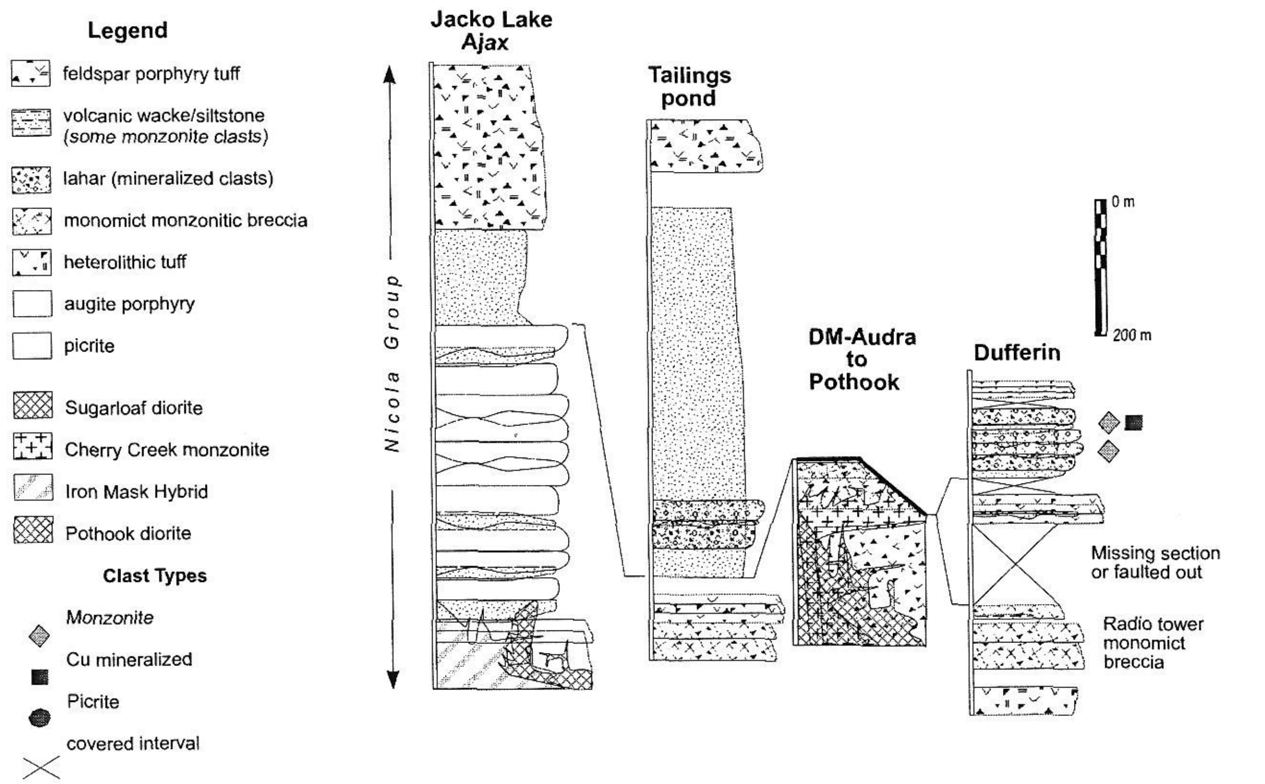


Figure 4. Stratigraphic sections for Nicola Group volcanic and sedimentary rocks at Jacko Lake, Afton tailings pond, DM-Audra to Pothook and Dufferin Hill areas.

Figure 5. Picritic basalt breccia interbedded with volcaniclastic units of the Nicola Group, southeast of Jacko Lake.

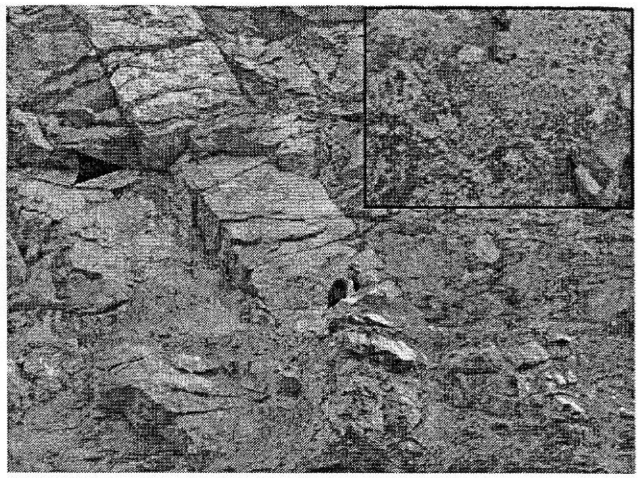


Figure 6. Serpentinized picrite intruded by north-trending hornblende-phyric Sugarloaf diorite dike, south wall of the Ajax West pit. Inset shows detail of picrite breccia texture.

contains coarse crystals of tremolite and talc. In the south wall of the Ajax West pit, serpentinized picrite is intruded by hornblende-phyric Sugarloaf diorite dikes (Fig. 6). From these observations, the picrite must be older than the batholith. Evidence derived from sections studied outside of the batholith by Snyder and Russel (1993, 1994) favours a brecciated basalt flow origin. Our observations are in accord with the conclusions of Snyder and Russell (1993, 1994), but indicate that the picrite is part of the Nicola Group stratigraphy and not younger, because massive picrite bodies in the Jacko Lake – Edith Lake area can be traced along strike to where they are interbedded with sedimentary strata.

AUGITE PORPHYRY BRECCIA, MINOR FLOWS

Dark green, maroon and purple clinopyroxene porphyritic and clinopyroxene-plagioclase porphyritic basalt breccias and massive flows or dikes are spatially associated with the picrite unit and occupy the area adjacent to the southern contact of the batholith (Fig. 2). The breccias, which dominate the unit, are entirely composed of pyroxene porphyritic fragments. The fragments are typically angular to subrounded and unsorted. They are commonly up to 10 cm but can exceed 100 cm in size. The matrix to the breccias consists of juvenile pyroxene and plagioclase crystals and small pyroxene porphyritic lithic fragments. Along strike and up section, the breccias become finer grained and epiclastic in nature. South of Jacko Lake, the breccias contain interclast laminated ash and dust tuffs.

Their position adjacent to the batholith has resulted in hornfelsing, fracture-controlled potassic and/or albite alteration, and their the incorporation as xenoliths and large screens.

AUGITE PORPHYRY TUFFITE,VOLCANIC SANDSTONE AND SILTSTONE

Green, grey and black interlayered pyroxene porphyritic breccias, crystal-rich tuffite and subordinate thin-laminated siltstone define a regionally mappable unit that extends northwesterly from Edith Lake to the Afton tailings pond (Fig. 2–4). Local sections contain plagioclase greater than pyroxene, but overall pyroxene dominates. The unit consists primarily of thick-bedded or massive, well-sorted sandstone units comprising primarily pyroxene and plagioclase crystals and rare lithic grains. Intercalated with these massive sandstone units are crystal-lithic tuff (tuffite) that form distinct graded beds, between 10 and 50 cm thick, and thin-laminated, commonly graded, siltstone-sandstone couplets. Crystal-rich sandstone displays good crosslaminations, normal graded beds and load structures that give bedding top directions in the finer grained volcaniclastic and epiclastic sections south of Jacko Lake.

North of the Afton tailings pond, the tuffite is interlayered with coarse pyroxene porphyritic breccia, polylithic tuff and polylithic conglomerate. Sections of the tuffite are normal-graded, pale green siltstone and coarse granule sandstone containing pink clasts and feldspar crystals, but most of the outcop is a chaotic mix of tuffite, pink plagioclase-phyric lapilli and green pyroxene-phyric lapilli. The rocks are irregularly fractured and veined by anastomosing, locally coalescing veins of specular hematite and rare disseminated chalcopyrite. Eastward, toward the open pit, are polylithic tuff and conglomeratic horizons within a section that contains pyroxene porphyry and other igneous clasts with compositions similar to the main intrusive phases of the Iron Mask batholith: tabular plagioclase microporphyritic monzonite and hornblende-phyric diorite fragments. Overprinting by fine-grained pyrite or epidote-chlorite produces a bleaching or green colouration. Disrupted fabrics in the tuffite are pre-lithification; alteration and mineralization postdate intrusion of the Iron Mask batholith.

FELDSPAR PORPHYRITIC LAPILLI TUFF

A great thickness of fine tabular feldspar porphyritic lapilli tuff, lesser breccia and tuffite is exposed in the Iron Mask region. Resistant, blocky outcrops are well exposed on the mountain slopes north of Kamloops Lake near Frederick, between Jacko and Goose Lakes, and on Dufferin Hill (Fig. 2). Probably more than 1 km thick, this unit displays wide textural variability from finely laminated to coarse, weakly stratified breccia, although the most abundant lithology is lapilli tuff, which is typically massive, with little indication of layering (Fig. 4).

Variegated lapilli tuff constitutes most of the outcrops at the Maxine (MINFILE 092I/032) mineral occurrence, north of Kamloops Lake. The matrix contains specular hematite and, as a result, is a conspicuous mottled maroon and green colour. Tabular white plagioclase–phyric lapilli constitute the majority of the fragments, which are supported in a plagioclase crystal–rich ash matrix. Inflating the section are hematitic, holocrystalline, crowded-plagioclase–phyric trachyte units. East of Frederick, the tuffs are finer grained and consist of more than 200 m of brown-weathering, fine plagioclase crystal tuff.

In the vicinity of Jacko Lake and Goose Lake, the tuffs are well indurated and consist of fine plagioclase laths and lesser pyroxene. Sections of light grey cherty tuff were noted, but most outcrops are dark green fine lapilli of feldspar porphyry.

Stratigraphy North of the Batholith

FELDSPAR PYROXENE BRECCIA, LAPILLI TUFF

Coarse breccia at Dufferin Hill has been mapped as Cherry Creek intrusive breccia. However, it is crudely stratified and interpreted here as a proximal, monomict flow breccia. The breccia is intermediate in composition, comprising 5 to 7 mm stubby plagioclase phenocrysts and slightly coarser pyroxene phenocrysts in an aphyric groundmass. Fragments are angular, poorly sorted and of highly variable size, from ash through lapilli to block, suggesting little reworking (Fig. 7). Massive centres, brecciated flow tops and intervening airfall tuffs indicate meter-scale flow thicknesses at this location. Blocks of identical composition and size occur in lahar units to the south.

Figure 7. Poorly sorted angular blocks of feldspar porphyritic breccia with lesser lapilli and ash fragments, forming the top of Dufferin Hill. Textures suggest little reworking.

LAHAR

A mottled purplish-green to maroon polymictic volcaniclastic is well exposed south of Dufferin Hill and the Trans-Canada Highway. The unit consists of mainly subangular blocks and cobbles of volcanic and intrusive rocks in a hematitic ash matrix. It is interpreted as a lahar. The most abundant clast type is a flesh-coloured, fine-grained monzodiorite, as blocks commonly between 0.5 and 1.0 m across. Subordinate clast compositions include potassium-metasomatized subporphyritic monzodiorite, tabular felted plagioclase-pyroxene porphyry, and augite porphyry. Conspicuously, some of the clasts are strongly copper stained, epidote and K-feldspar altered, and mineralized with chalcopyrite (Fig. 8). In addition, subangular to rounded clasts of volcanic breccia are present within the unit. Crude clast imbrication and sorting are locally apparent.

This unit is interpreted as coeval with mineralization within the Afton-Ajax system. A lateral gradation with breccia on Dufferin Hill seems likely.

IRON MASK BATHOLITH

The Iron Mask batholith is a northwest-trending, silica-saturated alkalic intrusive complex (Lang *et al.*, 1995). It consists of two separate bodies: the 22 km long by 5 km wide Iron Mask batholith in the southeast, which was the focus of our study (Fig. 2), and the 5 km by 5 km Cherry Creek pluton in the northwest. The two are separated by an east-trending graben structure filled with Eocene Kamloops Group volcanic and sedimentary rocks. Snyder and Russell (1993, 1995) have described the various phases of the batholith and studied the petrogenetic relationships between them and the picrite unit (Snyder and Russell,

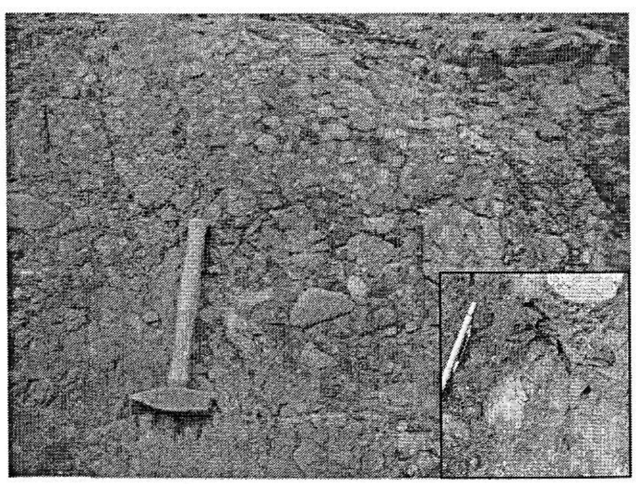


Figure 8. Maroon polymictic lahar consists of mainly subangular blocks and cobbles of volcanic and intrusive rocks in a hematitic ash matrix. Inset shows potassic altered, chalcopyrite mineralized clast. Exposure south of Dufferin Hill, and the Trans Canada Highway.

1994). We follow their revised sequence of major intrusions (i.e., from oldest to youngest: Pothook diorite, Cherry Creek monzonite and Sugarloaf diorite) and their conclusion that the Iron Mask hybrid was derived mainly from Pothook diorite and assimilated Nicola volcanic rocks, although xenolith-rich Sugarloaf diorite can also form a hybrid unit (e.g., East of Edith Lake).

The U-Pb ages for samples of the Pothook, Hybrid and Cherry Creek phases of the batholith (Mortensen *et al.*, 1995) are 204 ± 3 Ma, or Upper Triassic, using the time scale of Palfy (2000). The Sugarloaf diorite is the youngest phase but remains undated (results from samples collected for geochronology are pending).

Pothook Phase

Pothook diorite forms the northern part of the Iron Mask batholith (Fig. 2). Its distribution suggests that emplacement was controlled by northwest and northeast-trending faults. Contacts with the Hybrid unit are gradational, and contacts with Cherry Creek rocks are faulted and masked by strong potassic alteration. Contacts with the Sugarloaf phase are reportedly intrusive at the Pothook deposit (Stanley, 1994).

The Pothook unit is an equigranular, medium to coarse-grained biotite-pyroxene diorite, defined by the presence of poikilitic biotite (Northcote, 1974; Synder, 1994). The rock contains 40 to 60% subhedral plagioclase (An_{43} to An_{52}; Synder, 1995), 10 to 25% clinopyroxene, 5 to 10% magnetite, 5 to 7% biotite and up to several percent K-feldspar, apatite and lesser accessories including sphene and zircon. Poikilitic biotite (up to 2 cm) encloses earlier formed plagioclase, clinopyroxene and magnetite grains. Widespread alteration minerals include K-feldspar, sericite, epidote and chlorite.

Hybrid Phase

The Iron Mask Hybrid phase is a xenolith-rich, heterogeneous unit that forms approximately 45% of the Iron Mask batholith (Fig. 2). Hybrid rocks mark the contact zones between individual phases (i.e., Pothook, Cherry Creek and Sugarloaf) within the batholith, as well as the contact zones between the margin of the batholith and the volcanic country rock. Snyder (1994) redefined the Hybrid phase to be a facies equivalent of the Pothook diorite, suggesting it represented the outer margins to the Pothook intrusion (i.e., top and sides), which interacted and incorporated country rock of the Nicola Group. The matrix to all Hybrid rocks is not necessarily Pothook diorite. Locally, xenolith-rich marginal phases of Cherry Creek and Sugarloaf are hybrid zones.

The Iron Mask Hybrid phase has been subdivided into three main types on the basis of texture and clast abundance (Synder and Russell, 1995). Type 1 is restricted to contact zones between the Iron Mask batholith and the volcanic and sedimentary rocks of the Nicola Group. It is an intrusive breccia, characterized by angular fragments of hornfelsed country rock, veined by a matrix of pyroxene-hornblende diorite. Type 2 hybrid occurs in the centre of the batholith, enveloping a large body of Cherry Creek monzonite that is centred on Ironmask Hill. The unit is xenolith rich, characterized by abundant (15–80%) volcanic, plutonic and sedimentary rocks, some of which have reacted with the matrix. The matrix to Type 2 hybrid is variable: in places, it consists of medium to coarse-grained plagioclase, pyroxene, biotite, magnetite and rare hornblende that resembles Pothook diorite and, elsewhere, it consists of hornblende-plagioclase–rich trachytic phases. Type 3 hybrid occupies the northeastern margin of the batholith at Knutsford and a northerly-trending belt extending from the Ajax deposit to Coal Hill. This unit is a xenolith-poor intrusive breccia with textural and compositional variability that includes fine-grained to pegmatitic, and locally trachytic segregations of clinopyroxene, plagioclase, hornblende and magnetite.

The Iron Mask Hybrid phase contains abundant coarse interstitial grains of magnetite in a Pothook dioritic matrix and displays a magnetic susceptibility typically an order of magnitude higher than most other rock types.

Cherry Creek Phase

The Cherry Creek suite was defined by Livingston (1960 *in* Preto, 1967) and was originally restricted to a suite of felsic porphyritic intrusions, dikes and breccias found mostly along the northeastern margin of the Iron Mask batholith (e.g., Preto, 1967), and forming the satellite Cherry Creek pluton. Hoiles (1978), recognized four varieties of Cherry Creek rocks at the Afton deposit: breccias, porphyries, syenite to monzonite trachytes and non-porphyritic medium to fine-grained diorites. Work by Stanley *et al.* (1994), Lang (1994) and Snyder and Russel (1995) discussed the difficulty of separating the Cherry Creek from the Pothook phase and concluded that earlier maps may have overrepresented Cherry Creek due to the pervasive potassium metasomatism of Pothook and Cherry Creek rocks that is commonly developed adjacent to their contacts.

Cherry Creek rocks display textures that vary from plutonic to hypabyssal and locally volcanic. In the core of the batholith, near Ironmask Hill and south of Knutsford, Cherry Creek rocks are leucocratic, fine to medium-grained, equigranular biotite monzonite. Near the margins of the batholith, the rocks are characteristic orange to brown microporphyries speckled with fine-grained indistinct ferromagnesian minerals that range in composition from monzodiorite to monzonite. The pervasive pink to orange colouration results from the finely disseminated microcrystalline inclusions of red hematite in the secondary K-feldspar. In general, the rocks are fine-grained, holocrystalline subporphyritic units that exhibit crudely aligned tabular plagioclase crystals and minor chloritized mafic minerals.I In thin section, relicts of mafic minerals can be identified as clinopyroxene and less commonly hornblende. Magnetite is disseminated throughout the groundmass in amounts up to 10%. The rocks contain sparse primary quartz. Accessory minerals include apatite, zircon and titanite.

Finer grained varieties of the Cherry Creek phase include trachyte and latite porphyries (Preto, 1967). The matrix is commonly altered to a mixture of epidote, chlorite, sericite and carbonate. Commonly associated with these fine-grained porphyries are intrusive and hydrothermal breccias at the Crescent, DM and Kimberley mineral deposits (Preto, 1967). In addition, Snyder (1994) mapped a zone of Cherry Creek breccia east of the Iron Mask mine. Here, the intrusion breccia is characterized by angular metavolcanic fragments ranging in size from 10 to 100 cm and set in a fine to medium-grained biotite monzonite matrix. Snyder (1994) noted that the boundaries between clasts and matrix varied from diffuse to sharp, with the sharpest contacts (Fig. 9) at the shallowest intrusive levels. Surrounding the intrusive breccia are Iron Mask hybrid rocks that characteristically show a higher degree of assimilation, a greater variety of clast rocks types and a dioritic matrix to the breccia.

Northcote (1976) included outcrops of fine-grained, brecciated and ankeritic rocks east of Galaxy with the Cherry Creek phase. We have reassigned them, based on similarity with ankeritic rocks located between Wallender and Jacko lakes, to Nicola Group metavolcanic rocks (Fig. 2).

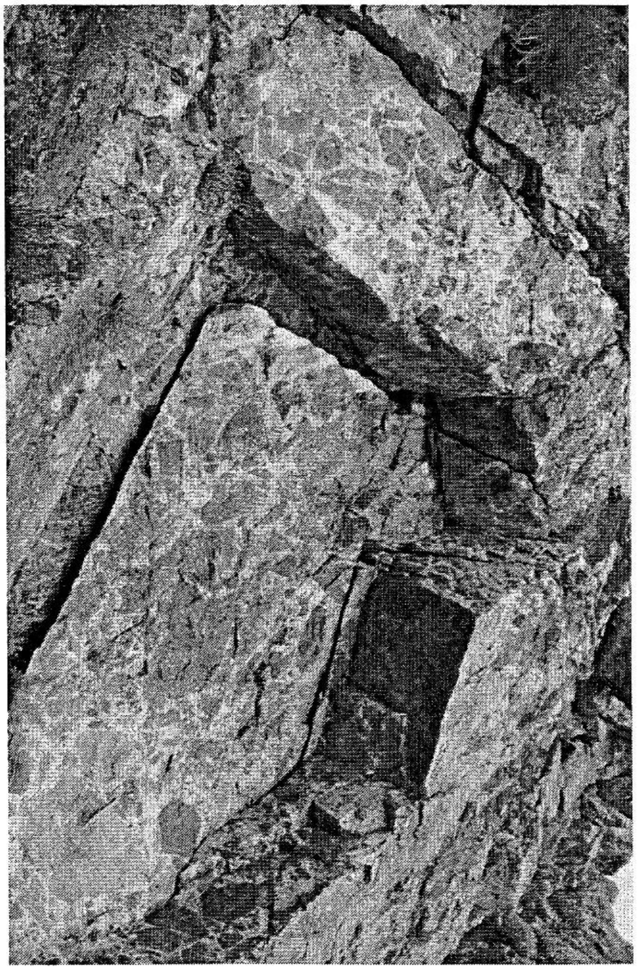


Figure 9. Cherry Creek intrusion breccia, consisting of angular metavolcanic fragments set in a fine to medium-grained biotite monzonite matrix, hilltop east of Iron Mask mine.

Sugarloaf Phase

The term 'Sugarloaf porphyritic diorite' was also introduced by E. Livingston in 1960 (*in* Preto, 1967) for a suite of hornblende porphyritic, trachytic rocks of dioritic composition. It primarily crops out along the western margin of the batholith (Fig. 2) as lenticular bodies (Sugarloaf Hill, Ajax East deposit) or as metre-wide dikes in the adjacent Nicola volcanic rocks (Coquihalla East zone, Pothook and Ajax West deposits). The distribution of the Sugarloaf rocks was apparently controlled by northwest-trending structures. Sugarloaf dikes are radially oriented around Sugarloaf Hill, which Snyder and Russell (1993) interpreted as a volcanic neck and intrusive centre. On the southwest flank of Sugarloaf Hill is a bleached, albite-altered, monomictic hornblende-phyric breccia. It is lithologically identical to the stock and represents either an extrusive equivalent or intrusive breccia. The unit possesses subhorizontal jointing planes suggestive of bedding, which favours an extrusive origin and accumulation on the flank of the stock. Further work is needed to confirm this interpretation.

Sugarloaf rocks are characterized by 1–1.5 mm hornblende and plagioclase phenocrysts in a fine-grained groundmass of plagioclase, clinopyroxene, magnetite and K-feldspar. Accessory minerals include apatite, sphene, pyrite and rare quartz (Snyder, 1994). The unit displays considerable textural variation, ranging from fine-grained to medium-grained holocrystalline trachytic porphyries. Albite alteration affects Sugarloaf rocks and extends into the Nicola Group volcanic rocks at the Ajax deposit.

Quartz-Feldspar Porphyry Dike

Quartz-feldspar porphyry dikes have been mapped at the Ajax (Ross, 1993) and Afton (Kwong, 1987) deposits and south of the Rainbow property. These dikes range in thickness from less than 1 m to more than 10 m. The rock varies in grain size and texture from a uniform, fine-grained, pinkish brown rock containing acicular hornblende, lesser biotite, quartz and feldspar to a coarse quartz-feldspar porphyry. Some of these dikes contain sparse to abundant xenoliths, including coarse-grained quartz monzonite, metabasalt and medium-grained holocrystalline granite. Where thickest, the dikes may contain up to 10% coarse quartz eyes and 30% tabular, zoned feldspar.

They cut the picrite and Sugarloaf phase in the vicinity of the Ajax deposits and Cherry Creek rocks in the Afton pit. Ross (1993) suggested that they postdate alteration, mineralization and many of the faults. However, samples of lithologically similar rocks from the Ajax pit are albitized, and mineralized with chalcopyrite.

KAMLOOPS GROUP

Sedimentary and volcanic rocks of the Kamloops Group unconformably overlie the Nicola Group rocks and the Iron Mask batholith. The unconformity is typically flat-lying and postdates development of supergene ore at Afton.

The Kamloops Group includes tuffaceous sandstone, siltstone and shale with minor conglomerate, and alkali olivine basaltic to andesitic flows and agglomerates with minor dacite, latite and trachyte (Ewing, 1981).

STRATIGRAPHIC RELATIONSHIPS

The picrite unit is an olivine greater than pyroxene porphyritic basalt breccia. All exposures of picritic basalt display brecciated textures, and at most localities are either bordered by clastic rock types that contain clasts of picritic basalt or can be traced laterally into facies that interdigitate with tuffaceous sediment derived from either a picritic or feldspathic volcanic source. At two localities, picritic clasts occur within argillaceous strata. Picrite may occur as isolated units within augite porphyritic volcanic strata, but can be traced as a stratigraphic unit across the study area. We were unable to conclusively demonstrate that the picrite is intrusive at any locality; however, intrusive feeders to the picritic basalts are expected. The picritic basalt is intruded by acicular hornblende-phyric monzodiorite (Fig. 6) and is a locally important constituent of the hybrid unit.

The Sugarloaf phase becomes hybridized with increasing contamination by picritic basalt and other Nicola units. This relationship is well displayed in the Ajax West pit, at Edith Lake and the Goose Lake road (Fig. 2). At Edith Lake, the picritic basalt breccia is hornfelsed by the Sugarloaf phase (which is locally chilled against the picrite), and dykes of Sugarloaf within the picrite decrease in abundance away from the contact, while xenoliths of picrite occur within the Sugarloaf where it becomes hybridized.

The Hybrid rocks possess a consistent east-trending magmatic foliation that suggests a regional 200 Ma tectonic control during emplacement: the pegmatitic mineral growth direction is perpendicular to the regional foliation, in the direction of dilatency (Fig. 10). Magmatic foliation in Cherry Creek monzonites at the Crescent deposit and mineral lineations in Sugarloaf dikes at the Ajax deposits are more northerly (010°–345°).

Northcote (1974, 1976) and Preto (personal communication, 2004) recognized intrusive rock fragments of Cherry Creek plagioclase porphyries within lahar and volcanic breccia units of the Nicola Group and concluded a close association in time between volcanism and intrusion. The polylithic Nicola tuff, located north of the Afton tailings pond, contains pink monzonitic lapilli of Cherry Creek affinity. This tuff is weakly mineralized and overprinted by the disseminated pyrite halo associated with mineralization at the Afton deposit. These relationships suggest that Cherry Creek magma was erupted and deposited as pyroclastic units before the alteration-mineralization event at Afton was complete. The fine-grained, holocrystalline Cherry Creek porphyries suggest near-surface conditions of emplacement and the andesite and latite breccias and flows that characterize the northern margin of the batholith probably represent extrusive equivalent rocks to the microdiorite and micromonzonite. Cherry Creek intrusive and diatreme breccias crosscut the northern margin of the batholith. Diatreme breccias within the Crescent pit contain a wide variety of angular to rounded clasts of syenite (potassium-metasomatized monzonite?), amphibolite, pyroxene porphyry, coarse magnetite and chalcopyrite mineralization. They postdate mineralization because they contain clasts of mineralization. Although we cannot prove conclusively that these vented to the surface, the presence of mineralized clasts within the lahar unit suggests that this may have been the case.

STRUCTURE

The structural setting of the Iron Mask intrusive complex is dominated by north to northwest-trending high and moderate-angle faults. Previous authors have considered these to be major deep-seated structures that were active as early as the mid-Triassic (Campbell and Tipper, 1970; Preto, 1977). As such, they were thought to have controlled deposition of the volcanic and sedimentary rocks of the Nicola Group (Preto, 1977) as well as the intrusion of various phases of the Iron Mask batholith.

Figure 10. East-west magmatic foliation in Iron Mask Hybrid phase, note, the pegmatitic mineral growth direction (hornblende) is perpendicular to the regional foliation, in the direction of dilatency.

Schistosity

For the most part, rocks in the study area are not penetratively deformed. Exceptions occur 2 km south of Jacko Lake, where Nicola volcanic rocks display an abrupt change from nonfoliated to strongly schitose rocks over a strike-normal distance of ~100 m. Two schistosities are developed. A primary, pervasive (S1) schistosity envelops pyroxene and feldspar porphyroclasts and flattened pyroclasts. It generally displays relatively steep northeast dips, suggesting a strain field orientation like that which produced the folds at Jacko Lake. Typical biaxial strain is about 4:1. This same fabric can be traced at least 12 km to the northwest to near the Afton tailings pond. The S1 schistosity is locally folded by southeast-verging chevron folds, with development of a second axial-planar crenulation cleavage (S2) that dips moderately northwest (Fig. 11).

Schistose rocks also occur locally within the batholith, at the Ajax East and West pits, and it is reported in drillcore from the Galaxy (Preto, 1967). Schistosity is well developed within carbonate porphyroblastic augite tuff and sericitic metasediment near the south rim of the Ajax West pit. There, Sugarloaf dike rocks are also foliated, but less intensely.

Folds

Previous authors have noted three zones of recurring near-vertical faulting: along the northeast and southwest margins of the batholith, and an arcuate zone just east of the batholith axis (best developed between the Evening Star and Iron Mask occurrences; e.g., Carr, 1957). These 'active zones' where thought to be the main locus of intrusion, beginning with the main Iron Mask phase (Pothook and Hybrid units), followed by picrite intrusions, and lastly the finer grained intrusions. However, if a volcanostratigraphic origin for the picrite is correct, the Makaoo–Larsen–Iron Mask picrite bodies could be parts of the same picrite horizon, now folded into a kilometre-scale synform. In this interpretation, the sheared limbs of the fold form the arcuate and northeastern zones of faulting. Picrite at the western contact of the batholith can likewise be interpreted as a volcanostratigraphic horizon, as noted for the section at Jacko Lake. In all cases, sheared mafic volcanic rocks occur with or near the picrite, further supporting a stratigraphic linkage. Orientations of mineralized veins between the Iron Mask and Larsen are consistent with dilational veins in a fold closure (Fig. 12) and, if related to the fold, suggest that folding and mineralization were synchronous. Subsequent strain has tended to concentrate in the relatively ductile, serpentinized picrite. This fold may have been decapitated by low-angle faults translating coarse, deep-level hybrid rocks in the fold core over microdiorite and hypabyssal or extrusive Cherry Creek phase (cf. 'Low-Angle Faults' section).

On the ridge east of Jacko Lake (Fig. 2), a crude stratigraphy (pyroxene porphyritic breccias, crystal-rich tuffite and thin-laminated siltstone) can be traced in a discontinu-

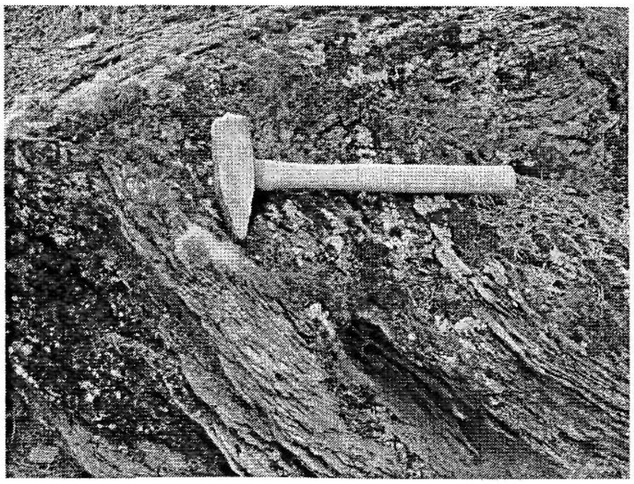


Figure 11. Folded schistosity Cherry Creek Fault zone.

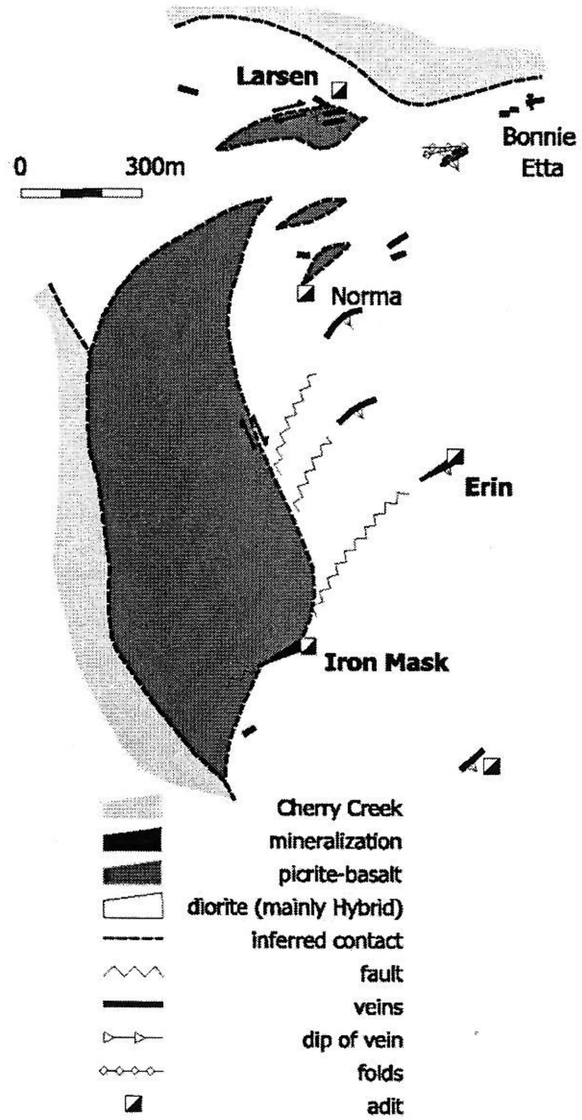


Figure 12. Dilational vein orientations, adapted from Figure 6 of Carr (1956): "Hypothetical structural interpretation in the area of the Iron Mask mine".

ous fashion through a fold closure. Confirmation of the fold is shown by reversal of facing direction in bedding.

On the south side of the Ajax West pit decline, foliated, carbonate-altered pyroxene porphyry is intruded by a 1.2 m thick Sugarloaf dike. Both foliation and dike are warped by a gentle upright fold. Foliation and the fold-axial plane average 120°/60°S; mineral elongation lineation developed around magnetite porphyroblasts in the adjacent picrite trends 10°/115°E.

Low-Angle Faults

Low-angle fault zones are sporadically observed in the batholith. Good examples are exposed in the Pothook and Ajax West pits. However, the best documented evidence is from Preto (1967) at the Galaxy deposit. At least 20 drillholes intersect a moderate to shallowly west-dipping mylonite zone that separates Nicola volcanic rocks, picrite and hybrid phase from fine-grained 'albitized microdiorite', considered to be part of the Cherry Creek intrusive suite. According to Preto (1967), copper mineralization is focused both within the hangingwall volcanic rocks and in the mylonite zone. Structural juxtaposition of the mineralized and nonmineralized rocks, as well as development of copper mineralization within the mylonite zone, suggest that deformation and mineralization were at least partly synchronous (Fig. 13). Kinematic analysis of the mylonite zone is lacking, and a compressional versus extensional origin cannot be determined from the available information. In both the Ajax and Pothook pits, low-angle faults also exert some control on mineralization.

In the Ajax West pit, a low to moderately west-dipping fault (average orientation 166°/42°W) juxtaposes albitized gabbroic rocks with diorite. Epidote and chalcopyrite-calcite veins parallel the fault. Some fault-parallel veins display fist-sized knots of chalcopyrite. Subsidiary, parallel faults in the hangingwall cut and offset a series of epidote-calcite veins. Apparent sense of offset on the subsidiary faults is consistent with gash veins (055°/68°S; Fig. 14, inset), indicating top-to-the-southeast sense of motion. Late open-space veins with vein-perpendicular quartz fibres and intergrown chalcopyrite also indicate extension in a northeast direction. Similar top-to-the-east apparent offset is displayed in the south wall of the Ajax West pit across a subhorizontal fault trace that truncates a north-trending dike of Sugarloaf hornblende porphyry (Fig. 6).

At the southwest margin of the Ajax East pit, a strong phyllitic fabric is cut by Sugarloaf intrusive upon which a less intense tectonic foliation has been imparted. A mineral elongation fabric developed within the foliation has undulating northeast and southwest plunges, averaging 004°/43°E on foliation planes that average 220°/44°W. Sense of rotation on foliation-parallel brittle shear zones indicates a top-to-the-northeast sense of motion, parallel with the mineral elongation direction. Millimetre-thick intrafolial chalcopyrite-quartz (or albite?) veinlets are oriented perpendicular to the extension direction. All fabrics are cut by a 3 m thick microdiorite dike (250°/80°N) that contains

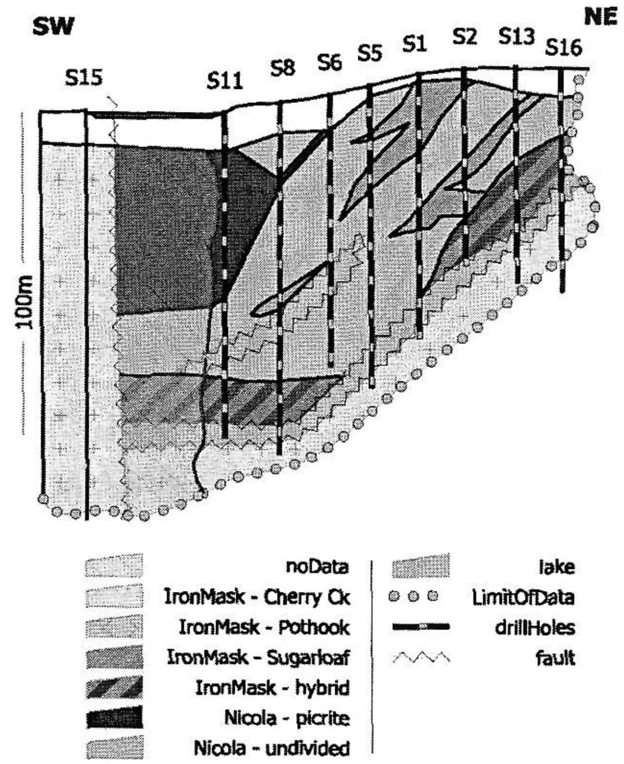


Figure 13. Section 1100 N from Galaxy Copper Ltd. plan showing surface cuts and diamond-drill holes (Preto, 1967, Fig. 14).

xenoliths of feldspar porphyry and medium-grained granite.

Cursory examination of the Pothook pit also reveals low-angle brittle shear zones. Near the base of the southern pit wall, banded shear veins dip shallowly to moderately southeast (Fig. 15; looking toward 200°). These 20 cm thick veins comprise brecciated quartz cemented by chalcopyrite (up to 60%) and pyrite. They bound panels that are cut by extensional vein sets dipping moderately southwest, indicating a top-to-the-southwest sense of motion across the

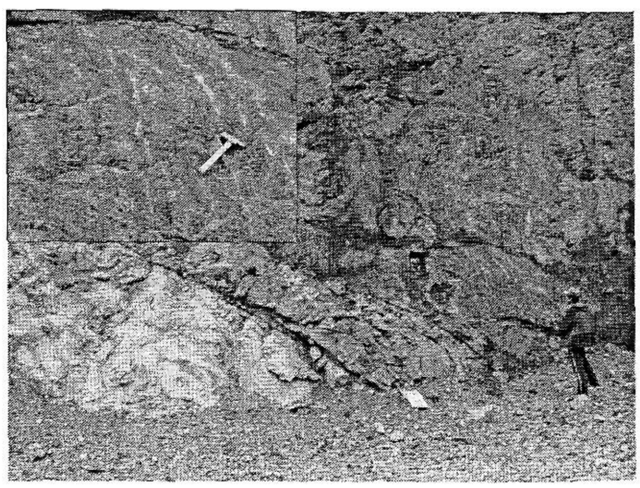


Figure 14. Low angle west dipping fault, juxtaposes albitic gabbroic rocks with diorite. Insert shows offset epidote-calcite veins with apparent tops to the southeast sense of motion.

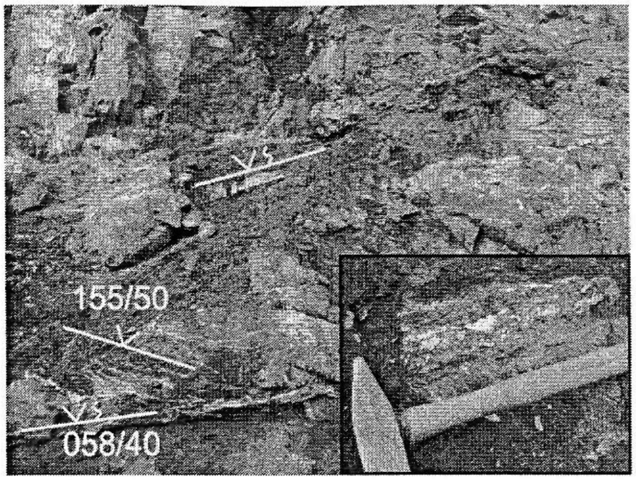


Figure 15. Banded, shear veins dipping moderately southeast and mineralized with quartz-chalcopyrite-pyrite, Pothook pit.

zone. A chaotic assemblage of rock types within this structural zone, including picrite breccia, lamprophyre, fresh hornblende porphyry and K-feldspar-epidote–flooded rock. This diversity of rock types suggests that motion on the zone could be substantial.

To what degree the low-angle shear zones contribute to economic mineralization within the Iron Mask batholith is unknown. It is, however, clear that such faults can be the loci of enhanced copper mineralization (e.g., Galaxy, Pothook), commonly with addition of quartz. Our preliminary observations indicate both top-to-the east and top-to-the-southwest sense of motion. If offset on such zones is substantial, they may decapitate vertically developed zones of porphyry mineralization, translating them to deeper or shallower crustal levels.

MINERALIZATION AND ALTERATION

At least 10 copper-gold deposits are hosted by the Late Triassic polyphase Iron Mask batholith (Fig. 2). Five of the deposits are past producers: Afton, Ajax East, Ajax West, Crescent and Pothook. The Big Onion, DM, Python-Makaoo and Rainbow have published reserves but no production (Lang and Stanley, 1995). Mineralization consists primarily of fracture-controlled chalcopyrite and bornite associated with magnetite, while pyrite or pyrrhotite occur peripherally. Mineralization is hosted in all of the different phases of the batholith (Table 1). To date, no significant mineralization has been delineated outside the batholith in the Nicola volcanic rocks (although Nicola strata do host much of the mineralization at Copper Mountain, 140 km to the south). Lang *et al.* (1994) showed that distinct alteration assemblages affected different intrusive phases. Magnetite-apatite±actinolite are dominant alteration minerals in the Pothook and hybrid units; potassic alteration affects the Cherry Creek monzonite; and sodic alteration affects the Sugarloaf diorite (Fig. 16). In each case, alteration accompanies mineralization, but not all altered zones are mineralized. Mineral occurrences visited during the course of this study are grouped according to their host/causative intrusive phase and described below.

Pothook and Hybrid Phases

MAGNET MINE (MINFILE 092I/022)

The Magnet showing is located east of the Afton pit (Fig. 2). It consists of a zone of northwest-trending, steeply dipping veins of massive magnetite containing euhedral white crystals of apatite and green amphibole. The apatite is coarsely crystalline (up to 3 cm) and has grown perpendicular to the vein walls into the centre of the veins. The magnetite displays fine-grained exsolution of ilmenite (Cann, 1979). Magnetite veins trend 120–140°, and dip vertically and locally show well-developed dilatent zone splays filled with magnetite. The geometry indicates sinistral shear at the time of magnetite deposition (Fig. 17). The shear veins are crosscut and offset by specular hematite±chlorite veins with K-feldspar alteration envelopes, and crosscut but not offset by a younger set of pyrite-epidote-calcite and calcite veins.

PYTHON (MINFILE 092I/002)

The Python property straddles the northeastern margin of the Iron Mask batholith, about 7 km east of the Afton de-

TABLE 1. MINERALIZATION HOSTED IN PHASES OF BATHOLITH

Intrusive Host	Deposit	MTonnes	Cu%	Au ppm	Source
Sugarloaf-Hybrid Contact zone	Ajax (mineable+prod)	20.7	0.45	0.34	Ross et al. (1995)
	Pothook (prod)	2.36	0.35	0.77	Lang and Stanley (1995)
	Rainbow (indicated)	0.015	0.52		GCNL, 1997; BC MINFILE
Cherry Creek	Afton (mineable+prod)	30.8	1	0.58	Kwong (1987)
	Afton (meas+Indicated)	68.7	1.08	0.85	DRC Res. (2004)
Pothook-Cherry Creek Contact Zone	Crescent (prod)	1.448	0.44	0.18	Lang and Stanley (1995)
	DM/Audra (geologic)	2.68	0.38	0.27	Lang and Stanley (1995)
	Big Onion (mineable)	2.4	0.84	0.4	Vollo (1985)
Pothook/Hybrid	Magnet Mine (prod)	0.005	magnetite		1960-1961, BC MINFILE
Nicola-Hybrid Contact Zone	Python/Makaoo (indicated)	0.19	1.11	-	Seraphim, 1972; MINFILE
Nicola Group	Galaxy (indicated)	0.003	0.65	0.34	BC MINFILE

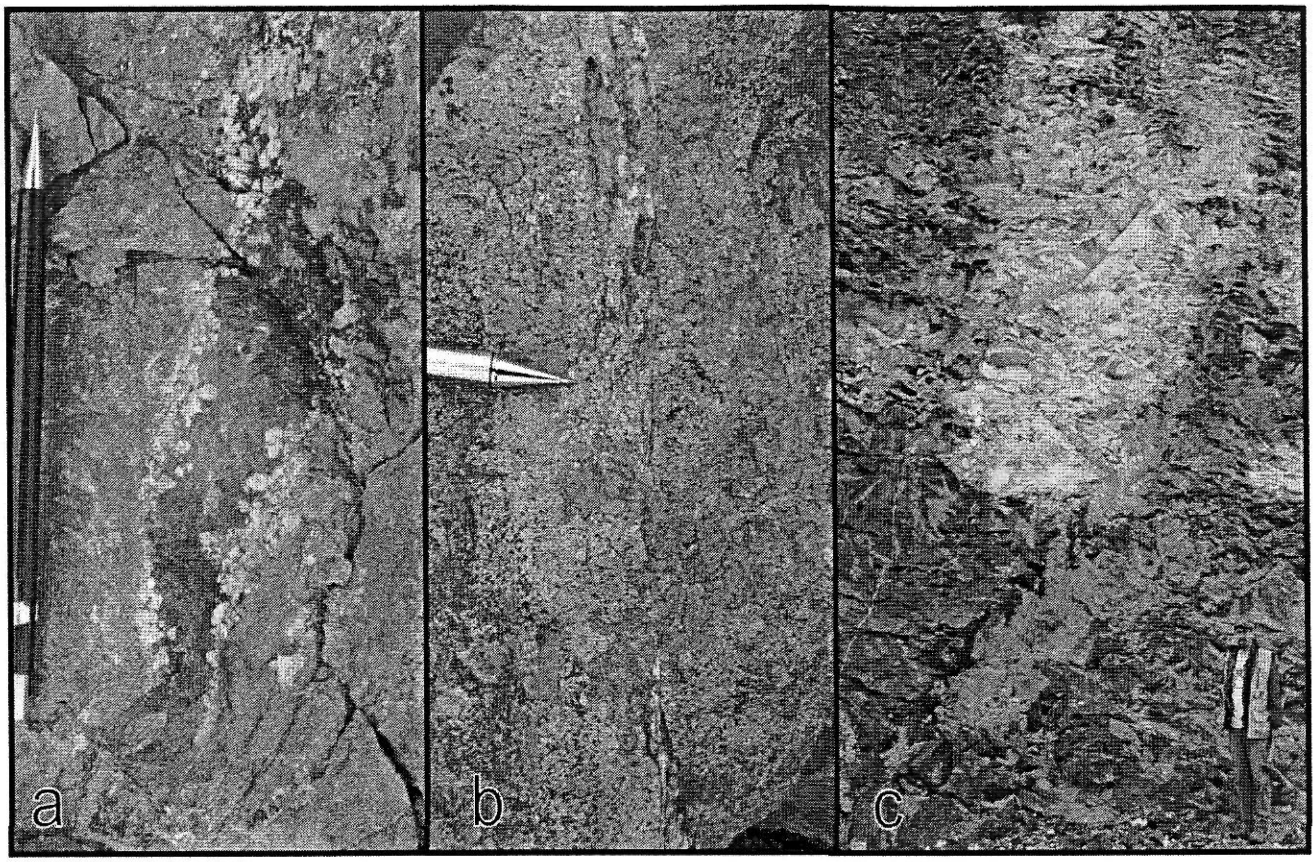


Figure 16. Hydrothermal alteration assemblages: **a)** magnetite-actinolite-apatite dilatent veins, Afton; **b)** K-feldspar alteration of Pothook diorite, Audra area; **c)** pervasive zone of white albitic alteration in metavolcanic Nicola rocks, north of Jacko Lake.

posit (Fig. 2). Three mineralized zones are known to occur on the property: the Python, Copper Head and Noonday. These are localized along the northwest-trending sheared contact between serpentinized picrite of the Nicola Group and coarse-grained diorite agmatite of the Iron Mask hybrid unit. Alteration assemblages consist of epidote-actinolite-magnetite-calcite±chalcopyrite with pink K-feldspar alteration envelopes that replace the matrix to the breccia and fill fractures and veins that vary in width from 1–20 cm. Copper minerals include chalcopyrite and lesser malachite and azurite. Alteration and mineralization are primarily focused in the shear zone and hangingwall hybrid intrusive unit.

The Python showing is hosted in a breccia pipe that cuts the northern margin of the Iron Mask batholith. The breccia has ill-defined margins and grades into less altered diorite. It is reported to be elongate east-west, and thought to form a steeply dipping tabular pipe (MINFILE). Chalcopyrite and magnetite occur as disseminated blebs, stringers and thick lenses, intergrown with epidote, albite, calcite and K-feldspar. The faults and mineralized fractures trend 145°. These are cut by K-feldspar-epidote±chalcopyrite veins that contain hematite (specular) and lesser magnetite. The veins trend 075° with little or no offset. Mineralization displays the same sinistral shear/dilatent relationships that were observed at the Magnet mine.

Cherry Creek Phase

AFTON (MINFILE 092I/023)

The Afton deposit is the largest of the porphyry deposits located in the Iron Mask batholith (Fig. 2). It is situated at the intersection of an easterly-trending corridor of potassic alteration, brittle shearing, hydrothermal breccias

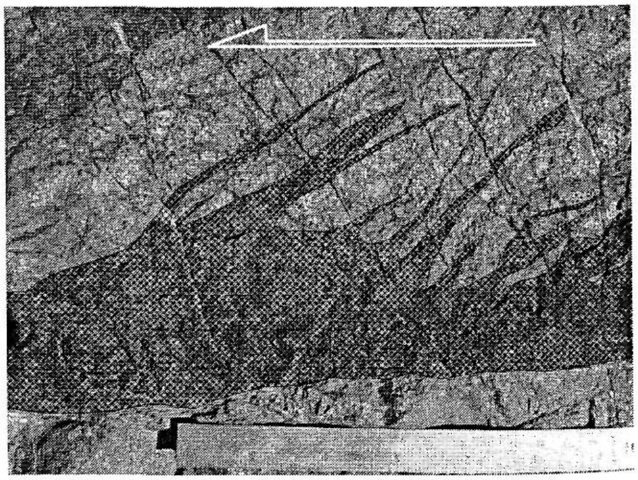


Figure 17. Magnetite-apatite±actinolite vein at the Magnet mine, viewed toward southwest. Vein trends 140°/90°W; dilatent vein splays indicate a sinistral shear sense.

and copper mineralization, which extends for more than 5 km and includes the DM, Audra, and Big Onion mineral occurrences, with a northwesterly-trending corridor of albitic alteration, brittle shearing and copper-mineralized hydrothermal breccias that includes the Pothook, Rainbow, Ajax East and Ajax West mineral occurrences. It is located 10 km west of Kamloops and produced 23.0 million tonnes of ore with an average grade of 0.85% Cu and 0.52 g/t Au between 1977 and 1987 (BC Ministry of Energy and Mines, MINFILE). Start-up reserves were 30.8 million tonnes of ore grading 1.0% Cu , 0.58 g/t Au and 4.19 g/t Ag at 0.25% Cu cutoff grade (Kwong, 1987).

The Afton orebody is a west-striking (290°) tabular body that plunges 30–50° to the south. Alteration at the Afton deposit was divided by Kwong (1987) into a potassic alteration assemblage comprising K-feldspar, epidote, magnetite and hematite in the northeastern part and an assemblage dominated by ankeritic alteration and/or amphibole and pyrite in the southwestern part of the pit. A pyritic (up to 10%) propylitic alteration zone surrounds the orebody and occupies much of the hangingwall Nicola Group volcanic rocks to the deposit. The eastern portion of the deposit is superposed by a southeast-trending magnetite-apatite-hematite alteration zone (800 by 300 m) that extends to the Magnet mine. This iron oxide zone is flanked on either side by a pyrite-enriched propylitic alteration zone with epidote, chlorite and calcite. A narrow zone of quartz-sericite (phyllitic) alteration was recognized by Preto (1972). It is situated peripheral to the main orebody and grades outwards into the propylitic zone. In addition, albite, sericite, kaolin, montmorillonite, talc, pyrophyllite, titanite, zoisite and less commonly prehnite, zeolite, quartz, barite, dolomite, ankerite gypsum and chalcedony have been identified (Hoiles, 1978). Plagioclase is replaced by epidote and a fine-grained mixture of sericite, carbonate and chlorite, while ferromagnesian minerals are replaced by chlorite, calcite, epidote and pyrite. Vein calcite deposition appears to have accompanied several stages of alteration and mineralization, but most prominently occurs as late, crosscutting features.

Easterly and northeasterly-trending faults are thought to have controlled the emplacement of the Afton intrusion (Preto, 1972; Northcote, 1974). Steep to vertical magnetite veins in the Afton pit trend mainly 110° but also 310° and 170°. The easterly-trending, steep southerly dipping magnetite veins are thought to predate and accompany copper mineralization and may be part of the same event that results in dilational veins at the Magnet mine.

Hypogene mineralization consists of bornite, chalcopyrite, lesser chalcocite, tetrahedrite and tennantite, and traces of molybdenite. Supergene alteration extends to depths of up to 400 m and consists of native copper and chalcocite, with minor amounts of cuprite, malachite and azurite (Hoiles, 1978; Kwong, 1987; Nixon, 2003).

CRESCENT (MINFILE 092I/026)

The Crescent deposit is located along the northern margin of the Iron Mask batholith, within an easterly-trending corridor of potassic alteration, brittle shearing, hydrothermal breccias and copper mineralization that extends for over 5 km and includes the Afton, DM, Audra, and Big Onion mineral occurrences. It is located 3 km east of the Afton pit (Fig. 2) and produced 1.36 million tonnes of ore with an average grade of 0.46% Cu and 0.2 g/t Au during production between 1989 and 1990.

Crescent pit geology was mapped by Lang *et al.* (1994). The pit straddles the northeast-trending contact between Pothook diorite (on the south) and Cherry Creek porphyritic monzodiorite (on the north). North-trending, metre-scale, intermediate and plagioclase porphyritic dikes cut the Cherry Creek monzodiorite in the pit and in outcrop exposures on Highway 1. Unaltered, Pothook diorite is typically a green-grey, medium-grained, equigranular pyroxene diorite that contains large poikilitic biotite crystals, abundant magnetite and apatite. Most of the Pothook diorite in the vicinity of the Crescent deposit has been overprinted by potassium metasomatism, which increases in intensity as the contact is approached. The Cherry Creek rocks are fine-grained plagioclase porphyritic monzodiorite with trachytic to magmatic foliated fabrics (010-015°) that are pervasively potassium metasomatized near the contact.

The deposit is a tabular zone that trends 050° and dips 60° southeast. It is centred on an intrusion breccia that developed at the contact between the Pothook and Cherry Creek phases. The zone is characterized by the pervasive potassium metasomatism, intrusive breccias, hydrothermal stockwork veining and phreatomagmatic breccias. The breccias are heterolithic with clast compositions dominated by Pothook diorite, pyroxene porphyritic Nicola Group metavolcanic rocks, and magnetite. Mineralization occupies the matrix to the clasts. Younger, phreatomagmatic breccias are characterized by the addition of rounded mineralized clasts in addition to a wide variety of the volcanic and intrusive rock types of the area.

Three major east-trending faults, as well as several sets of prominent spaced fractures, are exposed in the pit walls. Lang (1994) measured three dominant fracture orientations, 350°, 060° and 120°, all with dips greater than 60°. Vein fillings comprise calcite-chlorite-quartz±pyrite±epidote±chalcopyrite assemblages, invariably with K-feldspar alteration envelopes. The North and Central faults trend east and dip north; the South fault trends 070° (*see* Lang, 1994, Fig. 2). They are 1–5 m wide brittle features, characterized by gouge and shattered rock, that contain white calcite, chlorite and minor quartz-calcite±pyrite veins.

Chalcopyrite is the dominant ore mineral; bornite and molybdenum are present in trace amounts. Chalcopyrite occurs as blebs and fine disseminations in fractures, veins and filling the matrix to the breccias. Constant copper-gold ratios suggest that gold and copper were deposited together in a single hydrothermal event (Lang, 1994).

Sugarloaf Phase

AJAX (MINFILE 092I/012 AND 013)

The Ajax West and Ajax East deposits are located on the southwest side of the Iron Mask batholith, approximately 12 km southwest of Kamloops (Figure 2) and produced 7.9 million tonnes of ore with an average grade of 0.37% Cu and 0.27 g/t Au during production between 1989 and August of 1991. The pits were mapped by Ross *et al.* (1992, 1993 and 1995).

The deposits are localized at the contact between medium to coarse-grained Iron Mask hybrid diorite and Sugarloaf diorite. The contact trends easterly in the West pit and more northeasterly in the East pit. The main alteration stages include propylitic, albitic and potassic assemblages, with scapolite veins developed only locally in the Ajax East (Ross *et al.*, 1995). Alteration in the West deposit consists of a core of pervasive albite alteration that passes outwards to less pervasive albite alteration and into a peripheral zone of propylitic alteration characterized by chlorite, epidote, calcite±pyrite. The ore zones are spatially distributed along the contact between the intermediate albite alteration and the propylitic zone (Ross *et al.*, 1995, Fig. 9). Areas of intense albitization, carbonatization and brecciation mark the location of breccia pipes, and the centre of the hydrothermal system. The alteration-mineralization system in the East pit is essentially identical, but hosted primarily within the Sugarloaf diorite.

Chalcopyrite is the predominant copper mineral in both West and East deposits. It occurs as disseminations and blebs in fracture fillings and breccias associated with calcite. Pyrite is equally abundant and occurs in concentrations up to 2%, together with chalcopyrite or alone in the propylitic zone. Magnetite occurs as disseminations associated with potassic alteration. Low values of molybdenum are reportedly widespread throughout.

An en echelon set of salmon pink K-feldspar veins cuts Iron Mask Hybrid rocks in the north wall of the West pit. The bounding surface veins (10–50 cm wide) trend 300°/62°N and the en echelon tension gash veins (5–10 cm wide) trend 160°/72°W, consistent with tops-to-the-southeast sense of motion. The vein assemblage from wall to core consists of magnetite intergrown with biotite±chlorite, and a vuggy intergrown aphyric matrix of K-feldspar and albite with calcite, chalcopyrite, pyrite and coarse euhedral crystals of titanite filling fractures and interconnected vugs (Fig. 18). The titanite was submitted for U-Pb age dating; results are pending.

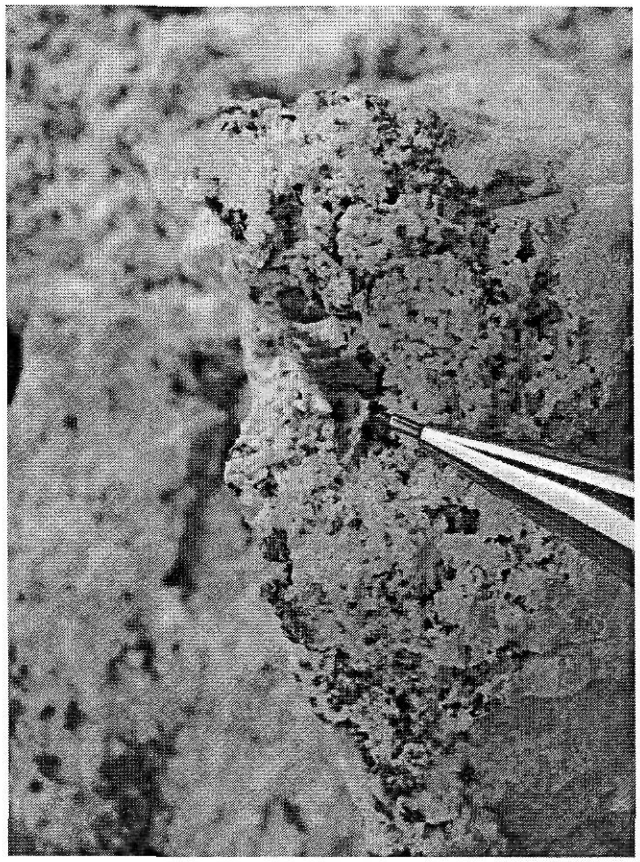


Figure 18. Vuggy intergrown matrix of K-feldspar and albite with calcite, chalcopyrite, pyrite and coarse euhedral crystals of sphene filling open spaces.

POTHOOK (MINFILE 092I/023)

The Pothook deposit is located on the southwest edge of the Iron Mask batholith, approximately 10 km west of Kamloops (Fig. 2) and less than 1 km southeast of the Afton pit, which produced 2.60 million tonnes of ore with an average grade of 0.35% Cu and 0.21 g/t Au between 1986 and 1988 (L.Tsang, personal communication, 1993, in Stanley, 1994). The deposit is centred on an intrusion breccia that developed close to the southwestern margin of the batholith. Pyrite is dominant over chalcopyrite, and bornite is present in trace amounts. Chalcopyrite occurs as disseminations and veinlets and filling matrix to breccias. Supergene minerals consist of chalcocite, native copper and remnant bornite and chalcopyrite. Copper-gold ratios show considerable variation and suggest that gold and copper have been deposited separately (Stanley, 1994).

The Pothook pit exposes the complex southwestern contact zone between the Iron Mask batholith and mafic volcanic rocks of the Nicola Group. The geology of the pit was mapped by Stanley (1994). He documented three episodes of steep faulting that followed the intrusion and cooling of successively younger phases of the batholith (i.e., post-Pothook, post-Cherry Creek and post-Sugarloaf). The faults are oriented north-northwest and east-northeast, and have disrupted the northwest-trending contact and have interleaved the Pothook diorite with picrite, pyroxene porphyritic flows and volcaniclastic units of the Nicola Group. Cherry Creek monzonite intruded and caused potassic alteration of the Pothook diorite exposed in the north wall of the pit. Intrusion of fine-grained hornblende porphyritic dikes of Sugarloaf diorite was focused near the batholith contact, primarily in volcanic rocks and locally in the Pothook diorite but not in the Cherry Creek monzonite. Pervasive albite alteration is developed on the east wall of the pit in Pothook diorite and less pervasive alteration affects dikes of Sugarloaf diorite. A younger fracture-controlled potassic alteration overprints the albite alteration (Stanley, 1994). Veins of K-feldspar-biotite-epidote dip steeply and strike north-northwest. These veins contain pyrite, copper (chalcopyrite, bornite) and gold, but they are not the major source of economic mineralization.

The main copper-gold mineralizing event was associated with iron-oxide and iron-sulphide vein deposition. "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.... They 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°." (Stanley, 1994, page 280). A heterolithic, hydrothermal breccia comprising clasts of Nicola volcanic rocks and all phases of the batholith was intersected in drilling below the centre of the pit. The breccia contains subordinate magnetite, chalcopyrite and bornite mineralization, and is interpreted to be a deeper manifestation and hydrothermal link to the vein mineralization (Stanley, 1994). Evolution or collapse of this system produced the propylitic overprint of chlorite±pyrite veining that pervades all but the albitite rocks in the open pit. White calcite veins crosscut the chlorite veins. The youngest events are low-angle southwest-dipping faults, mafic dike emplacement and late chalcedonic quartz veins that reflect the Eocene extension that affected the area (Souther, 1992; Stanley, 1994; this study).

RAINBOW (MINFILE 092I/028)

The Rainbow deposit is located on the southwest margin of the Iron Mask batholith, approximately 7 km southwest of Kamloops (Fig. 2). It is located on the eastern slopes of Sugarloaf Hill, less than 4 km southeast of the Afton pit. The property has been mapped and drill tested (Oliver, 1995), and is one focus of active exploration by Abacus Mining and Exploration Corp. Drill-indicated resources on the combined #2 and #22 zones is 15 860 tonnes of ore with an average grade of 0.528% Cu (BC Ministry of Energy and Mines, MINFILE). Subsequent drilling (2002 and 2004) indicated that the #2 and #22 zones form a northwest-trending zone of steeply dipping copper-gold mineralization, 700 m long and up to 500 m deep, that is open along strike and at depth. A new drill-indicated resource is currently being calculated.

The area of interest straddles the northwestern contact zone of the batholith. The contact is a complex northwest-trending fault zone, referred to as the Leemac Fault, which separates the main batholith, comprising the Pothook and Hybrid phases, from picrite, metavolcanic and metavolcaniclastic rocks of the Nicola Group. The fault is a brittle shear zone up to 300 m wide that parallels the intrusive-volcanic contact. Directly southwest of the fault is a northwesterly-elongated intrusion of Sugarloaf diorite that intrudes the Nicola country rock and underlies most of Sugarloaf Hill. Oliver (1995) has shown Sugarloaf Hill to comprise three contemporaneous but mappable stocks of hornblende diorite, albite-phyric monzodiorite and microphyric hornblende diorite. Northeast-trending apophyses of porphyritic hornblende diorite crosscut the main Leemac Fault structure, intrude older phases of the batholith (Pothook and Hybrid), and host copper-gold mineralization. Younger (?) northeast-trending faults crosscut hornblende diorite on Sugarloaf Hill.

Mineralization on the Rainbow property is focused close to the Leemac Fault. The #1 and #17 zones are hosted in Sugarloaf hornblende porphyry; the #2 and #22 zones in Pothook/Sugarloaf hybrid and metavolcanic rocks, respectively. All mineralization is fracture or breccia controlled and consists of chalcopyrite±magnetite accompanied by pyrite and alteration mineralogy. Crosscutting veins in drillcore give the following paragenesis: 1) pale creamy green to white albite zones, accompanied by narrow K-feldspar envelopes and commonly mantled by epidote; 2) the first set of veins, fractured and cut by flat zones of massive pyrite replacement ± chalcopyrite; 3) final veining, comprising tight 1–3 mm, white, crustiform calcite veinlets with brown iron-carbonate selvages and narrow black chlorite envelopes. Selective zones of early andradite alteration of Sugarloaf rocks occurs along the Leemac Fault and in the #17 zone (Oliver, 1995). The fault zone is characterized by carbonate, silica and less often sulphide-healed breccias and open-space fillings.

Several types of mineralization that are under-documented for the Iron Mask camp are present on the Rainbow property. These include a single occurrence of visible gold (DDH R-04-44) and massive pyrite replacements containing elevated cobalt values (0.21% cobalt over 37.80 m; DDH R-04-023). The gold grain (0.5 by 2.0 mm) occupies a narrow white calcite veinlet cutting albitized Sugarloaf diorite in the #2 zone. The cobalt enrichment was intersected in drilling on the #1 zone in an interval of massive pyrite replacement of Sugarloaf diorite.

COQUIHALLA EAST (MINFILE 092I/120)

The Coquihalla East zone is gold-rich, copper-poor mineralization that was first recognized by TeckCominco in the 1990s. It comprises two northwest-trending zones that are located immediately southwest of the Pothook pit (Fig. 2) in the structurally complicated contact zone between the Pothook/Cherry Creek phases of the batholith and Nicola country rocks, where a number of Sugarloaf diorite dikes intrude the package. Alteration styles include pervasive and patchy albite, fracture-controlled potassium±epidote, and pyrite-chlorite-calcite propylitic overprint. The Coquihalla east zone lies within the broader propylitic alteration zone that encompasses the Afton alteration-mineralization system. The relationship between the Coquihalla East, and the Afton or the Pothook mineralizing systems remains to be established. It may be a younger event that locally overprints earlier mineralization. The poor correlation between Cu:Au ratios in the Pothook may reflect an overprint from a gold-only copper-poor mineralization.

DISCUSSION

Mineralized intrusions display high-level textures/features, such as aphanitic to microporphyritic textures, magmatic flow banding, miarolitic cavities and numerous open spaces filled with alteration (sphene, calcite, K-feldspar) and hypogene (chalcopyrite, magnetite, chalcocite, pyrite) minerals.

The Iron Mask batholith is characterized by three distinct hydrothermal events that accompanied the intrusion and fractionation of its three main phases, the Pothook, Cherry Creek and Sugarloaf. Within the Pothook diorite, hydrothermal magnetite-apatite-actinolite-epidote veins are common and form large dilatent veins at Afton, the Magnet mine and the Rainbow property (Figure 16a). No significant amount of copper or gold was introduced with this early hydrothermal event. Potassic metasomatism has a close spatial association with Cherry Creek monzonite and those deposits it hosts (Afton, Crescent, DM and Big Onion), suggesting that the potassic fluids originated as a deuteric product during cooling of the Cherry Creek monzonite (Stanley *et al.*, 1994). Potassic alteration weathers a characteristic pink to orange colour due to the finely disseminated hematite that accompanied introduction of secondary K-feldspar and biotite±magnetite that makes up this assemblage (Figure16b). Disseminated copper sulphides accompanied potassic alteration in the Crescent, DM and Afton deposits, but similar sulphide-barren zones are present along the margins of the Cherry Creek phase throughout the northern margins of the batholith (Lang *et al.*, 1995). Sodium alteration is spatially associated with and genetically related to the youngest, Sugarloaf diorite phase. Alteration is characterized by features ranging from individual albite fractures to wide zones of pervasive white albitic alteration (Figure 16c), specifically at the Pothook, Ajax West and East deposits. Copper and gold mineralization is fracture hosted in zones of intermediate albitic alteration, located peripheral to the hydrothermal centre, which is characterized by pervasive albitic alteration and weak mineralization (Ajax West and East; Ross *et al.*, 1995).

Due to the spatial distribution of Cherry Creek monzonite along the northern margin of the batholith and the Sugarloaf diorite along the southern margin, Na-rich and K-rich alterations are rarely present together. A caveat to this generalization occurs at the Pothook deposit, where both alteration assemblages are present and define the following paragenesis: a pervasive potassic metasomatism related to the Cherry Creek phase; pervasive albitic alteration zones related to Sugarloaf dike emplacement; and late crosscutting K-feldspar-biotite-epidote veins and later mineralization related to an Fe-oxide–Cu-sulphide stage of veining associated (?) with chlorite (Stanley, 1994). Late-stage banded shear veins of quartz-chalcopyrite and pyrite related to low-angle shear zones are the youngest episode of mineralization. The relationships in the Pothook pit suggest that the bulk of copper-gold mineralization postdates albite alteration and Sugarloaf diorite. Mineralization at Afton is related to potassic alteration; at Crescent and DM/Audra, fracture-controlled mineralization closely follows an early pervasive barren potassic event; and, at Ajax, mineralization is directly associated with albitization related to Sugarloaf diorite. Copper-gold mineralization apparently is not restricted to one or even two hydrothermal events.

The temporal relations between various mineralized and unmineralized structures also infers that mineralization continued over a protracted period of time. Mineralized vein arrays at the Magnet and Python mines indicate a northwesterly-oriented sinistral shear sense at the time of mineralization. East-trending dilatent structures or 'alteration and mineralization corridors' host intrusive breccias (Crescent) and preferred vein sets (DM/Audra). Potassium-metasomatized Cherry Creek rocks in the west wall of the Crescent pit display a well-developed, north-trending vertical magmatic foliation, defined by hornblende and plagioclase phenocrysts and xenoliths.

Restoration of alteration asymmetries in the footwall and hangingwall contacts to the #17 mineralized zone on the Rainbow property suggests that the Leemac fault may have 350 m of dextral movement, interpreted by Oliver (1995) to be synchronous with mineralization.

CONCLUSIONS

Magmatic, stratigraphic and tectonic features of the Iron Mask area support the following conclusions. Intrusion of the main phases of the batholith occurred over a short time span in the Late Triassic (204 ± 3 Ma), probably in a shallow or subvolcanic environment with rapid vertical and horizontal facies transitions from mineralized intrusion breccias to monolithic layered volcanic breccias to lahar deposits that contain mineralized clasts. An apparent regionally consistent magmatic foliation in the Hybrid phase, trending ~280°, indicates a Late Triassic tectonic control. Chemically distinctive hydrothermal systems accompanied each intrusive phase of the batholith. Copper and gold mineralization are associated with at least two of these: the potassic alteration associated with the Cherry Creek monzonite, and the sodic alteration associated with the Sugarloaf diorite. Alteration and mineralization are localized along intrusive contacts between the older Pothook/Hybrid phases and the younger feldspar and hornblende-phyric phases. Mineralized vein arrays at the Magnet and Python mines indicate a northwesterly-oriented sinistral shear sense at the time of mineralization. East-trending dilatent zones may have accommodated the ore zones at the Afton deposit, the intrusive breccias and veins at Crescent, and the preferred vein sets noted on the DM/Audra zones. Structures in the batholith and Nicola Group along the southwest margin of the batholith postdate the bulk of copper-gold mineralization and show consistent southwest-trending ductile mineral lineations.

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