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J. A.

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SUMMARY AND CONCLUSIONS

ABSTRACT

The J.A. deposit is situated 370 km northeast of Vancouver. It underlies Highland Valley in a graben block bounded by high angle faults. Mineralization forms an elliptical body which is elongated northwestward parallel to the valley. Reserves are estimated from diamond drilling to be 260 million tonnes containing 0.43 percent copper and 0.017 percent molybdenum.

The deposit straddles the north striking contact between granodiorites of the Guichon variety and the younger Bethlehem phase of the Guichon Creek batholith. A small elliptical stock with long axis subparallel to that of the ore lies along its southern contact. The stock cuts the Guichon/Bethlehem contact. It has a carapace of quartz plagioclase aplite which grades inward to porphyritic biotite quartz monzonite. This carapace is mineralized and weakly disseminated sulphides occur throughout the stock.

strike

Regional geology and bedrock geometry suggest that a series of steeply dipping northward and northwestward striking faults comprise the framework of the deposit. Information from other Highland Valley deposits indicates that the faults were initiated prior to ore formation. There is however good evidence to indicate that post-ore movement also took place. Along the Highland Valley, apparent offset of contacts suggests some left lateral movement along the Highland Valley fault. Block faulting in Highland Valley accompanied by sedimentation and volcanism during the Tertiary is well documented.

Mineralization occurs primarily in fractures, veins and their alteration envelopes. The predominant economic mineral is chalcopyrite with lesser bornite. Sulphide zoning is apparent as follows: a core zone in which bornite equals or exceeds chalcopyrite grades outward

through a zone with chalcopyrite in excess of bornite, to a zone with chalcopyrite in excess of pyrite, and finally to a zone with pyrite in excess of chalcopyrite. Pyrite in the "halo" averages less than 2 percent by volume. The orebody is predominantly within the chalcopyrite and chalcopyrite + pyrite zones; the pyrite and much of the bornite zone have subeconomic grades. Although sulphide-bearing quartz and quartz-epidote veins and quartz-sericite zones markedly influence grades locally, the density of sulphide-bearing mineralized fractures is the most important overall grade control. Most veins and fractures in the deposit have moderately steep to steep dips.

Molybdenite is common in small amounts throughout the bornite, chalcopyrite, and chalcopyrite-pyrite zones. In General, the best molybdenum values appear to coincide with the best copper grades.

The main stage of mineralization apparently occurred in two major episodes. In the earlier one, sulphides are associated with quartz or quartz and flaky sericite; in the later one they are associated with epidote and quartz. Hydrothermal chlorite was formed throughout the main ore stage. Minor amounts of magnetite, specularite, calcite, zeolite (laumontite), and anhydrite (now gypsum) are also associated with the sulphides.

K-feldspar and secondary biotite are widely distributed in and adjacent to the orebody. Biotite is not concentrated to form a coherent zone in the deposit. K-feldspar alteration is however concentrated both in and adjacent to the carapace of the porphyry stock. Although this alteration zone is largely controlled by geology, it could be argued that the altered northern border of the stock forms a subeconomic potassic core zone in the deposit.

The orebody is centred in a zone of weak to moderate pervasive alteration of feldspar. Sericite predominates, but in the typical alteration assemblage, is accompanied by kaolinite and montmorillonite with or without carbonate. Variations in proportions of each mineral and their intensity of development change markedly on a small scale. Typically, these variations are associated with fractures, faults, and veins. Mafic minerals in the deposit may be fresh, chloritized, sericitized, or epidotized. Locally, early formed hydrothermal biotite replaces hornblende, to be partially replaced in turn by chlorite.

The epidote zone largely overlaps the ore zone but seems to be more closely allied to geologic setting than ore grade. It is most commonly developed in the more calcic and mafic-rich Guichon Granodiorite.

Deposition of zeolite and later gypsum and calcite are largely post-ore features. These minerals are widely distributed both in and outside the ore zone. They mark the waning of hydrothermal activity.

LOCATION AND SETTING

The J.A. deposit is situated in the Highland Valley area about 370 km northeast of Vancouver, British Columbia (Lat. $50^{o}28.5'$, Long. $120^{o}58.5'$, N.T.S. 92I/7W, elev. 1,220 m). The deposit underlies the road along Highland Valley, about 3 km east-southeast of Quiltanton Lake (see McMillan, this volume).

The Highland Valley is a relatively deep but broad, almost flat-bottomed, northwest-trending depression with average elevation 1,200 m incised into an upland plateau of moderate relief. The plateau has average elevation 1,500 m but rises locally to 1,800 m or more.

East of Quiltanton Lake granitic bedrock in Highland Valley is covered by a wedge of Tertiary volcanic and sedimentary rocks (McMillan, this volume) that thins eastward and feathers out 2.5 km west of the J.A. deposit. In Highland Valley in the vicinity of the J.A. deposit bedrock has little or no preglacial cover but glacial sediments infill the valley to depths of 170 m on average and more than 300 m locally.

Pleistocene stratigraphy in Highland Valley is complex because the area was significantly influenced by three or possibly four major glaciations. In a general way, however, the valley is infilled by a thin discontinuous basal sand, gravel, and till succession which is overlain by a thick sequence of thin-bedded lacustrine silts, silty sands, and clayey silts. This in turn is overlain by a moderately thick, well to poorly bedded silt, sand, and gravel succession in which depressions and erosional channels are filled by deltaic outwash sediments. The valley walls are veneered by ablation morraines, bedded silt, sand, and gravel.

Kettle lakes occur along the valley while eskers and numerous kame terraces line its walls. The kame terraces apparently formed along the margins of a stagnant body of ice which filled the valley. Successive levels of terraces were formed as the ice wasted downward.

HISTORY

The J.A. deposit, named in honour of Mr. J.A. McClelland, Chairman of Bethlehem Copper Corporation, was discovered in the summer of 1971. Early drilling was hampered by deep overburden but the problem was overcome by using rotary drills to reach bedrock, then diamond drills to penetrate it. More than 100 drill holes have delineated the deposit and outlined reserves of 260 million tonnes containing 0.43 percent copper and 0.017 percent molybdenum.

A perliminary pit described in the company's 1972 Annual Report was designed to recover 115 to 135 million tonnes of material from the deposit with grade 0.60 to 0.65 percent copper equivalent. Stripping ratio for this pit would be 2.5:1. At this time, the property is not in production and all grade and tonnage figures are based on drill information.

GEOLOGIC SETTING

The J.A. deposit is elongated in a northwest direction and has average dimensions 1,300 m by 300 m (Figure 1). It straddles the north-striking contact between rocks of the Guichon variety of the Highland Valley phase and those of the Bethlehem phase (for details about the geology of the batholith, <u>see</u> McMillan, this volume). Roughly 60 percent of the mineralization is in Bethlehem Granodiorite. Along the south margin of the deposit, there is a zone of quartz plagioclase porphyry. The porphyry cuts the Guichon-Bethlehem contact and is elongated subparallel to the ore zone. Mineralization extends only a short distance into the porphyry before grades become very low. The porphyry is variously interpreted to be a stock which is an offshoot of the Bethsaida phase (McMillan, 1973), or a metasomatic alteration zone (Guilbert and Lowell, 1974). Embayed quartz crystals and complex oscillatory zoning which are strong evidence for a magmatic origin are found in relatively fresh zones in the porphyry. Furthermore, dykes exist which have chilled margins and interior zones similar to the porphyry stock.

Rocks of the Bethlehem phase were apparently modified adjacent to the stock and mineralization in these rocks lies within the modified halo. The modified Bethlehem Granodiorite contains medium to coarse grained subhedral quartz phenocrysts in otherwise normal Bethlehem Granodiorite. Away from the stock quartz phenocrysts are absent.

Near the stock, rocks of the Guichon variety are granodiorites to quartz diorites with typical textures. In the southeast part of the property there are intercalated finely crystalline zones and local areas of Chataway Granodiorite. Both the fine grained and Chataway rocks have gradational contacts with normal Guichon Granodiorite. Similar textural variations are seen elsewhere in the Guichon variety and they are not thought to be related either to the stock or the ore forming process.

TECTONIC SETTING

The J.A. deposit is located in a down-dropped fault block, the Highland Valley graben. As indicated elsewhere (McMillan, this volume), initiation of the high angle west-northwest striking faults along Highland Valley took place after emplacement of the batholith but prior to mineralization at Valley Copper (Allen and Richardson, 1970; McMillan, 1971). Similarly, north striking faults at Valley Copper and at Bethlehem Copper (Covenay, 1962) predate mineralization. On the basis of bedrock contours and drill hole information, west-northwest and north striking faults are interpreted to exist in the J.A. zone (McMillan, 1973). By inference, they are assumed to have existed prior to mineralization and to have played a role in initiating the many fractures which were subsequently mineralized to form the deposit. Faulting probably occurred twice subsequently. Some movement probably occurred during Mesozoic block faulting which controlled deposition of Jurassic sediments a few miles to the west (Carr, 1962) and in the Tertiary, block faulting created embryonic Highland Valley. These movements formed en echelon grabens which were partly infilled by lava flows and immature sediments. Projections of the Guichon/Bethlehem contact from north and south of the ~~Valley~~ Highland Valley probably indicate an aggregate left lateral movement.

PETROLOGY OF ROCKS ASSOCIATED WITH THE DEPOSIT

Guichon Variety

Rocks of the Guichon variety are granodiorites to quartz diorites with minor variations in grain size, mafic abundance, and relative proportions of biotite to hornblende. However, the unit as a whole has similar textural characteristics that make it distinctive and mappable.

Where crystals are sufficiently fresh, plagioclase compositions have been determined to range between An_{43} and An_{30} in core zones to An_{20} in rims. Zoning is generally simple and normal. Crystal habit varies from subhedral and interlocking to eroded, where plagioclase is in contact with primary K-feldspar. Plagioclase, magnetite, apatite, and locally sphene crystallized early. In the area of the deposit, plagioclase is variably altered to sericite, clay minerals, carbonate, chlorite, and epidote.

Characteristic mafic minerals are biotite which is red brown in thin sections and hornblende which is green. These minerals crystallized almost simultaneously and there is little reaction between them; albeit biotite may be slightly younger. Mafic minerals tend to occur in unevenly distributed clumps of subhedral crystals. In the area of the deposit alteration to chlorite with or without epidote is common; biotite is generally more pervasively altered than hornblende. Locally, mafic minerals are altered to green hydrothermal biotite, less commonly to actinolite and uncommonly to prehnite. In mineralized samples, mafic minerals are often speckled with sulphide mineralization.

Quartz and microperthitic K-feldspar crystallize late as anhedral interstitial grains. They have mutual contacts which suggest simultaneous crystallization. Where K-feldspar is in contact with plagioclase, the latter is partially replaced. Quartz generally occupies small angular areas between plagioclase crystals to form a closed interstitial texture. Quartz commonly displays ruptures and undulatory stress extinction under crossed polarizers. K-feldspar may be intergrown with quartz, occupy similar closed interstitial areas, or form larger poikilitic grains. The abundance of K-feldspar varies widely from specimen to specimen hence the composition ranges from quartz diorite to granodiorite. Alteration in K-feldspar is similar to that in co-existing plagioclase but is usually less intense.

Bethlehem Phase

Almost all rocks of the Bethlehem phase in the area of the deposit are slightly porphyritic granodiorites. They are unusual in that they carry not only mafic phenocrysts but also several percent rounded to subhedral early crystallized quartz crystals; typical Bethlehem granodiorites have omeboid, interstitial quartz.

As in the Guichon variety, plagioclase in these rocks crystallized early and is subhedral. Unlike Guichon rocks, it typically has complex oscillatory zoning. Again core zones are more calcic (An_{37} to An_{30}) than rims (An_{23} to An_{14}). Feldspar alteration is like that in the Guichon variety.

Mafic minerals are less abundant in these rocks than in the Guichon variety, but alteration is similar. Only biotite and hornblende have been seen. Mafic minerals comprise a few percent euhedral coarse grained poikilitic hornblende and several percent disseminated fine to medium grained subhedral crystals. The poikilitic crystals carry inclusions of plagioclase, magnetite, apatite and sometimes sphene.

Quartz occurs both as rounded partially resorbed crystals and as interstitial grains that are larger and slightly more abundant than in Guichon variety rocks. Interstitial quartz commonly encloses plagioclase crystals and the resulting texture is described as open interstitial. Almost invariably quartz is crackled or shows stress extinction.

K-feldspar is microperthitic, and roughly equal in average abundance to that in most Guichon variety rocks. In general, K-feldspar is less altered than co-existing plagioclase and has open interstitial texture.

Dykes in the J.A. Deposit

Several varieties of dykes occur in and adjacent to the J.A. orebody. The two most common types, aplite and mafic quartz plagioclase porphyry, predate at least some of the mineralization. Less common, thin, dark coloured dykes are post-ore.

Aplites typically form thin and discontinous dykes and stringers. They may be porphyritic; rarely with biotite and commonly with plagioclase. The matrix consists normally of plagioclase, K-feldspar, and quartz. Aplites cut all the major rock types in the deposit but are not common in the porphyry stock.

Pre-ore porphyries are generally thicker and more continuous than the aplites and maximum true width of pre-ore porphyry dykes may be as much as ten metres. Some can apparently be projected between drill holes (Figure 2) and similar dykes which crop out to the northeast and south have been traced as much as two kilometres along strike. Like the aplites, pre-ore porphyry dykes cut all major rock types but are uncommon in the porphyry stock. At one locality pre-ore porphyry cuts biotite quartz plagioclase aplite. However, crosscutting relationships show at least two generations of pre-ore porphyry so the true aplite-porphyry relationship is not certain.

Pervasive alteration in the pre-ore porphyries is similar to that in the country rock. Plagioclase is typically altered in varying degrees to sericite and clay minerals and locally to carbonate and epidote. Mafic minerals are chloritized and epidotized.

Phenocrysts of mafic minerals, quartz, and plagioclase (andesine) comprise on average 40 percent of the pre-ore porphyries. Complex oscillatory zoning characterizes plagioclase phenocrysts, but crystal borders are always more sodic than cores. Porphyry matrices are quartzo-feldspathic and vary in texture from aphanitic to finely aplitic. Most matrices are speckled with finely crystalline mafic minerals, normally biotite. Accessory minerals are magnetite, apatite, and locally chalcopyrite. K-feldspar is generally absent in these rocks.

Post-ore dykes are dark coloured, fine grained, and in general amygdaloidal. Most are slightly porphyritic with fine to medium grained plagioclase (An_{55}) and pyroxene phenocrysts. The matrix has plagioclase and some hornblende microlites in a groundmass of devitrified glass. Amygdules consist primarily of calcite. These dykes closely resemble nearby lavas of the Tertiary Kamloops group and therefore are probably of Eocene age. However, it is possible but unlikely that they were intruded during Lower Cretaceous time when lamprophyre dykes were intruded into the Valley Copper deposit (Jones et al., 1972, p. 557).

Porphyry Stock

Rocks of the porphyry stock vary in texture and grain size. Toward the outer edges of the stock porphyritic aplites predominate; within it, porphyritic quartz monzonites predominate. Phenocrysts are quartz and plagioclase with small amounts of mafic mineral locally and occasional

K-feldspar. Biotite is the typical mafic mineral. The matrix is largely quartz and K-feldspar but some specimens also have finely crystalline subhedral plagioclase. The phenocrysts and matrix of the aplites are finer grained than those of the quartz monzonites.

Quartz phenocrysts have been partially resorbed so they are generally somewhat rounded with contacts which in detail are finely scalloped. In some coarser grained areas they have a squarish aspect. Most have stress extinction or are crackled and some have deformation lamellae.

Plagioclase phenocrysts are predominantly subhedral but have also been partially resorbed so outer contacts are uneven in detail and corners are often rounded off. In relatively fresh samples, complex oscillatory zoning is preserved locally. In general, the central seven-eights of the crystals have weak normal zoning (An_{32} to An_{28}) that passes outward across narrow fringe zones of gradually more sodic plagioclase to an outer rind of sodic oligoclase (An_{14}). In general, calcic core zones are more altered than the rims. Sericite, clay minerals (?), and lesser calcite are the dominant alteration assemblage but epidote occurs locally.

K-feldspar is microperthitic in both phenocrysts and the matrix. Phenocrysts are not common and where present are subhedral to anhedral with their borders intergrown with matrix K-feldspar. The latter varies from anhedral to rounded where it is intergrown with ameboid clumps of quartz crystals in aplitic rocks. Alteration of K-feldspar consists generally of a light or dense clouding of the crystals by clay(?) alteration; locally they are altered to carbonate.

Biotite is the predominant mafic mineral in these rocks and generally occurs as phenocrysts. Commonly it is pervasively chloritized, locally it has associated epidote, sericite, or carbonate alteration.

Rocks of the stock bear a strong textural and compositional resemblance to various members of the composite Gnawed Mountain dyke and locally to porphyritic areas within the Bethsaida phase. Field mapping strongly suggests that the Gnawed Mountain dyke is an offshoot of the Bethsaida phase (McMillan, this volume). By analogy the J.A. porphyry stock is also inferred to be an offshoot of the Bethsaida phase.

DISTRIBUTION OF ALTERATION AND ORE MINERALS IN THE DEPOSIT

Much of the following data is based on two sections (89E and 105E) across the deposit which were logged in greater detail than the core of other drill holes. Grades were estimated visually in the detailed sections, then compared to assay values in Bethlehem Copper Corporation's drill logs. Grade information and data on vein mineralogy and alteration in sections which were not logged in detail by the author are from Bethlehem's logs.

Because the work was done to facilitate comparisons with other deposits in Highland Valley, data were collected on rock types, on pervasive feldspar and mafic alteration, and on alteration and mineralization related to fractures and veins.

Geometry of the Deposit

At bedrock surface the J.A. mineralized zone is roughly elliptical in plan view. It encroaches on and appears to partially wrap around the central porphyry stock (Figure 1). The ore contact is relatively uneven. Part of this unevenness probably reflects fault control of mineralization and part, post-ore fault offsets.

On the 762 m level (Figure 2a), ore is narrow and occurs in two bodies. The western body is elongated eastward but has a southerly projecting apophysis. Upward, these two bodies coalesce and the ore zone widens and expands southeastward. By the 914 m level, the ore zone is a single body with a pronounced southeastward elongation.

In section, the border of the mineralization is not sharply defined and better and lesser grade zones interfinger. The ore contact shown on the sections (Figure 3) represents a statistical 0.3 percent copper isopleth. In contrast, the base of the deposit is somewhat more sharply defined. It normally occurs between 750 and 900 m in elevation. In section it is evident that the base of the core dips gently southward. Several drill holes south of the porphyry failed to intersect mineralization of potential economic interest.

The area of highest grade mineralization encountered during test drilling occurs immediately north of the porphyry stock and straddles the Bethlehem/Guichon contact. This zone contains the highest average density of mineralized fractures noted in the deposit and more than average numbers of quartz veins and zones of quartz plus flaky sericite. The closely broken nature of the rock is attributed to the combined effects of tectonism, intrusion of the Bethlehem Granodiorite, and later intrusion of the porphyry stock.

Geology

In section 105E, the country and host rock is granodiorite to quartz diorite of the Guichon variety. Local thick to thin porphyry dykes cut the granitic rocks (Figure 3a). In the section, apparent dips of the dykes are low. However, most dykes studied in nearby outcrops are steeply inclined and are oriented northward. It is likely therefore that the dykes intersected in drill core are similarly steeply inclined but have low apparent dips because they strike subparallel to the section.

In section 89E, the country and host rocks include rocks of the Guichon variety, Bethlehem phase, and the porphyry stock. The orebody is primarily in Guichon and Bethlehem rocks and extends only a short distance southward into the stock. At bedrock surface, the stock is in contact with Bethlehem Granodiorite. However, because the Bethlehem-Guichon contact is moderately inclined southward, it is projected to intersect the border of the stock at depth.

Pervasive Feldspar Alteration

Pervasive feldspar alteration occurs throughout and for more than 200 m outside the J.A. deposit. Overall, it forms an elliptical zone in which alteration intensity gradually decreases outwards (Figure 4). In detail, alteration intensity is highly variable.

Alteration was logged according to intensity of development and color. Overall, weak to locally moderate white alteration predominates. However, zones within various drill holes have pervasive weak to strong pink, green, or cream alteration. In most zones, areas of pervasive alteration have local development of other alteration types. For example, local pink alteration occurs in zones of pervasive white alteration. In some areas, various alteration types are mixed.

Alteration in the porphyry stock differs. It has a carapace of moderate to intense alteration which gradually weakens northward outward into the country rock. The southernmost drill hole in the stock ended in weakly altered porphyry. This suggests that deeper levels in the porphyry are less altered than its outer layer. Alteration types vary in the stock but cream, green, and pink varieties predominate.

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Judging from the distribution of pervasive feldspar alteration in the sections and on the 762 m and 914 m levels, changes in intensity with depth in the deposit are slight. The extent of the zone of weak and stronger alteration is very similar on the two levels although that on 914 m level is slightly larger. In both, the alteration zone is generally diffuse but can be relatively sharp. Within the gross zones, local areas of less or more intense alteration are common. Most local intensely altered zones can be related to faults, fractures, or veins. Both sections have a more or less centrally located zone in which alteration intensities range from weak to strong but are moderate on average. In general, alteration is somewhat more pronounced in the northwest part of the deposit.

On 762 level, feldspar alteration is most intense in the stock and congruent to it on the north. Virtually all of the more intensely altered zone is either within the stock or in Bethlehem Granodiorite country rocks. On 914 m level, the relationship to rock type is less obvious but similar. The zone of intense alteration is along the northern border of the stock and north of it. Although it extends into Guichon Quartz Diorite country rock, again it is more prominent in Bethlehem Granodiorite west of the Guichon contact.

The overall zone of pervasive feldspar alteration envelops the ore deposit. Ore is roughly centrally located with respect to the alteration but the zone is narrower on the east and broader on the west side of the ore. The zone of best mineralization roughly coincides with the generalized zone of most intense alteration. However, the average intensity change associated with better grades is only from weak to moderate.

Using X-ray diffraction techniques, an attempt was made to define the mineral assemblages in the altered feldspars. Despite variations in color seen in drill core, the typical assemblage is sericite plus kaolinite plus montmorillonite. Chlorite occurs locally. However, in rocks containing feldspar logged as having weak to moderately intense white alteration, kaolinite and montmorillonite are relatively important. In those with intense chalky white alteration kaolinite predominates. Pink alteration may be caused by pervasive zeolite alteration, K-feldspar alteration, hematitic staining of plagioclase, or alteration to sodic plagioclase. The alteration assemblage in hematitic stained feldspars varies but normally sericite is more prominant than kaolinite or montmorillonite.

Clay-size minerals may or may not be present where the alteration is zeolitic or feldspathic. Green alteration is generally dominated by sericite which is easily identifiable microscopically. Clay-size sericite may also be present and most samples carry weakly developed kaolinite and montmorillonite. In samples with feldspars that are various shades of olive green, thin sections show that sericite is joined by carbonate alteration and fracture fillings; kaolinite and montmorillonite are weakly developed.

Mafic Mineral Alteration

Primary mafic minerals in the host rocks of the deposit are biotite and hornblende. Typical alteration products are chlorite and sericite with less common epidote, secondary biotite, and copper or iron sulphides.

Just as feldspar alteration zones vary in intensity, corresponding changes occur in type and intensity of mafic alteration. However, mafic alteration is also partly related to rock type. In section 105E where Guichon Quartz Diorite predominates, mafic minerals are normally partly chloritized and locally are pervasively chloritized. Other alteration types are present but uncommon and no significant difference in mafic alteration occurs in the ore zone. In contrast, zones of sericite or epidote alteration accompany chloritization in section 89E. In the zone of best copper grades, which occurs in Bethlehem host rocks, mafic minerals are pervasively altered to chlorite and sericite. In the remainder of the orebody in either quartz eye Bethlehem or Guichon host rocks there is complete or partial chloritization. Outside the ore zone in Guichon Granodiorite, partial chloritization is typical although alteration to sericite or epidote occurs locally. In the porphyry stock, partial to complete chloritization of biotite and hornblende also predominates but epidotization is common and sericitization occurs. It is uncertain whether the presence of epidote is controlled by lithology or by alteration zoning.

Veins and Fractures

Most of the mineralization at J.A. is either in veins or in fractures. To assess their relative importance across the deposit data on mineralogies, densities and orientation of fractures and veins were assembled.

Quartz Veins

Quartz veins, which may be either mineralized or barren, are not prominent in the J.A. deposit. In section 105E, they are 3 m apart on average in and south of the ore but are uncommon north of it. In section 89E they are geneally 3 to 7 m apart but are only 1 to 2 m apart in the ore zone adjacent to the porphyry stock contact.

Quartz-Sericite Veins and Zones

Quartz plus flaky sericite as zones and as vein envelopes is important because it typically carries significant copper mineralization. In section 105E, quartz plus flaky sericite zones or vein envelopes are on average less than 0.3 m apart in the northern part of the ore zone. They are uncommon elsewhere.

In section 89E, quartz plus flakey sericite is sparsely distributed in and adjacent to the ore zone but is absent in fringing holes

Fracture and Vein Orientation

All drill holes in the J.A. deposit are vertical. Therefore it is possible to estimate dips of mineralized fractures and veins by measuring their angles of intercept with the drill core. Dips of almost all the mineralized fractures and veins at J.A. exceed 40 degrees. In section 105E fracture orientation densities are bimodal and vein orientation densities unimodal (Figure 5). The most prominent set of fractures has dips exceeding 80 degrees. Veins in this section most commonly have dips near 60 degrees. Because the only data available is from drill holes which are generally greater than 100 m apart it has not been possible to estimate strike directions. However, the relative paucity of crosscutting features suggests that the strikes of many of the veins and fractures are subparallel.

When drill holes are compared on section 105E, it is evident that fracture and vein orientations change slightly from north to south. Those in drill holes north of the ore zone are unimodal with average dip 60 degrees. Those in or closely flanking the deposit are bimodal with maxima with average dips of 60 degrees and 80 to 90 degrees. within the deposit ~~and~~ maxima of fractures and those of veins differ locally. South of the ore zone fracture orientations are again unimodal and have average dips of 50 to 60 degrees.

Density of Mineralized Fractures

The density of mineralized fractures (Figure 6) varies from north to south in section 105E. Holes north of the orebody have mineralized fractures more than 1 m apart on average. Those to the south average 0.3 m. In and close to the ore they are 0.1 to 0.15 m apart. In section 89E, however, density patterns are more variable. Within the porphyry stock mineralized fractures are generally more than 1 m apart although local areas have spacing of 0.1 to 0.2 m. Within the ore zone areas with average spacing 0.05 to 0.1 m coincide with areas of highest copper grade; elsewhere in the ore zone, mineralized fractures continue to be common. They have average spacing 0.2 m although spacings range to 0.7 m locally. From these data, it is evident that mineralized fractures are the most important ore-controlling structures in the deposit. Mineralized quartz veins are sparse and mineralized quartz plus flaky sericite zones only locally influence grades.

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SULPHIDE MINERALIZATION

The most prominant sulphide minerals in the J.A. deposit are chalcopyrite, bornite, molybdenite, and pyrite. The relative abundances of the copper sulphides and the distribution of molybdenum and iron sulphides in sections 105E and 89E were estimated during study of the drill core.

Molybdenite Distribution

Molybdenite is common in small amounts throughout the orebody (Figure 7). However, copper and molybdenum distributions are not identical. Molybdenite in section 105E is very uncommon in the northernmost two drill holes but is fairly common in small amounts as far south as drilling extended. The zone of most continuous molybdenite occurrences coincides with the 0.3 percent copper contour in the north but extends about 200 m beyond it in the south. In section 89E, visual estimates indicate that the best molybdenum values occur in the zone with highest copper values. Molybdenite is present but sparse in all the drill holes and in all the rock types. It is most common in the ore zone and in the most intensely altered zone within the porphyry stock.

Chalcopyrite-Bornite Distribution

Bethlehem geologists estimate that the chalcopyrite to bornite ratio in the J.A. orebody is about 5:1. In the sections logged in detail it was found that chalcopyrite exceeds bornite throughout the upper part of the ore zone. Only in the keel of the deposit where the ore zone is narrow does bornite abundance equal or exceed that of chalcopyrite (Figure 8). The bornite zone is fairly extensive in both sections but the grade within it is predominantly less than 0.3 percent copper. In section 105E the bornite zone forms a broad dome with a nearly horizontal upper surface. Restricted areas within the dome have chalcopyrite in excess of bornite. In section 89E the bornite zone is again dome-shaped, but is narrower and straddles the contact between the porphyry stock and the country rock. In 89E the porphyry contact evidently controlled the distribution of the bornite zone; in 105E the control is obscure.

In almost all the sections, areas enriched in bornite relative to chalcopyrite form dome-shaped areas like those described for the detailed sections. The domes apparently have diffuse and digitating contacts but their smoothed, generalized contacts are relatively symmetrical in cross section. In plan, the major area of bornite enrichment is ameboid in outline and is poorly correlated with ore grades (Figure 9).

Bornite rich zones occur in all the major rock types of the deposit but a close spatial relationship exists with the porphyry stock or in one case (section 97E) a dome-like sill (?) of quartz plagioclase porphyry. It is obvious on the 762 m level plan that grades in much of the bornite zone are less than 0.3 percent copper equivalent. Bornite zones are distributed in several small areas on 914 m level. The largest occurs in the stock and northward in adjoining Guichon Granodiorite east of the Bethlehem contact.

Pyrite Distribution

Unlike some Highland Valley porphyry copper deposits, pyrite is relatively common within the ore zone and forms a dispersed, incomplete halo around the deposit. The common antipathetic relationship between the bornite and the pyrite zones is evident (Figures 8 and 9). In both sections studied in detail the base of the pyrite zone is subparallel to the upper contact of the bornite zone. In section 89E the relationship is less obvious because the configuration of the bornite zone north of the orebody is unknown. In each section the pyrite zone extends to bedrock surface and continues well beyond the north end of the orebody. In the pyrite zone Bethlehem geologists estimate that pyrite averages less than 2 percent by volume.

In most of the sections it appears that pyrite is distributed in basin-like areas. The borders of the "basins" are diffuse and apparently digitated. In general, the pyritic areas seen in various sections seem to dip northward at a low angle so that they have gently inclined south and steeply inclined north edges. Typically the pyritic zone considerably overlaps the ore zone (Figure 9). Locally the pyrite zone fringes the ore to the north, less commonly there is a pyritic area south of the ore and in one section weakly developed pyrite envelops the orebody.

On the 762 m level, pyrite is spottily distributed both north and south of the ore zone. On the 914 m level it is much more abundant. It adjoins much of the ore zone to the north and an apophysis even extends through the ore zone and to the south. Pyrite is uncommon in the porphyry stock but occurs in it in two places on the 762 m level and locally near its west end on the 962 m level. Pyrite occurs only in Bethlehem Granodiorite on 762 m level but is in all rock types on 914 m level. It is, however, most abundant in the Bethlehem for a distance of about 45 m west from the Guichon Quartz Diorite contact.

Sulphide Zonation

In the sections it is evident that bornite and pyrite are generally antipathetic. That is, there is an asymmetric sulphide zonation upward and outward from the areas which are relatively bornite-rich to those dominated by chalcopyrite. To the north and probably to the west the chalcopyrite zone grades outward to a chalcopyrite-pyrite and then locally to a pyrite-chalcopyrite zone. Most of the ore is in the chalcopyrite and chalcopyrite-pyrite zone. Except at the western edge of the deposit, no pyrite occurs south of the orebody. All the zones are variably developed.

Epidote Distribution

In general, epidote distribution seems to be more closely allied to rock type and geological setting than to the grade of mineralization. Epidote alteration is weakly developed on a large scale, moderately to intensely developed locally and is most abundant in the more mafic and calcic Guichon country rock. It occurs in veins, as fracture coatings, as disseminations in alteration haloes around veins or fractures, replaces mafic minerals or plagioclase and occurs as massive areas. Microscopic epidote alteration not visible to the eye is not considered in the discussion to follow. It is common for adjacent drill holes to have highly discordant epidote contents which suggests that lateral changes in epidote content occur rapidly. In section, contacts are inferred to be digitated. The epidote zone is also digitated in plan view (Figure 10). Overall, the zone is elongated northwestward and widens with depth.

The epidote zone overlaps the northwest edge of the stock and extends around its northeast edge on 762 m level. Epidote is most prominent in Guichon rocks and is uncommon in the Bethlehem except near the Guichon contact north of the stock. Areas of moderate abundance occur near the junction of stock, Guichon and Bethlehem phases and more or less around the edge of the east ore zone. On 914 m level the distribution of epidote is similar but the zone is less extensive toward the southeast. Again epidote is more abundant in Guichon country rock.

On 762 m level, epidote is weakly developed throughout the east ore zone but is virtually absent in the west zone. By the 914 m level, epidote is weakly developed throughout the eastern two-thirds of the orebody and is sparse or absent in the western third. Lobes of weakly developed epidote extend north of the ore and epidote is moderately developed in local areas of Guichon country rock adjacent to the Bethlehem contact.

Zeolite Distribution

Zeolite occurs in veins and less commonly in alteration zones adjacent to fractures. It is widespread throughout the deposit. Insufficient data is available to document the overall distribution of zeolite so only that in sections 105E and 89E will be discussed. Laumontite is the predominant zeolite present and the only other zeolite identified in the deposit is stilbite. Stilbite was found in only two specimens; in one it is intergrown with calcite, in the other with laumontite. Zeolite is generally alone but locally is intergrown with calcite, epidote, or sulphides.

In 105E, the distribution of zeolites is not obviously related to ore distribution and zeolite zones apparently transect the ore. Virtually every drill hole carries some zeolite but its abundance is highly variable (Figure 11). Apparently the zeolite zones dip gently northward but their true shape is not known. Although zeolite is locally intergrown with epidote or sulphides, it largely post-dates ore formation.

In 89E, zeolite is spottily distributed across the section both in and outside the ore zone. In this section zones appear to be subhorizontal. Differences between the two sections imply rapid lateral changes in zeolite abundance and possibly overall control by a steeply inclined northerly fracture system.

Gypsum Distribution

Much of the gypsum occurs in late stage fractures and veinlets. Many of these fractures are reactivated pre-existing structures because gypsum is often found in subparallel arrangement with older fracture fillings and veins. Its distribution is well known for sections logged in detail but information about its distribution in other drill holes is sketchy.

Consequently, the following interpretations must be regarded as tentative. At the 762 m level gypsum is distributed in a narrow, anastomosing zone which roughly coincides with the west orebody and the western half of the east orebody (Figure 12). Gypsum is present but weakly developed in the porphyry stock and better developed outside it in Bethlehem Granodiorite. Upward, gypsum is much more restricted than the ore zone. By the 914 m level, it forms an elliptical zone overlapping the central part of the orebody and extending north of it in Bethlehem Granodiorite but extends only a short distance eastward into Guichon Quartz Diorite. The gypsum zone has a general steep southwestward plunge.

Calcite Distribution

Calcite occurs in veins and fractures and as an alteration mineral in feldspars. Only structurally controlled occurrences are considered here. Calcite in most fractures and veins is post-ore. It typically occurs alone or intergrown with quartz or zeolite. Less commonly it fills vugs in sulphide-bearing veinlets.

In 105E calcite is weakly but widely distributed. It is uncommon in the ore zone and is most common in areas where zeolites are uncommon. That is, although calcite and zeolite are intergrown in veins, they occur largely in independent zones. Normally, calcite appears to be younger than zeolite.

In 89E calcite is sparse in the ore zone but fairly common though not abundant in the stock and the Guichon country rock. It is most abundant beyond 100 m north of the ore zone.

Other Alteration and Vein Minerals

Other alteration and vein minerals which are sporadically developed in the deposit are, in estimated order of abundance, K-feldspar, biotite, ocherous hematite, magnetite, specularite, actinolite, and tourmaline.

Biotite and K-feldspar which are indicative of potassic alteration seldom form discrete zones. Biotite is widely but sparsely distributed and thin section studies suggest that biotite alteration of mafic minerals occurred early in the alteration sequence. Secondary biotite was often subsequently altered to chlorite, epidote, or sericite. Primary biotite is red brown in thin section whereas secondary biotite is greenish brown.

K-feldspar was not recognized in the ore zone and is sparse and sporadically developed outside it in section 105E. In section 89E K-feldspar is relatively common both in the outer shell of the stock and in adjacent country rocks (Figure 13). Away from the stock it is sparse but widely distributed. Biotite alteration could have been more important than it now appears to be. K-feldspar alteration is apparently influenced more strongly by geologic setting than proximity to the orebody.

PARAGENESIS OF THE DEPOSIT

Mineralogy and Age Relationships of Vein and Fracture-Filling Minerals

As can be seen from Figure 14, sulphide and silicate components of J.A. system overlap extensively in time of emplacement. Crosscutting relationships seen in both hand specimens and thin sections of drill core were used to construct the figure. The main stage of mineralization occurred in two parts; first an episode of mineralization characterized by formation of sulphides with quartz and flaky sericite either as veins or as vein selvages; than an episode dominated by sulphides associated with quartz-epidote veining and alteration. Successive stages have only minor amounts of associated sulphide mineralization. It should be stressed that each stage and episode represent more than one period and probably many periods of injection of hydrothermal fluids. It should also be stressed that successive waves of mineralization generally used the same systems of fractures.

For want of better information, the time sequence interpretation rests largely on the assumption that formation of flaky sericite occurred during only one episode of mineralization; the early main stage. This assumption seems reasonable on the basis of data now available for this and other Highland Valley deposits.

As can be inferred from overlapping times of formation in Figure 14, vein and fracture mineralogy is highly variable. During the main stage of mineralization any of the common minerals in them can be found with any of the other common minerals or virtually any combination of them. However, judging from section 105E, certain mineral combinations were more common than others at different times. Prior to main stage mineralization information is ambiguous but quartz and chlorite apparently were deposited. During the main stage mineralization the following fracture and vein types are most common:

chlorite + chalcopyrite ± pyrite
chlorite + bornite ± chalcopyrite
chlorite + chalcopyrite ± bornite

quartz ± chalcopyrite ± bornite ± molybdenite
quartz + chlorite + chalcopyrite ± bornite
chlorite + epidote ± chalcopyrite
quartz + epidote ± chalcopyrite ± bornite
quartz + epidote
epidote + chlorite

Zeolite, gypsum, and calcite veins and fracture fillings which may carry minor chalcopyrite or pyrite as well as zeolite veins with minor amounts of epidote were deposited during the waning stages of mineralization. Although calcite and gypsum coexist with zeolite in veins, both generally appear to post-date zeolite.

Calcite which formed during main stage mineralization is generally disseminated in sericitized plagioclase where it is a by-product of feldspar alteration. Locally, however, it occurs in the cores of veins where it evidently filled vugs. In veins it often accompanies sulphides which also tend to be in vein cores. Similarly, zeolite intergrown with abundant sulphide is generally well crystallized and formed in vugs. The zeolite in these veins, as in the majority of zeolite veins analysed, is laumontite. Crosscutting relationships for zeolite-bearing sulphide veins are ambiguous but they were tentatively placed in the main stage of mineralization. Gypsum occurs as fibrous mats filling vugs in main stage veins whereas it forms small prismatic crystals in late stage veins. That in main stage veins is inferred to have been anhydrite initially. Ocherous hematite replaces primary magnetite in quartz plus flaky sericite zones and is a component in some calcite veins. Placement of uncommon vein components such as magnetite specularite, tourmaline, and actinolite in Figure 14 is based on mineral associations rather than crosscutting relationships.

Vein Alteration Selvages

Alteration selvages on veins are predominantly of four kinds:

Quartz ± flaky sericite ± chalcopyrite ± bornite ± pyrite
Epidote + quartz ± sericite ± sulphides
Pervasive pink, cream, or dark green alteration
Bleaching

Quartz plus flaky sericite selvages occur mainly around quartz + chalcopyrite ± chlorite ± pyrite; quartz + chlorite + bornite; quartz + epidote + chalcopyrite; quartz + chalcopyrite + bornite; and quartz + chalcopyrite + molybdenite veins. Zones of quartz plus flaky sericite alteration also occur which apparently have no central veins. These suggest that at least locally there could be a significant time lapse between these alteration zones and veins which occur within them. Perhaps they are analogous to composite veins built up from several generations of smaller veins formed during successive episodes of re-opening of one fracture.

Quartz-epidote selvages occur primarily around epidote, quartz-epidote, and quartz veins and fractures. As with quartz-sericite, quartz-epidote may also form alteration zones with no associated veins. Veins and selvages of this type may contain chalcopyrite, bornite, or molybdenite.

Pervasive fine grained pink, cream, or green alteration selvages have the same mineralogy as similar zones discussed previously under pervasive feldspar alteration. Pink alteration selvages mantle: quartz + sulphides; chlorite ± copper sulphide; quartz + epidote ± chlorite + sulphides; and zeolite veins and fractures. Cream alteration with associated chlorite and epidote mantles: quartz _ chlorite ± chalcopyrite; quartz; chlorite; and quartz + epidote + chlorite ± chalcopyrite veins and fractures. Waxy green sericitic alteration is most common around quartz + sulphide veins and dark green sericite + carbonate alteration typically has associated carbonate and chlorite veins and fractures.

Bleached zones were noted around: quartz + epidote ± chlorite ± chalcopyrite ± bornite; quartz + chlorite; and quartz + chalcopyrite veins and fractures.

In some specimens vein selvages are mixed. For example, a fine grained green selvage will grade outward to pervasive pink alteration or a quartz plus flaky sericite selvage grade outward to pervasive cream alteration. Throughout the deposit, alteration in areas logged as having pervasive alteration are probably related to fractures and veins in detail.

SUMMARY AND CONCLUSIONS

The J.A. deposit is situated in a graben block which underlies Highland Valley. The deposit is structurally controlled and most of the fractures and veins in it are moderately steep to steeply inclined. It is inferred from the structural setting and bedrock topography that the deposit occurs within a framework of northerly and northwesterly faults. It seems likely from regional information that the faults are largely pre-ore but several episodes of post-ore movement probably occurred on them.

At bedrock surface the deposit is elliptical with long axis oriented northwestward. At depth it splits into two root zones, each of which is similarly elongated. Much of the ore is in granodiorites of the Bethlehem phase and Guichon varities of the Guichon Creek batholith. The ore zone extends a short distance southward into but is essentially bounded by a quartz plagioclase porphyry stock which appears to be an offshoot of the Bethsaida phase of the batholith. The deposit is extended along and beyond the north edge of the elliptical stock and seems to wrap around it slightly. The best copper grades occur adjacent to the Guichon Bethlehem contact which was probably already fairly closely fractured by tectonic and intrusive forces then enhanced as a porous trap by further fracturing during emplacement or the porphyry stock.

Mineralized quartz veins and mineralized quartz-sericite zones are important local ore grade controls but the density of mineralized fractures is the most important ore control. Copper mineralization occurs in fracture fillings and veins and in their alteration selvages. Sulphides often partially replace mafic minerals in these selvages.

The stock and its underlying parent magma are presumed to be the source of hydrothermal fluids and associated mineralization. Minor quartz and chlorite veining marked the initiation of the hydrothermal system. The main ore stage occurred in two major episodes. The earlier episode was characterized by the association of sulphides with quartz and flaky sericite or with quartz alone. During the second episode sulphides were generally associated with quartz and epidote. Hydrothermal chlorite was deposited throughout the main ore phase. As the hydrothermal system waned, sulphide, quartz, and epidote deposition diminished and that of zeolite, typically laumontite, predominated. Zeolite was joined to a minor degree by calcite and was succeeded by late stage calcite and gypsum deposition. Apparently minor amounts of calcite, zeolite, and anhydrite, now hydrated to gypsum, were deposited with sulphides during the main stage of mineralization.

Main stage mineralization was accompanied by overall weak to moderate pervasive feldspar and mafic alteration. Sericite is the predominant alteration mineral but it is joined by varying amounts of kaolinite, montmorillonite, and calcite. Much of this alteration is associated with fractures, faults, and veins and it is generally weakly developed away from such structures. Mafic minerals are variable from fresh to chloritized to sericitized. Locally hornblende is altered to secondary biotite and partial epidotization of it and biotite is common.

Considering the number of fractures and veins examined, few clear crosscutting relationships were observed. Locally it is evident that veins were broken by faulting before the next wave of hydrothermal fluids recemented them but features of this nature are also relatively uncommon. It is also evident that various ages of veining followed roughly the same fracture patterns. These data suggest that fault movement was not significant during the tenure of the hydrothermal system. Re-opening of healed fractures and propagation of new fractures is ascribed to pressures generated during influx of hydrothermal fluids. Whether boiling of the fluids occurred is open to speculation. However, the deposit is thought to have been relatively shallow and is in an area where there are numerous dykes. Consequently, boiling and venting of hydrothermal fluids to the surface are certainly possibilities.

The hydrothermal system collapsed following zeolite and possibly during gypsum and calcite deposition. Subsequently the deposit was down-dropped during block faulting that produced Highland Valley and later intruded by dykes which apparently fed Tertiary flows. Minor development of oxide minerals suggests that erosion exposed bedrock either during or before Tertiary time. During Pleistocene time the deposit was covered to an average depth of 170 m by glacial deposits.

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Paper 15

FIGURES

1. Bedrock geology and drill plan of the J.A. deposit.
2. Geology and ore distribution on the 762 m (2,500 feet) and 914 m (3,000 feet) levels of the J.A. deposit.
3. Geology and ore distribution in sections 105E and 89E, J.A. deposit.
4. Pervasive feldspar alteration on 762 m and 914 m levels.
5. Fracture and vein orientations in section 105E.
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12. Gypsum distribution on the 762 m and 914 m levels, J.A. deposit.
13. Distribution of hydrothermal biotite and secondary K-feldspar in section 89E, J.A. deposit.
14. Synopsis of age relationships of vein and fracture-filling minerals in the J.A. deposit.