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BETHLEHEM COPPER'S JERSEY, EAST JERSEY,
HUESTIS, AND IONA DEPOSITS

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ABSTRACT

The Bethlehem porphyry copper deposits are near the center of the 200 m y old Guichon Creek Batholith, which is a concentrically zoned calc-alkaline pluton that intrudes eugeosynclinal assemblages of the Permian Cache Creek and Upper Triassic Nicola Groups. Four ore zones comprise the Bethlehem deposits considered in this article and are named the East Jersey, Jersey, Huestis ^{& Iona} deposits, ~~which have been or are being mined and the Iona which has not.~~ The J.A. and Lake segment of the Valley deposits are considered in separate articles in this volume. Intrusive breccias; dacite and rhyodacite porphyry dykes; small masses of granite, granodiorite, and porphyritic quartz latite; faults and fractures; and hydrothermal mineralization and alteration have been localized along the irregular intrusive contact that separates the older Guichon Granodiorite and younger Bethlehem Granodiorite phases of the batholith. Late-stage concentration of mineralizers in the dacite porphyry melt(s) were probably the source of hypogene metallization, which post-dates all intrusive rocks and breccias at Bethlehem. Important faults of post-breccia age strike north, northeast, and northwest, and dip steeply. Detectable offsets are unusual.

Mineralization in the Bethlehem deposits includes variable amounts of chalcopryrite, bornite, pyrite, specularite, and molybdenite; and white mica, chlorite, epidote, calcite, quartz, zeolites, secondary biotite, and tourmaline. These minerals occur in veins, veinlets, fracture coatings, irregular blebs, and disseminations.

The Bethlehem orebodies (especially the Jersey) exhibit metallic and nonmetallic mineral zones. Peripheral zones of specularite and epidote, and intermediate zones of pyrite and white mica surround a central copper-rich core defined by relatively large amounts of bornite and secondary biotite. The mineralogy and arrangement of these zones suggest that the hydrothermal fluids responsible for mineralization and alteration moved upward and outward from the central core. Zones of secondary sulphide enrichment are not developed at Bethlehem although the Iona orebody has mineable quantities of oxide ore (malachite).

The Bethlehem deposits (especially the Jersey orebody) generally possess geological, mineralogic, and geochemical features consistent with those described for other porphyry deposits of western North America. However, in detail, they differ in the degree to which many of these features are developed. The more unique characteristics include: (1) an intrabatholith location; (2) a probable old age for mineralization (200 m y); (3) dominance of fracture controlled copper mineralization; (4) mineralogic simplicity of the metallic constituents; (5) absence of lead, zinc, and silver occurrences; (6) well-defined zonation of iron-bearing metallic minerals; (7) low total sulphide content (average <2 percent) and a paucity of pyrite (average <1 percent in the halo zone); (8) large bornite:chalcopyrite ratios (>1) in the central copper-rich core; (9) molybdenite peripheral to the central parts of the ore zones; (10) association of chalcopyrite and bornite with epidote; (11) restriction of significant hydrothermal alteration to the ore zones; (12) scarcity of potassium feldspar alteration; and (13) widespread post-metallization hydrothermal zeolites, especially laumontite.

LOCATION

The property is located in south-central British Columbia on the north side of the Highland Valley at Lat. $50^{\circ} 29.5' N$, Long. $120^{\circ} 59' W$, N.T.S. 92I/7W. It lies approximately 32 km southeast of Ashcroft and 48 km southwest of Kamloops. Elevations vary from 1400 m to 1525m.

HISTORY

Initial surface showings were discovered prior to 1896 and the original mineral claims were staked in the area in 1899. Sporadic interest was maintained in the prospect first by the B.C. Department of Mines which drilled 8 holes in 1919 and then by several private companies which conducted various programs of surface and underground exploration.

In 1954, about 100 claims were staked by a syndicate which later transferred these claims to the newly formed Bethlehem Copper Corporation Ltd. in early 1955. Surface trenching and bulk sampling followed until an option agreement was completed with ASARCO. After $2\frac{1}{2}$ years of work ASARCO was forced to drop its option but results proved sufficient for Bethlehem to begin an underground program to check the drilling results. An agreement was negotiated with Sumitomo Metal Mining Co. of Japan in 1960 to provide financing for a mill installation of 2700 tonnes per day and to purchase full production for a period of ten years. Plant construction commenced in the fall of 1961 with the project going on-stream in December, 1962. Five increases in plant size ensued and currently the mill has a rated capacity of 15,400 tonnes per day.

Production

Ore tonnages mined to December, 1974 (including stockpiled material) are as follows:

East Jersey	1962-1965 and 1974	3.384 million tonnes
Jersey	1964-1972, 1973-1974	28.656 million tonnes
Huestis	1970-1974	17.163 million tonnes
TOTAL	1962-1974	49.203 million tonnes

Reserves

The reserves available to the present mill as of December 31, 1974⁵, ~~were published as being approximately 58,000,000 tonnes of 0.46 percent copper~~ based on a cutoff value of 0.25 percent copper were as follows:

<u>Deposit</u>	<u>Tonnes</u>	<u>Grade</u>
Huestis	7,430,000	0.45 percent copper
Iona	12,050,000	0.47 " "
Jersey	31,640,000	0.46 " "
TOTAL	51,120,000	0.461 " "

GEOLOGY

The Bethlehem porphyry copper deposits are near the centre of the 200 m y old Guichon Creek Batholith (see location map, this volume), which for the past decade has been the subject of considerable study (see Northcote, 1969; McMillan, 1971, 1972, this volume; Hylands, 1972; Ager and others, 1972; Field and others, 1974; and Jones, 1974). The batholith is a concentrically zoned calc-alkaline pluton, which is interpreted to be shaped like a flattened funnel, the spout of which underlies Highland Valley and plunges 80 degrees to the northeast (Ager and others, 1972). The average thickness of the batholith is 6 km, increasing to more than 12 km over the central root zone (Ager and others, 1972). Major intrusive phases become progressively younger and change in composition inward from a border of gabbro, through quartz diorites and granodiorites, to a core of granodiorite or quartz monzonite. The batholith intrudes eugeosynclinal assemblages of the Permian Cache Creek and Upper Triassic Nicola Groups. Sedimentary rocks of Middle and Upper Jurassic age, and volcanic and sedimentary rocks of Lower Cretaceous and Tertiary age, unconformably overlie the batholith.

The first comprehensive geologic investigations of the Bethlehem property were by White and others (1957) and Carr (1960, 1966). After mining began in 1962, these studies were supplemented with observations by mine personnel including Coveney (1962), Coveney and others (1965), and Ewanchuk (1969). In 1966-67 Wood (1968) conducted a geologic and mineralogic study of the property. Most recently the deposits have been re-examined and briefly described by McMillan (1972) and Hylands (1972). The present report incorporates

information obtained from a program of detailed and reconnaissance mapping and sampling carried out by J.A. Briskey¹ during the summers of 1970-73 as part of a detailed geological, mineralogical, and chemical study of the Bethlehem area and particularly the Jersey orebody; field observations and detailed mapping by H.G. Ewanchuk in the East Jersey orebody; and detailed studies of outcrops and drill core in the Iona mineralized zone by J.R. Bellamy. Because the present investigation is not yet completed this paper should be regarded as a progress report.

LITHOLOGY

The Bethlehem deposits formed along an irregular intrusive contact separating two major phases of the Guichon Creek batholith (see Figure 1). Rocks of the younger Bethlehem phase form a digitated northward elongated apophysis that is intrusive into rocks of the older Guichon phase. This apophysis apparently followed the north trending zone of structural weakness that subsequently localized the intrabatholith porphyry dyke swarm, which transects the property (McMillan, this volume). Intrusive breccias; dacite and rhyodacite porphyry dykes; small masses of granite, granodiorite, and porphyritic quartz latite; faults and fractures; and hydrothermal mineralization

¹ J.A. Briskey's participation in this portion of the Bethlehem study occurred during his tenure as a graduate student in the Department of Geology at Oregon State University, and prior to his employment by the U.S. Geological Survey.

and alteration have been localized along digitations in the contact of the apophysis. Mining operations removed thin cappings of Guichon granodiorite~~x~~ from parts of the Huestis, Jersey, and East Jersey orebodies. These cappings indicate that the current level of exposure is near the roof of the apophysis. Though not shown in Figure 1, between 50 and 60 percent of the property is mantled by glacial deposits.

Guichon and Bethlehem Granodiorites

The Guichon Granodiorite may gradationally approach quartz diorite in composition (see Tables 2 and 3). It is typically a medium crystalline hypidiomorphic granular rock composed of plagioclase feldspar (46-60%)¹, quartz (15-25%), orthoclase (8-16%), hornblende (5-10%), biotite (1-10%), and minor augite. Orthoclase and quartz are interstitial and commonly show pronounced reaction boundaries with plagioclase feldspar. Mafic minerals are of uniform size and distribution.

The Bethlehem Granodiorite normally is a medium crystalline hypidiomorphic granular rock that may grade into quartz dioritic and porphyritic varieties. Representative samples (see Tables 2 and 3) contain plagioclase feldspar (53-65%), quartz (16-25%), orthoclase (5-16%), hornblende (2-22%), and biotite (0.5-6%). Phenocrysts of plagioclase feldspar, poikilitic hornblende, and quartz (eyes) are common in the porphyritic varieties. Orthoclase and usually quartz are inter-

¹ Volume percent unless otherwise indicated. Where unaccompanied by percentage estimates, minerals will be listed approximately in order of decreasing abundance.

stitial, and may display reaction boundaries with plagioclase feldspar. Uneven size and distribution of mafic minerals in Bethlehem Granodiorite distinguishes it from Guichon. White and others (1957) and Wood (1968) mapped a leucocratic subphase of the Bethlehem Granodiorite (see Figure 1). It is characterized by alteration of mafic minerals to actinolite and absence of orthoclase, and occurs exclusively within the normal Bethlehem. Guichon and Bethlehem Granodiorites are separated by a steeply dipping sharp but irregular intrusive contact along which Bethlehem Granodiorite may display weak chill textures. ^S~~Scarce~~ xenoliths of Guichon in Bethlehem have been reported from the East Jersey pit (Wood, 1968) and Iona mineralized zone (White and others, 1957). Other contact features include quartz veinlets, which ^{are} present in both rock types, and the development of incipient foliation in Bethlehem Granodiorite.

space A small north trending intrusion in the bottom of the Jersey pit is tentatively called Bethlehem porphyry (see Figure 1 and 2). Although superficially similar in appearance to Bethlehem Granodiorite, it possesses a definite porphyry texture. The rock is a dacite, which contains plagioclase feldspar (50-60%), quartz (25-35%), hornblende and biotite (5-10%), and orthoclase (0-10%). Phenocrysts, up to 7 mm in the largest dimension, include plagioclase feldspar, quartz, hornblende, and biotite. The groundmass, which comprises 25 to 35 percent of the rock, consists of a mosaic of quartz and plagioclase feldspar, with variable smaller amounts of orthoclase, hornblende, and biotite. Although the age of the Bethlehem porphyry is unknown, it has been mapped as a subphase of Bethlehem Granodiorite. Contacts

of the porphyry are sharp and steeply dipping where it intrudes Guichon. It locally exhibits a weak foliation and (or) a slight decrease in crystallinity adjacent to this contact. As suggested in a later section, the Bethlehem porphyry may be genetically related to the source of the hydrothermal fluids that formed the Jersey orebody.

Porphyritic Quartz Latite

Irregularly shaped intrusions of porphyritic quartz latite occur in the southeast and west-central parts of the Jersey pit (Figure 2), and in a slump block on the east wall of the Huestis pit (see Figure 1). This rock is ~~a~~ fine to medium crystalline hypidiomorphic porphyritic, ^{and} ~~one that~~ contains plagioclase feldspar (40-50%), quartz (25-30%), orthoclase (25-30%), and hornblende and biotite (2-5%). Phenocrysts, up to 4 mm in the largest dimension, comprise plagioclase feldspar, quartz, biotite, and hornblende. The groundmass, which constitutes approximately 50-60 percent of the rock, is composed primarily of finely crystalline, saccharoidal quartz and interstitial orthoclase. Contacts between porphyritic quartz latite and Guichon or Bethlehem Granodiorites are generally sharp however a contact with Bethlehem in drill core was gradational over several centimetres. Porphyritic quartz latite may rarely contain small xenoliths of Bethlehem, and locally exhibits a weak foliation within 6 mm of sharp contacts. Contacts are vertical or dip steeply to the west.

Igneous Breccias

Occurrences of breccia are widespread at Bethlehem, and are also found at the nearby Trojan and Highmont properties. They occur locally within the north trending zone characterized by swarms of porphyry dykes in the central part of the Guichon Creek batholith (McMillan, this volume). At Bethlehem, breccias are associated with all but the Huestis orebody (Figure 1). The southern extent of the main Iona breccia has not yet been determined, however its northern extension, and a smaller parallel roofed breccia, extend northward into the East Jersey pit. Exploratory drilling has intercepted several small breccia bodies at depth in the southeast part of the Iona zone. All of the Bethlehem breccias are near the contact between Guichon and Bethlehem Granodiorites but only locally are these two rock types separated by breccia. The breccias are preferentially localized within Bethlehem Granodiorite, and none have been found entirely within the Guichon. Bodies of breccia tend to be anastomosing, steeply dipping masses with a north elongation. With increasing depth they commonly decrease in size and some pinch out. Mining operations and drilling to date have exposed breccia to depths of over 300 m.

Breccia fragments include Guichon and Bethlehem Granodiorites, dacite porphyry, porphyritic quartz latite, and silicic aplite. Guichon fragments ordinarily predominate. Breccias in the Iona ore zone are virtually enclosed in Bethlehem Granodiorite but clasts are predominantly of Guichon Granodiorite. Fragments of dacite porphyry are widely distributed in the breccias, but are abundant only in the breccia mass on the northeast wall of the Jersey pit. Pink stained dacite porphyry has not been found as a component of the breccias. Clasts of porphyritic quartz latite are abundant in and near

gradational contacts between intrusions of this rock type and breccia, but occur sporadically elsewhere. Diameters of many clasts are between 1 and 20 cm. Their shapes range from angular to rounded, but those which are subangular to subrounded predominate. Rounding appears to have resulted from corrasion during transport, and rarely from corrosion by hydrothermal fluids or dacite porphyry magma. Blocks of included dacite porphyry may be markedly tabular, and suggestive of prebrecciation sheet fractures or joints.

Comminution of entrained fragments has resulted in a cataclastic matrix reflecting the mineralogic composition of the host rocks. Broken and crushed crystals of plagioclase feldspar and quartz, with or without smaller amounts of orthoclase, hornblende, and biotite, compose most of the matrix. Where comminution was more intense, crystal fragments are mixed with, or grade into fine grained rock "flour". The matrix is usually compact, but irregular vugs up to 30 cm in length are not uncommon. Finely crystalline biotite and chlorite are widely distributed throughout the breccia matrix, and locally predominate over all other matrix components. Biotite is particularly abundant in the upper parts of the Iona breccias. Tourmaline is a widespread but minor constituent of the breccia matrix. In some upper parts of the Iona breccias, porous granular quartz that is commonly intergrown with finely to coarsely crystalline aggregates of tourmaline, encloses the breccia fragments. This quartz does not normally replace the fragments so that it probably filled open spaces in a loosely consolidated breccia. Induration of the breccia, either as the result of or following deposition of this quartz, preceded the formation of later sulphide-filled fractures that crosscut both matrix and fragments alike. Breccia fragments in a matrix

that closely resembles some of the dacite porphyrities has been observed in two small, isolated areas. Reaction between this matrix and many of the fragments is indicated by contacts that are corroded and gradational over as much as 8 cm. Where unaffected by corrosion, contacts between fragments and cataclastic matrix are generally sharp. Lineations caused by the subparallel alignment of matrix components are conformable to fragment faces, and are attributed to either flowage or compaction, or both.

Contacts between breccia masses and host rock are usually steep. They may be sharp or gradational over as much as several metres. Many of the well defined contacts show fingers or embayments of breccia extending into the surrounding country rock. Breccia contacts in the Iona zone may coincide with shear zones, which are common along the tops of protrusions of Bethlehem Granodiorite that extend up into the breccia from below. Although restricted zones of horizontal fracture sheeting are present in the upper parts of some Bethlehem breccias, their vertical counterparts have not been observed in either the breccias or their adjacent host rocks. In general, there is little evidence of severe fracturing in host rocks adjacent to the breccia masses.

The north elongation of the breccia bodies probably reflects control by the same structural weaknesses that localized the parallel ^{trending} Bethlehem Granodiorite apophysis, major faults, and emplacement of porphyry dykes. The major faults as presently exposed do not appear to have exerted either spatial or structural control over the emplacement of the breccia masses. Moreover, all of these faults exhibit movement younger than breccia consolidation. Alternatively, it is possible that breccia intrusion along pre-existing fault zones largely obliterated these zones and that later shearing

along presently exposed major faults may have resulted from renewed displacement along these older structures. The localization of breccia dykelets in small gouge zones on the southeast wall of the Jersey pit suggests some local fault control of breccia emplacement. The coincidence of a few breccia contacts with shear zones in the Iona orebody may also be interpreted as a structural control, or as the result of breccia compaction.

Granodiorite and Granite

An oblong mass of granodiorite is exposed west of the Iona zone (Figure 1). The rock is predominantly medium crystalline hypidiomorphic granular but gradational increases in the size of plagioclase feldspar or biotite crystals locally render the texture porphyritic. The principal minerals are plagioclase feldspar (45-55%), quartz (30-35%), orthoclase (15-20%), biotite (3%), and rare hornblende. This granodiorite is distinguished from the Bethlehem Granodiorite by the near absence of hornblende, larger and more abundant crystals of quartz, and the presence of biotite phenocrysts. The granodiorite ^{apparently} ~~apparently~~ intrudes Bethlehem but contacts with the older rocks are not exposed. Wood (1968) reported the presence of orthoclase stringers in the granodiorite and suggested that they were derived from a nearby aplitic granite intrusion that is also exposed west of the Iona zone (Figure 1).

Dykelets compositionally and texturally similar to the granite intrusion are widespread elsewhere in the Guichon and Bethlehem Granodiorites as well as in the breccias although these dykelets may or may not be related to the larger mass of granite. Textures in the granite body and dykelets are finely to medium crystalline allotriomorphic granular (aplitic) or porphyritic. Graphic intergrowths of quartz and orthoclase or plagioclase

feldspar are common and locally cryptocrystalline spherulites may be present. Typical constituents are orthoclase (50-60%), quartz (30-50%), sodic plagioclase feldspar (5-20%), and biotite (0-3%). Phenocrysts, where present, are plagioclase feldspar. The proportion of plagioclase feldspar to orthoclase increases in the northern part of the main granite mass and locally the composition approximates a quartz monzonite. Contact relationships of this pluton as described by previous investigators are contradictory and the critical outcrops are now obscured by mining operations. White and others (1957) described marginal chilling in Bethlehem granodiorite adjacent to granite, whereas Wood (1968) described granite chilled against granodiorite and Iona breccia. Although the interpretation by Wood (1968) is favored, the apparent conflict would be resolved had the granite mass formed by temporally distinct intrusions as is consistent with observed compositional and textural variations. Further evidence indicating multiple ages of granite emplacement is the presence of small aplitic granite dykelets chilled against Guichon and Bethlehem Granodiorites and breccia, and their present^{ce} ~~x~~ as fragments or within fragments in breccia.

Dacite Porphyry

Dykes of dacite porphyry exposed on the Bethlehem property (Figure 1 and 2) are part of ^a the north trending swarm. The swarm is 34 km long and the Bethlehem deposits occur midway along its length. Dykes are spaced irregularly across the 5 to 10 km width of the swarm, and average one dyke every 100 to 300 m (Carr, 1960). At Bethlehem the dykes are clearly of several ages. They

predate and are probably coeval with ore deposition. They also predate and postdate brecciation ^{and} although the individual relationships have not been satisfactorily distinguished, more than one age of post-brecciation dyke emplacement has been recognized. Most dykes are less than 15 m wide but some are as much as 60 m. The prevailing trend is northerly but a significant number strike northeasterly. Dips are normally within 20 degrees of vertical. The large dyke at the east margin of the area (Figure 1) is texturally distinct and probably not closely related to the others on the property.

Dacite porphyry is characterized by phenocrysts of plagioclase feldspar (50-70%), hornblende (2-5%), and quartz (0-3%) set in a finely crystalline groundmass composed of a mosaic of anhedral to subhedral quartz, plagioclase feldspar, minor hornblende, and variable small amounts of orthoclase. Where the orthoclase content is relatively high, these rocks may approximate rhyodacite in composition. Phenocrysts of plagioclase feldspar occur as roughly equant subhedra and euhedra 3 to 5 mm in the largest dimension. Quartz phenocrysts normally form rounded "eyes" up to 3 mm in diameter but square cross sections are not uncommon and bipyramidal crystals may be present. Subhedral and euhedral phenocrysts of poikilitic hornblende, ordinarily replaced by aggregates of epidote, reach a maximum length of about 10 mm. Samples of typical porphyry contain 50 to 70 percent phenocrysts, except at finely crystalline margins. In the vicinity of the Jersey and East Jersey pits, the plagioclase feldspar of a late dacite porphyry dyke has been stained pink presumably by the presence of finely crystalline hematite. Although similar in texture and mineralogy to other dacite porphyry, this particular dyke (Figure 1 and 2) even where it is not stained can usually be recognized by the higher content (5-10%) and larger

size (up to 5 mm) of its quartz phenocrysts. Finely crystal-line orthoclase occurs sporadically in the groundmass.

Dykes of dacite porphyry intrude older lithologies, including breccias and other dacite porphyries. Contacts are sharp, highly irregular, steeply dipping, and have finely crystalline margins that range from several to more than 100 cm in thickness. The margins of some dykes contain inclusions of breccia. These contact features imply that the breccias were lithified prior to emplacement of at least some of the dacite porphyry dykes. Moreover a gradational contact occurs between breccia and a mass of leucocratic dacite porphyry immediately south of the East Jersey pit (see Figure 1 and Wood, 1968). Fragments of similar porphyry also occur in breccia on the south wall of the Jersey pit. Although other dacite porphyry fragments are also present in the Bethlehem breccias, this is the only exposed mass with a demonstrable prebreccia age of formation.

Genesis of Breccias and Porphyries

The association of breccias and porphyries with copper mineralization at Bethlehem was stressed by Carr (1960, 1966) and Wood (1968). Wood (1968) proposed that the breccias formed primarily as intrusion breccias caused by magma stopping along the leading edges of the Bethlehem Granodiorite intrusion. However several characteristics of the breccias would preclude such an origin. These features include (1) numerous fragments of Bethlehem Granodiorite and those of younger porphyritic quartz latite and dacite porphyry; (2) the occurrence of breccia elsewhere than at the contact between Guichon variety and Bethlehem phase; (3) absence of Bethlehem Granodiorite as matrix material; and (4) the paucity of xenoliths in Bethlehem Granodiorite.

Carr (1966) postulated that impermeable chilled rinds formed around porphyry magmas that were intruded into cold, well-fractured country rocks so that the volatiles released during later stages of crystallization were impounded. "Explosive" release of these volatiles and consequent brecciation occurred when increasing internal pressures exceeded confining pressures imposed by the host rocks.

A mechanism involving the rapid release of confined volatiles from crystallizing dacite porphyry magma is believed to best explain the formation of the Bethlehem breccias. However the scarcity of prebrecciation porphyry masses and the comparatively small number of porphyry fragments in the breccias indicate that the major episode of porphyry magma intrusion followed, rather than preceded, breccia formation.

The Bethlehem breccias are interpreted to have originated in the upper parts of the magma chamber(s) that produced the dacite porphyry dykes. Similarities in texture and mineralogy between the porphyries and Bethlehem Granodiorite suggest a related source. After initial intrusion of minor prebrecciation porphyries, a relatively large hydrous vapor bubble(s) may have formed in the upper part of the porphyry magma chamber(s). Norton and Cathles (1973) postulated that such a bubble may form when coalescing upward-migrating water exsolved from a magma is trapped and contained by the cooled rind of the pluton. Several features of the Bethlehem breccias suggest that subsequently, in contrast to the simple collapse mechanism of breccia formation proposed by Norton and Cathles (1973), fracturing of the cooled rind and adjacent wall rocks permitted the rapid escape of this bubble, with consequent brecciation in a fluidized system as proposed by Reynolds (1954). Features which imply forceful (intrusive) breccia emplacement, rather than collapse,

clude: (1) the transgressive nature of breccia contacts (Figure 1), particularly in the Jersey pit (Figure 2); (2) the occurrence, below Bethlehem Granodiorite roof rocks, of breccia containing predominately Guichon fragments; (3) the heterogeneous distribution of fragment types; (4) the presence of abundant cataclastic matrix, including interstitial rock "flour"; and (5) the rounded shapes of many fragments. Rapid escape of contained volatiles would have abruptly enhanced crystallization of the adjacent dacite porphyry melt; thus causing the formation of a second chill rind, which may have trapped much of this melt. However small quantities of magma probably escaped at this time to form those few areas where the breccia contains porphyry matrix. After compaction and consolidation of the breccias, additional pulses of magma injection, withdrawal, and (or) crystallization that was accompanied by fracturing and faulting may have broken the second chill rind and permitted the injection of porphyry magma. Repeated tapping of this magma would explain the multiple ages of dacite porphyry emplacement. A significant portion of the relatively small quantity of porphyry fragments in the breccia were probably derived from the initial chilled rind.

The various breccia masses may be the by-products of several vapor bubbles, or of a single vapor bubble that escaped along several channelways. Pressures necessary to cause an "explosive" release of trapped volatiles may have resulted simply from their accumulation in a restricted water-rich magma, or from subsequent injection of magma originating at depth in the crystallizing batholith. McMillan (personal communication, 1972) believes that magma surges did occur during emplacement of at least the later phases of the Guichon Creek batholith.

Regardless of mechanisms, brecciation and most porphyry intrusions were accompanied and (or) followed by widespread and intense fracturing and associated hypogene mineralization and alteration which presumably was accomplished by fluids and mineralizers derived from late-stage concentration in the dacite porphyry magma chamber(s).

Faults

Numberous faults and zones of closely spaced fractures at Bethlehem have exerted varying degrees of control on the emplacement of porphyry dykes, intrusive breccias, and hydrothermal alteration-mineralization (Figure 1 and 2). Faults are arbitrarily divided into major and minor types on the basis of gouge zone thicknesses of greater or less than 1 m, respectively. Most of the major faults trend north. They occur in the east-central part of the Huestis pit, the west-central part of the Jersey pit (Jersey fault), east-central part of the East Jersey pit (East Jersey fault), and central part of the Iona zone. Dips are vertical or steep to the west, although that of the Iona fault is unknown but inferred to be steep. Horsetail patterns are displayed by the East Jersey fault at the north and south ends of the Jersey pit and by the Jersey fault on the north wall of the Jersey pit. Although McMillan (1971; personal communication, 1975) has weak evidence that the Jersey fault extends 1.7 km southward to the J.A. orebody, it is not known to extend north of the Jersey pit. Major faults of other orientations are less common but several strike northeastward and dip steeply to the southeast. A few of the major faults have northwest trends, particularly in the Iona ore zone, but their extent is not known. Numerous are minor faults subparallel and adjacent to the major faults are numerous hence most strike northward although others strike northeast and northwestward and a few strike eastward.

Many of the faults cut the Bethlehem breccias. Although they may have been partly synchronous with dacite porphyry dyke injection, most have evidence of later movement. However offsets have been detected at only three faults. Recent drilling between the East Jersey and Iona ore zones has confirmed 60 to 90 m of apparent left-lateral displacement of breccias and copper mineralization along a northeast trending fault (Figure 1). A dacite porphyry dyke in the East Jersey pit has undergone 12 m of apparent left-lateral offset along a northeast trending splay of the East Jersey fault. Immediately south of the Jersey Pit, Wood (1968) mapped a dacite porphyry dyke have 38 m of apparent right-lateral offset along an east trending fault.

Mineral Deposits

Common epigenetic minerals on the Bethlehem property include white mica, chlorite, epidote, calcite, quartz, zeolites, chalcopryrite, bornite, pyrite, specularite, geothite, malachite, secondary biotite, tourmaline, and molybdenite. These minerals occur in veins, veinlets, fracture coatings, irregular blebs, and disseminations. Veinlets, fracture coatings, and disseminations predominate. Veins, which are defined to be greater than 2.5 cm in width, contain variable proportions of specularite, quartz, calcite, epidote, chalcopryrite, bornite, pyrite, and tourmaline. They occur in a zone peripheral to the central parts of the Jersey and Huestis orebodies, but in contrast, they are more centrally located in the East Jersey and Iona ore zones.

The four Bethlehem orebodies are outlined in Figure 1. A detailed plan view and cross section of the Jersey orebody was constructed from blast hole assays and is shown in Figure 3. Mineralization in the Jersey orebody is concentrically zoned, the central core of high grade copper metallization is surrounded by a peripheral zone of progressively diminishing copper grade. At depth the high grade core splits into downward extending roots. All rock types exposed within the ore zone predate mineralization. Mineralization is commonly higher in grade and more uniformly distributed in the breccias which probably reflects their higher initial porosity and their greater frangibility relative to surrounding granitic host rocks. Major faults have only a minor and probably secondary influence on overall ore disposition. Although these structures locally provided channel ways for ore deposition and seepage of mineralizing fluids into the peripheral vein system, they do not appear to have been a primary control of copper metallization in the central part of the orebody (Figure 3). Pods of sheared copper sulphides in faults indicate post-ore movement but nowhere has displacement been sufficient to offset the outline of the ore zone. The Jersey and Huestis orebodies are roughly oval in plan. In contrast, the East Jersey and Iona deposits are elongate northward reflecting control by breccias and major shear zones. The East Jersey orebody has been described by several authors including Coveney (1962), Coveney and others (1964), and Ewanchuk (1969). The orebody is composed of multiple, narrow, northerly trending ore shoots that dip steeply westward. Most of these bodies occur within breccia and commonly coincide with shear zones. Copper mineralization in the Iona ore zone is chiefly confined to the breccias but these are unevenly mineralized. Zones of weak mineralization are interpreted to be areas where the breccias

were tightly consolidated and resisted fracturing. Moreover, fragments and wall rock of Bethlehem phase in the breccia are usually only weakly mineralized, whereas the reverse is true for the more mafic Guichon variety. Consequently rock composition has influence^d the distribution of copper metallization, ^{a characteristic} which is also observed in the Jersey orebody.

The intimate spatial association of copper mineralization with the emplacement of late-stage plutonic phases of the Guichon Creek batholith suggests a close temporal relationship as well. Copper-bearing fractures are numerous throughout the breccias, and crosscut both fragments and matrix alike. Thus the main episode of metallization must have postdated breccia consolidation. However, several occurrences of brecciated sulphides suggest that minor amounts of mineralization may have preceded breccia formation, and (or) that there was some local, late-stage rebrecciation of previously mineralized breccia. The presence of more widely spaced fractures and proportionately lower grades of ore in some of the dacite porphyry dykes that postdate brecciation may indicate that either mineralization or fracturing, or both, largely preceded this late period of dyke emplacement. Bornite and chalcopyrite in joints in pink-stained dacite porphyry indicate that copper sulphide deposition continued beyond, or began after the cooling of this youngest unit. A potassium-argon age of 199 ± 8 m y was reported by Dirom (1965), White and others (1967), and Northcote (1969) on a mixture of magmatic and hydrothermal biotite from the Iona ore zone (Dirom, 1965). This age is in agreement with the 198 ± 8 m y age for the Guichon Creek batholith (see Northcote, 1969), and 202 ± 4 and 198 ± 4 m y ages for hydrothermal sericite from the Valley Copper deposit (Jones and others, 1973) 6 km west of Bethlehem. However, because of the relatively large analytical uncertainty (± 8 m y) the Iona sample may not be a reliable indicator of the age of mineralization.

Hypogene Metallic Minerals

The common hypogene metallic minerals on the Bethlehem property are chalcopyrite, bornite, pyrite, specularite, and molybdenite. Minor amounts of magnetite and chalcocite are also present, and microscopic traces of tetrahedrite, galena, and possibly linnaeite have been reported (Wood, 1968; White and others, 1957). Trace analyses for copper, molybdenum, zinc, lead, and silver are included with the whole rock chemical analyses shown in Table 3. The consistently low values for silver, lead, and zinc, particularly between "unaltered" and equivalent altered and mineralized lithologies, further emphasize the simplicity of the metallic mineral assemblage. Specularite is present in minor amounts as disseminations but usually occurs in veins and veinlets associated with quartz, calcite, epidote, chalcopyrite, bornite, and rarely tourmaline. Chalcopyrite, bornite, and pyrite are present in veins; however, veinlets and fracture coatings of these sulphides and of molybdenite predominate in the ore zone. Disseminated finely crystalline sulphides that replace primary and secondary mafic minerals adjacent to mineralized fractures are common but quantitatively subordinate to fracture controlled mineralization. The following are customary mineral associations: chalcopyrite with chlorite, bornite, pyrite, quartz, secondary biotite, epidote, and calcite; bornite with chalcopyrite, chlorite, secondary biotite, quartz, and calcite (in veins); and pyrite with chlorite, chalcopyrite, epidote, calcite, and quartz. The combined abundances of bornite and chalcopyrite within the ore zones rarely exceed 2 percent by volume. Concentrations of pyrite in the halo zones are normally less than 1 percent although locally they reach 5 percent. Molybdenite is sporadically distributed and commonly peripheral to the central parts of the ore zones. Occurrences may be monomineralic or associated with chalcopyrite, quartz, and bornite in

veinlets or less commonly in quartz stockworks.

Distributions of specularite, pyrite, chalcopyrite, and bornite in the Jersey pit (Figure 4) were determined using quantitative visual estimates obtained from (1) microscopic examination of 560 hand samples, (2) detailed logging of core from five diamond drill holes, and (3) field investigations. Specularite occurrences are peripheral to those of pyrite and the distributions of both these minerals form crudely concentric zones about a bornite-rich core. The outer zone of low grade copper mineralization (Figure 3) approximately coincides with the pyrite halo and the high grade core is largely contained within the bornite-rich central zone. Chalcopyrite is present throughout the deposit and is most abundant within the outer limits of the pyrite zone. Reconnaissance work suggests similar zonal patterns in the Huestis orebody and that peripheral specularite also occurs around the Iona ore zone. Comparative data are not available for the East Jersey orebody. Mineralogic and chemical variations between the hypogene metallic mineral zones in the Jersey pit are shown in Table 1. Features of particular interest are: (1) high bornite:chalcopyrite ratios in the bornite-rich core, (2) low total sulphide content, and (3) a well defined zone of specularite beyond the pyrite halo.

Several features of the Bethlehem porphyry (Figure 2) may imply a close genetic relationship to the source of the hydrothermal fluids that formed the Jersey orebody. These are: (1) increase in the amounts of secondary biotite, copper sulphides (esp. bornite), and quartz (veinlets) in Guichon Granodiorite host rocks near contacts with Bethlehem porphyry, (2) central position of the porphyry with respect to zoning of metallic and alteration minerals (cf. Figure 2, 3, 4, and 5), (3) paucity of fractures in the porphyry relative to surrounding rocks; and (4) presence of disseminated copper sulphides in the porphyry that apparently are spatially unrelated to fractures.

Hypogene Nonmetallic Alteration and Vein Minerals

Common hypogene nonmetallic minerals include white mica, chlorite, epidote, calcite, quartz, zeolites, secondary biotite, and tourmaline. Smaller amounts of kaolinite, albite, actinolite, montmorillonite, secondary potassium feldspar, rutile, and prehnite are also present. Scheelite and possible alunite were reported by White and others (1957). In addition to the vein-type occurrences of hypogene minerals previously described for the Bethlehem property, alteration selvages in host rocks adjacent to faults, joints, and fractures commonly contain quantities of white mica, chlorite, calcite, and some epidote. The selvages are ordinarily 1 m or less in width, but are as much as 30 m wide adjacent to major faults.

Epidote is most abundant at the outer margins of the Jersey and Huestis orebodies. The approximate distributions of epidote and secondary biotite in the Jersey pit are shown in Figure 5. The distributions form a roughly concentric zonal pattern with epidote peripheral to a central biotite-rich core. Most vein occurrences of hypogene minerals are contained within the epidote zone, and the majority of these are confined to the specularite-rich portion (Figure 4). Epidote is rare in the Iona breccias but is common in adjacent host rocks. It is also common throughout the East Jersey ore zone. Epidote is usually found in veins, veinlets, and coating fractures and as disseminations replacing calcic plagioclase feldspar and primary mafic minerals. Where ~~disseminated~~ disseminated, it may compose up to 20 percent of the host rock, however, amounts between 1 and 10 percent are typical. Epidote is normally associated with chlorite, white mica, calcite, quartz, specularite, chalcopryite, and pyrite. The association with chalcopryite and, less commonly bornite is unusual in porphyry copper deposits and may represent a late-stage

or retrograde mineralization event.

The term "white mica" as used in the text of this report includes all optically unidentifiable, finely crystalline alteration products of feldspars. Preliminary X-ray diffraction studies indicate the presence of sericite and small amounts of kaolinite and montmorillonite in this material. White mica is widespread in all but the most unaltered rocks of the Jersey and Huestis orebodies. Significant quantities of white mica roughly coincide with areas of greater than 0.1 weight percent copper even though zonal distributions are not obvious (Figure 3). In the Iona zone white mica is predominantly restricted to breccias and pervades host rocks only near areas of quartz flooding. Reconnaissance studies of the East Jersey orebody indicate that white mica alteration accompanies significant copper metallization. White mica preferentially replaces orthoclase, which is usually completely destroyed, whereas plagioclase feldspar is typically more than 20 percent unaltered. White mica is generally associated with small but variable amounts of calcite and epidote.

Secondary biotite in the Jersey orebody is largely restricted to the lower parts of the bornite-rich core zone. It is widespread in near surface localities of the Iona breccias, but is only a minor constituent in the Huestis and East Jersey ore zones. Although some secondary biotite occurs in veinlets and fracture coatings, most replaces primary biotite and hornblende, secondary chlorite and actinolite, and breccia matrix. Breccias may contain as much as 50 percent secondary biotite whereas other rock types seldom have more than 15 percent. Quantities between 3 and 8 percent are representative of most biotite-rich areas. Secondary biotite is usually associated with chlorite, bornite, and chalcopyrite.

Chlorite is the first alteration mineral encountered at the outermost margins of the mineralized zones. Epidote and white mica become common closer to the orebodies. Chlorite occurs as replacements of primary biotite and hornblende, breccia matrix, and secondary actinolite, biotite, and epidote, and also as veinlets. The local abundance of chlorite is predominantly controlled by rock type although the mineral is present throughout the deposits. Within mineralized zones and in rocks other than breccia, chlorite typically composes 5 to 15 percent of a sample. Breccias having a chloritic matrix, may contain as much as 25 percent chlorite. Chlorite is normally associated with epidote, chalcopryite, bornite, pyrite, secondary biotite, and calcite.

Calcite is common in the peripheral vein assemblages. It is also abundant in veinlets, some of which are post-ore age, where it may be associated with zeolites. Moreover calcite is a nearly ubiquitous alteration product of plagioclase feldspar and, less commonly, hornblende. Calcite is ordinarily associated with white mica, epidote, chlorite, quartz, chalcopryite, pyrite, specularite, and bornite.

Quartz is the predominant constituent of veinlets that are locally abundant in the central parts of the Huestis and Easy Jersey orebodies and the bornite-rich core of the Jersey orebody and is also a common component of the peripheral vein assemblages. As previously mentioned, quartz is an abundant constituent of the matrix in breccias of the Iona zone. These occurrences of quartz are monomineralic or are components of assemblages that also include bornite, chalcopryite, calcite, epidote, specularite, pyrite, and tourmaline.

Black schlorlitic tourmaline has widespread but erratic distribution. It is present both within, and marginal to, all the ore zones but is abundant only in breccias of the Iona zone that have a quartz-rich matrix. Tourmaline occurs as crystalline aggregates intergrown with quartz; as replacements of small breccia fragments and breccia matrix in veinlets; veins, and fracture^{coatings}; and rarely as rosettes in gouge zones. It is predominantly associated with quartz, epidote, chalcopyrite, calcite, actinolite, and specularite.

The presence of the zeolites laumontite, stilbite, heulandite, and chabazite have been confirmed by X-ray diffraction studies. Numerous veinlets of laumontite that generally contain smaller amounts of calcite, stilbite, and heulandite crosscut all rock types and hypogene mineralization. They are ubiquitous in all four ore zones. Veinlets of stilbite are abundant, and stilbite and rarely chabazite encrust vugs in the south breccia of the Jersey pit. Post-ore zeolites, especially laumontite, are interpreted to be low temperature products deposited during cooling and collapse of the Bethlehem hydrothermal system(s).

Zonal development of hydrothermal alteration in the Jersey orebody (Figure 5) is similar to that described for most porphyry copper deposits. Distributions of epidote and secondary biotite in the Jersey orebody outline propylitic and potassic alteration zones respectively (samples 4 and 8, in Tables 2 and 3). The intervening area, dominated by white mica, is probably equivalent to a mixed zone of phyllic and argillic alteration (samples 3 and 7, in Tables 2 and 3). The potassic zone is atypical because of the near absence of secondary potassium feldspar (sample 8 is the only known occurrence). Significant hydrothermal alteration is restricted to the immediate area of the orebody and only the epidote zone and associated

chlorite extend beyond the limits of conspicuous copper sulphide mineralization.

Oxidation and Supergene Enrichment

Minerals identified from the zones of oxidation at Bethlehem include goethite, hematite, malachite, manganese oxides, chrysocolla, azurite, cuprite, native copper, and ferrimolybdenite. Possible occurrences of powellite and erythrite were reported by White and others (1957). Although the effects of oxidation are largely surficial (less than 20 m deep), its distribution and intensity is controlled by structure. The shattered southern one-third of the Iona ore zone is strongly oxidized and total oxidation of sulphides is common to depths exceeding 100 m. Open fractures may be stained by limonite for considerable distances below the zone of oxidation. Assays for copper are relatively unchanged between zones of sulphide and oxide ore in the Iona orebody and this consistency reflects the scarcity of pyrite and the relative abundance of carbonate, both of which effectively inhibited the migration of copper. Minute quantities of supergene chalcocite and covellite occur in surficial exposures and drill core but there is no zone of secondarily enriched ore.

COMMENTS

At Bethlehem hypogene mineralization probably began during the later stages of post-brecciation porphyry dyke emplacement and continued beyond the cessation of this period of intrusive activity. If hydrothermal mineralization proceeded upward and outward from the bornite-rich core of the ore zones as the arrangement of alteration zones probably indicates the deposition of metallic minerals may have begun with the precipitation of sulphide assemblages having low iron to copper ratios (i.e. bornite:chalco-

pyrite ≤ 1) from fluids initially low in both iron and sulphur. However hydrothermal alteration of primary mafic minerals may have increased the availability of iron with increasing distance from the bornite-rich core. This would favor lower bornite to chalcopyrite ratios and eventually the formation of pyrite. Subsequent depletion of sulphur could have sufficiently decreased the fugacity of sulphur relative to that of oxygen to the extent that remaining iron was deposited primarily as specularite (Meyer and Hemley, 1967). Alternatively, the relatively rapid transition from sulphide to oxide dominated assemblages may have resulted from the mixing of magmatically derived fluids with oxygenated ground water. Faults, joints, and fractures in the peripheral vein system would have provided favourable channel ways for the intermingling of magmatic fluids with ground water, and might account for the restriction of most occurrences of specularite to these structures. The possible role of ground water is currently being investigated through studies of fluid inclusions and light stable isotope distributions.

The Bethlehem orebodies generally possess geologic, mineralogic, and geochemical features that are similar to those described for other porphyry-copper-molybdenum deposits of western North America (e.g. Creasey, 1959, 1966, 1972; Burnham, 1962; Titley and Hicks, 1966; Meyer and Hemley, 1967; Sutherland Brown, 1969; Lowell and Guilbert, 1970; Rose, 1970; James, 1971; De Geoffroy and Wignall, 1972; and Field and others, 1974). However, in detail the Bethlehem deposits, especially the Jersey orebody, differ in the degree to which many of these features are developed. Distinctive characteristics of Bethlehem include: (1) an intrabatholith location, (2) relatively old mineralization (200 m y), (3) dominance of fracture controlled copper mineralization, (4) mineralogical simplicity of the metallic

constituents, (5) absence of lead, zinc, and silver occurrences, (6) well defined zonation of iron-bearing metallic minerals, (7) low total sulphide content (averages <2 percent) and sparse pyrite (averages <1 percent in the halo zone), (8) large bornite to chalcopyrite ratios (≥ 1), (9) molybdenite peripheral to the central parts of the ore zones, (10) association of chalcopyrite and bornite with epidote, (11) restriction of significant hydrothermal alteration to the ore zones, (12) scarcity of potassium feldspar alteration, and (13) widespread presence of post-metallization zeolites, especially laumontite.

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Table 1: Features of Metallic Mineral Zones in the Jersey Pit¹

Zone	Dominant Metallic Mineral(s)	Total Sulfides	$\frac{\text{Bn}}{\text{Cp}}$	$\frac{\text{Py}}{\text{Cp}}$	$\frac{\text{Fe}}{\text{Cu}}$	$\frac{\text{S}}{\text{Metal}}$
Bornite core (bn-cp)	Bn	1 - 2%	≥ 1	$\ll 1$	< 0.4	< 0.4
Outer margin of bornite core to inner margin of pyrite halo (cp-bn)	Cp	1 - 3%	< 1	$\ll 1$	> 0.4	< 0.4
Pyrite halo (py-cp)	Py + Cp	1 - 5%	$\ll 1$	~ 1	~ 2.5	~ 0.8
Specularite zone (sp-cp)	Sp	$< 1\%$	$\ll 1$	$\ll 1$	> 2.5	$\ll 0.4$

¹ The ratios of Fe:Cu and S:metal are calculated in terms of weight percent of the indicated metallic mineral assemblages; other values are volume percent.

Table 2: Modal Analyses

	1 ¹	2	3	4	5	6	7	8
Quartz	14.9	17.2	26.0	20.1	19.0	15.9	30.1	22.8
Primary K-feld.	9.4	9.6	-	-	6.7	9.7	-	-
Plagioclase feldspar (An content, x=sodic)	60.1 (34)	48.7 (38)	26.8 (x)	23.0 (x)	63.4 (32)	53.4 (35)	32.8 (28)	14.9 (x)
Augite	0.6	0.6	-	-	-	-	-	-
Hornblende	8.6	5.0	-	3.6	7.8	10.0	-	-
Primary biotite	5.0	7.9	3.6	-	1.3	1.4	-	-
Opaques	1.0	1.7	3.4	4.0	0.2	0.7	1.0	0.8
Accessories ²	0.4	1.2	0.9	0.6	0.4	1.5	0.6	0.7
Epidote group	-	1.3	0.8	1.9	0.8	0.6	5.2	1.2
Chlorite	-	0.3	20.8	3.6	0.6	0.8	2.2	3.3
Carbonate	-	-	-	0.3	-	-	0.8	0.8
F. c. a. p. ³	-	5.0	16.0	35.8	-	4.4	12.4	35.8
White mica	-	1.5	1.7	-	-	1.6	14.6	1.7
Secondary biotite	-	-	-	7.1	-	-	-	3.1
Secondary K-feld.	-	-	-	-	-	-	-	14.5
Points counted	500	800	500	800	500	800	500	800
Grid spacing (mm.)	?	1.0	?	1.0	?	1.0	?	1.0

	<u>Coords. (m.)</u>	<u>Elev. (m.)</u>
¹ 1: Unaltered Guichon granodiorite (Wood, 1968)	-	-
2: Unaltered Guichon granodiorite	3804N 1844E	1504
3: Altered and mineralized Guichon granodiorite (Wood, 1968)	Jersey Pit	-
4: Altered and mineralized Guichon granodiorite	3496N 1939E	1341
5: Unaltered Bethlehem granodiorite (Wood, 1968)	-	-
6: Unaltered Bethlehem granodiorite	2164N 2347E	1387
7: Altered and mineralized Bethlehem granodiorite (Wood, 1968)	Jersey Pit	-
8: Altered and mineralized Bethlehem granodiorite	3548N 1978E	1341

² Accessories include: apatite, sphene, rutile, and zircon.

³ Finely crystalline alteration products include: white mica and small amounts of kaolinite, montmorillonite, and carbonate.

Table 3: Chemical¹ and Trace Element² Analyses

	1	2	3	4	5	6	7	8
SiO ₂	61.44	62.37	60.35	62.32	62.91	64.33	67.51	65.75
TiO ₂	0.48	0.69	0.78	0.70	0.55	0.51	0.48	0.44
Al ₂ O ₃	17.43	16.27	18.67	16.15	16.42	16.79	15.76	17.32
Fe ₂ O ₃	1.46	2.39	1.60	1.76	3.26	2.37	1.06	0.78
FeO	4.19	2.56	4.56	2.45	3.06	1.54	3.04	1.27
MnO	0.09	0.08	0.06	0.08	0.06	0.08	0.04	0.03
MgO	2.48	2.34	2.29	2.64	1.10	1.37	0.95	0.90
CaO	5.27	4.88	2.67	4.83	6.09	4.73	3.33	2.72
Na ₂ O	3.99	3.93	2.99	3.84	2.88	4.60	4.50	4.99
K ₂ O	1.99	2.35	1.12	1.20	1.32	1.66	0.69	2.25
H ₂ O ⁺	0.81	1.13	4.63	2.32	1.64	0.97	1.70	2.04
H ₂ O ⁻	0.20	0.05	0.11	0.19	0.44	0.04	0.59	0.23
P ₂ O ₅	0.16	0.11	0.14	0.11	0.09	0.15	0.12	0.08
	99.99	99.15	99.97	98.59	99.82	99.14	99.77	98.80
Elements - parts per million ³								
Ag	1	-1	2	-1	1	-1	1	-1
Cu	95	150	9900	4900	420	55	3900	1400
Mo	3	4	54	-1	3	-1	4	10
Pb	25	10	30	10	35	10	50	10
Zn	30	30	25	35	20	50	25	15

¹ Standard wet chemical analyses by Dr. Ken-ichiro Aoki, 1966 and 1974, Tohoku, Univ.

² Trace element analyses by Rocky Mountain Geochemical Laboratories, 1973, Salt Lake City, Utah. Molybdenum determined colorimetrically; others determined by atomic absorption. Silver digested by aqua regia with an acetate buffer; others digested by hot perchloric acid.

³ Minus sign (-) means "less than".