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Title: A GEOLOGIC AND MINERALOGIC STUDY OF THE BETHLEHEM COPPER PROPERTY AT HIGHLAND VALLEY, BRITISH COLUMBIA

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The Bethlehem Copper Mine, a porphyry copper deposit, is situated near the geographical center of the Guichon Creek batholith. The Guichon Creek batholith is located on the east flank of the Canadian Coast Range in south central British Columbia approximately 250 miles northeast of Vancouver, B. C. The batholith trends northerly, is 40 miles long, 16 miles wide and divided in half by a broad easterly trending saddle, the Highland Valley. Moreover, it is composite and consists of two principal phases, an older quartz diorite and a younger granodiorite.

The Bethlehem copper deposit is situated on the contact between these two phases. Seven igneous rock types and several breccia bodies have been recognized. The Guichon quartz diorite, Early Jurassic in age, has been intruded by Bethlehem quartz

diorite, leucocratic porphyritic dacite, granite, granodiorite, dacite porphyry, and mesocratic porphyritic dacite. The Bethlehem quartz diorite is thought to be a marginal or cupola phase of the granodiorite. Dacite porphyry, granodiorite, mesocratic porphyritic dacite and possibly leucocratic porphyritic dacite occur as dike rocks. The breccia bodies are believed to be related to the emplacement of Bethlehem quartz diorite and leucocratic porphyritic dacite with coincident or later explosive events.

Mining operations in the Jersey pit have exposed Guichon quartz diorite, Bethlehem quartz diorite, dacite porphyry and breccia. Bethlehem quartz diorite and breccia nearly circumscribe a huge block of Guichon quartz diorite some 700 feet in diameter. All rocks in the pit have been faulted, fractured, mineralized and hydrothermally altered.

Faults consist of a northerly trending, west dipping essentially parallel set. Obvious fractures are related to faults while the more significant, indistinct, and randomly orientated hairline fractures that control mineralization apparently are not.

Chalcopyrite, bornite and other metallic minerals occur as scattered grains on fracture surfaces or less commonly as disseminations replacing secondary mafics. The degree and extent of mineralization is a function of permeability produced by fracturing.

Hydrothermal alteration associated with the Jersey pit is of both the propylitic and argillic types. Propylitic alteration fringes and Jersey ore body and is characterized by the development of epidote and chlorite at the expense of primary hornblende, biotite, and less commonly plagioclase. Argillic alteration is restricted to the central area of the pit, as is most of the significant mineralization and is characterized by strong lime leaching and the development of fine grained, but optically unresolvable, minerals believed to be one or more types of clay minerals.

A Geologic and Mineralogic Study of the Bethlehem Copper Property at Highland Valley, British Columbia

by

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INTRODUCTION

Location and Accessibility

The Bethlehem Copper property occupies an area of approximately six square miles in south-central British Columbia, Canada, about 30 miles southeast of Ashcroft and 40 miles northwest of Merritt (Figure 1). A paved road connects the area with Ashcroft, a town of approximately 1000 people. Ashcroft is served by the Canadian National railways as well as Provincial (Cariboo) Highway 1. It is 204 rail miles and 247 highway miles northeast of Vancouver, British Columbia.

In the summer months the area is readily accessible on foot. Vegetation and relief are not excessive. A number of Induced Polarization survey lines and old logging roads greatly facilitate movement. Deadfall hinders movement on some slopes. During the winter months heavy snowfall causes difficulty in ascending or descending steep slopes.

Topography

The thesis area lies near the geographical center of the

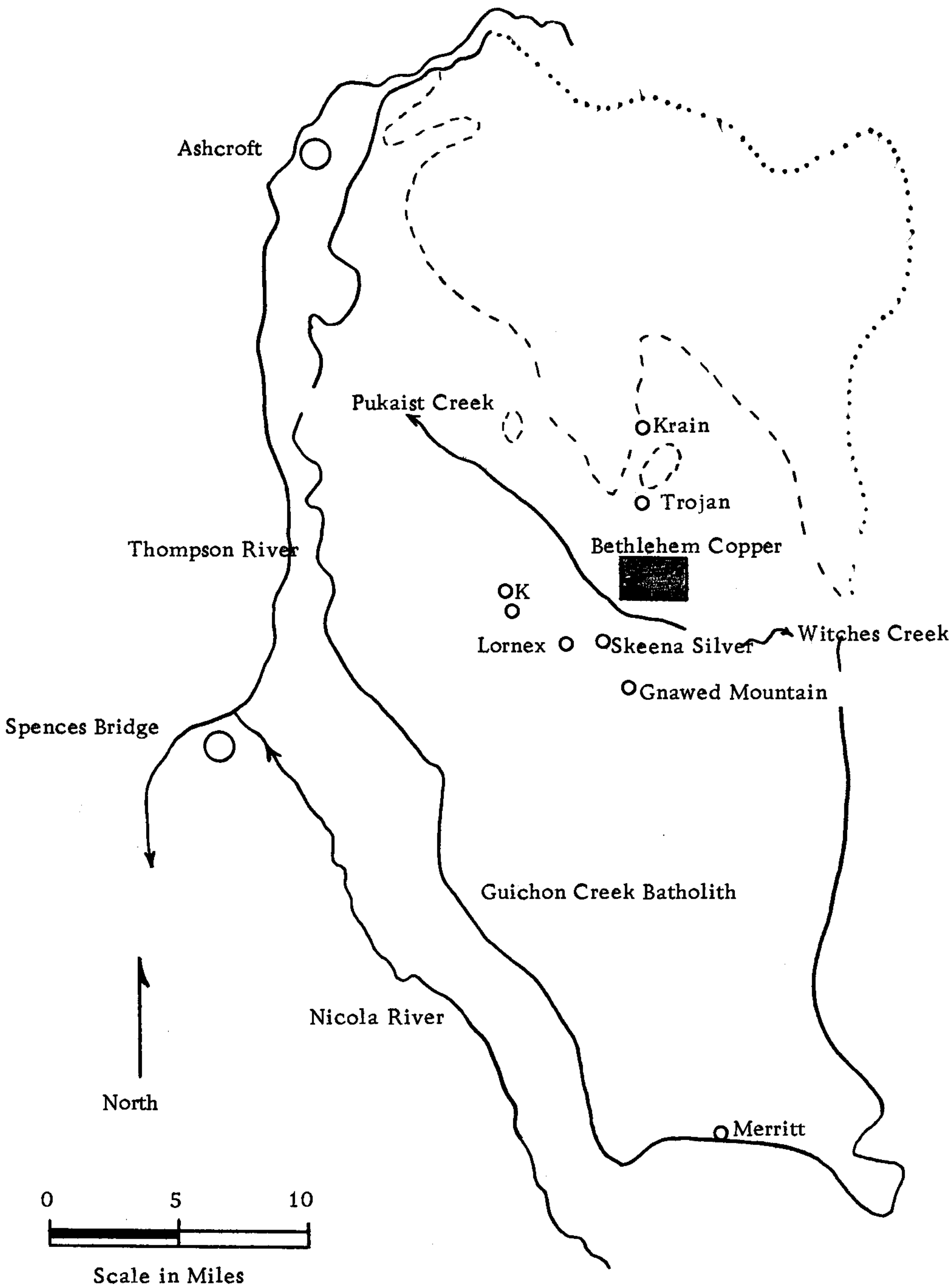

Figure 1. Showing location of thesis area (solid box) within Guichon Creek batholith and various other copper properties.

Guichon Creek batholith within the Interior Plateau of southern British Columbia (Figure 2). Topographically the area is one of rolling uplands. A broad east trending saddle, the Highland Valley, divides the batholith in half. Highland Valley drains westward through Pukaist Creek to the Thompson River and eastward through Witches Creek to Guichon Creek (Figure 1). This valley, 1-3 miles wide, is floored by swampy grasslands and small lakes (Figure 3). Its sides are gentle, moderately forested and the valley walls rise about 1000 feet to the rolling uplands. Near the Bethlehem Copper Mine the valley floor is underlain by at least 850 feet of glacial debris as a drill hole to that depth failed to encounter bedrock.

The map area lies on the north side of the valley. It includes a small part of the valley floor, the valley slope and about four square miles of the rolling uplands. Altitudes within the map area range from 4000 to 5151 feet above sea level.

Glaciation modified the topography by rounding off high areas and filling the lower areas with drift. As a consequence drainage is very poor.

Climate and Vegetation

The Bethlehem Copper property lies in the dry belt of British Columbia. At Ashcroft, altitude 1000 feet, the average precipitation over a 30 year period was 7.07 inches per year. Highland Valley,

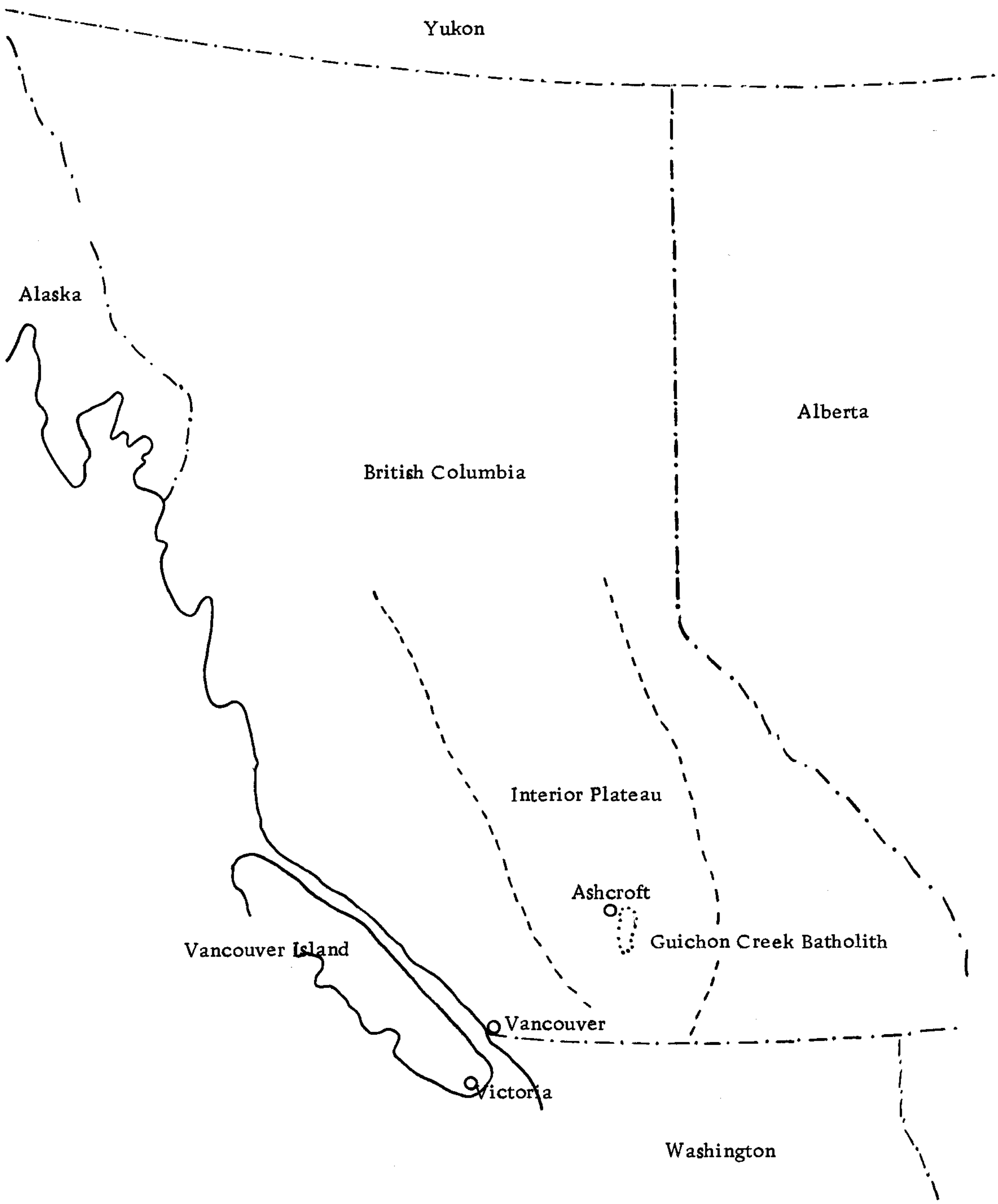

Figure 2. Showing location of Guichon Creek batholith (dotted line) and Interior Plateau (dashed line) in south central British Columbia.

however, is considerably higher (4000 feet) than Ashcroft and receives more precipitation. No records are available but a reasonable estimate would be about 15 inches per year. Summers are warm with a maximum temperature of approximately 90 degrees Fahrenheit. Winters are cold and windy with the temperature occasionally falling to 20 or 30 degrees below zero.

Slopes are forested with small pine and juniper. Upland grasses occur on slopes underlain by glacial drift. Below 2500 feet where precipitation is lower, sage brush is prevalent.

Previous Work in the Area

The earliest geological work in British Columbia was a reconnaissance survey by A. R. C. Selwyn, Director of the Geological Survey of Canada. This survey, an expedition reminiscent of the early surveys in the western part of the United States, began in 1871. Travel was on foot and most exploration was restricted to the Fraser and Thompson River valleys. The Cache Creek and Jackass Mountain groups were first named and described by this party (Selwyn, 1872). At its closest point the expedition was 15 miles west of the thesis area.

The Snowstorm, East Jersey, Jersey and Iona claim groups are included in the area mapped (Plates I and II). The mineral rights to the Snowstorm group were filed by Stuart Henderson and Gilbert

Couverette of Ashcroft in 1907. In the same year H. P. Christie, Mine Recorder, Ashcroft, British Columbia, examined and described the rock exposed on these claims as follows:

> ...a dark porphyritic, volcanic rock, through which are darker hornblendic seams, usually iron stained at the surface; along the line of these seams a movement seems to have taken place and a considerable amount of gouge matter formed, a soft kaolin material in which is found a considerable percentage of copper sulphide and carbonates... (British Columbia Minister of Mines Annual Report, 1907, p. 137).

In 1914, a pilot shipment of ore was sent to the Tacoma, Washington smelter. W. M. Brewer investigated the claims in 1915 under the auspices of the British Columbia Department of Mines.

In 1917 the Mining Recorder in Ashcroft, reported that 90 tons of ore had been shipped from the Snowstorm zone. Smelter returns averaged 30.06 percent copper, with small values in gold and silver. In 1919 development came under the direction of the British Columbia Department of Mines. Development and exploration was directed toward the Iona zone (Plate II). Here a mineralized area approximately 1000 feet in length and 300 feet wide was delineated by test pits and trenches. Surface assay values varied from 0.5 percent to 2 percent copper, with the lower values predominating.

Stevenson (1939) suggested that hematite and tourmaline are characteristic gangue minerals in the district. He thought these two minerals were a guide to copper mineralization in the area and other parts of the Highland Valley.

Cockfield (1948, p. 117) summarized the history of the Snowstorm and Iona claims. He also gave a brief description of rock types and mineralization associated with the Snowstorm, Iona and Jersey zones. Duffell and MacTaggart (1952, p. 99) very briefly mention the Highland Valley copper camp.

In the early 1950's, H. H. Huestis acquired the mineral rights of 166 claims. The Snowstorm zone and most of the thesis area are included in these claims. In 1955, the property was optioned to the American Smelting and Refining Company. This company spent $1, 500, 000 in development work before relinquishing their option. Huestis promptly formed his own firm, the Bethlehem Copper Corporation, of which he is now President.

White, Thompson and MacTaggart (1957, p. 487-503) described the mineralization and general geology of the Highland Valley district. Special attention was given the Bethlehem Copper property. Perhaps the most important contribution of their work, albeit there are many others, was the recognition of a close spatial relationship between breccia, porphyritic rocks, and mineralization. Another significant contribution on their part related to paragenesis and X-ray indentification of various minerals. Carr (1960, p. 71-73) described the surface geology and some of the subsurface geology through diamond drill hole interpretations.

Purpose

The purposes of this investigation are: (1) to determine the relationships between mineralization, hydrothermal alteration and structure of the Jersey ore zone; (2) to determine the nature and geologic relations of several breccia bodies exposed on the property; and (3) to define the areal distribution and mutual relations of the various igneous and volcanic rock types.

Methods of Investigation and Field Work

Approximately 18 weeks were spent in the field during the summers of 1965 and 1966. Pit mapping began in the Jersey pit and proceeded from bench to bench (Figure 4). The benches were mapped by measuring out a 100 foot section, and placing numbers on the toe of the face at both ends of the section. The points were then located by the pit surveyor and plotted on graph paper at a scale of 40 feet equal to 1 inch. Later the scale was photographically reduced to 80 feet equal to 1 inch. Irregularities in slope of the face were sketched on the graph paper between these two points. Fault traces were drawn on the horizontal projection of the face. Samples were taken every 40 feet from the 5000, 4920, 4800 (east) and 4733 benches. Ten samples were collected from the north 4880 bench.

Surface mapping was accomplished by pace and compass methods with reference to Induced Polarization survey lines and topography. Cutcrops were plotted on topographic sheets at a scale of 200 feet to the inch and later reduced to 400 feet to the inch. Diamond drill core from 14 holes was examined to check geologic interpretations.

A total of 204 thin sections of surface rock and selected pit samples were examined.

REGIONAL SETTING

The oldest rocks in the region are those of the Cache Creek and Nicola Groups. The Cache Creek Group is a thick sequence of cherts, argillites, minor limestones, quartzites, andesites, agglomerates and tuffs. Though the aggregate thickness is probably 15,000 to 20,000 feet, deformation, metamorphism, paucity of outcrops, and repetition of beds by folding and faulting have prevented any determination of the overall succession and thickness. Thompson et al. (1950, p. 240) correlated at least part of the Cache Creek Group with Late Permian strata in Texas by paleontological evidence.

The Nicola Group which consists mostly of volcanic rocks with lesser amounts of argillites, limestones and, rarely, conglomerate, disconformably overlies the Cache Creek Group. The volcanic rocks are chiefly greenstones, andesites, breccias, tuffs and agglomerates which have a thickness of approximately 6,500 feet. Fossils indicate that the group is late Middle to Late Triassic in age.

The Guichon Creek batholith, named by Cockfield (1948, p. 16) has intruded both Cache Creek and Nicola Group rocks. The batholith is one of several that fringe the eastern margin of the main Coast Range intrusions. This batholith, Late Triassic-Early Jurassic in age, is one of the oldest known silicic products of the

Coast Range orogeny. It is about 40 miles long and 16 miles wide, with the long axis trending north-northwest. Cockfield (1948, p. 16) described the batholith as consisting of quartz diorite, granodiorite, and local gabbro phases. It is now known to be a composite batholith, and locally the rock is quite variable in texture and composition. In most places the batholith is massive. Faults are abundant at or near the contacts with the sedimentary host rocks.

The batholith has been dated both by stratigraphic and radiometric means. Duffel and MacTaggart (1952, p. 79 note:

> ...because of the batholith's relations with rocks of the Nicola group and the Ashcroft Jurassic rocks it is possible to date its period of intrusion closely. The Nicola rocks intruded by the batholith are of Upper Triassic age, whereas the Jurassic rocks overlying it are of early Middle and Upper Jurassic age. Therefore, the batholith was emplaced between early Upper Triassic and early Middle Jurassic time, most probably during the Lower Jurassic...

Marine Jurassic rocks are exposed near Ashcroft. Lithologically these rocks consist of conglomerate and sandstones intercalated with fossiliferous black shale. Approximately seven miles southeast of Ashcroft the Guichon Creek batholith is unconformably overlain by these fossiliferous Middle Jurassic marine sediments.

Baadsgaard *et al.* (1961, p. 694) obtained a K-Ar date of 186 my. on biotite collected from the batholith. White (1965, written communication) dated both biotite and hornblende collected at the

Figure 3. Highland Valley looking south.

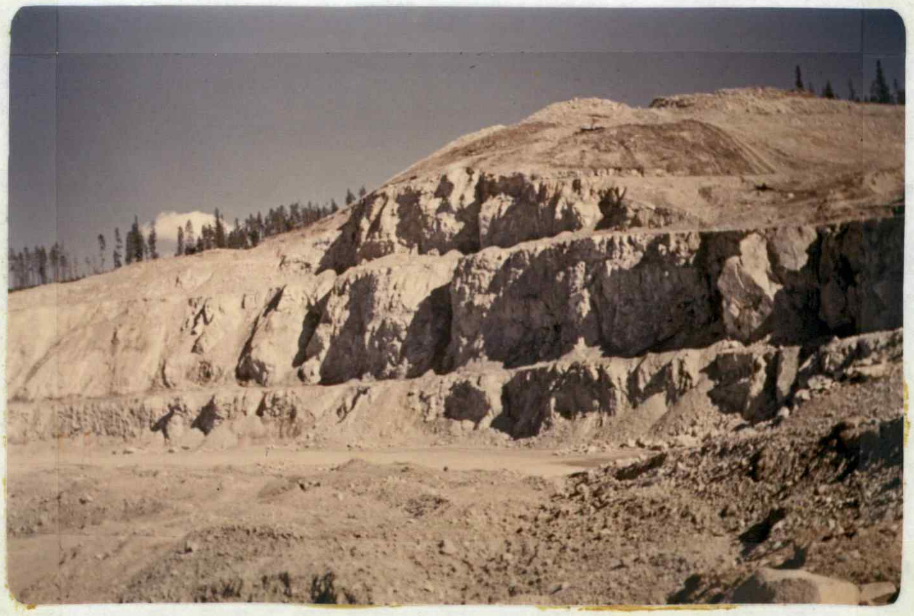

Figure 4. Jersey pit in 1965, looking south-east.

same localities from a number of sites on the batholith. Both the biotite and hornblende gave ages within the range 200 $\pm$ 10 my.

The contact between the sedimentary groups and the Guichon Creek batholith is exposed along the course of the Thompson River south of Ashcroft. Here the sedimentary rocks, particularly the limestone members of the Cache Creek group are hydrothermally altered. In addition the rocks are strongly folded and faulted so that attitudes change markedly over very short distances.

Much of the northern half of the batholith is noncomformably overlain by early to middle Tertiary volcanic rocks. These rocks include andesite, basalt, trachyte, rhyolite, breccia and minor tuffs. Only erosional remnants of andesite, rhyolite and basalt occur in the southern half.

The entire region was glaciated during the Wisconsin age and possibly during earlier glacial ages. At the beginning of the last glacial age, ice advanced onto the Interior Plateau from the Coast Range on the west, from the Skeena Mountains to the north and from the Cariboo and Monashee Mountains on the east. Ultimately the coalescent piedmont glaciers on the eastern flank of the Coast Range covered much of the plateau and began to flow southward (Nasmith, 1962, p. 24). Glaciers are still present in the Skeena Mountains to the north.

GUICHON CREEK BATHOLITH

The Guichon Creek batholith is composite and consists of two principal phases: quartz diorite and granodiorite. The granodiorite, which is younger and intrusive into the older quartz diorite, occurs in the southern half of the batholith. This area is largely unmapped and consequently the areal extent of the granodiorite is unknown. The granodiorite, however, extends at least as far north as the Highland Valley where it is separated from the older quartz diorite by a marginal phase of quartz diorite. The only known exposure of the granodiorite north of Highland Valley occurs as a northerly trending dike near Spud Lake in the thesis area.

Textural terms used in this report are defined as follows: phaneritic rocks are ones in which the minerals are discernable to the naked eye. Aphanitic rocks have a fine-grained groundmass that appears to be crystalline but the individual minerals are only discernable through magnification. If phenocrysts in an aphanitic rock constitute 50 percent or more of the total rock the term dacite porphyry is used. If the phenocrysts make up between 5 and 50 percent of the rock then the term porphyritic dacite is used and if phenocrysts comprise less than 5 percent of the rock then dacite is more appropriate.

Seven different intrusive rock types, several breccia bodies and a small patch of volcanic rocks are exposed on the thesis area. An older quartz diorite, termed the Guichon quartz diorite by White, Thompson and MacTaggart (1957, p. 488) has been intruded by younger quartz diorite, leucocratic porphyritic dacite, granodiorite, dacite porphyry, granite and mesocratic porphyritic dacite. White, Thompson and MacTaggart (1957, p. 488) applied the term Bethlehem quartz diorite to the younger quartz diorite which they believe to be a marginal or cupola phase of the granodiorite to the south. The Guichon quartz diorite crops out north and east of the Jersey pit whereas the younger intrusives are concentrated south of the Jersey pit (Plate II). Dacite porphyry, granodiorite, mesocratic porphyritic dacite and possibly leucocratic porphyritic dacite occur as dike rocks (Plate II). The major dikes trend north to northeasterly but dikes under 10 feet in width may strike in any direction. One dike can be traced along strike for a mile, but most crop out over much smaller areas. Granite occurs west of the Iona zone, and breccia is exposed in the East Jersey, Jersey, White and Iona zones.

Except for the granite, these rocks are mineralogically similar. The mafics are almost invariably hornblende and biotite. Hornblende is most common and may be secondary after augite. The feldspars are chiefly plagioclase, usually sodic andesine or calcic oligioclase. Orthoclase is a common but minor constituent and is always microperthitic. Secondary albite occurs in some rocks. The common accessory minerals in decreasing order of abundance are iron oxides, sphene, apatite, zircon, monazite and tourmaline.

Except for some dikes these rocks are massive and lack observable linear of planar orientation of minerals.

Guichon Quartz Diorite

The Guichon quartz diorite makes up about 50 percent of the rocks exposed in the area. It is best exposed in elevated knobs east and north of the Jersey ore zone, and on the north 4880 bench of the Jersey pit. Xenoliths of the Guichon quartz diorite occur in the younger Bethlehem quartz diorite, and fragments and large blocks are common in the intrusion breccias.

The quartz diorite is a medium-grained, pinkish gray, hypidiomorphic rock, comprised of 60 percent plagioclase, 15-20 percent quartz, 5-10 percent hornblende, 5 percent biotite and 5-10 percent orthoclase.

Plagioclase (An_{32-38}) forms subhedral crystals 2 to 4 mm in length that contain inclusions of anhedral quartz, subhedral iron oxide and hornblende and euhedral apatite. The crystals show both oscillatory and progressive zoning, but may have unzoned cores. The unzoned cores commonly show patchy extinction. Untwinned crystals show the most obvious zoning, indicating that twinning has partially obliterated some of the zone bands.

Selective replacement has accentuated the zoning. Clay minerals and very fine grained white mica frequently define the zones of different composition, and partially replace the cores of plagioclase crystals. Orthoclase and quartz rim and fill embayments in many of the plagioclase crystals producing a crude myrmekitic texture.

Plagioclase also occurs as patchy and tabular relics in interstitial orthoclase, producing a checkerboard appearance which resembles that of antiperthite. The gradation of irregular patchy relics into the tabular checkerboard variety in a single interstitial mass of orthoclase suggests that this is a replacement phenomenon. This is further substantiated by optical continuity among the plagioclase relics.

Orthoclase is always anhedral, interstitial and perthitic. Crystals rarely exceed 3 mm in the longest dimension. Exsolution lamallae of albite are present as small discontinuous lensoidal stringers, and most crystals contain small inclusions of plagioclase. Most of the albite is altered to clay minerals. Hornblende and plagioclase reacted with the remaining liquid producing embayments which are now filled with orthoclase. In some cases the plagioclase is nearly completely corroded with only small irregular aligned remnants remaining.

Quartz occurs as anhedral interstitial grains up to 6 mm in diameter that show faintly shadowy extinction. Most quartz crystals contain inclusions of all the earlier forming minerals, particularly plagioclase. Plagioclase inclusions are anhedral and have been largely altered to quartz by the residual fluids.

Primary hornblende forms euhedral to subhedral crystals up to 3 mm long. It is pleochroic from pale green to nearly colorless. The pale color of this hornblende may denote iron deficiency (Winchell and Winchell, 1959, p. 437). Most crystals contain inclusions of plagioclase, quartz, apatite and iron oxides. Iron oxide inclusions are particularly abundant and in extreme cases, the hornblende is clouded with minute crystals. Within a given crystal about eight percent of the hornblende has been altered to epidote, chlorite, and fiberous amphiboles. Crystal boundaries between hornblende and the late forming quartz and orthoclase are commonly sutured, attesting to the activity of quartz and orthoclase-bearing solutions. Both primary and secondary hornblende are present. Secondary hornblende is an alteration product of primary augite.

Nearly all augite has been replaced by hornblende. Augite relics are often enclosed by randomly orientated hornblende crystals; however, in other examples single hornblende crystals of one orientation have almost completely replaced augite crystals. The conversion begins around the periphery of an augite crystal, then follows the cleavage until only augite relics remain.

Biotite generally occurs as subhedral crystals averaging about 2 mm in length. It is strongly pleochloric from deep to pale brown suggesting that the biotite is rich both in TiO_2 and ferrous iron (Hayama, 1959, p. 21). Pleochloric halos are rare.

Biotite shows good crystal boundaries against orthoclase, quartz and some plagioclase. It is often closely associated with hornblende and its period of crystallization was probably partly coincident with that of hornblende. The biotite crystals commonly show protoclastic deformation while hornblende does not. This deformation is reflected in bent and sinuous cleavage traces. In several instances the late crystallizing quartz has wedged apart the biotite along cleavage traces. Iron oxides, quartz and, rarely, plagioclase form inclusions in the biotite. The iron oxide inclusions may be as large as 1 mm in diameter. Incipient alteration to green (ferric?) biotite and chlorite occur peripherially and the elimination of TiO_2 results in tiny, aligned euhedral sphene and rutile crystals paralleling the cleavage.

Iron oxides (ilmenite and magnetite) are the most abundant accessory minerals. Minute euhedral grains and larger (1 mm) anhedral grains both occur as inclusions and probably formed early in the crystallization history. Small laths and rods of iron oxide parallel the cleavage traces of secondary hornblende and are probably a by-product of the conversion of augite to hornblende. Leucoxene is associated with ilmenite. Frequently a thin film of green chlorite surrounds iron oxide grains.

Sphene usually occurs as anhedral grains, irregular aggregates or elongated stringers along crystal boundaries of other minerals or along fractures. Irregular aggregates may be as large as 1 mm in diameter. Iron oxides (ilmenite?) are often surrounded by tiny euhedral crystals of sphene orientated normal to the periphery of the opaque mineral. These tiny crystals are also aligned along cleavage traces in biotite. Sphene tends to replace hornblende and to occur along its grain boundaries. Rarely, all four titanium-bearing minerals found in the rock occur in close association: ilmenite being replaced by sphene with the sphene altering to rutile and the whole aggregate lightly coated with leucoxene. Where sphene is associated with fractures it may be an introduced mineral.

Apatite occurs as euhedral crystals approximately 0.2 mm in length. It typically forms inclusions in or immediately adjacent to hornblende. Small aligned fluid inclusions are common parallel to the c axis. Zircon is sparingly present as euhedral crystals up to 0.1 mm in length. Monazite is a rare accessory mineral and forms euhedral crystals up to 0.5 mm in diameter. Minute euhedral crystals of rutile occur as an alteration product of sphene, biotite and ilmenite.

Bethlehem quartz diorite is chilled against and contains inclusions of Guichon quartz diorite in the East Jersey pit. The inclusions are subrounded, as large as two feet in diameter, and become smaller in size and more rounded with increasing distance from the contact, suggesting progressive assimilation. The Guichon quartz diorite-Bethlehem quartz diorite contact is also exposed in the White zone. Here there is little or no chilling, the contact is highly irregular and large xenoliths of Guichon quartz diorite up to five feet in diameter occur adjacent to the contact. Dike rocks are chilled against and have incorporated fragments of the earlier Guichon quartz diorite.

Xenoliths of a dark gray, granular, non-foliated, medium-grained rock are widespread in the Guichon quartz diorite. They vary in size from two feet in diameter to several inches, the latter size being the most common. In outcrop the contacts are gradational but distinct over short distances.

Under the microscope, the xenoliths are finer grained but texturally similar to the Guichon quartz diorite. Compositionally, they are more basic but still a quartz diorite. A modal analysis of one thin section shows: plagioclase (An_{42}) 61 percent, hornblende 16 percent, quartz 10 percent, biotite 7 percent, augite 3 percent, orthoclase 2 percent and iron oxides 1 percent. This sample is not strongly altered, but about 10 percent of the original biotite has been altered to chlorite; the rest is intact and pleochloric from deep to pale brown. White mica has partly replaced plagioclase.

These xenoliths may be partially resorbed fragments of country rock, or they may be fragments of a marginal or roof phase of the Guichon quartz diorite that became incorporated through subsequent movement of a still molten magnma. The hypabyssal texture, apparently erratic distribution, relatively slight degree of alteration, finer grain size and slightly more basic composition than Guichon quartz diorite enhance the second possiblity. These are therefore more aptly termed autoliths.

Bethlehem Quartz Diorite

About 30 percent of the outcrops in the area are of Bethlehem quartz diorite. It is best exposed south and southwest of the Jersey pit. The Bethlehem quartz diorite is a light gray to pinkish gray rock characterized by variable content and distribution of mafic minerals. Plagioclase makes up about 65 percent, quartz 15-20 percent, orthoclase 5 percent, hornblende 5-10 percent and biotite 5 percent of the rock. The mafic mineral content is usually less than that of Guichon quartz diorite but the two rocks are not always easily distinguished. This is particularly true in the central part of the map area where the Bethlehem quartz diorite often has a pinkish gray color. The color change may be due to contamination by or partial assimilation of Guichon quartz diorite. Where chilled against a contact the Bethlehem quartz diorite grades to a dark colored dacite porphyry. White, Thompson and MacTaggart (1957, p. 494) designated areas of a white weathering light gray rock occurring within the Bethlehem quartz diorite as its leucocratic phase. The leucocratic phase is compositionally and texturally a quartz diorite but different than Bethlehem quartz diorite in that the plagioclase is more calcic (An_{42}), hornblende is invariably altered to actinolite, and biotite is absent and orthoclase nearly so. It is similar, in outcrop appearance, to leucocratic porphyritic dacite but is not porphyritic and contains more but smaller crystals of actinolite.

The variations mentioned previously plus shearing, alteration, and incipient mineralization commonly make this rock difficult to identify in the field.

Bethlehem quartz diorite typically has a hypidiomorphic, medium-grained texture. Plagioclase sometimes forms poikilitic phenocrysts and may be crudely micrographic. Plagioclase crystals (An_{21-40}) are usually subhedral to anhedral and range from 2-4 mm in length. Oscillatory and progressive zoning are well developed. As in the Guichon quartz diorite progressive zoning is found within a given oscillatory band. Oscillatory bands become considerably narrower and more numerous toward the margin of a given grain. Zone shells rarely exceed 20 in number and unzoned cores exhibit patchy extinction. Some crystals have been shattered and the fractures subsequently filled by quartz. Euhedral apatite, zircon, iron oxide, rarely hornblende and anhedral quartz blebs are common inclusions in plagioclase. Alteration is somewhat variable both in type and intensity. Pale yellow iron-bearing epidote often fills fractures and replaces plagioclase crystals in the Bethlehem quartz diorite exposed on the steep slopes in the western part of the area. The epidote typically develops along cleavage traces of the plagioclase and grows laterally until the entire crystal is replaced. About 15 percent of the plagioclase has been replaced by epidote and 3 percent by white mica. Calcite is a minor alteration product. South of the Jersey pit the dominant alteration product is white mica which accentuates zoning and has selectively replaced some plagioclase cores. Crystal boundaries are irregular and ragged with embayments filled with quartz giving rise to a sutured texture. Plagioclase may or may not be rimmed by orthoclase.

A rather wide variation in the calcium content of the plagioclase (An_{21} - An_{40}) is partially the result of alteration. In several cases where plagioclase determinations were made near epidote veinlets or aggregates the plagioclase is more sodic (An_{21-25}). Presumably some of the calcium that went into the formation of epidote was derived from the nearby plagioclase.

Orthoclase is anhedral and variable in grain size although most grains are small (0.2-0.4 mm). It is partially altered to clay minerals. It commonly forms a thin rim around plagioclase. Quartz fills embayments in the weakly microperthitic orthoclase. Inclusions are mostly anhedral quartz.

Quartz occurs as individual anhedral grains up to 1 mm in diameter and as tiny interlocking grains in the groundmass. When replacing plagioclase, quartz becomes vermicular and the texture crudely micrographic. Most quartz grains contain abundant plagioclase inclusions and relics. The relics have a diversity of form and give the quartz a spotted or dappled appearance. Other inclusions are euhedral apatite and subhedral iron oxides. Extinction is shadowy.

Hornblende is subhedral to euhedral, pale green in color, and pleochroic from pale green to a very faint green. Larger grains ranging up to 4 mm in length are poikilitic with plagioclase, iron oxide and apatite inclusions. The plagioclase inclusions are euhedral, up to 0.5 mm in diameter and largely altered to white mica. Smaller hornblende crystals mostly below 0.3 mm in length are largely non-poikilitic. Alteration products include green chlorite, pale yellow epidote, colorless tremolite, faintly green actinolite, pale brown sphene and iron oxides; epidote is the most common. Rarely pyrite and chalcopyrite replace hornblende. The collective alteration products have replaced about a quarter of the hornblende present.

Biotite occurs as subhedral grains up to 2 mm in diameter and as small (0.2 mm-0.4 mm) pseudohexagonal plates closely associated with iron oxides. Pleochroism is from a moderate brown to a pale brownish yellow. Most of the biotite has been altered to green chlorite, pale yellow epidote and sphene. Sphene is concentrated around the margins and along the cleavage traces of the biotite. Inclusions in biotite are almost exclusively iron oxide and apatite.

Iron oxides have an erratic distribution similar to biotite and hornblende. In areas where iron oxides are abundant the rock usually has a darker green hornblende and more biotite. Iron oxides occur as inclusions in hornblende, biotite and less commonly in plagioclase.

Sphene occurs as isolated aggregates of small euhedral crystals, fracture fillings, interstitial fillings and as alteration products of ilmenite (?), hornblende and particularly biotite.

Apatite occurs mostly as inclusions in other minerals. It is euhedral and rarely exceeds 0.2 mm in diameter. Monazite and zircon are rare euhedral accessory minerals.

Field relations mentioned previously show the Bethlehem quartz diorite to be younger than Guichon quartz diorite. Bethlehem quartz diorite is older than the dacite porphyry and the granite as both are chilled against it. Granitic dikelets intrude Bethlehem quartz diorite in a roadcut 1200 feet northwest of the Iona ore zone. The Bethlehem quartz diorite is also cut by leucocratic porphyritic dacite 600 feet south of the East Jersey pit. The rock occurs as fragments in breccia.

Leucocratic Porphyritic Dacite

Leucocratic porphyritic dacite exposed south of the East Jersey pit is linear, dikelike in form, and extends south 1400 feet to the Iona zone. The width varies from 100 to 300 feet, and the contacts are covered with glacial drift and talus. Leucocratic porphyritic dacite is easily recognized in the field because it forms bold white knobs. Isolated dikes of leucocratic porphyritic dacite, commonly less than 4 feet wide, crop out in the Iona zone trenches and the western part of the area.

Texturally the rock is fine-to medium-grained, hypidomorphic, and porphyritic with hornblende and plagiocase phenocrysts. The hornblende has altered to actinolite. The groundmass, largely microcrystalline quartz and plagioclase, constitutes 60 percent of the rock and the phenocrysts 40 percent. Plagioclase phenocrysts (An_{35}) are euhedral to subhedral and up to 4 mm in the longest dimension but most are in the 1-2 mm range. Many, but not all plagioclase phenocrysts show strong oscillatory zoning. According to Pilkington and Dubois (1961, p. 157) such zoning is made up of a large number of thin shells with sharp contacts between successive shells. Here, however, the shells are not numerous, seldom exceeding 18 and the contacts may be sharp or gradational. Tuttle and Bowen (1958, p. 28) have discussed the role of volatiles during crystallization and conclude that local pressure changes and loss of volatiles during crystallization can account for oscillatory zoning. The interaction of twinning and zoning cause patchy extinction. Inclusions, though not abundant, are anhedral quartz and euhedral apatite, zircon and iron oxides. Plagioclase is also found as inclusions in and replacing hornblende suggesting an overlap in the crystallization periods for these two minerals as might be expected. Crystal boundaries are ragged and indicate reaction with the quartz-rich liquid when final consolidation occurred.

Quartz constitutes most of the microcrystalline groundmass but also occurs as phenocrysts. The phenocrysts are anhedral, subrounded, partially resorbed and up to 0.5 mm in diameter.

Most hornblende has been altered to a faintly green actinolite. Grain sizes range up to 3 mm in length and the larger grains are poikilitic with plagioclase and iron oxide inclusion (Figure 5). Due to the freshness of other minerals in the rock, the actinolite is attributed to deuteric alteration.

Sphene, the most abundant accessory mineral, occurs as euhedral crystals, elongate stringers and irregular aggregates. Sphene replaces actinolite and is concentrated along its crystal boundaries.

Euhedral apatite is rarely more than 0.2 mm in length. Iron oxides are notably scarce, fine-grained and occur only as inclusions. Zircon is a rare euhedral accessory mineral.

Leucocratic porphyritic dacite dikes cut Bethlehem quartz diorite south of the East Jersey pit. The rock is therefore younger than Guichon and Bethlehem quartz diorite but its relationships with granodiorite and granite are unknown. Leucocratic porphyritic dacite also occurs as fragments in breccia and apparently is older than dacite porphyry. The margins of the leucocratic porphyritic dacite cropping out south of the East Jersey pit have been cataclastically deformed and grade, in a distance of six feet, into a breccia. The cataclastic rock is a broken jumble of angular plagioclase fragments less than 0.4 mm in diameter in a groundmass of apparently ungranulated microcrystalline quartz. The recognizable fragments in the breccia are of leucocratic porphyritic dacite. They have a rectangular form and show a subparallel alignment. Individual fragments may be up to 10 cm in length and 1-3 cm in the other dimension visible. Apparently the rock was sufficiently solid to have well developed joints before renewed movement and brecciation occurred. Slender, fragile fragments of leucocratic porphyritic dacite occur in the Iona breccia (Figure 6). These fragments make up 80 percent of the northernmost exposure of Iona breccia.

Contacts are not visible but must be very near these areas of cataclastic deformation as other rock types crop out a short distance away. Therefore, it is likely that continued movement after marginal consolidation and jointing produced a cataclastic texture which grades into a breccia near the contacts.

Breccia

Breccia is exposed in the Jersey, East Jersey, Iona and White zones. The White, Jersey and East Jersey breccias are situated near Bethlehem quartz diorite salients into the Guichon quartz diorite. Most breccias consist of similar rock fragments and vary only in the relative abundance of matrix and rock fragments. The matrix is commonly either a compact mosaic of fine-grained quartz and plagioclase or a poorly consolidated, vuggy, comminuted, angular, fine grained aggregate of quartz, plagioclase and rock fragments. The rock breaks across matrix and fragment alike. Contacts are usually gradational and distinguishable only by close-spaced rock fragments that merge into the host rock.

An important factor when considering the origin of these breccias is the apparent mechanism of intrusion of the Bethlehem quartz diorite. This mechanism seems to be one of three dimensional piecemeal stoping with salients of Bethlehem quartz diorite penetrating and eventually engulfing large blocks of Guichon quartz diorite. When this piecemeal mechanism is in its initial stages, i.e. apophyses and salients of the younger material probing the Guichon quartz diorite, breccias are likely to be formed but with little chance of assimilation.

White, Thompson and MacTaggart (1957, p. 492), and Carr (1961, p. 72) have attributed these breccias to an explosive origin caused by sudden volatile escape.

Jersey Zone

The Jersey breccia in plan nearly circumscribes a huge block of Guichon quartz diorite some 700 feet in diameter (Plate I). The breccia dips steeply both east and west and the eastern member extends to depths of 600 feet. Contacts are usually indistinct but may locally be sharp, particularly where the breccia has an igneous matrix. Where contacts parallel the pit walls small pods of breccia appear to be suspended in Bethlehem or Guichon quartz diorite. The shape of the breccia was apparently controlled by the mechanism of intrusion of the Bethlehem quartz diorite i.e. three dimensional piecemeal stoping. The occurrence of breccia between Guichon and Bethlehem quartz diorite in the eastern part of the pit supports this hypothesis.

Rock fragments may range up to two feet in the largest dimension. Most consist of Guichon quartz diorite, Bethlehem quartz diorite and a bleached rock resembling the leucocratic phase of the Bethlehem quartz diorite. Fragments of Guichon quartz diorite are nearly always less angular than those of Bethlehem quartz diorite or the bleached rock. Commonly, and particularly in the surface exposures of breccia, fragments are broken into a number of barely discernable, unrotated smaller fragments and all rock fragments are more altered and bleached than those at depth. Moreover, the fragments are well separated, rarely touch one another and are set in a pale green groundmass characterized by abundant chlorite (Figure 7). In contrast, in the breccia exposed in the lower parts of the pit the rock fragments are much closer spaced and the matrix is darker and denser. In certain areas, generally the lower regions of the pit, it is difficult to distinguish breccia from xenolith-laden Bethlehem quartz diorite which itself may be a kind of breccia. The xenoliths are largely Guichon quartz diorite. The majority of fragments are sufficiently altered to prevent plagioclase determinations. The mafic minerals are invariably replaced by chlorite, epidote, iron oxides and less commonly sulfides.

The origin of the breccia is believed to be complex. It probably began as an intrusion breccia perhaps later modified by explosive forces, and culminated as an intrusive breccia. Intrusion breccia is

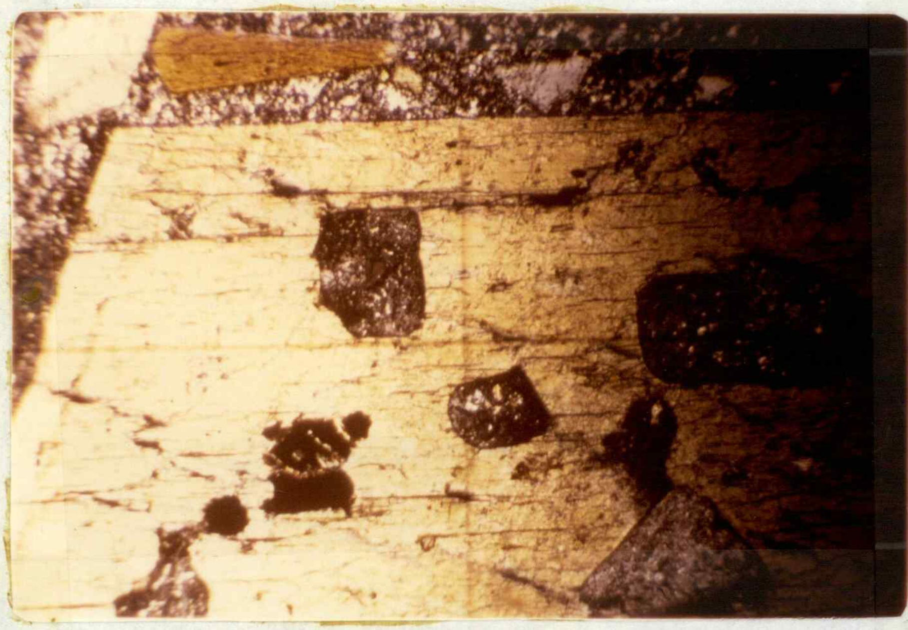

Figure 5. Photomicrograph (crossed nichols, 50x) showing hornblende poikilitically enclosing plagioclase in a leucocratic porphyritic dacite.

Figure 6. Iona zone breccia, arrows point out leucocratic porphyritic dacite fragments.

here used to include breccias formed by the intrusion of one rock into another, explosion breccia as that created by a sudden violent escape of volatiles and intrusive breccia as that which became mobile enough to be intrusive in its own right.

The initial meeting of the two rock types, one hot, the other relatively cold must have caused some brecciation. This view is supported by the close association of Bethlehem quartz diorite, Guichon quartz diorite and breccia in the eastern part of the pit (Plate I). The xenolith laden Bathlehem quartz diorite and gradational Bethlehem-breccia contacts also support this view. The existence of intrusion breccia separating Guichon and Bethlehem quartz diorite in the White zone adds credence to this proposed mechanism.

Features compatible with an explosive origin are the angular nature of the fragments and the matrix/rock fragment ratio. The angularity denotes a lack of abrasion and/or prolonged movement. The matrix/rock fragment ratio decreases with depth; that is, with increasing confining pressure. If an explosive event is assumed, the rocks nearer the surface on disruption could be expected to travel farther and become more widely separated from one another because of considerably lower confining pressures. An explosive event, in this case, must be attributed to a sudden escape of volatiles. The method of entrapment and accumulation of these volatiles, however, is conjectural. Marginal cooling and crystallization of probing apophyses and salients of Bethlehem quartz diorite may have caused volatile pressure to exceed confining pressure and resulted in an explosion.

Small veinlets of breccia that cut the Guichon quartz diorite up to 800 feet from the Jersey pit indicate that the breccia was at least locally intrusive. The breccia veinlets are not numerous and rarely more than an inch wide. They consist of broken quartz and feldspar crystals and small rock fragments (Figure 8). The mafic minerals are altered to epidote and chlorite.

Iona Zone

The Iona zone breccia appears to be the largest breccia body in the mapped area, and is the most heterogenous. Rock fragments include Guichon quartz diorite, Bethlehem quartz diorite, leucocratic porphyritic dacite and a fine-grained brown rock. Guichon quartz diorite fragments may be as much as 15 feet across but are commonly shattered so that the large fragment is actually a multitude of smaller fragments. Fragments of Bethlehem quartz diorite are much smaller and not as common. The leucocratic porphyritic dacite fragments are slender, frangible laths (Figure 6). The preservation of these slender laths and the presence of shattered unrotated blocks of Guichon quartz diorite argue against prolonged viscous

Figure 7. Jersey breccia near the present surface.

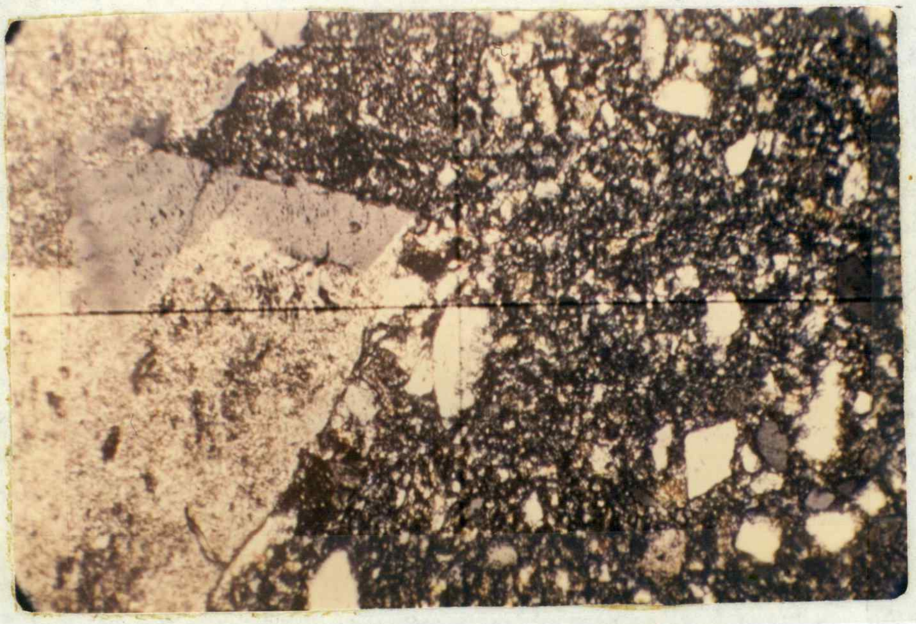

Figure 8. Photomicrograph (crossed nichols, 50x) showing a portion of breccia veinlet cutting Guichon quartz diorite.

transport.

The matrix may be an igneous rock composed of fine-grained quartz and feldspar or a broken jumble of quartz, plagioclase and rock fragments.

The origin of the breccia is probably related to the intrusion of leucocratic porphyritic dacite which occurs as fragments and small dikes in the breccia. Marginally the leucocratic porphyritic dacite itself has a cataclastic and brecciated texture.

East Jersey Zone

The breccia exposed in the East Jersey pit was mapped in haste and not studied in detail. The pit is unsafe as large volumes of rock sporadically slide into the pit (Figure 9).

White Zone

Fragments in the White zone breccia are exclusively Guichon quartz diorite and Bethlehem quartz diorite. These fragments vary in size from microscopic to more than five inches in diameter. The smaller sizes are commonly subrounded while the larger are mostly subangular to angular. Some of the Bethlehem quartz diorite fragments are slightly bleached and may have been incorporated from a marginal phase. Guichon quartz diorite fragments are most abundant and generally larger. The matrix is a black, dense heterogenous mixture of broken plagioclase and quartz crystals and small rock fragments. Small crystals of undeformed biotite and chlorite are probably secondary. The matrix makes up 30-50 percent of the rock and contains disseminated chalcopyrite and sparse bornite.

The shape of the White zone breccia in outcrop is lenticular with the long axis closely paralleling the contact between the Bethlehem and Guichon quartz diorites. The lenticular shape and the Bethlehem and Guichon quartz diorite suggest that this is an intrusion breccia caused by the emplacement of Bethlehem quartz diorite.

Granite and Granodiorite

Granite is exposed just west of the Iona zone. It is a medium-grained and hypidiomorphic-granular rock that is pinkish red on a fresh fracture and a light pink in outcrop. Its margins may be aplitic.

The age of the granite relative to dacite porphyry is unknown. It is, however, chilled against the Iona breccia and is therefore younger than Guichon quartz diorite, Bethlehem quartz diorite and leucocratic porphyritic dacite. Moreover, granite stringers cut both Guichon and Bethlehem quartz diorite in the White zone. These stringers, mostly less than five inches across, commonly contain quartz, pyrite and chalcopyrite centrally. Granitic stringers in Bethlehem quartz diorite are also present a short distance north of the main granite outcrop. Granite is also chilled against a small adjacent exposure of granodiorite to the east.

Microperthitic orthoclase makes up 60 percent of the rock, quartz 30 percent, deep brown biotite three percent and unzoned plagioclase (An_{22}) six percent. Prehnite occurs interstitially.

A small oblong exposure of granodiorite immediately east of the granite may cut Bethlehem quartz diorite in a road exposure north of the main outcrop. It is not clear whether these granitic stringers are related to the granite or granodiorite. The former seems more likely. The orthoclase content of the granodiorite can be quite variable and is sometimes closely related to tiny fractures. Much of the orthoclase in this rock may well have been derived from potassium-rich fluids emanating from the adjacent and younger granite. Texturally the rock is similar to Bethlehem quartz diorite and distinctly different from the granodiorite dike near Spud Lake. This particular exposure of granodiorite may be nothing more than potassium-metasomatized Bethlehem quartz diorite.

The granodiorite occurring as a north-striking dike in the eastern part of the area is coarse-grained, somewhat porphyritic and displays conspicuous books of biotite and large sub-rounded quartz grains. Hornblende is present as euhedral crystals. In thin section the granodiorite consists of large, commonly equidimensional quartz grains, large books of biotite and zoned plagioclase (An-25) surrounded by somewhat finer-grained plagioclase, quartz and orthoclase.

This dike is about 150 feet wide and extends from the bluffs overlooking Highland Valley north to Copper Lake a distance of 6400 feet. The granodiorite intrudes and is strongly chilled against Guichon quartz diorite. The chill zone is up to one foot wide. Weathered outcrops show the rough, pitted surface characteristic of the narrower dacite porphyry dikes. In fact, marginally, and just inside the aphanitic chill zone, the rock is strikingly similar in appearance to dacite porphyry with the exception that more quartz is present. The similar weathering, marginal appearance of the granodiorite and the large strongly resorbed quartz phenocrysts in the dacite porphyry suggest that these two rocks might be genetically related. The granodiorite is a dike form of the large body of granodiorite to the south.

Dacite Porphyry

Dacite porphyry occurs in numerous north-trending dikes. Most are less than 40 feet in width but several are over 100 feet wide, and nearly vertical. Usually the dikes are wider where they cut rocks younger than the Guichon quartz diorite. The dikes are well exposed south of the Jersey and East Jersey pits.

The rock is light to medium green, chlorite and epidote pseudomorphs after hornblende are visible and weathered surfaces are exceeding rough and pitted. Green epidote aggregates up to 1.5 cm in diameter are characteristic. In the East Jersey pit hydrothermal laumontite has permeated and coated a dacite porphyry dike resulting in a distinct pink color.

Texturally the rock is hypidomorphic, holocrystalline, medium- to fine-grained, commonly micrographic and in wide dikes the groundmass is spherulitic. Marginally, and in dikes less than 15 feet wide, it is a porphyritic dacite whose prismatic and platy minerals are aligned parallel to contacts. Plagioclase, hornblende and quartz phenocrysts make up 55 to 70 percent of the rock.

Dacite porphyry dikes intrude Guichon quartz diorite and Bethlehem quartz diorite. It is chilled against and contains fragments of breccia in the Jersey pit. Mesocratic porphyritic dacite is chilled against dacite porphyry in the East Jersey pit.

Plagioclase (An_{34}) is euhedral to subhedral, up to 3 mm long and has weakly developed oscillatory and progressive zoning. Crystal boundaries are either minutely ragged, lined with small spherulitic halves of quartz, or micrographic with quartz.

Alteration is, however, intense enough to obscure most zoning and some inclusions. Plagioclase is progressively less altered and better zoned with increasing distance from ore zones. Alteration products of plagioclase include epidote, prehnite, carbonate and white mica. The latter is most prevalent and may completely replace plagioclase phenocrysts. Alteration is most intense in those areas where incipient mineralization has occurred. In these areas plagioclase phenocrysts no longer exist as such but are represented by white mica pseudomorphs bearing irregular patches of malachite and minor calcite. Rarely cloudy, unzoned albite replaces plagioclase. Malachite and calcite are closely associated and the presence or absence of copper ions probably determined which carbonate developed.

Quartz has four modes of occurrence. One is as large (3.0 mm in diameter) rounded and deeply corroded phenocrysts (Fig. 10). These phenocrysts are more abundant in the marginal phases and have considerable variation in form. Some are almost spherical and others are elongate lobate remnants of larger grains that are bound by either finely spherulitic quartz or a thin zone (0.1 mm) of microcystalline quartz. These are regarded as resorption (replacement) features. Quartz also occurs as independent spherulites up to 1.0 mm in diameter and as discrete microcystalline grains in the ground mass. Another occurrence is as micrographic intergrowths adjacent to plagioclase phenocrysts.

The origin of the rounded quartz phenocrysts is unknown.

Figure 9. Upper benches of now partially filled East Jersey Pit.

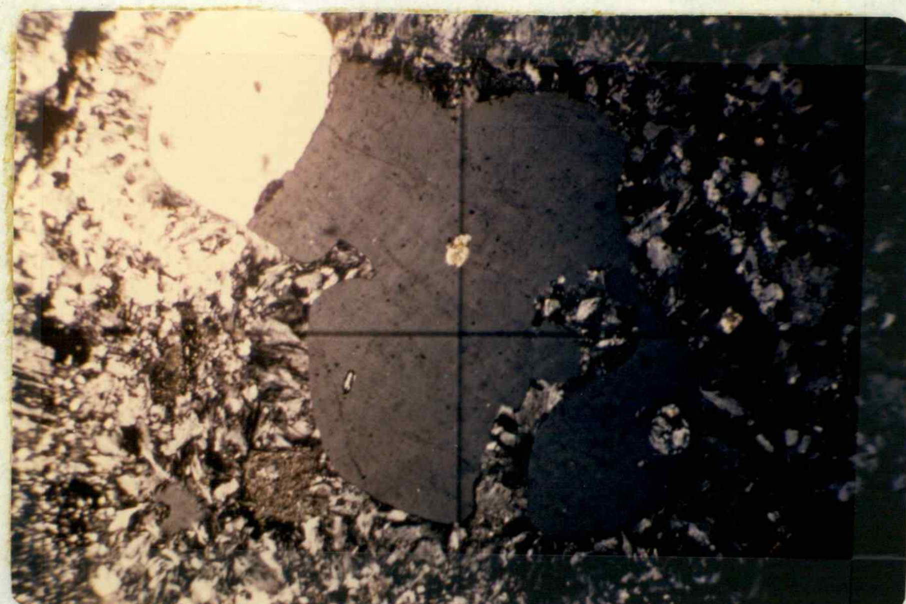

Figure 10. Photomicrograph (crossed nichols, 50x) resorbed quartz in dacite porphyry.

Apparently the magma from which the quartz phenocrysts developed was able to attack previously formed crystals. This may be attributed to any mechanism which destroys equilibrium between the solid and liquid phase, such as a change in chemical composition, a recovery from undercooling or more likely in this case a change of depth within the crust.

Unaltered hornblende is rare, but where present is a pale green in color and weakly pleochroic from pale green to colorless. Pseudomorphs of epidote or chlorite and combinations of the two, after hornblende, are common in the area between the Iona and Jersey zones (Figure 11). Many of the pseudomorphs are euhedral and have a maximum length of 2.0 mm. Epidote is pleochroic from pale yellow to colorless. The chlorite occurs as overlapping sheafs and is for the most part penninite. Actinolite, sphene, and calcite are also alteration products of hornblende. In slightly mineralized areas very minor amounts of sulfide have partially replaced hornblende.

Iron oxides are most abundant in the least altered dikes where they occur in finely disseminated euhedral crystals. In areas of incipient mineralization only skeletal crystals, partly replaced by sphene, chlorite, and rutile have survived. Pseudomorphs after hornblende often contain concentrations of fine-grained opaques that probably represent a by-product of the alteration.

Mesocratic Porphyritic Dacite

Mesocratic porphyritic dacite occurs as narrow dikes seldom exceeding 20 feet in width and as small irregular masses. The rock is medium gray to light green with a slightly vitreous luster.

Mesocratic porphyritic dacite is probably the youngest rock exposed on the property and is chilled against Guichon quartz diorite, Bethlehem quartz diorite, granite and dacite porphyry.

Texturally, the rock is fine- to medium-grained, porphyritic and holocrystalline. Subhedral scattered hornblende phenocrysts poikilitically enclose smaller plagioclase crystals. Plagioclase (calcic andesine) also occurs as phenocrysts in which zoning is usually visable to the naked eye. The groundmass, mostly microcrystalline quartz, makes up 60 to 70 percent of the rock. Accessory minerals are apatite, magnetite and sphene.

Andesite

A small erosional remnant of Tertiary andesite crops out approximately 2,500 feet west of the Jersey pit. The rock is aphanitic with microphenocrysts of andesine plagioclase and less commonly hornblende. It exhibits well formed flow banding. Stilbite commonly occurs in drusy cavities.

STRUCTURE

General Features

Breccia zones, dikes and faults in the central part of the Guichon Creek batholith strike north to northeast.

Three prominent occurrences of breccia occur in the Highland Valley area and these all lie along a north-trending line. From south to north the breccia occurrences are Gnawed Mountain, five miles to the south, the Bethlehem property and the Trojan property 2.2 miles to the north (Figure 1). Bethlehem and Gnawed Mountain are situated on or near the contact between Guichon quartz diorite and younger intrusives but the Trojan breccia apparently is not.

The dacite porphyry dikes that crop out at the Bethelehem property are part of a north-south dike swarm at least 10 miles long. The dike swarm extends from Gnawed Mountain to the south, north through the Bethlehem and Trojan properties to the Krain claims five miles north of Bethlehem. Carr (1960, p. 72) noted that:

> the dikes are spaced across the swarm at irregular intervals, averaging one dike every 300 feet to 1000 feet. The density of the dike swarm is highly variable; on the Bethlehem property and elsewhere, dikes occur very close together... Individual dikes seldom exceed 100 feet in width and most are less than 60 feet wide. They tend to die out within, at most, a few thousand feet along strike...

On the Bethlehem property the dikes are somewhat variable in strike and smaller dikes often deviate markedly from the overall northerly trend. The dikes are evidently more closely spaced where structural features such as faults are well developed. This fact may be of exploration value, in that, relatively closely spaced dikes elsewhere on the batholith could indicate the presence of faults that may have acted as channelways for ore-bearing fluids.

Faults exposed in the Jersey and East Jersey pits, regardless of dip, nearly always strike within 20 degrees of north. Faulting in the Iona, White and Snowstorm zones also has a northerly strike. A major fault zone exposed on the Skeena Silver property, 3.5 miles southwest of Bethlehem, strikes N. 22°E. Northerly and northeasterly striking faults are common on the Trojan and Krain properties. Aerial photographs of the general area show a number of long linear structural (?) valleys trending north at a slight angle to the glacial lineation. These may be structurally controlled faults.

Faults and Fractures

Nearly all the faults observed on the Bethlehem property are exposed in the East Jersey and Jersey pits.

A distinction between major and minor faults in the pit exposure is made on the width of fault gouge or fault breccia and the degree of wall rock alteration. Where fault gouge, breccia or wall rock alteration is mappable at a scale of 40 feet equal to one inch the fault is considered a major fault.

Most of the faults in the East Jersey pit strike about N. 15°E. and dip 50° to 80°W. Several of the major faults, however, strike roughly N. 30°E. and dip steeply east. Essentially all are high angle faults. Any attempt to classify these faults on the basis of apparent movement rests on slickensides and offsetting relationships between faults. Offsetting relationships are rare in both pits but those present suggest normal movement. Slickensides, in many instances, also suggest that these are normal faults. Slickensides, in soft gouge material, however, may have resulted from movement during or after either blasting or mining and in any case record only the last movement.

Faulting in the Jersey pit is more intense and more persistent in strike and dip than that in the East Jersey pit. With several important exceptions, all of the major and most of the smaller faults form a high angle parallel set striking about N. 10° E. and dipping 60°-80°W. This set predominates in the western three quarters of the pit. The largest fault in both pits, the Jersey fault, strikes N. 10°E. degrees east and dips about 68°W. (Figure 12). This fault has 20 to 40 feet of gouge or fault breccia and the adjacent rocks are intensely altered to a green chloritic rock. This fault controls the structure for about 250 feet to either side as many of the faults in this area are coincident in strike and dip. In addition,

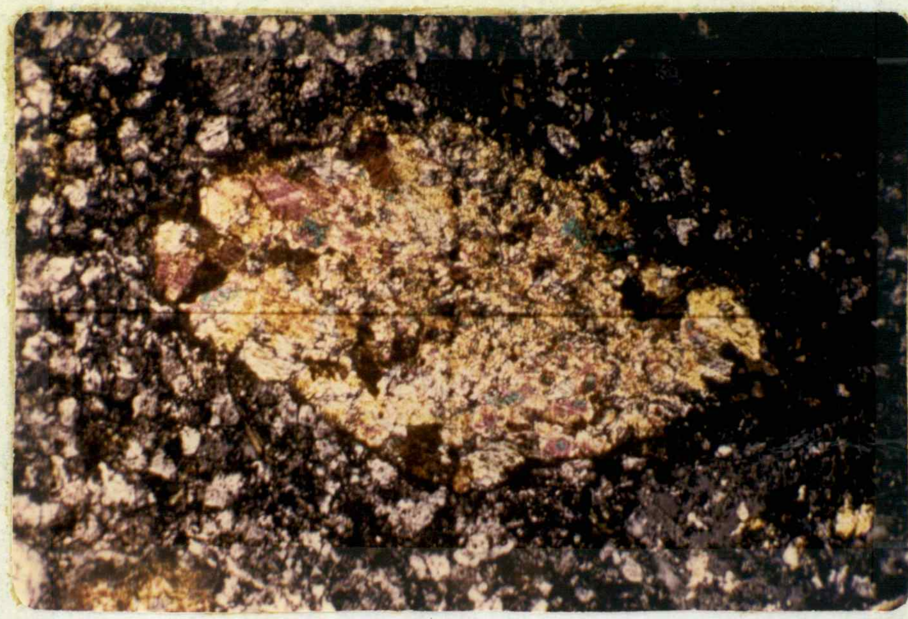

Figure 11. Photomicrograph (crossed nichols, 50x) hornblende replaced by epidote and chlorite. Illustrates fixation of lime in propylitic alteration. Rock is dacite porphyry.

observable fractures and shears are intensified, and have the same orientation as the Jersey fault. The most notable exception to this parallel set occurs in the most eastern limits of the pit. Here a large fault, with some 10 to 20 feet of gouge, strikes N. 30°W. and dips steeply east. Several smaller faults parallel the major fault. An upward projection of the westerly and easterly dipping fault planes just discussed results in an asymmetrical inverted v which may have helped localize the ore bearing fluids. Another exception occurs in the extreme northwestern part of the Jersey pit where several major faults strike N. 60° E. and dip 55° N.

Jointing

Jointing in the younger intrusions is variable but well developed. The Guichon quartz diorite shows the most consistent joint system. The system consists of sets that strike N. 20° E. and dip 75° E.; N. 70° E. and dip 60° S.; and N. 75° W. and dip both vertically and 40° N. These joints may be filled or their surfaces coated with quartz, epidote, aplite, pyrite or copper sulfides.

CONTROL OF ORE DEPOSITION

The hydrothermal theory of ore deposition requires a source of ore-bearing fluids, channelways for flow of the fluids and space for deposition of gangue and ore. The necessity for channelways and space for deposition stems from the hypothesis that large volumes of metallic and other elements have been brought to their site of deposition by fluids and from evidence indicating that in replacement deposits the space for deposition has become available through the removal of large volumetrically similar quantities of rock and minerals from the host.

At Bethlehem breccia zones, contacts, faults and fractures provided the channelways and for the most part space of deposition for the ore bearing fluids.

The Bethlehem-Guichon quartz diorite contact, where exposed, is very irregular and the adjacent rocks are nearly always incipiently mineralized. The breccias no doubt permitted the passage of fluids but more important the development of breccia may have led to significant fracturing in the adjacent rocks.

Fractures are considered to be the most important structural feature in localizing the Jersey ore body. The dominant observable fracture set strikes N. 10^{o} E. and dips about 65^{o} W. This fracture set is believed to be related to faulting. However, the rocks, when struck with a hammer, may break in nearly any direction along hairline fractures. These hairline fractures contain more than half the copper fulfides in the ore body. No rock type in the ore body is unfractured, but on the other hand, the intensity of fracturing may vary locally. Usually the Guichon quartz diorite breaks very easily into fist-size pieces. Apparently this marks the average distance between hairline fractures. The Bethlehem quartz diorite, however, breaks into long rectangular slabs that are commonly less than 2 cm thick. Fractures in the breccia are similar to those in the Guichon quartz diorite. The origin of the randomly orientated hair-line fractures is uncertain. A reasonable postulate would be that this area of fracturing is representative of one, or perhaps of many, pressure points between two igneous bodies. That is, if after em-placement and consolidation either igneous body tended to move, it is unlikely that the resulting stress would be evenly distributed throughout the bodies or along the contacts. The fractured areas may be zones along the contact geometrically related to stress in one or both igenous rock bodies. Another, perhaps more likely, possibility is that the same forces that caused brecciation caused the development of fractures in breccia. If after the development of breccia the emplacement mechanism of Bethlehem quartz diorite continued for a short period in a diminished degree it could have caused, at least, fracturing in the breccia. Or a subsequent minor explosive event could have fractured the rock without displacing it.

Fracture intensity diminishes rapidly with distance from ore zones. Figure 13 illustrates a small displacement, microfault, in the Bethlehem quartz diorite.

Faults and fault zones are second only to fractures in controlling and allowing the passage of mineralizing fluids. Faults in the Jersey pit may contain undisturbed chalcopyrite, bornite and hematite-bearing quartz veins or granulated fragments of similar material suggesting that mineralization and faulting were at least in part contemporoeous. The aforementioned inverted v of fault planes apparently helped centralize the ore. Most copper deposits in the Highland Valley occur in fault zones as mineralization of the Krain, Bethsaida, O.K., Empire and Jericho properties is largely fault controlled.

Space for deposition of disseminated ore was derived through metasomatic replacement of mafic minerals but far more important was open space deposition provided by fractures and faults.

Structural features are considered to be of great importance in localizing significant mineralization both in the Bethlehem property and batholith in general. They acted as channelways that allowed the passage of the apparently great quantities of ore bearing fluids necessary for the development of the ore body and attendent hydrothermal alteration.

Metallic Minerals

Metallic minerals present include chalcopyrite, bornite, pyrite, molybdenite, specular hematite and rare chalcocite and tetrahedrite.

Chalcopyrite is the most abundant copper sulfide and has four modes of occurrence; as quartz-chalcopyrite-pyrite veinlets, as disseminations, as granulated grains in fault gauge and as disseminated grains on fracture surfaces. The quartz-chalcopyrite-pyrite veinlets are most common on the south side of the Jersey pit where the great majority of them parallel the Jersey fault. The veinlets, locally less than one foot apart, are rarely greater than one half inch in width. The chalcopyrite and pyrite are situated centrally relative to the quartz. Disseminated chalcopyrite shows a preference for secondary mafic minerals such as chlorite and epidote. It never, however, replaces all the secondary mafics, but rather selectively replaces those nearest a fracture. The chalcopyrite grains in fault gouge were deposited in the fault and subsequently disrupted. Chalcopyrite on fracture surfaces is the most important. It may be associated with bornite, pyrite, chlorite, epidote, zeolites or calcite. These minerals, with the exception of pyrite, are all orientated with their longest dimension parallel to the plane of the fracture surface indicating that they formed in the space available.

Much of the chalcopyrite, as well as bornite, is fine grained and cause classification and recovery problems in the mill.

The occurrence of bornite for the most part is analagous to that of chalcopyrite. It seems to have a wider distribution as disseminations that replace secondary or less commonly primary mafics. Bornite in veins is closely but not invariably associated with calcite. Quartz-bornite veins also occur. Bornite on fracture surfaces may be so fine-grained that it appears as a bluish sheen. The wide (up to two feet) hematite-quartz-bornite veins of the Snowstorm zone are located along faults. White, Thompson and MacTaggart (1957, p. 495) report orientated exsolution lamellae of chalcopyrite in bornite. Chalcocite is rare and closely associated with bornite. White, Thompson and MacTaggart (1957, p. 496) reported galena as minute inclusions in bornite.

Molybdenite tends to occur on slickensided faults. Rarely it is finely disseminated in quartz veinlets. Molybdenite is more abundant on the south side of the Jersey pit and is found on surface outcrops immediately south of the pit. Breccia seems to be the most favorable host. Chalcopyrite, tourmaline and blebs of hydrothermal biotite are associated with molybdenite.

Tetrahedrite was observed only twice, as euhedral crystals in bornite-calcite veinlets.

Pyrite occurs as disseminated grains on fracture surfaces, as narrow veinlets with quartz and as scattered euhedral crystals in quartz-chalcopyrite-pyrite veinlets. Pyrite occurs within the ore body as outlined by assays but is more abundant around the periphery. Pyrite forms an ill defined halo around the ore body.

Specular hematite is not restricted to but is closely associated with fault zones.

OXIDATION AND SUPERGENE ENRICHMENT

Secondary minerals include malachite, azurite, chrysocolla, goethite, jarosite, manganese oxide, ferrimolybdite, and cuprite. White, Thompson and MacTaggart (1957, p. 497) noted native copper, chalcocite, powellite and erythrite.

Oxidation of primary sulfides is best developed in the Iona zone (Figure 14). Even at the surface, however, primary sulfides are still present but in various stages of destruction. Malachite, azurite, jarosite, geothite, hematite, and manganese oxide occur in surface outcrops. In the mineralized areas overlain by glacial drift an examination of drill core shows the same oxidation products, with the exception of azurite. These secondary minerals persist to a depth of 130 feet. Usually the sulfides become fresher with depth while the collective alteration products diminish in abundance. Hydrous iron oxides and malachite occur in fault zones at much greater depths. The White and Snowstorm zones are virtually unoxidized except for surface staining.

The Jersey and East Jersey ore bodies are both oxidized to a depth of 30 feet. Oxidation extends to much greater depths in fault zones. Jarosite, hydrous iron oxides, malachite, azurite, manganese oxide and ferrimolybdite constitute the oxidation products.

Apparently the limited zones of oxidation have developed since

Pleistocene time. The Krain property exhibits a completely oxidized capping some 200 feet thick, which is protected and preserved by overlying Miocene basalts. The zone of oxidation developed before Miocene time. White, Thompson and MacTaggart (1957, p. 501) attribute the absence of copper leaching and supergene enrichment to the scarcity of pyrite and the presence of fairly reactive gangue minerals capable of neutralizing any sulfuric acid developed. Pyrite to copper sulfide ratios of two or higher are not uncommon on the margins of the Jersey ore body. Evidently the amount of pyrite present is still insufficient to induce significant migration of copper at or near the surface. A thick zone of oxidation and supergene enrichment may have developed prior to the Pleistocene only to be stripped off by glaciation. The very limited leaching and the absence of supergene enrichment would then be due to the short period of time since the glaciers retreated.

Paragenesis

According to White, Thompson and MacTaggart (1957, p. 496) the first metallic mineral introduced was hematite, followed by pyrite, molybdenite, bornite, chalcopyrite and chalcocite. The molybdenite, bornite, chalcopyrite sequence, however, is ambiguous and these three may overlap or be transposed in the sequence.

HYDROTHERMAL ROCK ALTERATION

General

Pumpelly's (1873) report on the Michigan copper district appears to be the first detailed description of hydrothermal alteration. Many of the concepts still in use today, however, are a consequence of Lindgren's (1894) study of the Ophir District of California.

Hydrothermal alteration may be a metasomatic or metamorphic process and can result in retrograde or prograde mineral assemblages with respect to the parent rock. Ideally it forms a conspicuous zone about an ore body or mineralized area. This zone may be divisable into subzones primarily on the basis of mineral assemblages.

There is no generally accepted nomenclature for types of hydrothermal alteration. Herein the classification proposed by Creasey (1959) is adopted. Creasey recognizes three principal types of alteration associated with porphyry copper deposits: propylitic, argillic and potassic. The propylitic type is distinguished from the argillic type by the fixation of CaO in lime bearing minerals such as epidote and calcite. The argillic type is characterized by minerals of the two clay mineral groups and strong leaching of CaO. Potassic alteration is marked by the development of abundant muscovite, biotite and orthoclase. Chlorite is stable in the propylitic and argillic types and quartz is in excess in all three types.

The propylitic and argillic types have formed at Bethlehem. Propylitic alteration is the weskest alteration recognized in porphyry copper deposits. It commonly fringes the argillic or potassic type but may be widespread and pervasive. In the event of significant mineralization, it most commonly occurs in conjection with argillic or potassic alteration.

Weak propylitic alteration is widespread in the Guichon Creek batholith and is well developed in the thesis area. Epidote is ubiquitous and occurs as veinlets, coating on joint surfaces and partially or wholly replacing hornblende, biotite or more rarely plagioclase. Chlorite has a similar mode of occurrence but is not as abundant and usually replaces biotite rather than hornblende. Calcite occurs on joint surfaces and in shear or fault controlled veins. Introduced quartz is restricted to shear and fault zones. Tremolite-actinolite is sparse and may incipiently replace hornblende but most commonly occurs as radiating fibers on joint surfaces. Prehnite is rare and occurs intimately associated with epidote. Feldspars are weakly altered to white mica or a fine grained mineral or aggregat of minerals of the clay group.

In the western part of the area, as previously indicated, plagioclase of the Bethlehem quartz diorite is partly replaced by epidote. Sulfide replacement of primary or secondary mafics increases as the Jersey ore body is approached.

Rock Alteration Closely Associated With Mineralization

Discussion of rock alteration associated with mineralization is restricted to two zones; the Iona and Jersey. Of these two the Iona was studied superficially, the Jersey in detail.

Iona Zone

The Iona zone alteration is characterized by quartz, fine-grained biotite, chlorite, epidote and tourmaline. Quartz replaces matrix and rock fragments alike. Less commonly quartz occurs as vein material and larger veins are flanked by silicified breccia. Quartz veins carry sparsely disseminated but coarse grains of chalcopyrite and tourmaline. Biotite occurs as fine-grained, light brown, aggregates up to 1.5 cm in diameter or as minute laths scattered throughout the matrix; disseminated biotite may impregnate rock fragments. Figure 14 shows an aggregate of fine grained biotite closely associated with partly oxidized pyrite. Although supergene in origin the zoned oxidation of the pyrite is noteworthy. The iron oxide immediately adjacent to a pyrite core appears to be hematite which is bound marginally by goethite or lepidocrocite.

Figure 12. Jersey fault with parallel faults and fractures (view southeast).

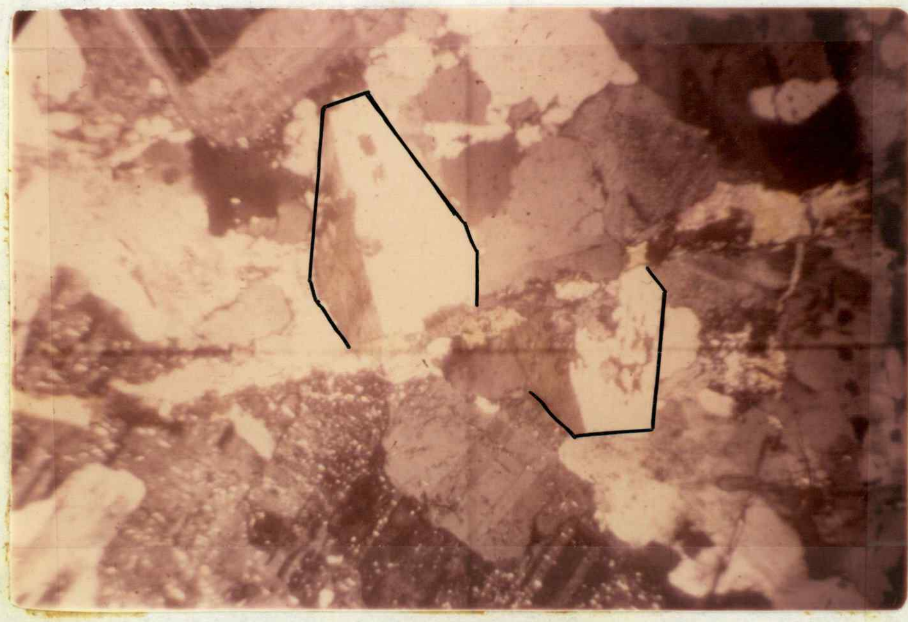

Figure 13. Photomicrograph (crossed nichols, 50x) displaying hornblende crystal offset by microfault. Fault contains epidote.

The biotite is similar in occurrence, grain size and color to that described by Creasey (1966) in the potassic alteration at the Ajo, Bagdad and San Manuel deposits of Arizona. Chlorite generally occurs as radiating sheafs (Figure 15). This is in contrast to its wispy intergranular and replacement occurrence in the Jersey zone. An interesting feature of Figure 15 is that in plain light the outer portion of the chlorite sheaf displaying an anomalous interference color is pleochroic in green while the inner portion is not. Epidote replaces mafics and chlorite and occurs as fracture fillings. Tourmaline occurs as narrow veinlets, irregular aggregates up to six inches in diameter and as disseminated crystals. Orthoclase, albite, and prehnite were observed. Hydrothermal alteration in the Iona zone is propylitic to weakly potassic in character.

Jersey Zone

Seventy nine thin sections from the Jersey pit were point counted with emphasis on the distribution of epidote, chlorite, quartz, white mica and mineral aggregates too fine grained for optical identification. The latter are henceforth referred to as clay minerals. Two altered-mineralized samples, one of Guichon, the other of Bethlehem quartz diorite from the Jersey pit and two samples of fresh but similar rock types have been chemically analyzed and compared.

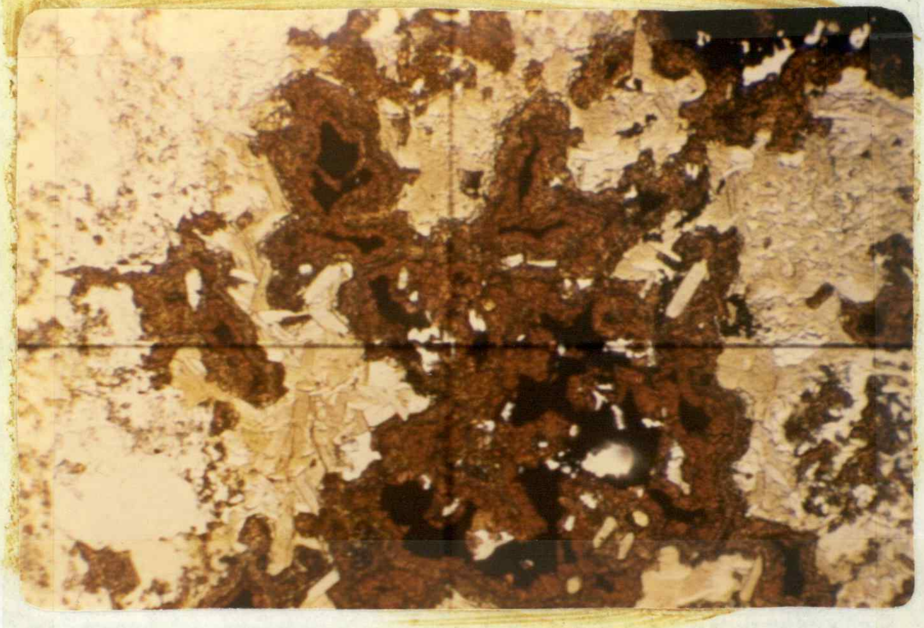

Figure 14. Photomicrograph (plain light 50x) showing aggregate of fine grained biotite surrounding pyrite altering to iron oxides (Iona zone).

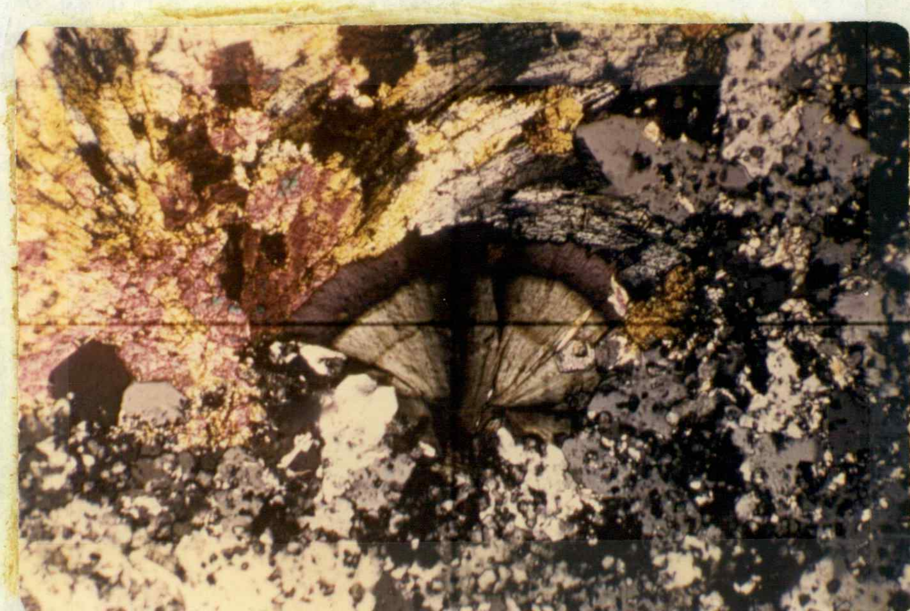

Figure 15. Photomicrograph (crossed nichols 50x) showing chlorite sheaf and replacement quartz and epidote (Iona zone).

Hydrothermal rock alteration in the central part of the Jersey pit is considered to be of the argillic type. According to Creasey (1959) this type of alteration is characterized by members of the kaolinite or montmorillionite groups in conjunction with the leaching of lime. Some authors, for example Howard (1965), indicate that a corresponding decrease in MgO, Na_2O and total iron with a slight decrease in K_2O are also characteristic of argillic alteration. The common minerals include quartz, albite, orthoclase, montmorillionite, kaolinite, white mica and chlorite. Of these, albite and orthoclase are not abundant and neither kaolinite nor montmorillonite have been positively identified in the Jersey pit. The megascopically chalky appearance of feldspar and the microscopically abundant very fine-grained aggregates of colorless to buff colored, low birefringent minerals concentrated in the feldspars strongly suggest that clay minerals are present.

Table I is a tabulation of four chemical and trace element analysis and illustrates the difference between relatively fresh and altered-mineralized Guichon and Bethlehem quartz diorite. Particularly noteworthy is the decrease of CaO, MgO and K_2O from fresh to altered-mineralized rock. Most of the other oxides show inconsistent trends between the two rock types. Table II is the modal analysis for the same four specimens.

The five percent increase of chemical SiO_2 (Table I) for the

Table I. Chemical[1] and Trace[2] Element Analysis.

Oxide	Guichon quartz diorite "fresh"	Guichon quartz diorite "altered-mineralized"	Bethlehem quartz diorite "fresh"	Bethlehem quartz diorite "altered-mineralized"
SiO_2	61.44	60.35	62.91	67.51
TiO_2	0.48	0.78	0.55	0.48
Al_2O_3	17.43	18.67	16.42	15.76
Fe_2O_3	1.46	1.60	3.26	1.06
FeO	4.19	4.56	3.06	3.04
MnO	0.09	0.06	0.06	0.04
MgO	2.48	2.29	1.10	0.95
CaO	5.27	2.67	6.09	3.33
Na_2O	3.99	2.99	2.88	4.50
K_2O	1.99	1.12	1.32	0.69
H_2O^+	0.81	4.63	1.64	1.70
H_2O^-	0.20	0.11	0.44	0.59
P_2O_5	0.16	0.14	0.09	0.12
	99.99	99.97	99.82	99.77
Elements - parts per million				
Ag	1	2	1	1
Cu	95	9900	420	3900
Mo	3	54	3	4
Pb	25	30	35	50
Zn	30	25	20	25

[1] Chemical analysis, Dr. K. Aoki, 1966, Tohoku University.

[2] Trace element analysis, 1966, Rocky Mountain Geochemical Laboratories.

Table II. Modal Analysis.

	Guichon quartz diorite "fresh"	Guichon quartz diorite "altered-mineralized"	Bethlehem quartz diorite "fresh"	Bethlehem quartz diorite "altered-mineralized"
Quartz	14.9	26.0	19.0	30.4
Plagioclase	60.1_{An-34}	$26.8_{(?)}$	63.4_{An-32}	31.6_{An-28}
Orthoclase	9.4	--	6.7	--
Hornblende	8.6	--	7.8	--
Biotite	5.0	3.6	1.3	--
Augite	0.6	--	--	--
Opaques	1.0	3.4	0.2	1.0
Apatite	0.2	--	--	--
Sphene Rutile Leucoxene	0.2	0.9	0.4	0.6
Chlorite	--	20.8	0.6	5.2
Epidote group	--	0.8	0.8	2.2
White mica	--	1.7	--	14.6
Clay minerals	--	16.0	--	12.4
Albite	--	--	--	1.2
Carbonate	--	--	--	0.8
Actinolite	--	--	0.2	--

altered-mineralized Bethlehem specimen is attributed to quartz veinlets. The significant loss of CaO (Table I) in both altered rocks is attributed to the elimination of hornblende and its secondary counterpart epidote and the partial conversion of plagioclase to various clay minerals and white micas. The decrease in MgO (Table I) is probably due to the alteration of primary pyroxene, hornblende and biotite. A common alteration product of these minerals, however, is chlorite and this probably accounts for the restricted magnitude of the MgO loss. The near absence of recognizable orthoclase and the elimination of potassium in the conversion of biotite to chlorite, in the altered-mineralized specimens (Table II) are responsible for the decrease in K_2O (Table I). The Na_2O increase in the altered-mineralized Bethlehem quartz diorite specimen (Table I) is attributed to albitization of plagioclase (Table II). The remaining oxides show no consistent trends. The lack of consistent trends for the remaining oxides might be due to the small number of analyses or to differences in the degree of alterations in the samples analyzed.

The trace element analysis (Table I) indicates the abundance of Ag, Cu, Mo, Pb and Zn in parts per million.

A number of overlay and auxillary maps have been prepared. Contoured distribution maps of epidote, chlorite, white mica, clay minerals and quartz within the Jersey pit are represented by

Figures 16 through 20 respectively. These data were derived by point-counting (500 points) 79 selected samples from locations in the Jersey pit as indicated on the maps. A geologic map and cross-section have been prepared to the same scale. Copper values of 0.50% Cu and above, derived from blast hole analyses, are enclosed by the red line on the geologic map (Figure 22). Because blast hole drilling shortly preceeds and progresses with mining the plus 0.50% copper contour represents copper values in rock already mined. The geologic map (Figure 22) is a reduction of Plate I, approximate scale is 176 feet to the inch. Figure 23 is a generalized geologic cross-section through B-B' on Plate I.

The distribution maps are intended as overlays on the geologic map, or other mineral distribution maps. Ideally they enable on to discriminate between hydrothermal and primary (rock type) mineralogical effects.

The northeast grain of Figures 16 through 20 is largely a consequence of the sample pattern; i.e. samples closely spaced east-west and widely spaced north-south. The northeast-striking fault system (Plate I), however, is still considered to be important in controlling the distribution of the various alteration products. A square grid sampling pattern would have been much more effective. Contours in the extreme eastern part of the pit are left open for lack of data.

Epidote Group

The epidote group includes both epidote and zoisite but will be referred to simply as epidote. Figure 16 illustrates epidote forming a well defined fringing anomaly enclosing the argillic alteration. The innermost three percent contour nicely outlines the area of lime leaching indicated in Table I. The outer five percent contours indicate the area of propylitic alteration and lime fixation where epidote replaces hornblende and biotite. A comparison of epidote distribution to the geologic map and copper contour on that map indicates that the epidote distribution is associated with the intense faulting in the western part of the pit and that the fringing anomaly encloses the bulk of the ore body as currently exposed (Figure 22). The distribution of epidote, with the possible exception of breccia, is independent of rock type. In general the incidence of white mica and clay minerals is greater within the area of lime leaching. Epidote within the leached area occurs most often as relics partially replaced by chlorite or as disseminations in breccia. Less commonly it may occur in breccia as compact aggregates up to six inches in diameter. Zoisite occurs as tiny crystals along fractures and in association with epidote.

Chlorite

The distribution of chlorite appears to be controlled by both rock type and faults. Because of fault control the correlation with mineralization is good.

The chlorite distribution superimposed on the geologic map shows a reasonable correlation of the 25 percent contours to breccia. Microscopic examination confirms a high content of the aforementioned wispy chlorite in breccia. Chlorite, in fact, gives much of the breccia a pale green color. Faults, however, are also important and a combination of faulting and breccia account for the distribution and abundance of chlorite in the western part of the pit. Faults alone appear to be responsible for the central 15 and 20 percent contours. The development of chlorite appears to be inversely proportional to the incidence of white mica (Figure 18). Chlorite occurs replacing plagioclase, epidote an d biotite in addition to its occurrence in breccia as previously noted.

White Mica

This group includes fine grained muscovite (sericite), its polymorphs, hydromuscovite and possibly paragonite as deduced from petrographic examinations. The optical distinction between white mica and clay aggregate minerals is largely one of grain size.

When grain size was large enough to be resolved at high magnification and possessed optical properties similar to those of the aforementioned minerals the grain was counted as white mica. The small grain size and intimate intergrowths with clay minerals and the absence of x-ray data limit the value of both the white mica distribution (Figure 18) and the clay mineral distribution (Figure 19).

The occurrence of white mica is known to be concentrated in or adjacent to fault planes or zones within the Jersey pit and on the nearby Skeena, O.K. and Lornex properties. The Skeena and O.K. (Figure 2) mineralization are fault controlled vein-type deposits that exhibit intense white mica alteration in the adjacent wall rock. At Lornex (Figure 2), geophysical and diamond drill core data indicate a disseminated deposit controlled by a fault zone or intersection of fault zones. The host rock is bleached nearly white and consists almost entirely of white mica and clay minerals. The copper occurs as fine grained bornite and chalcopyrite.

The development of white mica in association with fault planes and zones suggests that the hydrothermal fluids reacted more readily with host rocks in these structurally controlled zones of relatively high permeability. White mica also occurs replacing plagioclase and rarely hydrothermal biotite.

A comparison of the white mica distribution (Figure 18) to the geologic map (Figure 22) illustrates fault control in spite of the northeast grain. Correlation with the higher grades of mineralization is considered to be good.

Clay Group

The distribution of clay minerals is a visual estimate of the percent of optically unresolvable minerals in a given thin section. Much of this material which is colorless to buff or pale yellow with low to moderate birefringence .010 - .018 and low relief is believed to be a member of the montmorillionite group. The occurrence is nearly always as a replacement of feldspar. The correlation with mineralization is good. The visual estimates, lack of positive identification and dubious distinction between clay minerals and white mica minimizes the significance of this map.

Quartz

Values of quartz below 20 percent are considered to be modal quartz. The quartz distribution map shows no particular correlation with either rock type or structure (Figure 20). It does, however, correlate in a general way with mineralization. Quartz above 20 percent, tends to favor areas where white mica and clay minerals are prevalent and where chlorite and epidote are at minimum values. Quartz is stable in both the propylitic and argillic environments. Quartz occurs as quartz-chalcopyrite-pyrite, quartz-hematite and quartz veinlets and as replacements of plagioclase and other minerals.

Other Hydrothermal Minerals

The development of albite, tourmaline and hydrothermal biotite is restricted. Albitized plagioclase is not abundant. Zoned tourmaline with elbaite centrally and schorlite marginally occurs in breccia. Hydrothermal biotite is uncommon. Albite and biotite are most prevalent in areas of intense argillic alteration. Tourmaline is localized in breccia in the southeast part of the pit.

Calcite occurs almost exclusively in thin crusts on joint and fracture surfaces and in veinlets. Fankhauser (1966) subjected ten calcite samples to x-ray analysis in order to determine the magnesium content. The calcite was taken from joint and fracture surfaces of samples collected from the Jersey pit. Fankhauser had hoped to show, by selecting samples progressively deeper in the ore body, a linear relationship between temperature and magnesium content of calcite. The results were negative as the magnesium content varied, apparently randomly, between 1.15 percent and 5.00 percent.

Zeolites occur as thin films on joint planes and as fracture fillings. Laumontite and Beta leonhardite fracture fillings up to one foot wide are numerous on the northern margin of the pit. Stilbite occurs as drusy crystals in vugs but most commonly as smooth, bluish white coatings on joint surfaces. White, Thompson and MacTaggart (1957, p. 495) reported heulandite occurring on joint planes.

In general, the correlation between mineralization, alteration and structure is good. The highest incidence of chlorite, white mica, clay minerals and quartz are directly related to significant mineralization. Faults and fractures controlled the localization of both alteration and mineralization. The outer fringes of the mineralized area have been only weakly altered and copper mineralization in these areas is negligible.

Alteration Summary Map

Figure 21 shows in a general way the limits of argillic versus propylitic alteration. The area of argillic alteration is characterized by maximum values of white mica, clay minerals and significant leaching of lime. The area of propylitic alteration contains the maximum values for epidote, variable amounts of chlorite and minimum values for white mica and clay minerals. Quartz was not considered in distinguishing the two alteration types of the alteration summary map.

SUMMARY

Copper mineralization in the Highland Valley district was discovered in the early 1900's. Mining activity progressed from small high grade veins to large volumes of low grade disseminated copper ore.

In may respects the Bethlehem copper deposit is similar to the porphyry copper deposits of the southwestern United States. The deposit is smaller, lower grade and alteration less intense than most, but these are differences in degree. It is also similar in having abundant faults, fractures and a complex sequence of hypabyssal rocks. It does not, however, have a supergene capping of secondarily enriched ore.

The Bethlehem ore body is situated near the center of the elongate Lower Jurassic Guichon Creek batholith. The batholith, quartz diorite in composition, intruded both Permian and Upper Triassic sedimentary and volcanic rocks and has been intruded by a younger complex of quartz diorite and granodiorite. Remnants of Middle Jurassic marine sediments unconformably overlie the batholith. The emplacement of the younger complex was closely followed by the intrusion of leucocratic porphyritic dacite and both caused the development of breccia on or near the contacts with the older quartz diorite. The breccia has a complex history and probably began as an intrusion breccia which was later modified by an explosive event and finally became mobile enough to be intrusive. The intrusion of dacite porphyry dikes and a small body of granite followed the development of breccia. Mineralization, faulting and fracturing began or perhaps continued after the emplacement of the dacite porphryr dikes. Attendent hydrothermal alteration caused the development of argillic alteration within the orebody and a fringing area of propylitic alteration. Mineralization and hydrothermal alteration were followed by the intrusion of mesocratic porphyritic dacite dikes and continued faulting. The extrusion of andesite and basalt occurred in early and middle Tertiary time. Erosion, Pleistocene glaciation and more erosion followed the extrusive rocks.

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