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MINERAL DEPOSITS DIVISION
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NUMBER 1

David Lefebure

# GEOLOGY AND ORE DEPOSITS OF THE HIGHLAND VALLEY CAMP

by

W.J. McMILLAN



SERIES EDITOR: A.J. SINCLAIR

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by

W.J. McMillan
Geological Branch
Mineral Resources Division
Ministry of Energy, Mines and Petroleum Resources
Parliament Buildings
Victoria, B.C. V8V 1X4

with contributions by:

K. Newman
Valley Operations
Box 520, Ashcroft, B.C. VOK 1A0

and

L. Tsang and G. Sanford
Highmont Operating Corporation
Box 3000, Logan Lake, B.C. VOK 1W0

Series Editor: A.J. Sinclair
Department of Geological Sciences
University of British Columbia
Vancouver, B.C. V6T 2B4

Cover Photo: Aerial view of the Highland Valley looking westerly with Bethlehem Pit in the foreground and Valley Pit in the middle distance. Couresty of I.A. Paterson, Cominco Ltd.

# PREFACE

The concept of a Field Guide and Reference Manual Series for Canadian mining camps originated with the executive of the Mineral Deposits Division of the Geological Association of Canada in early 1980. At that time D.F. Strong of Memorial University was charged with initial enquiries into the form such a publication should take. Subsequently, many executive members including J.A. Coope, V.F. Hollister, J.A. McDonald, S.D. Scott and others have contributed their opinions and eventually the present form emerged as a compromise between limitations on cost and content. Our aim is to provide a manual useful in the field and of such quality that the scientific and factual content will not be outdated quickly. In this, the first of what we anticipate will be a continuing series, we are grateful to Dr. W.J. McMillan for undertaking the arduous task of assembling his storehouse of information on the Highland Valley camp and for his cooperation with the editor and an ad hoc review committee consisting of R.V. Beavon, K.M. Dawson, R.S. Hewton, J.A. McDonald and I.A. Paterson. The contributions of personnel from operating companies - K. Newman of Valley Operations and L. Tsang and G. Sanford of Highmont Operating Corporation and the cooperation of personnel from Lornex Mining Corporation Ltd. are gratefully acknowledged.

A.J. Sinclair
February 1985

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# PART 1

## GEOLOGY AND ORE DEPOSITS OF THE HIGHLAND VALLEY AREA

(W.J. McMillan)

### 1 INTRODUCTION

The Highland Valley district, known for its large low-grade open pit porphyry copper-molybdenum mines, is situated in south-central British Columbia about 350 kilometres northeast of Vancouver (Fig. 1).

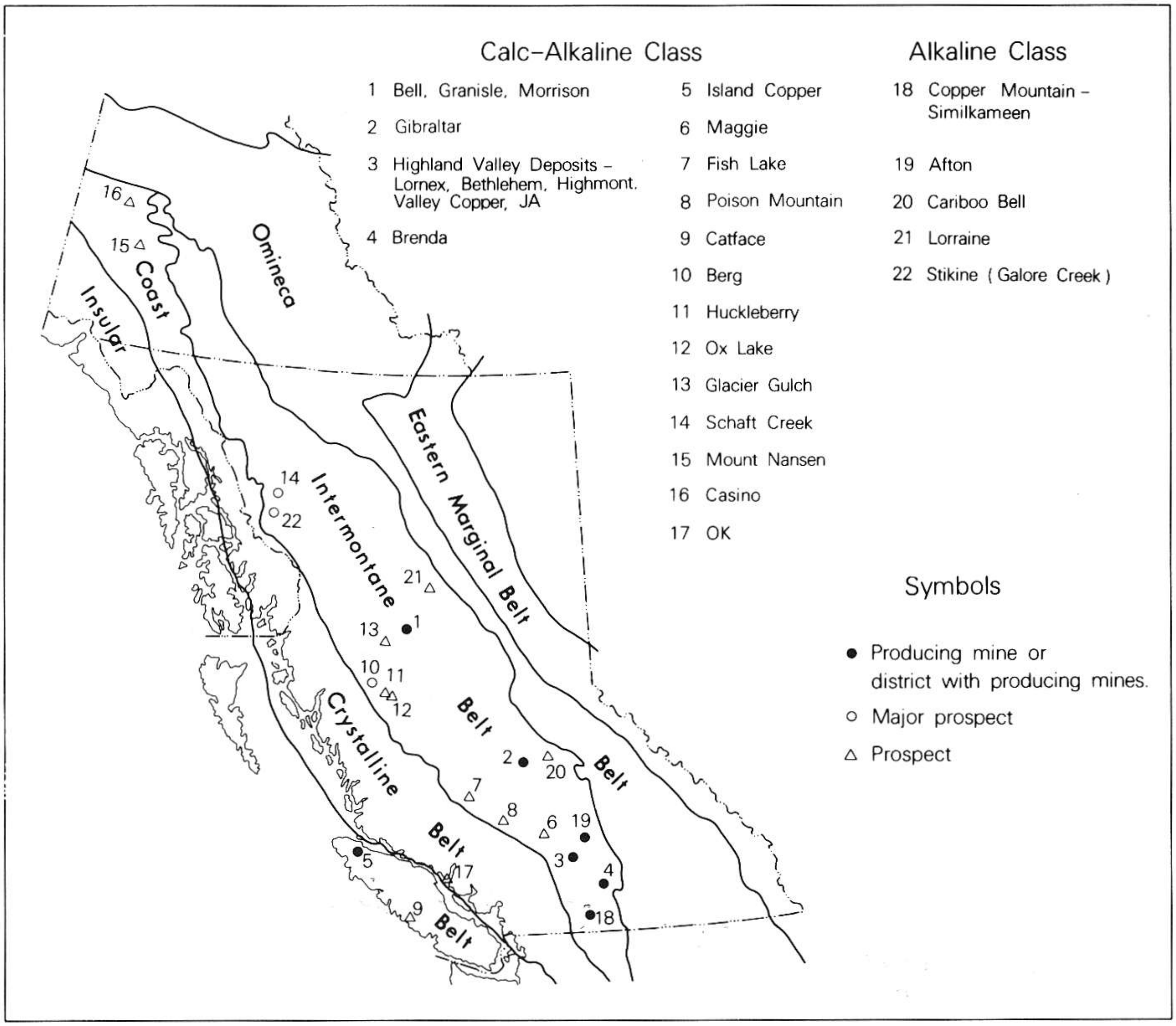



Figure 1. Distribution of porphyry copper deposits of the calc-alkaline and alkaline classes in the Canadian Cordillera relative to tectonic belts. Most are in the Intermontane Belt.

Five major deposits constitute the heart of the Highland Valley district. These are: Lornex, Highmont, and Valley Copper, which are operating mines; Bethlehem Copper, which closed in 1982 due to metal prices; and the J.A. deposit which is a potential producer. Two other deposits, Krain and South Seas, which have similar grades but smaller tonnage potential, have also been tested extensively. Numerous small, high-grade vein deposits first attracted attention to the district, and several, OK (Alwin), Snowstorm and Aberdeen, are former small-scale producers.

Aggregate ore reserves for the 13-square-kilometre central part of the Highland Valley district are nearly 2 billion tonnes of 0.45 per cent copper equivalent. This figure includes former production and proven reserves (Table 1), as well as geologically inferred reserves.

**TABLE 1. MINING STATISTICS FOR MAJOR PORPHYRY COPPER-MOLYBDENUM DEPOSITS, HIGHLAND VALLEY, NTS 921/6, 7**

| Deposit (Start of Production) | Orebody | Ore Mined to Dec. 1984 (million tonnes) | Mined Grades Cu% | Mined Grades Mo% | Strip Ratio (waste /ore) | Daily Rate (Tonnes) | Reserves (Cutoff) (million tonnes) | Grades Cu% | Grades Mo% | Status* |
|---|---|---|---|---|---|---|---|---|---|---|
| Bethlehem Copper (1962) | East Jersey | 8.96 | 0.60 | - | - | - | 20.6 | 0.40 | | N |
| | Jersey | 53.16 | 0.50 | - | - | - | 22.9 | 0.40 | | (1982) |
| | Huestis | 29.46 | 0.52 | - | - | - | - | - | | |
| | Iona | 1.43 | 0.40 | - | - | - | 6 (oxide) | 0.40 | | |
| | Combined Total | 105.87 | 0.502 | - | 1.93:1 | Combined Total | 37.67 | 0.40 | | |
| Krain | - | - | - | - | - | - | 9.1<br>4.9 (oxide) | 0.53<br>0.64 | appx. 0.01 | P |
| Highmont (1980) | West Pit | 14.2 | 0.15 | 0.048 | 2:1 | - | 0.8 | 0.15 | 0.048 | N |
| | East Pit | 20.5 | 0.26 | 0.021 | 2.2:1 | | 87.6 | 0.26 | 0.021 | (1984) |
| J.A. | - | - | - | - | - | - | 286 (1983) | 0.43 | 0.017 | P |
| Lornex (1972) | Lornex Pit | 228** | 0.421 | 0.159 | 2.3:1 | 76 000 | 350 (appx) (0.25) | 0.374 | 0.0129 | O |
| Valley Copper (1983) | Valley Pit | 15.6 | 0.51 | - | 0.7:1 | 20 000 | 559 (indicated)<br>141.6 (inferred) | 0.471<br>0.482 | | O |

*O - Operating Open Pit Mine; N - Former Producer, temporarily closed (and when); P - Potential Producer
**calculated from average daily production; grades refer to material produced to December 31, 1983 - they may change slightly when data from the 28 million tonnes mined in 1984 becomes available

## 2 HISTORY AND EXPLORATION METHODS

Prior to Bethlehem Copper coming on-stream in 1957 there were no producing porphyry copper deposits in British Columbia. The success of Bethlehem spurred intense exploration. Within a few years exploration companies discovered Lornex, Valley Copper and the J.A. deposit, and many showings in the district were evaluated thoroughly.

Copper was not a new commodity in the area. What is now Bethlehem Copper mine was first staked in 1899. Work at that time and into the early 1900's explored small high-grade veins of the Snowstorm zone, with shipment of 90 tonnes of hand-cobbed ore during 1915 and 1916. Diamond drilling of Snowstorm began in 1917 and underground testing of what is now the Iona zone began in 1919. Eighty-five metres (280 feet) of 0.64 per cent copper were cut in the Iona zone but at that time the copper price was too low for the zone to be of economic interest. A few more holes were drilled in 1942 then the property lay idle until 1954 when the area was staked by the Huestis-Reynolds-McLellan syndicate. In 1955 work by American Smelting and Refining Company outlined large tonnage, low-grade copper deposits; the exploration focus shifted, the hunt for porphyry copper deposits in Highland Valley began in earnest.

Exploration was intense and exciting in those early years. In 1964 bulldozer trenches spotted by veteran prospector Egil Lorentzen opened up the Discovery zone at Lornex. In 1966 and 1967 an extensive percussion drill program at Highmont outlined the No. 1 orebody. Valley Copper was discovered in 1967 and the J.A. deposit in 1971.

Soaring costs accompanied by low copper prices over the last few years delayed production decisions at Cominco Ltd.'s Valley Copper deposit and Teck Corporation Limited's Highmont deposit. However, Highmont was brought into production in 1980 and Valley Copper in 1982. No production plans appear likely for the J.A. deposit in the near future.

The main exploration tools effective in these discoveries were prospecting, geology, and geophysics (mainly induced polarization). Glacial deposits, particularly till, and lacustrine and glaciofluvial sediments, cover many areas and mask geochemical responses, although auger samples taken in till overlying the bedrock surface gave meaningful geochemical anomalies. In areas of thin glacial cover bulldozer trenching was an important method of revealing geology and checking geophysical or geochemical anomalies. Generally trenching was followed by percussion or diamond drilling to delimit mineralization.

As is pointed out later in the text, the ore deposits have geochemical dispersion halos and peripheral alteration that can provide exploration 'vectors' (see also Table 2). All the major deposits are related to younger phases of the host Guichon Creek batholith.

Probably the best indirect exploration tool is induced polarization. Deposits, like Lornex, with shallow cover give distinct anomalies; even those with deeper cover may respond. The J.A. discovery hole, for example, penetrated 100 metres of overburden; it was drilled on an induced polarization anomaly. Anomalous zones are generally subtle, overall sulphide content is low, and pyritic halos poorly developed - pyrite abundance is typically less than 1 per cent in the halos.

TABLE 2. GEOLOGIC CHARACTERISTICS OF HIGHLAND VALLEY

| Name | Location | Size* | Grade %Cu | Grade %Mo | Relative Age | Host Rock | Estimated proportion of ore contained |
|---|---|---|---|---|---|---|---|
| Bethlehem Copper | 50°29.5'; 120°59' | 143 | 0.48 | only recoverable in times of high prices | After Bethlehem Before Bethsaida | Guichon granodiorite<br>Bethlehem granodiorite<br>Breccia & dacite porphyry dykes | 35%<br>45%<br>20% |
| Krain | 50°35'; 120°58 | 14 | 0.56 | 0.01 | After Bethlehem | Guichon granodiorite<br>Dyke-like stock of Bethlehem (?) granodiorite | |
| Highmont | 50°26'; 120°35' | 116 in two main zones | 0.246 | 0.025 | Late stage Bethsaida | Skeena granodiorite<br>Gnawed Mountain quartz feldspar porphyry | 95%<br>5% |
| J.A. | 50°28.5'; 120°58.5' | 286 | 0.43 | 0.017 | Late Stage Bethsaida ? | Guichon granodiorite<br>Bethlehem granodiorite<br>J.A. porphyry stock | 47%<br>50%<br>3% |
| Lornex | 50°27'; 121°03' | 578 | 0.393 | 0.014 | Late stage Bethsaida | Skeena granodiorite<br>Quartz±feldspar porphyry dyke<br>Bethsaida quartz monzonite | 93%<br>7%<br>0% |
| Valley Copper | 50°29'; 121°02' | 716 | 0.474 | not significant | Late stage Bethsaida | Bethsaida quartz monzonite<br>Quartz feldspar porphyry dykes | 99%<br>1% |

Note: K - potassic, sil - silicic, phyl - phyllic, arg - argillic, prop - propylitic, Fr - fresh rock, *million tonnes (includes mined ore and reserves)

PORPHYRY COPPER-MOLYBDENUM DEPOSITS

| Alteration and Cu mineralization<br>Core Medial Rim | Relative age of alteration types | Associated minerals | Oxide zone | Comments |
|---|---|---|---|---|
| K phyl/<br>(bio) arg prop Fr<br>bo py<br>ch sp<br>>0.3% Cu | Main stage potassic (biotite & sericite) - phyllic/argillic-propylitic<br>Late calcite zeolite | Specularite<br>Tourmaline<br>Zeolites | Generally weakly developed, no enrichment blanket, deep in part of Iona deposit | Small subequant to elongated orebodies<br>Zoning concentric |
| phyl prop/ prop Fr<br>arg<br>bo cp cpy py | Main stage propylitic-argillic to propylitic | | Significant tonnage, slightly enriched | Oxide zone unconformably overlain by Tertiary lavas |
| phyl/<br>K (bio, arg prop Fr<br>Kspar)<br>bo ch py<br>>0.3% Cu | Early biotite, propylitic<br>Main stage potassic (k-feldspar) phyllic<br>Later argillic-propylitic<br>Late calcite | Tourmaline<br>Actinolite<br>Zeolites | Thin, no enriched blanket | Zoning outward from Gnawed Mountain dyke, linear trends |
| bo ch py<br>K (bio, phyl/arg? prop<br>Kspar)<br>>0.3% Cu | Early potassic (biotite after mafics; potassic feldspar related to stock)<br>Main stage phyllic-argillic propylitic<br>Late calcite, gypsum | Actinolite<br>Gypsum<br>Tourmaline | Not certain due to drilling method | Elliptical deposit elongated parallel to Highland Valley; zoning related to central stock |
| sil phyl/arg prop<br>patchy K<br>(bio,<br>Kspar)<br>bo ch py<br>>0.3% Cu | Early potassic<br>Main stage phyllic-argillic-propylitic<br>Late fracture-controlled argillic calcite, gypsum | Some tourmaline gypsum | Best developed at south end, minor enriched zone locally | Ore zone elliptical, zoning sub-concentric<br>Cut off by younger fault on west side |
| sil K phyl/ prop<br>(kspar arg (nar-<br>very weak row)<br>bio)<br>ch bo ch py (weak)<br>>0.3% Cu | Early potassic-propylitic (?) some silicic<br>Main stage phyllic-argillic-propylitic<br>Late main stage silicic ±phyllic<br>Late fracture-controlled argillic, calcite, gypsum | Gypsum<br>Anhydrite | Overall thin | Subequant deposit, zoning concentric |

bio - biotite, py - pyrite, bo - bornite, ch - chalcopyrite, sp - specularite

## 3 REGIONAL SETTING OF THE GUICHON CREEK BATHOLITH

Highland Valley porphyry copper deposits occur within the Guichon Creek batholith, one of several large plutons in the southern Intermontane Belt (Fig. 1) that are associated and possibly comagmatic with Late Triassic volcanic rocks. These intrusive and volcanic rocks occur in a belt the length of the Cordillera; they are variously interpreted to be products of island arc volcanism (Gabrielse and Reesor, 1974) or rifting in an island arc environment (Preto, 1977); they display both calc-alkaline and alkaline (Barr, et al., 1976) differentiation trends. Monger (1982) argues that these rocks, derived from melting of subducted oceanic crust, were deposited on Late Paleozoic oceanic and arc rocks (Cache Creek Group and Harper Ranch Group). Fossil and paleomagnetic evidence indicates that the entire Late Triassic volcanic belt is allochthonous; it originated over 1 000 kilometres south of its present location (Irving, et al., 1980). In this plate tectonic interpretation, the Cordillera is seen as a collage of allochthonous terranes 'plastered' onto the western margin of North America by convergent and transform plate motions (Monger, et al., 1982).

A melange that is part of the Cache Creek terrane lies along the western side of the Guichon Creek batholith. The melange consists largely of Late Paleozoic clasts but has local Nicola clasts (Shannon, 1981). Clasts range from several centimetres to hundreds of metres in size and lie in a sheared chert and argillite matrix of Triassic age (Travers, 1978). If the melange represents the time when collision locked these two areas together, then they have been in their present relative positions since some time during the Triassic. However, it is not certain when this composite terrane moved northward to its present geographic location; possibly it was as late as Early Tertiary time (Irving, et al., 1980). Continuing geological and paleomagnetic analyses are under way to attempt to clarify some of the uncertainty of present interpretations.

# 4 GEOLOGY AND GEOCHEMISTRY OF THE GUICHON CREEK BATHOLITH

## 4-1 INTRODUCTION

The Guichon Creek batholith intrudes and metamorphoses Late Triassic (Karnian and perhaps Norian) volcanic and sedimentary rocks of the Nicola Group (Figs. 2, 2a). Isotopic ages from the batholith average 202±8 Ma by potassium-argon and 205±10 Ma by rubidium-strontium methods, apparently slightly younger than the faunal ages for the Nicola Group. However, in the Promontory Hills area at the south end of the batholith, quartz feldspar porphyry stocks have comagmatic volcanic flows which are part of the Nicola Group. These stocks are interpreted to be satellitic intrusions derived from the Guichon Creek batholith, which apparently was emplaced during Nicola volcanism and appears to have generated part of the volcanic pile. Northcote (1969) concluded that early, more even-grained phases of the batholith are mesozonal, whereas younger, more porphyritic phases are epizonal. Initially the batholith was probably subvolcanic; younger phases rose higher into the crust and intruded the lower part of the comagmatic but slightly older volcanic pile.

Initial $Sr^{87}/Sr^{86}$ ratios for rocks of the batholith are primitive, at 0.7025 to 0.7046 (Preto, et al., 1979), similar to those of modern island arcs. The magma probably was derived either from partial melting of upper mantle material or from recycled subducted oceanic crust.

Gravity profiles (Ager, et al., 1972) suggest that the intrusion has a pipe-like root zone under Highland Valley, steeply inclined contacts on the east and west borders, and a relatively shallow, flat-lying base north and south of the root zone (Fig. 3). The configuration suggests that the magma was injected along intersecting basement structures, then spread southward and northward along the dominant zone of weakness. Reactivation of the basement structures during and after plutonism controlled not only fault patterns in the batholith, but also the distribution of younger sedimentary and volcanic rocks that lie on and around the pluton (Carr, 1962; McMillan, 1976). Faults and fractures controlled the distribution of swarms of porphyry dykes and localized ore deposition.

Much of the batholith is covered by a thin layer of glacial deposits. In Highland Valley itself, however, Pleistocene stratigraphy is complex; the area was influenced significantly by three or possibly four major glaciations (Ryder, 1976). In a general way, the valley is infilled by a thin discontinuous basal sand, gravel and till succession, which is overlain by a thick sequence of thin-bedded lacustrine silts, silty sands, and clayey silts. This in turn is overlain by a moderately thick, well to poorly bedded silt, sand, and gravel succession in which depressions and erosional channels are filled by deltaic outwash sediments. The valley walls are coated by ablation moraines, bedded silt, sand, and gravel. Kettle lakes occur along the valley, and eskers and numerous kame terraces line its walls. Near the end of the glacial epoch the kame terraces apparently formed along the margins of a stagnant body of ice which filled the valley. Successive levels of terraces were formed as the ice slowly melted.

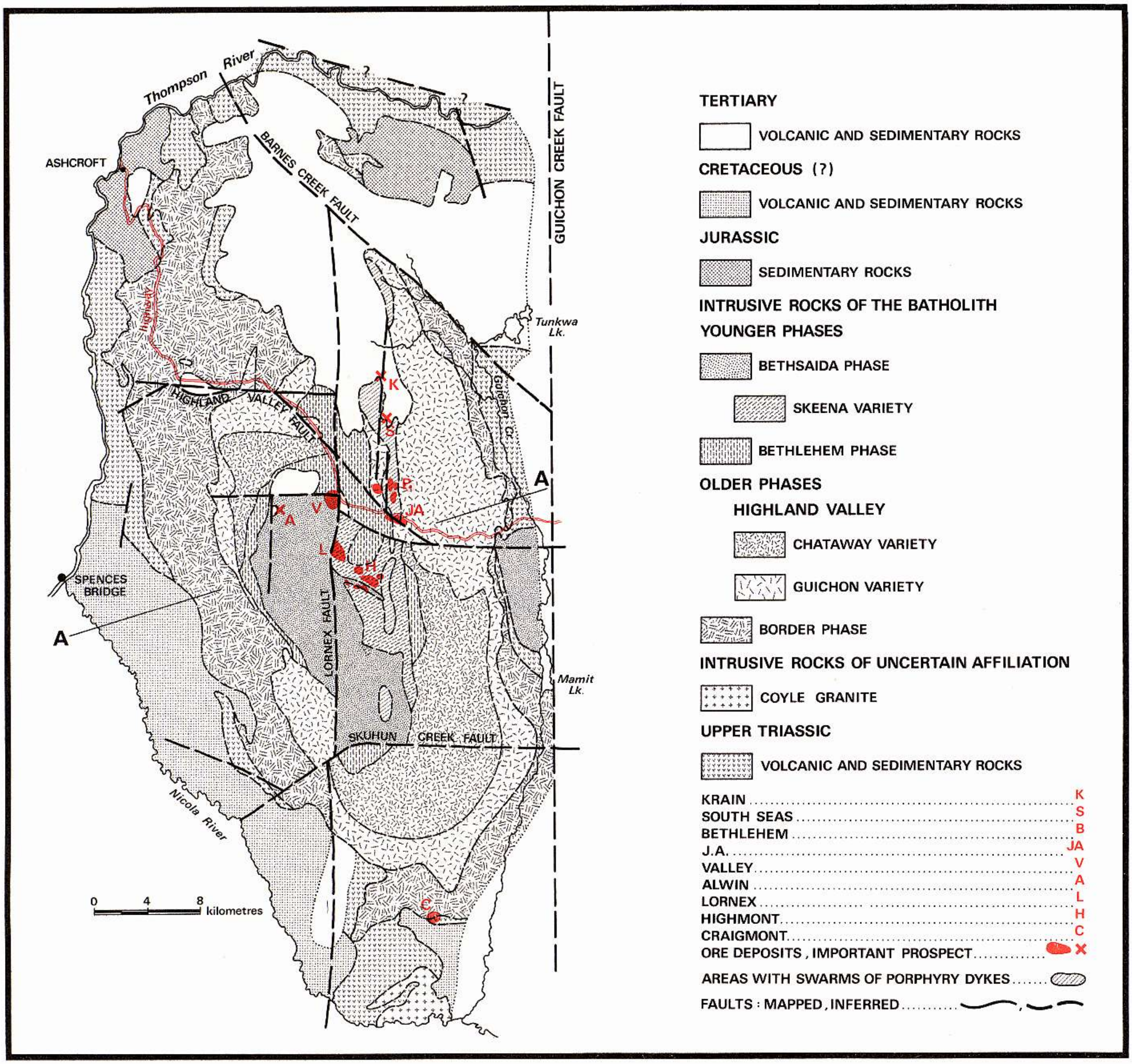



Figure 2a. Geology and major mineral deposits of the Guichon Creek batholith (modified after McMillan, 1976).

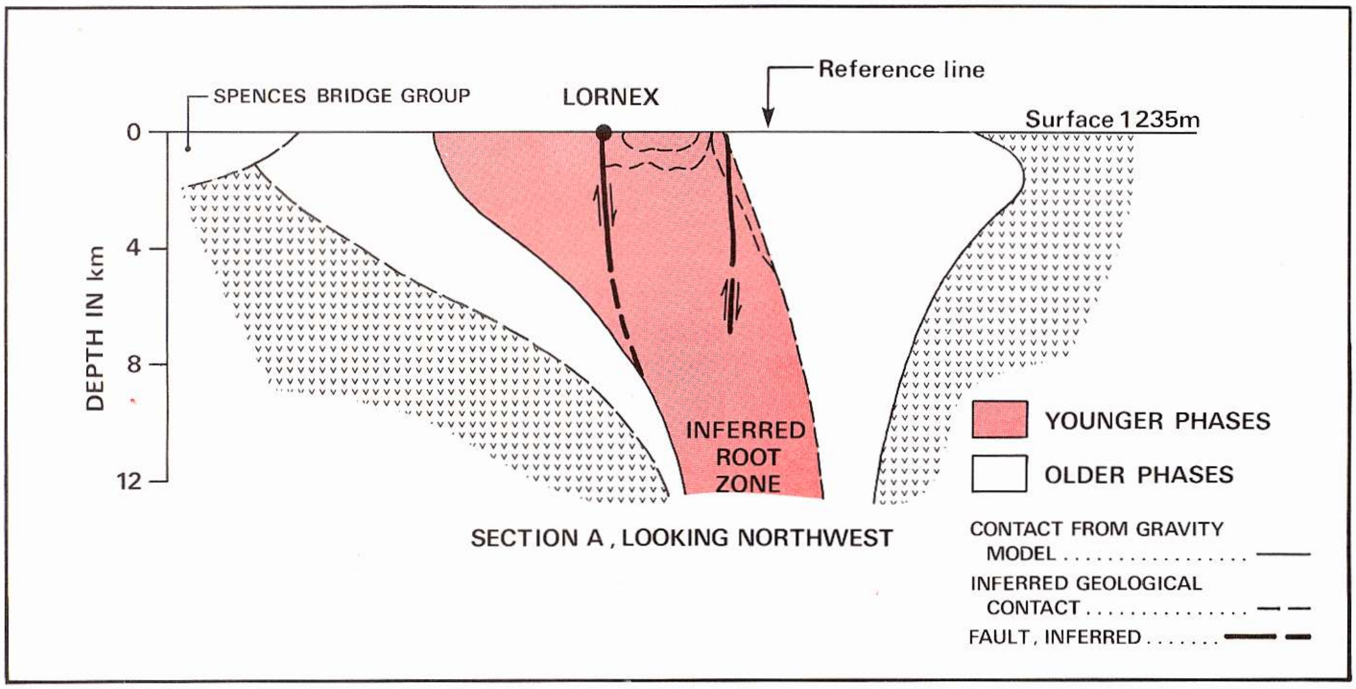



Figure 3. Gravity profile and geological model showing rock type distribution and the interpreted shape at depth of the Guichon Creek batholith (after Ager, et al., 1972). For location see Figure 2a.

## 4-2 GEOLOGY

The oldest rocks in the batholith lie at its edge; the youngest in its core. Large segments of the batholith (Figs. 2, 2a) consist of mappable 'phases' with distinctive mineralogical and textural features (Northcote, 1969). From edge to core these phases are: Border, Highland Valley, Bethlehem, and Bethsaida. Mappable subunits or 'varieties' occur within some phases: the Highland Valley phase consists of the Guichon and Chataway varieties; the Bethlehem phase has subareas that are mapped as the Skeena variety.

Contacts between phases are generally gradational and rarely chilled; locally, however, they crosscut. Contacts between the older Border and Highland Valley phases are everywhere gradational. The younger Bethlehem and Bethsaida phases seem to cut the older phases but, again, contacts can be gradational. Evidently, successive phases were often injected before the preceding phase was completely solidified (Northcote, 1969; McMillan, 1976).

Within the batholith, episodic dyke emplacement began after intrusion of the Bethlehem phase. The Bethlehem ore deposits and South Seas and Krain prospects are associated with a swarm of north-trending dykes that have related explosion breccias (Carr, 1960) and cut Bethlehem and older rocks north of Highland Valley. Texturally and chemically (this study; Briskey and Bellamy, 1976; Briskey, 1981) these dykes have affinities to the Bethlehem phase. They represent late-stage intrusions tapped from Bethlehem phase magma and are related in time to the first major period of ore formation in the batholith. In a younger event dykes and plugs were emplaced that trend not only northward parallel to the older dyke swarm but also northwesterly; most are in or south of Highland Valley. They represent offshoots of Bethsaida phase magma and later, more evolved magmas. The largest ore deposits in the batholith were deposited during and after this younger event.

## 4-3 PETROLOGY

Rocks of the batholith are composed of varying proportions of plagioclase, amphibole, biotite, quartz, and potassic feldspar with the ubiquitous accessories magnetite, apatite, and sphene (Table 3). In the oldest rocks, amphibole locally contains cores of pyroxene; in the youngest rocks biotite may be the only ferromagnesian mineral. The rocks are oversaturated with respect to quartz, hypersthene normative, and equivalent to an andesitic rock series (Johan, et al., 1980). From border to core, normative compositions range from diorite or quartz diorite through quartz monzodiorite to granodiorite. Late-stage porphyry dyke compositions extend into the granite field (Fig. 4). Older phases are medium grained and relatively equigranular, younger phases are coarser and more porphyritic.

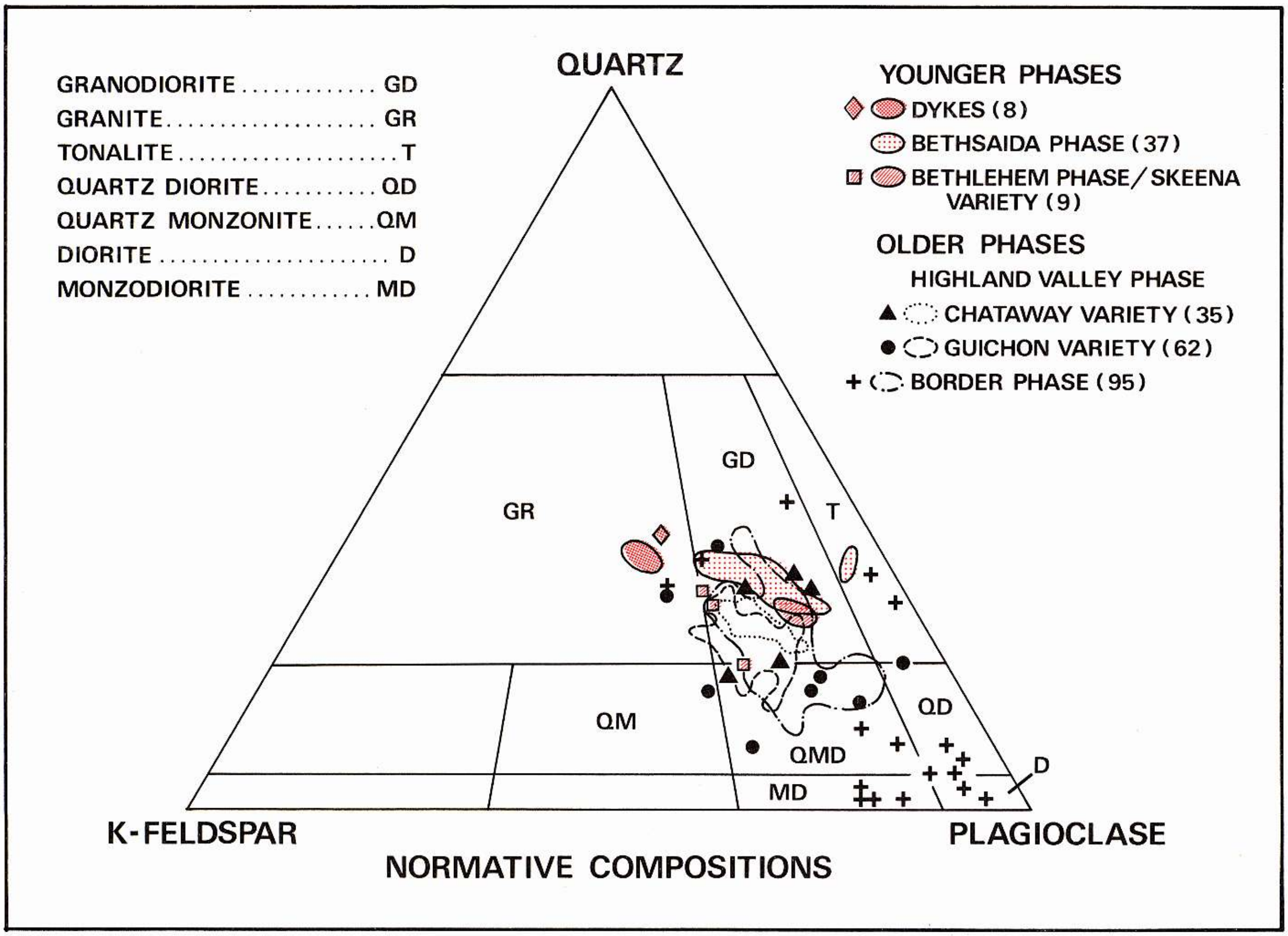



Figure 4. Ternary plot of normative compositions of rocks of the Guichon Creek batholith (numbers in brackets indicate number of analyses of each phase or variety).

TABLE 3. AVERAGE MODAL ANALYSES OF ROCKS OF THE GUICHON CREEK BATHOLITH
(modified after Northcote, 1969)

| PHASE OR VARIETY | MINERALOGY* Plagioclase | Potassic Feldspar | Quartz | Biotite | Hornblende | Pyroxene | Opaque |
|---|---|---|---|---|---|---|---|
| Border | 52.2 | 3.7 | 19.6 | 7.8 | 11.3 | 2.7 | 2.5 |
| Highland Valley | | | | | | | |
| Guichon | 48.7 | 12.8 | 18.9 | 7.2 | 9.8 | 0.6 | 1.5 |
| Chataway | 54.3 | 10.9 | 20.6 | 5.2 | 6.7 | - | |
| Bethlehem | 59.0 | 9.9 | 20.8 | 3.2 | 4.3 | - | 2.3 |
| Skeena | | | | | | | |
| Bethsaida | 52.1 | 10.6 | 29.4 | 6.3 | 0.4 | - | 1.0 |

*Typical accessory minerals are sphene, apatite, and zircon.

TABLE 4. COMPOSITION AND ZONING IN PLAGIOCLASE, GUICHON CREEK BATHOLITH

| Relative Age | Phase | Variety | Average Plagioclase Composition Range* core | | medial | | rim | Zoning Scheme |
|---|---|---|---|---|---|---|---|---|
| | Border | - | $An_{48}$ | | | | $An_{10}$ | simple, normal |
| Early Phases | Highland Valley | Guichon | $An_{48}$ | | | | $An_{10}$ | simple, normal |
| | | Chataway | $An_{44}$ | $An_{40}$ | $An_{44}$ | | $An_{31}$ | simple, mainly normal, local subtle reverse |
| | Bethlehem | - | $An_{42}$ | $An_{35}$ | $An_{42}$ | | $An_{30}$ | partly resorbed core, more calcic corona, |
| | Feldspar Porphyry Dykes | | $An_{48}$ | $An_{33}$ | $An_{46}$ | $An_{32}$ | $An_{15}$ | reverse and complex oscillatory medial zone, normal rims |
| Later Phases | | Skeena | $An_{42}$ | $An_{25}$ | $An_{32}$ | | $An_{11}$ | |
| | Bethsaida | - | $An_{40}$ | $An_{31}$ | $An_{37}$ | $An_{21}$ | $An_{13}$ | |
| | Quartz Porphyry Dykes | - | $An_{32}$ | $An_{25}$ | $An_{40}$ | $An_{30}$ | $An_{18}$ | normal core, reverse and complex oscillatory medial zone, normal rims |

*In the matrix, all phases have small, anhedral sodic plagioclase grains ($An_{10}$-$An_{15}$) intergrown with potassic feldspar.

The Border phase contains inclusions of Nicola volcanic and sedimentary rocks. Locally, interaction with these inclusions has produced hybrid amphibolitic to monzonitic zones. Mafic-rich granitoid inclusions also occur; these can be so abundant that they form breccias with subangular inclusions 'floating' in a quartz diorite matrix.

The granitoid inclusions are mafic rich; they consist largely of plagioclase, clinopyroxene, orthopyroxene, and amphibole; some have subordinate amounts of biotite; accessory minerals are abundant magnetite, sphene, and apatite. Plagioclase crystals are either unzoned or have diffuse, subtle zoning ($An_{47}$ to $An_{44}$). Crystallization of amphiboles took place under elevated water pressures in the magma (Johan, et al., 1980); orthopyroxene-clinopyroxene pairs, according to the method described by Wells (1977), give an estimated temperature of formation of 890°C. These granitoid inclusions are interpreted to be cumulates formed at depth during crystallization of the Guichon Creek batholith.

Composition ranges and zoning patterns change across the batholith (Table 4). Zoning is generally normal and simple in the older Border and Highland Valley phases in contrast to reverse and complex in the younger, more central Bethlehem and Bethsaida phases (Westerman, 1970; this study). The distinct change in the form of plagioclase crystallization occurred after solidification of the Chataway variety of the Highland Valley phase (Table 4). Plagioclase crystallization traits, therefore, divide rocks of the batholith into two series: the older phases (Border and Highland Valley) and the younger phases (Bethlehem and Bethsaida).

## 4-4 MAJOR ELEMENT GEOCHEMISTRY

Rocks of the batholith show a clear calc-alkalic differentiation trend on an AFM plot (Fig. 5). Some samples lie in the alkaline field slightly below the boundary line but no evidence of a second, alkaline magma exists. Iron depletion due to early crystallization of magnetite which settled in the cumulate phase may explain the relatively low iron content of these samples.

All the phases probably derive from a single source magma (McMillan, 1978; Johan, et al., 1980; McMillan, 1982; Tombale, 1984). Most oxides have smooth evolution curves when plotted against $SiO_2$ or Larson differentiation index. The Larson index is defined as (1/3 $SiO_2$ + $K_2O$) - (CaO + MgO + FeO). The distribution of manganese between biotite and hornblende in rocks of the batholith also shows a smooth evolution curve; this indicates both near-equilibrium conditions in each phase, and a single source magma.

Alkalis, however, are not distributed simply. Total alkalis plotted against $SiO_2$ fall largely in the calc-alkaline field in the domain of high alumina basalt (Kuno, 1968). When $K_2O$ is plotted against Larson differentiation index, trends for older phases and those for younger phases and dykes are discontinuous; they define two separate trends (Fig. 6). Plotting alkalis versus lime on a ternary plot (Fig. 7) also shows a discontinuity. Dykes are included in the interpretation because there is field and chemical evidence that they are late stage differentiates from either Bethlehem or Bethsaida phases (Briskey and Bellamy, 1976; McMillan, 1976). If dykes are ignored, the discontinuity is less evident and the evolution appears to be trondhjemitic (Olade, 1976). Essentially, the discontinuity results because many rock samples from the Bethlehem and Bethsaida phases are deficient in $K_2O$ relative to samples of Highland Valley phase rocks (Chataway variety).

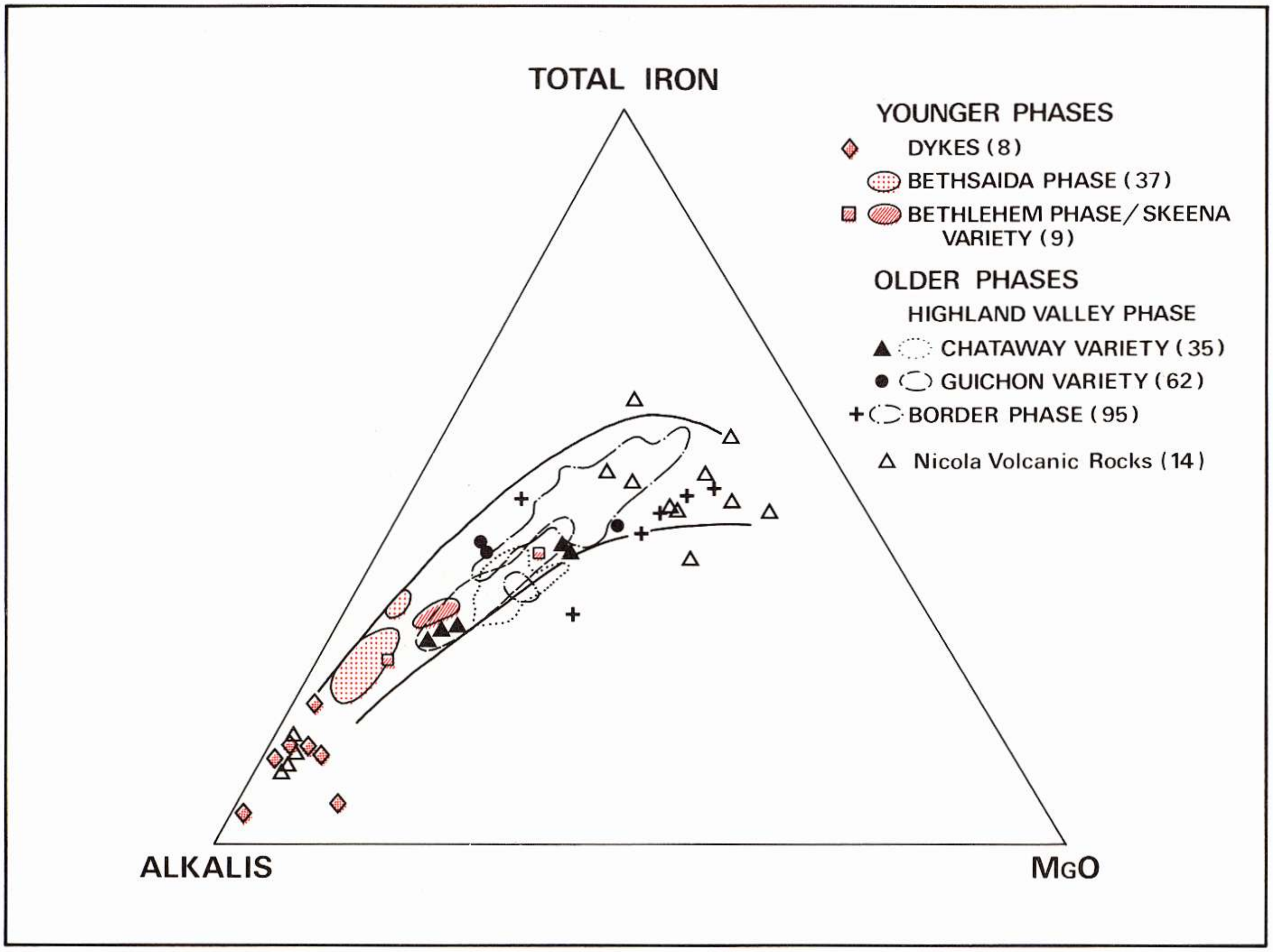



Figure 5. Ternary plot of alkalis, total iron, and magnesium for rocks of the Guichon Creek batholith (numbers in brackets indicate the number of analyses carried out). Alkalic and tholeiitic trend lines are plotted; the rocks show a clear calc-alkalic trend.

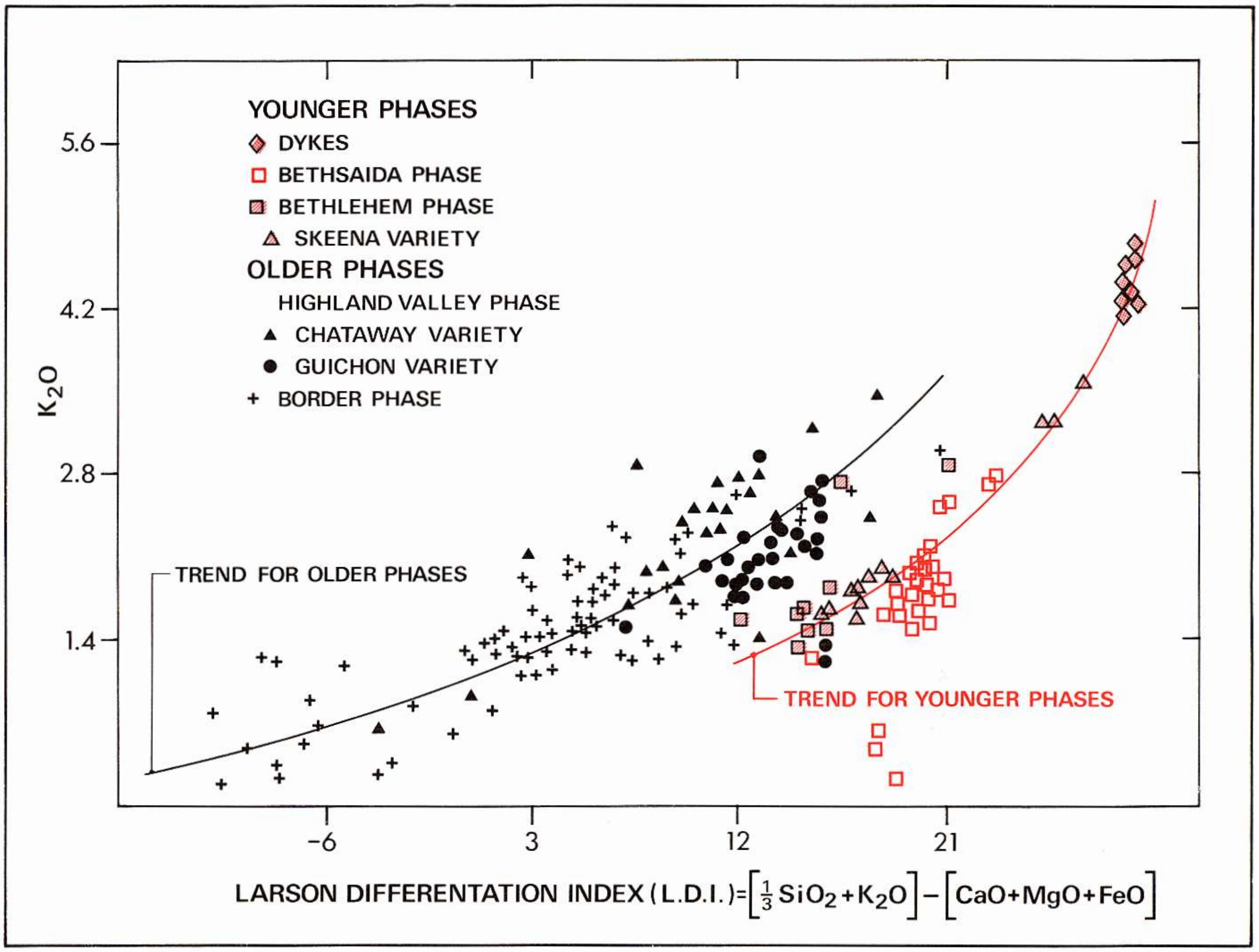



Figure 6. Plot of $K_2O$ versus Larson differentiation index for rocks of the Guichon Creek batholith showing a discontinuity in concentration and evolutionary path for $K_2O$ in 'younger' and 'older' phases.

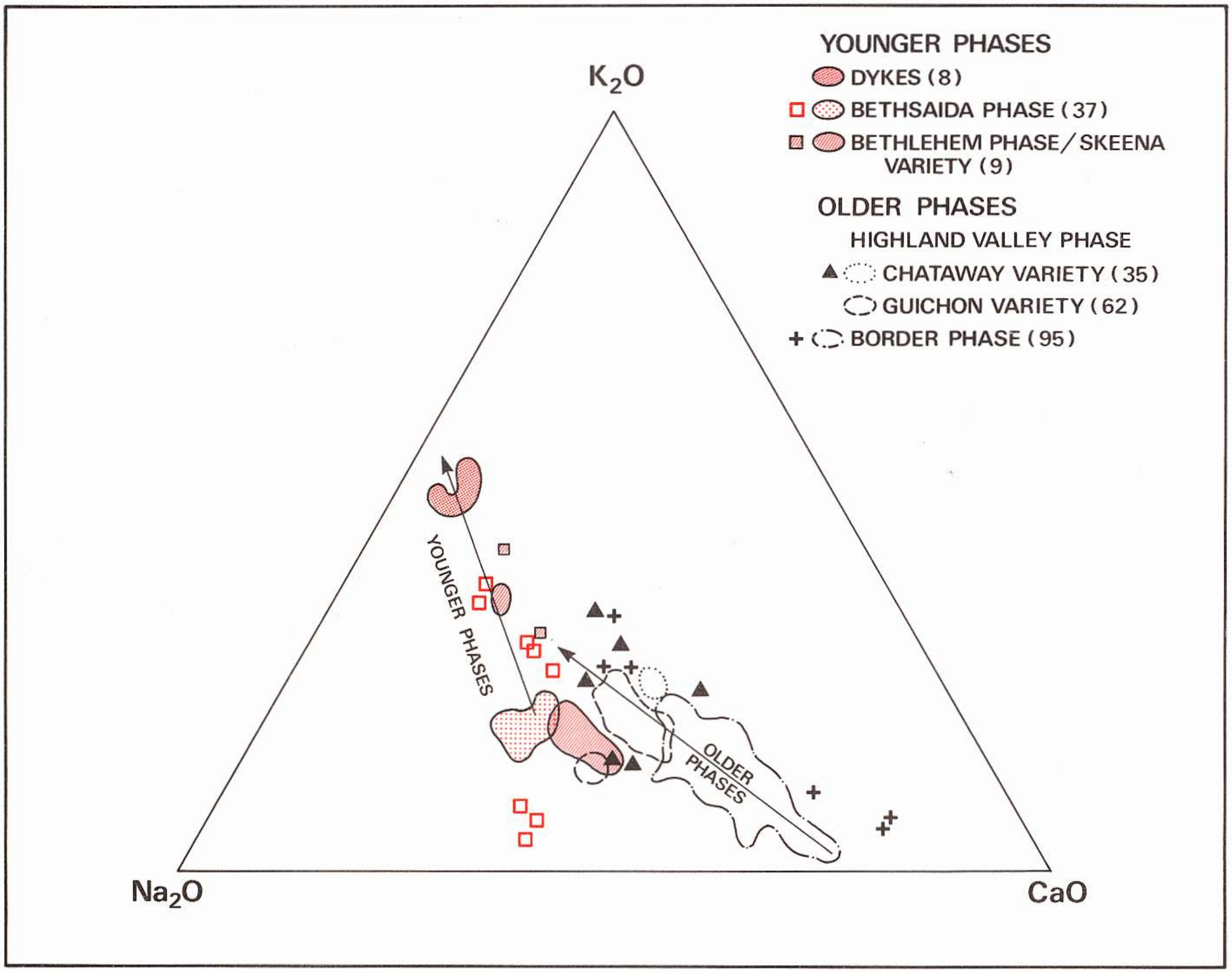



Figure 7. Ternary plot of alkalis versus lime for rocks of the Guichon Creek batholith. As in Figure 6, there is a discontinuity in the evolution path between the 'older' and 'younger' phases.

## 4-5 MINOR ELEMENT GEOCHEMISTRY

Minor elements in the batholith form three main groups (Fig. 8). Some, primarily Co, Cr, Ni, and Sc, are influenced by ferromagnesian mineral trends and have smooth evolution curves indicative of a single source magma. Zinc roughly follows this group but its distribution is complicated by its affinity for sulphur. Others, particularly those with large ionic radii, Ba, Sr, Pb, Cs, Li, and perhaps Eu, are influenced by Na, K, and Ca; their abundances were controlled by cumulate crystallization (McMillan and Johan, 1981). The third group, most notably Rb, Cu, U, Th, La, and Zr, shows a discontinuity between the older and younger phases. Arsenic levels are relatively unchanged with differentiation whereas those of silver and mercury decrease slightly; halides have more complex patterns.

Biotites from major phases were analysed for Cl and F with the microprobe (Johan, et al., 1980). Chlorine in biotite in Highland Valley phase rocks averaged 1300 ppm; those in Bethlehem phase 600 ppm; those in Bethsaida phase only 380 ppm. Results plotted as Cu versus Cl + F (Fig. 9) are scattered. Best fit lines drawn for analyses from older phase samples and younger phase samples have distinctly different slopes. The approximate linear relationships suggest that halide and copper distributien were affected by the same mechanism - we interpret that mechanism to be fractionation into a developing hydrothermal phase.

## 4-6 SUMMARY AND DISCUSSION

All the phases of the Guichon Creek batholith evolved from a single source magma. However, petrologic and chemical data show a discontinuity between the older and the younger phases of the batholith. A model to account for the mineral and chemical changes follows:

(1) The source magma is calc-alkaline and of andesitic composition.

(2) Crystallization of all the phases began at depth but was completed at higher levels.

(3) Evolution of the phases was controlled by cumulate crystallization under conditions of high partial pressure of water, with early separation of plagioclase, amphibole, and magnetite.

(4) As crystallization continued at depth, water content in the remaining melt rose and biotite began to crystallize along with amphibole and other minerals (Johan, et al., 1980). Biotite left in the cumulate fraction caused a 'sudden' drop in potassium in the remaining crystal-liquid mush that, when injected, became the 'younger phases' of the batholith. Perhaps a fluid phase separated from the water-rich magma at depth; however, even if this interpretation is incorrect, injection and continued crystallization of the water-saturated melt at higher level with lower confining pressure and more rapid cooling would certainly initiate or accelerate separation of a fluid phase.

(5) More mobile major and minor elements were partitioned preferentially into the fluid phase, so the host rock became depleted in these elements.

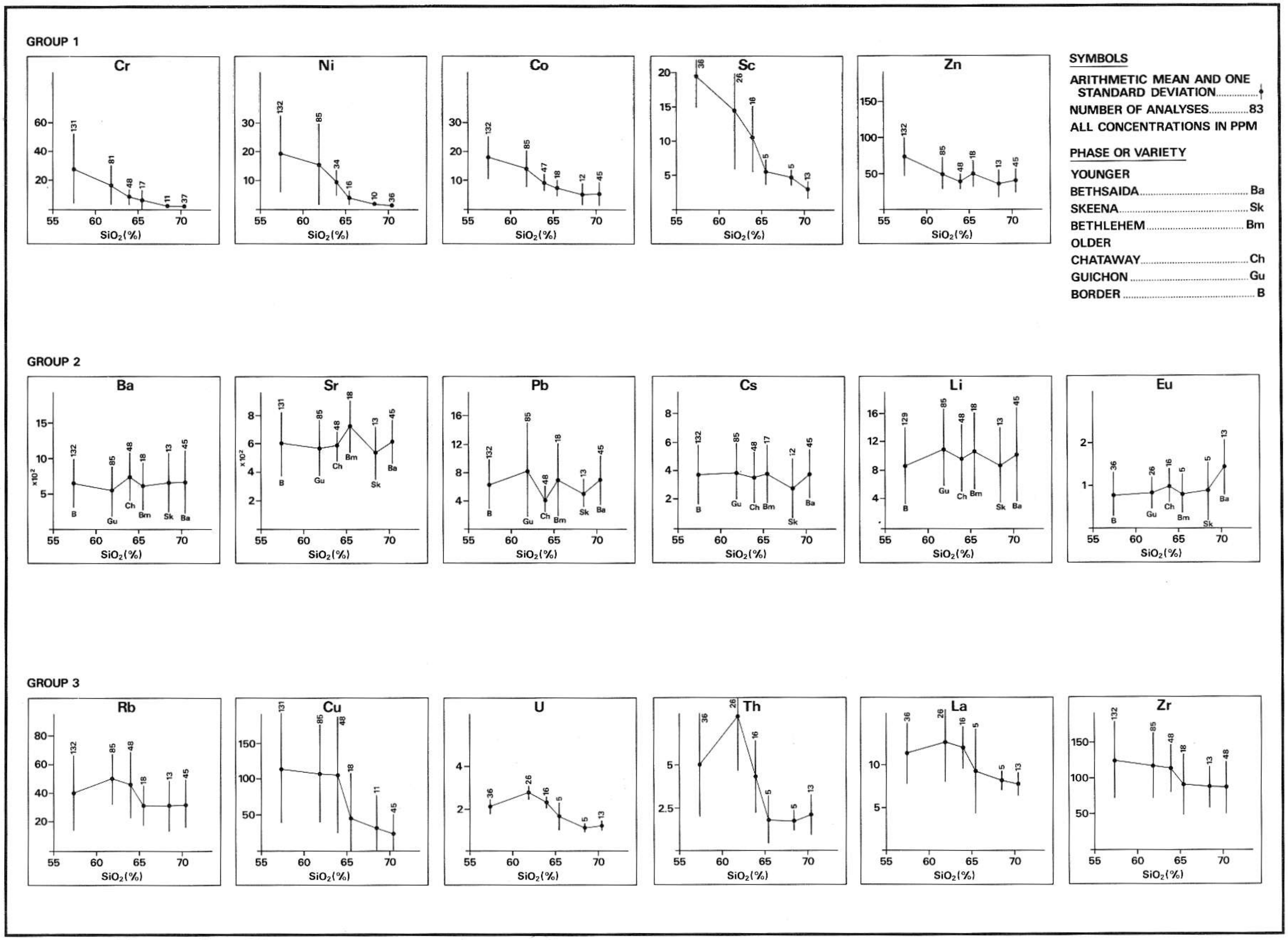



Figure 8. Plots of minor element abundances in parts per million versus average $SiO_2$ content for phases and varieties of the Guichon Creek batholith (modified after McMillan, 1982).

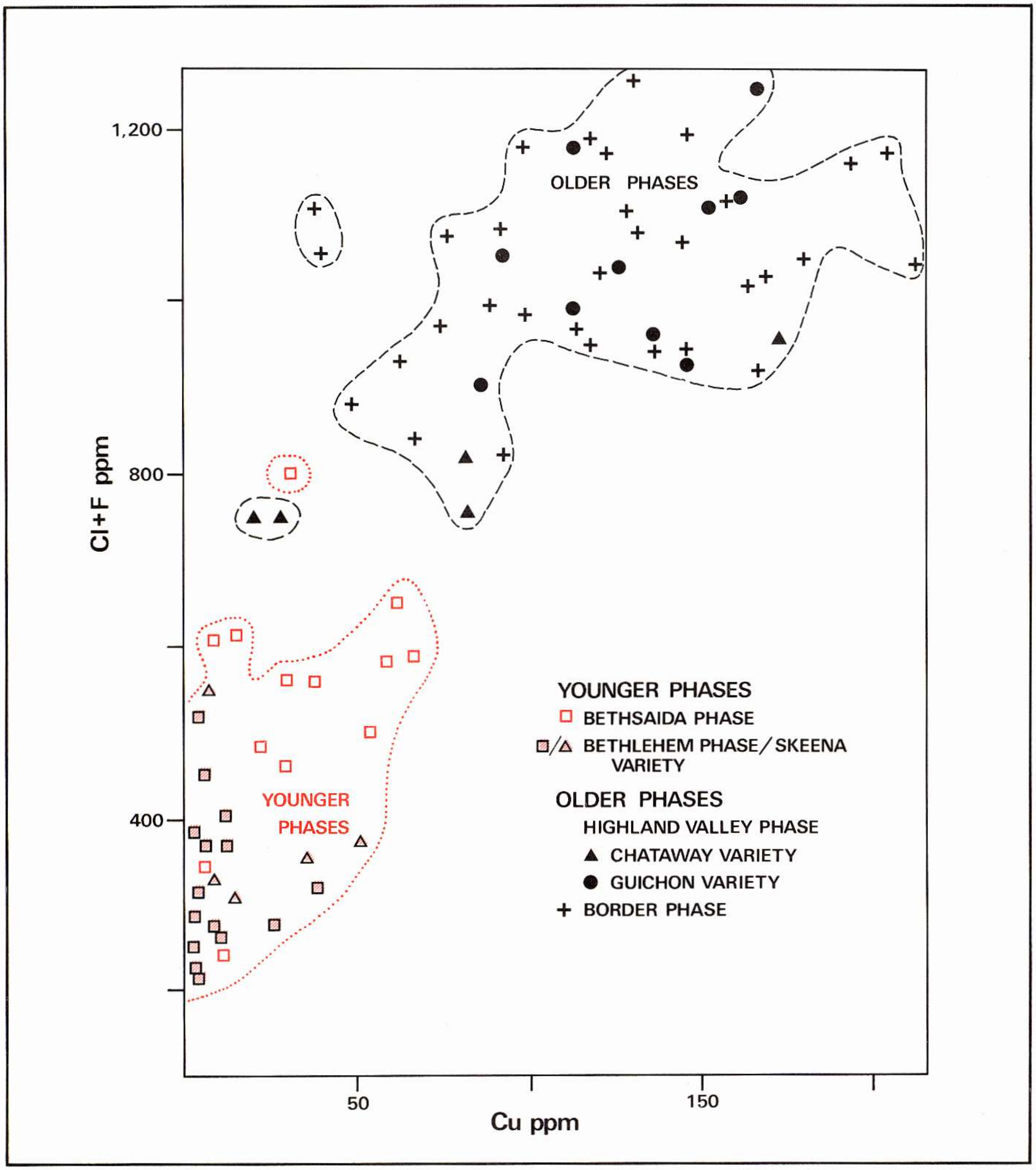



Figure 9. Plot of copper versus chlorine and fluorine from microprobe analyses of biotites from the Guichon Creek batholith (after Johan, et al., 1980). There is a distinct change in slope or discontinuity in evolutionary trends between the 'older' and 'younger' phases.

Several lines of evidence led to development of the model. Petrologically, cores of plagioclase crystals in all phases have similar compositions. In the older phases zoning is simple and normal but in younger phases core zones are partially resorbed and medial zonos have reverse or first complex oscillatory then normal zoning. These textures reflect the effects of early crystallization at depth and, in the younger phases, rapid changes in pressure that caused formation of complex oscillatory zoning after they were emplaced at higher levels. Geochemically, concentrations of alkalis and several trace elements show a discontinuity between the older and younger phases. Similarly, lower abundances of more mobile elements in the younger phases may reflect their selective removal and concentration into a fluid phase. For example, at less than 8 kbars pressure, chlorine is preferentially taken up in the fluid phase if one is present. Chlorine in biotites from the batholith decreases sharply between the older and younger phases. The change in plagioclase character, and the discontinuity in alkalies and mobile trace element abundances may reflect separation of a fluid phase.

Geologically, this hypothesis is supported by the timing of mineralization and dyke emplacement. Dyke swarms in the batholith were injected after Bethlehem phase and during and after Bethsaida phase emplacement. Explosion breccias (Carr, 1960) associated with the dykes attest to high volatile pressures.

In this model, separation of a fluid phase at depth impoverished the host magma in Cu, Cl, Rb (Fig. 8), and probably B and Hg (Olade, 1977); the parallel behaviour of Zr is unexplained. Similarly, lower Ni/Co ratios in the younger phases, along with minor amounts of cobalt and nickel sulphides and tellurides in the ore deposits, show the presence of these transition elements in the fluid. Apparently, transfer of Na into the fluid phase raised K/Na ratios in the melt and initiated biotite crystallization in the cumulates. This separatien of biotite caused lower than expected $K_2O$ values in the Bethlehem phase fluid and a discontinuity in its evolutionary path (Figs. 6 and 7). Unfortunately molybdenite concentration in rocks of the batholith was too low to delineate evolutionary patterns (Brabec, 1971).

# 5 AN OVERVIEW OF HIGHLAND VALLEY ORE DEPOSITS

## 5-1 INTRODUCTION

Petrologic and chemical evidence indicate that crystallization of the source magma of the Guichon Creek batholith took place at depth under relatively high partial pressures of water. This factor was probably instrumental in allowing saturation and subsequent separation of a fluid phase to occur. Geochemical evidence argues that metals in Highland Valley deposits were derived from granitic rocks of the younger phases; calculations, using estimated volumes of depleted rock (Fig. 10), indicate that this depletion model more than adequately accounts for all known copper reserves estimated for the batholith.

The host magma was injected along and localized by basement structures; subsequently it was fractured during periodic reactivation of these regional structures. A strong pattern of northerly and northwesterly faults and fracture swarms and northerly trending dyke swarms resulted. Early ore deposition, such as that at Bethlehem Copper, was controlled by faults and porosity caused by brecciation during dyke swarm emplacement. As the copper lithogeochemical distribution map shows (Fig. 10), younger ore deposits, such as Highmont, Lornex, and Valley Copper, were deposited north of the depleted source magma from which the ore fluids were derived. Mineralization in the deposits is dominantly fracture controlled.

## 5-2 GEOLOGIC SETTING

All known major Highland Valley ore deposits cluster in the central part of the batholith. They occur in younger phase rocks, in dyke swarms, or in intrusive breccias associated with younger phase rocks (Fig. 11; Table 2). If post-ore fault movements are removed, the major deposits lie close to the surface projection of the root or feeder zone of the batholith that underlies Highland Valley (Figs. 2, 3, and 10).

Ore deposits of Bethlehem Copper Corporation include the East Jersey, Jersey, Huestis, and Iona deposits; they occur near contacts where Bethlehem phase granodiorites intrude more mafic Guichon variety granodiorites. They are associated with dacite porphyry dykes and intrusive breccias. Ore occurs in the country rock, the dykes, and the breccias, although not all dykes are mineralized. The Highmont and Lornex deposits are largely in Skeena granodiorite adjacent to or near the large, composite Gnawed Mountain dyke. Breccia bodies occur at Highmont but are not significant in the ore reserve picture. Lornex is also adjacent to the Bethsaida quartz monzonite contact but the Bethsaida is not mineralized. The Gnawed Mountain dyke is largely pre-ore; it is weakly to moderately well mineralized in the ore zones. The Valley Copper ore deposit is entirely within Bethsaida quartz monzonite; porphyry dykes are volumetrically insignificant and no breccia bodies are known.

North of Bethlehem Copper there are many showings and two moderate-sized deposits, South Seas and Krain. South Seas deposit is a breccia pipe cutting Guichon granodiorite and is associated with porphyry dykes like those at Bethlehem Copper. Krain is also in Guichon granodiorite; it is allied with a sheet-like body of Bethlehem granodiorite.

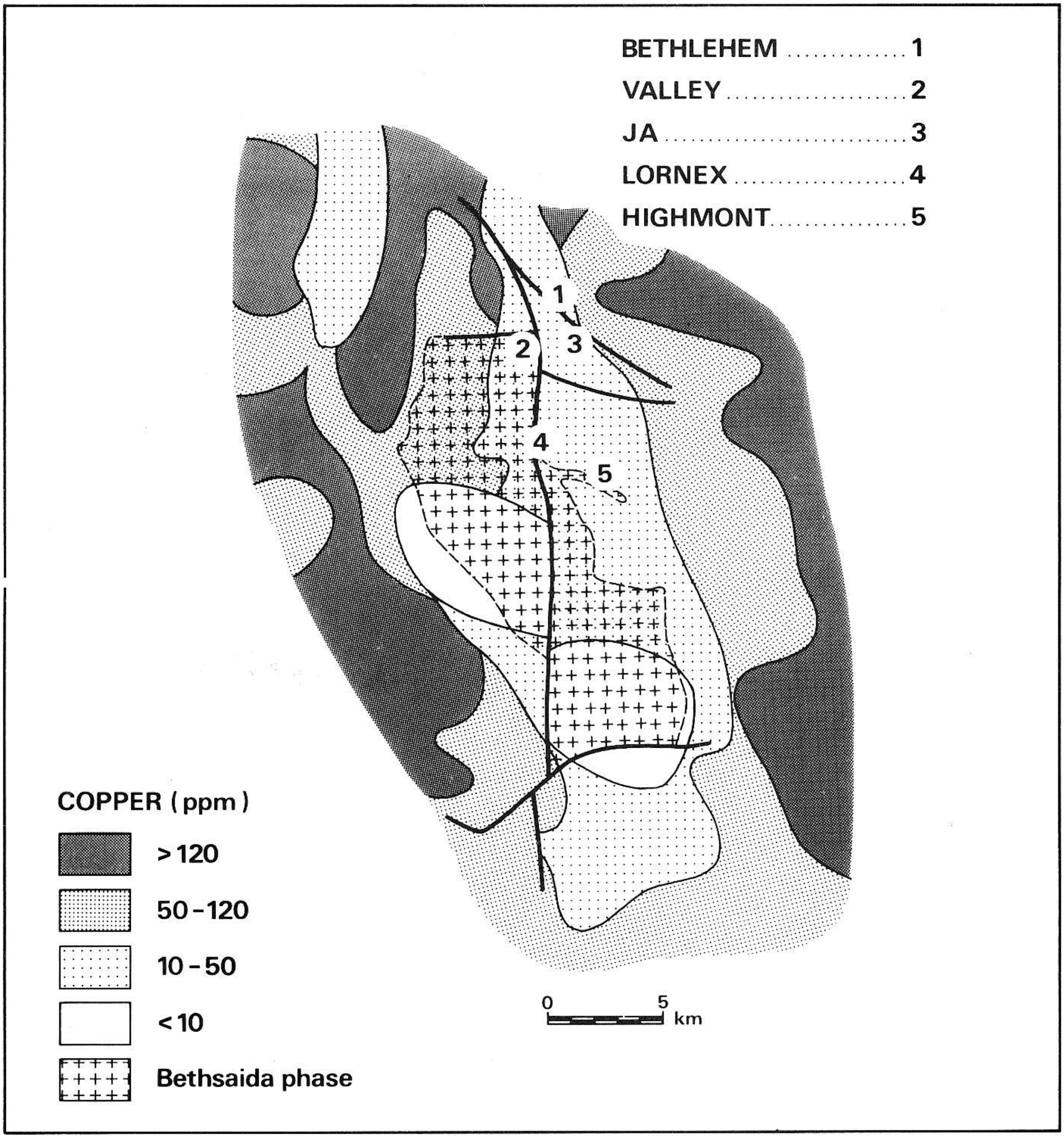



Figure 10. Simplified geological map of the Guichon Creek batholith showing copper abundances; strong depletion occurs in the Bethsaida phase south of the major ore deposits (modified after McMillan and Johan, 1981).

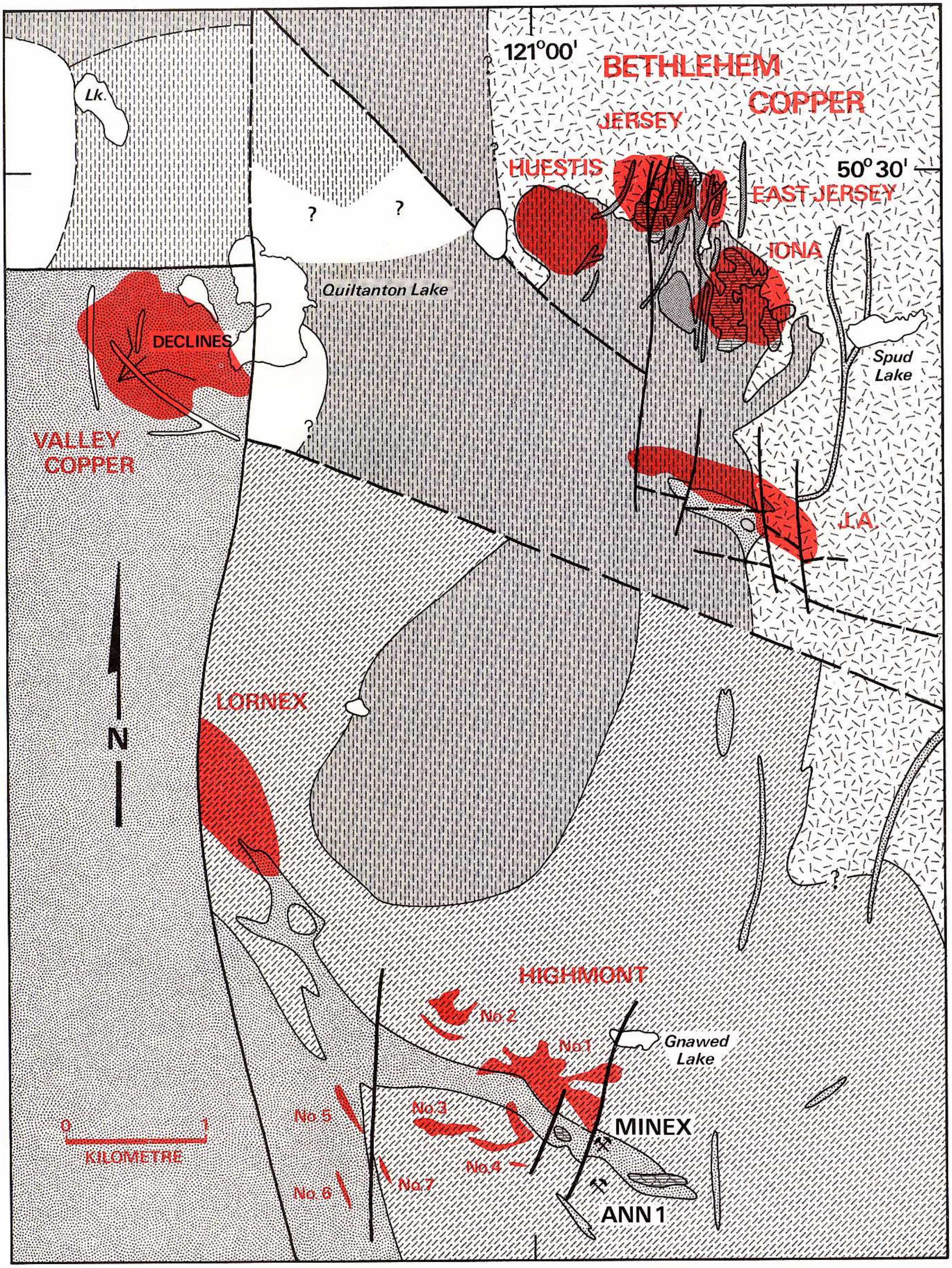



Figure 11. Geology, ore deposits and major prospects of the Highland Valley area (for legend see Fig. 2a).

Breccia bodies associated with Highland Valley ore deposits are intrusive, normally multilithic, and commonly mineralized; they generally show evidence of explosive release of volatiles (Carr, 1966). Tourmalinized breccias at Bethlehem and Highmont represent both syn-ore and late-stage events.

## 5-3 STRUCTURAL SETTING

Almost all the sulphide mineralization in Highland Valley deposits is either in or closely associated with veins, fractures, faults, or breccias. Fracture density was apparently the most important single factor influencing ore grades, although mineralized breccias are important at Bethlehem, South Seas and, to a lesser extent, at Highmont, and mineralized fault zones are significant local ore controls at Bethlehem. Typically grades are higher where swarms of fractures occur and higher still where sets of fracture swarms overlap. At Bethlehem northeast and lesser north-trending fracture sets predominate; consequently, better grade zones are elongated northeastward. In the Highmont area ore grades occur where swarms of northeast and northwest-trending fractures overlap in a general zone of fracturing adjacent to the Gnawed Mountain dyke (Bergey, et al., 1971; Reed and Jambor, 1976; McMillan, 1984). At Lornex, which occupies a closely fractured area at the contact of Skeena granodiorite with Bethsaida quartz monzonite, north-northeast, northeast, and east-trending mineralized fractures predominate; the best grades occur where all three sets overlap (Waldner, et al., 1976). The predominant fracture sets at Valley Copper strike north-northwest and east-southeast (McMillan, 1971); the orebody occupies a shatter zone in which fractures are more evenly distributed than those in the other deposits.

These fractures, fracture swarms, shatter zones, breccias, and, to a lesser extent, faults, represent permeable, porous zones; they provided migration paths, 'the plumbing system,' for hydrothermal, metal-rich brines, and sites for sulphide deposition. Economically interesting deposits formed where the plumbing system was best developed; subeconomic, widely spaced mineralized fractures are nearly ubiquitous in the Highland Valley area.

## 5-4 ALTERATION AND VEINING

The following synopsis of the types of alteration and veining in Highland Valley deposits is based on work done by the writer, but also draws heavily on data from the various deposits presented in Canadian Institute of Mining and Metallurgy Special Volume 15, Porphyry Deposits of the Canadian Cordillera. The synopsis will begin by comparing the distribution of silicic, then potassic, phyllic, argillic, propylitic, and other types of alteration. Subsequently, vein and alteration chronology will be considered (see also Table 2).

### 5-4-1 Silicic Alteration

Silicic alteration is expressed both as quartz veins without flaky sericite (muscovite) halos, and as quartz flooding in the host rocks. Where quartz stockworks are well developed, flooding is also prominent. At Valley Copper, for example, the deposit is outlined by the 10 per cent secondary quartz contour and areas of greater than 0.5 per cent copper have between 10 and 20 per cent secondary quartz (Osatenko and Jones, 1976).

Only Valley Copper and Lornex have well-developed quartz stockworks. That at Valley Copper forms an elliptical, dome-like zone which plunges northwestward (McMillan, 1971). Throughout this poorly mineralized quartz core, veins are less than 30 centimetres apart and the country rock is silicified; in the ore zone, quartz veins are 60 to 150 centimetres apart; the contact between the zones is gradational. The quartz stockwork zone at Lornex also forms an elliptical dome with an axis which apparently plunges northwestward. However, there are two differences: the vein frequency at Lornex is lower; and the zone at Lornex is relatively well mineralized. Most other Highland Valley deposits have only relatively widely spaced quartz veins and patchy zones of silica flooding.

### 5-4-2 **Potassic Alteration and Occurrence of Hydrothermal Biotite**

Potassic alteration is characterized by deposition of hydrothermal biotite or hydrothermal potassic feldspar; its abundance is highly variable in Highland Valley deposits. At Valley Copper, fracture-controlled potassic feldspar alteration is moderately well developed in the central, deeper part of the deposit, where most is in or adjacent to quartz veins. J.A. is the only other deposit with a pervasive zone of potassic feldspar alteration. Adjacent to the deposit the carapace of the porphyry stock is flooded and veined by potassic feldspar, however, the zone may be more closely allied to stock emplacement than to ore-forming processes. Potassic alteration at Lornex forms spotty zones of replacement or vein potassic feldspar or biotite. Such zones are apparently becoming more common as mining penetrates deeper into the orebody; they may represent remnants of an early, pervasive potassic alteration zone. At Bethlehem, Highmont, and within the J.A. deposit, only hydrothermal biotite is present. This biotite is typically greenish brown in thin sections; it occurs in fractures, as overgrowths on mafic minerals, and as crystal aggregates that replace mafic minerals. At Bethlehem Copper the Jersey deposit has a higher grade core zone in which hydrothermal biotite is distributed widely. Secondary biotite zones at J.A. and Highmont are less prominent, and largely overprinted by later propylitic alteration; occurrences at Lornex and Valley Copper seem to be sporadic.

### 5-4-3 **Phyllic Alteration**

Phyllic alteration in Highland Valley is characterized by fracture-associated zones or vein envelopes of mixed quartz and 'flaky sericite.' Although it is called 'flaky sericite,' the 'flakes' are generally several millimetres in size and the mineral should be called muscovite ($2M_1$). Phyllic alteration is particularly important at Valley Copper where it is widespread and abundant; the majority of the associated sulphide is bornite. Phyllic alteration is less well developed at Lornex. There, vein envelopes predominate and quartz-sericite alteration zones are uncommon; vein envelopes also tend to be thinner. Phyllic alteration characterizes the ore zone at Lornex. At Highmont and J.A., phyllic alteration is generally weakly developed, although Reed and Jambor (1976) found a fairly good correlation at Highmont between phyllic alteration and areas of greater than 0.2 per cent copper equivalent. The average intensity of phyllic alteration decreases from Valley Copper to Lornex to Highmont and J.A.; it is poorly developed at Bethlehem Copper.

### 5-4-4 **Argillic Alteration**

The term 'argillic alteration,' as used in Highland Valley, describes alteration of feldspars and, less commonly, mafic minerals to an assemblage typified by microscopic sericite and kaolinite with or without montmorillonite. This alteration occurs throughout the ore deposits and can extend for significant distances beyond the 0.3 per cent copper isopleth. Judging from data on Bethlehem Copper Corporation's Jersey deposit, argillic alteration is still mappable where copper grades are as low as 0.1 per cent (Briskey and Bellamy, 1976).

The relationship between argillic alteration and ore grades is not consistent. At Krain moderate to intense argillic alteration occurs in the higher grade core zone (Christie, 1976). At J.A. it encloses the potassic core and coincides with the phyllic alteration zone; at Highmont it is adjacent to the Gnawed Mountain dyke, and in the borders of the dyke itself, which is not of ore grade. Elsewhere in the J.A. and Highmont ore zones argillic alteration is present but weakly developed. At Lornex and Valley Copper the orebody and the zone of moderate to intense argillic alteration virtually coincide. However, the most intense zones of argillic alteration in all the deposits occur along and adjacent to late-stage faults, where the country rock is totally altered to a soft, white mixture of kaolinite and sericite.

### 5-4-5 **Propylitic Alteration**

All Highland Valley deposits have propylitic alteration zones of varying width, location, and intensity. In general, there is a gradation between propylitic and argillic alteration zones. In hand specimen, epidote is the characteristic mineral for propylitic alteration. Chlorite is almost ubiquitous in all the deposits except Valley Copper, so is not generally a useful indicator mineral. Feldspars in propylitic zones are altered to sericite, carbonate, and some clay minerals; mafic minerals alter to chlorite and carbonate with associated epidote.

At Krain and Jersey, fairly well-defined propylitic halos enclose the orebodies; immediately outside the propyiitic halo the rock is almost fresh, albeit cut by local fracture-coatings and veinlets of quartz, chlorite, and epidote. At J.A. and Highmont, propylitic facies assemblages occur throughout most of the mineralized zones. At J.A. the intensity of propylitic alteration is greater in the more mafic-rich Guichon quartz diorite than in the Bethlehem granodiorite country rock. At Lornex there is a narrow propylitic alteration zone peripheral to the orebody. At Valley Copper such alteration is weakly developed and ill-defined in the leucocratic host rocks. Propylitic alteration is more prominent where host rocks are more mafic.

### 5-4-6 **Tourmaline Distribution**

At Bethlehem, South Seas, and Highmont, tourmaline occurs in and near breccia bodies, where it forms crystalline aggregates, replaces clasts, or replaces comminuted rock of the matrix. It is commonly associated with quartz, specularite, epidote, calcite, copper sulphides, and, locally, actinolite. At South Seas, specularite, quartz, and chalcopyrite fill openings in the breccia and are generally slightly younger than quartz and tourmaline in the matrix. At Bethlehem and Highmont quartz and tourmaline-bearing breccias are mineralized, but also contain clasts that were mineralized with copper sulphides prior to brecciation. Thus, some brecciation and associated tourmaline deposition occurred after the initiation of sulphide deposition. Tourmaline is uncommon at Lornex and Valley Copper.

### 5-4-7 **Late-stage Vein and Alteration Minerals**

Typical late-stage veins in Highland Valley deposits are calcite and zeolite or gypsum. These minerals occur as minor components of main-stage mineral assemblages, but typically they are post-ore and were deposited during collapse of the hydrothermal system.

Zeolites occur primarily as veins and fracture coatings, but also form pervasive alteration halos around fractures and zeolite veins. Laumontite is the most common zeolite present but some stilbite and uncommon chabazite, heulandite, and other species occur (White, et al., 1957). Zeolites frequently are intergrown with calcite; in places they are intergrown with gypsum. Zeolites are abundant at Bethlehem and J.A., less common at Highmont, and sparsely distributed in the other deposits.

Calcite forms veins, coats fractures, and replaces feldspars in all the deposits. Replacement calcite accompanies propylitic alteration; fracture and vein calcite is generally late stage and predominantly post-ore; much of it also post-dates zeolite deposition. Gypsum, which is also largely post-zeolite, is abundant as veins and fracture fillings at J.A. and Valley Copper. It occurs at Lornex but is of local extent; it has been reported at Highmont. Rarely, main-stage quartz-sulphide veins at J.A. have vugs filled with fibrous gypsum. Anhydrite occurs in a similar setting in several deep drill holes at Valley Copper, therefore such fibrous gypsum may be derived from anhydrite.

### 5-4-8 **Age Relationships of Alteration Types**

Age relationships of alteration types in Highland Valley apparently vary from deposit to deposit (Table 2). At Jersey (Briskey and Bellamy, 1976) ore fluids are thought to have moved upward and outward. Thus, formation of the potassic core and the fringing argillic and propylitic zones are interpreted to have been virtually synchronous. At J.A. there may have been a pre-ore stage of weak propylitic alteration. During the main stage of sulphide mineralization at J.A., weak potassic and phyllic with associated argillic alteration was followed by propylitic with associated argillic alteration. At Highmont, Reed and Jambor (1976) concluded that an early phase of hydrothermal biotite alteration accompanied by propylitic alteration occurred and was followed successively by phyllic, argillic, and additional propylitic alteration.

They infer that most of the metals were introduced during the early phase of alteration. At Lornex (Waldner, et al., 1976) argillic alteration apparently initiated prior to main-stage sulphide mineralization and continued for a short time after it; phyllic alteration and quartz stockwork formation occurred primarily during main-stage mineralization; propylitic alteration was later. At Valley Copper, the indicated sequence of alteration (Osatenko and Jones, 1976) is propylitic, then argillic, phyllic, and potassic; the quartz stockwork post-dates potassic alteration. The various alteration types overlap in time but the main period of sulphide deposition at Valley Copper occurred during the phyllic stage. In a contrasting interpretation, Reed and Jambor (1976) concluded that alteration sequences at Valley Copper and Lornex followed the sequence described at Highmont. Zeolites in the deposits are predominantly later than sulphide deposition, and calcite and gypsum veins and fracture fillings are younger still.

In all cases, age sequences are based on crosscutting features; however, disagreement remains. It seems likely that the discrepancies are caused in part by overlapping of alteration types in time, in part by variations related to permeability and travel distances of the hydrothermal solutions, in part by repetition of alteration types in response to new influxes of hydrothermal fluid, or influx of meteoric water, and in part by the effects of country rock composition on the alteration assemblages generated. The system is complex and three-dimensional; it changes with time and is subject to external influences; local variations are to be expected.

## 5-5 METALLIC MINERAL ZONING

In most Highland Valley deposits there is a fairly well developed metallic mineral zoning, but, because grades are structurally controlled, these patterns do not everywhere correlate closely with grade distribution patterns (Table 2). That is, although most of the deposits have zones in which bornite and then chalcopyrite and then pyrite are the predominant sulphide minerals, not all bornite zones are ore and parts of ore zones may extend into the pyrite zone. At Krain, in the Jersey deposit, at Valley Copper, and at Lornex, the core zones, which have better than average grades, are enriched in bornite relative to chalcopyrite. In contrast, most of the better grade zones at J.A. and a significant proportion of the ore zones at Highmont are in the chalcopyrite dominant zone.

At Valley Copper and Jersey sulphide zoning is almost concentric, with a central bornite zone giving way outward to chalcopyrite then pyrite zones, although the pattern at Valley Copper is complicated by superposition of younger chalcopyrite in the central quartz stockwork. Inside the 0.3 per cent copper isopleth at Valley Copper, bornite abundance equals or exceeds that of chalcopyrite. Outside it, there is a narrow zone dominated by chalcopyrite, then a narrow, very weak pyritic halo. Pyrite in the halo is much less than 1.0 per cent by volume (Osatenko and Jones, 1976). At Jersey grades exceed 0.5 per cent copper in the bornite zone and there are fringing chalcopyrite, pyrite, and specularite zones. On the north side of the orebody, the pyrite and specularite zones are discontinuous. At Highmont, Lornex, J.A., and Krain, sulphide zoning is not concentric. Zoning at Highmont is subparallel to the Gnawed Mountain dyke, that at Lornex is elongated and symmetric about either the quartz porphyry dyke or the structure along which it was emplaced. Zoning at J.A. is related to a quartz monzonite porphyry stock and that at Krain is related to a quartz diorite porphyry stock.

Sulphide deposits and areas of hydrothermal alteration virtually coincide; however sulphide zoning and associated alteration zones vary from deposit to deposit. Bornite dominant zones at Valley Copper and Lornex are in areas with phyllic and argillic alteration, those at Highmont and Jersey are associated with hydrothermal biotite, and those at J.A. and Krain are in areas with argillic alteration. Chalcopyrite zones generally are associated with argillic alteration, although those at J.A. and Krain partially overlap into the propylitic alteration zone. Pyritic zones generally have associated propylitic alteration.

The distribution and abundance of molybdenite varies widely in Highland Valley deposits. Molybdenite grade is below economically recoverable levels at Krain, marginally economic at Bethlehem, and slightly lower at Valley Copper. It is economically significant at J.A. and Lornex and very important at Highmont. Molybdenum distribution in the deposits is similar, but not identical, to that of copper. Molybdenite occurs with quartz in veinlets in the central bornite zone at Krain; it is in the chalcopyrite zone at Bethlehem; it occurs sparsely along the southwest side of the orebody in the pyrite zone at Valley Copper. However, at Lornex, J.A., and Highmont molybdenite is sparsely but widely distributed. Most molybdenite in these deposits occurs in quartz and sulphide veins. That at J.A. is most abundant in the zone with best copper grades, but it is also concentrated along the southern edge of the orebody near and in the stock. At Lornex zones with grades exceeding 0.02 per cent molybdenum occur in both the bornite and chalcopyrite zones and locally extend out into the pyrite halo. Molybdenite and copper zones overlap considerably at Highmont, but the top of the molybdenite zone is below that of copper and its base extends below that of copper (Reed and Jambor, 1976).

## 5-6 GEOCHEMICAL ZONING PATTERNS

Zonal arrangements of major and trace elements (Fig. 8) also occur in Highland Valley ore deposits. Olade (1974) studied geochemical variations around the Valley Copper, Lornex, Highmont, and J.A. deposits. Osatenko and Jones (1976) conducted a detailed geochemical study of the Valley Copper deposit. Both studies found variations in chemical elements in the different alteration zones, and both found progressive changes from the edge to the centre of each deposit studied.

In general, lithophile elements, Ca, Na, Mg, Sr, Ba, and Mn, decrease from the borders of deposits to their centres. At Valley Copper the most depleted zone is characterized by phyllic alteration; less depletion occurred in zones of propylitic and argillic alteration. Osatenko and Jones (1976) report that argillic alteration locally extends more than 300 metres beyond the 0.3 per cent copper isopleth. The writer found that alteration of plagioclase to sericite and clay also occurred well out into the country rock at the Lornex, Highmont, and J.A. deposits. Geochemically, this alteration causes depletion in Na and Ca relative to background values.

Other elements, notably Si, K, Rb, Fe, and Ti, are enriched in the Valley Copper deposit. Highest K values occur in areas of phyllic alteration, which correspond to areas with the best grades of mineralization. Copper is, of course, enriched and the border of the deposit is an assay boundary. Zinc and Mo form halos that are primarily outside the deposit and Mn forms a distinct halo roughly 300 metres in width around it.

Olade reports similar elemental distribution patterns for the other Highland Valley deposits. In contrast to Osatenko and Jones, he reports that the deposits are depleted in iron. Olade found that potassic alteration zones were enriched in Rb, Ba, Si, K, and S, but lost Ca, Mg, Fe, Na, and Al. In general Olade found that lithophile element distribution was controlled by alteration; zoning more or less coincided with alteration zones. Femic elements (Zn, Mn, Ti, V, Ni, Co, Fe, and Mg) are largely controlled by primary lithology; hydrothermal redistribution of these elements is minor.

Sulphur, Cu, and, locally, Hg and B distributions were interesting from an exploration point of view. Sulphur and Cu both formed halos up to 500 metres wide around deposits, but the sulphur distribution was more consistent. Mercury formed a broad halo around the J.A. deposit, but not around Valley Copper. Boron anomalies marked Lornex and Highmont, but boron was inconspicuous at Valley Copper and J.A. Patterns defined by Rb and Sr distribution and Rb/Sr ratios also outline some ore deposits. At Valley Copper and J.A., Rb contents were highest and Sr contents lowest in the potassic core zones; contours of Rb/Sr ratios at the 0.1 level broadly delineated both deposits (Olade and Fletcher, 1975).

## 5-7 INTERPRETATION OF THE CHARACTER OF THE ORE-FORMING FLUIDS

As Beane (1982) indicated, hydrothermal solutions derived from a magma are initially in equilibrium with igneous minerals; injection along fractures into cooler rocks causes cooling and disequilibrium. With cooling, potassium in the solution crystallizes in veins and replaces plagioclase or produces overgrowths on primary biotite. With continued cooling potassic feldspar becomes unstable and muscovite (sericite) begins to replace feldspars and perhaps biotite; eventually the muscovite becomes unstable and kaolinite begins to replace feldspar and earlier alteration minerals. That this simple model is partly correct can be seen on vein-scale in all Highland Valley deposits. At Valley Copper in particular many veins have alteration selvedges with inner potassic feldspar grading out through muscovite-quartz to sericite-kaolinite to relatively unaltered rock; this sequence may reflect decreasing temperature outward from the vein. However, other veins display apparently reverse zoning; at Valley Copper quartz-potassic feldspar veins cut muscovite-quartz zones. As a generalization, the deposits have early 'potassic' alteration, intermediate phyllic alteration, and late argillic alteration. In detail the system is multiphase and overlapping in space and time; many generations of hydrothermal solutions operated on the systems. Boiling, venting to surface, brecciation, and varying salinity influenced some of the alteration patterns.

Isotopic data indicate that sulphur in the hydrothermal systems had a mantle source (see also Christmas, et al., 1969; Johan, et al., 1980). Sulphur and oxygen isotopic data from Valley Copper (Jones, 1975) indicate that alteration temperatures increased from 260°C in the early stages of alteration to 480°C during the main stage of mineralization. These data also suggest that 70 per cent of the hydrothermal water had an oceanic source during early pervasive argillic alteration; 80 per cent of the hydrothermal fluid was of magmatic origin during early main stage mineralization; but 94 per cent of the water was oceanic during gypsum vein deposition. Presumably the system was quenched by the large influx of oceanic water. If, however, pervasive argillic alteration is late stage (Reed and Jambor, 1976), the data indicate a progressive decrease in temperature and increase in oceanic water content with time; that is, early in main-stage mineralization magmatic water at 480°C dominated, during late pervasive argillic alteration 70 per cent of the water was oceanic at 260°C, and later, during gypsum deposition, 94 per cent of the water was oceanic. It is uncertain which interpretation is correct; the writer favours the idea of two main periods of argillic alteration - one early, one late.

Although there is disagreement in detail, both Osatenko and Jones (1976) and Olade (1974) concluded that acidity in the hydrothermal system gradually decreased with time. Osatenko and Jones argue that during passage from conditions of argillic to phyllic to potassic alteration, sulphur fugacity first increased then decreased and oxygen fugacity gradually decreased. In several deposits the alteration sequence was potassic (+ propylitic ?) to argillic/phyllic to propylitic to late argillic. This sequence argues for swings in acidity during early and main stage events and relatively acid conditions during late stage alteration. According to Beane (1982) pH values in porphyry systems are generally between 3 and 5.

Fluid inclusion data are sparse. However, Jones (1975) reported a few halite, sylvite and carbonate crystals as well as liquid $CO_2$ in some fluid inclusions. The fluid inclusions are small and occur along linear zones, which suggests that most may be secondary. However, some containing solid phases or liquid $CO_2$ may be primary. Liquid $CO_2$ suggests main stage pressures in the range of 100 to 300 bars, which would occur at a depth of 1 to 2 kilometres.

Alteration and sulphide mineralogy in all the deposits is similar, geologic settings are alike, and the deposits occur in close proximity to one another. Therefore ore-forming fluids in all the deposits were probably similar. That being the case, the fluid must have been a chloride brine, probably containing HCl, $H_3BO_3$, HF, HS, $H_2SO_4$, and other volatiles (Olade, 1974). It would be partly of deep-seated origin; at least in part, it would be derived from the Guichon Creek magma, although conceivably the metal and part of the hydrothermal fluid could be from a deep-seated but separate source than the magma.

Alteration initiated during the influx of hydrothermal fluids into structurally favourable areas. Initial intermixing with oceanic waters might be caused by formation of convective cells. Apparently proportions of magmatic and oceanic water and temperature varied across the deposits (Osatenko and Jones, 1976); host rock mineralogy, temperature, and water composition controlled alteration types and intensity (see, for example, Taylor, 1974). Main-phase mineralization was dominated by upwelling magmatic fluids and this stage probably consisted of several waves of hydrothermal fluid of varying composition. As magmatic supply waned, oceanic water proportionally increased, which diluted and cooled the ore-forming brines. Finally, oceanic water predominated, the hydrothermal system collapsed, and mineralization ceased.

## 5-8 ORE DEPOSIT MODEL

Highland Valley porphyry copper-molybdenum deposits are interpreted to be dominantly of orthomagmatic origin. Most of the metal was apparently concentrated into hydrothermal solutions that were derived from the relatively water-rich, more evolved, 'younger' phases of the batholith. These metals were subsequently deposited in structural traps adjacent to subvolcanic source cupolas (Fig. 12a). Initially, the ore fluid consisted primarily of magmatic water; later, as the hydrothermal system collapsed, a large component of meteoric (oceanic) water was involved (Fig. 13).

Relative depth and temperatures of the deposits were inferred from tectonic setting, intensity of alteration, temperature information, presence of porphyry dyke swarms and intrusive breccias, and their present locations and elevations. From deepest and hottest to shallowest and coolest the deposits sort as follows: Valley, Lornex, Highmont and J.A., Bethlehem and South Seas, then Krain (Fig. 12b).

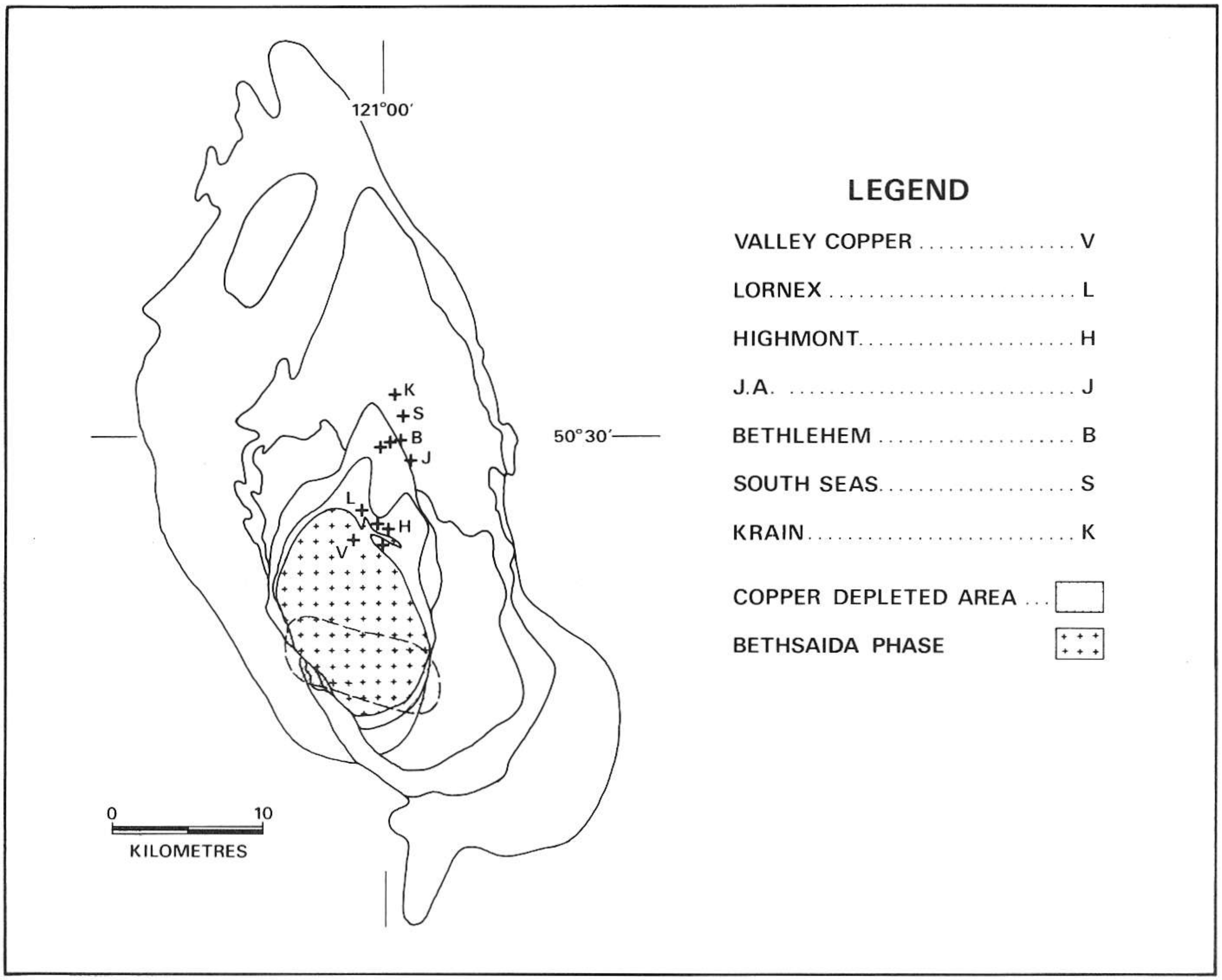



Figure 12a. Diagrammatic representation of the geologic setting of major porphyry copper-molybdenum deposits in the Guichon Creek batholith (younger cover rocks and effects of strike-slip fault movements removed).

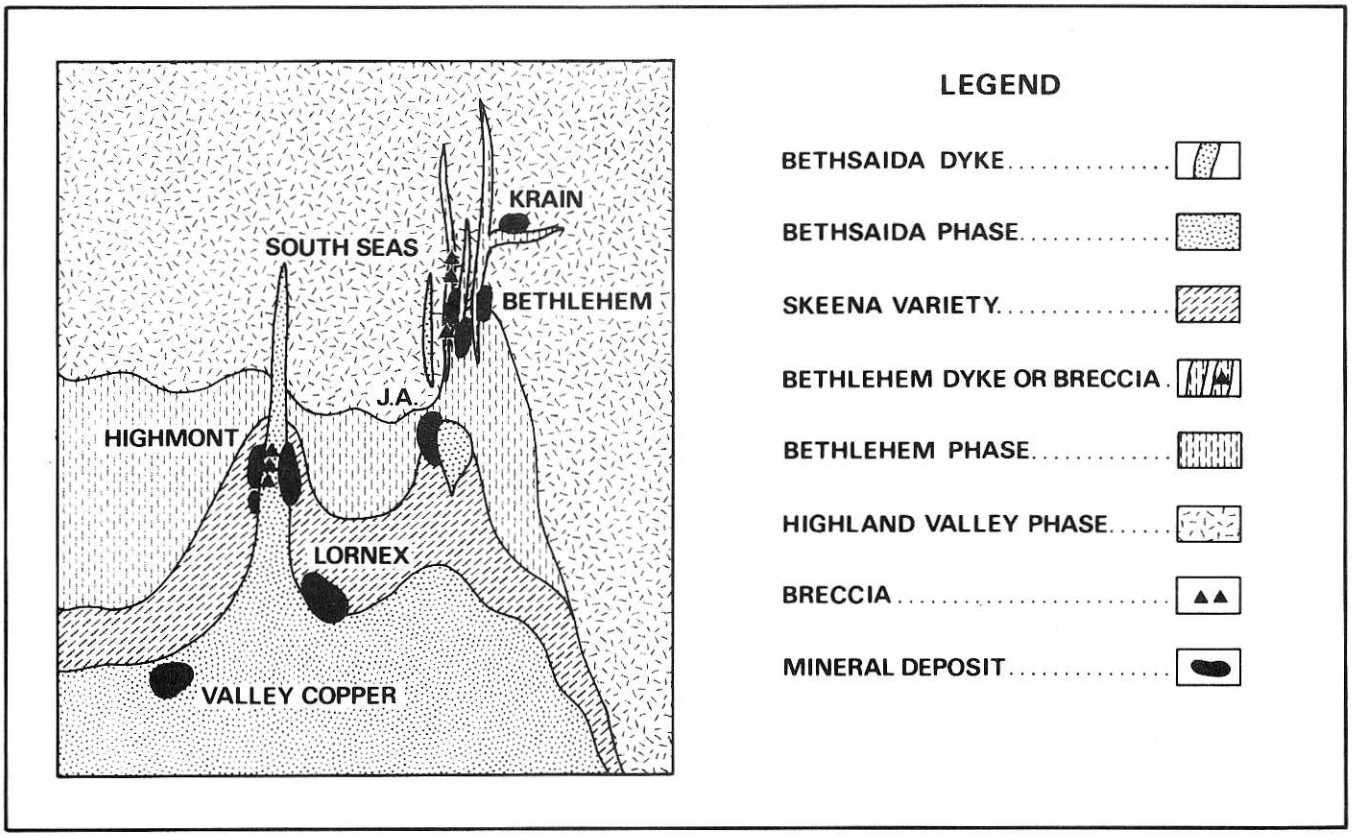



Figure 12b. Schematic cross-section showing major deposits and their inferred geologic settings at time of formation.

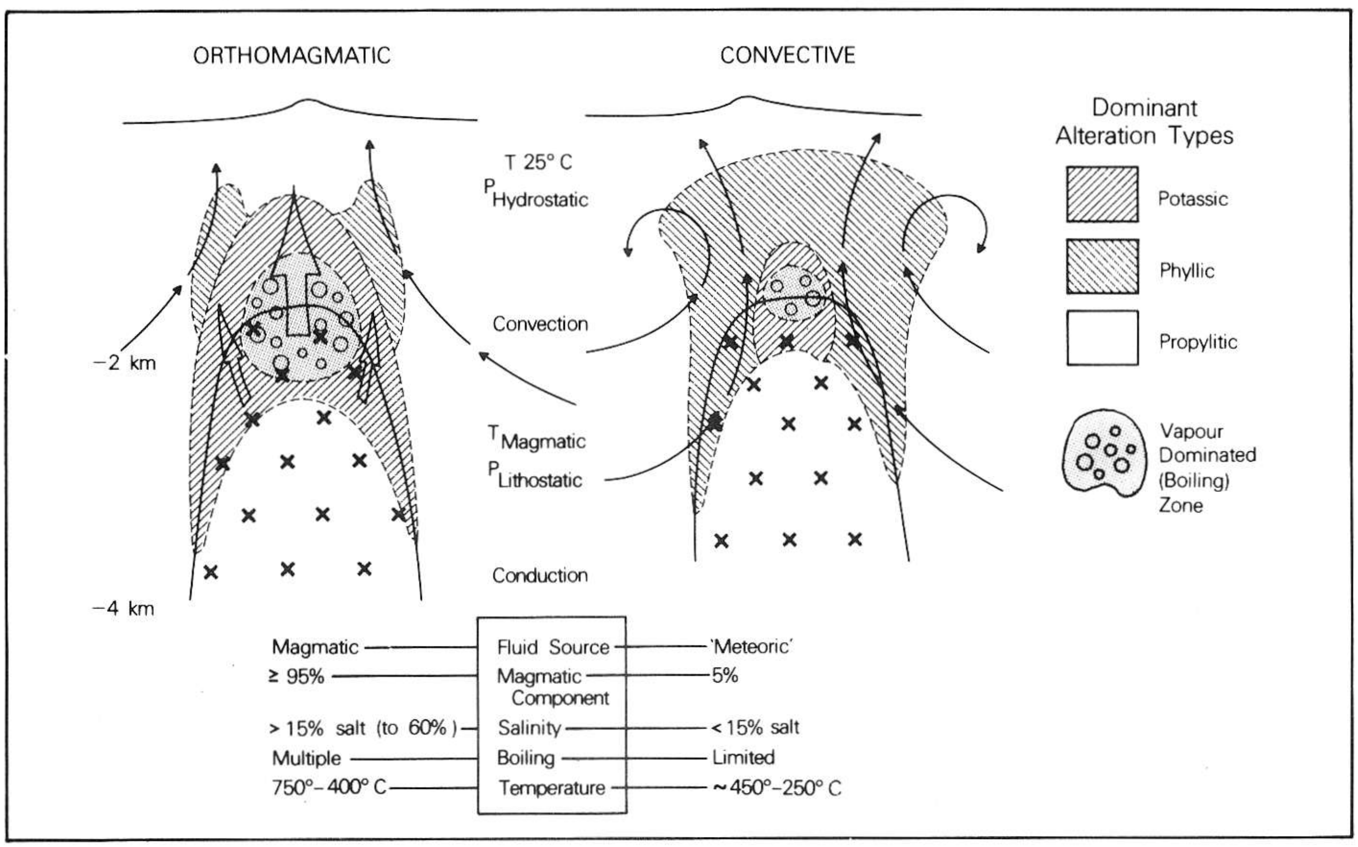



Figure 13. Model of hydrothermal systems with contrasting orthomagmatic and convective fluid flow patterns (after McMillan and Panteleyev, 1980).

# PART 2
# ORE DEPOSIT DESCRIPTIONS

## 6 BETHLEHEM COPPER DEPOSITS

(K. Newman)

### 6-1 INTRODUCTION

The Bethlehem Copper property consists of four major deposits and several smaller prospects situated on the north side of Highland Valley north of Quiltanton Lake. Elevations vary from 1 400 to 1 525 metres. The property centres on latitude 50°29.5'N, longitude 120°59'W, on NTS map sheet 92I/7W. Access is by paved road from Ashcroft or Kamloops.

### 6-2 HISTORY

Exposures of copper mineralization near the present pits were known prior to 1896. The first claims were staked in 1899 and by 1907 a wagon road had been constructed from Ashcroft to the central Highland Valley. Between 1914 and 1915, 124 tonnes of hand-sorted ore were shipped to smelters in Trail, British Columbia and Tacoma, Washington. From 1915 to 1953 there were brief periods of staking, trenching, and diamond drilling.

In 1954 the Huestis-Reynolds-McLellan Syndicate relocated the claims and formed the Bethlehem Copper Corporation Ltd. Rather than focusing on the high-grade copper veins, the company explored the low-grade zones and they realized that a viable mining operation was possible if large tonnages of low-grade ore were milled each day.

Plant construction commenced in 1961 and the mill went on stream in December, 1962. As of December 31, 1981, total ore production has been 96 million tonnes of 0.50 per cent Cu with an ore-to-waste strip ratio of 1.93:1. Production has been from four pits: the East Jersey, Jersey, Huestis, and Iona (Table 1). The latest source of ore was the East Jersey extension (Fig. 14). Due to continuing low copper prices, mining operations at Bethlehem Copper were shut down in 1980.

### 6-3 GENERAL GEOLOGY AND STRUCTURAL SETTING

The geology of all the pits is shown on Figure 14 and the geology of the Jersey pit on Figure 15. The main host rocks are the Guichon and Bethlehem granodiorites, and igneous breccias. These are intruded by north-trending dyke swarms which have compositions similar to the enclosing rocks. With the exception of younger lamprophyre dykes, the dyke swarms are mineralized where they occur within the ore zones.

The Guichon granodiorite is mainly a medium-grained hypidiomorphic granular rock composed of 40 to 60 per cent plagioclase feldspar, 15 to 25 per cent quartz, 8 to 16 per cent orthoclase, 5 to 10 per cent hornblende, 1 to 10 per cent biotite, and minor

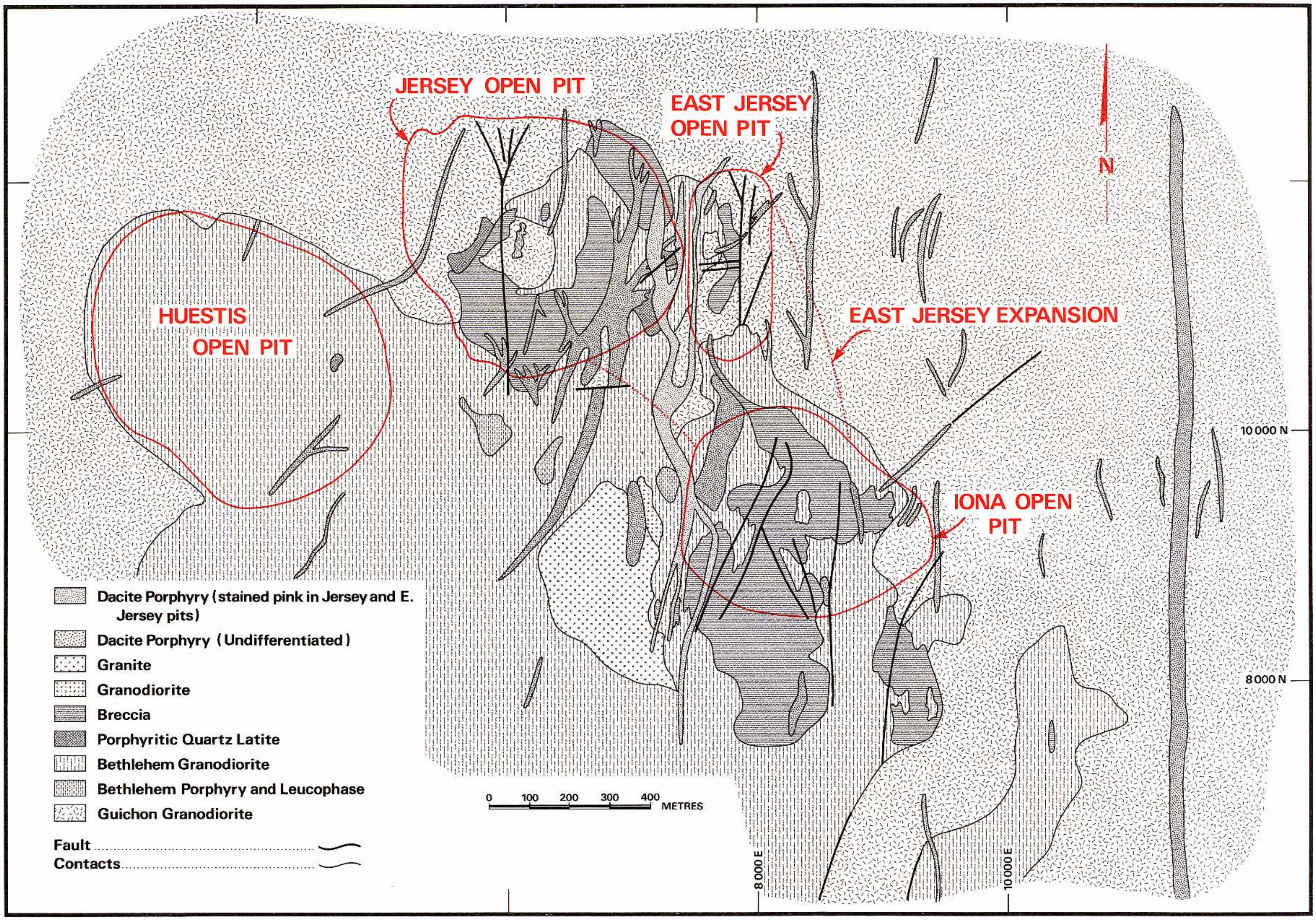



Figure 14. General geology of the Bethlehem property (after Briskey and Bellamy, 1976).

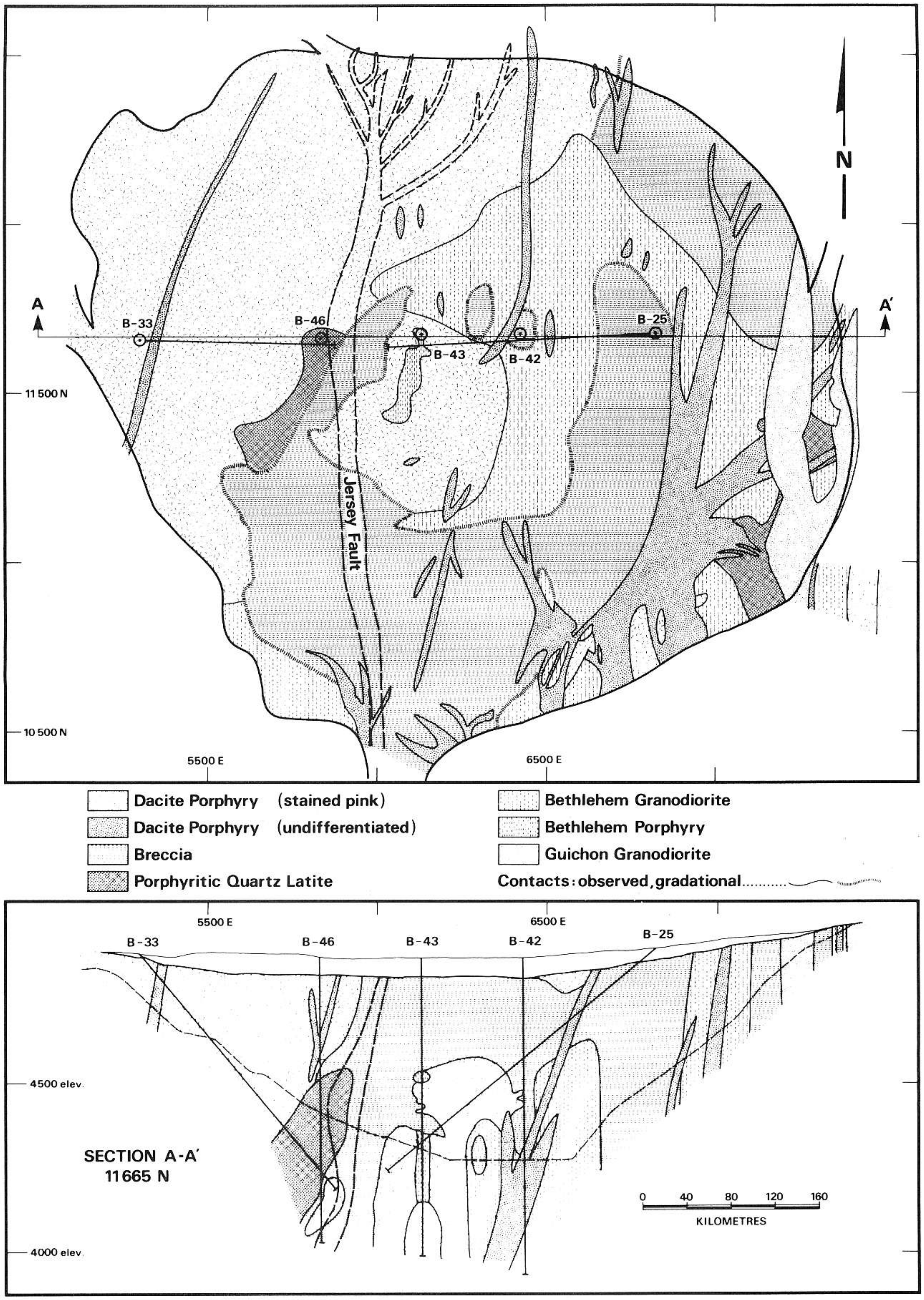



Figure 15. Plan and section of the geology of the Jersey Pit, Bethlehem Copper property (after Briskey and Bellamy, 1976).

amounts of augite. The Bethlehem granodiorite is mainly a medium-grained hypidiomorphic granular rock but it grades into porphyritic varieties. The composition is: 53 to 65 per cent plagioclase feldspar, 16 to 25 per cent quartz, 5 to 16 per cent orthoclase, 2 to 22 per cent hornblende, and 0.5 to 6 per cent biotite. In both rock types, quartz and orthoclase are interstitial and may display reaction boundaries with plagioclase feldspar. The most pronounced distinguishing feature between the two rock types is that mafic minerals in the Bethlehem granodiorite have an uneven size and distribution.

Igneous breccias on the property are postulated to have been forcefully emplaced, rather than formed by the collapse of the batholith roof into the chamber (Carr, 1966; Briskey and Bellamy, 1976). Breccias are associated with all orebodies except the Huestis ore zone, which is concordant with the Bethlehem-Guichon contact. Breccia clasts are subrounded to angular with a diameter up to 20 centimetres; the matrix is generally compact, however, it is not uncommon to observe vugs up to 20 centimetres in width. The vugs commonly are lined with calcite, quartz and/or bornite, and chalcopyrite. Contacts between the igneous breccia and the host rock are sharp to gradational.

The dykes are variable in width from less than a metre to 60 metres. They strike north-south and dip steeply. Contacts generally are chilled and, rarely, are associated with wallrock breccias. In the East Jersey extension, composite dykes are common. Most of the dykes are dacite porphyry; in most cases they are altered to the same degree as the enclosing rocks.

## 6-4 STRUCTURE

Bethlehem ore deposits are controlled in part by north-trending faults and localized in zones with closely spaced fractures. Thus ore grades are found in breccia bodies, in some faults, and in highly fractured areas. Such highly fractured areas occur near digitations in the Bethlehem contact in both the Guichon granodiorite country rock and the intruding Bethlehem granodiorite, as well as in association with some dyke swarms.

## 6-5 ALTERATION AND ZONING

Hydrothermal alteration is restricted to the immediate area of the ore zones. The distribution of secondary biotite defines an inner potassic zone, sericite mixed with lesser amounts of kaolinite and montmorillonite define an intermediate phyllic-argillic zone, and epidote defines a peripheral propylitic zone. The outer halo of the alteration zone is defined by chlorite derived from the mafic minerals (Fig. 16).

Laumontite and other zeolites associated with fracture zones form numerous veinlets in all rock types (White, et al., 1957). Calcite is common in the peripheral vein systems as well as in vugs associated with the igneous breccias. Quartz generally is confined to veins in the inner cores of the alteration zones, but also is common infilling vugs in the igneous breccias.

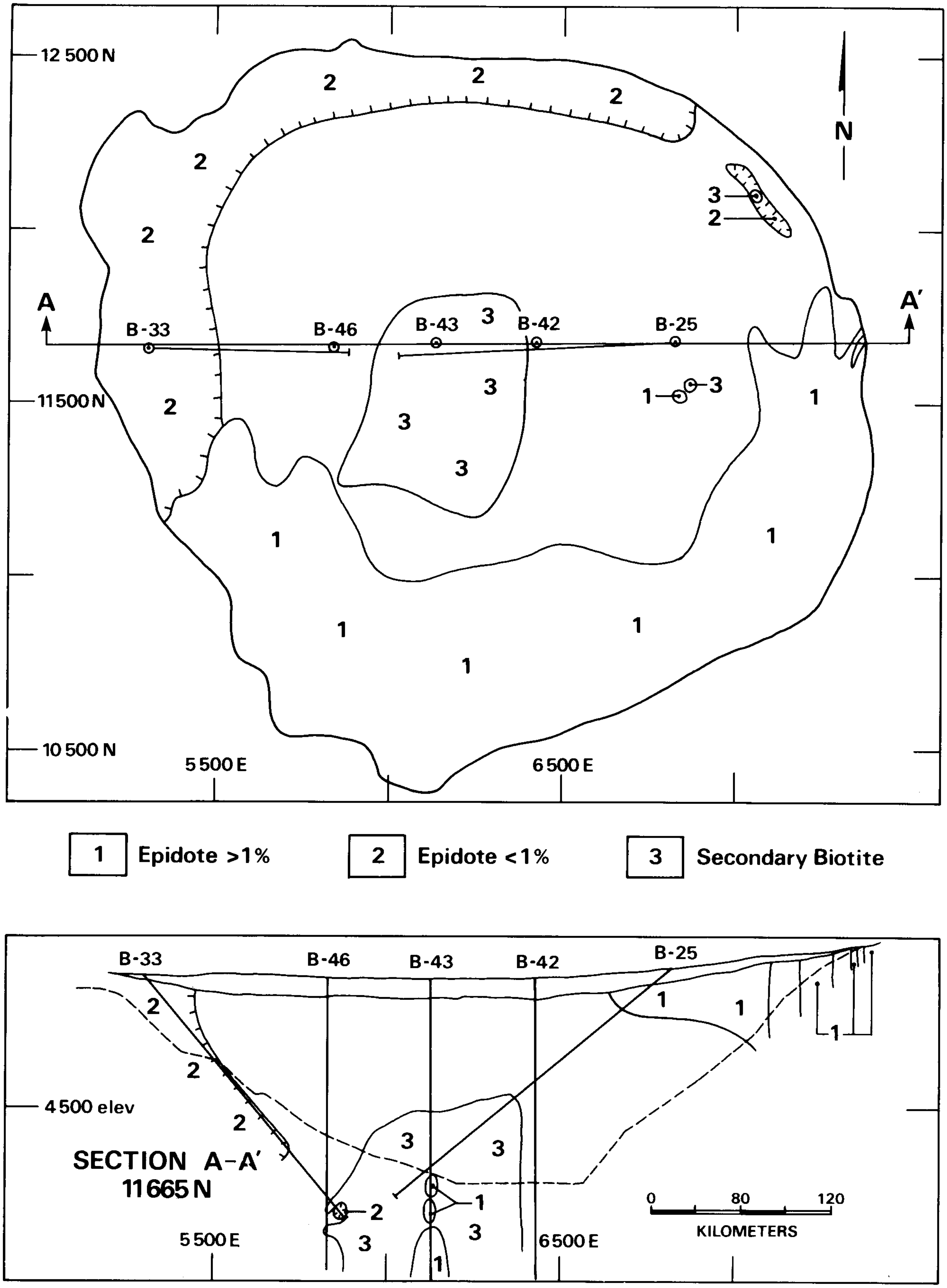



Figure 16. Plan and section showing alteration patterns in the Jersey deposit, Bethlehem Copper property (after Briskey and Bellamy, 1976).

## 6-6 METALLIC MINERAL ZONING

The common hypogene metallic minerals are chalcopyrite, bornite, specularite, and molybdenite; less common minerals are magnetite and chalcocite. The oxide zone contains malachite, azurite, chrysocolla, cuprite, native copper, hematite, goethite, and manganese oxides. Oxidization in the south side of the Iona pit was intense; it extends to a depth of 100 metres. Because of the intensity of oxidization, mining of this portion of the pit was abandoned.

Combined bornite and chalcopyrite rarely exceeds 2 per cent by volume; there is less than 1 per cent by volume pyrite in the pyrite halo.

Fracture-controlled vein-type minerals predominate over the disseminated type. Veins are irregular and discontinuous; they vary in abundance and widths range from 'hairline' to 1 metre. The bulk of the ore is from a system with very narrow but closely spaced veins. Vein and disseminated mineralization can be monometallic or may include all the metallic minerals. Megascopic molybdenite is distributed erratically throughout the East Jersey extension, generally as 'smears' along narrow fracture planes.

A comparison of the alteration halo (Fig. 16) and metallic mineral zoning in the Jersey pit (Fig. 17) shows a close correlation. The bornite to chalcopyrite ratio is 1:1 in the secondary biotite zone and the specularite halo closely corresponds with the epidote zone.

## 6-7 GENESIS

Studies of the Jersey pit indicate five stages of metallic and nonmetallic mineralization: early, early main, main, late main, and late (Briskey and Bellamy, 1976). Early and early main stages were characterized by oxide and silicate mineral deposition - magnetite, tourmaline, epidote, quartz, chlorite, pink carbonate, and secondary biotite. Specularite deposition began during the early main stage. Deposition of some of these minerals continued into the main stage, which was dominated by sulphide mineralization - molybdenite, bornite, chalcopyrite, and pyrite. Clear carbonate, whitish carbonate, and chalcocite typify late main stage mineral deposition. During the final stage, zeolites were deposited in shear and fracture zones.

Late stages of magmatic intrusion within the central portion of the batholith were accompanied by shattering, swarms of porphyry dykes, and emplacement of intrusive breccias. This established a plumbing system for upward migrating hydrothermal solutions and ore fluids which altered the wallrocks and localized the various sulphides and nonmetallic minerals. Migrating outward from the main zones of deposition and alteration, the fluids followed shear zones resulting in restricted wallrock alteration and deposition of narrow, lensy bornite veins. Exposures of these veins of high-grade copper mineralization attracted the first prospectors to the central Highland Valley.

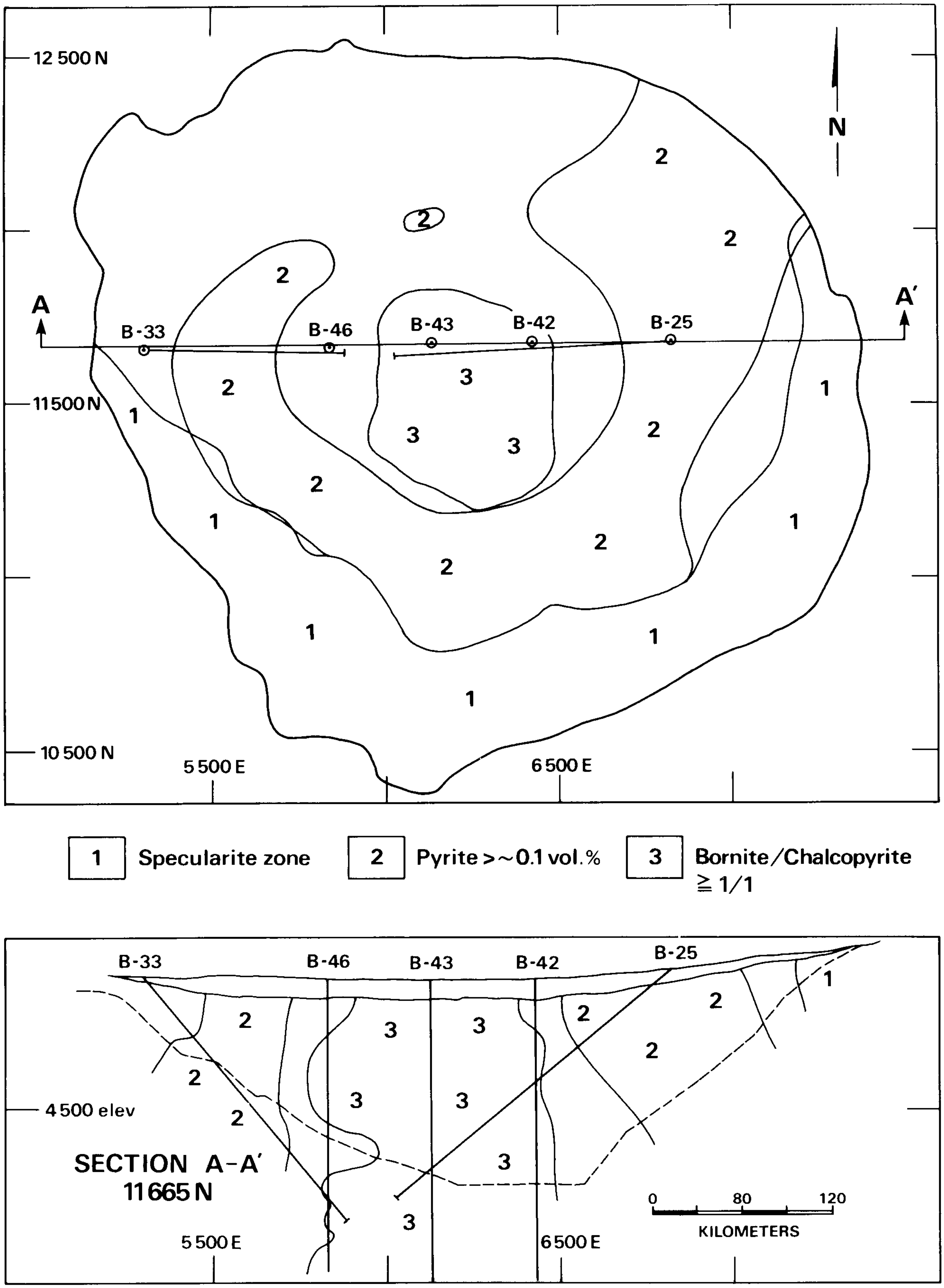



Figure 17. Metallic mineral zoning patterns in the Jersey deposit, Bethlehem Copper property (after Briskey and Bellamy, 1976).

# 7 HIGHMONT DEPOSITS

(L. Tsang and G. Sanford)

## 7-1 INTRODUCTION

The Highmont property contains four large, low-grade mineralized zones and three smaller zones clustered along the western slope of Gnawed Mountain at elevations between 1 600 and 1 700 metres. These deposits are at the south end of the Highland Valley porphyry copper district, 6.4 kilometres south of the Bethlehem deposits, and 3.2 kilometres southeast of the Lornex deposit. Indicated reserves are 122 200 000 tonnes at 0.26 per cent copper and 0.027 per cent molybdenum. Both copper and molybdenum are recovered.

## 7-2 HISTORY

Claims on the property were first staked in the 1950's; subsequently both American Smelting and Refining Company and Kennco Explorations, (Canada) Limited optioned the property and performed preliminary exploration work, including a minor amount of diamond drilling. In 1962 Torwest Resources Ltd. acquired the property, did more detailed exploration, and drilled 20 holes, some of which are in the largest of the known Highmont deposits. In 1966 Highmont Mining Corp. Ltd. was formed, with Torwest Resources Ltd. as the chief shareholder. Between 1966 and 1967 a major program of diamond and percussion drilling outlined the largest or No. 1 deposit, now called the East Zone. Highmont continued a program that included drilling grid pattern percussion holes, diamond drilling, and an induced polarization survey.

In July, 1967 a drift was initiated to further evaluate the property. By spring, 1968, 872 metres of drift and crosscuts and 298 metres of raises had been driven, mostly along surface or underground diamond-drill holes.

Underground work was financed initially by Nippon Mining Company, Limited but, upon their withdrawal, Highmont Mining Corp. Ltd. completed the financing by equity sales to the public. In mid-1969 Teck Corporation Limited entered into a financial arrangement under which they continued exploration and had the right to finance the property to production. By 1971 drilling indicated that mineralization persisted to depths of at least 450 metres. Feasibility studies in 1971 indicated that the operation was economically viable but socio-economic conditions changed, discouraging development. In 1978 the feasibility studies were reviewed and updated, and on April 24, 1979 a production decision was announced. Pre-production stripping commenced in June, 1980 and the first ore was milled in late December, 1980.

By mine start up, the orebodies had been delineated by 45 185 metres of surface diamond drilling in 256 holes and by 1 208 metres of underground diamond drilling in 12 holes driven in 1967 on the 5240 level (1 597-metre elevation). Percussion drilling results were largely ignored for ore delineation and ore reserve calculations. Of the seven mineralized zones located to date, only two have been examined sufficiently to give reliable reserve figures. The largest of these, Zone 1 or East Pit, contained 101 million tonnes grading 0.26 per cent copper and 0.023 per cent molybdenum; the other, Zone 2 or West Pit, contained 21 million tonnes grading 0.25 per cent copper and 0.047 per cent molybdenum. The West Pit, with its higher grade of molybdenum, was mined first; East Pit production began concurrently. Waste-to-ore strip ratios of Stage I East and West pits are 2:1. Mine production is currently 59 000 to 68 000 tonnes per day, supplying 13 000 to 27 000 tonnes per day of ore to the fully autogenous mills.

## 7-3 GEOLOGY

### 7-3-1 General Relationships

Most of the Highmont deposits are covered by a thin layer of glacial till, although copper and molybdenum minerals are exposed in outcrops on nearby higher ground. Bedrock on most of the property is Skeena variety quartz diorite (Fig. 18). Bethsaida phase quartz monzonite underlies the western part, and extends into adjoining Lornex ground; the contact strikes north 20° west and dips 50° east. Three of the smaller deposits are subaligned with this contact; Zone 7 is in Skeena quartz diorite and Zones 5 and 6 are in Bethsaida quartz monzonite.

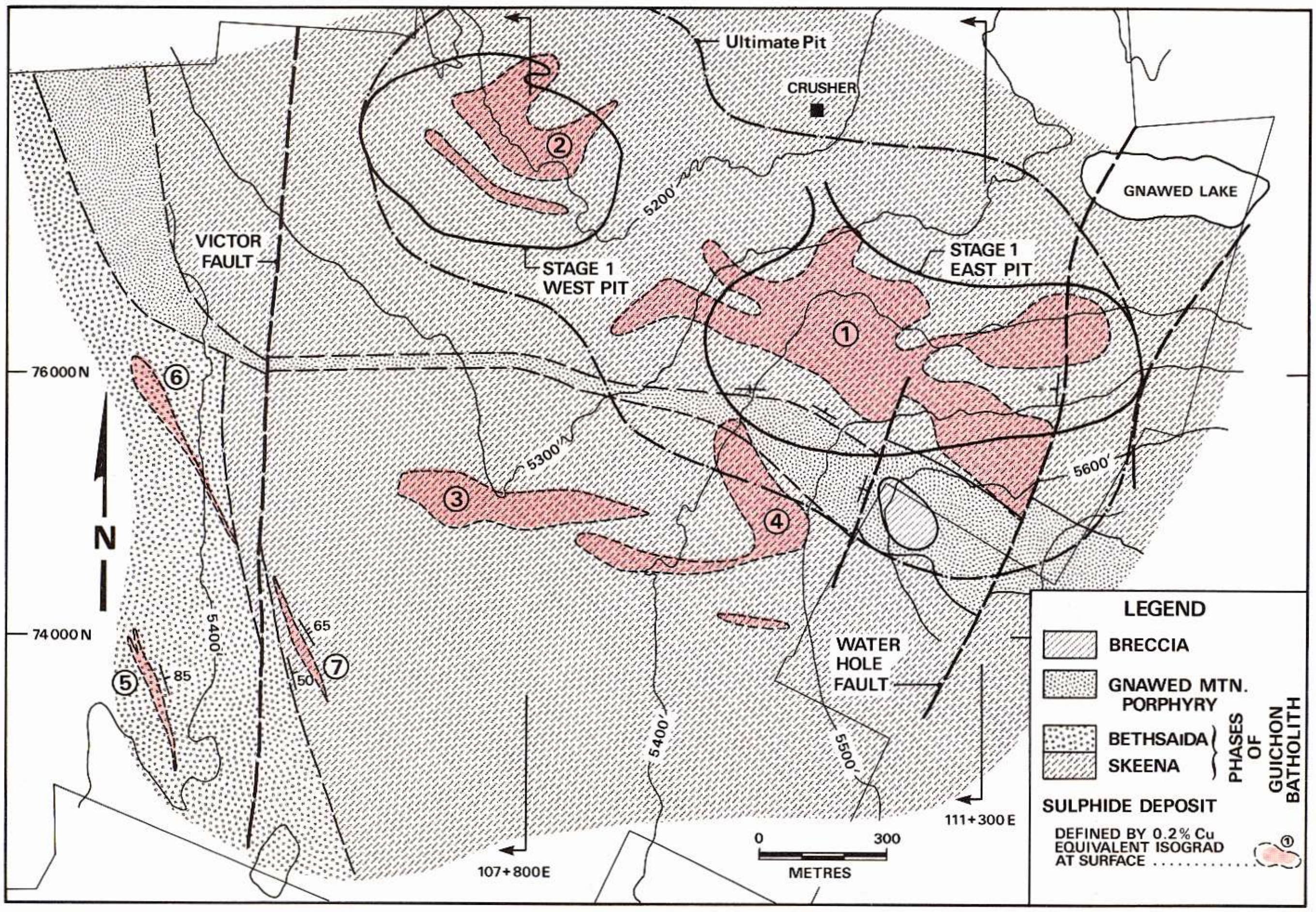



Figure 18. Geology of the Highmont property and locations of the seven known sulphide deposits (modified after Reed and Jambor, 1976).

The dominant geological feature at Highmont is the composite Gnawed Mountain porphyry dyke that trends west-northwesterly. The two major orebodies are elongated parallel to the dyke on its northern side and dip away from it; two smaller zones (3 and 4) are elongated parallel to the dyke on its southern side and also dip away from it (Fig. 19).

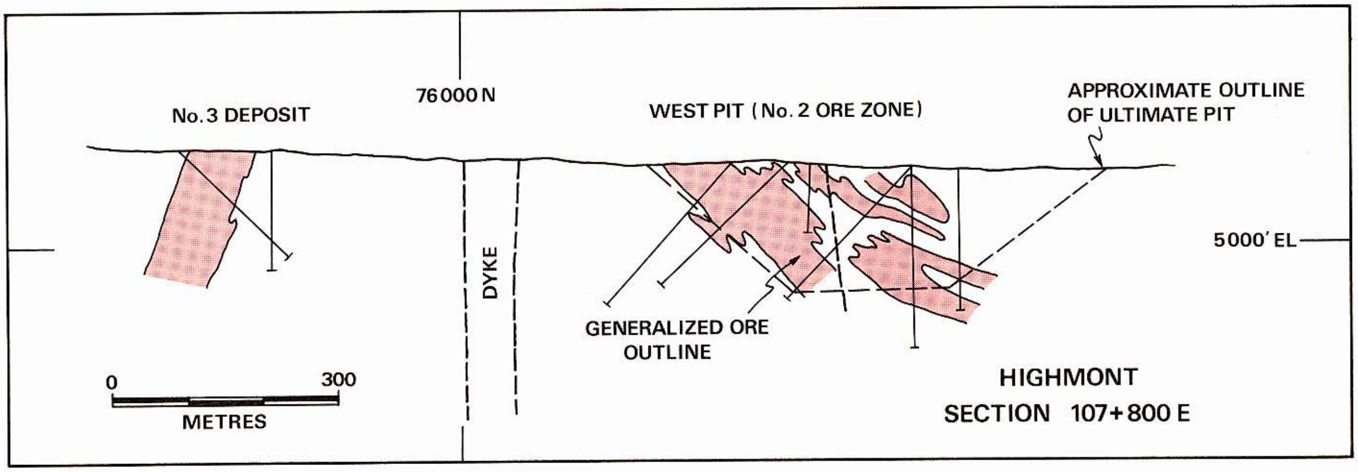



Figure 19. North-south cross-section 107+800E showing drill holes and the relationship of the ore zones to the Gnawed Mountain porphyry dyke (for location of section see Fig. 18).

The Gnawed Mountain dyke consists of biotite quartz feldspar porphyry that is derived from the Bethsaida phase, leucocratic quartz porphyry, and breccia. Although the Bethsaida phase is finer grained in the composite dyke than elsewhere, there is little change in grain size toward dyke margins. The westernmost portion of the dyke trends northward and appears to have been intruded along the Bethsaida-Skeena contact; elsewhere it trends northwest and intrudes Skeena country rock. The dyke is vertical in the central part of the property, but dips about 75° north in the eastern part.

Leucocratic quartz porphyry in the composite dyke is well exposed on high ground east of the Highmont property and on Lornex ground west of it. The porphyry forms irregular bodies; some local offshoots have chilled contacts. At Highmont, offshoots extend 200 to 300 metres from the main dyke into Skeena host rocks. Plagioclase phenocrysts in the quartz porphyry are common and locally abundant; however, because their abundances vary considerably over distances of only a few metres, they do not form mappable units. Portions of this composite dyke are mineralized and locally attain ore grades in the East Pit.

## 7-3-2 **Breccias**

Two distinct types of breccia occur at Highmont; one is confined to the composite dyke, the other is mainly external to it. The first type, which is present at the southeastern corner of the East Pit, is similar to more extensive, probably pipe-like bodies that occur to the east on Gnawed Mountain. The breccia matrix is abundant and consists mainly of tourmaline and hematite. Fragments, although predominantly granitoid, are of diverse composition and not exclusively of local derivation. At Highmont this type of breccia appears to be gradational into 'crackle' breccia in which angular fragments of dyke rocks, which have undergone minimal transport, lie in a sparse matrix of tourmaline and hematite. Sulphide deposition overlapped this brecciation (Reed and Jambor, 1976).

The second type of breccia has a comminuted matrix. Occurrences of this type in the composite dyke are apparently uncommon and remain ill-defined. However, such breccia was intersected in a drill hole at the partially explored southern end of the property. The breccia carries numerous quartz, chalcopyrite, and molybdenite-bearing fragments.

### 7-3-3 **Less Common Dykes**

Plagioclase-rich portions of the quartz porphyry of the composite dyke may be related to later intrusions of quartz-plagioclase porphyry that occur scantily throughout the central part of the batholith. This porphyry is characterized by abundant plagioclase, and lesser quartz and biotite phenocrysts in a dark grey aphanitic groundmass. The quartz-plagioclase porphyry is not an abundant component of the composite dyke, but is present as dykes, commonly several metres wide, throughout the Highmont property. These dykes are chilled against Bethsaida and Skeena rocks, but not against the quartz porphyry of the composite dyke. These porphyry dykes intruded before sulphide deposition ceased.

Pink aplitic dykes represent the final phase of magma injection related to sulphide deposition at Highmont. Aplite dykes are rarely more than a metre wide. Commonly they are associated with dykes of quartz-plagioclase porphyry; some contain a few small phenocrysts of quartz and plagioclase.

Post-sulphide igneous activity at Highmont was limited to uncommon narrow dykes that seem to be of two different ages. The older dykes are northwesterly trending lamprophyres that may be correlative with the vogesites at Valley Copper, which were dated by Jones (1975) as 132±3 Ma. The younger dykes are grey, vesicular, andesite porphyry with abundant 1 to 5-millimetre needles of hornblende and abundant plates of biotite. These dykes, which strike north 70° west and dip 80° north, are presumably Tertiary and related to volcanic flows which crop out northwest of the Highmont property.

## 7-4 STRUCTURE

### 7-4-1 **Faults**

The known major faults at Highmont all have northerly strikes (Fig. 18). At the western edge of the property, a prominent northerly striking air photo lineament lines up with the Victor fault, which has been mapped north of Highmont in Skeena rocks. The projected Victor fault at Highmont has not been tested by drilling, so its attitude and width are not known. Although displacement of the Gnawed Mountain dyke by this fault cannot be defined precisely because of inadequate exposure, the offset is considerably less than that of the Bethsaida-Skeena contact, which has an apparent horizontal left-lateral displacement of 54 metres. The differences in relative displacement suggests that the western side of the Victor fault was uplifted vertically.

The Water Hole fault at the eastern side of the property strikes north 25° east and dips westward at about 60°. The structure owes its name to the fact that some drill holes which penetrated the fault plane tapped water under sufficient pressure to flow to surfaoe. Where intersected in drill holes, this fault has sections of clay and gouge up to 7.5 metres wide bounded by hematitic shattered zones. Movement on the fault was largely or wholly post-ore. Apparent left-lateral horizontal displacement is evident where the fault crosses the Gnawed Mountain dyke. Thirty metres of left-lateral displacement of the dyke also occurred along an unhamed, subparallel westerly dipping fault 330 metres west of the Water Hole fault.

Numerous additional fault zones were intersected in drill holes, but their trends are not known. Very low frequency electromagnetic surveys show several northeasterly trending structures that are probably faults; these change strike abruptly to become northerly trending structures and may be either conjugate faults or splays from the dominant north-trending faults.

### 7-4-2 **Fracture Orientations**

The fracture pattern in the East Pit (No. 1 Zone) is well defined and mainly involves fractures of four distinct attitudes (Bergey, et al., 1971). The majority of fractures belong to two major sets (F1 and F2); most of the remainder belong to two minor sets (f1 and f2). The attitudes of the fracture sets are as follows:

F1: Strike 140°-150°; dip 80° northeast
F2: Strike 040°-050°; dip 45° northwest
f1: Strike 075°; dip vertical
f2: Strike 095°; dip vertical

Fractures are not distributed uniformly in the deposit, but rather tend to be concentrated in parallel swarms. The width of each swarm is as much as 60 metres. Swarms of mineralized F1 and F2 fractures coincide with zones of higher grade mineralization. Intervening areas between the swarms have a lower density of fracturing and consequently lower grade (see also McMillan, 1984).

Shear zones and faults are numerous and partly follow the same directions as the veins and fracture swarms. Although showing evidence of post-mineral movement, their actual displacements are unknown. A major northeasterly fault apparently forms the eastern limit of ore in the East Pit, but the mapped geology shows no major displacement.

## 7-5 ALTERATION TYPES AND DISTRIBUTION

The Highmont deposits exhibit the lowest overall intensity of alteration of any of the producing Highland Valley deposits. Large amounts of relatively fresh rock occur throughout the deposit. Rock is mapped as 'weakly,' 'moderately,' or 'strongly' altered, depending on biotite and hornblende alteration, and changes in feldspar colour. The volume of rock affected by alteration is related directly to fracture density.

Moderately altered rock has chloritized mafic minerals and greenish feldspars; in strongly altered zones mafic minerals have been destroyed completely and feldspars are chalky white. Zones of intense alteration are found adjacent to fractures and decrease in width with decreasing fracture size. Rock competency does not appear to be appreciably affected by alteration, even in wide, strongly altered zones, but these areas are generally more closely fractured than average.

Much of the area of the West Pit has been weakly to moderately altered. Only the eastern end of the pit, coinciding with the high copper areas, has been strongly altered.

### 7-5-1 Potassic Alteration

Potassic alteration is weak, although potassic feldspar occurs in and adjacent to mineralized veins in the East Pit (McMillan, 1984). Much of what appears to be pervasive potassic feldspar alteration is plagioclase containing finely disseminated iron oxide. Hydrothermal biotite has been observed in thin sections but occurrences are often overprinted by propylitic alteration (McMillan, 1984). Microprobe analyses of hydrothermal and magmatic biotites from Highmont show a relatively high $TiO_2$ content in the primary biotites in contrast to lower levels in the hydrothermal biotites (Reed and Jambor, 1976).

### 7-5-2 Phyllic Alteration

Quartz-sulphide veinlets with envelopes of sericite comprise phyllic alteration at Highmont. Field mappable phyllic alteration is more prevalent in the East Pit than in the West Pit. Work by Reed and Jambor (1976) showed that the zone of phyllic alteration nearly coincided with the 0.2 per cent copper isopleth.

### 7-5-3 Argillic and Propylitic Alteration

Argillic and propylitic alteration at Highmont are entirely fracture related. Feldspars take on various greenish to pink to chalky white shades and biotite and hornblende are chloritized, epidotized, or sericitized as alteration increases. Alteration grades outward from a central vein, fracture, or shear, through a zone of intense argillic alteration into propylitic alteration then into virtually unaltered rock. Veins can vary from a few centimetres to a metre wide; alteration zones extend from several centimetres to 50 metres outward from the veins.

In the argillic alteration zones immediately adjacent to the central veins or shears, thin section and X-ray analysis (McMillan, pers. comm.) show that feldspars are replaced extensively by montmorillonite, kaolinite, and carbonate. Outlines of primary mafic minerals are vague; they have been replaced by chlorite-carbonate or sericite-carbonate pseudomorphs. Magmatic magnetite has been completely hematized. As distance from the vein increases, feldspar colours change from chalky white to buff or greenish in propylitic zones to light cream or glassy in virtually unaltered zones. Outward, the intensity of clay alteration decreases and outlines of mafic minerals and rock textures are better preserved. In propylitic zones plagioclase replacement is less extensive; alteration consists of flecks and patches of sericite and carbonate, generally accompanied by small amounts of epidote.

Correlation of generalized propylitic and argillic zones from one drill hole to another is not possible. Even the most intensely altered zones are pod-like and are separated by rock which is altered only weakly. Overall this weak alteration forms a propylitic background throughout the area of the deposits.

Early hydrothermal alteration in the Highmont deposits consists of a central zone in which mafic minerals are altered variably to biotite and a peripheral zone of propylitic alteration (Reed and Jambor, 1976). Later, retrogressive, superimposed alterations were successively phyllic, argillic, and a second generation of propylitic alteration.

## 7-6 MINERALIZATION AND METALLIC MINERAL ZONING

The principal economic minerals are chalcopyrite, bornite, and molybdenite, occurring predominantly in veins and fractures. Chalcocite is present in minor amounts. Pyrite and specular hematite are gangue minerals. Disseminated sulphides are less than 5 per cent of the total. Generally, disseminations are predominantly chalcopyrite which has migrated a few centimetres into altered wallrocks on either side of mineralized veins and shears. Oxidation is not significant in the West Pit.

### 7-6-1 Fracture and Vein Minerals

Four common types of veins or fracture fillings are recognized in the East Pit; most sulphides occur in the dominant F1 and F2 fractures (Bergey, et al., 1971) described previously.

Type 1 veins contain quartz, chalcopyrite, and bornite in addition to scattered flaky molybdenite; generally they range in width between 1 and 25 millimetres. In these veins quartz has a vuggy texture, and chalcopyrite and bornite occupy the central part of the vein; a 2.5 to 5-centimetre-wide envelope of altered wallrock is characterized by relatively coarse (1-millimetre) flakes of white sericite, and tourmaline clusters are common. This envelope is pink near the vein because of potassic feldspar or iron oxide particles. Type 1 veins predominate in the East Pit. Similar veins, without the sericite and tourmaline, occur in the West Pit.

Type 2 veins contain quartz and chalcopyrite, in places with pyrite and minor amounts of molybdenite; they range in width to 10 centimetres. The quartz is massive rather than vuggy and may enclose tourmaline; chalcopyrite is not restricted to the centre of the vein and sericite is not conspicuous in the wallrock.

Type 3 veins cut type 1 veins; they contain quartz, molybdenite, and clay minerals in widths of up to 1 metre. The quartz is greyish, brecciated, and cut by seams of molybdenite and chalky white clay minerals. Clays also occur at the edges of veins as a variegated black, cream, or yellow gouge that contains significant copper and molybdenum values. These zones consist mainly of quartz, albite, calcite, and kaolinite, with or without montmorillonite, sericite, illite, molybdenite, and oxides of manganese and molybdenum (McMillan, pers. comm.). Type 3 veins generally are accompanied by several metres of intensely argillized wallrock and are most prominent in the West Pit.

Type 4 veins are barren and apparently later than the mineralized veins. They consist of greyish white quartz with a fine-grained, sugary texture. Other late-stage veins and fractures contain calcite, siderite, epidote, zeolites (including prehnite), and gypsum.

Wallrock alteration is controlled largely by fracturing and locally is intense. Several alteration types are recognized, which includes those mentioned in the discussion of veins as well as pervasive development of chlorite and microscopic green sericite.

### 7-6-2 Megascopic Sulphide Zoning

The general interpretation of sulphide zoning at Highmont is based on drill core, as yet little information is available from pit development. Pyrite is not abundant and zones noted as pyritiferous signifies only that pyrite is present.

Sulphide zoning shown on Figure 20 represents the projection of drill hole data to surface. Although the 0.2 per cent copper equivalent isopleth represents this parameter only at surface, it is clear that ore grade areas do not coincide with specific sulphide zones. Sulphide zones near the composite dyke are distinctly elongate parallel with it. In common with the dominant fractures, the sulphide zones dip away from the dyke (Fig. 21).

Vertical section 111 + 300E (Fig. 21) demonstrates mineral zoning north of the dyke. Bornite accompanies chalcopyrite in approximately equal amounts for distancos of up to 350 metres northward from the dyke, then there is a zone of chalcopyrite with minor amounts of pyrite and rare bornite, followed at the northern limits of ore by an increase in the amount of pyrite, which may locally form 1 per cent of the rock. Molybdenite, although widespread, is concentrated in restricted zones; several occurred in the No. 2 zone and caused molybdenite grades in the West Pit to be relatively high.

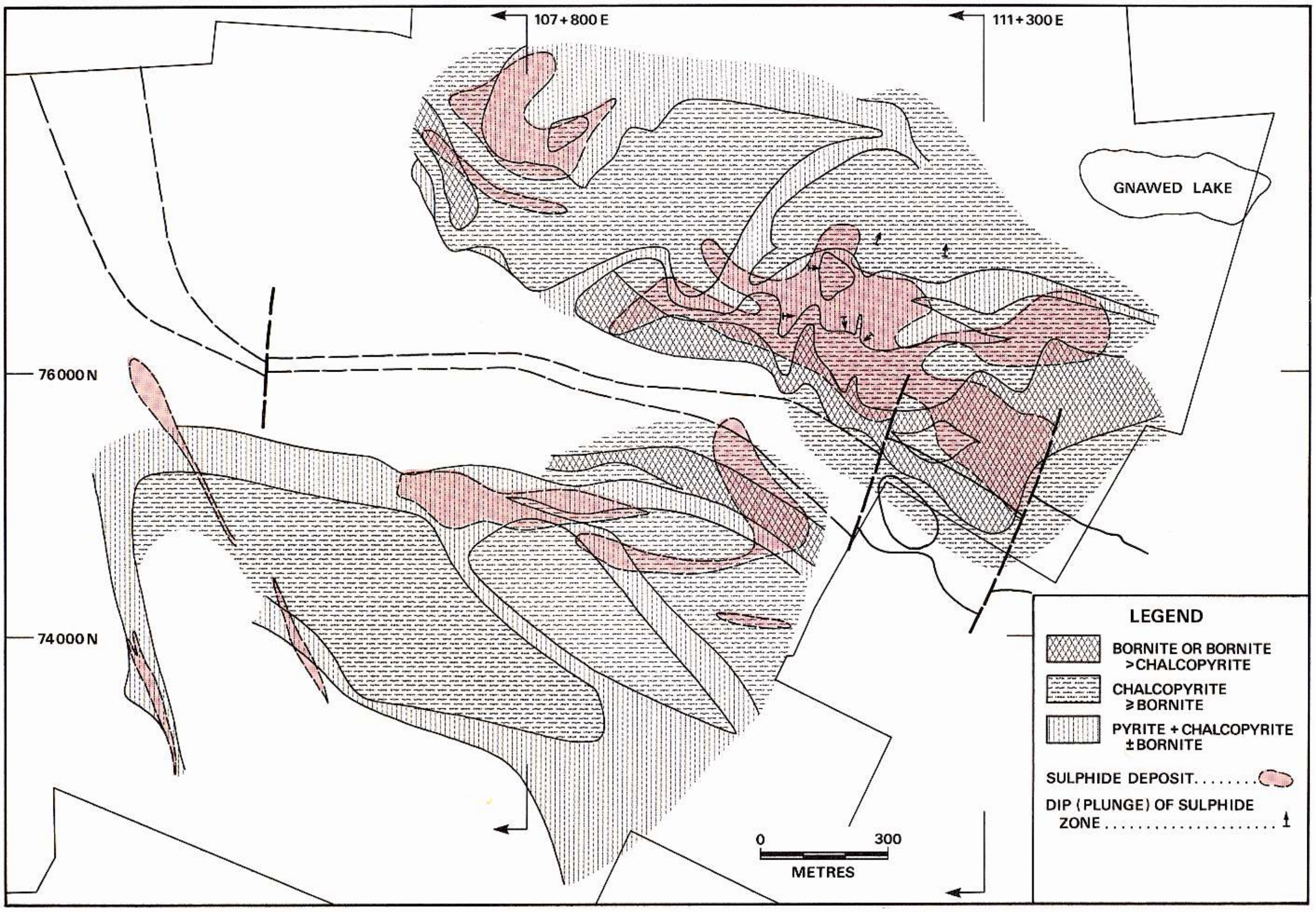



Figure 20. Distribution of sulphide zones (projected to surface) for Highmont deposits (modified after Reed and Jambor, 1976).

Although one might expect that bornite zones would coincide with highest copper grades, this is not the case. Possible explanations are that bornite zones were not fractured sufficiently or that only one of the major fracture directions in the bornite zones was mineralized extensively. Although quartz-sericite-sulphide and quartz-sulphide veinlets may be gradational into one another, they also occur separately. Where they are separate, each occupies a different structural trend. Furthermore, in each veinlet set there is a pronounced dominance of a single sulphide mineral. For example, only chalcopyrite may occur in quartz-sulphide veinlets, whereas coexisting quartz-sericite-sulphide veinlets may contain bornite as the only sulphide. As would be expected, grades are lower where only one fracture set carries sulphides and much better where two or more sets are sulphide bearing and closely spaced.

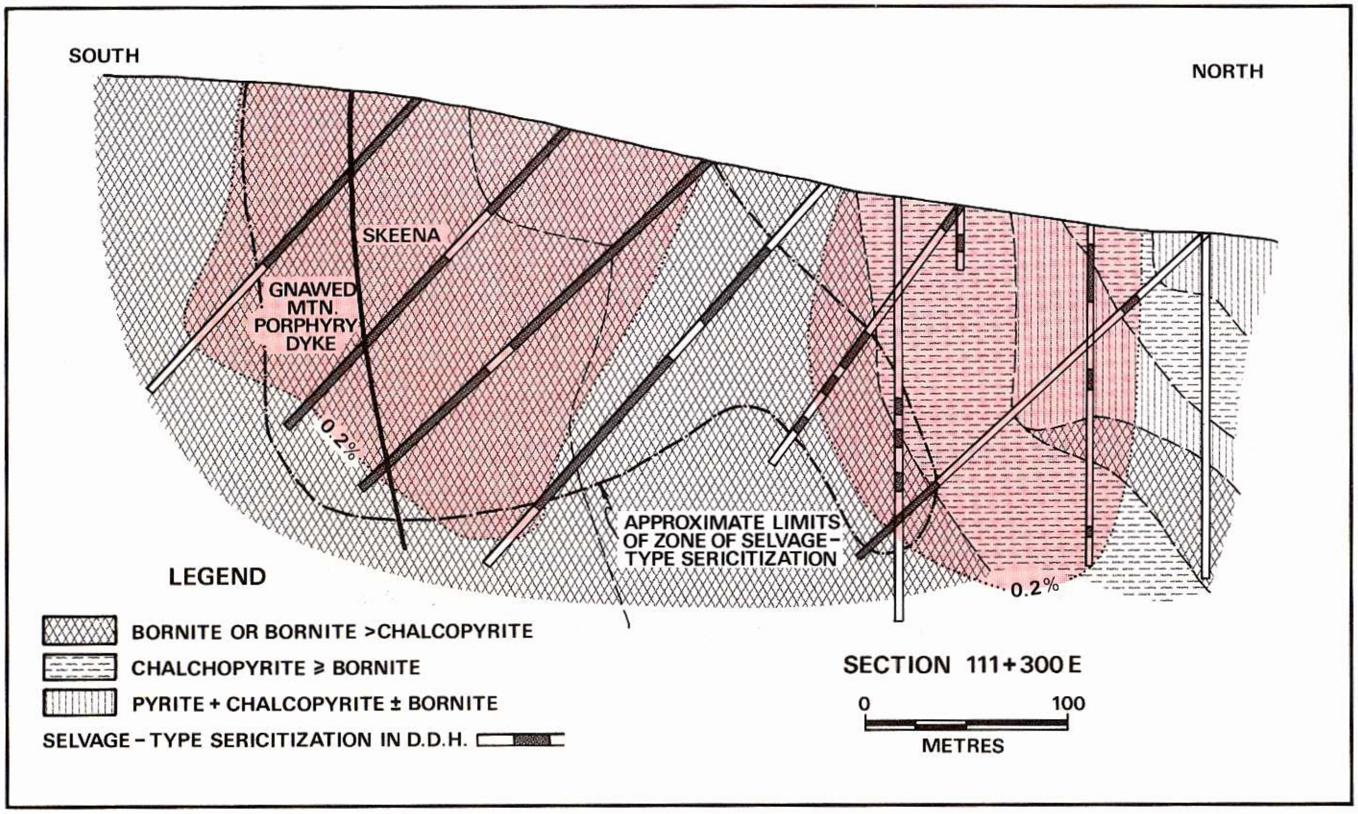



Figure 21. Section across the No. 1 deposit showing the distribution of sulphide zones and selvage-type sericitic alteration (phyllic alteration) in relation to the composite Gnawed Mountain porphyry dyke (modified after Reed and Jambor, 1976).

### 7-6-3 **Distribution of Molybdenum and Copper**

In general, there is little correlation between areas of high-grade copper and areas of high-grade molybdenum in the West Pit. Individual copper or molybdenum zones can be projected from bench to bench, but in most cases there is little overlap between the metals. Studies based on blast hole assay results for the West Pit indicated three màjor zones going from west to east:

(1) Molybdenum with no copper,
(2) Molybdenum-copper, and
(3) Copper with some molybdenum.

Contoured molybdenum values display prominent trends in a band some 150 metres wide, that strike slightly northwesterly, subparallel to the porphyry dyke. Copper contours exhibit this same pattern and width, but plot north of the molybdenum zone with an overlap of 60 metres. This gives rise to the apparent zonations described previously. Over the first 65 metres of vertical development, the relative positions of these broad bands remained constant.

## 7-7 GENESIS

Crystallization of the Skeena and Bethsaida phases of the Guichon Creek batholith was followed by intrusion of the Gnawed Mountain porphyry dyke. After solidification of the dyke, its eastern part was brecciated and healed, predominantly by tourmaline and specular hematite, which also spread into adjacent country rocks. Contemporaneous igneous breccia and quartz-plagioclase porphyry dykes were injected; emplacement of pink aplite dykes was the last of the magmatic events. Sulphide deposition occurred after intrusion of the Gnawed Mountain porphyry, but prior to formation of tourmalinized breccias; some mineral deposition continued until after intrusion of the aplite dykes.

The distribution of the Highmont deposits, the metal zoning, the alteration patterns, and related dykes and breccias indicate that the Highmont deposits were influenced by the Gnawed Mountain dyke. The dyke is clearly pre-ore and crystallized prior to the hydrothermal event. However, the evidence suggests that the dyke was still hot and influenced the distribution and intensity of the mineralizing hydrothermal system. This hydrothermal event formed in order: weak potassic and propylitic, then phyllic, argillic, and additional propylitic alteration products.

# 8 THE LORNEX DEPOSIT
(W.J. McMillan)

## 8-1 INTRODUCTION

This report is mainly after a description published by M.W. Waldner, G.D. Smith, and R.D. Willis in 1976; it includes updated geological plan and section maps courtesy of Lornex Mining Corporation Ltd..

The Lornex copper-molybdenum deposit is in the interior plateau of British Columbia on the southern slope of the Highland Valley at latitude 50°27' north, longitude 121°03' west, NTS 92I/6E. The pre-mining surface of the orebody was about 1 550 metres above sea level. The property is 42 kilometres by road southeast from Ashcroft and 72 kilometres by road from Kamloops.

## 8-2 HISTORY

Copper mineralization was discovered in bulldozer trenches spotted by Egil Lorentzen in 1964. Mr. Lorentzen formed Lornex Mining Corporation Ltd., and in 1965, under agreement with Lornex, Rio Tinto Canadian Exploration Limited began an investigation of the property. A program of geochemical, induced polarization, magnetometer, and geological surveys followed. The induced polarization survey outlined two zones where chargeabilities were in excess of 5 milliseconds - twice mean background. Subsequent diamond drilling of the anomalous zones returned encouraging copper grades. A total of 26 200 metres of surface diamond drilling and 27 000 metres of percussion drilling were completed by 1967. An underground bulk sampling and a small open pit provided feed for a pilot mill at 90 tonnes per day.

The developed orebody, which contained an estimated 266 million tonnes of mineable ore, was put into production in the spring of 1972 by Lornex Mining Corporation Ltd., which is controlled by Rio Algom Mines Limited. During the period from 1973 to 1974, additional reserves were outlined by 20 700 metres of diamond drilling.

The mill was initially designed to process 34 500 tonnes of ore per day; however, actual throughput attained 43 500 tonnes per day. In 1979 expansion was initiated and increased design capacity to 84 000 tonnes per day.

## 8-3 GEOLOGY

Lornex copper-molybdenum deposit is approximately 1 900 metres long, 500 metres wide, and plunges northwesterly to a depth in excess of 750 metres (less than 850 metres above sea level). The ore deposit is mantled by 2 to 75 metres of overburden, which gradually thins eastward from a maximum depth in Award Creek Valley, the surface expression of the Lornex fault.

The orebody occurs within Skeena variety, a slightly porphyritic, medium to coarse-grained granodiorite (Fig. 22). It consists of quartz (20 per cent), plagioclase (50 per cent), orthoclase (10 per cent), biotite (5 to 20 per cent), and hornblende (5 to

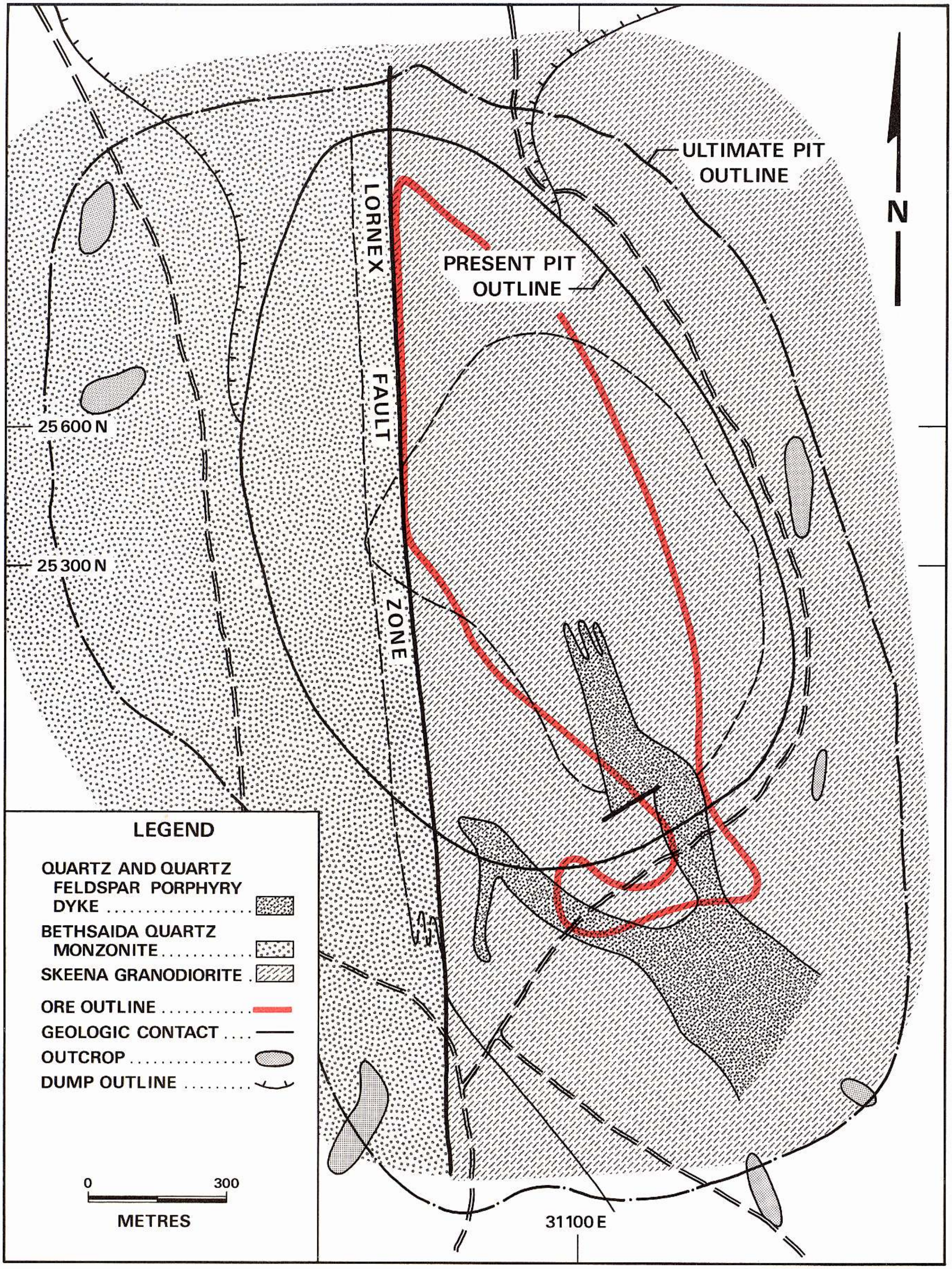



Figure 22. General geologic setting of the Lornex copper-molybdenum deposit (modified after Waldner, et al., 1976).

10 per cent), with accessory sphene, apatite, zircon, and magnetite. Quartz occurs interstitially, as subhedral grains that show undulatory extinction. Plagioclase is twinned with complex oscillatory zoning; crystal cores are generally $An_{30-35}$. Orthoclase is interstitial and perthitic. Biotite is subhedral to euhedral; hornblende is irregular, anhedral, and commonly poikilitic.

A pre-mineral quartz porphyry dyke (Fig. 22), which probably is related to the Bethsaida phase (McMillan, 1976), trends northwesterly through the Highmont property and pinches out in the Lornex orebody. Contacts of the dyke are indistinct because adjoining Skeena quartz diorite is silicified and sericitized. The dyke is presumed to have intruded one of a series of structural zones parallel to Highland Valley (Bergey, et al., 1971). Quartz phenocrysts normaliy compose 20 to 25 per cent of the dyke and plagioclase phenocrysts occur locally. The grey aphanitic matrix is composed of 60 to 70 per cent plagioclase ($An_{40}$) and 10 per cent quartz.

## 8-4 STRUCTURE

Mineralization is controlled by the distribution and density of fracture sets. Mineralized and post-mineral fractures formed during at least three periods of deformation. More than 11 000 structural measurements from mineralized veins in the Lornex pit defined three major sets of copper-molybdenum veins: 022°/55° southeast, 064°/57° southeast, and 090°/58° south. Certain of these veins are dominant in distinct zones of the orebody. The veins striking 022° are concentrated in the southern and southeastern zones. In the central and western zones all three vein sets overlap, which results in a greater concentration of veins and higher copper grades (Fig. 23).

Two post-mineral fault and fracture systems have been recognized in the open pit. One system has two sets of fractures: one set trends 094°/52° to 092°/62° south, the other 021°/46° to 032°/54° southeast; these are subparallel to the northeast and east-striking copper-molybdenum veins. A second system, which offsets the first, has three dominant trends: 112°/69° southwest, 036°/66° southwest, and 172°/68° west. Where faults cut vein mineralization, displacements are from 1 centimetre to 2 metres.

The most prominent structural feature in the area is the Lornex fault (Figs. 22 and 23); it has been exposed by mining and intersected by diamond-drill holes. The fault, which strikes northerly and dips 55 to 85° westward, truncates the northwestern part of the ore deposit and juxtaposes Bethsaida quartz monzonite and Skeena quartz diorite in the vicinity of the orebody. In general, the dip is lowest in the south and steepens toward the north. Black gouge, which forms on the footwall of the fault zone, varies in thickness from 10 centimetres to 1.5 metres. Mylonite forms discontinuous pods 1 te 50 metres wide in the hangingwall of the fault zone; it has been exposed in the pit over a strike length of 75 metres.

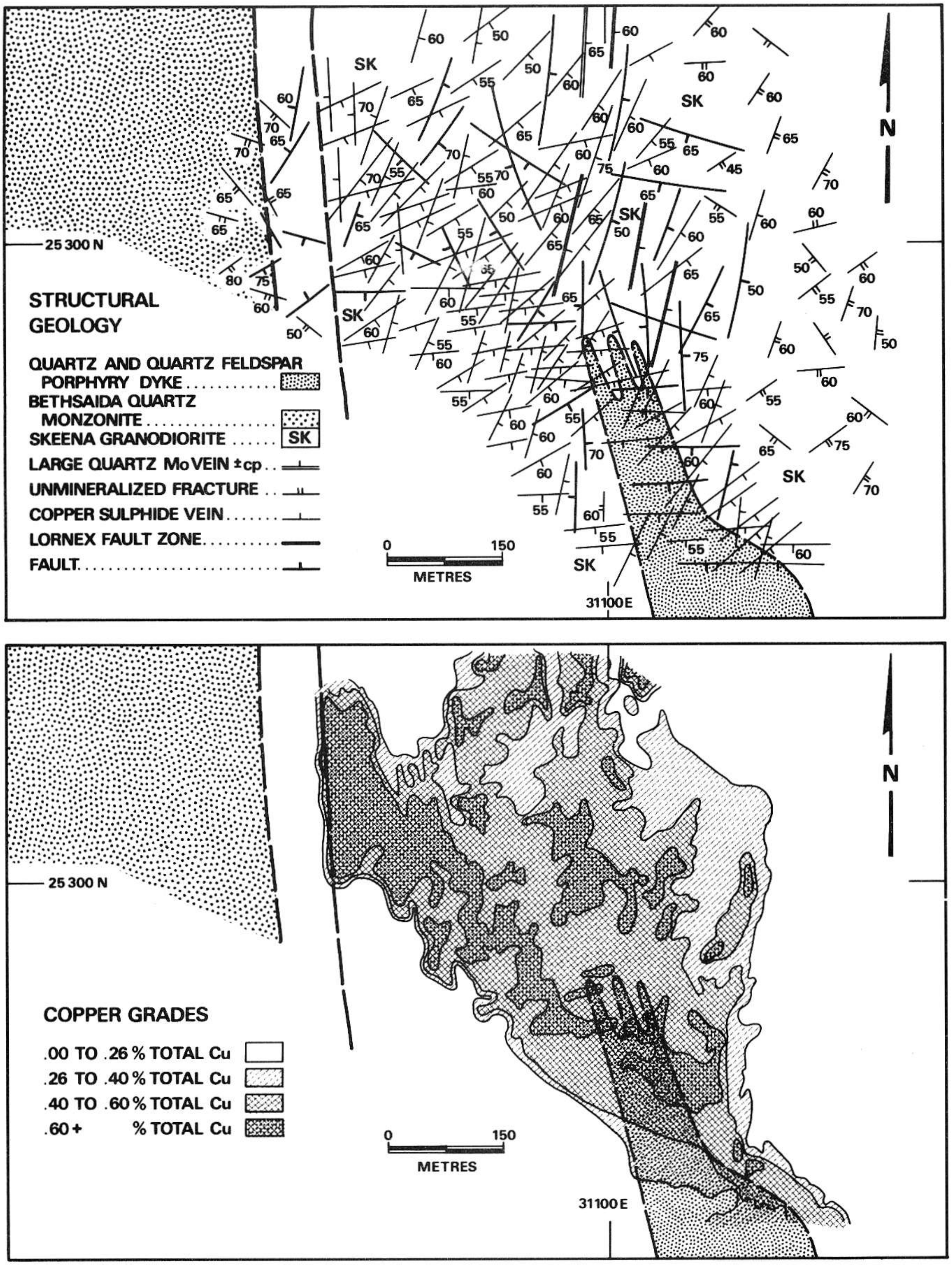



Figure 23. Composite maps of the 1426-metre and 1524-metre benches, Lornex mine, illustrating structural trends and copper grade distribution (after Waldner, et al., 1976).

## 8-5 ALTERATION

Five main types of hydrothermal alteration related to quartz and sulphide mineralization occur at Lornex: silicic, potassic, phyllic, argillic, and propylitic (Fig. 24).

### 8-5-1 **Silicic Alteration**

Pervasive silicification appears to be related to the pre-mineral quartz porphyry dyke. This dyke is weakly affected by hydrothermal alteration, in contrast to the Skeena quartz diorite host, which is altered pervasively. The silicic alteration zone is marked by closely spaced quartz veins with associated quartz alteration. Unlike that at Valley Copper, the silicic alteration zone at Lornex is moderately to well mineralized with copper.

### 8-5-2 **Potassic Alteration**

Potassic alteration is distributed erratically and no well-defined potassic zone exists at the levels explored in the Lornex orebody. Hydrothermal potassic feldspar occurs sporadically in thin discontinuous veinlets and hydrothermal biotite locally replaced mafic minerals in zones of intense argillic alteration.

### 8-5-3 **Phyllic Alteration**

Phyllic alteration consists of grey quartz-sericite envelopes as borders on quartz-copper sulphide and quartz-molybdenite veins within the argillic alteration zone. These envelopes, which commonly form sharp boundaries with pervasive, moderate to intense, argillic alteration, average approximately 3 centimetres in width.

### 8-5-4 **Argillic Alteration**

Argillic alteration, which is pervasive throughout the ore zone (Fig. 24), is characterized by the presence of quartz, sericite, kaolinite, montmorillonite, and chlorite. Sericite and kaolinite, with minor amounts of montmorillonite and chlorite, form pseudomorphs after plagioclase. The cores of the plagioclase crystals are generally more intensely altered than the rims, but in intense stages of argillic alteration the entire plagioclase crystal is replaced by sericite and clays. Kaolinite, sericite, and lesser montmorillonite also replace primary orthoclase; alteration progresses from the rim toward the core with increasing intensity of argillic alteration. Primary biotite and hornblende alter to chlorite and sericite. Pervasive argillic alteration of Skeena quartz diorite produces a cream or apple green rock. In the cream varieties kaolinite predominates over sericite, in the apple green variety sericite predominates. Generally, copper grades increase as the intensity of argillic alteration increases.

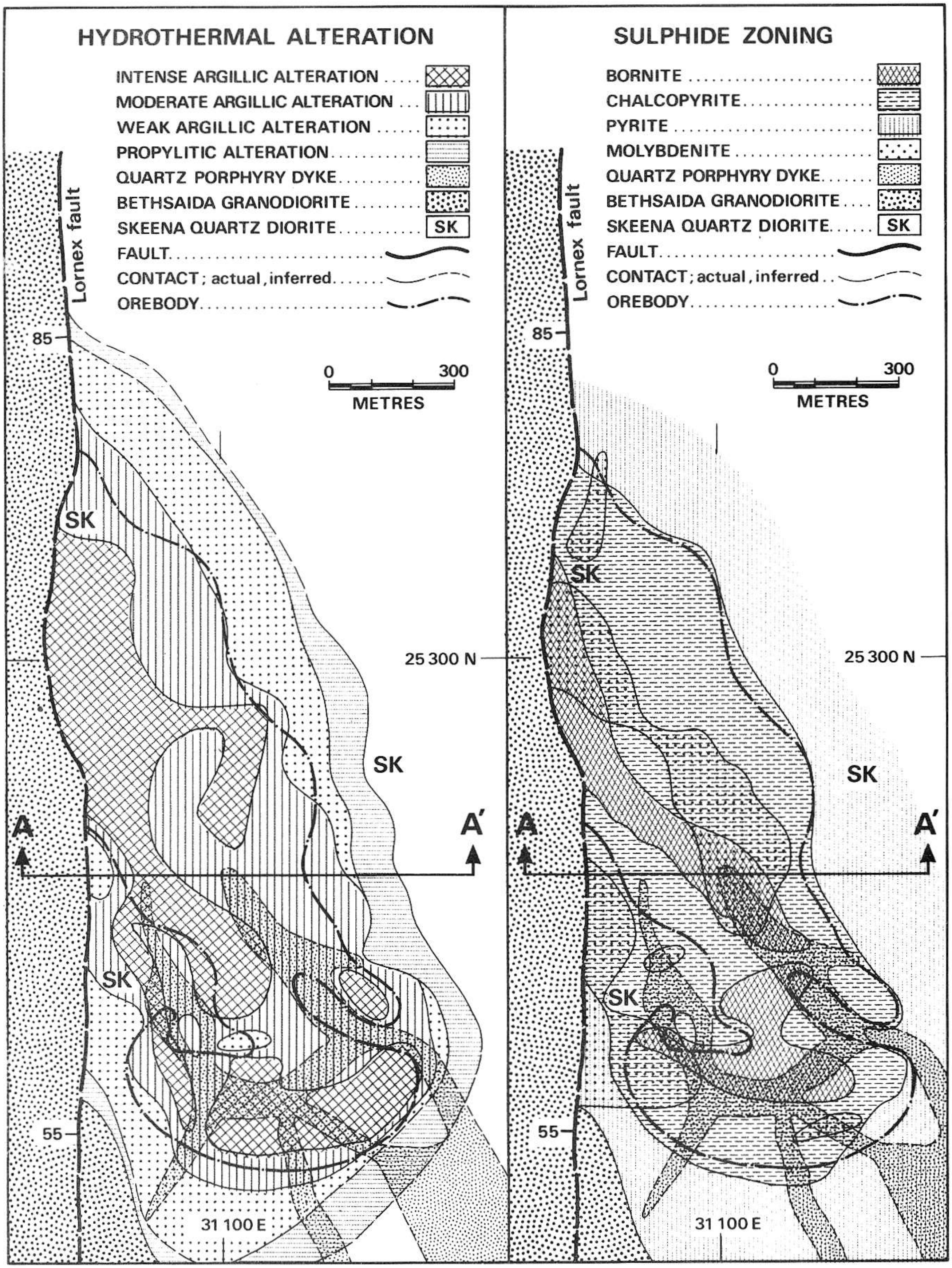



Figure 24. Plan views of the Lornex deposit illustrating alteration and hypogene sulphide zoning patterns (modified after Waldner, et al., 1976).

### 8-5-5 **Propylitic Alteration**

Pervasive propylitic alteration is peripheral to the argillic alteration; typically it consists of epidote (zoisite), chlorite, and carbonates (calcite), with minor amounts of sericite and hematite. Epidote and calcite are most common in veins. Quartz and orthoclase in the host rock are unaltered, but plagioclase, which has a fresher appearance than in the argillic alteration zone, is altered to calcite and epidote with minor amounts of sericite and chlorite. Mafic minerals alter to chlorite, calcite, and sericite, with lesser hematite and epidote.

### 8-5-6 **Gypsum Distribution**

An erratic zone of late-stage gypsum occurs at elevations below approximately 1 100 metres. The gypsum is generally at a higher level on the fringe of the orebody and deeper in its centre. Gypsum is post-ore and occurs mainly as 5 to 10-millimetre-thick veins.

## 8-6 **MINERALIZATION AND METALLIC MINERAL ZONING**

The predominant hypogene sulphide minerals, in order of abundance, are chalcopyrite, bornite, molybdenite, and pyrite. Minor amounts of sphalerite, galena, tetrahedrite, and pyrrhotite also occur. Total sulphide content averages 1 to 1.5 weight per cent in the ore zone, but gradually decreases from the central part of the orebody toward its periphery. Common gangue minerals include quartz, calcite, epidote, hematite, magnetite, and gypsum.

Sulphides occur primarily with quartz as fracture fillings and as fracture coatings. Only an estimated 5 per cent of the total bornite, chalcopyrite, and pyrite occur as disseminations or partial replacements of mafic constituents of the host rock. Veins average 5 to 15 millimetres in width, but vary in width from 'hairline' to more than a metre. Larger veins, some of which have been mapped for more than 200 metres of strike length, commonly are composed of quartz, molybdenite, and chalcopyrite. Molybdenite normally occurs as thin laminae in banded quartz veins, although it may occur as rosettes in vuggy quartz veins. Drummond and Kimura (1969) describe similar veins at Endako and suggest that these types of vein structures represent repetitive pulses of mineralization. Molybdenite veins more than a metre in width are prominent on the eastern side of the orebody (Fig. 23). Post-ore faults are prevalent along these veins.

Sulphide zones illustrated on Figures 24 and 25 are defined as follows:

Bornite Zone: bornite > chalcopyrite > pyrite
Chalcopyrite Zone: chalcopyrite > bornite > pyrite
Pyrite Zone: more than 0.05 per cent pyrite and $\leq$0.26 per cent copper
Molybdenite Zone: molybdenum $\geq$0.02 per cent

Total sulphide content averages 1 to 1.5 per cent in the bornite, chalcopyrite, and molybdenite zones, but only 0.25 to 0.5 per cent in the pyrite zone. According to

Olade (1974) an increase of pH could cause the sulphide zonation if the rate of decrease of copper caused by deposition of copper sulphide was less than the rate of decrease of H+ activity caused by hydrothermal alteration.

Trace-element studies of the orebody and the Lornex fault zone discovered anomalous values for several elements. Anomalously high amounts of Zn, Ag, and Bi, and, according to Olade (1974), Pb, Mn, Hg, Cd, and Ca exist in the Lornex fault zone where it truncates the orebody. Zinc values as high as 1 200 ppm have been determined from analyses of Lornex fault gouge. Sphalerite and discontinuous pods of massive pyrite occur in the zone, but chalcopyrite, bornite, and molybdenite have not been observed. Assays of over 70 ppm Bi in the fault are probably due to the presence of bismuthinite, which was identified by microprobe analyses of copper concentrate. The orebody is enriched in B, Ti, and V, but is low in Mn, Sn, and Ba.

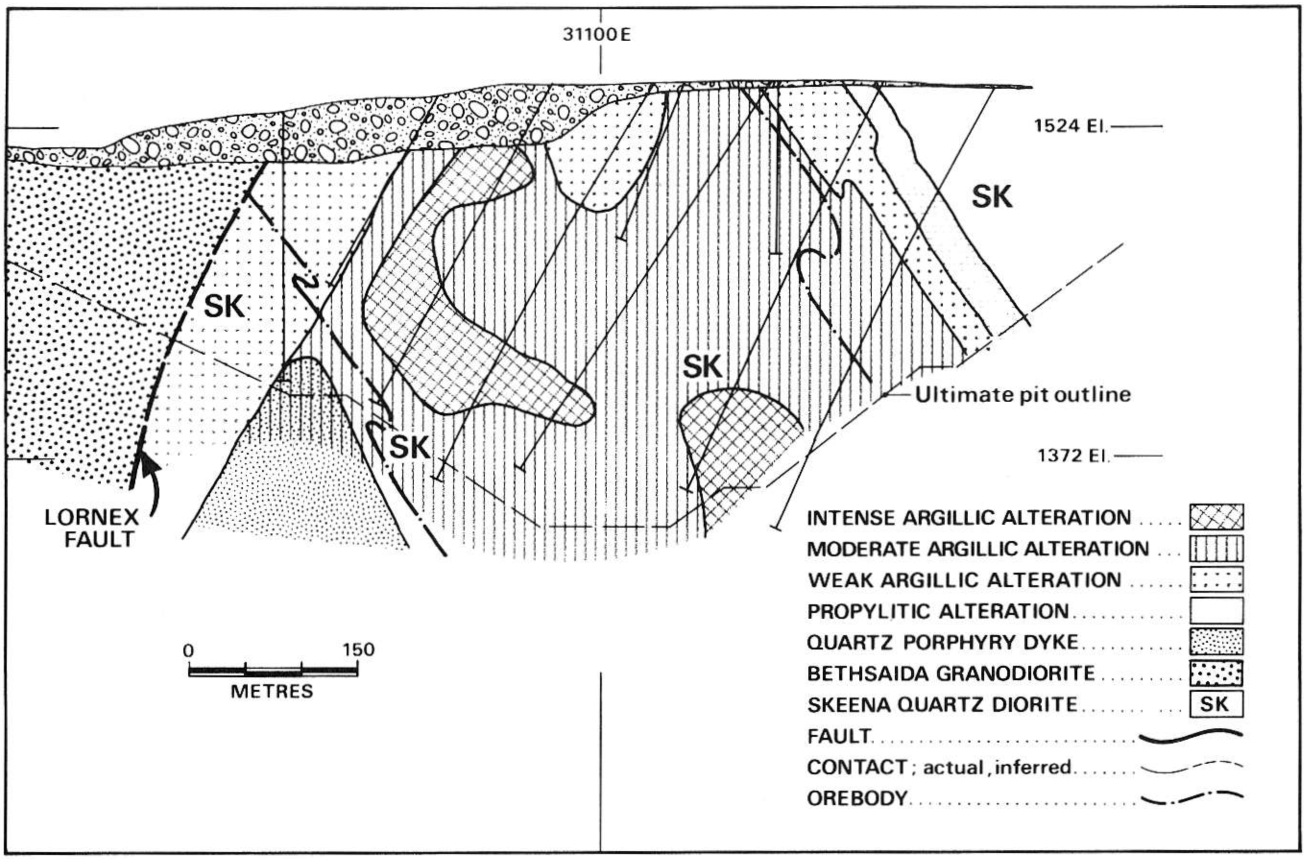
### 8-6-1 **Weathering and Supergene Characteristics**

The oxide zone averages 3 to 30 metres in thickness and contains only minor amounts of recoverable copper sulphides. It is thickest on the west side of the orebody and thins toward the east. The depth of the zone is irregular, apparently controlled by local fracture density. Malachite is the predominant copper mineral in the oxide cap, but azurite, cuprite, chalcocite, covellite, and native copper are common. Limonite and pyrolusite are also abundant in this zone. No molybdenum oxide minerals have been identified. Copper enrichment in the oxide zone is not important economically, although a discontinuous 5 to 10-centimetre-thick layer of chalcocite occurs at the oxide-sulphide interface.

## 8-7 **GENESIS**

Relative ages of mineralization have been determined from crosscutting relationships, polished section exsolution features, and vein zoning. The stages of mineralization and related alteration types are illustrated on Figure 26. Quartz is ubiquitous in all but the two youngest stages of mineralization. Molybdenite occurs in stages 2 to 5, but is most abundant in stages 4 and 5. Copper mineralization generally is confined to stages 3, 4, and 5. Pyrite mineralization is mainly in stage 7 and peripheral to the ore zone. Calcite veining is associated with propylitic alteration as a late-stage alteration product. The final stage of mineralization, gypsum, has no associated alteration. It occurs mainly below the 'gypsum line' near the 1 200-metre elevation on Figure 25.

Plan and section views show concentric zonal distributions of principal sulphides and major hydrothermal alteration types at Lornex (Figs. 24 and 25). Sulphide and alteration zones plunge northwesterly at 30 to 40° and terminate abruptly against the footwall of the Lornex fault. Bottoms of zones have been determined by drilling in the south-central portion of the orebody and by interpretation in the northern part. The shallow depth of the zones in the south-central area coincides with the highest level of quartz porphyry dyke intrusion.



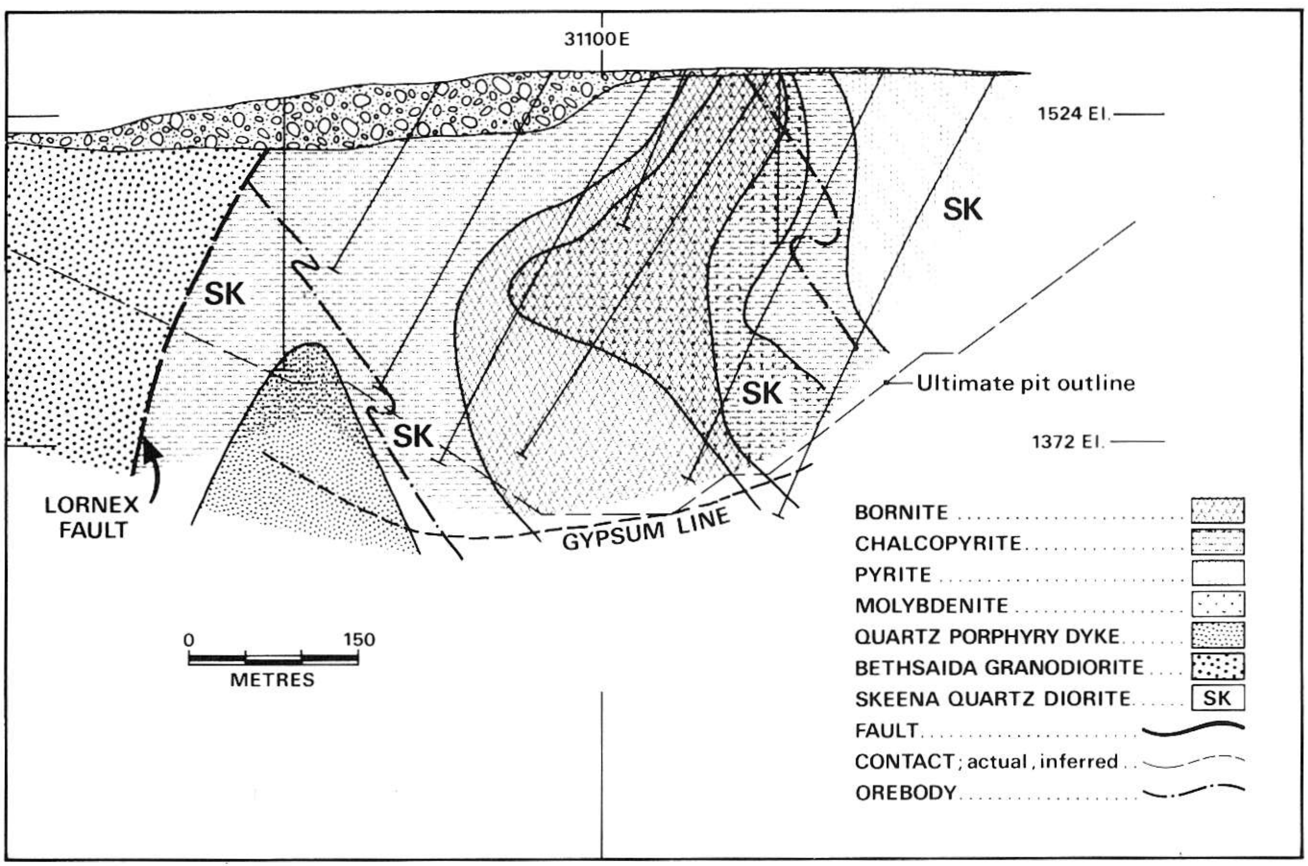




Figure 25. Section A-A', looking north, through the Lornex orebody showing zones of hydrothermal alteration and sulphide mineral distribution patterns (modified after Waldner, et al., 1976).

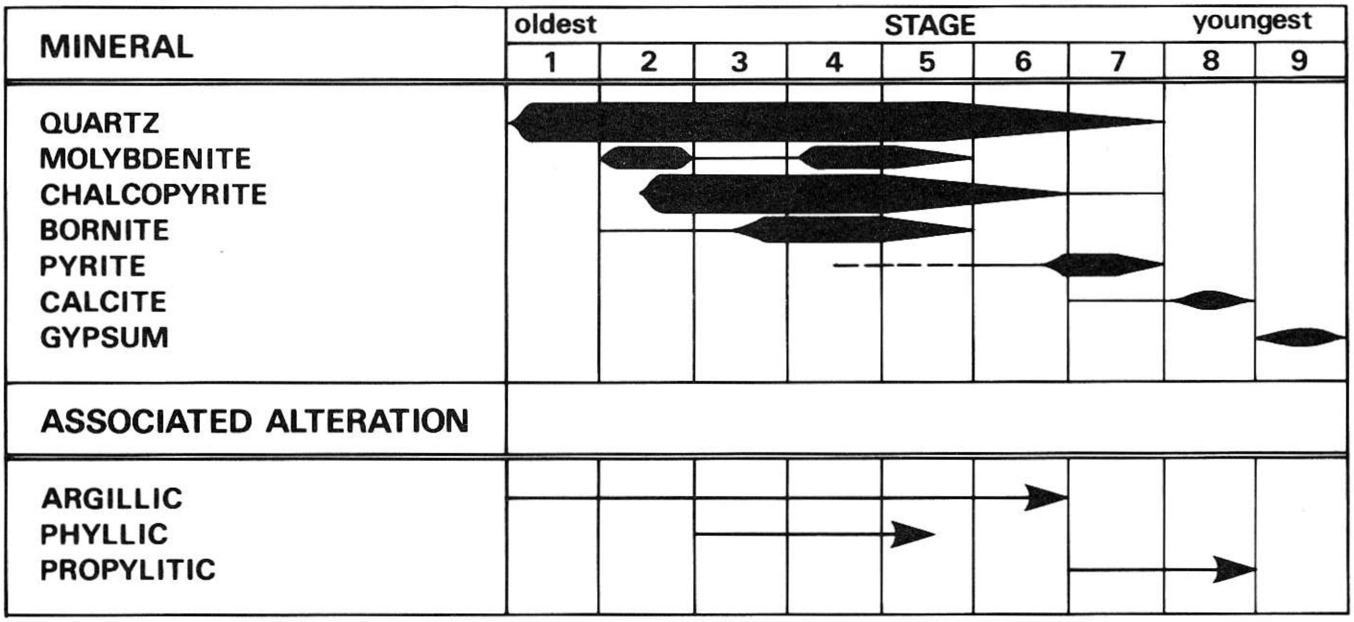



Figure 26. Stages in the paragenetic sequence showing relative abundance of metallic and non-metallic hypogene minerals and related alteration facies (after Waldner, et al., 1976).

Hydrothermal alteration in the dyke is weak; sulphide content is also relatively low. This may be due in part to the very fine-grained nature of the dyke matrix, in part to low fracture density, and in part to its halo of silicified rock. These factors may have impeded flow of hydrothermal fluids into the dyke.

The following general statements regarding the mineral and alteration zoning of the orebody can be made:

(1) The principal sulphides form a concentric pattern, with bornite in the centre, chalcopyrite outside bornite, and a molybdenite zone overlapping portions of the bornite and chalcopyrite zones. Pyrite forms a halo around the ore zone.

(2) Copper grades and total sulphide content decrease outward from the core of the orebody to its periphery.

(3) Sulphide and alteration zones continue to depth in the northern portion but are shallow in the southern portion of the orebody, indicating a 30 to 40°-northwest plunge to the orebody.

(4) Zones of moderate to intense argillic alteration correspond to grades higher than 0.26 per cent copper and total sulphide content greater than 1 per cent.

(5) The propylitic alteration zone occurs on the margin of the orebody; it is associated with subeconomic copper grades, the pyrite zone, and a total sulphide content of less than 0.5 per cent.

Any interpretation of the genesis of the orebody must take the following factors into account:

(1) Mineralization is slightly younger than the Bethsaida phase.

(2) The Lornex fault and the quartz porphyry dyke represent zones of weakness.

(3) The Skeena quartz diorite and the ore zone are truncated by the Lornex fault.

(4) Right-lateral and reverse movement occurred on the Lornex fault.

(5) Sulphide mineralization occurs primarily as fracture infillings.

(6) Copper-molybdenum veins are mainly in discrete sets of fractures.

(7) The density and spatial distribution of veins in the orebody control grades.

(8) There are two post-mineral structural systems.

(9) Hydrothermal alteration related to stages of mineralization changes with time.

(10) Hydrothermal alteration is weaker and sulphide content lower in the quartz porphyry dyke.

(11) Sulphides and phases of hydrothermal alteration are concentrically zoned.

(12) The ore deposit plunges 30 to 40° toward the northwest.

Emplacement of the Guichon Creek batholith appears to have been controlled by major, deep-seated zones of weakness (Carr and McMillan, 1970). The Lornex fault may be the rejuvenated supracrustal expression of one of these deep-seated structures. The quartz porphyry dyke, which probably was derived from the Bethsaida phase, was emplaced along a northwest-trending zone of weakness which intersects the Lornex fault.

Pre-mineral tectonic stresses are thought to have formed a conjugate shear system at the intersection of the Lornex fault and the quartz porphyry dyke. Maximum principal stresses from the east-northeast and west-southwest produced shear fractures striking 022° and 090°, and extension fractures striking 064°. Ore-bearing hydrothermal fluids, which may have developed by late-stage fractionation from the batholith, migrated along the fractures and formed an epigenetic ore deposit with sulphide minerals and hydrothermal alteration concentrically zoned around a more permeable core zone (Fig. 24).

Following mineralization, it is thought that regional stresses, with maximum principal stresses from the east-northeast and west-southwest, produced further shearing subparallel to and along 022° and 090°-striking veins. It is probable that right-lateral displacement took place on the Lornex fault during this period of deformation. Apparently, the Lornex orebody (the portion east of the fault) was tilted down in the north and relatively up in the south at this time. This tilt is invoked to explain why mineralized fractures now dip in a southerly direction and why sulphide and alteration zones plunge 30 to 40° northwesterly.

A late-stage deformation produced by maximum principal stresses, oriented from the northwest and southeast, developed a conjugate shear set oriented 115° and 172°, and extension fractures striking 136°. Displacements related to this period of deformation are generally small.

Tertiary weathering and Pleistocene glaciation and other geomorphological processes developed the present oxide cap and cover of glacial, fluvial, and lacustrine sediments.

# 9 J.A. DEPOSIT
(W.J. McMillan)

## 9-1 INTRODUCTION

The J.A. deposit is in the Highland Valley at latitude 50°28.5', longitude 120°58.5' in NTS 92I/7W, at elevation 1 220 metres. The deposit underlies the road along Highland Valley, about 3 kilometres east-southeast of Quiltanton Lake; it is not exposed in outcrop.

East of Quiltanton Lake, granitic bedrock underlying Highland Valley is covered by a wedge of Tertiary volcanic and sedimentary rocks that thins eastward and feathers out 2.5 kilometres west of the J.A. deposit. In the vicinity of the deposit bedrock has little or no pre-glacial cover, but glacial sediments infill the valley to depths of 170 metres on average and more than 300 metres locally.

## 9-2 HISTORY

The J.A. deposit, named for J.A. McClelland, chairman of Bethlehem Copper Corporation Ltd., was discovered in the summer of 1971. Early drilling was hampered by deep overburden, but the problem was overcome by using rotary drills to reach bedrock and then diamond drills to penetrate it. More than 100 drill holes have delineated the deposit (Figs. 27 and 28) and outlined reserves of 260 million tonnes containing 0.43 per cent copper and 0.017 per cent molybdenum. A preliminary pit described in the company's 1972 annual report was designed to recover 115 to 135 million tonnes of material from the deposit, with a grade of 0.60 to 0.65 per cent copper equivalent and a stripping ratio of 2.5:1.

## 9-3 GEOLOGY

### 9-3-1 Introduction

The J.A. deposit is elongated in a northwest direction with average dimensions of 1 300 metres by 300 metres (Fig. 27). It straddles the north-striking contact between rocks of the Guichon variety of the Highland Valley phase and those of the Bethlehem phase. Roughly 60 per cent of the deposit is in Bethlehem granodiorite. Along the south margin, there is a 'zone' of quartz-plagioclase porphyry that cuts the Guichon-Bethlehem contact and is elongated subparallel to the ore zone. Mineralization extends only a short distance into the porphyry before grades become very low. The porphyry is variously interpreted to be a stock which is an offshoot of the Bethsaida phase (McMillan, 1973), or a metasomatic alteration zone (Guilbert and Lowell, 1974). The outer chilled rind of the stock was fractured and flooded by potassic feldspar alteration; away from the contact, in relatively fresh zones, are found embayed quartz crystals and plagioclase with complex oscillatory zoning - strong evidence for a magmatic origin. Further, dykes exist which are texturally similar to the porphyry.

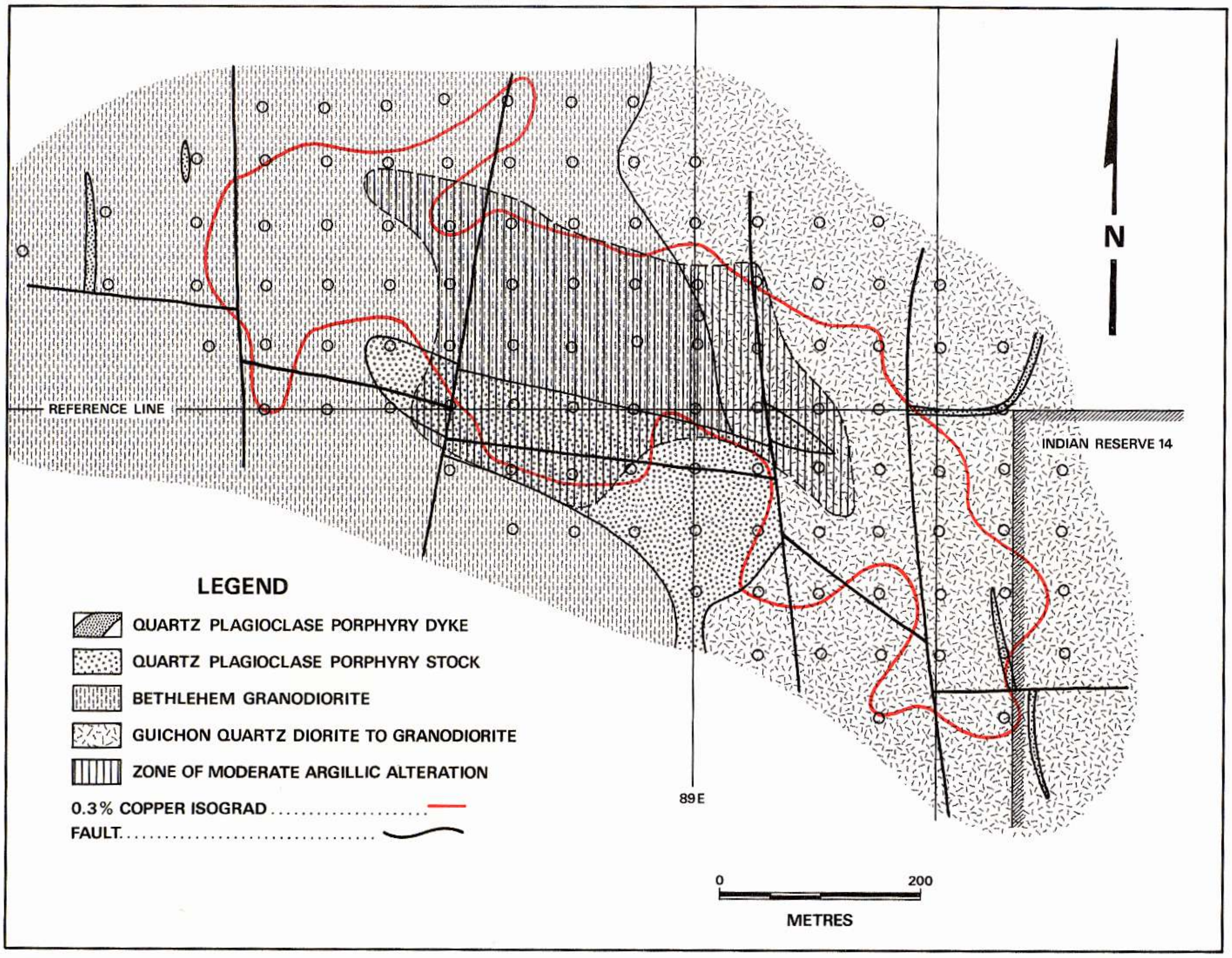



Figure 27. Bedrock geology, drill hole plan, distribution of mineralization, and the zone of moderate argillic alteration in the J.A. deposit (after McMillan, 1976).

## 9-3-2 **Host Rocks**

Rocks of the Guichon variety near the stock are granodiorites to quartz diorites with typical textures. In contrast, Bethlehem phase granodiorites in the area of the deposit are unusual in that they carry not only mafic phenocrysts, but also several per cent rounded to subrounded quartz phenocrysts; typical Bethlehem granodiorites have ameboid, interstitial quartz. As is typical for the Bethlehem phase, plagioclase in these rocks is subhedral with complex oscillatory zoning; core zones are more calcic ($An_{37}$ to $An_{30}$) than rims ($An_{23}$ to $An_{14}$).

## 9-3-3 **Dykes**

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

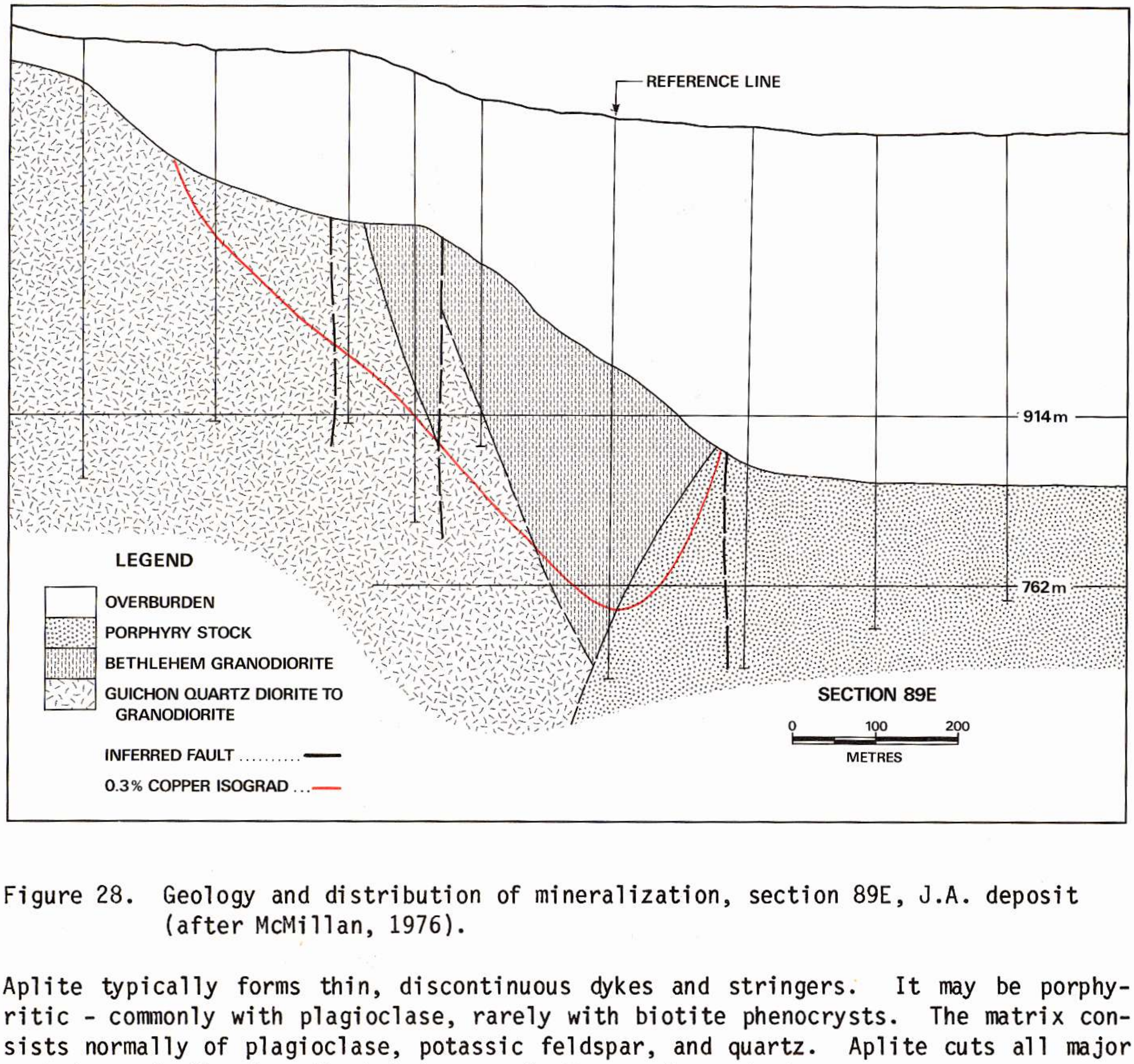



Figure 28. Geology and distribution of mineralization, section 89E, J.A. deposit (after McMillan, 1976).

Aplite typically forms thin, discontinuous dykes and stringers. It may be porphyritic - commonly with plagioclase, rarely with biotite phenocrysts. The matrix consists normally of plagioclase, potassic feldspar, and quartz. Aplite cuts all major rock types in the deposit, but is rare in the porphyry stock.

Pre-ore porphyry dykes are generally wider and more continuous than the aplites; the maximum true width of the porphyry dykes may be as much as 10 metres. Some can apparently be projected between drill holes (Fig. 27), and similar dykes which crop out to the northeast and south have been traced as much as 2 kilometres along strike. Like the aplites, the porphyry dykes cut all major rock types but are uncommon in the porphyry stock. At one locality, a porphyry dyke cuts biotite-quartz-plagioclase aplite; however, crosscutting relationships show at least two generations of porphyry dykes, so the overall aplite-porphyry relationship is not certain.

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

Phenocrysts of mafic minerals, quartz and plagioclase (andesine) comprise, on average, 40 per cent of the pre-ore porphyries. Complex oscillatory zoning characterizes plagioclase phenocrysts, but crystal borders are always more sodic than cores. Matrices are quartzofeldspathic and aphanitic to finely aplitic; most are speckled with finely crystalline mafic minerals, normally biotite. Accessory minerals are magnetite, apatite, and locally chalcopyrite; potassic feldspar is generally absent.

Post-ore dykes are dark coloured, fine grained, and generally amygdaloidal. Most are slightly porphyritic, with fine to medium-grained plagioclase ($An_{55}$) and pyroxene phenocrysts. The matrix has plagioclase and some hornblende microlites in a groundmass of devitrified glass. Amygdules consist primarily of calcite. These dykes closely resemble nearby lavas of the Tertiary Kamloops Group which are of Eocene age. However, it is possible that they are of Lower Cretaceous age, analogous to lamprophyre dykes at Valley Copper (Jones, et al., 1972, p. 557).

### 9-3-4 **Porphyry Stock**

Rocks of the porphyry stock vary in texture and grain size. Toward the outer edges, porphyritic aplites dominate; within the stock porphyritic quartz monzonite predominates. Phenocrysts are mostly quartz and plagioclase; mafic phenocrysts occur locally, and there are rare potassic feldspar phenocrysts. Biotite is the typical mafic mineral. The matrix is largely quartz and potassic feldspar, but some specimens also have finely crystalline subhedral plagioclase.

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

Phenocryst and matrix potassic feldspar are microperthitic. Where present, phenocrysts are subhedral to anhedral; their borders are intergrown with matrix potassic feldspar. The latter varies from anhedral to rounded where it is intergrown with ameboid clumps of quartz crystals in aplitic rocks. Alteration of potassic feldspar consists generally of a light or dense clouding of the crystals by clay (?) alteration; locally they are altered to carbonate.

Biotite is the predominant mafic mineral in the stock; it generally occurs as phenocrysts. Commonly it is pervasively chloritized; locally there is associated epidote, sericite, or carbonate alteration.

Rocks of the stock bear a strong textural and compositional resemblance to various members of the composite Gnawed Mountain dyke and locally to porphyritic areas within the Bethsaida phase. By analogy, the J.A. porphyry stock is inferred to be an offshoot of the Bethsaida phase.

## 9-4 STRUCTURE

### 9-4-1 **General Setting**

The J.A. deposit is in a down-dropped fault block, the Highland Valley graben (Fig. 11). Initiation of the high-angle west-northwest-striking faults along Highland Valley took place after emplacement of the batholith, but prior to mineralization at Valley Copper (Allen and Richardson, 1970; McMillan, 1971). Similarly, north-striking faults at Valley Copper and at Bethlehem Copper (Coveney, 1962) pre-date mineralization. On the basis of bedrock contours and drill hole information, west-northwest and north-striking faults are interpreted to exist in the J.A. zone (McMillan, 1973). By inference, they are assumed to have existed prior to mineralization and to have played a role in initiating the many fractures which were subsequently mineralized to form the deposit. Faulting probably occurred twice subsequently - during Mesozoic block faulting, which controlled the deposition of Jurassic sediments a few kilometres to the west (Carr, 1962), and during Tertiary block faulting, which created the embryonic Highland Valley. Projections of the Guichon-Bethlehem contact from north and south of Highland Valley suggest that there is also aggregate left-lateral movement.

### 9-4-2 **Veins and Fractures**

Most of the mineralization at J.A. is either in veins or fractures. To assess their relative importance across the deposit, data on mineral assemblages, and fractures and vein orientation and density were analysed.

#### 9-4-2a Orientation of Veins and Mineralized Fractures

All drill holes in the J.A. deposit are vertical; therefore, it is possible to estimate dips of mineralized fractures and veins by measuring intercept angles in the core. Dips of almost all mineralized fractures and veins at J.A. exceed 40°. In general, fracture and vein dips are bimodal at 60 and 80 to 90° in the mineralized zone; they tend to be unimodal outside the zone. Maxima for veins and fractures in various sections differ; for example, in section 105E most fractures dip 80° but most veins dip 60°. Because the only data available are from drill holes which are generally greater than 100 metres apart, it has not been possible to estimate strike directions. However, crosscutting features are uncommon, which suggests that the strikes of many of the veins and fractures are subparallel.

#### 9-4-2b Density of Veins and Mineralized Fractures

The density of mineralized fractures varies within and outside the mineralized zone. However, areas with an average fracture spacing of 0.05 to 0.1 metre coincide with areas of highest copper grade; elsewhere in the zone, mineralized fractures have an average spacing of 0.2 metre, although spacings range to 0.7 metre locally. It is evident that mineralized fractures are the most important grade-controlling structures in the deposit. Mineralized quartz veins are sparse and mineralized phyllic alteration zones only locally influence grades.

## 9-5 ALTERATION

### 9-5-1 Introduction

Alteration patterns at the J.A. deposit apparently are complicated by the interaction of the porphyry stock and the hydrothermal system. The carapace and country rock adjacent to the stock are altered; however, the hydrothermal system overlapped with and was probably driven in part by the heat of the stock, so alteration reflects the effects of both events. Overall, alteration is largely vein and fracture related; its intensity is highly variable.

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

Just as feldspar alteration zones vary in intensity, corresponding changes occur in the type and intensity of mafic alteration. However, mafic alteration is also partly related to rock type. Where Guichon quartz diorite predominates, mafic minerals are normally partly and locally pervasively chloritized. Other alteration types are present, but uncommon, and no significant difference in mafic alteration occurs in the best copper grade zone. In contrast, mafic minerals in Bethlehem host rocks in the zone of best copper grade are pervasively altered to chlorite and sericite. Elsewhere, complete or partial chloritization is characteristic.

### 9-5-2 Silicic Alteration

Quartz veins, without sericite alteration halos may be mineralized or barren; they are not abundant. On average they are 3 metres apart in the mineralized zone, but uncommon away from it. They are only 1 to 2 metres apart in the mineralized zone adjacent to the contact of the porphyry stock.

### 9-5-3 Potassic Feldspar and Hydrothermal Biotite Distribution

Potassic feldspar alteration is sparse in the ore zone and generally sporadically developed outside it. However, potassic feldspar is relatively common both in the outer shell of the porphyry stock and in adjacent country rocks. Potassic feldspar alteration apparently is influenced more strongly by proximity to the stock than to the orebody; perhaps this alteration is related to fluids released during crystalization of the stock.

Hydrothermal biotite is distributed widely but sparsely as an alteration product of mafic minerals; it formed early in the alteration sequence. Much hydrothermal biotite was altered subsequently to chlorite, epidote, or sericite. Primary biotite is red-brown in thin section, whereas hydrothermal biotite is greenish brown. Biotite alteration might have been more widespread than it now appears to be.

### 9-5-4 **Phyllic Alteration**

Phyllic alteration consists of quartz plus flaky sericite (muscovite) assemblages that occur as zones or selvedges on veins. It is typically associated with significant copper mineralization. Generally, it is distributed sparsely in holes in and adjacent to the mineralized zone but absent in fringing holes; it is important in the northern part of the ore zone but uncommon elsewhere.

### 9-5-5 **Argillic Alteration**

Pervasive argillic alteration of feldspar to sericite and lesser amounts of kaolinite, montmorillonite, and calcite occurs within and for more than 200 metres outside the J.A. deposit. Overall, it forms an elliptical zone in which the ore zone is roughly central and alteration intensity decreases gradually outward. The highest grade mineralization roughly coincides with the generalized zone of more intense alteration (Fig. 27); however, in detail, alteration intensity is highly variable.

Changes in intensity of pervasive alteration with depth in the deposit are slight, judging from the drill data. However, local areas of less or more intense alteration are common. Most local zones of intense alteration are related to faults, fractures, or veins. In general, alteration is somewhat stronger in the northwestern part of the deposit.

Alteration in the porphyry stock differs. It has a carapace of moderate to intense alteration, which gradually weakens northward outward into the country rock. The southernmost drill hole in the stock ends in weakly altered porphyry. This suggests that alteration also lessens at deeper levels in the porphyry stock.

### 9-5-6 **Propylitic Alteration**

In general, epidote distribution, which is the main indicator mineral for propylitic alteration, seems more closely allied to rock type and geological setting than to grade of mineralization. Epidote alteration is weakly developed on a large scale, moderately to intensely developed locally, and most abundant in the more mafic-rich Guichon granodiorite. It occurs in veins, as fracture coatings, and disseminated in alteration halos around veins or fractures. It also replaces mafic minerals or plagioclase, and occurs as replacement masses. In plan, epidote abundance changes rapidly. In section, contacts are inferred to be digitated. Overall, the propylitic alteration zone is elongated northwestward and widens with depth.

### 9-5-7 **Zeolite Distribution**

Zeolites occur in veins and less commonly in alteration zones adjacent to fractures; they are widespread throughout the deposit. Insufficient data are available to document the overall distribution, so only that in sections 105E and 89E will be discussed. Laumontite predominates; the only other zeolite identified is stilbite. Stilbite was found in only two specimens; in one it is intergrown with calcite, in the other with laumontite. Zeolite veins are generally monomineralic, but locally they also contain calcite, epidote, or sulphide minerals. Apparently the zeolite zones dip gently northward, but their true shape is not known. Zeolite distribution may be controlled by a steeply inclined northerly fracture system; zeolite deposition largely post-dates ore formation.

### 9-5-8 Gypsum Distribution

Gypsum occurs in late-stage fractures and veinlets. Many follow pre-existing structures, because gypsum fractures or veins are often within or subparallel to older fracture fillings and veins. Its distribution is well known for sections logged in detail, but information about its distribution in other drill holes is sketchy. At depth, gypsum is distributed in a narrow, anastomosing zone which roughly coincides with the mineralized zone. Gypsum is present, but sparse, in the porphyry stock and more abundant outside it in Bethlehem granodiorite. Upward, gypsum is much more restricted; it forms an elliptical zone that overlaps the central part of the mineralized zone and extends north of it in Bethlehem granodiorite; it extends only a short distance eastward into the Guichon granodiorite.

### 9-5-9 Calcite Distribution

Calcite occurs in veins and fractures and as an alteration mineral in feldspars in propylitic alteration zones. Calcite in most fractures and veins is post-ore. It typically occurs alone but may be intergrown with quartz or zeolite; less commonly, it fills vugs in sulphide-bearing veinlets.

## 9-6 MINERALIZATION AND ZONING

### 9-6-1 Introduction

The most prominent sulphide minerals in the J.A. deposit are chalcopyrite, bornite, molybdenite, and pyrite. The relative abundances of the copper sulphides and the distribution of molybdenum and iron sulphides were estimated during study of the drill core. Much of the following discussion is based on two cross-sections (89E and 105E) across the deposit which were logged in greater detail than core of other drill holes. In sections which were not logged in detail by the author, grade information and data on vein mineralogy and alteration are from Bethlehem Copper Corporation's drill logs.

At bedrock surface, the J.A. mineralized zone is roughly elliptical in plan. The zone is mainly in Bethlehem and Guichon granodiorite but encroaches slightly on the central porphyry stock (Fig. 27). The contact is relatively uneven; part of this unevenness probably reflects fault control of mineralization, part probably reflects later fault offsets.

On the 762-metre level (Fig. 29), mineralization is narrow and occurs in two zones. Upward, these coalesce and the mineralized zone widens and expands southeastward. By the 914-metre level, there is a single zone with a pronounced southeastward elongation.

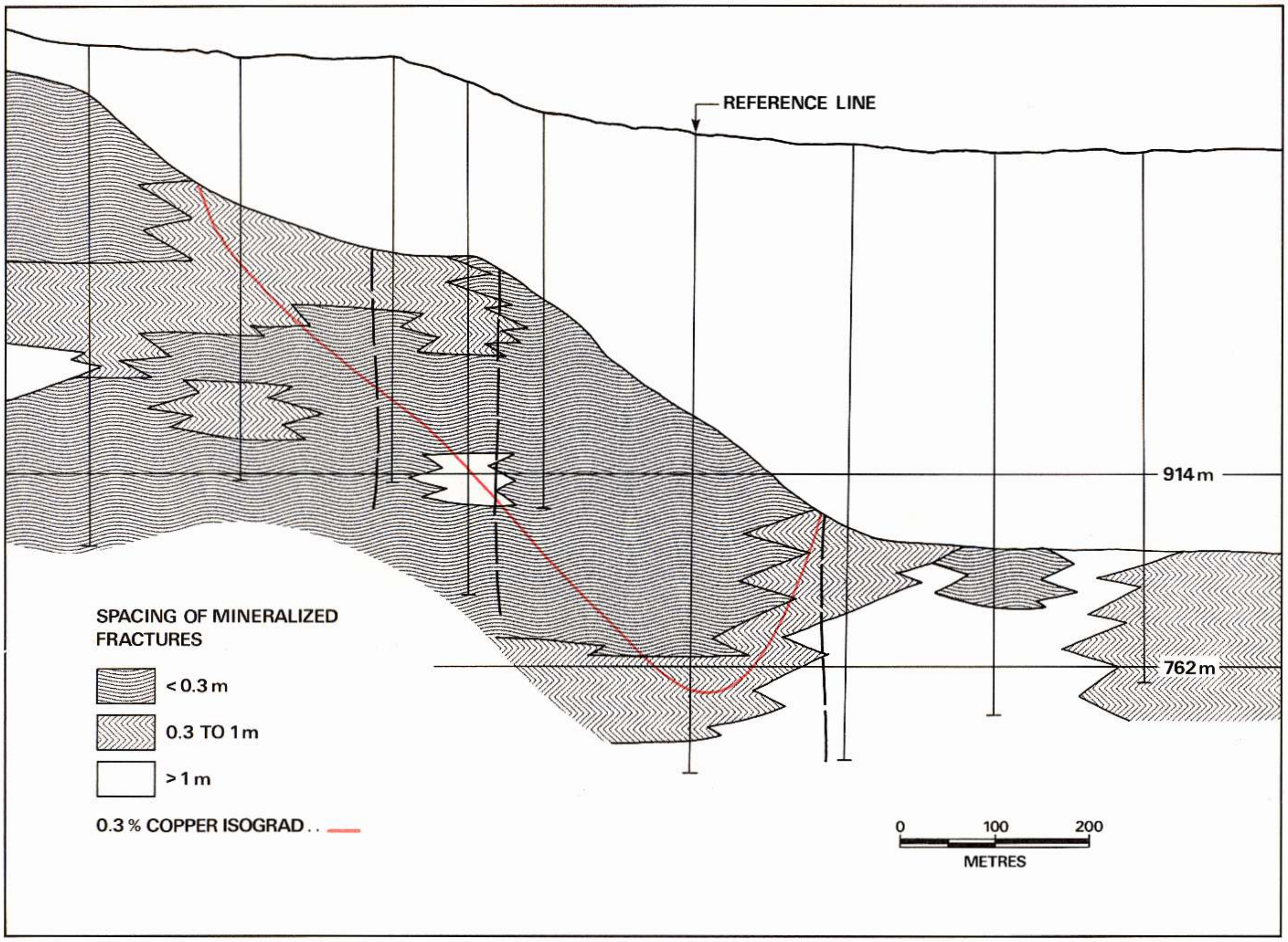



Figure 29. Density of mineralized fractures relative to mineralization, section 89E, J.A. deposit (after McMillan, 1976).

In cross-section, the border of the mineralized zone is not sharply defined; higher and lower grade zones interfinger. The 0.3 per cent copper isopleth shown on the section (Fig. 30) is generalized. However, the base of the deposit is more sharply defined and normally occurs between elevation 750 and 900 metres. Evidently, it dips gently southward. Several holes drilled south of the porphyry failed to intersect any mineralization that is of potential economic interest.

The area of highest grade mineralization encountered lies immediately north of the porphyry stock and straddles the Bethlehem-Guichon contact. This zone has the highest average density of mineralized fractures noted in the deposit, more than average numbers of quartz veins, and zones of phyllic alteration. The closely broken nature of the rock is attributed to the combined effects of tectonism, intrusion of the Bethlehem granodiorite, and intrusion of the porphyry stock.

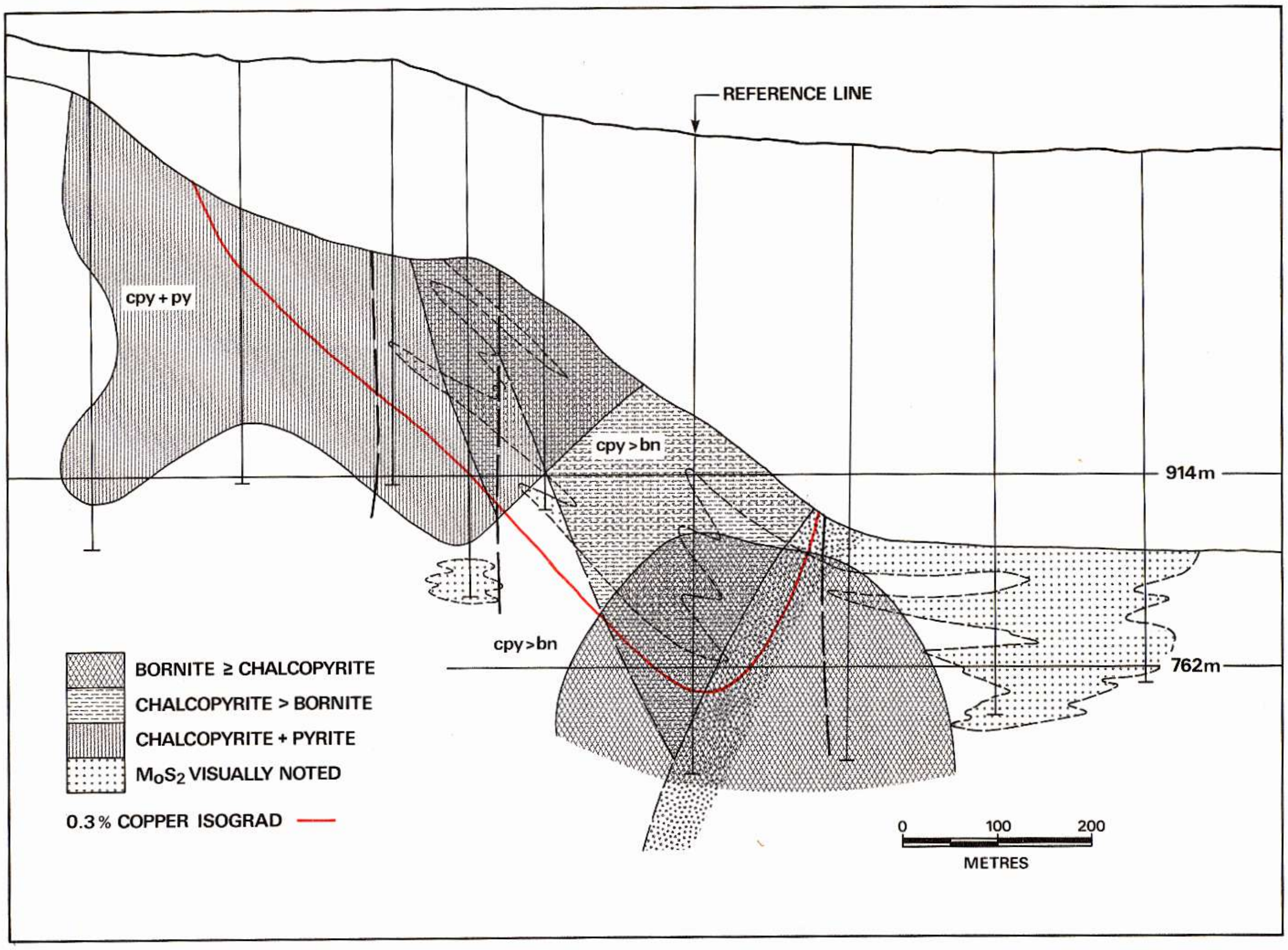



Figure 30. Distribution of bornite, chalcopyrite, pyrite, and molybdenite, section 89E, J.A. deposit (after McMillan, 1976).

## 9-6-2 **Molybdenite Distribution**

Copper and molybdenum distributions are not identical (Fig. 30). The zone of most continuous molybdenite occurrences generally coincides with the copper mineralized zone in the north, but extends beyond it in the south into the most intensely altered zone in the porphyry stock. Molybdenite is present, but sparse, in all drill holes and all rock types.

## 9-6-3 **Chalcopyrite-bornite Abundances**

Bethlehem Copper Corporation geologists estimate that the chalcopyrite-bornite ratio in the J.A. deposit is about 5:1. In general, chalcopyrite exceeds bornite throughout the upper part of the mineralized zone. In the keel of the deposit, where the zone is narrow, bornite abundance equals or exceeds that of chalcopyrite (Fig. 30). The bornite zone is fairly extensive, but the grade within it is predominantly less than 0.3 per cent copper. Overall, the bornite zone forms a series of dome-shaped areas with nearly horizontal upper surfaces. The domes apparently have diffuse and digitating contacts, but their generalized contacts are relatively symmetrical in cross-section. Bornite-rich zones occur mainly in and adjacent to the porphyry stock, although one zone is associated with a quartz-plagioclase porphyry sill (?).

### 9-6-4 **Pyrite Distribution**

Pyrite is relatively common within the mineralized zone and forms a dispersed, incomplete halo around it. The bornite and the pyrite zones are antipathetic (Fig. 30). The base of the pyrite zone is subparallel to the upper contact of the bornite zone. The pyrite zone extends to bedrock surface and northward well beyond the 0.3 per cent copper isopleth. Bethlehem Copper Corporation geologists estimate that pyrite averages less than 2 per cent by volume in the pyrite zone.

### 9-6-5 **Sulphide Zoning**

Sulphide zonation is similar to that at Highmont. There is a bornite-dominated zone in and adjacent to the porphyry stock succeeded upward and outward by chalcopyrite then pyrite-dominated zones. Bornite and pyrite are generally antipathetic. To the north and probably to the west, the chalcopyrite zone grades outward to a chalcopyrite-pyrite, then locally to a pyrite-chalcopyrite zone. Most of the areas with grades exceeding 0.3 per cent copper are in the chalcopyrite and chalcopyrite-pyrite zone. Except at the western edge of the deposit, no pyrite occurs south of the zone. In detail, the sulphide zones can be mixed and all are variably developed.

## 9-7 GENESIS

The J.A. deposit is in a graben which underlies Highland Valley. The deposit is structurally controlled and most of the fractures and veins in it are moderately steep to steeply inclined. From the structural setting and bedrock topography it is inferred that the deposit occurs within a framework of northerly and northwesterly faults. It seems likely from regional information that the faults largely pre-date mineralization.

At bedrock surface, the deposit is elliptical, with its long axis oriented northwestward. At depth, it splits into two root zones, each of which is similarly elongated. Much of the deposit is in granodiorites of the Bethlehem phase and the Guichon variety of the Guichon Creek batholith. The mineralization extends a short distance southward into, but is essentially bounded by, a quartz-plagioclase porphyry stock, which appears to be an offshoot of the Bethsaida phase of the batholith. The deposit extends along and beyond the northern edge of the elliptical stock. Highest copper grades occur adjacent to the Guichon-Bethlehem contact, which was probably closely fractured during injection of the Bethlehem phase, then further fractured during emplacement of the porphyry stock.

The density of mineralized fractures is the most important grade control, although mineralized quartz veins and mineralized quartz-sericite zones are important locally. Copper minerals occur as fracture fillings, in veins, and in alteration selvedges. Sulphides commonly partially replace mafic minerals in these selvedges.

The underlying parent magma of the stock is presumed to be the source of mineralizing fluids and associated mineralization. The earliest alteration event followed emplacement of the porphyry stock. It consisted of potassic feldspar alteration in and adjacent to the stock and local (?) development of secondary biotite after mafic minerals in the country rock. Minor quartz and chlorite veining also mark this early event. It is not certain whether sulphide mineralization occurred during this stage. The main hydrothermal stage of mineralization occurred in two major episodes. The earlier episode was characterized by the association of sulphides with phyllic alteration or quartz veining. During the second episode, sulphides generally were associated with quartz and propylitic alteration. Hydrothermal chlorite formed in veins and replaced mafic minerals throughout the main ore phase. Apparently, minor amounts of calcite, zeolite, and anhydrite, now hydrated to gypsum, were deposited with sulphides during the main stage of mineralization. As the hydrothermal system waned, sulphide, quartz, and epidote deposition diminished and that of zeolite, typically laumontite, increased. Zeolite was joined to a minor degree by calcite and was succeeded by late-stage deposition of calcite and gypsum.

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

Few clear crosscutting relationships were observed. Locally, it is evident that early veins were broken by faulting before the next wave of hydrothermal fluids recemented them. It is also evident that various ages of veining followed roughly the same fracture patterns. These data suggest that fault movement was not significant during the tenure of the hydrothermal system. Reopening of healed fractures and propagation of new fractures is ascribed to pressures generated during the influx of hydrothermal fluids. Whether boiling of the fluids occurred is open to speculation. However, the deposit is thought to have been relatively shallow and is in an area where there are numerous dykes. Consequently, boiling and venting of hydrothermal fluids to the surface are possibilities. The hydrothermal system collapsed following zeolite and possibly during gypsum and calcite deposition.

Subsequently, the deposit was preserved in the down-dropped block that produced the Highland Valley; later it was intruded by dykes which apparently fed Tertiary flows. Minor development of oxide minerals suggests that erosion exposed bedrock either before or during Tertiary time. The deposit is covered to an average depth of 170 metres by Pleistocene glacial deposits.

## 10 VALLEY COPPER DEPOSIT
(W.J. McMillan)

### 10-1 INTRODUCTION

The Valley Copper porphyry deposit (latitude 50°29' north, longitude 121°02' west, NTS 92I/6E) has been explored extensively by drilling and underground workings; development began in spring, 1982. Published reserves, to a depth of 442 metres, are 790 million tonnes of 0.48 per cent copper. A historical summary of the discovery of the deposit may be found in Allen and Richardson (1970). Except where otherwise acknowledged, data in this paper are mainly after Osatenko and Jones (1976).

### 10-2 HISTORY

In the 1920's shallow shafts were sunk on high-grade chalcopyrite veins on the Bethsaida claims southwest of the Valley Copper deposit. After the second World War, Western Beaver Lodge Mines Ltd. acquired the claims and performed geochemical surveying and trenching. Kennco Explorations, (Canada) Limited optioned the Bethsaida claims in 1957 and after performing a wide-spaced induced polarization survey, one line of which crossed the western edge of the Valley Copper deposit, Kennco relinquished its option. In 1964 and 1965 most of the mineral claims that comprise the Valley Copper property, including the Bethsaida claims, were acquired by Cominco Ltd. through agreements with Northwest Ventures Ltd., Hueatis Mining Corporation Ltd., Buttle Lake Mining Company Limited, B.X. Mining Company Limited, and various individuals. As part of the agreement, Valley Copper Mines Limited was incorporated. Also in 1964, three holes were drilled on the Bethsaida claims. Subsequent drilling of 10 additional holes in 1966 indicated large amounts of sub-ore grade copper mineralization just southwest of the Valley Copper deposit. This find, in addition to information gained from a geologic study of the Guichon Creek batholith and discovery of the Lornex orebody, nearby to the south-southeast, indicated that the Valley Copper site warranted more intense exploration. Favourable results obtained from an induced polarization survey and percussion drilling over the Valley Copper site in 1967 were followed by a large-scale drilling program that led to discovery of the orebody and to its continuous exploration and development through 1970; production began in the spring of 1982.

### 10-3 GEOLOGY

The rocks that contain the Valley Copper deposit are mainly porphyritic quartz monzonites and granodiorites of the Bethsaida phase of the Guichon Creek batholith (Fig. 31). These rocks are medium to coarse grained with coarse phenocrysts of quartz and biotite. Accessory minerals are hornblende, magnetite, hematite, sphene, apatite, and zircon.

Feldspar porphyry and quartz feldspar porphyry dykes occur in the western, central, and southern parts of the deposit. These dykes, which vary in width from about 0.6 to 35 metres, dip steeply eastward in the western and central areas, and northward in the southern area. Feldspar porphyry dykes consist approximately of 60 per cent medium to coarse-grained plagioclase and a small number of quartz phenocrysts in a fine-grained matrix consisting of quartz, potassic feldspar, and lesser plagioclase, with trace amounts of magnetite, hematite, and biotite. Quartz feldspar porphyry, which ranges from fine to coarse grained, contains 50 per cent plagioclase and 8 per cent quartz phenocrysts in a fine-grained matrix of quartz and plagioclase that contains minor amounts of potassic feldspar, magnetite, and hematite. These dykes are invariably cut by mineralized fractures and quartz veinlets. A single potassium-argon determination on biotite gave an age of 204±4 Ma (Osatenko and Jones, 1976).

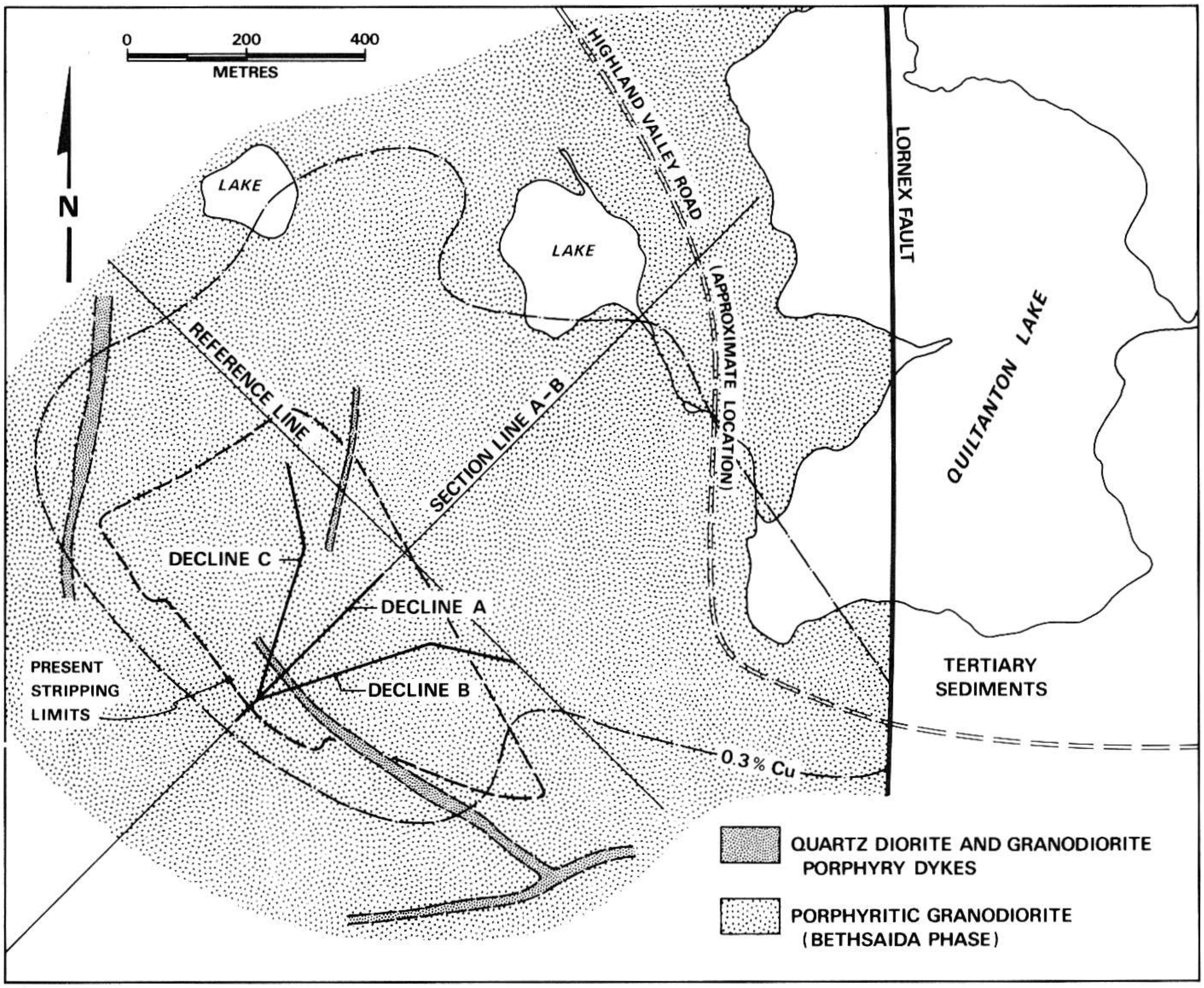



Figure 31. Plan view showing the geology and the ore outline in the Valley Copper deposit (after Osatenko and Jones, 1976).

Aplite dykes, up to 0.3 metre in width, occur throughout the deposit. They consist of potassic feldspar and quartz with lesser amounts of plagioclase and biotite. The aplite dykes are invariably cut by mineralized fractures.

A swarm of tan-coloured felsite porphyry dykes intrude the Bethsaida granodiorite in the northwestern part of the deposit. These dykes, which are up to 4.5 metres in width, are characterized by a higher proportion of matrix (about 80 per cent) than the other porphyry dykes. Their matrix is light tan in colour and consists primarily of potassic feldspar and quartz. Phenocrysts make up 20 per cent of the rock and include quartz, plagioclase, potassic feldspar, and biotite.

Tan felsite porphyry dykes may have been intruded during the waning stages of mineralization. Some unaltered dykes contain inclusions of sericite-veined Bethsaida granodiorite, but others contain disseminated chalcopyrite and bornite and are sparsely veined by mineralized quartz.

Three types of lamprophyre dykes - spessartite, hornblende vogesite, and vogesite - were intersected in drill holes. Alteration and mineralization are cut by these younger dykes. Further, the vogesite lamprophyre has a potassium-argon age of 132±3 Ma (Jones, 1975).

## 10-4 STRUCTURE

Cominco Ltd. geologists made about 14 000 structural measurements on faults, fractures, and quartz veinlets in the exploratory declines. Faults comprise four distinct sets, represented by the following orientations: 173°/75° east, 004°/90°, 108°/84° south, and 000°/16° east. Fractures include corresponding sets at 169°/80° east, 000°/90°, and 108°/85° south, and additional sets at 073°/18° south and 035°/70° northwest. Quartz veinlets show well-developed sets at 161°/80° east and 111°/79° south that are subparallel to the earlier formed principal sets of fractures and faults (McMillan, 1971). The main structural orientations that occur in the declines are parallel to the Lornex and Highland Valley faults respectively (Allen and Richardson, 1970).

## 10-5 ALTERATION

### 10-5-1 Introduction

Alteration types recognized at Valley Copper are: silicic, potassic, phyllic, argillic, and propylitic. In general, alteration types are associated intimately, even at hand specimen scale. A generalized diagram of the distribution of dominant alteration types is depicted on Figure 32. A major zone of potassic feldspar alteration in the west-central part of the deposit is associated with and enveloped by an extensive zone of moderate to strong phyllic and pervasive argillic alteration. These grade outward into a zone dominated by weak to moderate pervasive argillic alteration fringed by a peripheral zone of weak to moderate propylitic alteration. Locally this peripheral zone contains minor amounts of phyllic and pervasive alteration as well as quartz veining. An area of well developed barren quartz veinlets occurs in the southeastern part of the deposit. Elsewhere, quartz veinlets (commonly mineralized, but some barren) are only moderately abundant within the 0.30 per cent copper isopleth.

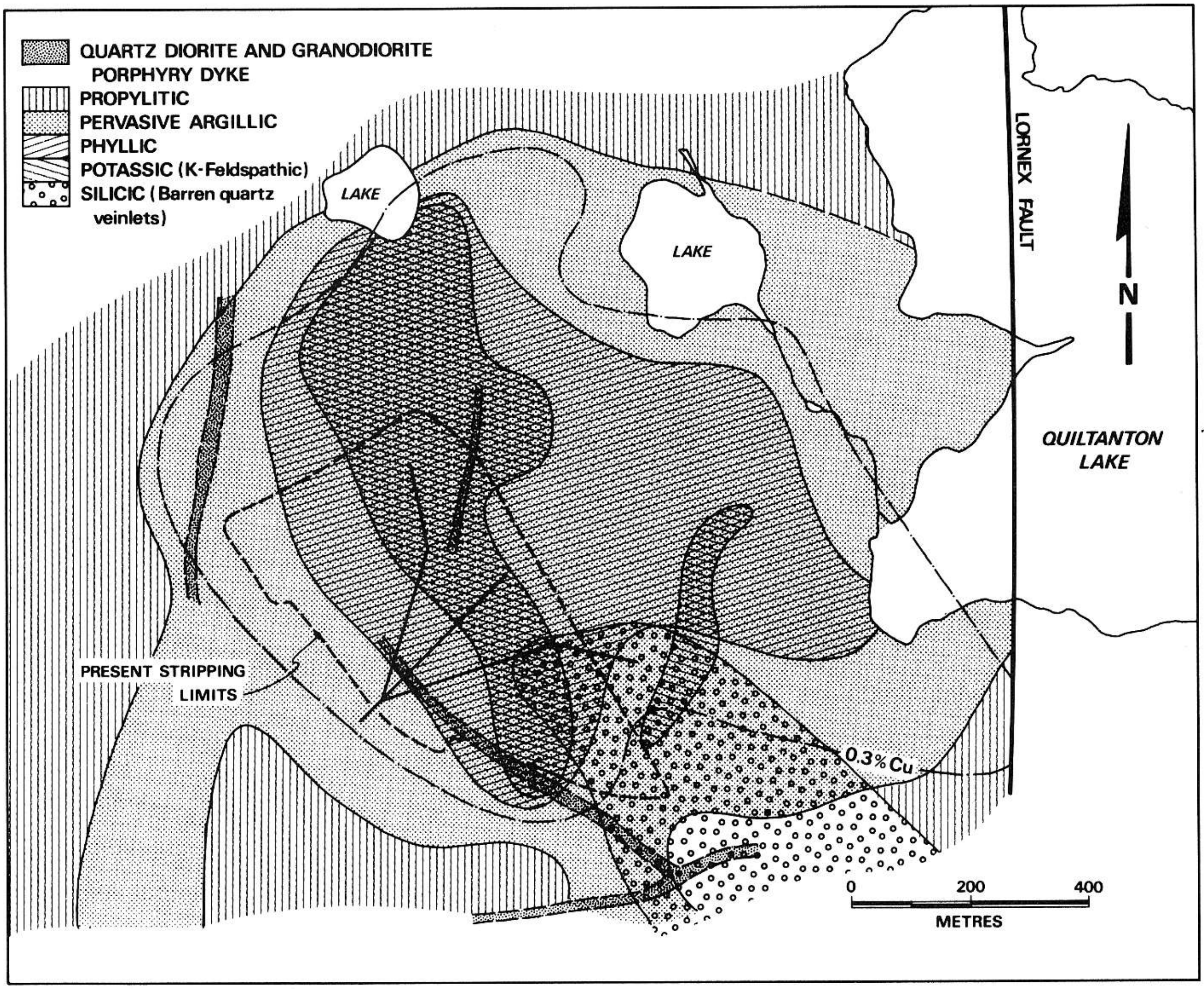



Figure 32. Plan view showing the distribution of major alteration types in the Valley Copper deposit (after Osatenko and Jones, 1976).

### 10-5-2 Silicic Alteration and Veining

Quartz veinlets in the form of a stockwork are a common feature at Valley Copper; typically veinlets are about 1 to 2 centimetres in width, although some are up to 25 centimetres. The term silicic alteration refers to quartz veining and secondary quartz produced as a by-product of sericitization and kaolinitization of plagioclase.

The quartz stockwork consists of two main classes of quartz veinlets. The first, which is commonly vuggy, usually has envelopes of medium-grained sericite, or intergrown sericite and potassic feldspar, or potassic feldspar. Veinlets of this class are closely associated with mineralization. They vary in grain size from 0.4 to 2.5 millimetres (average 1.5 millimetres). These veinlets frequently contain minor amounts of sericite, sericitized plagioclase, secondary potassic feldspar, calcite, hematite, bornite, chalcopyrite, pyrite, molybdenite, digenite, and covellite.

The second class of quartz veinlets have no alteration envelopes and carry essentially no sulphides. Veinlets of this class are most abundant in the southeastern part of the deposit, where they comprise two types: a fine-grained variety, varying in grain size from 0.02 to 1.0 millimetre (average 0.5 millimetre); and a medium-grained variety with grain sizes of from 1.0 to 1.5 millimetres (average 1.3 millimetres). Both types have sharp contacts with the unaltered or pervasively altered country rocks and generally contain minor amounts of potassic feldspar; muscovite is notably absent.

The distribution of silicic alteration and quartz veinlets on the 1 097-metre level shown on Figure 32 is based on the abundance of secondary quartz. Quartz content is expressed as the actual percentage minus the background primary quartz content of the unaltered country rock (29 per cent). The 10 per cent secondary quartz contour outlines the deposit. In areas of greater than 0.50 per cent copper, levels of secondary quartz range up to about 20 per cent. The very low grade zone in the southeastern corner of the deposit is highly silicic, with secondary quartz content ranging from 19 to 27 per cent. It should be stressed that these secondary quartz percentages comprise both barren and mineralized quartz veinlets and a component, which is approximately three-quarters of the total, of secondary quartz that formed from silica liberated during alteration of plagioclase to sericite and kaolinite.

### 10-5-3 **Potassic Alteration and Hydrothermal Biotite Formation**

Potassic feldspar alteration is common at Valley Copper, especially at deeper levels (Fig. 33). It occurs in association with vein sericite (muscovite) in some replacement zones, as veinlet envelopes, along fractures, and disseminated in quartz veinlets.

Potassic feldspar associated with vein sericitic (phyllic) alteration typically forms thin, discontinuous selvedges (about 1 millimetre thick) at the outer margins of sericitic replacement zones, where it apparently replaces sericitized plagioclase or vein sericite. Secondary potassic feldspar is most common in quartz veinlets but also occurs as thin, fracture-controlled replacement zones. Copper mineralization is typically sparse with this type of alteration, and consists of chalcopyrite with trace amounts of bornite and molybdenite.

The upper part of the zone of moderate potassic alteration (5 to 15 per cent) forms a lensoid or mushroom-shaped body. Its upper surface is largely below the 1 036-metre level and conforms closely to the gypsum line. Within the lens are found scattered areas of more intense alteration (15 to 35 per cent). The low-grade copper zone in the central part of section AB (Fig. 33) is a clear expression of the poor correlation between copper mineralization and potassic alteration.

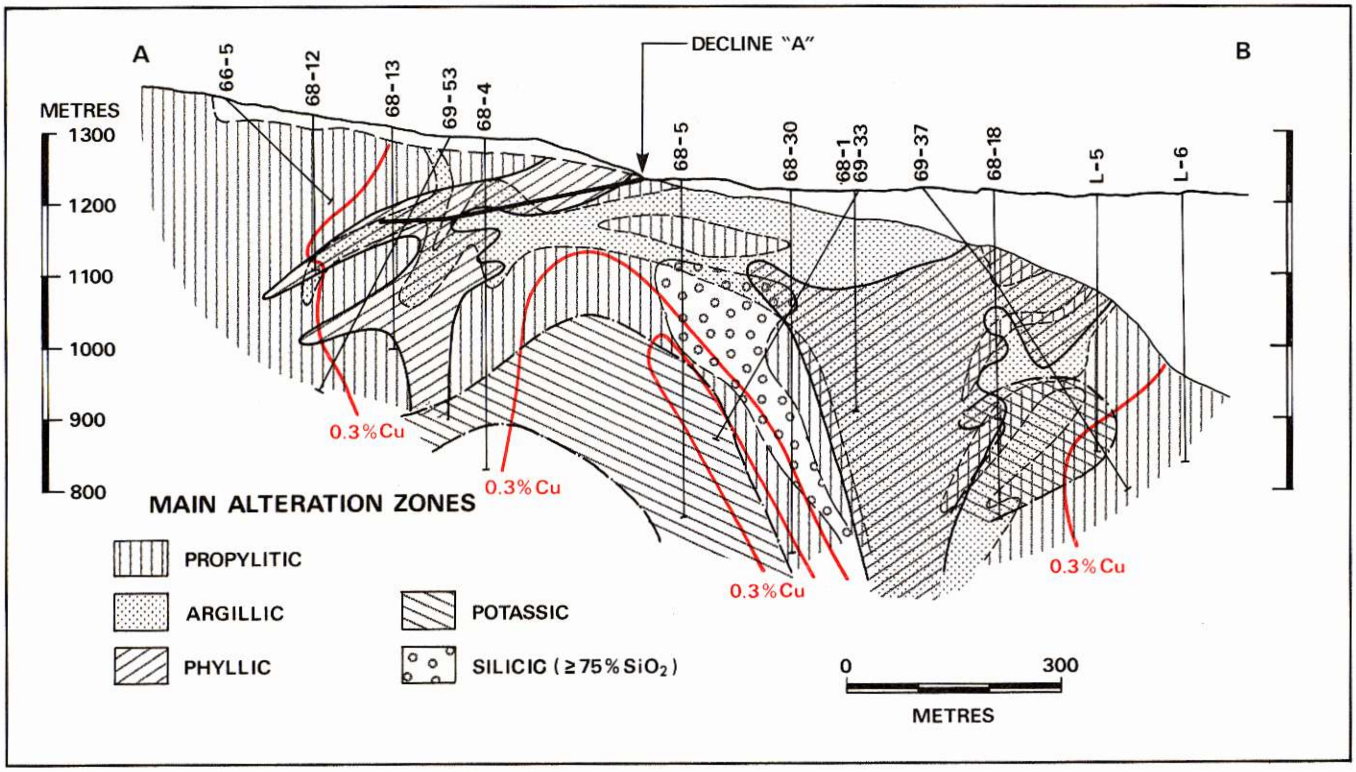



Figure 33. Cross-section A-B through the Valley Copper deposit showing geology and major alteration types (after Osatenko and Jones, 1976). For location see Figure 31.

Minor amounts of hydrothermal biotite (brown to green) replace primary biotite and less commonly plagioclase, or form thin veinlets and replacement patches. Secondary biotite does not appear to form distinct alteration zones.

### 10-5-4 **Phyllic Alteration**

Phyllic alteration consists of flaky sericite (muscovite) and quartz both as replacement zones and as envelopes around quartz veinlets. It is the most common alteration type associated with copper mineralization at Valley Copper. Sericite replacement zones follow fractures and range in width from about 0.5 to 30 millimetres. They typically show irregular, diffuse contacts with adjacent rock and are commonly vuggy. Locally they contain narrow, discontinuous quartz veinlets and grade into the veinlet envelope type. Sericitic borders on quartz veinlets range in width from 0.5 to 25 millimetres but widths do not correlate closely with the thickness of associated quartz veinlets.

Flaky sericite replacement zones and veinlet envelopes consist predominantly of fine-grained quartz and medium-grained muscovite ($2M_1$ type). Minor constituents are calcite, brick-red hematite, highly sericitized and kaolinitized feldspar, sericitized biotite, bornite, chalcopyrite, and trace amounts of pyrite and molybdenite.

The relationship of phyllic alteration zones to adjacent, argillically altered rock is not entirely clear. It might be argued that the two represent different products of the same process. The fine-grained pervasive argillic alteration zones, which grade outward from phyllic areas might constitute transitional zones between phyllic and weakly propylitized rocks. Locally, however, replacement zones and veinlet envelopes have sharp contacts against and apparently crosscut pervasively altered rock. This suggests that solutions causing pervasive argillic alteration preceded solutions causing phyllic alteration; however, both followed the same channelways.

The zone of moderate phyllic alteration (5 to 15 per cent) closely follows the 0.30 per cent copper isopleth, but extends slightly beyond it. The areas of strongest phyllic alteration (greater than 15 per cent) are closely ccincident with areas of greater than 0.50 per cent copper.

### 10-5-6 **Argillic Alteration**

Argillic alteration, characterized by pervasive alteration of feldspar, is gradational to propylitic alteration. X-ray and thermogravimetric analyses show kaolinite to be the dominant clay mineral species in the deposit, although some montmorillonite occurs on its west side (Jones, 1975). Pervasive alteration is strongest where fractures are most closely spaced, whereas propylitic alteration characterizes areas of little or no fracturing. Where pervasive argillic alteration is most intense, plagioclase is completely altered to a green or white, soft mixture of sericite, kaolinite, quartz, and calcite. In these areas, biotite has been completely altered to sericite, siderite, kaolinite, and quartz; primary potassic feldspar has been weakly altered to sericite and kaolinite; and magnetite has been oxidized to hematite. Chalcopyrite, pyrite, and sphalerite are present in trace amounts.

Where moderate to strong pervasive argillic alteration occurs copper content exceeds 0.30 per cent. Propylitic alteration characterizes the peripheral regions of the deposit and, to some extent, the area below the 853-metre level on the west side of the deposit.

### 10-5-6 **Propylitic Alteration**

Propylitic alteration occurs in relatively small areas within the deposit and in zones peripheral to it. It is characterized by weak to moderate alteration of plagioclase to clay, some sericite, epidote, clinozoisite, and calcite, and alteration of biotite to chlorite and epidote. Thermogravimetric analyses of composite samples suggest that a calcite-rich zone, with calcite contents of up to 4.2 per cent, surrounds the deposit. By comparison, calcite contents within the deposit are about 1 per cent. Despite these data, a zone of propylitic alteration spatially associated with the Valley Copper deposit is difficult to define because propylitic minerals have been developed in the country rocks on a regional scale.

### 10-5-7 **Post-mineralization Veining**

Late-stage gypsum, anhydrite, kaolinite, and fluorite veinlets occur at Valley Copper. Gypsum veinlets, which are the most common type, are fracture fillings that are generally less than 2 millimetres in width. They form white to orange, fibrous crystal aggregates which are oriented perpendicular to wallrock contacts. Gypsum is most common in areas with potassic feldspar alteration; it is rare above the 1 036-metre level (Fig. 32).

### 10-5-8 **Paragenesis**

The main alteration types at the Valley Copper deposit display, to some extent, overlapping periods of formation. However, crosscutting relationships defined certain general trends: (i) fracture-controlled vein sericitic (phyllic) alteration appears to be younger than pervasive sericitic and kaolinite (argillic) alteration, but is consistently crosscut by quartz veinlets with vein sericitic (phyllic) alteration envelopes; (ii) pervasive argillic alteration and phyllic alteration are typically cut by quartz veinlets with associated secondary potassic feldspar; (iii) gypsum veinlets cut all alteration types.

The age of barren quartz veinlets with no alteration envelopes is uncertain. They generally cut both phyllic and potassic feldspar replacement zones, but in some cases are cut by phyllic alteration; there are at least two generations of barren quartz veinlets.

Potassium-argon ages of hydrothermal muscovite range from 198±4 Ma (Jones, 1975) to 189±6 Ma and 186±8 Ma (Blanchflower, 1971). These results suggest that the age of the hydrothermal alteration (average 191 Ma) is slightly younger, but not significantly different than the age of crystallization of the batholith, which is 202±8 Ma (Northcote, 1969).

## 10-6 **MINERALIZATION**

### 10-6-1 **Introduction**

Sulphides in the Valley Copper deposit occur chiefly as disseminations in quartz veinlets and in phyllic and potassic alteration zones. The greater part of the copper sulphides are in areas with abundant phyllic alteration and associated quartz veinlets. Bornite is the dominant sulphide in this association, whereas chalcopyrite is the dominant sulphide associated with potassic alteration.

### 10-6-2 **Oxidized Zone**

Typical minerals in the oxidized zone are limonite, malachite, pyrolusite, digenite, native copper, and possibly tenorite. The zone generally varies in thickness from 0.3 to 14 metres and averages 4.5 metres; however, in the southeastern corner of the deposit, where the thickness ranges from 18 to 98 metres, it averages 33 metres.

Profiles of copper grades in the southeastern area show depletion of copper from 0.45 per cent in the unoxidized to 0.35 per cent in the oxidized zones. Grades range up to 0.65 per cent copper in a zone 3 to 6 metres thick that occurs just below the oxidized zone; this probably represents a poorly developed zone of supergene enrichment.

### 10-6-3 **Hypogene Sulphides**

Hypogene sulphides in the Valley Copper deposit are bornite and chalcopyrite, with minor amounts of digenite, covellite, pyrite, pyrrhotite, molybdenite, sphalerite, and galena. Petruk (1970) reported minor amounts of gudmundite (FeSbS) and native gold. According to Osatenko and Jones (1976) the sequence of the sulphide formation, based on crosscutting, filling, and rimming relationships, is as follows: pyrite I; chalcopyrite I; bornite; molybdenite, pyrite II, and chalcopyrite II; sphalerite with minor pyrrhotite and galena; digenite and covellite. The position of sphalerite, pyrrhotite, and galena in the sequence is not certain.

Bornite/chalcopyrite ratios and pyrite contents on the 1 158-metre level plan are shown on Figure 34. Bornite/chalcopyrite ratios on the 1 158-metre level show a distinct high zone (greater than 3.0) in the central part of the deposit; small highs occur in the southern and southwestern parts. Bornite/chalcopyrite ratios decrease progressively away from the centre of the mineralized zone until, outside the 0.30 per cent copper isopleth, bornite is uncommon.

Pyrite abundance on the 1 158-metre level in the central part of the deposit (Fig. 34) is less than 5 per cent of the total sulphides. There is a very subtle pyrite halo around the deposit; in it, pyrite rarely exceeds 1 per cent by volume.

### 10-6-4 **Geochemical Patterns**

Geochemical data were obtained by the analysis of assay pulp composites from various percussion and vertical diamond-drill holes. Percussion hole composites represent the bottom 15 metres of each hole. In the diamond-drill holes, 30-metre composites were made at 76-metre intervals down the holes. Copper sulphide ratios and pyrite contents were found by point-counting polished sections made of sulphide concentrates from the composites (Osatenko and Jones, 1976).

Contents of major and trace elements in fresh Bethsaida granodiorite relative to those in composite samples of different alteration types from various parts of the deposits (Osatenko and Jones, 1976) show that CaO, $Na_2O$, MgO, Sr, Ba, and Mn decrease from the peripheral zone of the deposit, where propylitic and argillic alteration are present, to the central area where phyllic and argillic alteration are best developed. In contrast, contents of $SiO_2$, $K_2O$, Rb, and $TiO_2$ increase from the peripheral regions of the deposit to its centre. $K_2O$, which varies from 2.0 to 3.8 per cent, and Rb, which varies from 35 to 69 ppm, show the most pronounced increases.

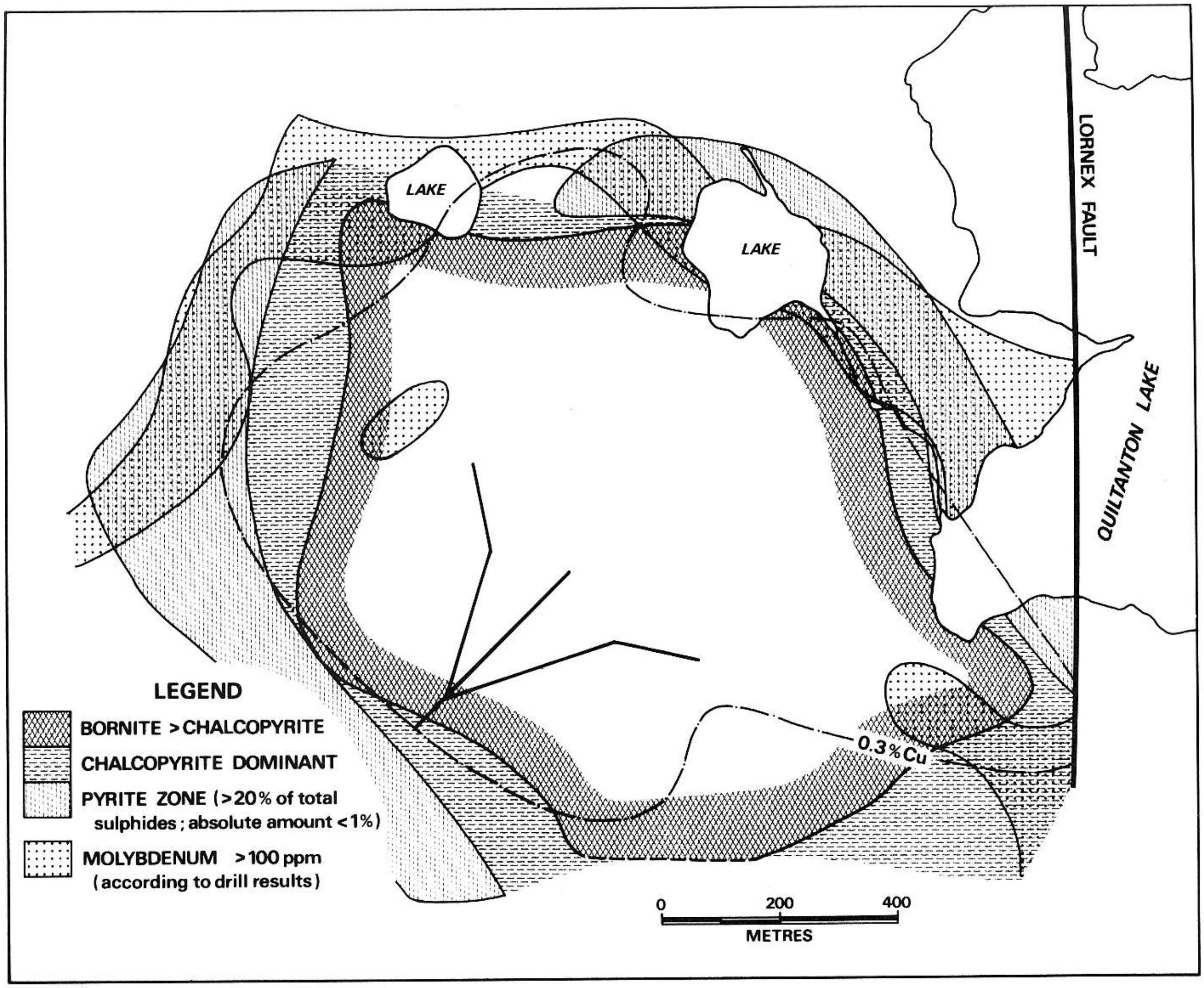



Figure 34. Plan view showing hypogene sulphide zoning in the Valley Copper deposit (after Osatenko and Jones, 1976).

Copper distribution for the 1 158-metre level (Fig. 34) shows a zone containing greater than 0.30 per cent copper that is roughly oval in plan (1 370 metres by 915 metres, long axis striking 130°). Several areas of greater than 0.50 per cent copper occur within the 0.30 per cent copper isopleth and a zone about 300 metres in width, containing between 0.10 and 0.30 per cent copper, is peripheral to it. In vertical section (Fig. 33), the zone of greater than 0.30 per cent copper shows two distinct extensions to depths around a west-central low-grade zone.

Molybdenum and zinc (Fig. 34) form distinct halos marginal to and generally outside the 0.30 per cent copper contour. Values in the molybdenum halo range from 50 to 530 ppm over a width of 300 metres; values in the zinc halo range from 50 to 1 700 ppm. Within the deposit, molybdenum averages about 30 and zinc 20 ppm respectively.

Silver values are less than 1 ppm outside the deposit and range to 2.4 ppm in the zone of strong vein alteration. Analyses of sulphide concentrates suggest that silver is concentrated in bornite, which contains about 270 ppm, relative to chalcopyrite with 30 ppm.

Elements referred to by Olade (1974) as 'pathfinder' elements are Hg, B, Cl, and F. Mercury values range from 1 to 51 ppb and average 3 ppb. Boron dispersion is erratic, although values exceeding 11 ppm are generally confined to the outer margins of the deposit, especially along its northwestern fringe. Chlorine values are generally in the range of 160 to 350 ppm, whereas the regional background is 115 ppm. Fluorine values exceeding 564 ppm occur principally in the area immediately northwest of the deposit; elsewhere, fluorine contents are generally between 250 and 500 ppm. Regional background is about 188 ppm.

### 10-6-5 **Isotopic Analyses**

Sulphur isotopic compositions of Valley Copper sulphides are characteristic of Cordilleran hydrothermal deposits with magmatic associations that formed at relatively high temperatures. Mean values are near zero per mil with small standard deviations (Field, 1966; Jensen, 1967; Field, et al., 1971). A deep or mantle source (typical range of $\delta S^{34}$ values for mantle sulphur is -0.3 to +3.0 per mil) for the sulphur in sulphides is consistent with the probably deep source of the Guichon Creek magma based on $Sr^{87}/Sr^{86}$ ratios (Christmas, et al., 1969; Preto, et al., 1979).

The $\delta S^{34}$ value in the sulphates are about +13.6 per mil which precludes their derivation by supergene oxidation of sulphides. Alternatively, the sulphates may have precipitated from a hydrothermal solution that contained seawater sulphate.

Analyses of coexisting chalcopyrite-pyrite pairs from other Highland Valley deposits gave temperatures ranging from 294°C (Fiddler prospect), to 327°C (Highmont), to 477°C (Bethsaida showing); average formation temperatures were near 400°C (Johan, et al., 1980).

Equilibration temperatures calculated from oxygen isotope pairs of coexisting minerals (Jones, 1975) suggest a range of temperatures from 260°C for early pervasive sericitic alteration to 480°C for potassic alteration. Temperatures calculated from three sulphur isotope pairs range from 266°C for pyrite-sphalerite in a zone of argillic alteration to 480°C for anhydrite-bornite in secondary potassic feldspar. The bulk of the phyllic alteration and mineralization apparently took place at about 400°C, with a range from 370°C to 500°C, over a depth interval of 550 metres. Temperatures ranged from about 500°C in the deeper, central part of the deposit to about 300°C near the periphery.

The isotopic compositions of hydrothermal fluids and average magmatic water at Valley Copper were calculated from the oxygen and hydrogen isotopic values of six samples of sericite and two samples of primary biotite, respectively. The Valley Copper hydrothermal waters plot on or near a line that connects SMOW with the average composition of primary magmatic water. That is, the hydrothermal fluid was apparently a mixture of seawater and magmatic waters. The degree of mixing is estimated to range from 16 to 44 per cent SMOW for the main period of sulphide deposition (average is about 25 per cent).

### 10-6-6 **Fluid Inclusion Analysis**

Fluid inclusions in mineralized quartz veinlets from the Valley Copper deposit are extremely small, about 0.005 millimetre in diameter; they tend to occur in planar clusters and linear zones and may not be primary. Most are composed of 70 to 80 per cent liquid and 20 to 30 per cent gas phases, although daughter crystals of chloride and carbonate have been identified. Average salinity, as indicated by freezing techniques, is 5 weight per cent (Osatenko and Jones, 1976). A few inclusions contain liquid $CO_2$, indicating pressures between 100 and 300 bars and a depth of formation of about 1 to 2 kilometres.

The structurally dependent arrangement and low homogenization temperatures (<200°C) of the fluid inclusions suggest formation by dominantly secondary processes, perhaps during the waning stages of hydrothermal activity.

## 10-7 **GENESIS**

The sequence of major events leading to formation of the Valley Copper deposit are believed to have been as follows:

(1) The Bethsaida granodiorite was intruded in Late Triassic time about 200 million years ago.

(2) Movement on the Lornex and Highland Valley faults initiated a zone of intense fracturing in Bethsaida granodiorite near the fault intersection.

(3) Pre-mineralization aplite, and feldspar and quartz feldspar porphyry dykes were injected along northerly and easterly trends.

(4) Hot saline fluids moved upward in the zone of fracturing and mixed with downward-percolating seawater to produce a fluid with a temperature of about 260°C (Osatenko and Jones, 1976). This fluid reacted with wallrocks, leaching $Na_2O$ and CaO while adding $K_2O$ and $H_2O$. This stage of alteration produced extensive pervasive sericitic and kaolinitic (argillic) alteration, with associated trace amounts of pyrite and chalcopyrite.

(5) A continued influx of magmatic hydrothermal fluids and seawater gave rise to a hydrothermal fluid with a temperature of about 400°C, and a slightly higher pH and sulphur fugacity. These fluids reopened many of the access channelways used by previous hydrothermal fluids and produced phyllic alteration. Deposition of main-stage copper mineralization occurred, probably as a result of increased sulphur ion concentration. Tan felsite dykes, of syn-mineralization age, were also intruded at this time.

(6) In the main part of the deposit, a further influx of fluids again reopened the old channelways and formed quartz veinlets containing vugs lined by or filled with bornite and chalcopyrite.

(7) Continued fracturing of the rock mass occurred, along with the formation of quartz veinlets containing disseminations and envelopes of secondary potassic feldspar. Mineralization of this stage was limited to minor amounts of chalcopyrite, probably as a result of decreased sulphur fugacity. Chemically, this stage is characterized by a pronounced addition of $K_2O$ and $SiO_2$ and a marked depletion of $H_2O$, relative to zones with argillic and phyllic alteration.

(8) Further fracturing occurred, followed by the deposition of essentially barren quartz veinlets.

(9) In close spatial association with previously formed secondary potassic feldspar, fractures were reopened and gypsum deposited. The hydrothermal solutions were rich in seawater sulphate.

(10) Lamprophyre dykes were intruded about 132±3 Ma ago.

(11) During subsequent uplift and erosion, the overlying rocks and the upper part of the deposit were removed; an oxidized zone and weak supergene blanket developed. Glaciation followed by glaciofluvial deposition and continued erosion produced the present-day surface.

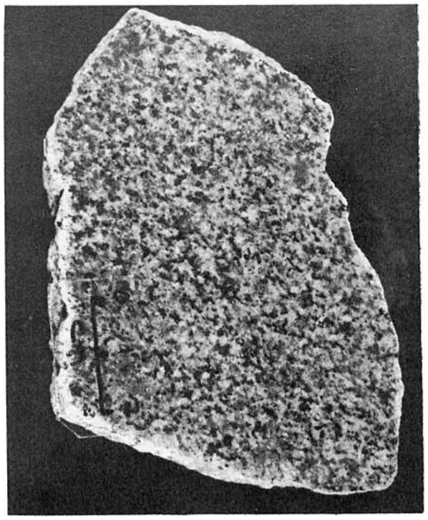
## Plate I

Rock types in the batholith form distinguishable, areally mappable units. Distinguishing criteria are grain size, mineralogy, colour index, and texture. The plate illustrates the major mapped units - called phases or varieties - and some of the variations within each unit. Plates Ia to Ic portray the 'older phases'; Id and Ie the 'younger phases; and If some porphyry dykes.

Ia (i to iii) Border phase - diorite to quartz diorite, generally fine to medium grained, relatively high colour index, mafic minerals are amphibole, biotite, and local pyroxene (as cores in amphiboles).

Ib (i to iii) Guichon variety of Highland Valley phase - quartz diorite to granodiorite, mafic minerals are amphibole and biotite; locally potassic feldspar is as much as 15%; contacts with Border phase and Chataway variety are gradational; characteristically mafic minerals are subhedral and distributed in clusters of crystals; quartz is generally interstitial - as wedge-shaped areas.

Ic (i to iii) Chataway variety of Highland Valley phase - granodiorite, mafic minerals are amphibole and lesser biotite; locally it contains coarse poikilitic potassic feldspar; characteristically mafic crystals are sub- to euhedral, relatively evenly distributed, and poikilitic; quartz crystals are rounded.



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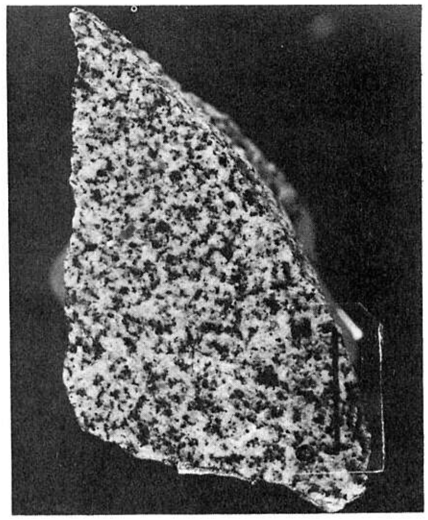

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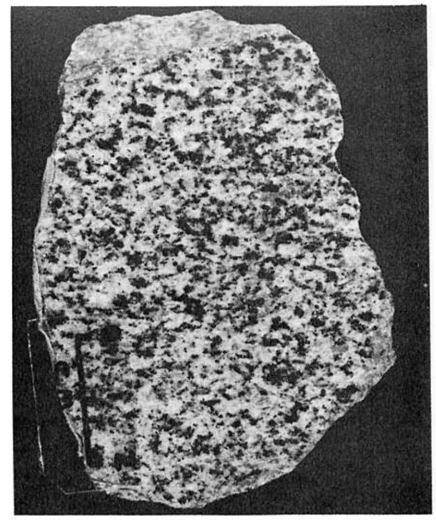

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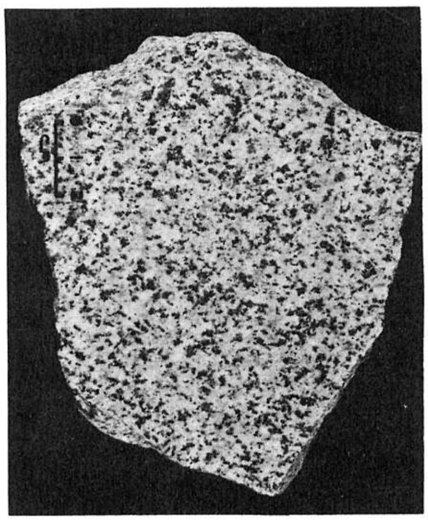

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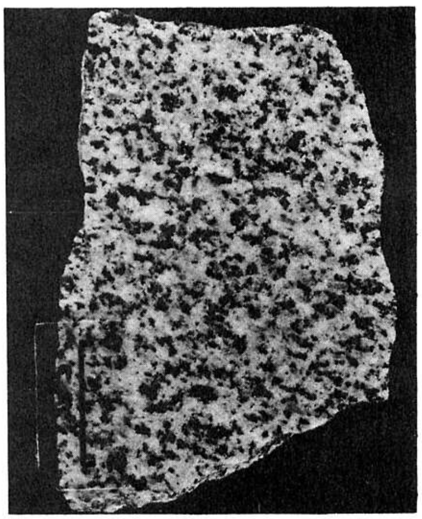

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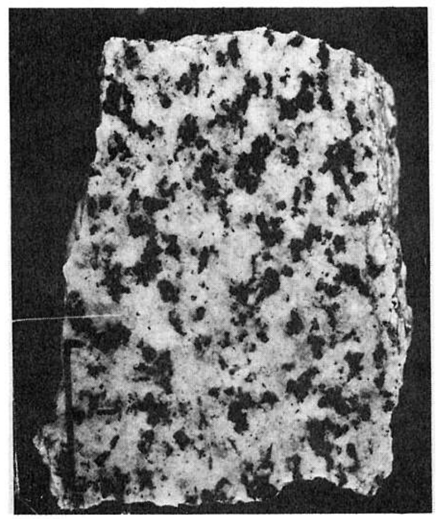

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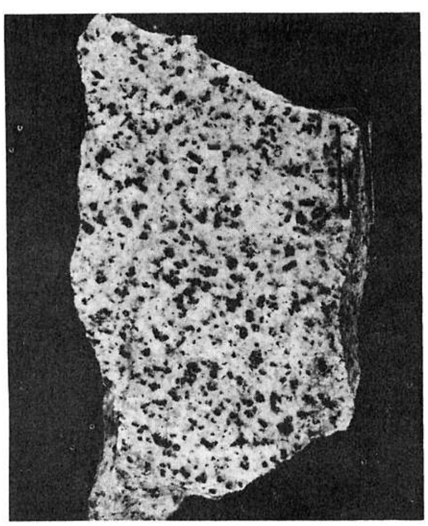

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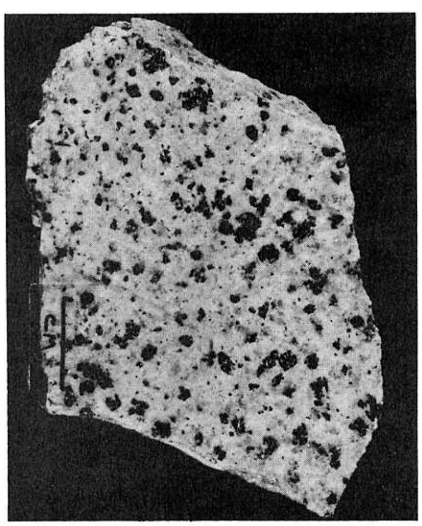

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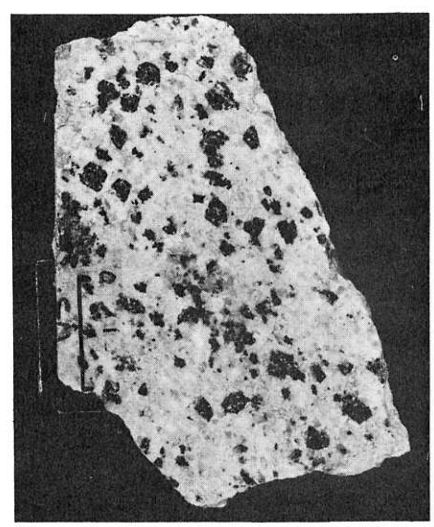

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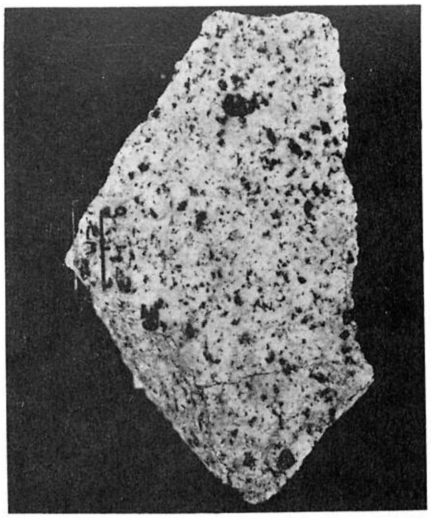
Iciii

## Plate I (continued)

Id (i and ii) Bethlehem phase - granodiorite with lower colour index, mafic minerals are amphibole and biotite; quartz crystals are rounded. Characteristically several per cent of poikilitic, coarse-grained amphibole are unevenly distributed in a matrix with disseminated, finer amphibole and biotite.
(iii) Swarms of feldspar and quartz feldspar porphyry dykes cut Bethlehem phase - some have chilled contacts; many apparently predate the Bethsaida phase.

Ie (i) Skeena variety - granodiorite with slightly lower colour index again; it is coarser grained and texturally intermediate between Bethlehem and Bethsaida phases. The sample in the photograph is cut by a quartz chalcopyrite vein with associated phyllic alteration.
(ii and iii) Bethsaida phase - often porphyritic, granodiorite to quartz monzonite; the rock is coarser with overall lower colour index; biotite is the predominant mafic mineral; plagioclase, quartz, and biotite form sub- to euhedral phenocrysts.

If (i to iii) Late stage quartz porphyry (i) and quartz feldspar porphyry (ii) dykes cut Bethsaida phase and older rocks. Some, such as the Gnawed Mountain dyke, are texturally composite; the matrix is variably aphanitic to aplitic to crystalline; the dyke rocks are locally texturally indistinguishable from normal Bethsaida phase (not illustrated here).



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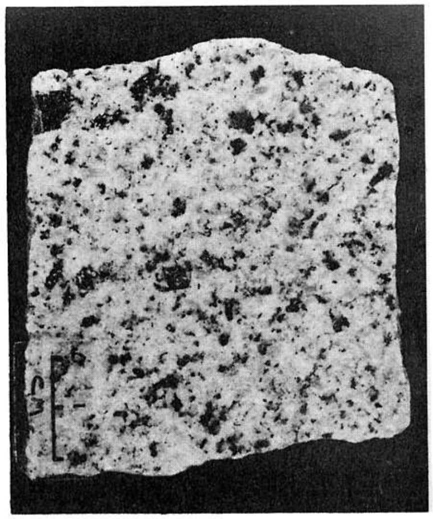
Idi



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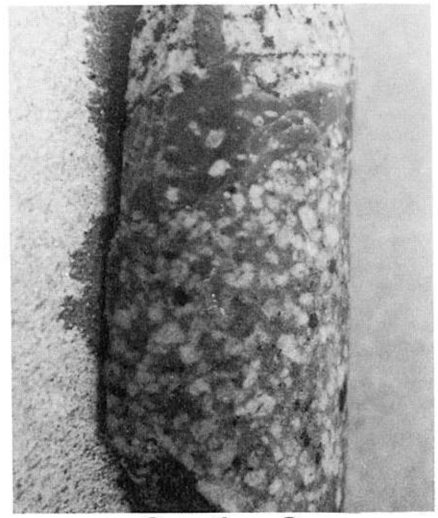

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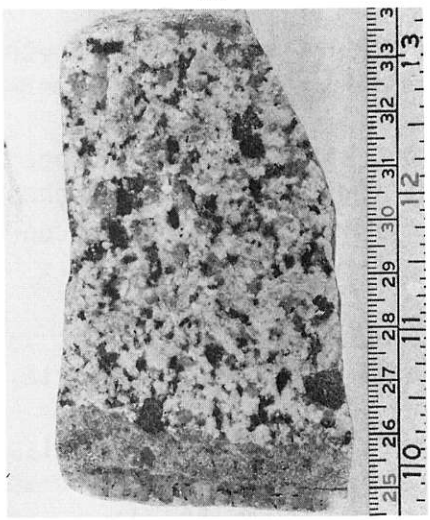

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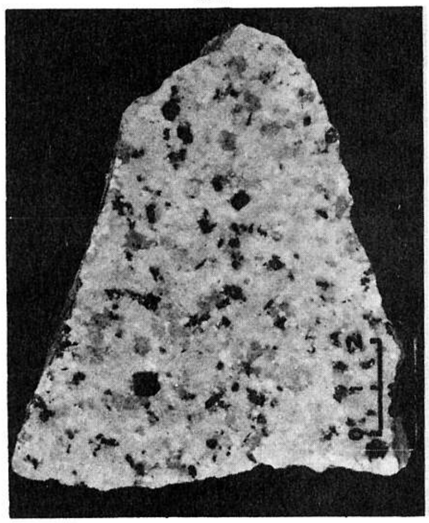

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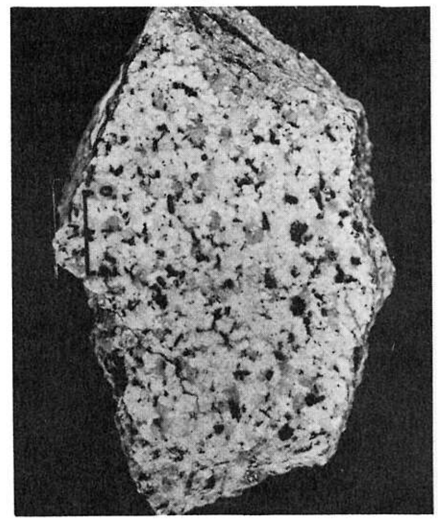

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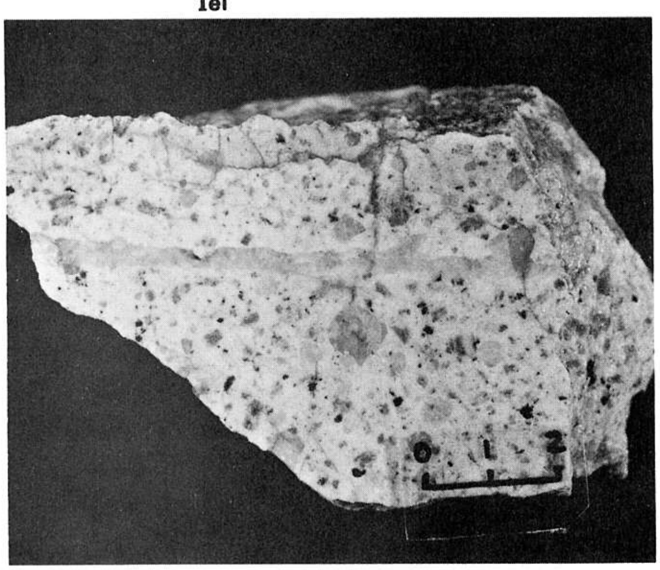

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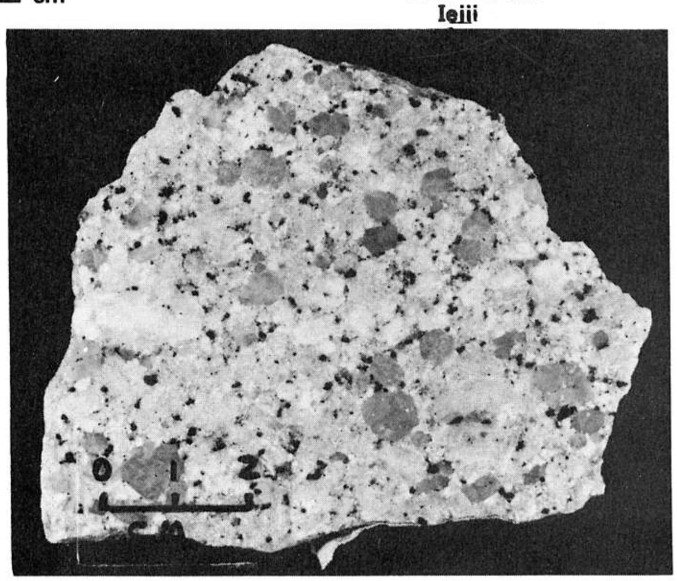

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Ifii

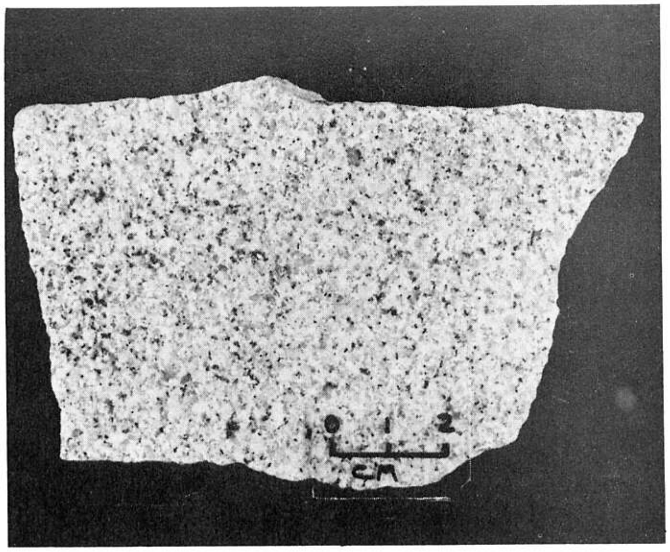
## Plate II

Stocks satellitic to the Guichon Creek batholith are texturally similar and probably genetically related to it. Dyke swarms related to the 'younger phases' are prominent in the central part of the batholith; these have associated intrusive breccias that are probably explosion breccias (Carr, 1966).

IIa (i) Spatsum quartz monzonite stock, near Basque; it is texturally similar to some dykes that cut Bethlehem phase rocks.
(ii) Gump Lake granodiorite stock crops out near Mamit Lake; it is texturally similar to Bethsaida phase rocks.

IIb (i) Guichon granodiorite country rock is crackle brecciated along the edge of the South Seas breccia pipe; the contact is sharp to gradational over tens of metres. The dark fracture filling material is dominantly quartz-tourmaline.
(ii) Multilithic, sharply angular intrusive breccia occurs within the South Seas breccia pipe. Fragments are Guichon granodiorite and quartz feldspar porphyry. Fragments have been transported but not milled.
(iii) Milled intrusive breccia is found in the Jersey Pit, Bethlehem copper mine. The clasts are multilithic but locally derived; they consist of Guichon granodiorite, Bethlehem granodiorite, and feldspar porphyry. The matrix consists largely of rock fragments and rock flour.

IIc (i) The monolithic Minex breccia occurs within the Gnawed Mountain dyke; it is characterized by sharply angular quartz porphyry clasts cemented by quartz, tourmaline, specularite, and some chalcopyrite.
(ii) The enigmatic, milled, multilithic Gnawed Mountain breccia body is also within the Gnawed Mountain dyke. Clasts are porphyry and Bethsaida as would be expected, but also more mafic granitic rocks and what appear to be clasts of Nicola volcanic rocks. Perhaps this breccia reflects intrusion, explosive venting to surface, then collapse back into the conduit.

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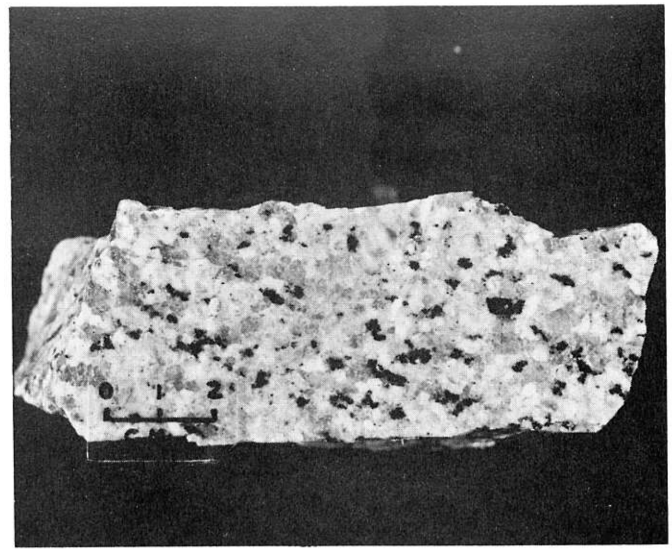


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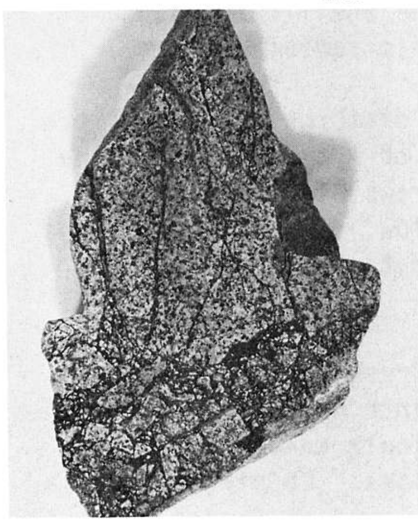

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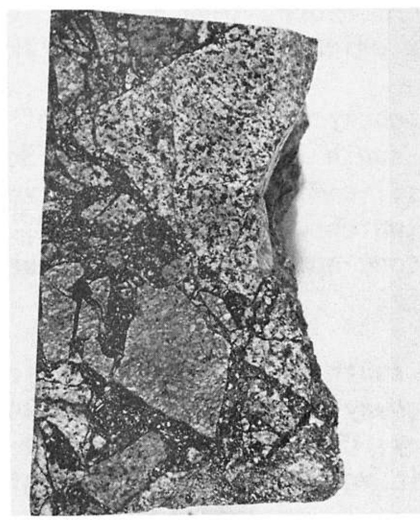

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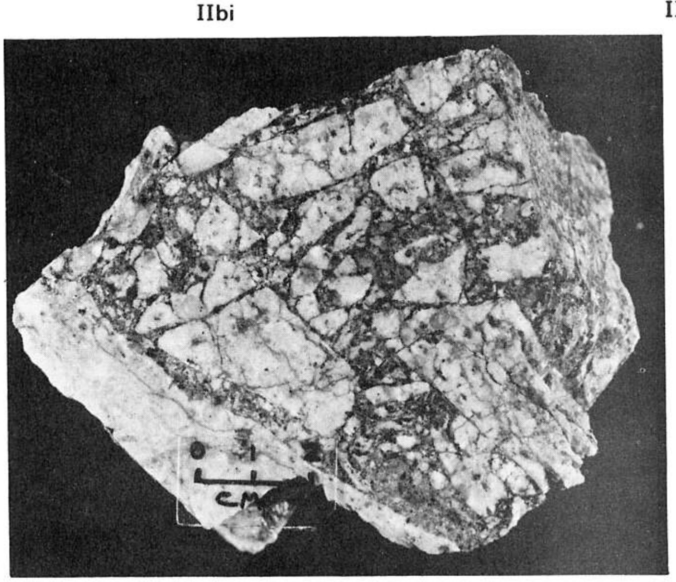

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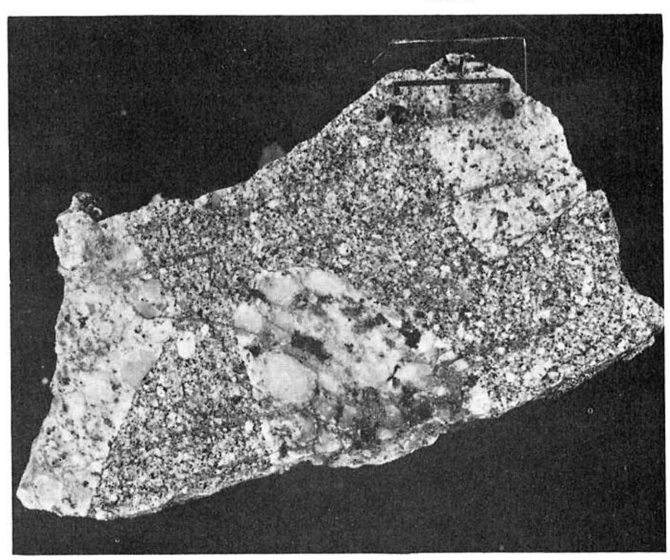

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IIcii

20.1 White-weathering cliff exposures east of the highway are biotite quartz andesine porphyry of Eocene age. The outcrops are part of a small stock which cuts through Jurassic sedimentary rocks. Outliers of porphyritic lava derived from the stock unconformably overlie the Jurassic rocks south and west of the stock.

20.9 Just beyond the Barnes Lake switchback are small outcrops of recrystallized basic volcanic rocks of the Late Triassic Nicola Group. The edge of the Guichon Creek batholith is exposed in the hills east of the highway and accounts for the metamorphism of the volcanic rocks.

to 24.0 Nicola volcanic rocks underlie this stretch of road; granitic rocks crop out to the east and Jurassic sedimentary rocks crop out to the west.

to 27.5 Local outcrops of Jurassic sedimentary rocks occur. These are generally brown sandstones, siltstones, and shales, but local conglomerate beds are encountered. Here the conglomerates appear to be stream bed deposits.

At 27.5 the highway enters the Guichon Creek batholith. The batholith is concentrically layered with an older, more basic, finer grained border and successively younger, more acidic, coarser grained phases inward toward the core. Composition changes from diorite and quartz diorite at the edge to quartz monzonite in the core.

The batholith consists of two major zones. The outer zone is made up of the Border phase and the Highland Valley phase (Guichon and Chataway varieties); the inner zone contains the Bethlehem phase, the Skeena variety, and the Bethsaida phase.

to 32.0 Sporadic Border phase quartz diorite outcrops occur.

31.7 to 32 **STOP 1:** Exposed in this outcrop are more or less equigranular quartz diorites of the Border phase. They are biotite and hornblende-bearing with colour index about 25. Mafics are generally fresh but can be chloritized. The host rock carries a variable number of fine to medium-grained basic xenoliths. Some xenoliths have sharp borders and are evidently basic volcanic rocks, others have diffuse contacts, are recrystallized, and have less certain origins. Much of the quartz has a bluish colour; K-feldspar is fine grained and interstitial. Overall, the rock is a dark, grey-green colour. Halos of green, sericitic feldspar alteration occur around some north-striking joints and several slickensided shear zones carry malachite. Medium-grained biotite quartz monzonite dykes and veinlets of calcite, quartz-epidote, and chlorite cut the quartz diorite country rock.

to 37.0 Although there is little outcrop, the highway is underlain either by small Tertiary grabens infilled with lavas and sediments or by quartz diorites of the Border phase.

37 to 44.5 Outcrops along the highway are variably rocks of the Highland Valley or younger Bethlehem phases. These are granodiorites with colour index generally ranging from 10 to 20 and medium to coarse-grain size. Some varieties are porphyritic.

43.7 **STOP 2:** Rocks are well exposed in a highway cut. Granodiorite of intermediate age comprises the outcrop; both Bethlehem phase and Chataway variety rocks are recognizable but much of the outcrop is texturally ambiguous. The rock is jointed on metre scale.

In the ambiguous areas, textural variations are patchy and locally the rock looks brecciated. Some of these variations may be due to assimilation; xenoliths and xenocrysts are common. About 5 metres from the east end of the large rock cut the rock becomes recognizable as Chataway granodiorite. There is a break in outcrop, then Chataway continues until about 8 metres from the east end of the next outcrop where it is in contact with Bethlehem granodiorite. After an 8-metre break in outcrop, Chataway is in contact with Bethlehem granodiorite, which continues to the east end of the exposures. The contact is uneven, and although no chilling is evident, Bethlehem becomes slightly finer grained near contacts. It is cut by a few aplite stringers.

Chataway variety is characterized by 12 per cent evenly distributed, euhedral mafic minerals. Bethlehem phase has several per cent, unevenly distributed, coarse-grained poikilitic hornblende phenocrysts and 8 per cent more evenly distributed biotite and hornblende in the matrix.

In the main outcrop xenoliths are generally rounded; reaction rims vary from 1 to several centimetres. In Bethlehem granodiorite at the east end of the exposure, the xenoliths are more mafic and angular; concentrations define steeply dipping zones. Assimilation is minimal, however, associated clots of hornblende quartz alkali feldspar rock suggest local partial remelting.

Large hornblende xenocrysts to 1 centimetre in diameter scatter through the outcrop. Generally they develop narrow, biotite-rich reaction rims. The source of these xenocrysts may be disaggregated xenoliths - one quartz diorite xenolith in the outcrop carries 30 per cent, 1 to 2-centimetre hornblende phenocrysts.

Epidote and chlorite or zeolite fill fractures. Pink alteration may extend a centimetre or more into adjacent country rock.

At 44.1 to 44.2 a small rusty-weathering outcrop of Chataway granodiorite lies along the highway. The outcrop in the bank above offers an opportunity to study typical Chataway granodiorite.

46.2 to 46.5 **STOP 3:** Exposures on both sides of the highway are in cuts made for the highway and the Lornex tailing pipeline. They expose granodiorite of the Skeena variety. The rocks are relatively leucocratic, with colour index 8 to 10, generally coarse grained and somewhat porphyritic. Mafics are biotite and hornblende in approximately equal abundance. About 2 per cent coarsely crystalline poikilitic hornblende to 1 centimetre in long dimension are characteristic and these rocks are linked to the Bethlehem phase; they have been designated the Skeena variety. Except for those at the south end, along the disused Lornex tailings pipeline, rocks in these outcrops are transitional in character to those of the Bethlehem phase.

Three characteristics distinguish Skeena variety from Bethlehem phase granodiorites. Skeena is coarser grained, has slightly lower colour index, and has medium to coarse-grained anhedral quartz that is easily visible in hand specimen. Contacts are typically gradational.

Overall the outcrop is blocky jointed on metre scale.

On the west side of the road exposures are rusty weathering; however, on a freshly broken surface, component minerals are nearly unaltered. Exposures along the east side are less rusty but those along the tailings pipeline are very rusty weathering.

Concentrations of mafic minerals, mainly hornblende, define layers that strike northeasterly and dip steeply. These are interpreted to reflect flow 'banding' developed during emplacement of the intrusion.

Granophyre dykes to 2 centimetres in width strike northeasterly and dip moderately northwest. The dykes cut north-northeast-trending steeply dipping aplite stringers; both cut the mafic-rich layers.

Chlorite and epidote coat fracture faces that have pinkish halos. Other fractures contain iron oxide or calcite deposits and have rusty halos. In outcrops along the tailings pipeline these halos are several centimetres wide and much more abundant.

Hornblende xenocrysts are scarce. Xenoliths are also less common and most are partially resorbed.

49.1 Continue past the turnoff to Bethlehem Copper toward Logan Lake. The trace of the major north-trending Lornex fault crosses the highway near the turnoff. The fault has significant vertical and lateral movement components. Some movement is post-ore; the Lornex and possibly the Valley Copper deposits are truncated by the fault.

49.5 Valley Copper open pit - The deposit is in rocks of the Bethsaida phase, which is leucocratic, coarsely crystalline, and somewhat porphyritic quartz monzonite. Biotite is the predominant mafic mineral and colour index is normally 5 to 8. Biotite, quartz, and plagioclase form coarse subhedral to euhedral crystals in a fine to medium-grained matrix of quartz, plagioclase, and K-feldspar.

52.9 Lornex access road junction.

53.4 or 53.7 Highmont access road junctions.

64.0 **STOP 4:** The outcrop was drilled and blasted during highway construction; a good pullout spot is opposite. Overall, the outcrop consists of relatively mafic-rich Guichon granodiorite to quartz diorite. There are xenolith-rich areas and crosscutting porphyritic dykes. Guichon variety generally has 15 per cent mafic minerals, both hornblende and biotite. Mafic crystals are unevenly distributed and subhedral to euhedral; typically they are aligned to define a flow foliation.

Across from the pulloff, the rock is an intrusive breccia with Guichon granodiorite enclosing and filling fractures in dark-coloured xenoliths. Most of the xenoliths are angular; some are only separated by narrow selvages of Guichon.

The degree of assimilation and recrystallization of xenoliths varies. Some are sharply defined; others are wispy. Many of the larger fragments have narrow partly assimilated and recrystallized rims. Hornblende xenocrysts range to 1 centimetre and have altered rims; hornblendite pods occur locally. Some recrystallized zones are relatively leucocratic but have scattered clusters of hornblende crystals.

The rock is crossed by quartz-K-feldspar or quartz-K-feldspar-tourmaline stringers that locally carry chalcopyrite.

At the western end of the outcrop there is a dyke of hornblende plagioclase porphyry. Fracture faces in it are coated by epidote and chlorite.

At the east end there are fewer xenoliths and those present are more completely assimilated and rounded.

64.4 The next outcrop, at 64.4, is also relatively hornblende-rich Guichon granodiorite. Xenoliths and xenocrysts are present but less abundant than at STOP 4. Most of the west side of the outcrop is a chloritized hornblende plagioclase porphyry dyke. The dyke has local areas with disseminations of chalcopyrite and uncommon rounded Guichon xenoliths. The xenoliths are neither recrystallized nor resorbed.

Fractures in the Guichon granodiorite may be coated by tourmaline with associated chalcopyrite or occupied by quartz-chlorite veinlets with pink-bleached halos. Hornblende is chloritized in these alteration halos.

64.75 Variations in texture occur rapidly and it is difficult to distinguish Guichon country rock from younger dykes in this outcrop. Where contacts are recognizable, the dykes are not chilled and the contact is uneven on centimetre scale. Patchy areas of K-feldspar and quartz-K-feldspar patches and stringers or veins occur.

Quartz-tourmaline veins are about 1 metre apart and up to 1 centimetre wide in the central part of the outcrop. They carry chalcopyrite but chalcopyrite is also disseminated in the country rock. Many fractures are coated by chlorite.

Patchily distributed darker and lighter zones and quartz-K-feldspar veins in the outcrop may reflect assimilation and perhaps partial melting of more mafic xenoliths. Locally, the rock would be mapped as transitional between Guichon variety and Border phase.

66.5 This is the approximate location of the eastern edge of the Guichon Creek batholith; there is no outcrop.

67.8 Junction with road to Merritt or Savona.

69.5 Village of Logan Lake.

## PART 4
## FIELD TOURS OF THE GUICHON CREEK BATHOLITH

### INTRODUCTION

In this section a series of tours display the range of rock types within the batholith and units with economic potential adjacent to the batholith. Many of the roads are in poor condition; four-wheel drive vehicles are recommended.

No attempt is made to describe individual stops in detail; each tour is designed to illustrate variations within and between phases of the batholith or flanking Triassic country rock, or Jurassic or Cretaceous cover rocks. No attempt is made to include Tertiary cover rocks; these were not studied in detail; they have minimal potential for metallic mineral deposits of economic interest.

The number in brackets at various stops are catalogue numbers of samples in the Geological Branch type collection.

The tour routes (Fig. 2) were laid out in the office, so distances to stops are scaled off the map. Further, although care has been taken in selecting sites, some roads marked may now be unusable; the writer apologizes for any inconvenience this may cause.

### TOUR 1

Starting south of the batholith at Lower Nicola, the route winds northward through most of the phases of the batholith and also introduces several of the types of mineralization that characterize the district.

A paved road leads north from Lower Nicola toward Craigmont mine. Past the tailings pond, at kilometre 6.2 a dirt road that provides access to the Chataway Lakes fishing camp branches off to the right.

**STOP 1-1** (8-205, 8-206) is at approximately kilometre 13. The low-lying outcrop of Border phase quartz diorite has 30 per cent mafic minerals that are variably fine to coarse grained, unevenly distributed, and dominated by amphibole relative to biotite. Plagioclase forms subhedral laths; it is not obviously zoned. Quartz is fine and occurs as interstitial 'wedges.' Weak chlorite and epidote alteration affects the mafic minerals. Steeply inclined joint sets striking southerly and east-northeast are at about 0.2-metre spacing.

**STOP 1-2** (15-12) at kilometre 20 is the portal to the old Aberdeen mine; there are a few remnants of dumps and mine buildings. The workings are in relatively fine-grained Guichon granodiorite east of the contact with Chataway granodiorite. The rock is closely fractured; a 3-metre-wide reddish weathering alteration zone strikes 128° and a specularite vein with chalcocite and malachite strikes 131°; both are nearly vertical. Dump material shows quartz-lined vugs in the specularite veins that carry bornite with chalcocite and other secondary copper minerals; tourmaline has also been reported. There are local stringers of flaky sericite. The last year of production from Aberdeen was 1968; to that time 2 million tonnes of 0.6 per cent copper was milled. Remaining reserves are unknown.

Just to the north, at kilometre 20.4, a short adit was driven along veins of specularite at the edge of a 4-metre-wide shear zone in Chataway granodiorite. The shear strikes southeast and dips steeply.

**STOP 1-3** (16-37) at kilometre 22.5 is an outcrop of relatively fine-grained Guichon granodiorite. The rock has sugary textured feldspar and quartz with 18 per cent interstitial potassium feldspar. Amphibole is the dominant mafic mineral but biotite is present; mafic minerals are weakly altered to chlorite and epidote. The rock is cut by narrow chlorite-epidote veinlets that locally contain malachite. Dominant joints dip steeply and strike northeast and southeast; a third, shallow set strikes northeast. This type of rock has been called 'Le Roi' variety by other workers (Northcote, 1969).

**STOP 1-4** at kilometre 24.5 features a series of trenches that expose mineralization of the No. 4 zone of Chataway Exploration Co. Ltd. The zone strikes 170° and dips steeply west. Adjacent to mineralized quartz veins in the zone the country rock is altered to a dark, olive green colour; feldspar alteration minerals are sericite, carbonate, and some epidote; mafic minerals are chloritized. Many veins are poorly mineralized but some have cores, pockets, or veins of chalcopyrite and bornite; commonly there are flaky sericite pods in the better mineralized veins. Joint faces may be coated with hematite, sericite, or chlorite; some have pink, hematized alteration halos. Larger veins in the mineralized zone strike northerly and dip moderately to steeply eastward. Vein borders are uneven and branching - they follow older fractures. Carbonate and zeolite veinlets are late stage events.

Drill indicated geological reserves for the No. 4 zone are 1.2 million tonnes at 0.86 per cent copper.

There are many small trenches alongside the road in this area. Most have some development of sericitic and fracture-related olive green alteration; many have quartz veins; some have associated copper sulphides.

**STOP 1-5** (16-34) at kilometre 26.0 lies just south of the south end of Gypsum Lake. The outcrop is relatively coarse-grained Chataway granodiorite. Other outcrops of 'typical' Chataway granodiorite may be seen at kilometre 28.9 at the south end of Dot Lake (south of the old mining company cabins). The rock contains both biotite and amphibole but amphibole is more abundant; they are weakly altered to chlorite and epidote. Quartz forms ameboid grains that are intergrown with potassium feldspar. Fractures are coated by epidote, chlorite, and, locally, potassium feldspar. Dominant joint sets strike northerly and easterly; they are subvertical.

Continue past Dot Lake at kilometre 29 onward toward Chataway Lake Lodge but at the Lodge turnoff (kilometre 32.2) keep left and follow the Roscoe Lake road.

**STOP 1-6** (5-12, 2-310A) at kilometre 35.1 consists of several outcrops in, north, and east of an old bulldozer trench. The rocks have transitional characteristics. The northern part of the outcrop area is Chataway granodiorite but the drill hole and the trench are in Bethlehem granodiorite. Inter-relationships of the two rock types are ambiguous albeit Bethlehem should post-date Chataway. In the trench the rock is silicified and sericitized with associated epidote, chlorite, hematite, and malachite. There is also quartz-epidote veining. Dominant joints strike northeast and southeast; they dip steeply.

The road follows Rusty Creek then swings westward. At kilometre 38.4 it swings sharply north and a branch leads south; follow the north branch to Roscoe Lake.

**STOP 1-7** (5-22) is at kilometre 39.0 on the west side of the lake. A short climb leads to good, bluff exposures of Skeena granodiorite cut by narrow, north-striking aplitic dykes. The rock is typical Skeena granodiorite with 12 per cent mafic minerals consisting of relatively fine-grained biotite and relatively coarse-grained poikilitic amphibole. Quartz forms relatively coarse, anhedral grains. Plagioclase occurs as subhedral laths; potassic feldspar is late and interstitial.

Return to the junction (kilometre 39.6) and follow the south branch.

**STOP 1-8** (1-252, 1-253) at kilometre 40.0 is at the Yubet showings. The exposures occur in a series of trenches. The host rock is a small, elongated quartz aplite to quartz granophyre stock that lies along the north-striking Skeena/Bethsaida contact. Similar rocks also occur as dykes elsewhere along this contact and as dyke swarms within the Bethsaida quartz monzonite. The stock is locally cut by aplite dykes so it has a compound intrusive history. Mineralization occurs in vugs and fractures in the stock; the deminant sulphides are bornite and chalcopyrite. Mineralization is in quartz stockworks and veinlets with halos of apple green, sericitized feldspar. Bornite with sericitized coronas also forms disseminations in the porphyry stock.
Geological reserves are estimated to be 120 000 tonnes at 2.25 per cent copper.

**STOP 1-9** (1-254), further along the road at kilometre 41.5, is east of Skuhun Creek; there is a small outcrop of Bethsaida quartz monzonite on the north side of the road. In this region the Bethsaida is unusual in that it contains both biotite and amphibole in equal abundance; generally biotite is the only mafic mineral. Mafic minerals are weakly chloritized. There are narrow southeast-striking aplite dykes and scattered quartz-chalcopyrite coatings in fractures. Dominant joints strike north and east-southeast and dip steeply.

Return to the Roscoe Lake junction (kilometre 43.4). About 1.5 kilometres eastward (at cumulative kilometrage 44.9) a rough branch road leads northward toward Gnawed Mountain.

Trenches at kilometre 47.5 contain quartz aplite float. The road then swings west around Mystery Lake; follow a branch that heads west at kilometre 48.5, at the north end of the lake. There are a series of poor exposures of Skeena granodiorite in trenches adjacent to the road.

**STOP 1-10** (1-244) at kilometre 50.0 consists of Skeena granodiorite cut by stringers of aplite or quartz feldspar porphyry. Biotite and amphibole comprise 10 per cent of the rock; biotite is more abundant. The size distribution is bimodal. Locally biotite is weakly chloritized. Aplitic dykes in the outcrop may be offshoots of a northerly striking quartz porphyry dyke that is exposed in trenches about 0.5 kilometre to the south along a branch road.

Small outcrops from kilometre 50.5 to 50.7 are finer grained and were initially mapped as Bethlehem granodiorite; subsequently they were grouped with surrounding Skeena rocks. Turn right at the junction at kilometre 50.8.

**STOP 1-11** (1-232) at kilometre 52.4 is in Skeena granodiorite at the south contact of the composite Gnawed Mountain porphyry dyke. Dyke rock near the contact has fractures and a wide vein of quartz containing bornite that have been tested by a 2-metre adit. The quartz vein strikes southeast and dips steeply southwest.

**STOP 1-12** is reached by walking along a short branch road leading eastward at kilometre 52.5. Exposures show the rounded to angular multilithic nature of the Gnawed Mountain breccia. The matrix of the breccia consists of rock fragments cemented by tourmaline. Fragments range from Guichon granodiorite to various types of Gnawed Mountain porphyry. The clasts are commonly angular but locally are milled and rounded; they are a few millimetres to tens of centimetres in size.

Gnawed Mountain peak, to the east, is underlain by Skeena granodiorite; the dyke contact is about 150 metres north of the peak.

Return to the main road and travel westward to kilometre 53.5. Several zones of mineralization were discovered and drilled by Highmont Mining Corporation south of the Gnawed Mountain dyke; locations are given in the Highmont mine report. A similar deposit, the Ann No. 1, that lies just south of the road at kilometre 52.8 was drill tested by several companies; estimated probable reserves are 19 million tonnes at 0.30 per cent Cu and 0.005 per cent $MoS_2$. There is (or was) a small cabin and a trench leading northward up the ridge; the area is 0.7 kilometre south of the East Pit of Highmont Mining Corporation and 0.3 kilometre east of Highmont's No. 4 zone.

**STOP 1-13** (69-348 to 69-353, 1-222, 1-221) comprises a short loop traverse north along the trench east of the cabin to line 33E then east to the Minex breccia. The trench features exposures of dyke-laced Skeena granodiorite south of the Gnawed Mountain dyke, rocks of the dyke, and the angular to milled, monolithic Minex breccia. The breccia is mineralized with quartz, tourmaline, specularite, and minor amounts of chalcopyrite.

Unfortunately, access northward through Highmont is no longer possible so it is necessary to return to Chataway Lake along the same route used to get to Gnawed Mountain. Generally, the road down Skuhun Creek is in better condition than the other choices; check at the fishing lodge for more timely information or for a rustic place to stay (bring your own food, cooking utensils, and sleeping bags).

## TOUR 2

Tour 2 starts at the south end of the bridge east of the village of Spences Bridge; it briefly examines the Cretaceous Spences Bridge Group before following the road up Skuhun Creek through most of the phases of the batholith. Spences Bridge Group rocks are dominantly subaerial volcanic rocks; no mineral deposits have been found in them but locally they may have potential for economic deposits of zeolites or other industrial minerals.

**STOP 2-1** (6F-77-WJ-1) at kilometre 1.5 is a small quarry which exposed dark grey to hematized dacitic volcanic rock with an interlayered 2-metre-thick, brick red tuff layer. The rocks are veined by calcite and zeolite (laumontite). The flows are amygdaloidal to massive. Bedding is 085°/25°SE.

Continuing eastward across the first of several narrow bridges over the Nicola River, the next few outcrops are amygdaloidal to massive dark grey andesite cut by pink zeolite (laumontite) and calcite veins. By kilometre 4 rock bluffs to the north are purplish; they consist mainly of subaerial flows.

**STOP 2-2** is at kilometre 6.5 opposite the fruit stand. The land belongs to the people who own the farm so please 'check in' with them. The overall green outcrop is a mix of flows and volcanic breccia cut by a swarm of basaltic dykes that feed flows higher in the section. The highway follows this dyke swarm until kilometre 8.3; it caused confusion initially for mapping because the dykes are subparallel (160°) to the road. As before, the rocks are veined by calcite and laumontite.

**STOP 2-3** (16-87-2) at kilometre 8.8 contains green porphyritic and fragmental andesitic volcanic rocks. From a distance, intercalations of flows and fragmental volcanic units are visible; layering is estimated to be 060°/15°SE.

**STOP 2-4** (6G-77-WJ-3, 4) at kilometre 13.2 is a rock cut along the Canadian Pacific railway line. The outcrops are rhyodacites to dacites with local quartz and potassic feldspar phenocrysts. Colour ranges from green to tan.

**STOP 2-5** (16-77) at kilometre 19.5 consists of thickly bedded volcanic sedimentary rocks that dip at low angles to the southeast. Bedding strikes 025° and dips 25° southeastward. The epiclastic rocks are interlayered with dark grey plagioclase porphyritic andesite flows. The flows display columnar jointing.

At kilometre 22.5 a branch road cuts back to the northeast along Skuhun Creek; it should have a sign pointing the way to Chataway Lakes fishing resort.

**STOP 2-6** (17-92A) at kilometre 23.4 consists of Spences Bridge flows and fragmental rocks with interlayers of waterlain tuff and black shale. The bedded layers dip southeastward at low to moderate angles. The shales occur as lenses in the tuffaceous units. The largest lens is 4 metres wide and 0.5 metre thick. Some of the tuffaceous units are crystal rich, some look welded. Fragments in lapilli tuff are flow banded, possibly rhyolite. To the southwest along the creek, the tuffaceous units overlie basaltic flows.

By **STOP 2-7** (17-90) at kilometre 28.6, erosion has cut through the younger cover rocks to expose metamorphosed plagioclase porphyritic, basic volcanic rocks of the Late Triassic Nicola Group. The outcrops are approximately 150 metres south of the road at elevation 700 to 750 metres (2300 to 2500 feet).

At **STOP 2-8** (1-265), opposite the Wild Horse Ranch at kilometre 31, outcrops north of the road are well-foliated quartz diorites of the Border phase of the Guichon Creek batholith. Foliation is nearly horizontal. Plagioclase comprises 72 per cent of the rock; it forms subhedral to euhedral laths. Medium-grained amphibole and coarse-grained poikilitic plates of biotite are about equally abundant; together they compose 20 per cent of the rock. Quartz occurs as fine, interstitial grains; there is no potassic feldspar. Mafic-rich or metasedimentary xenoliths, thin aplitic dykes, and joint-controlled Cretaceous (?) dykes to 5 metres wide occur locally. Epidote veinlets cut both the granitic country rock and the dyke rocks.

Continue along the road past the crossing of Skuhost Creek and around a large switchback at kilometre 34.6 to kilometre 35.2, where a steep branch road leads north up the hillside (there was a tree across the road at kilometre 36.2 but it could be driven around).

**STOP 2-9** (1-287, 13-95) at kilometre 38.0 displays a series of outcrops of Bethsaida quartz monzonite. These rocks are cut locally by aplite and granite pegmatite stringers with associated chalcocite mineralization. Quartz and potassic feldspar are intergrown in the rock and locally it is distinctly porphyritic with quartz, plagioclase, biotite, and some amphibole phenocrysts. Narrow quartz veins have malachite staining and sericitic alteration along their borders. Dominant steeply dipping joints strike easterly and southeasterly; there is also a southeasterly set that dips 20° toward the southwest.

Return to the Skuhun Creek road (kilometre 40.8) and continue eastward. At kilometre 49.3 follow a branch road that leads southward toward Tyner Lake.

**STOP 2-10** (17-68) at kilometre 52.6 is a small outcrop of Chataway granodiorite. The rock has typical Chataway texture, with 15 per cent evenly distributed medium-grained amphibole and biotite; biotite is more abundant. Quartz forms interstitial ameboid grains, intergrown with potassic feldspar; together they form 30 per cent of the rock. Sericitic feldspar alteration is of variable intensity. The rock is cut by veinlets of quartz and epidote, and east-southeast fractures are coated by chlorite and epidote. Dominant joint sets strike north-northeast and east-northeast; they dip steeply.

Continuing onward past the north end of Tyner Lake, the road swings westward.

**STOP 2-11** (3-324, 8-189) at kilometre 55.4 consists of several outcrops of Chataway granodiorite. Several small exploration trenches occur south of the main outcrop. The Chataway granodiorite again has blocky, relatively evenly distributed, medium to coarse-grained biotite and poikilitic hornblende; hornblende is more abundant; together they compose 10 to 18 per cent of the rock. Quartz averages 15 per cent and potassic feldspar 8 to 10 per cent. Locally the rock is cut by quartz-potassic feldspar veinlets. The trenched areas have quartz-epidote fractures with some specularite and pyrite. Dominant joint sets dip steeply and strike north-northeast, east-southeast, and south-southeast.

Travel back to Skuhun Creek road (kilometre 61.5), which swings northward shortly after the junction. At kilometre 62.3 a branch road leads eastward to the Sho 11 showing.

**STOP 2-12** (2-311B) at kilometre 63.2 is about 0.5 kilometre north along a branch road from the junction. Trenches and outcrops at the Sho 11 occurrence contain bornite mineralization in a zone of strong flaky sericite (muscovite) alteration in Chataway granodiorite. Other alteration minerals are chlorite, epidote, and hematite. The showing is north of what appears to be a small, elongated stock of Bethlehem granodiorite. Rock exposures are in the trench east of the road and southward along the creek bed.

If you wish to continue, return to the Skuhun Creek road (kilometre 65.1), head north toward Chataway Lake and travel northward through the fishing resort (kilometre 70.6). It would be wise to stop and ask about road conditions; the road north of Chataway crosses a glacial boulder field so the going is slow for several kilometres.

**STOP 2-13** (3-321 or 69-65) Outcrops at kilometre 73.4 consist of foliated, fine to medium-grained Chataway granodiorite. Mafic minerals comprise 15 per cent of the rock; quartz is ameboid and interstitial; plagioclase is lightly saussuritized. Amphibole is the dominant mafic mineral and most crystals are poikilitic. Various samples from the outcrop are transitional in nature to Bethlehem granodiorite; these may be dykes. Dominant joint sets strike northeast and east-southeast; they dip steeply.

**STOP 2-14** (3-315, 69-62, 69-63) at kilometre 74.6 is at the south end of Billy Lake. Outcrops and trench exposures of Chataway granodiorite have about 18 per cent mafic minerals with roughly equal amounts of medium-grained biotite and amphibole. Quartz is generally bluish with an ameboid, open interstitial texture; pink areas of potassium feldspar to 1 centimetre diameter are optically continuous but highly poikilitic; they form 12 per cent of the rock.

The road location and access northward from this point may have changed; the tailings lake for Highmont mine is now situated just north of Billy Lake. The following stops assume that the road route is unchanged.

At kilometre 77.0 the branch road leading west (if it still exists) provides access to the Bornite Ridge showing, which is at the interlayered contact between Chataway granodiorite on the east and Bethlehem granodiorite on the west. Mineralization of the showing consists of bornite, chalcopyrite, malachite, and chrysocolla in quartz veins; associated alteration minerals are chlorite, epidote, and sericite. Pyrite occurs locally. Stringers of aplite strike east to north-northeast.

The rocks in the area north of Billy Lake have nondistinctive textures and are cut by feldspar porphyry dykes; combined with poor exposure, mapping becomes tricky. It is also an interesting area because there are numerous occurrences of mineralization and one significant showing is known.

At **STOP 2-15** (3-283) (kilometre 78.5) the outcrops were mapped as Bethlehem granodiorite; they may be dykes. The rock is relatively fine grained and exhibits pervasive propylitic alteration. Biotite and amphibole compose 18 per cent of the rock; hornblende is more abundant; quartz is ameboid, interstitial, and 10 per cent. Potassic feldspar is interstitial and 3 per cent. Some north-striking joints are coated by malachite-stained epidote and chlorite. Another prominent joint set strikes northeast and dips steeply.

Near kilometre 79.0 the road swings west and a branch road leads north about 0.3 kilometre to a short adit (STOP 2-16).

At **STOP 2-16** (69-60), rocks adjacent to the adit have mixed characteristics; the majority of the rock resembles relatively fine-grained Chataway granodiorite but there are scattered coarse poikilitic amphiboles, larger than are typical in Bethlehem granodiorite - perhaps these are xenocrysts. Locally, small rounded mafic-rich xenoliths occur; they have more felsic alteration rims.
Mineralization occurs as quartz veins containing bornite and chalcopyrite that have chloritized and sericitized alteration selvedges.

Go back to the main road (kilometre 79.6), and continue northwestward. The road switches around to bear northeast at kilometre 80.7.

**STOP 2-17** (69-57) at the switchback at kilometre 81.7 displays aplitic quartz feldspar porphyry dykes in rocks that have been mapped as Chataway granodiorite. The granodiorite has approximately equal amounts of slightly chloritized biotite and amphibole that are relatively uniformly distributed. Quartz forms anhedral, ameboid grains and potassic feldspar coarse, highly poikilitic patches. In hand specimen, plagioclase is not obviously zoned; it is lightly sericitized. Steep-dipping joints strike northerly and southeasterly.

**STOP 2-18** (69-56) At kilometre 82.8 a short branch road leads 0.1 kilometre south to the Jericho portal and dump. Bornite and chalcopyrite mineralization occur in quartz-carbonate veins which are cut by chalcedonic quartz, calcite, and zeolite veinlets. The country rock is relatively fine grained Guichon granodiorite; it is chloritized and sericitized adjacent to the veins. Adjacent to the veins it is also brecciated; feldspars in the breccia are green and pervasively seriticized; biotite is tan, altered to sericite and carbonate; amphibole is chloritized. Some fragments that are engulfed in chalcedonic vein material have quartz overgrowths. The country rock is probably Chataway granodiorite.
Probable reserves are reported as 313 000 tonnes at 1.06 per cent copper.

**TOUR 3**

Tour 3 concentrates on viewing a section from Bethlehem through Highland Valley to Border phase rocks, porphyry dykes, and the South Seas breccia pipe and associated mineralization.

Start at the Bethlehem turnoff on Highland Valley highway and proceed eastward toward the mine. Turn north onto the 'Trojan' road at kilometre 1.8, just west of the Bethlehem guard house.

**STOP 3-1** (2-114, 1-74) is reached by following a small branch road at kilometre 5.6 westward 0.9 kilometre to Bethlehem phase outcrops on the ridge. The rock is granodiorite with foliation at 060°/73° northwest that is moderately well developed. Plagioclase forms subhedral to euhedral laths; 15 per cent mafic minerals consist of coarse, poikilitic amphibole and finer mixed amphibole and biotite. Quartz forms ameboid grains; it is 20 per cent by volume of the rock. Potassic feldspar, which is not prominent (5 per cent), is interstitial. Weak alteration of mafic minerals to chlorite and epidote and scattered epidote veinlets occur along flat-lying joints. The dominant joint set strikes south-southeast and dips steeply.

Back at the main road at kilometre 7.4, continue to kilometre 8.0 then follow the branch road that leads south then eastward toward Bose Lake. The east end of Bose Lake is at about kilometre 11.

**STOP 3-2** (2-1) (1-2, 1-6) (69-38-41) is reached by walking along a short branch road north from kilometre 13.2. The outcrops display a small, northeast-elongated stock of quartz feldspar porphyry cutting Guichon granodiorite country rock. The Guichon granodiorite is weakly foliated and contains 17 per cent biotite and hornblende. Mafic minerals are fine to coarse grained and have associated magnetite; they tend to form clusters of subhedral grains. Plagioclase laths are subhedral to euhedral. Potassic feldspar (12 per cent) forms blotchy, pink interstitial areas. Quartz is interstitial and anhedral (10 per cent).
The dyke rock varies in texture. Phenocrysts are plagioclase, which is commonly weakly sericitized, and amphibole. The matrix is a mixture of quartz, potassic feldspar, and plagioclase speckled with fine amphibole and biotite.

Continue northeastward along the road.

At **STOP 3-3** (69-27, 3-17) (kilometre 16.4) there are small outcrops along the road and a large mound of outcrop about 300 metres to the west. The smaller outcrops are Guichon granodiorite; in the large outcrop it is cut by several east and east-southeast-striking plagioclase porphyry dykes.

The granodiorite is foliated with 25 per cent biotite plus amphibole in clusters of subhedral grains. Plagioclase is euhedral and not obviously zoned. Quartz forms fine-grained, wedge-shaped interstitial areas. Potassic feldspar forms pink, poikilitic patches; it is 15 per cent of the rock by volume. Accessory minerals visible in hand specimen are sphene and magnetite. There is weak alteration of mafic minerals to chlorite and epidote; plagioclase is weakly sericitized. Dominant joint sets strike north and east-northeast; they dip steeply. Dykes are amphibole (12 per cent) plagioclase (50 per cent) porphyry with fine-grained, sugary quartz-potassic feldspar matrix.

The road continues northeastward to about kilometre 18 then swings gradually east and south-southeast. Rock exposures adjacent to the road are mainly Guichon granodiorite.

**STOP 3-4** (3-30, 3-31, 3-75) at kilometre 20.5 is alse in Guichon granodiorite. Near the south end of the outcrop it is cut by a thick (?) plagioclase porphyry dyke. The massive to foliated granodiorite has 18 per cent amphibole plus biotite; amphibole is most abundant. Quartz (12 per cent) is angular and interstitial; potassic feldspar (18 per cent) forms pink patchy zones. The porphyry dyke is similar to that at STOP 3-3.

To pass out of Guichon variety and examine Border phase rocks it is necessary to hike easterly (075°) about 650 metres to a series of ridge outcrops.

**STOP 3-5** (3-72, 3-76, 3-77) is in Border phase quartz diorite. Texturally the rock resembles Guichon granodiorite but is more mafic rich and commonly finer grained; potassic feldspar is sparse or absent. Mafic minerals are 30 to 40 per cent by volume; amphibole generally exceeds biotite. Quartz is not prominent (10 per cent) and is interstitial. The rock is variably massive to foliated. Aplitic dykes occur locally. Dominant joint sets dip steeply and strike northerly, northeasterly, and southeasterly.

It might be possible to continue along the road, which passes through the south Dansey property and out to Tunkwa Lake road; however, the creek crossing at kilometre 21.5 may be impassable. I recommend returning along the route you followed in. Back at the Bose Lake junction reset the trip odometer to zero and continue north along the Trojan road.

**STOP 3-6** is at kilometre 1.5, the chein saw-collapsed head frame of the South Seas (Trojan) prospect. The Guichon granodiorite country rock around the South Seas breccia pipe is propylitically altered with quartz-epidote coatings on fractures. Plagioclase porphyry and quartz plagioclase porphyry (Trojan rhyolite of Carr, 1966) dykes cut the country rock but are crackled or totally dismembered within the breccia pipe. The pipe is subcircular in plan with borders gradational over a few tens of metres. Textures vary from closely spaced fractures to distinct, angular separate fragments to rounded fragments in a clastic matrix. Clasts are both Guichon granodiorite and porphyry dyke; they are variably bleached and altered. Angular fragments are separated by quartz-tourmaline veins and infillings; commonly there are central crystal-lined vugs that carry specularite and chalcopyrite mineralization. Rounded fragments lie in a dust to sand-sized matrix of ground up country rock; such areas tend to be poorly mineralized. Crosscutting veins and cut-off veins in fragments attest to multicycle brecciation.
Mineralization is highly erratic. Tonnage and grade estimates, based on underground and drill testing, remain unreliable.
Immediately to the east and north of the breccia pipe the granodiorite is unconformably overlain by Tertiary lava flows. These range from brittle, slightly porphyritic, dark grey dacitic andesites to amygdaloidal, light grey amphibole-needle porphyritic dacite flows.

Continue northward on the road to approximately kilometre 4.5 where it swings westward then north toward the Krain deposit. Rocks in this area are laced with several varieties of porphyry dyke, and have pervasive propylitic alteration. Dyke and country rock are often difficult to distinguish because the area is also just below the Tertiary unconformity and the rocks are oxidized and rusty.

**STOP 3-7**, kilometre 6.5, is the site of the former Krain camp, now vandalized. Just north of the camp walk down a spur road that angles off to the right from the main road. Outcrops near the junction show steep southeast-dipping plagioclase porphyry dykes that strike 160 and 135° cutting Guichon granodiorite country rock. The two adits are in weathered, rusty, propylitically altered Guichon granodiorite. Blocky outcrops a short way up the slope are Tertiary amphibole-needle porphyritic dacitic andesites. The only copper minerals seen near the adits are chrysocolla, neotocite, malachite, and azurite; hyopgene sulphides have been destroyed by weathering. Krain is unusual in that the slightly enriched oxidized capping is up to 100 metres thick in areas covered by Tertiary volcanic rocks; elsewhere the oxidized capping is largely eroded.

As described by Christie (1976) mineralization at Krain occurs in Guichon granodiorite to quartz diorite and in younger anastomosing dykes and small stocks that texturally resemble Bethlehem phase rocks. Christie quotes reserves of 14 million tonnes of 0.56 per cent copper and 0.01 per cent molybdenum.

Continuing onward, the road loops southward then westward. Keep south at the junction at kilometre 8.0.

**STOP 3-8** (69-314 to 69-318) at kilometre 8.3 examines the Transvaal showing. An adit driven on the showing is collared in Guichon granodiorite. Fractures in the country rock are coated with epidote. Steep-dipping crowded plagioclase porphyry (15 metres wide) and plagioclase porphyry (25 metres wide) dykes striking north and 025° cut the country rock in outcrops west of the dump and southeast up the slope from the portal. Mineralization seen in dump material consists of quartz-tourmaline-specularite veins with fracture and vug fillings of chrysocolla interlayered with agate or chalcedony.

At kilometre 8.7 take the south fork which traverses the old Highland Valley workings area. The road passes numerous trenches and there are several short adits and shafts. The rock is mainly Guichon granodiorite cut by porphyry dykes; almost all exposures are weathered and hypogene sulphides are generally oxidized.

At **STOP 3-9** (69-306 to 69-311) (kilometre 9.0), there is a shallow shaft with headframe just north of the winding road. More recent trenching was also carried out to test the mineralization. The country rock consists of rusty-weathering relatively fine-grained, chloritized Guichon granodiorite and plagioclase porphyry dykes. Mineralization in the dump consists of quartz-tourmaline-epidote-chlorite-chrysocolla veins with chlorite-epidote alteration envelopes; chalcopyrite also occurs in some of the trenches. Epidote-coated fractures are commonly slickensided. The relationship between porphyry dykes and mineralization is unclear.

Continue onward along this road and it joins the Trojan road about half a kilometre south of the South Seas headframe.

## TOUR 4

Tour 4 starts on the Highland Valley highway at the turnoff to Bethlehem Copper. The tour crosses a section of the batholith from Bethsaida phase through a narrow zone of Bethlehem and Highland Valley phase rocks into Border phase rocks that are contaminated by partially assimilated metasedimentary and metavolcanic rocks; it also includes Alwin (OK)-type mineralization and a Tertiary diatreme. Warning: south of Calling Lake the road is rough.

Near the Bethlehem turnoff a dirt road branches off to the west toward the now inactive Alwin (OK) mine - there should be a sign. Thick glacial cover fills the valley; a drill hole 290 metres (950 feet) long did not reach bedrock. Drive along the road to kilometre 4.25, the Lornex water pipeline crossing; the outcrops are just north of the road along the pipeline.

**STOP 4-1** (1-168) is about 100 metres along the water pipeline, where exposures are Tertiary fragmental volcanic rocks dated at 50 Ma by Northcote (1969). The rock consists of amphibole-needle quartz plagioclase porphyry fragments in a matrix of finer material derived from the larger fragments. In drill core, foliation occurs locally; it is defined by alignment of amphibole needles and segregations of mafic and felsic components and has dips ranging from 40 to 70°; there are also local 'mud' layers that dip at high angles. In thin section, these 'mud' layers are clearly cataclastic zones; they appear to be crystal lithic tuffs but the geometry from drilling and the steeply inclined foliation in the rock suggest that at least in part this Tertiary body is a diatreme. Mineralogically similar bodies that are clearly small plugs occur about 5 kilometre northwest of the STOP, and under the small lake west of Alwin mine.

Continue westward along the main road.

**STOP 4-2** (69-3, 10-160) at kilometre 5.8 is in medium-grained Bethlehem granodiorite. The rock contains about 17 per cent mafic minerals and amphibole exceeds biotite in abundance; both are weakly chloritized. The amphibole is poikilitic and subhedral. Plagioclase crystals vary widely in size and borders are eroded; potassic feldspar is not abundant. Quartz is anhedral and interstitial. Accessory minerals are sphene, apatite, zircon, and magnetite.

At kilometre 7.4 follow the Alwin bypass road west of the small lake. Mineralization at Alwin occurs largely in quartz veins with well-developed phyllic (flaky sericite plus quartz) halos. Dominant sulphide minerals are bornite and chalcopyrite with lesser amounts of primary chalcocite and local pyrite. The veins are developed in Bethsaida quartz monzonite. Several pre-ore quartz feldspar porphyry dykes cut the Bethsaida country rock.

A K/Ar analysis of flaky sericite from a mineralized zone returned an apparent age of 189 Ma (Blanchflower, 1971).

Rock exposures along the road south from Alwin are Bethsaida quartz monzonite to granodiorite. The west end of Calling Lake is at kilometre 10.0.

**STOP 4-3** (8-136, 7-143, 2-218) is at kilometre 11.2. Just east of the road are a series of trenches and a short decline on the Empire-Kathleen showing. Mineralization and alteration at the showing are very similar to those at Alwin mine.

The country rock away from the showing is Bethsaida quartz monzonite. Biotite is the dominant mafic mineral; mafics are 5 per cent by volume and weakly altered to chlorite and epidote. Quartz and plagioclase are subhedral to euhedral and coarse grained; potassic feldspar is interstitial, intergrown with finer quartz and plagioclase. Plagioclase is weakly sericitized. Aplite dykes occur locally. Dominant joint sets dip steeply; they strike north and east-southeast. Uncommon quartz-bearing fractures carry chalcopyrite partly altered to malachite.

Easterly from the road a trench trending 155° exposes nearly fresh to argillically altered Bethsaida quartz monzonite; some joints are coated by sericite, chlorite, or epidote. In the trench are sericite-chlorite alteration zones trending northerly, northeasterly, and southeasterly; narrow quartz stringers in these zones are stained with malachite.

Follow bearing 105° from the trench to the old shaft and decline. Mineralization in the dump material is mainly bornite in quartz veins and as disseminated blebs in dark green flaky sericite alteration zones. Locally pervasive pink (potassic feldspar ?) alteration accompanies the sericite. The border of the intense alteration zone at the decline strikes 082° and is vertical. Late-stage infillings in the quartz veins include the bornite, carbonate, and less common chalcocite (hypogene ?); some vein borders are lined by molybdenite.

Continue southward to kilometre 14.3 where a rough branch road leads west. If you wish to examine more Bethsaida phase rocks, a branch road leads eastward about half a kilometre further south along the main road. Follow the west branch road.

**STOP 4-4** (69-383, 7-41, 7-41A) at kilometre 15.5 are small outcrops of Bethlehem granodiorite. It is debatable whether the rock at the STOP is Skeena or Bethlehem granodiorite; the two have gradational contacts and are telescoped in this area. Plagioclase forms subhedral to euhedral laths; quartz is ameboid and 22 per cent by volume; potassic feldspar (10 per cent) is salmon pink and interstitial. Biotite is most abundant but both biotite and amphibole are present. Mafic minerals are 15 per cent by volume; large poikilitic amphiboles (2 per cent) give a bimodal size distribution. Plagioclase is weakly sericitized and mafics are weakly chloritized. Some fractures are filled by chlorite and epidote; these are commonly slickensided. Dominant joint sets strike easterly and southeasterly; dips are moderate to steep. Further westward, the rock is finer grained and clearly Bethlehem granodiorite.

**STOP 4-5** (7-41B): Small Bethlehem granodiorite outcrops occur locally to STOP 4-5 at kilometre 15.7 where there is a single small outcrop of Chataway granodiorite alongside the road. Other small outcrops of similar rock are about 200 metres north of the road. The rock is Chataway granodiorite that is characterized by relatively evenly spaced, blocky-shaped biotite and amphibole. Plagioclase is subhedral to euhedral; quartz is ameboid; potassic feldspar is interstitial.

**STOP 4-6** (69-384) at kilometre 15.8 is in hybridized Border phase rock. The rock is variable in texture and composition changes rapidly from quartz diorite to mafic diorite across the outcrop. Concentrations of mafic minerals impart a gneissic texture locally and foliation is commonly moderatbly well developed. Both biotite and amphibole are present but amphibole predominantes. Foliation swirls and strikes vary from north to southeast but dips are invariably steeply inclined.

At kilometre 15.9 follow the southwest branch road. Other exposures of Border phase rock can be seen along the route; continue westward.

**STOP 4-7** (2-266, 69-393 to 395) at kilometre 17.1 examines an outcrop of Border phase hornblende diorite north of a small trench. The rock consists essentially of plagioclase and 35 per cent amphibole; quartz is a minor component, potassic feldspar is absent. Grain size varies from fine to coarse. Amphibole is weakly altered to chlorite and epidote. Magnetite is a prominent accessory mineral. Fracture faces are coated with quartz and epidote. These are scattered aplite dykes. Foliation strikes 160° and dips 75° southwest. Dominant joint sets are northeast and east striking; they have moderate to steep dips.
Xenoliths are common in the outcrop; most are mafic rich but one recrystallized calc-silicate layer is 8 centimetres wide, strikes 145°, dips 58° southwest, and could be followed for 12 metres. The rock is also cut by narrow, quartz-rich amphibole feldspar porphyry dykes.

**STOP 4-8** (69-399, 400; 9-124) is at kilometre 18.0 at the end of the road. A bluffy outcrop west of roads end exposes hybridized Border phase rocks. Assimilation has created rocks of amphibolite to monzonite composition. It is probable that much of the assimilated material was calcareous sedimentary rock; at another location about a kilometre to the southwest a remnant of such material was recognizable. Textures and compositions change on metre scale across the outcrop. These stops are within a zone approximately 10 kilometres long in which Border phase rocks have assimilated significant amounts of Nicola country rock.
The rock near the STOP ranges from quartz-poor amphibole needle monzonite to amphibole diorite to amphbibolite. Amphibole needles in the monzonite range to 1 centimetre in length. Foliation is well developed locally and textures are almost gneissic; strikes are generaly 005 to 040° but locally range to 090°; dips are steep.

## TOUR 5

The intent of Tour 5 is to examine older and younger sedimentary and volcanic rocks along the west side of the Guichon Creek batholith, to visit small stocks along the periphery of the batholith, and to look at Border phase rocks of the batholith.

Start at the southeast end of the Thompson River bridge at the village of Ashcroft. Go west across the railway tracks then south along the paved Highland Valley highway.

**STOP 5-1** (10-29) at kilometre 2.1 affords an opportunity to examine sedimentary and structural features of black siltstones and shales of the Jurassic Ashoroft Formation. A section of these rocks is well exposed in a creek gully east of the road. Along the gully, there are chevron folds, small-scale thrusts, fracture cleavage in siltstones, and 'pencil' cleavage in the shales. Further up the east fork of the gully the rocks contain carbonized tree fragments, sole markings, and other sedimentary features. No diagnostic fossils have been found at this locality. Elsewhere fossils from the Jurassic section range from Sinemurian to Callovian age. This part of the section is probably several hundred metres above the base.

**STOP 5-2** (11-17) at kilometre 3.8 has good exposures of a Tertiary biotite quartz feldspar porphyry stock in a Ministry of Highways quarry. The stock cuts and has a narrow aureole of contact metamorphism in Jurassic sedimentary rocks. The stock is medium to coarse grained and fresh. Further south, outliers that are extrusive equivalents of the stock overlie Jurassic sedimentary rocks.

Take the dirt road that branches off to the right at kilometre 6.8; it is also the access road for the BQ Guest Ranch.

**STOP 5-3** (9-52) is at kilometre 8.6. The hill to the northwest is underlain by pebble to cobble conglomerate of the Jurassic Ashcroft Formation. Most of the clasts are derived from Nicola Group rocks but there are uncommon granitic clasts. The stratigraphic position of this conglomerate is uncertain but similar rocks occur near the base of the section where they unconformably overlie Nicola volcanic rocks.

Continue along the road; keep right at the junction at kilometre 10.3 and switchback down the hill toward Thompson River. Be cautious, the road base is loose sand on one of the switchbacks. After the second switchback the road heads south.

**STOP 5-4** (9-60) at kilometre 12.7 is on the hill top about 200 metres west of the road; small outcrops are mottled, grey-green flow-banded (?) Nicola Group rhyodacites (?); some may be welded ash flow tuff. The rocks are crossed by epidote veinlets with epidote alteration halos.

**STOP 5-5** (9-63A) is past another set of switchbacks to kilometre 14.6. Small outcrops are dark grey-green, epidote-veined and altered, plagioclase porphyritic Nicola Group basaltic andesites.

**STOP 5-6** (7-1, 7-24, 7-25), south of Basque railway station at kilometre 18.5, is at the western end of cliff-forming outcrops of Nicola metasedimentary rocks that are cut by green plagioclase andesite dykes. Fossils, mainly ammonites and pelecepods, from these rocks have yielded Carnian ages. The sequence here consists of siliceous limestones, calcareous chert, pyritic argillite, epidotized sandstone, and pebble conglomerate. Rip-up clasts, soft sedimentary deformation structures, flame structures, and graded bedding are common. These shallow-water marine sedimentary rocks are lower in the Nicola section than the volcanic rocks seen at STOPS 5-4 and 5-5. Bedding is 080 to 100°/40 to 55° north.

Continue southward to the Lornex pump house near Spatsum (kilometre 23.7), then follow a branch road eastward toward the point where the Lornex water pipeline right-of-way can be seen coming down the slope. The road then follows the creek gully northeasterly from the base of the slope. Nicola Group rocks exposed in the valley walls are mainly basalt flows, lapilli tuffs, and volcanic breccias; they apparently underlie the sedimentary rocks seen at STOP 5-6.

**STOP 5-7** (8-8, 8-9, 10-60) is at kilometre 27.5 at the start of several sharp switchbacks. The outcrops expose both Spatsum quartz monzonite near the road, and Border phase quartz diorite up the hill to the east. Unfortunately the contact is covered. The Spatsum quartz monzonite is characterized by coarse-grained green plagioclase, abundant quartz (30 per cent), interstitial potassic feldspar (30 per cent), and few mafics. Amphibole is the only mafic mineral present; it forms 3 per cent of the rock by volume. Some joint surfaces are coated by epidote. Dominant joint sets strike north and east and dip at moderate to steep angles.
Border phase rocks in this area are quartz diorites that have 30 per cent amphibole with lesser biotite. Mafic minerals are moderately altered to chlorite and epidote. Various fractures are coated by epidote, quartz, potassic feldspar, and carbonate. Dominant joint sets strike northeasterly and southeasterly with moderate to steep dips.

Continue up the road and along the pipeline/powerline to kilometre 35.8 where a branch road leads northwestward back to the Highland Valley highway (kilometre 38.0). Follow the highway back toward Ashcroft but turn north toward Barnes Lake at kilometre 52.0. Turn right at kilometre 52.05 and follow the road around and along the east side of Willard Lake.

**STOP 5-8** (8-99, 8-99A) is east of the road at kilometre 53.2. Outcrop and rubbly subcrop expose the satellitic Barnes Lake plagioclase aplite stock. The stock is elongated northeastward; it cuts Nicola volcanic and sedimentary rocks on the west and Border phase quartz diorite on the east. The rock has 25 per cent weakly sericitized plagioclase and 15 per cent mafic mineral phenocrysts in a sugary quartzofeldspathic matrix. Amphibole is more abundant than biotite; both are weakly chloritized and epidotized.
Two prominent joint sets strike northeasterly and south-southeasterly and dip steeply; a third set is subhorizontal.

Return to the Barnes Lake road (kilometre 54.4) and continue northward to the junction at kilometre 57.9 then eastward; park at the outcrop at kilometre 61.6.

**STOP 5-9** (8-20, 10-130) is on the hill about 550 metres north of the road. The outcrops are Nicola Group plagioclase porphyritic basaltic andesite with areas of volcanic breccia. The rock is cut by stringers of epidote, quartz, and pyrite. Most fragments in the breccia are Nicola volcanic rock but granitic clasts occur that are of uncertain origin; perhaps they represent subvolcanic Nicola stocks; they are not obviously derived from the Guichon Creek batholith. About 300 metres east of the hill top Nicola Group gives way to either metamorphosed, granitized Nicola rocks or highly contaminated Border phase rocks. Similar rocks occur about a kilometre further east, north of YD ranch.

## TOUR 6

Tour 6 complements Tour 5; it looks at the Gump Lake quartz monzonite, another granitic body at the periphery of the Guichon Creek batholith. Start about 2 kilometres west of Logan Lake on the Highland Valley highway at the Lower Nicola turnoff. Take the south road and go about 10 kilometres to the north end of Mamit Lake, where a branch road leads westward; at kilometre 10.8 a second road heads north then up the powerline. At kilometre 12.1 take the north branch road to kilometre 13.0 then roads that lead up the slope toward large, blocky outcrops.

**STOP 6-1** (6-1 to 4, 17-59A) exposes Gump Lake quartz monzonite that is locally cut by porphyry dykes. The Gump Lake quartz monzonite is locally porphyritic and well to poorly foliated. The strike of the foliation varies from northeast to southeast and the dip from 50 to 80° easterly. Phenocrysts are plagioclase, quartz, amphibole, and biotite; the matrix is quartzo-feldspathic. Quartz is generally 25 to 30 per cent by volume; mafics are 8 to 17 per cent. Locally aplite or quartz feldspar porphyry dykes cut the quartz monzonite. At least locally, foliation results from cataclastic deformation; in extreme cases the rock is gneissic. In some of the eastern exposures, xenoliths of Nicola metasedimentary rock consist of biotite chlorite schist with quartz, chlorite, epidote, and magnetite layers. Dominant steep-dipping joint sets strike easterly and south-southeasterly; a set with moderate dips strikes northeasterly.

To see the northern edge of the Gump Lake stock, where it cuts Late Triassic Nicola Group metasedimentary and metavolcanic rocks, return to the paved road and follow it north to the Highland Valley highway. One-half kilometre west of the junction follow a dirt road that branches southwestward off the highway. Keep left at the first junction (0.7 kilometre). To see the Nicola country rock keep on straight at the first split in the road (kilometre 1.0) or follow the west branch at kilometre 1.7. To reach Gump Lake intrusive outcrops follow the road southward to kilometre 3.2 where it swings westward.

**STOP 6-2** (7-99) is at kilometre 3.3. Outcrop south of the road is foliated Gump Lake quartz monzonite; foliation strikes 045° and dips 60° southeast. The outcrop is cut by aplitic dykes that strike southeasterly and contains inclusions of metasedimentary rock. The quartz monzonite is porphyritic with plagioclase, quartz, and amphibole phenocrysts. Mafic minerals average 10 per cent; biotite is a lesser component. Potassic feldspar averages 10 per cent by volume. Locally there are schistose, layered metasedimentary xenoliths. The dykes are variably aplite to granite pegmatite, commonly in the same dyke; some carry accessory molybdenite. Dominant joints strike southeasterly and dip steeply.

Other outcrops of Gump Lake rocks can be seen by hiking 500 metres west along the creek from the end of the road at kilometre 4.0. There also the rock is foliated (100°/70° northeast) and cut by aplitic dykes. Rare fractures striking 095° and dipping 75° south contain blotches of chalcopyrite associated with green sericitic feldspar alteration.

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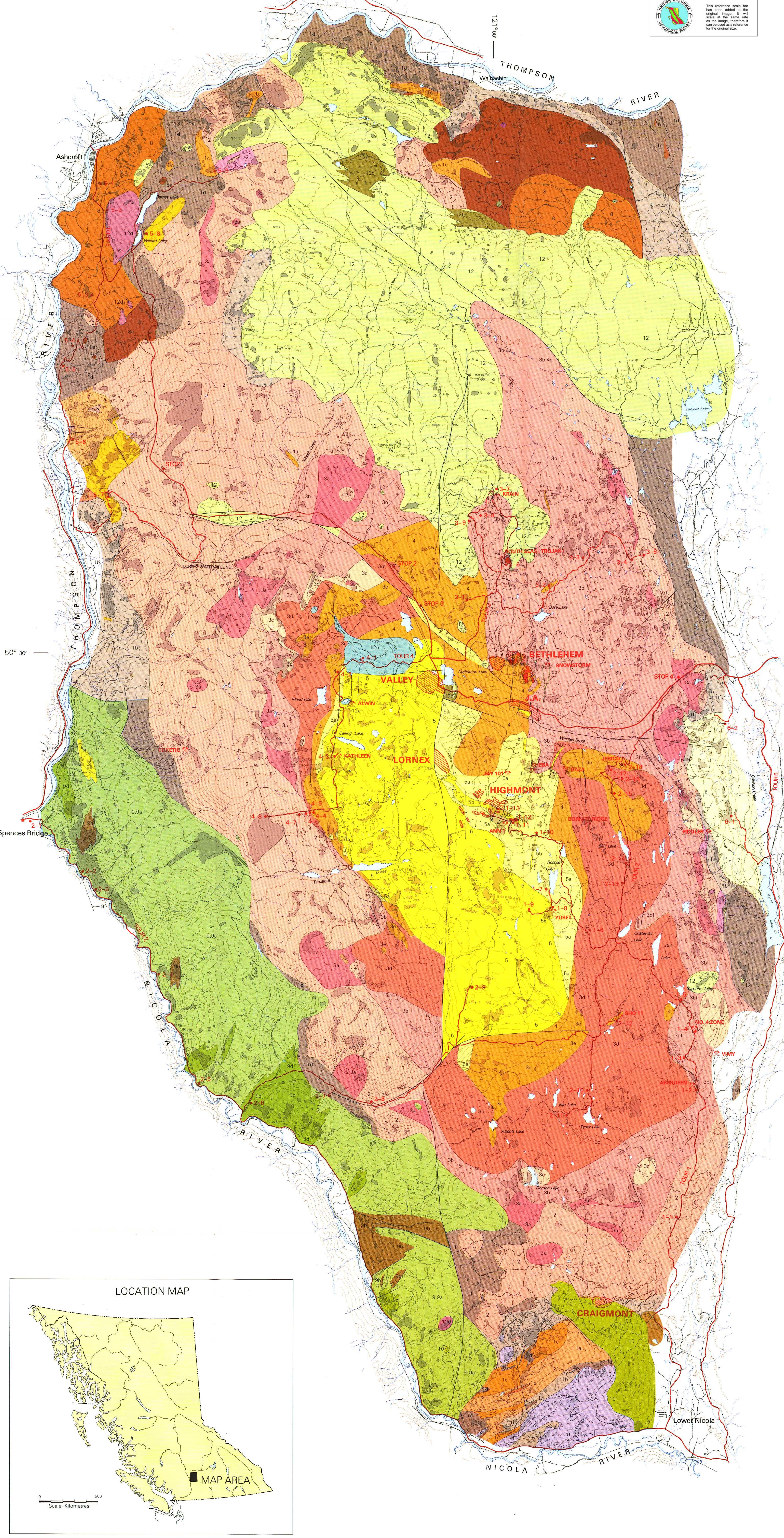


FIGURE 2

Province of British Columbia
Ministry of Mines and Petroleum Resources

# GEOLOGY OF THE GUICHON CREEK BATHOLITH AND HIGHLAND VALLEY PORPHYRY COPPER DISTRICT, BRITISH COLUMBIA

0 1 2 3 4 5000 6 7 8 9 10000

SCALE ~ METRES

## LEGEND

### EOCENE AND YOUNGER (?)

**KAMLOOPS GROUP***

- 12e — ARLINGTON VOLCANIC AND INTRUSIVE ROCKS: BIOTITE QUARTZ PLAGIOCLASE PORPHYRY; INTRUSIVE AND EXTRUSIVE BRECCIA
- 12d — STOCKS AND ASSOCIATED FLOWS OF BIOTITE HORNBLENDE PLAGIOCLASE PORPHYRY
- 12b 12c — VOLCANIC PEBBLE CONGLOMERATE, SANDSTONE, MUDSTONE, MINOR AMOUNTS OF DIATOMITE, AND SCATTERED LAVA FLOWS
- 12 12a — PREDOMINANTLY INTERMEDIATE, SOME ACID AND BASIC LAVA FLOWS; MINOR TUFFS AND VOLCANIC BRECCIAS

### EOCENE (?)

COLDWATER SERIES

- 11 — SEDIMENTARY ROCKS: SANDSTONE, SHALE, CONGLOMERATE, COAL MEASURES

### CRETACEOUS

**KINGSVALE GROUP**

- 10 — BASALT, ANDESITE, HORNBLENDE NEEDLE PORPHYRY (DACITE), VOLCANIC BRECCIA, LOCAL BASAL SANDSTONE AND CONGLOMERATE

**SPENCES BRIDGE GROUP**

- 9f — SWARMS OF ANDESITE TO BASALTIC DYKES
- 9e — RHYOLITE AND RHYODACITE FLOWS
- 9c 9d — VOLCANIC BRECCIAS, SOME AGGLOMERATE, TUFF, RED ANDESITIC LAVAS
- 9b — SANDSTONE, PEBBLE CONGLOMERATE, SHALE (CARBONIZED PLANT REMAINS COMMON)
- 9 9a — MAINLY INTERMEDIATE LAVA FLOWS, DARK–COLOURED PORPHYRITIC PLAGIOCLASE ANDESITES, BASALT

### JURASSIC

**ASHCROFT FORMATION**

- 8 — BLACK SHALE, SILTSTONE, SANDSTONE, MINOR CONGLOMERATE AND LIMESTONE
- 8a — PEBBLE TO BOULDER CONGLOMERATE

### TRIASSIC

GUICHON CREEK BATHOLITH** AND ASSOCIATED INTRUSIONS

**INTRUSIONS OF POST–BORDER PHASE AGE**

- 7 — **GUMP LAKE PHASE** – GRANODIORITE TO QUARTZ MONZONITE
- 6 — SPATSUM QUARTZ MONZONITE; BARNES LAKE PLAGIOCLASE APLITE

**GUICHON CREEK BATHOLITH**

- 5 5b — **BETHSAIDA PHASE** – QUARTZ MONZONITE TO GRANODIORITE AND SLIGHTLY YOUNGER (?) PORPHYRY DYKES AND PLUGS
  - 5a — **SKEENA VARIETY** – GRANODIORITE, INTERMEDIATE IN COMPOSITION AND TEXTURE BETWEEN BETHLEHEM AND BETHSAIDA PHASES
- 4 4a — **BETHLEHEM PHASE** – GRANODIORITE AND SLIGHTLY YOUNGER PORPHYRY DYKES AND PLUGS
  - Bx — BRECCIA BODIES OF EXPLOSIVE ORIGIN
  - 3e — ROCKS WITH TEXTURES AND COMPOSITIONS TRANSITIONAL BETWEEN HIGHLAND VALLEY AND BETHLEHEM PHASES OR AREAS WITH SWARMS OF BETHLEHEM PHASE DYKES IN HIGHLAND VALLEY PHASE

**HIGHLAND VALLEY PHASE**

- 3d — **CHATAWAY VARIETY** – GRANODIORITE
- 3c — GRANODIORITES WITH TEXTURES AND COMPOSITIONS TRANSITIONAL BETWEEN GUICHON AND CHATAWAY VARIETIES
- 3b — **GUICHON VARIETY** – GRANODIORITE, INCLUDES AREAS OF FINER GRAINED GRANODIORITE NEAR CHATAWAY LAKE WHICH HAVE TEXTURES AND COMPOSITIONS LIKE THOSE OF NORMAL GUICHON VARIETY
- 3a — GRANODIORITE TO QUARTZ DIORITE WITH TEXTURES AND COMPOSITIONS TRANSITIONAL BETWEEN BORDER AND HIGHLAND VALLEY PHASES
- 2 — **BORDER PHASE** – QUARTZ DIORITE TO GRANODIORITE
  - 2a — DIORITE TO QUARTZ DIORITE WITH COMPOSITIONS AND TEXTURES TRANSITIONAL BETWEEN NICOLA GROUP ROCKS AND BORDER PHASE QUARTZ DIORITE

**INTRUSIONS OF POST–NICOLA, PRE–SPENCES BRIDGE GROUP AGE**

- 1f 1g — **COYLE STOCK** – DIORITE TO QUARTZ MONZONITE, LOCAL ALASKITE AND MAFIC QUARTZ PLAGIOCLASE PORPHYRY PLUGS; PROBABLY RELATED TO LATE–STAGE NICOLA VOLCANISM

**NICOLA GROUP**

- 1e — ACIDIC VOLCANIC FLOWS AND PYROCLASTIC ROCKS
- 1d — MAINLY VOLCANIC ROCKS OF INTERMEDIATE TO BASIC COMPOSITION
- 1c — VOLCANIC BRECCIAS AND FLOWS, FLOW BRECCIA AND DEBRIS SLIDES
- 1b — MIXED VOLCANIC AND SEDIMENTARY ROCKS
- 1a — MAINLY SEDIMENTARY ROCKS, SANDSTONE, LIMESTONE, ARGILLITE, SOME CHERT

*SUBDIVISIONS UNDER MAIN HEADINGS ARE BASED ON LITHOLOGY, NOT RELATIVE AGE.

**TERMINOLOGY FOR PHASES AND VARIETIES OF THE GUICHON CREEK BATHOLITH MODIFIED SLIGHTLY AFTER K.E. NORTHCOTE, *BRITISH COLUMBIA MINISTRY OF MINES AND PETROLEUM RESOURCES,* BULLETIN 56, 1969.

## SYMBOLS

**GEOLOGICAL**

- OUTCROP
- GEOLOGICAL CONTACT
- FAULT
- DYKE
- DYKE SWARM AREA
- ORE OUTLINE

**WORKINGS**

- OPEN PIT
- MINE DUMP
- SHAFT
- ADIT
- TRENCH

**GEOGRAPHICAL**

- HIGHWAY
- TWO–WHEEL–DRIVE VEHICLE ROAD
- FOUR–WHEEL–DRIVE VEHICLE ROAD
- TRAIL OR OVERGROWN ROAD
- POWERLINE
- CONTOUR, INTERVAL 250 FEET

GEOLOGY BY W.J. McMILLAN, 1969 TO 1974; J.D. BLANCHFLOWER, 1970 TO 1972; P. McANDLESS, 1970; D. COOMBES, 1970, 1971; P. GARVIN, 1971; ASSISTED BY N. JORGENSEN, D. HENDRY, B. LEE, J. CORDONIER, S. LANE, A. SEMENCHUK, AND W. ISHERWOOD.