896341 Xeroxed Feb/74
for WJ McMillan

QUEEN'S UNIVERSITY
KINGSTON, ONTARIO

VALLEY COPPER

Oct. 22/73

Dear Myron,

Enclosed is a copy of M. Jones' "Mini-thesis" on the Valley Copper deposit. He appears to have done a lot of petrology and some possibly important oxygen isotope work. I'm still a little hesitant about the usefulness of sulphur isotope data. Roughly, his ideas appear to correspond to yours but I believe you have much greater detail in your study. It is difficult to evaluate his data without full knowledge of his scope and actual methods of investigation. I hope you will find it useful. Perhaps Jim has his completed thesis now.

I obtained a copy of your Valley Copper report from JMA and am using a generalization of your mineralogical and geochemical results in my introduction to the Valley Copper area.

I received the samples from Rubiales and am having them analysed at Barringer. Will let you know the results.

Regards

Bob.

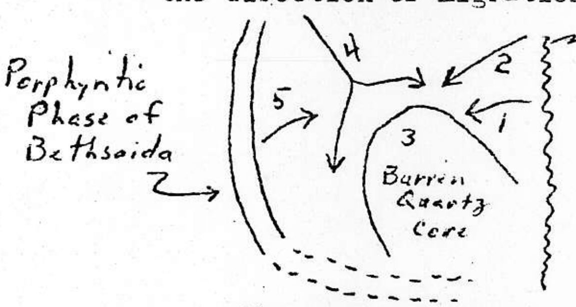
April 3, 1973

Dr. Jim Allen
COMINCO, Ltd.
1155 W. Georgia
Vancouver, B. C.

Dear Jim,

It has been a while since I last wrote you, so I think a progress report is in order. Right now, Cy is sitting on most of the thesis. As soon as he buys some new red ink pens, he will probably get back to reading it. I have one section left to write, the chapter on isotopes.

Valley Copper has been an interesting deposit to study. My work has given me a chance to see the inside of a porphyry deposit. Valley Copper contains classical alteration types, but I have let my imagination put them together in an unclassical zoning sequence. My story condences down to this diagram showing the direction of migration and timing of the alteration types.



1. Argillic (pervasive) alteration
2. Pervasive (green) sericite
3. Barren quartz core w/ some secondary K-spar and biotite
4. Vein sericite w/ principal sulfides
5. Mineralized quartz veins

The various solutions appear to have migrated inward rather than outward as in classical porphyry deposits in the Southwest. The isotope data interpretation is still a little fuzzy. A lot of the water appears to be magmatic, but there is a significant trend with the vein sericites that suggests mixing with connate (oceanic) water. The most difficult problem I have is coping with the amount of water I calculated was involved in the alteration processes. I get 220 cubic miles! I don't know if it is a believable number. If a convection cell existed, this would be the amount of water that ultimately passed through the altered rock.

Cy mentioned that Cominco has a U.S. based subsidiary, Cominco American, that may be needing geologists. I would appreciate any information you could give me about its operation and whom I should write concerning full time or summer employment.

My next letter to you should be inclosed with my thesis. How many copies would you like?

Sincerely,

Mike

Michael B. Jones

August 1, 1972

Dear Jim,

Inclosed is a mini-thesis and accompaning alteration maps. The intent of this report is to give you the major ideas and interpretations I have about the Valley Copper Deposit. Alteration distributions are given for the 3800 and 3000 foot levels, the Reference Line section, and Sections 12 and 16. I have rough drafts of the alteration distributions for Sections 10, 14, and 18 which I have not included in this report. I hope you will have the time to go through the report and criticize it. You are the only one who can adequately evaluate my interpretation of the distribution and genesis of the alteration types.

Here are just a few of the problems I have not yet resolved. Any thoughts you have about them would be greatly appreciated.

1. The order of emplacement of the dikes. I feel that the paragenesis is Bethsaida-Porphyritic Phase of the Bethsaida-Tan Felsite Porphyry-Aplites-Lamprophyre. The Bethsaida and the Lamprophyre I am sure about, but the other three I am not.

2. The location of the Porphyritic Phase of the Bethsaida. My imagination probably got the best of me when I ran it along the south side of the deposit. Is there any evidence in the odd numbered sections that the dike might exist south of Holes 68-12, 68-31, and 68-17?

3. The paragenesis of the molybdenite. I did not find any unequivocal evidence that indicates the molybdenite is definitely older or younger than the bulk of the copper mineralization.

4. Faults. I kept track of gouge zones, but they were too numerous to include on the sections. Most of the gouge zones have associated intense argillic alteration. If most of the gouge zones are post mineralization, my paragenesis of the argillic alteration must be wrong. The alteration distributions were drawn without including the effects of faults. Vertical offsets in the gypsum and vug lines may correspond to post-mineralization faults. In Section 10 the vug line drops from 3600 to 2800 feet between holes 68-26A and 69-48. In Section 12 the gypsum line shows sort of a graben outline. In Section 16 hole 68-23A shows the gypsum line about 200 feet lower and the vug line about 400 feet lower than in the other holes in that section. My problem may be lack of information from the odd numbered sections. I think I recall seeing one of your maps with north trending fault zones on the west and east sides of the deposit. Do you know if they are pre- or post-mineralization?

I hope this paper probides you with a few new insights to the Valley Copper Deposit. I felt like most of my mapping was kicking a dead horse due to the thoroughness with which you and Ron had studied and mapped the geology and alteration of the deposit. I look forward to any suggestions or criticisms you may have.

Mike

HYPOGENE ALTERATION AND MINERALIZATION AT VALLEY COPPER

BRITISH COLUMBIA

A Mini Thesis By

Michael B. Jones

Oregon State University

1972

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HYPOGENE ALTERATION AND MINERALIZATION AT VALLEY COPPER

ABSTRACT

Valley Copper is a structurally controlled porphyry copper-molybdenum deposit in the Highland Valley District of British Columbia. Hydrothermal alteration and mineralization were guided by faults and fractures localized in the Bethsaida Granodiorite, the youngest major phase of the 200 m.y. Guichon Creek Batholith. Principal ore minerals are bornite, chalcopyrite, and minor molybdenite. They were deposited in quartz and quartz-sericite veins and veinlets which cut previously kaolinized and pervasively sericitized Bethsaida host rocks. A stockwork of closely spaced barren quartz veins with minor potassium feldspar forms the low grade core to the deposit. A pre-mineralization quartz latite porphyry dike underlies the deposit at depth. The barren quartz-vein stockwork and the quartz latite porphyry dike may have originally channeled and dammed the ore-bearing hydrothermal fluids.

Clay, sericite, and potassium feldspar are the dominant alteration minerals and form pervasive and vein-type alterations. Pervasive argillic alteration, primarily as microcrystalline kaolinite replacement of plagioclase feldspar, occurs in three zones. They are vertically nested and concave-down. To the east in the vicinity of the Lornex Fault the three zones coalesce into one broad zone of intense argillic alteration. Kaolinite also forms selvages up to 2 cm wide adjacent to quartz-sericite veins. Intense pervasive sericite, primarily as microcrystalline muscovite replacement of plagioclase feldspar, forms an irregular zone of alteration. This zone dips northeast to east in the northeastern part of the deposit. Minor chalcopyrite and/or pyrite are commonly associated with the more intense pervasive sericite alteration.

Bornite and chalcopyrite bearing quartz and quartz-sericite veins up to 6 cm wide form three curved stockworks. These mineralized stockworks are nested and concave around the northwest plunging barren quartz-vein stockwork that forms the core of the deposit. The mineralized and barren quartz veins are probably open space fillings, and above the 3200 to 3400 foot levels they contain magascopic vugs. However, the quartz-sericite veins and sericite selvages adjacent to mineralized quartz veins replace the host rock. Most of the sulfide minerals are associated with the sulfide-bearing quartz and quartz-sericite veins. Hydrothermal potassium feldspar forms pervasive replacement masses and thin envelopes up to 5 mm wide adjacent to quartz-sericite veins. It is most abundant in a relatively deep zone (below the 3600 foot level) that is concave-downward. The approximate paragenesis of the alteration types is (1) argillic, (2) pervasive sericite, (3) barren quartz-vein stockwork, (4) pervasive potassium feldspar, and (5) sulfide-bearing quartz and quartz-sericite veins.

The sulfides consist of pyrite, molybdenite, chalcopyrite, bornite, and rare sphalerite, and chalcocite. Pyrite ($\ll$1 percent by volume) is disseminated, primarily in pervasive sericite, around the margin of the deposit. Molybdenite is a ubiquitous, but minor, sulfide that is most abundant around the margin of the deposit. Chalcopyrite and bornite are the principal ore minerals (total copper = 0.45 percent) and they are generally localized in the quartz and quartz-sericite veins. Bornite is more abundant than chalcopyrite, except towards the margin of the deposit. The approximate paragenesis of the sulfide minerals is (1) pyrite-sphalerite-chalcopyrite; (2) molybdenite-chalcopyrite-bornite-minor pyrite; and (3) bornite-chalcocite.

Gypsum and anhydrite occur in the deeper parts of the deposit.

Gypsum veinlets are ubiquitous below the 3500 foot level. They cut all other alteration types and are the latest hypogene event. Rare anhydrite crystals, commonly associated with bornite, are found below the 3400 foot level in mineralized quartz veins and as small replacement masses in zones of intense potassium feldspar alteration.

Sulfur isotope ratios near zero permil (+1.53 to -4.11 permil) of sulfide minerals and heavy oxygen isotope ratios (+12.5 to +6.5 permil) of the alteration minerals imply a magmatic source for the hydrothermal sulfur and water. Moreover, potassium-argon ages of 200 m.y. are the same for the hydrothermal sericite (198 to 202 ± 4 m.y.), the quartz latite porphyry dike (204 ± 4 m.y.), and the Bethsaida Granodiorite (198 ± 8 m.y., Northcote, 1969). The isotope ratios and age dates clearly suggest the genetic coincidence in time and space of the hydrothermal alteration and mineralization with the late magmatic processes of Bethsaida phase plutonism. Cross-cutting lamprophyre dikes (132 ± 3 m.y.) post-date both the plutonic and hydrothermal events.

INTRODUCTION:

The Valley Copper Deposit is 25 miles southeast of Ashcroft in the Highland Valley District of British Columbia (Fig. 1a). Through 1969, Cominco Ltd. drilled more than 100,000 feet of diamond drill holes from surface and underground locations. This study is based upon the detailed examination of 32,849 feet of diamond drill core in 31 holes from which over 500 samples were obtained for petrographic, chemical, X-ray, and isotopic studies. All the holes are collared in Valley Copper property and are in or near vertical sections 10, 12, 14, 16, 18, and the Reference Line section shown in the figures that accompany this report. The numbered sections are 825 feet apart and trend N. 44°55' E. The reference line is normal to the numbered sections. The choice of the 3800 and 3000 foot levels for plan views oompromises maximum vertical separation of the plans with the lack of data due to overburden at higher levels and the few number of holes at depth.

The seven sets of cross sections that accompany this report display the following information: (1) geology (Figs. 1a-f), (2) copper assays (Figs. 2a-h), (3) argillic alteration (Figs. 3a-h), (4) pervasive sericite alteration (Figs. 4a-h), (5) vein sericite alteration (Figs. 5a-h), (6) potassium feldspar alteration (Figs. 6a-g), and (7) sulfide distribution (Figs. 7a-h). Arbitrary cut offs for low grade (blue line) and high grade (red line) copper values (the same as on Figs. 2a-h) relate the information displayed on all section and plan maps to the distribution of copper.

GEOLOGY AND PETROLOGY

The 200 m.y. Guichon Creek Batholith is the host to the Valley Copper Deposit. The batholith is roughly oval in shape, about 37 miles across and 80 miles long, and elongate north-south. The major phases of the batholith are concentrically zoned and become more silicic and relatively younger toward the center. The Valley Copper Deposit is near the north edge of the Bethsaida Granodiorite, the central and youngest major phase of the Guichon Creek Batholith. Glacial drift and lakes completely mantle the deposit. The overburden ranges from 10 to over 200 feet in thickness. The northern part of the deposit is in the northwest trending Highland Valley depression. The Bethlehem ore bodies and their host rocks, the Bethlehem Granodiorite and Guichon Quartz Diorite, are 2 miles northeast of the Valley Copper Deposit. The eastern part of the deposit may terminate against the north striking Lornex Fault. The Lornex ore body and its host rocks, the Skeena Granodiorite, Bethsaida Granodiorite, and a porphyry dike, are 2 miles southeast of Valley Copper and along the east side of the Lornex Fault.

The principal host rock throughout the Valley Copper Deposit is the Bethsaida Granodiorite, which crops out nearby to the south and west. Accordingly, its distribution is not shown on the Geology sections (Figs. 1a-h). Three kinds of dikes are found within the deposit. In order of emplacement, they are a Porphyritic Phase of the Bethsaida Granodiorite, a Tan Felsite Porphyry, and a lamprophyre (see Figs. 1a-f).

In available literature the Bethsaida phase is generally classified as a granodiorite or quartz monzonite. Petrographic examination of samples collected for this study from within and outside the mine area are granodiorite with generally less than 10 percent total mafic minerals.

(trondhjemite). The Bethsaida Granodiorite characteristically has large squarish quartz phenocrysts (25 percent) to 1 cm in diameter, subhedral plagioclase (55 percent, normally zoned An_{35-10}) to 8 mm in length, anhedral orthoclase (15 percent) to 2 mm in diameter, and black biotite (5 percent) as books to 1 cm in diameter.

The Porphyritic Phase of the Bethsaida Granodiorite is a quartz latite porphyry that occurs as a dike with a maximum thickness of about 100 feet. Drill holes intersect this dike on the west and south sides of the deposit where it dips to the east and north, respectively (Figs. 1a-f). The Porphyritic Phase of the Bethsaida Granodiorite characteristically has a fine grained green matrix (about 46 percent) that consists primarily of granular potassium feldspar and quartz. The important phenocryst phases are subhedral to euhedral plagioclase (35 percent, An_{24-20}) to 7 mm in length, partially resorbed euhedral quartz (10 percent) to 8 mm in diameter, and biotite (1 percent) to 1 mm in diameter.

The Tan Felsite Porphyry is a quartz latite porphyry that intrudes the Bethsaida Granodiorite as a dike swarm cut by holes in Section 16 (Fig. 1e). Intersection lengths with the holes reach a maximum of 15 feet. The matrix of the Tan Felsite Porphyry is more abundant (about 87 percent) than that of the Porphyritic Phase of the Bethsaida Granodiorite. The matrix is light tan and consists primarily of serrate-edged potassium feldspar and quartz. The predominant phenocrysts are round to euhedral partially resorbed quartz crystals (5 percent) to 2 mm in diameter, euhedral plagioclase (4.5 percent, An_{32-24}) to 2 mm in length, euhedral potassium feldspar (2.6 percent) to 1.5 mm in length, and anhedral biotite (0.7 percent) to 1 mm in length.

Lamprophyre dikes are intersected by holes in Sections 10, 12, and 18 (Figs. 1b,c, and f). The lamprophyre is a vogesite with augite more abundant than phlogopite. The maximum intersection length with a hole is 37 feet. The lamprophyre dikes cut the Porphyritic Phase of the Bethsaida Granodiorite and sulfide-bearing veins of quartz and sericite, and thereby clearly postdate hydrothermal mineralization.

Northcote (1969) dated the major phases of the Guichon Creek Batholith by potassium-argon methods and found them to center around 198 ± 8 million years. This study obtained additional potassium-argon dates on the Porphyritic Phase of the Bethsaida Granodiorite (204 ± 4 m.y.) and a lamprophyre dike (132 ± 3 m.y.). Within the analytical limits of the potassium-argon method, the ages for the Bethsaida and other major phases of the Guichon Creek Batholith and the Porphyritic Phase of the Bethsaida Granodiorite are the same, about 200 million years. However, the lamprophyre dikes are significantly younger than the batholith and, therefore, are probably not genetically related to Guichon plutonism.

HYDROTHERMAL GANGUE AND ALTERATION MINERALS

The Geology sections given in Figures 1b-f also show the distribution of gypsum veins, anhydrite, vugs in quartz veins, and barren quartz veins. The alteration summaries in the cross sections and plan views (Figs. 3a-h through 6a-g) show the distribution and intensity of the argillic, pervasive sericite, vein sericite, and potassium feldspar types of hydrothermal alteration.

SULFATES:

Gypsum veins are common in the deeper parts of the deposit. The gypsum line (Figs. 1c-f) marks the topographically highest occurrence (approximately the 3500 foot level) of this sulfate mineral. Below this line gypsum veins are persistent. The abundance of veins ranges from less than one to greater than three veins per foot. The veins range from generally less than 3 mm to a maximum of 8 cm in width. A few gypsum veins contain rare anhydrite crystals. Gypsum veins cut all alteration types, sulfide-bearing veins, and host rocks except the lamprophyre dikes.

Although they are paragenetically late, available evidence suggests that the gypsum veins are not supergene. Gypsum does not occur near the surface. Sulfate sulfur could not have come from oxidized sulfide sulfur. The δS-34 value of +15.2 permil of the gypsum from a 5 cm wide vein is similar to the values of hypogene anhydrite (+11.8 to +14.5 permil) and is much heavier than the hypogene sulfide sulfur. Gypsum replacement of anhydrite veins is unlikely as no anhydrite veins have been found. Throughout much of the deposit, the gypsum line is close to the vug line (see Figs. 1c-f) which suggests that hypogene rather than supergene conditions controlled gypsum precipitation. The gypsum veins, therefore, probably represent the latest major hydrothermal hypogene event.

quartz veins than the earlier barren quartz veins, they fail to develop to megascopic size in both types of veins at about the same depth. Quartz and calcite crystals that line many of the vugs have euhedral terminations. The vug line probably corresponds to the depths at which pressures were sufficiently low to permit boiling of the hydrothermal fluids.

BARREN QUARTZ VEINS:

Barren quartz veins contain little or no sulfides and form a low grade quartz vein stockwork core to the deposit. The veins range from less than 1 mm to about 3 cm in thickness. Sericite envelopes, where present, are thin and discontinuous. Potassium feldspar commonly forms selvages adjacent to the barren quartz veins. Most unequivocal offsetting relationships indicate that the barren quartz veins are older than the sulfide-bearing quartz and quartz-sericite veins. However, in Sections 14 and 16 conflicting relationships were observed that suggest minor exceptions to this generalization.

Three barren quartz vein horizons are shown on Sections 10, 12, and 14 of Figures 1 through 7. The upper horizon, B1, marks the topographically highest occurrence of any barren quartz veins. The intensity of veining increases downward to the middle horizon, B2, where their frequency of occurrence is three to four or more per foot. Below the B2 horizon, the abundance of barren quartz veins generally decreases slightly and then increases again. The lowest horizon, B3, marks their reoccurrence at three to four or more per foot. In Section 16 drill holes intersected a few barren quartz veins between about the 3400 and 3100 foot levels (Fig. 1e). No barren quartz veins were encountered above or below these levels or in Section 18. Accordingly, the northwest front of the barren quartz core is interpreted to be very steep to overturned (see Reference Line Section of Figs. 2 through 7).

CLAY:

Hydrothermal clay (kaolinite), sericite, and potassium feldspar each have two principal modes of occurrence. They are present either in or adjacent to veins and fractures, or as pervasive alteration products of the host rock. Megascopic distinction and relative intensities of clay, sericite, and potassium feldspar alteration in the core was based primarily on color, hardness, and vein abundance.

Argillic alteration is generally white. Criteria for determining the relative intensity of argillic alteration in the Bethsaida Granodiorite were based on the amount, color, and hardness of altered plagioclase feldspar. Alteration was classified as weak, moderate, or intense where plagioclase feldspar was determined to be translucent and hard, white and hard, or white and soft, respectively. In the Porphyritic Phase of the Bethsaida Granodiorite, argillic alteration is defined by chalky white plagioclase phenocrysts in a purple-brown matrix, whereas in the Tan Felsite Porphyry it is marked by white plagioclase phenocrysts in a pink to white matrix.

X-ray identification of clays from both the envelope and pervasive replacements indicates that they are kaolinite. Montmorillonite-group clays are rare and apparently are restricted to the margins of the deposit.

Clay partly replaces plagioclase in envelopes up to 2 cm wide adjacent to sericite veins. It is relatively moderate to weak in intensity and is recognized only in host rocks with little or no pervasive argillic alteration. The pervasive argillic alteration varies from weak to strong in intensity. Where most intense, it generally coincides with sections of gouzy, crumbled, and broken core where clay completely replaces the plagioclase feldspar. Pervasive argillic alteration generally decreases within ten or more feet away from zones of disrupted core.

Plan and section views of argillic alteration given in Figures 3c-h show three vertically nested (concave-down) zones of intense argillic alteration. They are separated by zones of weaker alteration intensity. These zones plunge about 15° NW. (Fig. 3c) and to the east they coalesce into one zone of intense alteration.

Sections 10 through 16 (Figs. 3d-g) show the general similarity in shape and position of the concave-down profiles of the zones of intense argillic alteration with the concave-down profile of the barren quartz-vein core (B1, B2, and B3 horizons). However, the intense clay and barren quartz-vein distributions are independent of one another. Although similar in shape, the discordance of the zones of intense argillic alteration to the barren quartz core in Sections 10 through 16 and the Reference Line section (Fig. 3c) demonstrates the separate structural and temporal controls of their respective distributions.

SERICITE:

Sericite in veins is silver colored where coarsely crystalline. Otherwise, it is green where finely crystalline either in veins or as pervasive replacement of the host. Relative intensity of pervasive sericite alteration was based on the chroma of green coloration imparted to the host. Accordingly, pervasive sericite alteration ranges from very pale green where weak (incipient) to jade or emerald green where intense (complete). Relative abundance of vein sericite corresponds to the amount of core that is quartz-sericite veins. Vein sericite is weak where less than or equal to 10 percent of the core, moderate where

15 to 20 percent of the core, and intense where equal to or greater than 30 to 40 percent of the core.

Both the pervasive and vein types of sericite have been identified as 2M1 muscovite from X-ray diffraction patterns. Paragonite was not identified.

The Bethsaida Granodiorite, its Porphyritic Phase, and the Tan Felsite Porphyry are traversed by quartz-sericite veins and are pervasively altered to sericite. Quartz-sericite veins up to 6 cm and 2.5 cm wide cut the Bethsaida Granodiorite and the Porphyritic Phase of the Bethsaida, respectively. However, their maximum width in the Tan Felsite Porphyry is 5 mm. The weak sericite veining of the Tan Felsite Porphyry suggests that either these dikes were relatively unreactive with the hydrothermal fluids, or that the dikes were intruded during the later stages of vein sericite formation.

Sericite forms alteration envelopes and selvages adjacent to sulfide-bearing quartz veins and is a major component of quartz-sericite veins. In both occurrences the sericite appears to replace the host rock adjacent to the quartz vein or fracture. Vein-type sericite is relatively coarsely crystalline, 0.5 to 2 mm across. Most of the sulfide minerals are directly associated with the quartz-sericite veins. Bornite, chalcopyrite, minor molybdenite, and rare selenite and anhydrite form disseminated intergrowths with the sericite. Bornite and chalcopyrite also form discontinuous cores to some of the quartz-sericite veins. Pervasive sericite, predominantly microcrystalline in size, pseudomorphically replaces part to all of the plagioclase feldspar of the host. Zones of intense pervasive sericite that are inferred to have replaced older zones of intense argillic alteration generally contain disseminated chalcopyrite, with or without pyrite, and lack bornite.

Also, chalcopyrite is generally the sulfide mineral in quartz-sericite veins that traverse chalcopyrite-bearing zones of pervasive sericite. Availability of iron may be the parameter that determines the green color of the pervasive sericite and, in both the pervasive sericite and cross-cutting quartz-sericite veins, the precipitation of associated iron-rich sulfides, chalcopyrite and pyrite, rather than bornite.

Distributions of pervasive sericite (Figs. 4a-h) and vein sericite (Figs. 5a-h) alterations are different. Zones of moderate to intense pervasive sericite are most extensively developed on the east side of the deposit. These zones of more intense pervasive sericite alteration dip 15 to 30° NE. and tend to coalesce into one or two large zones to the east. Tongues of moderate and intense pervasive sericite alteration extend from the east side of the deposit into the central part. In Sections 10 and 12 (Figs. 4d and e) the pervasive sericite is strongly discordant to the barren quartz horizons.

Vein sericite is most abundant in three nested zones. These zones curve around the northwest side of the barren quartz core and plunge steeply to the northwest (Fig. 5c). They may coalesce at depth to the northwest. In contrast to the argillic and pervasive sericite alterations, the zones of moderate to abundant vein sericite are broadly parallel to the barren quartz horizons. In addition, they are not significantly developed within the B3 barren quartz horizon, except locally in Section 14 (Fig. 5f). The barren quartz core may have been a fundamental lithologic or structural barrier that controlled and (or) restricted the distribution of the quartz-sericite veins.

POTASSIUM FELDSPAR:

Potassium feldspar alteration is generally pink. Relative intensity of potassium feldspar alteration was based on the amount of secondary pink potassium feldspar in the core. It ranges from weak for a local 1 to 2 percent increase in the abundance of pink potassium feldspar to intense for almost complete replacement of the host by potassium feldspar.

Hydrothermal potassium feldspar has two principal modes of occurrence: as (1) partial to complete (pervasive) replacement of plagioclase feldspar, and as (2) veins of pegmatitic quartz-potassium feldspar and replacement envelopes adjacent to barren quartz veins, quartz-sericite veins, and fractures.

X-ray diffraction studies of potassium feldspars from the major phases of the batholith and the Valley Copper Deposit indicate that (1) primary magmatic potassium feldspars from the Bethsaida Granodiorite and other major phases are orthoclase, (2) pervasive and pegmatitic potassium feldspar range from disordered to maximum microcline, (3) potassium feldspar from envelopes around fine grained barren quartz veins and quartz-sericite veins are intermediate or relatively disordered microcline, and (4) there is a structural discontinuity between the primary and secondary potassium feldspars. All the potassium feldspars are orthoclase-rich (Or > 85). The more ordered structure of the hydrothermal potassium feldspars probably reflects their lower temperature of formation and more rapid attainment of temperature-structure equilibrium in a hydrous environment.

The zone of more intense potassium feldspar alteration (Figs. 6a-g) occurs as pervasive replacements of the host, pegmatitic quartz-potassium feldspar, and potassium feldspar envelopes adjacent to barren quartz veins. Zones of pervasive potassium feldspar replace the plagioclase of the host rock for several centimeters to a meter. The potassium feldspar is pink, 1 to 5 mm in diameter, and associated with sericite, disseminated bornite, chalcopyrite, and molybdenite, and rarely, purple anhydrite. In the pegmatitic potassium feldspar-quartz association, the quartz is up to 15 mm in diameter and the dark pink potassium feldspar crystals are up to 2 cm in diameter. The quartz is generally barren, however, small amounts of disseminated sulfide, mostly chalcopyrite, occur in some of the potassium feldspar. Sericite veins cut the pegmatitic potassium feldspar-quartz assemblage. In the fine grained potassium feldspar-quartz association, the quartz is less than 1 mm in diameter and forms thin veinlets. The potassium feldspar is about 1 mm in diameter, pink to flesh colored, and partly replaces the host rock next to the vein for distances up to a few centimeters.

The zones of less intense potassium feldspar alteration consist of potassium feldspar envelopes adjacent to quartz-sericite veins and fractures. These envelopes are generally less than 5 mm wide. They are normally continuous next to fractures, but are discontinuous on a scale of 1 to 2 mm next to quartz-sericite veins. The potassium feldspar envelopes, which are best developed in moderately argillized rock, occur throughout the deposit and are indicated on the cross sections as weak intensity potassium feldspar alteration.

The apparent equilibrium of potassium feldspar with kaolinite, evinced by the potassium feldspar envelopes between quartz-sericite veins and argillized rock, contradicts the relative stability fields of kaolinite, muscovite, and potassium feldspar given by Meyer and Hemley (1967). The T vs. aK^{+}/aH^{+} diagram of Meyer and Hemley indicates that potassium feldspar should not form at the outer edge of a sericite vein, between the sericite and kaolinite. However, Fournier (1967) has suggested that abnormally high activities of silica, which may result from the rapid break down of plagioclase to kaolinite, may depress the stability field of sericite relative to potassium feldspar and kaolinite. This mechanism may reasonably explain the potassium feldspar envelopes around sericite veins in the argillized rock.

The zone of more intense potassium feldspar alteration (Figs. 6a-g) is concave-down and symmetrical about the northeast and southwest sides of the barren quartz core. That part of the zone within and approximately parallel to the barren quartz horizons (Figs. 6d and e) reflects the pegmatitic quartz-potassium feldspar and the potassium feldspar-barren quartz vein associations. That part of the zone outside the barren quartz core represents patches and bands of pervasive potassium feldspar replacement and well developed potassium feldspar envelopes adjacent to quartz-sericite veins. The Reference Line section (Fig. 6b) shows the discordance of the potassium feldspar zone to the barren quartz horizons. The same general concave shape and maximum elevation (3600 feet in Figures 6b, d, e, and f) of the potassium feldspar zone, both within and outside the barren quartz core, suggests that a ubiquitous parameter, possibly a temperature gradient, governed the formation and distribution of potassium feldspar.

The potassium feldspar distribution is similar to that of vein sericite, but is dissimilar to those of argillic and pervasive sericite alterations, as defined by its symmetry about the barren quartz core and its apparent steep plunge to the northwest (Fig. 6b, and compare Figures 3, 4, 5, and 6). These similarities in distribution may indicate that the potassium feldspar alteration and deposition of vein sericite were closely related in time and in source of the altering fluids.

PARAGENESIS:

The paragenetic relationships (Table I) among rock types and subsequent hydrothermal alteration products have been deduced from megascopic examination of diamond drill core. Kaolinite is an early alteration product of the plutonic host. Sericite in veins and as pervasive replacement of the host traverses and alters both fresh rock and that previously subjected to varying intensities of argillic alteration. Megascopic and microscopic evidence suggest that the kaolinite does not replace sericite. The barren quartz core is discordant to and probably younger than the argillic and pervasive sericite alterations. Quartz-sericite veins are found in rock variably replaced by pervasive sericite and cut pegmatitic potassium feldspar-quartz and barren quartz veins. Sulfide-bearing quartz veins offset barren quartz and quartz-sericite veins. Anhydrite is associated with pervasive potassium feldspar, quartz-sericite veins, and sulfide-bearing quartz veins. Gypsum veins cut all other veins and alteration types. The lamprophyre dikes cut mineralized quartz and quartz-sericite veins and have been radiometrically dated as 60 m.y. younger than sericite that accompanies the sulfide mineralization.

TABLE I

PARAGENESIS OF HOST ROCKS AND ORE AND GANGUE MINERALS

Pre-alteration Rock Types

- Bethsaida Granodiorite
- Porphyritic Phase of Bethsaida
- Tan Felsite Porphyry
- Aplites

Hydrothermal Alteration

- Kaolinite
- Pervasive sericite (pyrite, sphalerite, chalcopyrite)
- Barren quartz veins
- Potassium feldspar (chalcopyrite, molybdenite)
- Vein sericite (bornite, chalcopyrite, pyrite, molybdenite)
- Sulfide-bearing quartz veins (bornite, chalcopyrite, pyrite, molybdenite, chalcocite)
- Anhydrite
- Gypsum

Post-alteration Rock Types

- Lamprophyre dikes

SULFIDE MINERALS

Copper values based on averages of 10 foot assays from the drill core were provided by Cominco Ltd. For the purposes of this study, the assay data have been reduced to three zones (Figs. 2a-h) that mark the approximate limits of low (significant copper content, but less than cut-off grade), intermediate, and high (significantly above the average copper content of 0.45 percent copper) intensities of copper mineralization. On the Copper Assay and other cross-section and plan maps the blue line separates low from intermediate total copper and the red line separates intermediate from high total copper.

The bornite:chalcopyrite ratios are given in Figures 7a-h, which display the relative abundance of bornite to chalcopyrite. The hachured line separates regions with bornite $\leq$ chalcopyrite from regions with bornite $>$ chalcopyrite (indicated by the hachures).

Comparison of the zones of high total copper (red line) with zones of intense vein sericite on the Vein Sericite sections (Figs. 5a-h) indicates the unmistakable correlation of high total copper with intense vein sericite. Additionally, the bornite:chalcopyrite ratios (Figs. 7a-h) when compared to the vein sericite distributions (Figs. 5a-h) show that nearly all zones of high bornite:chalcopyrite ratios correspond to zones of moderate to intense vein sericite. Nearly all of the high total copper values occur within zones having high bornite:chalcopyrite ratios.

The general distribution and zoning of chalcocite, pyrite, molybdenite, and sphalerite are shown on the 3800 foot plan view (Fig. 7a). Hypogene chalcocite and pyrite distributions are based on whether or not those sulfide minerals were observed in the core. Primary chalcocite is rare and was identified from only those holes connected by the heavy-dashed chalcocite line. Pyrite is abnormally scarce relative to other porphyry copper deposits; it averages much less than 1 percent by volume. The pyrite line (dashed with P's) separates pyritiferous (indicated by the P's) from non-pyritiferous regions. Molybdenite was found in all the diamond drill holes logged for this study. Although it is chiefly associated with quartz in veins having weak sericite envelopes, molybdenite is also found in quartz-sericite veins. Pyrite and/or chalcopyrite are commonly associated with the molybdenite. The molybdenite line (dotted with M's) is based on assays averaged over the entire hole in those vertical holes for which Cominco Ltd. supplied molybdenite assays. A significant molybdenite zone (indicated by the M's) fringes the deposit. Rare megascopic sphalerite was identified in three holes: 68-1, 69-28, and 69-30.

Pyrite, chalcocite, relatively high molybdenite, and relatively high chalcopyrite:bornite distributions overlap and are curved around the northwest part of the deposit (Fig. 7a). In hand specimens the pyrite, molybdenite, and chalcopyrite are commonly associated to the exclusion of bornite. In polished sections pyrite is generally replaced by any associated chalcopyrite. Some conclusions are indicated by these features:

1) The Valley Copper Deposit has a pyrite halo that is relatively weak.
2) The copper:iron ratios increase toward the center of the deposit.
3) The distribution and paragenesis of molybdenite is enigmatic.

In many porphyry copper deposits, molybdenite is most abundant in the deep central portion of the ore body. At Valley Copper the molybdenite is peripheral to the ore body and its distribution is similar in shape to one of the truncated molybdenite zones at Climax, Colorado. The association of molybdenite with pyrite suggests that molybdenite may form earlier than bornite-chalcopyrite in the paragenesis of the sulfides. However, because molybdenite occurs both in quartz-sericite and quartz veins, contemporaniety with the similar occurrence of bornite-chalcopyrite is suggested. If the molybdenite is contemporaneous with the copper sulfides, temperature-pressure-chemical gradients between the center and margin of the deposit must have caused the peripheral precipitation of the molybdenite.

Hypogene chalcocite coexists with bornite in quartz veins and exhibits microscopic exsolution and replacement textures with the bornite. The late paragenesis of mineralized quartz veins, the restricted areal distribution of chalcocite, and its association with bornite indicate that (1) chalcocite formed late in the paragenesis of the sulfides, that (2) either the parameters which influenced sulfide deposition became progressively more conducive to precipitation of higher Cu:Fe sulfides or that iron became progressively less available for precipitation in sulfides, and that (3) the chalcocite may be relatively near the source of the hydrothermal solutions.

ISOTOPE DATA

Sulfur and oxygen isotope data from the sulfide and alteration minerals strongly imply, on the basis of present knowledge, a magmatic source for both the sulfur and the hydrothermal fluids.

The δS-34 values of sulfides range from +1.45 to -4.11 permil and closely bracket the assumed zero permil value of mantle sulfur. In coexisting anhydrite-bornite, the sulfate sulfur is +11.76 permil and the sulfide sulfur is -0.94 permil. The marked isotopic difference implies equilibration between the sulfate and sulfide minerals. Interpolation of the calculated fractionation factor on theoretical curves

500°C suggests a depositional temperature of about 500°C.

The δO-18 values of hydrothermal kaolinite, sericite, potassium feldspar, and quartz range from +6.5 to +11.6 permil. They are equal to or larger than the oxygen values of the primary magmatic quartz, potassium feldspar, and plagioclase of the Bethsaida Granodiorite. Quartz-sericite mineral pairs give temperatures ranging from 475° to 260°C. Meteoric water could not have been a major component of the hydrothermal fluids unless the meteoric water were appreciably heavier than it is now.

Potassium-argon dates of sericite associated with bornite (198 ± 4 m.y.) and sericite associated with molybdenite (202 ± 4 m.y.) have the same age, within the limits of analytical error. This age, about 200 m.y., is also similar to those of the Bethsaida phase (198 ± 8 m.y., Northcote, 1969) of the Guichon Creek Batholith and the Porphyritic Phase of the Bethsaida Granodiorite (204 ± 4 m.y.).

The probable magmatic source of the sulfur and hydrothermal fluids and the contemporaniety of magmatism and hydrothermal processes strongly suggest that hydrothermal alteration and mineralization are integral parts of the late stage evolution of the batholith, not phenomena imposed upon the Bethsaida phase from an outside source. Geologic evidence, such as the centrally located late stage Bethsaida Granodiorite and younger porphyries, that are host rocks to the mineral deposits of the Highland Valley district, within a much larger batholithic mass, constitute additional evidence to support this inference.

CONCLUSIONS

Structure is the primary control that localized the Valley Copper Deposit. The deposit lies immediately southwest of the intersection of north-northwest striking faults in the Highland Valley depression and the north striking Lornex Fault (McMillan, 1972). The Lornex Fault may be intersected by hole 69-48. Within the deposit, fractures control the location of barren and sulfide-bearing quartz and quartz-sericite veins. Fractures and fault zones are also loci from which solutions permeated and pervasively altered the host rocks.

The recognized limits to the mineralization and alteration coincide with and may result from proximity to a dike of the Porphyritic Phase of the Bethsaida Granodiorite and the barren quartz core. The dike is tentatively considered to have diverted or impounded the ascending hydrothermal fluids. The fluids are considered to have risen from the north or east margins of the deposit along and above the dike. Initially, the fluids kaolinized then pervasively sericitized the plagioclase of the host rock. Following and in part contemporaneous with this initial alteration, the barren quartz veins were precipitated, perhaps in two or three pulses, in a northwest plunging zone above the Porphyritic Phase of the Bethsaida Granodiorite. The barren quartz veins effectively sealed off the core of the deposit to later fluids from which sulfide-bearing quartz and quartz-sericite veins were deposited. Subsequent fracturing of the host apparently did not appreciably increase the permeability of the barren quartz core to mineralizing fluids. These mineralizing fluids, partly contemporaneous with but generally younger than those forming the barren quartz veins, were diverted (by the dike) to flow over and around the northern sides of the barren quartz core.

Two possible hypothesesmay explain the distribution of the argillic and pervasive sericite alterations. Coalescence of the zones of intense argillic alteration to the east and the more extensive development of intense pervasive sericite in that area may indicate that the fluids that caused these effects emanated from the vicinity of the Lornex Fault. Alternatively, host rocks of the eastern part of the deposit may have been more highly fractured and permeable and thus susceptible to alteration by fluids from any source region.

The different distributions of the zones of intense vein sericite and intense argillic alteration may provide evidence for at least two different fracture sets that formed at different times. The zones of intense vein sericite plunge more steeply and are situated more to the northwest than the paragenetically older zones of intense argillic alteration. Within each of these alteration types, the three zones of intense alteration may have formed contemporaneously or sequentially with progressive fracturing of the host rock.

The development of the zone of more intense secondary potassium feldspar preceded, at least in part, the formation of some sericite veins. Its distribution may be a function of several parameters. Much of the potassium feldspar is associated with barren quartz veins and was precipitated with them. However, the zone of more intense potassium feldspar is restricted to elevations below the 3600 level, which may as likely reflect temperature and chemical controls. The kaolinite-muscovite-potassium feldspar stability diagram of Meyer and Hemley (1967) shows that potassium feldspar is stable relative to muscovite at higher temperatures and higher aK^+/aH^+ ratios. From oxygen isotope thermometry, the temperature below the 3600 level was greater than 350°C and high enough for the hydrothermal system to be within the potassium feldspar stability range. Consumption of K^+ by precipitation of potassium feldspar below the 3600 level or lower temperatures (350° to possibly 260°C, from oxygen isotope thermometry) at higher levels in the deposit may have shifted the hydrothermal system into the range of muscovite stability and precluded the development of significant amounts of potassium feldspar in the shallower environments of the hydrothermal system.

The hydrothermal fluids and their contained sulfur and metals had their source at depth from presumably late stage water-rich magmatic differentiates of the Bethsaida Granodiorite. A recent geophysical survey over the batholith has revealed a gravity low in the Valley Copper-Bethlehem-Lornex region that is interpreted to be the root zone of the batholith (McMillan, 1972). Fluid inclusions in quartz phenocrysts of relatively unaltered Tan Felsite Porphyry contain salt crystals which reflect high salinities in a water-rich phase that coexisted with magma from the source area of the intrusion. This saline hydrous phase may have subsequently become the ore-forming hydrothermal fluid.

If the Porphyritic Phase of the Bethsaida Granodiorite did channel the rising hydrothermal fluids, it may also have been a relatively impermeable cap to any fluids rising from beneath the dike. Rolls or relatively horizontal sections of the dike may have impounded these fluids. Seismic reflection surveys may be able to delineate the dike below the depths reached by present drilling. Any rolls or horizontal sections determined from the seismic profiles might be excellent targets for a deep drilling project.

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