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STRUCTURAL EVOLUTION OF PORPHYRY MINERALIZATION AT HIGHLAND VALLEY, BRITISH COLUMBIA

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ABSTRACT

Three major orebodies and several smaller ore zones have been discovered in Highland Valley. All of these exhibit abundant evidence of a structural control which can be correlated to the evolution of a structural system comprising the Lornex and Highland Valley faults. This structural system may have originated early in the history of the Guichon batholith, and as it evolved, provided for the periodic escape of mineralizing solutions from the magma chamber into structurally prepared sites. The system is composed of the intersecting Lornex and Highland Valley faults and their displaced segments. Simultaneous movement on these faults created the tensional fractures which were filled with both dykes and the mineral components which now make up the ore bodies. A porphyry copper model that derives minerals from a differentiating magma would best fit the data as interpreted in this paper.

INTRODUCTION

Excellent geologic (Northcote, 1969; Carr and Lee, 1966 ; McMillan 1970) and geophysical (Ager et al, 1972) descriptions of the Guichon Batholith (Fig. 1) of British Columbia, Canada, have appeared in the past decade, and these have been supplemented by detailed descriptions of the individual deposits (Allen, 1970; Hylands, 1972; Coveny et al, 1965; Bergey et al, 1971; McMillan, 1972). This paper follows the nomenclature of Symons (1971) in naming the pluton the Guichon Batholith, as do Bergey et al, (1971). Some attempts have been made in the past to meld magmatic differentiation into the mineralizing process (Hylands, 1972; Ager et al, 1972). The interpretation presented here is one way that simultaneous movements on the two major faults in the Highland Valley area could have permitted overlapping of the last pulses of igneous activity and mineralization, thus supporting a genesis which derives mineral from a differentiating magma. Establishment of cogenetic relationships between intrusion, alteration and mineralization through interpretation of ongoing fault displacements is rarely as clearly shown as is the case for Highland Valley. The conclusion of this structural study therefore is compatible with the finding of Northcote (1969), Hylands (1972), Ager et al (1972) and McMillan (1970), who unanimously considered magmatic differentiation as the source of porphyry mineralization.

GEOLOGY

General Setting:

The Guichon Batholith is a zoned calc-alkalic pluton which is intrusive into and appears to be comagmatic with Upper Triassic Nicola volcanic rocks. The Nicola Group, as known in the vicinity is a submarine sequence of alkalic and sub-alkalic tholeiites, tholeiites, andesites, their differentiation products and derivative sedimentary rocks. The Nicola rocks probably rest on oceanic crust, though its base has not been observed (Preto, 1974; Monger et al, 1972). The lower part of the Nicola group which has a more basic and more uniform volcanic stratigraphy than the upper, contains prominent pillow flows. The upper part of the sequence contains a much greater diversity of rock types, suggesting an origin from a differentiating centre as one possible source. Dacite and rhyolite tuffs are included in these volcanic and volcaniclastic products. Interbedded sediments include arkoses, wackes and shales. Fossils have only rarely been observed, and these have been found to have both Triassic and Lower Jurassic ages (Preto, Personal Communication, 1974). Presence of Lower Jurassic post-Guichon Batholith members in the Nicola suggest that deposition of this formation continued after the batholith formed.

The Guichon pluton is a zoned intrusion having an erratically sheared diorite border. Zoning within the pluton grades from diorite border through quartz diorite to a granodiorite and quartz monzonite core. Early phases are usually holocrystalline, with a granitic texture (if not sheared); the final pulses are dominantly porphyritic dykes. Gradational contacts may be seen between nearly all of the various pre-porphyry intrusive phases (Northcote, 1969), though sharp boundaries caused by faulting or dyke intrusion are also known. In the area of mineralization, the oldest equigranular phase is the Guichon phase quartz diorite. It is succeeded by the Bethlehem and finally the Bethsaida granodioritic phase. The zoning from basic outer margins to a silicic core, with gradational contacts visible for most of the various petrologic units, is compatible with an origin of the zoning in the pluton through magmatic differentiation.

For an adequate description of the petrology of the batholith, the reader is referred to Northcote (1969). Since mineralization did not begin until Bethsaida phase crystallization was well advanced, pre-Bethsaida phase rocks are temporally removed from magmatic differentiation which is associated with the ore deposits. Therefore this paper will briefly mention the pre-Bethsaida phases. A large number of age determinations (Northcote, 1969) place the intrusion and mineralization from 198 to 200 ± 8 m.y. It seems likely from geologic evidence that early stages of intrusion accompanied submarine volcanism (Northcote, 1969). The final stages accompanied sub-aerial eruptions. However, the clustering of K-Ar dates around the 198-200 m.y. interval suggests that the pluton was not capable of retention of argon until it had cooled as a whole, and separate K-Ar dating of the early and late phases has not entirely been successful. It seems likely that igneous activity continued without pause from the beginning to the end of the magmatic-hydrothermal episode.

The pluton is elongated north-south, and its major axis is approximately parallel to several segments of the only discernable continuous north-south fault, the Lornex fault. The Lornex fault is a complex zone of N.S. striking segments or strands, most of which dip vertically or steeply east. Dips vary from 60° east to 75° west (as exposed at the Lornex and Bethlehem deposits), but overall they appear to average about 80° east. As is explained elsewhere in this paper, mineralization is largely controlled by strands of the Lornex fault, with veinlets occupying the fault planes. Fig. 2, of the Jersey ore zone at Bethlehem shows mineralization to be controlled by linear features which in this case are various segments of the Lornex fault.

The intrusion also is transected at its widest point by a northwest-southeast trending structure, the Highland Valley fault. The Highland Valley fault is poorly exposed, but its dip as inferred from exposures on its displaced segments, appears to average about 80° north.

Local Setting:

Most importantly, faulting consisted of movements on the Lornex and Highland Valley faults. Other dilational movements on numerous radial and annular fractures (Northcote, 1969) have been related to pressures from a root zone intrusion.

Post-Lower Jurassic rift faulting permitted younger formations to cover the Pluton, and some of the Cretaceous and Tertiary formations still remain (McMillan, 1970). Glaciation and forest cover left large areas devoid of outcrop, so that the petrographic and structural details are not easily determined.

A root or core to the intrusion has been deduced from gravity studies (Ager et al, 1972). The two most important faults in the pluton, the Highland Valley and the Lornex faults, are inferred to intersect approximately at this core. As shown in the text and figures of this paper, the intersection of these faults may change with ongoing movement on both faults. However, if tensional features resulted from movement on these faults during mineralization that were filled with ore minerals and igneous dykes, and these faults intersect close to the core or root zone of the intrusion, then movement on the faults may have been instrumental in localizing the batholith or at least in the positioning of the feeder system for the pluton. The faults therefore could have formed early in the history of the pluton. The root zone portrayed by Ager et al (1972) is inclined 80° toward N64E which is fairly close to the plunge of the proposed intersection of the two major faults. These two faults, as noted above, are the two most important in the batholith, and movements on them may have been associated with distinct pulses of magmatic activity. These relationships are shown in Fig. 3

A minor vertical component of movement on the two major faults can be shown to exist by non-horizontal fault straie on some fault strands. Ager et al (1972) infer that the vertical component can not be significant since a vertical component of fault movement would result in very large apparent offsets in the gently dipping layers which make up the bulk of the batholith. This type of displacement has not been recognized in the pluton. For the purposes of this paper, therefore, we will consider only the horizontal component of movement.

FAULT MOVEMENTS

Sense of Displacement:

Determining the direction of fault movements in poorly exposed intrusive igneous rocks is always a problem. Allen (1970) proposed that the Lornex fault had a dextral and gradual (west block north) displacement relative to the east block, separating the Valley and Lornex orebodies. This paper further expands upon the hypothesis and proposes additional earlier fault displacements of the same sense for the Lornex fault. Many of the early fault branches or segments along which movement took place were then offset themselves. These were filled with dyke material or are lost in the poor outcrop of the homogenous rock.

Sense of movement on the Highland Valley fault was proposed as dextral by McMillan (1972). The youngest strand of the fault is called the Highland Valley lineament by Bergey et al (1971). Hyland (1972) generalizes this fault from several displaced segments. He also calls the Lornex fault the Big Divide fault. Here we follow the Allen (1970) terminology and trace for the Highland Valley fault. The sense of movement indicated where branches or splits can be seen in the fault in outcrop indicate that the south block moved west. This type of displacement is also indicated at Highmont by tension fractures in the block north of the fault, and confirms the dextral sense of movement proposed by McMillan (1972).

It appears that movements on the Lornex and Highland Valley faults occurred both simultaneously and alternately in the final phases of igneous activity, when hydrothermal events became important. The effect of the displacements was to move the southwest block northwesterly relative to the northeast block. It is perhaps noteworthy that this is the same sense of movement proposed by Monger et al (1972) for displacement of the Paleozoic crustal allochthon at about this same time (200 m.y.).

Displacements on the two major faults permitted a dilation of the host rocks by an order of 20 percent, as indicated by the amount of dykes and vein material now present which fill fractures in the Bethsaida ore zone. The openings formed were simultaneously filled with igneous and mineralization matter. To simplify the reconstruction of the fault displacements, however, the dilation effected by fault offsets has been minimized on Fig. 5 to 8 inclusive.

Should proposed movement on the north-south striking Lornex fault and the northwest trending Highland Valley fault have occurred as is shown in Figures 5 through 8 inclusive, the average direction of displacement of the southwestern block relative to the northeastern block is parallel to that found in the Hozameen fault system to the west. That is, the vector of displacement of the two faults coincides with the direction of movement in the blocks which comprise the Hozameen fault, but vector itself parallels the strike of this dextral fault. This coincidence suggests that for some as yet unknown reason, displacement normally accommodated by movement on the Hozameen fault was taken up by movement on the Lornex and Highland Valley faults about 200 m.y. ago.

PARAGENESIS OF FAULT MOVEMENT, INTRUSION AND MINERALIZATION

The sequence of fault movements interpreted from the igneous and hydrothermal events now deduced from outcrops, mine openings, and drill data, is summarized in this synthesis. Data on igneous rocks are taken from Carr and Lee (1966) and Northcote (1969), whereas data on mineralization are taken from already cited descriptions of mineral occurrences as well as from private, unpublished sources. This section will propose that all major mineralized areas (Highmont, Bethlehem, Valley and Lornex) are genetically related to movement on the Lornex and Highland Valley faults. Smaller areas of mineralization (e.g., Alwin, South Seas, Krain, Stellako, Trojan) are not specifically detailed in this section, though mineralization in these deposits also occurs in segments of either the Lornex or Highland Valley faults.

Initial Hydrothermal Stage (Highmont Stage):

Paragenetic studies on a district basis suggest molybdenum tends to be early (Hylands, 1972). The earliest detectable stage of significant hydrothermal activity appears to have been in and close to the Highmont ore body. The Highmont deposit has the highest Mo:Cu ratio in the district, and the ore body appeared to have formed as soon as consolidation of the differentiating pluton had advanced to the point where the walls were strong enough to support openings at the end of Bethsaida phase crystallization. The openings were then filled with sulphides and alteration silicates. Initially, mineralization took place away from the intersection of the Lornex and Highland Valley faults where the ancestral Highland Valley fault cut wall rock that Bergey et al (1971) describe as quartz diorite, but which Northcote (1969) calls granodiorite (Bethlehem Phase).

Displacement along the ancestral Highland Valley fault permitted more extensive mineralization to take place in conjugate wall tension fractures. Simultaneously, fault breccia was mineralized within the fault zone, and Gnawed Mtn. porphyritic granodiorite dykes (of Bethsaida composition) intruded the structure (Bergey et al, 1971) during mineralization.

Mineralization did not commence until differentiation had established the granodiorite-quartz diorite (Bergey et al, 1971) or Bethsaida-Bethlehem (Northcote, 1969) contact. The implication is clear from Fig. 5 in Bergey et al (1971) that faulting, mineralization and intrusion of Bethsaida type rocks (the Gnawed Mountain porphyries) were intimately associated. The timing of sulphide emplacement is closely associated with the end of Bethsaida phase. Dominant alteration minerals are orthoclase and biotite, and these constitute the potassic alteration suite of Lowell and Guilbert (1970). The broader relationships are shown in Fig. 5.

Bethlehem Stage:

Fig. 6 depicts the configuration of the batholith at the end of the formation of the Bethlehem ore bodies. Displacement of the various fault blocks infers simultaneous, continued movement on both the Lornex and the Highland Valley faults from the time of Highmont mineralization to, and through, the period of mineralization of all Bethlehem ore bodies. It seems logical to assume oldest Bethlehem mineralization to have been coeval with the youngest Highmont mineralizaiton since reconstruction of the faulting suggests openings to have occurred simultaneously in both areas. Significantly, the Bethlehem ore bodies formed entirely in the various strands of the Lornex fault in the northern portion of the Bethlehem phase (Northcote, 1969). These consist largely of sulphide veinlets which occupy N-S faults or northeast-striking fractures that are conjugate to them (Coveny et al, 1965). The veinlets are believed to have occupied separate strands of the ancestral Lornex fault. These strands were continuous briefly with the main Lornex fault south of the Highland Valley fault, but lateral movement on the Highland Valley fault moved the north block east and the period of activity of each strand remained only as long as continuity existed across the Highland Valley fault. Once the continuity was broken, that segment of the Lornex fault north of the Highland Valley fault apparently became dormant. Sulphides and gangue silicates occupied these strands as they formed. The results are the breccia and veinlets which make up the orebodies. Mineralization in the Krain area appears to have occurred at this time also, apparently contemporaneous with late stages of Bethlehem mineralization, and also within the Lornex fault as it then existed (see Fig. 10 for Krain-Bethlehem relationships).

Igneous activity appearing simultaneously with the Bethlehem and Krain mineralization is largely restricted to numerous quartz-plagioclase-biotite-orthoclase dykes. These are called pre-, intra-, and post mineral dacite dykes (Carr and Lee, 1966), but most are quartz monzonite to quartz latite porphyry in composition. Chacopyrite, bornite and molybdenite have been found disseminated in some dykes. The dykes trend N-S or fill NE striking fracture conjugate to the N-S fractures, as do most of the stockwork veinlets. Some dykes cross-cut sulphide veinlets whereas, elsewhere sulphide veinlets cut the dykes. The simultaneous appearance of N-S sulphide veinlets and dykes, most with a similar trend, suggest a close temporal as well as spatial relationship. Both the dykes and the veinlets in the orebodies appear to have formed as fracture fillings as the north-east block moved east on the Highland Valley fault relative to the other blocks. Large fault breccias formed as a result of dilation as the fault blocks moved, with the northwest block of the Highland Valley fault lagging behind the northeast block. The filling of the fractures left the N-S trend of the Lornex fault and the dominant trend for all material filling fractures, since it was this fault which provided the planes of weakness now occupied with sulphides, and silicate alteration minerals. The ultimate limits on the dykes that formed are shown on Fig. 8 (Bergey et al, 1971).

Potassic alteration suite minerals dominate. Orthoclase and biotite, characteristic of potassic alteration, dominate within the zone of Bethlehem stage ore deposition. Chlorite may occur with biotite in this zone.

Valley-Lornex Stage:

Fig. 7 shows the position of the core of the Guichon Batholith as proposed by Allen (1970), at the time of Valley-Lornex mineralization. Again, it is noteworthy that mineralization at Valley-Lornex followed and was simultaneous with movements on both major faults after metallization seemed to wane at Bethlehem, a relationship shown on Fig. 9. Most movement took place on the Lornex fault, however, even though it is postulated that, relatively, the Bethlehem orebodies moved east during mineralizaiton at Valley-Lornex. The result of the eastward movement along the Highland Valley fault was a repeated opening on various strands of the Lornex fault, with the openings being filled to produce sulphide and quartz-sulphide veinlets. The volume of igneous material injected during sulphide mineralization is substantially less than was the case at Bethlehem, though quartz latite dykes again were emplaced simultaneously with sulphide. Igneous activity had begun to decline by Valley-Lornex time.

Sericitic alteration (Allen, 1970) is more widespread in Valley-Lornex stage deposits than in earlier stages. Alteration accompanying mineral ization changed substantially from potassic to phyllic, suggesting a change in the chemistry and/or physics of the hydrothermal fluids. The Valley orebody also has among the lowest Mo:Cu ratios in the district. The relationships of ore sulphides to dykes indicates, however, that both may have been derived from a differentiating magma. Details of mineralization are presented by Allen (1970).

Fig. 9 is a summary of some 14,000 structural determinations taken in the Valley Copper decline. Included in these are faults, fractures, joints and quartz veins, i.e., all planar breaks in the rocks. Ranking of the sets by frequency of occurrence is given by the circled numbers. From this it is quite apparent that the two most common sets (1) and (2) (comprising 90% of the total) are roughly parallel to the Lornex and Highland Valley faults respectively. When planar breaks are classified, it is found that faults are almost entirely parallel to the Lornex structure and that quartz veins though showing a greater variation in strike are generally parallel to the Highland Valley fault. It would thus seem reasonable to attribute these features to stresses acting along and parallel to the two major structures. The nature and intensity of fracturing within the Valley and Lornex orebodies clearly indicate that some mechanism for focusing these stresses must have operated. Clearly, the intersection of the Lornex and Highland Valley faults is important but it is also clear that simple translation movement along one or the other of these structures is not adequate to explain the fracturing observed. It seems more likely that both faults were involved and that alternating movement on each produced a "stuttering effect" which can best explain the largely dilational nature of the resulting fracture zone.

Isotopic Data: Isotopic data on oxygen, sulphur and hydrogen at Valley are summarized by Jones (1974). These data show the O_{18} shift to be compatible with a hydrothermal fluid composed of magmatic and sea water, with early ore fluids containing 70% magmatic water. As mineralization progressed, isotopic data suggests continuing dilution of the magmatic fluids with sea water, a change again compatible with observed paragenetic change in ore mineralization and alteration minerals.

The presence of dominantly magmatic water in the early mineralization stages at Valley supports the differentiation-mineralization hypothesis. If mineralization accompanying dyke intrusion did not have, at least in part, a magmatic origin, then differentiation as a source for the ores would be more difficult to demonstrate, and the involvement of both magmas (dykes) and ore minerals in the evolving structure could have been coincidental. Therefore, indirectly the implied simultaneous movement on the two faults is supported by the stable isotope data.

DISCUSSION

Post-mineral movement on the Lornex fault had been shown by Allen (1970) to distribute the ore bodies in the district more or less as shown on Fig. 8. The final injection of dykes left their distribution approximately within the limits shown on Fig. 8 also. The final fault movement within the district appears to have been largely restricted to displacement along the Lornex fault.

Repositioning of fault blocks back to Highmont time (Fig. 5), the beginning of mineralization, clarifies several problems.

(a) It simplifies the geometry of the Bethsaida phase from its present elongate oval to a more symmetrical near circular shape. Though incompletely shown on Figure 4, the geometry of that phase shown in Fig. 4 is more plausible than that shown in Fig. 8. Fault movements since Highmont stage have merely complicated a simple geometry.

(b) The protrusions on the northern margin of the Bethlehem stage (Bergey et al, 1971) are explained as injections from the core along fault planes into Guichon phase. The configuration of the Bethlehem phase shown in Fig. 5 is much more realistic for a consolidating intrusion than is the configuration shown in Fig. 8.

(c) The limit of porphyry dykes, most of which strike N-S, is determined by the movements on the two faults. Strike-slip movement on the Highland Valley fault permitted dilation on the strands and off-set segments of the Lornex fault and provided the openings needed for dyke intrusion. Sulphides and alteration silicates were deposited from fluids using the same channel-ways as the dykes and thus occur in the same structures or in parallel structures. Fig. 8 clearly shows the limit of dyke formation to also outline the area of significant sulphide mineralization.

(d) Interpretation of the fault movements also permits speculatio concerning the positioning of the root core away from the centre of the Bethsaida phase, where it would be expected according to a simple differentiation hypothesis. The axis of the root zone appears to pass approximately through Bethlehem's J.A. orebody. The root is thus well centered relative to late dyke intrusion. Its location is compatible with fault movement proposed in this paper, and it has been displaced away from the centre of the Bethsaida phase in response to faulting.

(e) The root zone, being parallel to the plunge of the intersecti of the Lornex and Highland Valley faults, appears to have been a zone of tension whose origin may have stemmed from early, pre-mineral movements on these faults. In any case, the intersection makes such an hypothesis tempting and does provide a rational explanation for development of the conduit.

SUMMARY

Fig. 10 provides a summary of the timing of events as interpreted from the field data, from the Bethlehem phase onward. Bethlehem phase granodiorite gradually gave way to Bethsaida phase in differentiating magma. Highmont stage mineralization overlapped Bethsaida (and Gnawed Mtn. porphyry dykes which have Bethsaida composition) and provides the continuous link between purely magmatic events and magmatic events with accompanying hydrothermal activity. Bethlehem stage mineralization overlapped Highmont stage and continued after Highmont stage ceased, but was accompanied by dacite (Carr and Lee, 1966) or quartz monzonite dykes. The change from granodiorite to quartz monzonite accompanied younger mineralization in the Bethlehem ore bodies. Orthoclase, accompanied by chlorite or biotite or both, dominated both zones of mineralization. By the time the main surge of mineralization had developed at Lornex-Valley, mineralization had ceased at Bethlehem. Dyke intrusion had also diminished, and sericite became more abundant alteration mineral in the later Lornex-Valley stages.

An hypothesis of continuous intrusion of a differentiating Guichon magma, with sulphides appearing late in the granodiorite phase and continuing well into a quartz monzonite (dyke) phase may be constructed through the postulation of continuous and simultaneous movements on the two major faults. It is clear in this case that alteration and mineralization can be ascribed spatially and temporally to a logical sequence in the differentiation of a magma. The association of ore minerals with a differentiating magma need not infer the exclusion of ground water from the system, and the mineralization stages where sericite is most conspicuous may also represent those areas where ground water played a more significant role. Timing of sulphide veinlets and dyke intrusion as well as stable isotopic dat indicate copper and molybdenum to have been derived from a differentiating magma, however.

Acknowledgments:

Dr. J. M. Carr has materially helped with the hypothetical reconstruction of fault movements in the Highland Valley. His lengthy studies in this area have given him a background vital to understanding the problems involved. The authors wish to thank him for his very kind and generous expenditure of time with this paper. Dr. W.J. McMillan, while not necessarily endorsing the hypothesis proposed, has provided many stimulating questions for the authors to consider during the course of construction of this paper. His thoughtful queries are gratefully acknowledged. Most importantly, however, is the contribution by Prof. A.J. Sinclair. His background on the geology of this area permitted him to level many thoughtful criticisms which have been incorporated into this paper.

FIGURES

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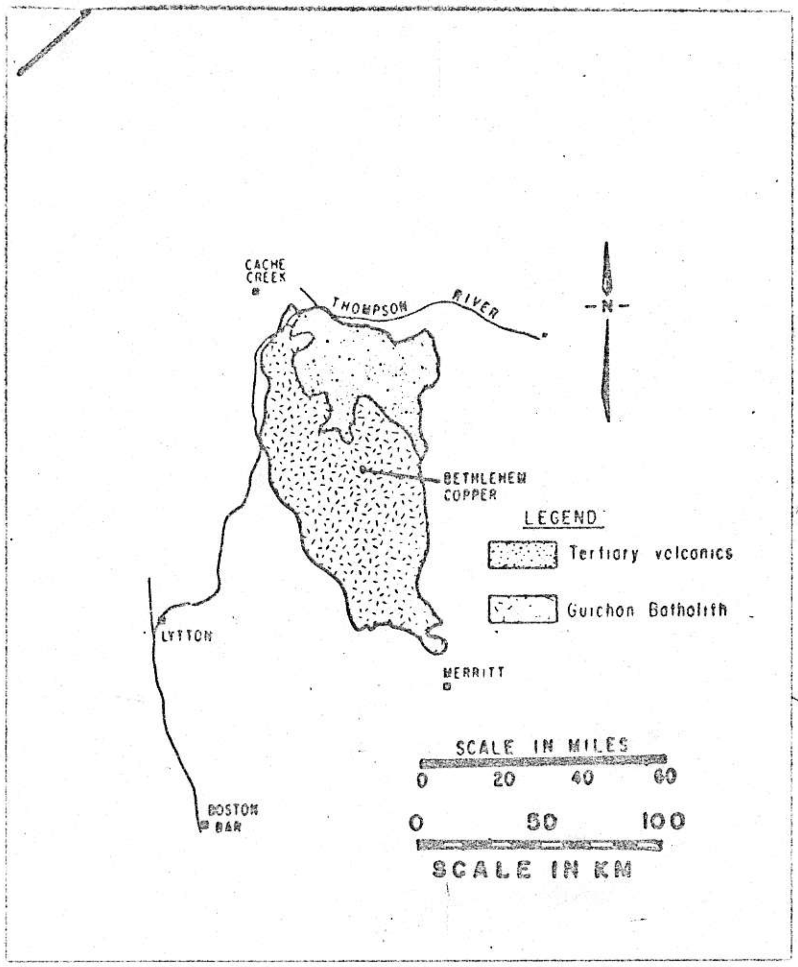


Fig. 1. Index Map of the Guichon Batholith, British Columbia. Bethlehem Copper is shown so that the most important areas of mineralization may be located.

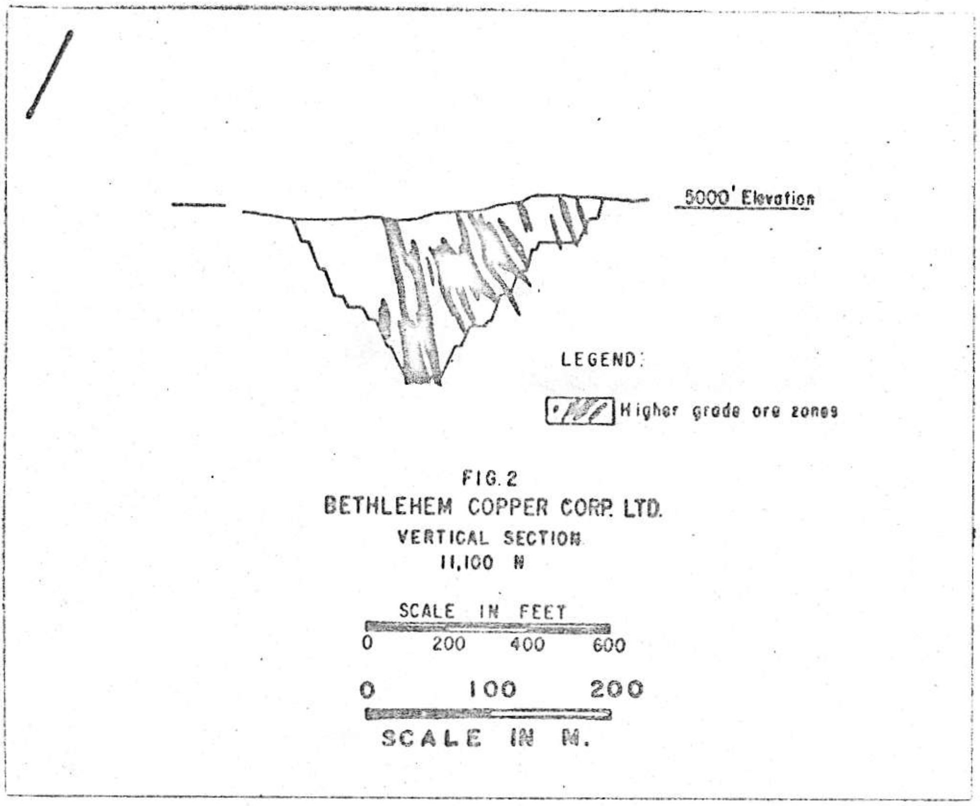
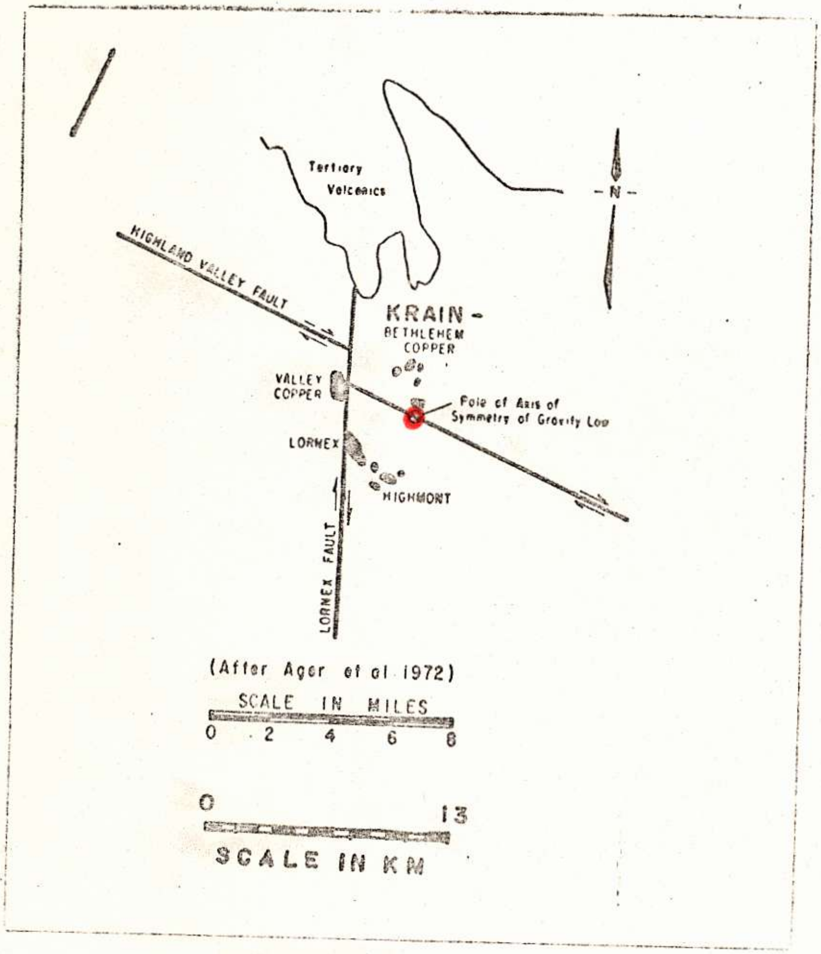


Fig. 2. An east-west section looking south through one of the Bethlehem ore zones.



(After Ager et al 1972)

Fig. 3. Geometric relationship in the central portion of the Guichon Batholith. The axis of symmetry of the gravity low is inclined 80° ma N64E direction, and the major ore bodies lie close to it.

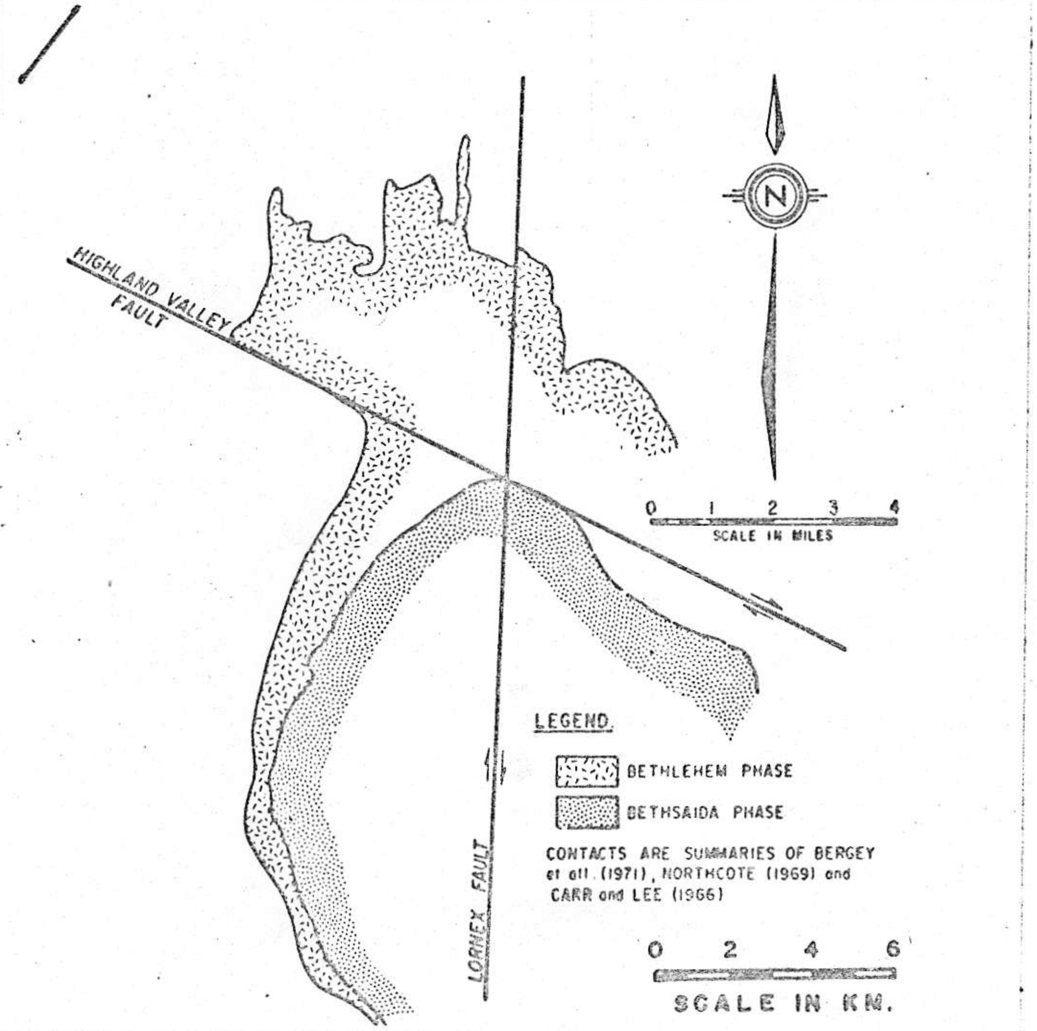


Fig. 4. Proposed position of the Lornex and Highland Valley faults as well as the Bethlehem and Bethsaida phases at the start of mineralization. The Bethsaida granodiorite phase is nearly consolidated, but with the Gnawed Mtn. porphyry dykes not yet intruded.

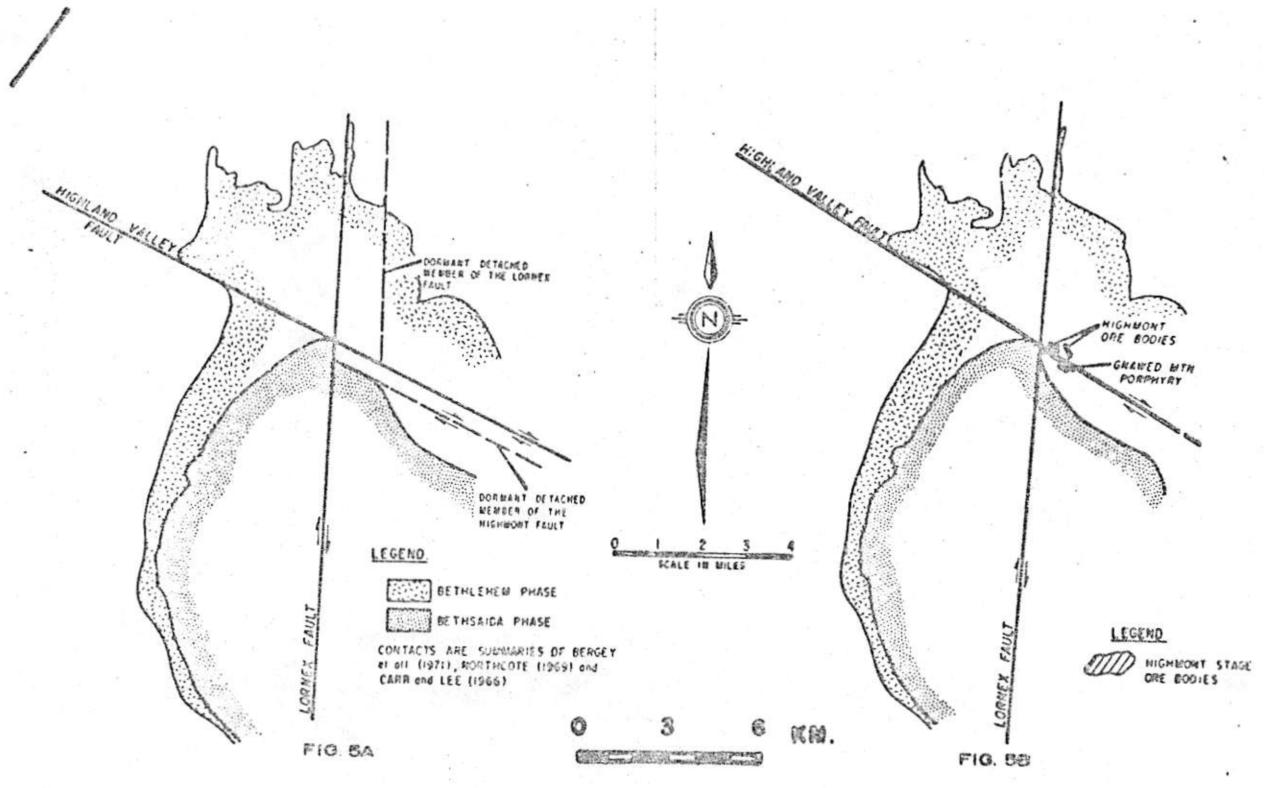


FIG. 5A

FIG. 5B

Fig. 5. Highmont Stage:Fig. 5a is Fig. 4 with proposed offsets on Highland Valley and Lornex faults up to the end of mineralization of Highmont stage. In Fig. 5a igneous rocks and mineral introduced after the time of Fig. 4 are omitted. Fig. 5b shows the proposed mineralization near the end of Highmont Stage, including the Gnawed Mtn. porphyry dyke.

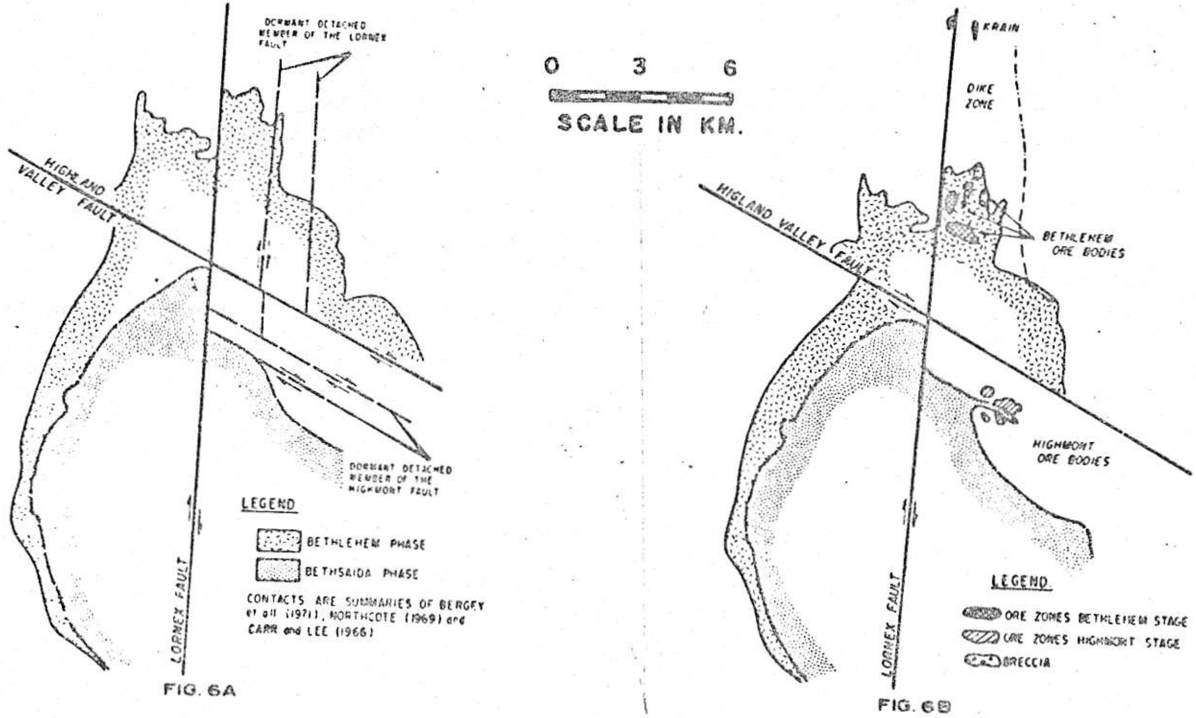


FIG. 6A

FIG. 6B

Fig. 6. Bethlehem Stage: Fig. 6a is Fig. 4 with proposed movement on the Highland Valley and Lornex faults to the end of development of the Bethlehem orebodies. Igneous rocks and mineralization are omitted from Fig. 6a but are included on 6b, which shows only the active fault traces as well as the ore zones. The dyke zone is from Bergey et al (1971).

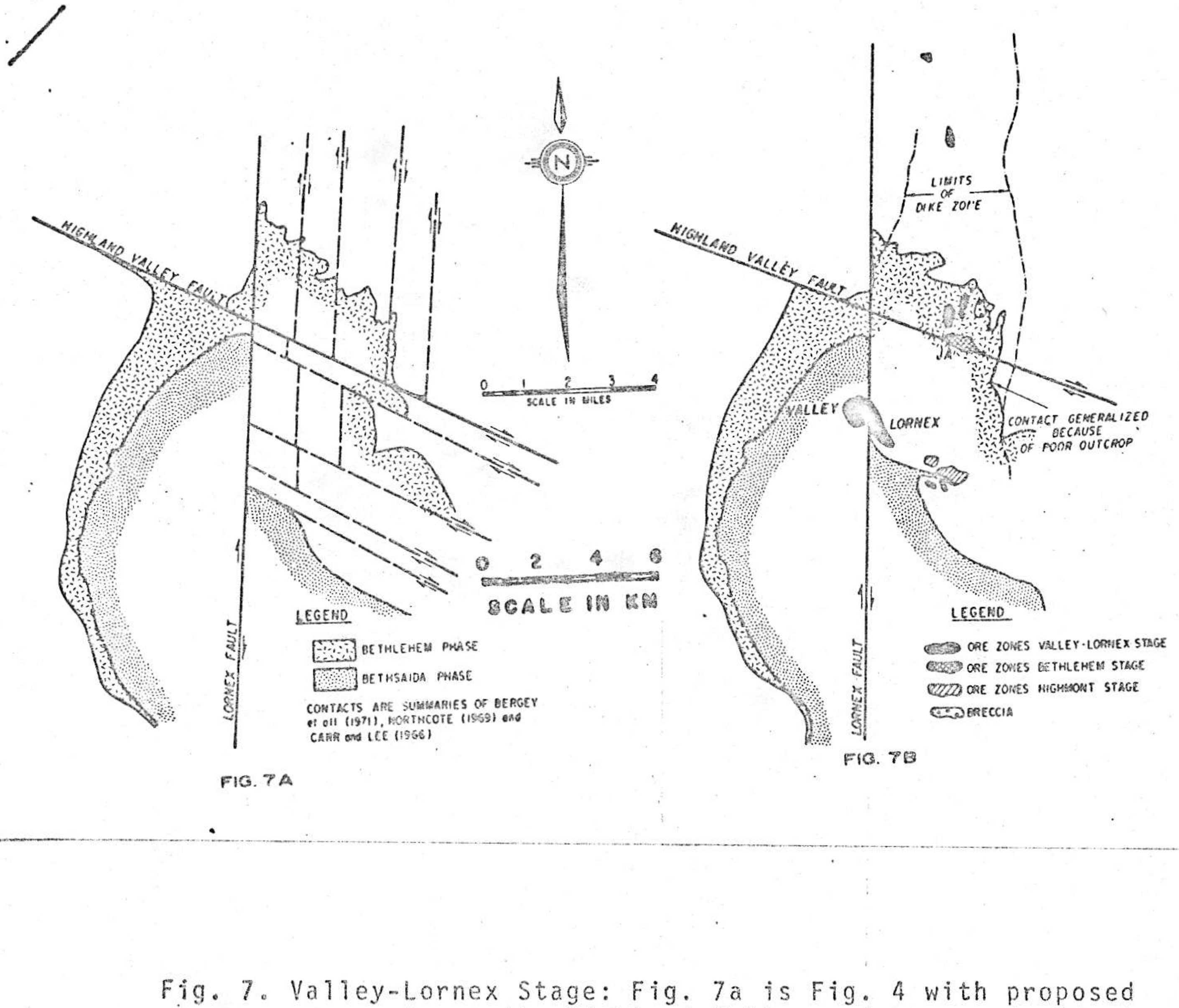


FIG. 7A

FIG. 7B

Fig. 7. Valley-Lornex Stage: Fig. 7a is Fig. 4 with proposed movements on the Highland Valley and Lornex faults to the end of Valley-Lornex stage mineralization. Igneous rocks and mineralization introduced since the time of Fig. 4 are omitted from 7a. Fig. 7b is the proposed position of the Highland Valley and Lornex fault zones at the end of Valley-Lornex stage mineralization. Only the active fault planes are shown, together with the ore bodies. Dyke zones are from Carr and Lee (1966) and Bergey et al (1971). Igneous contacts are generalized from Bergey et al (1971).

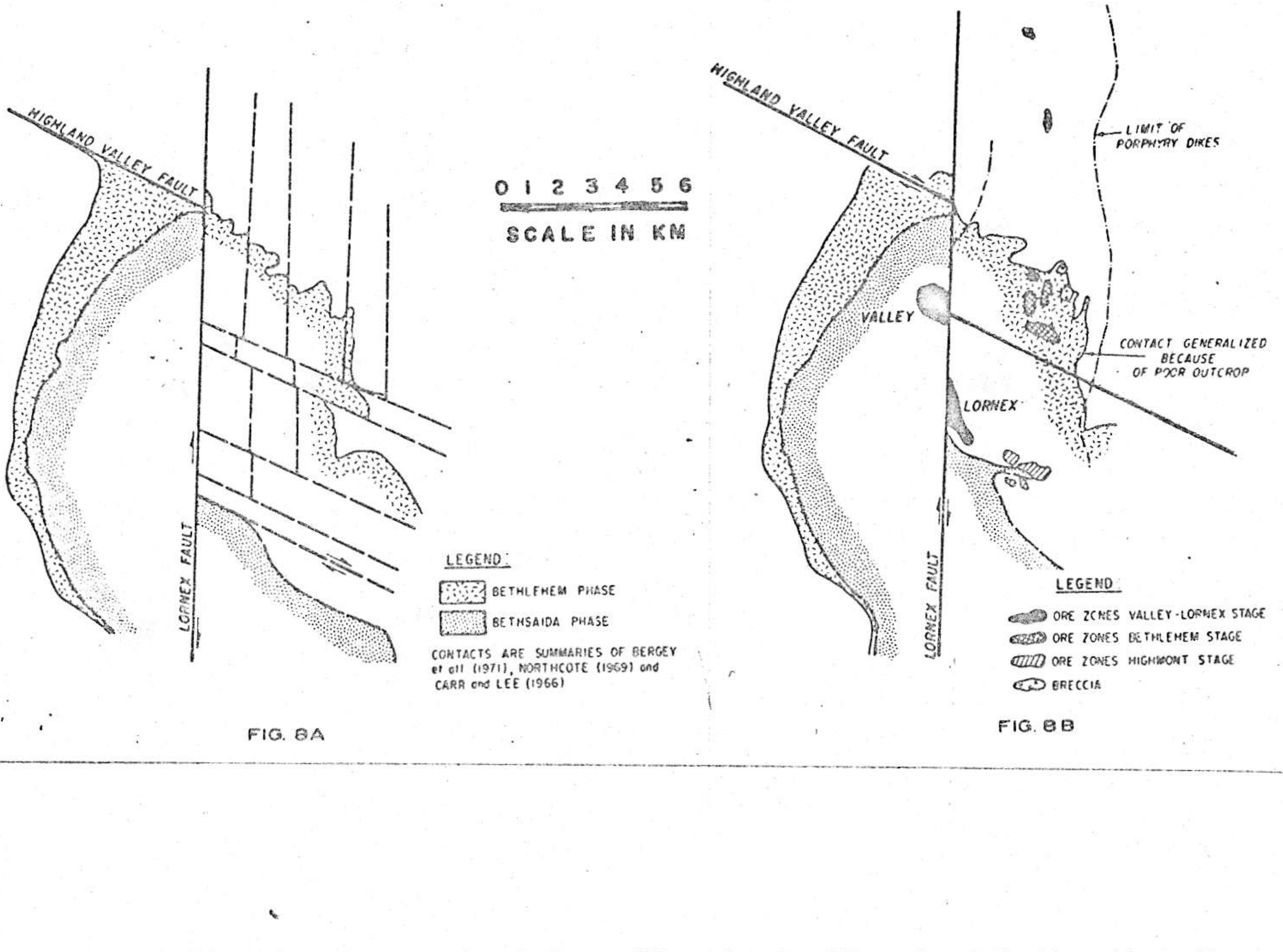


FIG. 8A

FIG. 8B

Fig. 8. Present Position: Fig. 8a is Fig. 4 with the distribution of rocks displaced on aggregate movements to their position today, but without post Fig. 4 igneous rocks being added. Fig. 8b is the present position of the intrusive phases, ore stages and faults, including material added since the time of Fig. 4. Contacts are after Bergey et al (1971).

Fig 9

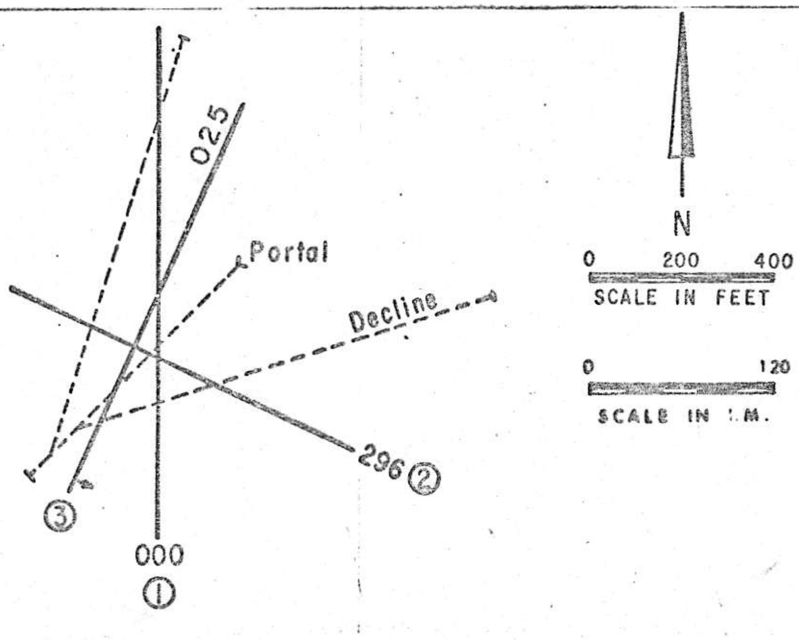


Fig. 9. Quartz vein, joint and fracture sets within the Valley Copper ore body. This figure is a summary of observations taken in the adit and decline. The north-south structures represent the Lornex fault, while the structures at 296° are the Highland Valley fault.

Fig 10

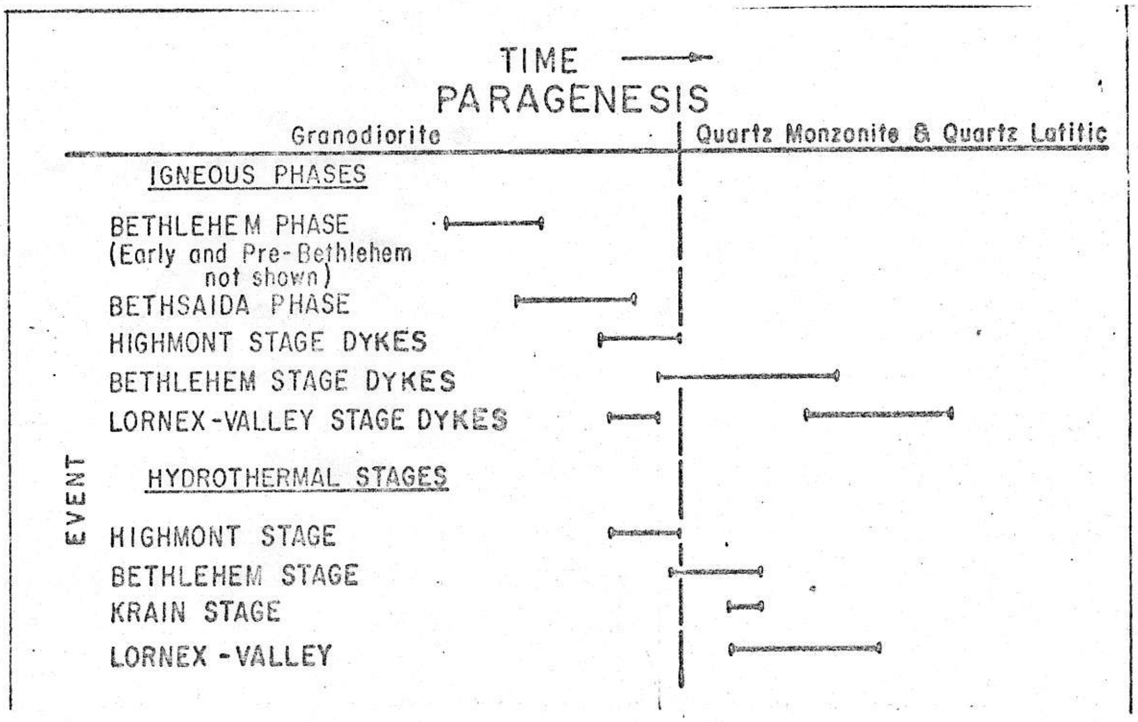


Fig. 10. Paragenetic Sequence: This figure shows the proposed overlap of mineralization stages at Highland Valley with igneous activity toward the end of the igneous cycle. For the Highmont and Bethlehem stages potassic suite minerals dominate in the alteration zone. Valley-Lornex deposits contain prominent phyllic alteration minerals indicating an early potassic zone development followed by a later phyllic zone.