DETAILED BEDROCK GEOLOGY OF THE BRENDA COPPER-MOLYBDENUM MINE

Peachland, British Columbia

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William Michael Oriel
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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
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ABSTRACT

Detailed mapping of the bedrock geology of the Brenda copper-molybdenum deposit has revealed a consistent sequence of geological events. Consolidation of the quartz diorite host rock that forms Brenda stock was followed by intrusion of small pegmatite and aplite dikes that probably relate to a residual fraction of the parent magma. Age dating of various quartz diorites (White and Harakal, unpublished) indicates that magma solidification occurred about 176 m.y. A concentration of biotite model ages at about 146 m.y. seems best interpreted as the time of ore mineralization.

Mineralization occurred at the beginning of a continuous sequence of related structural events. All mineralized ore fractures and younger shears, faults and intramineral dikes exhibit similar, strongly preferred orientations that are unlike orientations of felsic dikes or primary foliations in the quartz diorite host rock.

The ore occurs entirely in fractures as products of three sequential overlapping phases of mineralization and consists almost entirely of the ore minerals chalcopyrite and molybdenite with quartz gangue predominanting.

Hydrothermal alteration products exist mostly as thin envelopes of potassium feldspar and/or biotite and propylitic alteration. Large argillic alteration zones also exist, however, and are associated commonly with extensively sheared zones. An effort was made at finding a zoning pattern of ore minerals, minor elements and alteration minerals. Ore mineral zoning in the classical sense appears to be absent at Brenda. Metal grades show a crude zonal distribution

that correlates directly with density of ore fractures. Hydrothermal alteration minerals and minor elements in chalcopyrite also lack any obvious systematic zonation pattern on the scale of the mine pit.

Intramineral dikes of various textures and compositions have been dated at about 130 m.y. They formed after ore mineralization yet before late minor veining not associated with ore-producing veins.

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ACKNOWLEDGEMENTS

The writer wishes to acknowledge the assistance of the late Dr. J. A. Gower under whose supervision this thesis was initiated. Special thanks also to Dr. A. E. Soregaroli (Noranda Exploration, Ltd.) who gave continual help and encouragement during all phases of this work; and to Dr. A. J. Sinclair for his enthusiastic and tireless efforts for critique, review, and supervision of the compilation and writing phases of this thesis. Brenda Mines, Ltd. and Noranda Exploration, Ltd. provided means and finances without which the thesis could not have been undertaken. Doug Whitford, Chief Geologist, and Jim Cahoon were especially helpful at the mine site. Thanks also go to Dr. W. White and J. E. Harakal for allowing the writer to use their unpublished potassium-argon data for Brenda deposit; and to Dr. D. Brabee for his work on minor element zoning in chalcopyrite. Finally, the writer wishes to thank his wife for her understanding, support and timeless efforts in typing several drafts of this thesis.

CHAPTER I

INTRODUCTION

PURPOSE

The purpose of this thesis is to study and describe in detail the bedrock geology of the Brenda open pit mine with a view towards clarification of presently little studied features and forwarding an insight to the origin of the mineral deposit. The writer intends to examine such features as the diking, zones of shearing and faulting, the mineralogy and structure of the sulfide bearing veins, the wallrock alteration associated with veining, and the zoning of some sulfide minerals and minor elements within the boundaries of the open pit. The regional geology surrounding the mine and the petrology of the various rock types have been previously examined by J. M. Carr in 1967 and hence are not a subject of this thesis.

PHYSIOGRAPHY

The Brenda copper-molybdenum deposit is 18 miles west of Peachland, British Columbia, and one mile east of Brenda Lake at latitude 49°52'N and longitude approximately 120°W. It is accessable by an improved gravel road extending to the mine from the mouth of Peachland Creek at Highway 97. Roads are easily cleared in winter and provide little access difficulty. In addition, there are several side logging roads leading to fishing localities such as Pennask Lake and Brenda Lake. Other old exploration roads exist

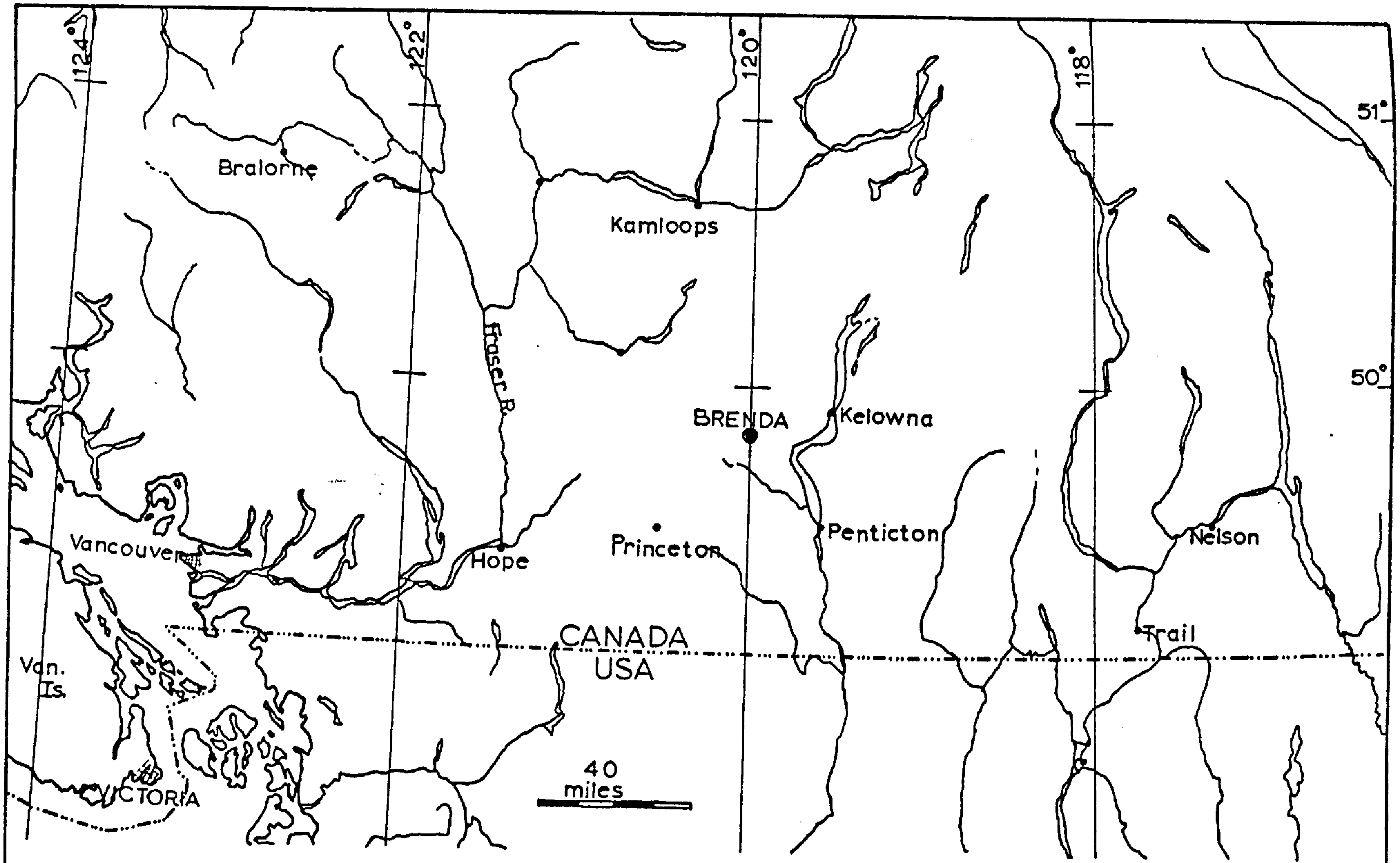


Figure 1. Location Map - The Brenda Mine

that normally require clearing for vehicle use and do not extend far into the countryside. Elevations range from 3,500 to 6,000 feet above mean sea level in the general vicinity of the mine. The uppermost point of the mine was 5,560 feet above mean sea level before being leveled to 5,510 feet elevation.

Slopes are moderate to gentle and thickly tree-covered. Outcrops are limited mostly to the tops of slopes that have been scoured glacially (and locally polished). Most of the ground is overlain by a thin cover of glacial debris and/or poorly developed soil.

Topography has been controlled to a large extent by glaciers that, in the vicinity of the mine, possibly flowed N52°W as suggested by glacial striations. Lineaments that probably reflect regional structures control minor topographic changes.

The mine area lies between Nicola and Similkameen Rivers to the west, and Okanagan Lake tributaries on the east. A small stream flowing through the center of the present pit eroded deeply enough to provide the first discovery showings. Presently, it is diverted around the open pit.

HISTORY

The first development work known to have been done on the property was by the Sandberg family of Kelowna beginning about 1938. They drove a 30 foot horizontal open-cut, a winze, and an adit into the rock along the creek near the center of the present pit, following a large quartz vein containing minor masses of chalcopyrite and pyrite. They apparently were prospecting for a gold-silver deposit and abandoned work on the claims (known as the Copper King Groups) after H. M. A. Rice visited the property in 1947. Rice described the showing as being a disseminated copper-molybdenum prospect. Despite Rice's call for further investigation into the potential for a large tonnage, low grade mineralized zone, the property lay dormant until 1954 when Bob Bechtel, a prospector, rediscovered the showing. Mr. Bechtel presented his showing to Noranda Exploration who made an arrangement with Northwestern Explorations to study the area.

This first geological study was undertaken in 1957 by C. S. Ney for Northwestern Explorations and included geology maps, hornblende-biotite ratio maps, fracture density maps, an induced polarization program and a drilling program. Drilling, however, was only carried out to a depth of 20 feet, not out of the range of leaching of copper and molybdenum. Noranda and Kennecott subsequently withdrew from the project and returned the property to Bob Bechtel (Menzies, 1969). Advancing markets and the development of the Endako and Boss Mountain mines gave new impetus and encouragement for the prospecting and evaluation of a low grade molybdenum deposit, which meant Brenda might be considered in a new light. Once again in 1964 Noranda considered the deposit because of the prompting of B. O. Brynelsen and M. Menzies but dropped further work because of the apparent low grades involved. Brynelsen and Menzies were permitted, however, to examine and develop the property separately. Also in 1964 Chapman of Chapman, Wood and Griswold, Ltd. examined the property and suggested a thorough examination. Financial support followed through Nippon Mining and M. E. Davis of Penticton, B. C. In 1965 the program suggested by

Chapman was completed and provided encouraging results. A $700,000 program was recommended. In January 1966, a 15 month $3.5 million feasibility program was initiated under the direction of Chapman, Wood, and Griswold. The final results were favorable, and in early 1970 full production of the mine was achieved at 24,000 tons per day (Menzies, 1969). The expected life of the mine is 20 years.

METHODS OF STUDY

The writer spent four months during the summer of 1971 at the mine site. All except two weeks of this time was spent studying the geology within the limits of the pit. Mapping of the pit took place at a scale of one inch to 50 feet. Controls were triangulated by the mine's survey crew at approximately 50 foot intervals along bench walls as mapping proceeded. Location errors are less than two feet. At the time of the study only five benches were partly developed and suitable for geologic mapping. All orientation measurements on geological features were taken with an induction damped Brunton compass.

Limited sampling and regional and detailed mapping within a radius of three miles from the mine was undertaken during the last two weeks of the summer. This was done to familiarize the writer with the geology that Carr (1967) had mapped previously.

Stereonet plots for structural data were done on a 10 cm radius Schmidt net. Contours represent percent of poles to planes per one percent area. High density centers were visually estimated to determine predominant attitudes of planar features.

Sample preparation for x-ray diffraction work was done as follows. Clays were ground in mortor and pestle, suspended in water and siphoned off to be placed on slides that were air dried at room temperature overnight. Standard glycollation and heating procedures were also used for the clays. Identification for minerals other than clays involved the same grinding procedure, but the powder was applied as an acetone slurry.

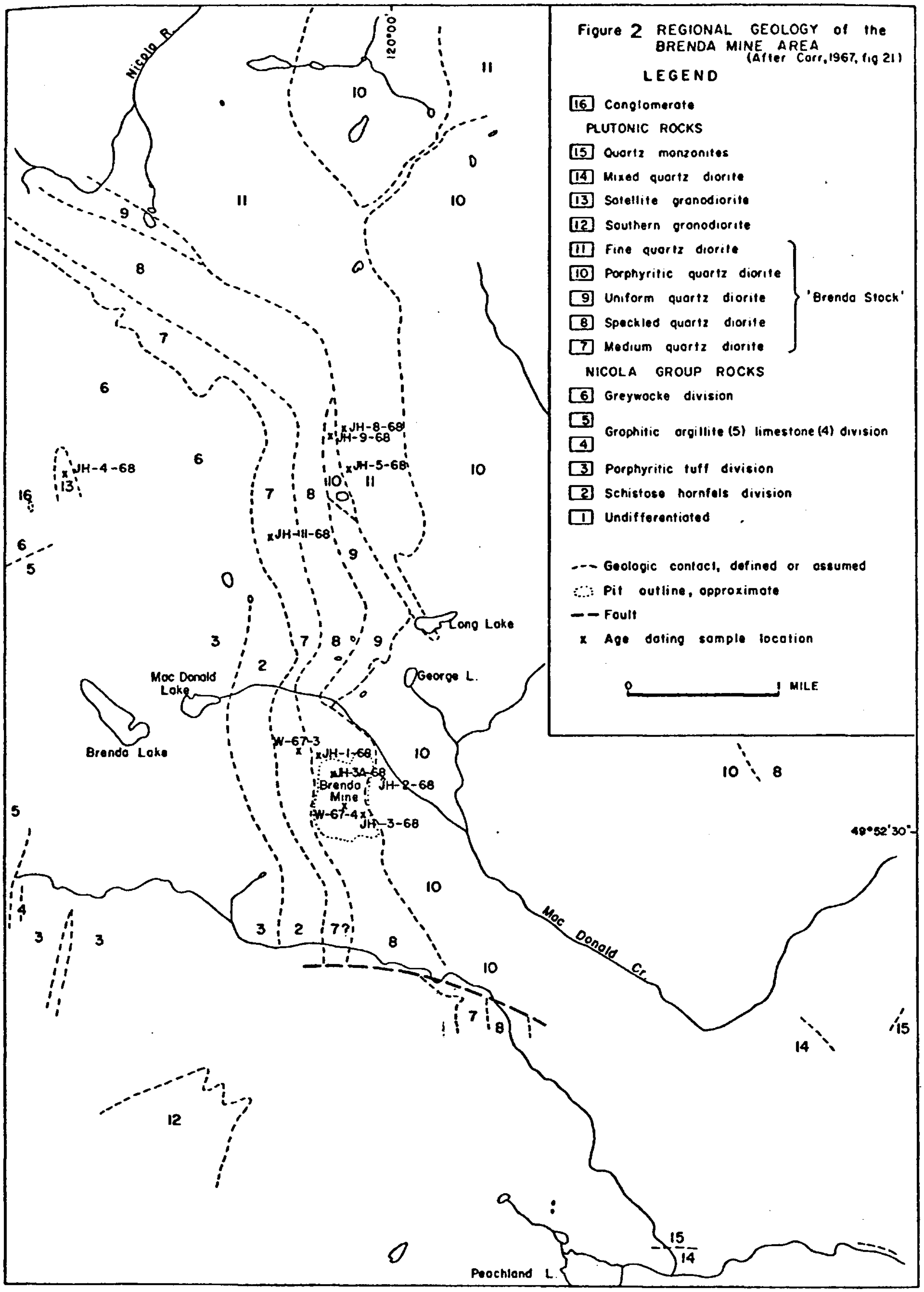


Figure 2 REGIONAL GEOLOGY of the BRENDA MINE AREA (After Carr, 1967, fig 21)

CHAPTER II

GENERAL GEOLOGY

INTRODUCTION

Small scale geologic mapping surrounding the Brenda Mine was done by J. M. Carr in 1967 for the B. C. Department of Mines (Figure 2). It is not the purpose of this thesis to expound further on the regional geology, hence Carr's study serves as the main source of regional geologic information. There are two main rock types: the Nicola Group tuffs and argillites and the intrusive quartz diorites that contain the Brenda ore body.

NICOLA GROUP

Carr (1967) defines four within the Nicola Group units that crop out west of Brenda stock. These are porphyritic tuff, schistose hornfels, greywacke, and argillite-limestone sequence. The schistose hornfels lies in contact with intrusive rocks for one mile south and north of the orebody and has an outcrop zone approximately 1/4 of a mile wide. Megascopically, it is a fine-grained, silica-rich rock possessing foliation cleavage and lineations as a result of a concentrated development of biotite plates up to four millimeters wide. Petrographically, it is a "fine-grained, quartz-feldspathic mosaic containing disseminated biotite and chlorite, lenticular knots of biotite, single unzoned plagioclase crystals and locally, grains of quartz" (Carr, 1967, p. 186). Schistosity strikes consistently N12°W and dips 40°SW. Probable original bedding in the tuffs around Brenda Lake strike N80°W and dip 65°S. The hornfels probably is a metamorphic equivalent of the porphyritic tuff and tuff breccia units recognized by Carr.

Porphyritic tuffs crop out in a wide northerly pinching zone closely parallelling the schistose hornfels. Exposed width of the outcrop zone at the southern end of the unit exceeds one mile. Contact relations with argillites and graywaekes are mostly hidden by deep glacial drift. They contain abundant fragments of volcanic material such as porphyritic andesites and dacites. Volcanic flows were not mapped in the region, however. Carr describes tuffs in the eastern part of the unit as a tuff breccia containing rounded to subangular volcanic rock fragments up to two inches long. In the western half the tuffs are characterized by massive, fine-grained or glassy rock interlayered or intermixed with clastic sedimentary material (Carr, 1967).

Graphitic argillite and limestone units (numbers 5 and 4 respectively on Carr's map) crop out about two miles west of the mine over an area extending for two miles north and a mile south of the pit. They consist of two black limestone beds 200-300 feet thick surrounded and separated by tuffaceous greywackes, siltstones and graphitic argillites. "The limestones are graphitic, recrystallized, schistose, fine-grained rocks containing rare quartz grains and particles of chert. Their schistosity shows minor dragfolds plunging southward at 40 degrees." The black argillites and greywackes "are thin-bedded, incompetent rocks, and the soft graphitic argillite has in places squeezed discordantly into faults." (Carr, p.185).

Another type of Nicola rock in the area is the greywacke unit. These are bedded volcanic greywackes and siltstones that apparently grade into increasingly metamorphosed hornfels close to the intrusive contact. Scour features in the siltstones suggest to Carr that the beds are upright. The hornfels are brown, quartzitic rocks with large amounts of finely dispersed biotite. Sericite was noted on cleavage surfaces. Fine-grained quartz, plagioclase, biotite and hornblende are the dominant constituents. Irregular patches of pale and/or dark minerals are common giving the rock a somewhat mottled appearance.

TERTIARY (?) CONGLOMERATE

A conglomerate of possible Tertiary age (Carr, 1967) is located one mile north of Brenda Lake on the old Noranda road. It consists of rounded pebbles and cobbles in a fine-grained matrix; all possessing an irregular, black manganiferous coating. The rock is poorly sorted with fragments of tuff, chert, quartz diorite and porphyry in an argillaceous matrix. It was also reported to have been glacially striated; however, when the writer examined the exposures, all traces of glacial polishing had been removed through bulldozer road clearing.

INTRUSIVE ROCKS

The Brenda ore body is within a body of quartz diorites termed by Carr the Brenda Stock. It appears more linear than equant, extending in a northerly direction. To the northwest, north and east, however, its limits have not been defined. The stock has a minimum width of 4 miles east to west and a length greater than 7 miles. To the immediate south is the Similkameen batholith and to the northwest is the Pennask batholith. The Brenda vicinity has been included as part of both the Similkameen and the Pennask batholiths by Peto (1970) and Schau (1968) respectively. Further work is clearly needed. The western contact of the intrusive is with Nicola tuffs and argillites as described previously. Nearly 3 miles north of the mine the contact diverts from a northerly to northwesterly trend.

Four successive subparallel quartz diorite units and a later intrusive phase were defined by Carr as comprising the Brenda Stock. These are the Medium, Speckled, Uniform, Porphyritic, and Fine quartz diorites. Separation of units was based on macroscopic textural differences arising primarily from small changes in the distribution, size, and ratios of biotite and hornblende. Basically, all units are similar; they are all quartz diorites possessing slightly varying amounts of quartz, plagioclase, potash, feldspar, hornblende, biotite, and magnetite, sphene and apatite; the latter three occur as accessory minerals. Quartz forms about 25 percent, plagioclase 50 percent, orthoclase and microcline up to 20 percent; and hornblende and biotite account for 10 to 30 percent of the rock volume.

Many outcrops possess a faint foliation due to the alignment of mafic minerals, especially biotite. Foliation attitudes are generally parallel to the contact of the adjacent unit of the Nicola contact. Most contacts dip from vertical to steeply westward.

"Medium Quartz Diorite(7)....A rough-weathering rock, the Medium quartz diorite is relatively dark and inhomogeneous, although less so with distance from the outer contact, and it has a medium-grained appearance due to a high content of crystals larger than 2 millimetres. Foliation is mostly well developed, and the rock is commonly streaky due to local variation of the dark mineral content. Hornblende mostly exceeds biotite in amount, and its crystals may reach a length of 2 centimetres. Quartz is partly wedge-shaped, and the larger grains have a blue colour in some outcrops. Potash feldspar is less abundant in this rock than others. The estimated range of modal compositions of the Medium quartz diorite is as follows: Quartz, 10 to 30 percent; potash feldspar, 0 to 5 percent; plagioclase, 45 to 60 percent; hornblende and biotite, 10 to 30 percent; magnetite, etc., 1 percent."

"Speckled Quartz Diorite(8)....Characteristic features aiding recognition of the rock include: A speckled appearance due to the interspersion of small biotite and hornblende crystals with larger ones; the presence of biotite in amounts equalling or exceeding those of hornblende, and its occurrence chiefly in sieve-like shapeless plates of size to 4 millimetres; a prismatic or needle-like shape of most hornblende crystals; and a finely granular appearance of most quartz. Quartz tends to be blue-coloured, as in certain other units. The estimated range of modal compositions of the Speckled quartz diorite is as follows: Quartz, 20 to 25 percent; potash feldspar, 10 to 15 percent; plagioclase, 45 to 55 percent; hornblende and biotite, 15 percent; magnetite, etc., 1 to 2 percent."

"Uniform Quartz Diorite(9)....Like the Speckled rock, the Uniform quartz diorite is predominantly medium grey in colour. It is distinguished chiefly by the even distribution of its dark minerals, of which hornblende is the best shaped and most abundant. Biotite occurs mostly in small plates, which are partly euhedral, and rarely in books as large as 3 millimetres. Quartz is also mostly fine grained but locally makes aggregates as large as one-half centimetre and containing small feldspars. The estimated range of modal composition of the rock is as follows: Quartz, 20 to 30 percent; plagioclase, 40 to 55 percent; potash feldspar, 5 to 15 percent; hornblende and biotite, 12 to 15 percent; rest, 1 percent."

"Porphyritic Quartz Diorite(10)....The rock is lighter coloured than others, and it generally has few inclusion. Dark minerals are relatively sparse and scattered and, together with quartz which forms 1/2-centimetre aggregates, they give the rock a porphyritic appearance. Biotite is typically in well-shaped books of size to one-half centimetre and it exceeds hornblende in amount. Hornblende makes relatively few crystals as large as 2 millimetres; quartz fails to occur in wedge shapes. The estimated range in mode of the rock is as follows: Quartz, 20 to 30 percent; plagioclase, 45 to 60 percent; potash feldspar, 8 to 15 percent; biotite and hornblende, 10 to 15 percent; rest, 1 to 2 percent."

> "Fine Quartz Diorite(11)....Although appearing rather like the Speckled quartz diorite, the Fine quartz diorite is somewhat finer grained and lighter coloured; it possesses quartz partly as small wedges, hornblende partly in excess of biotite, and biotite in plates and thick books mostly smaller than those in the Speckled quartz diorite. Additional useful features for identification are blue quartz grains, a well-developed foliation, unusually abundant sieve-crystals of potash feldspar, and well-shaped hornblendes and biotites distributed patchily in the rock." (Carr, 1967, pp. 190-191)

It should be noted here that the writer collected more than 70 samples of the above mentioned quartz diorites from random outcrops outside the pit area for a radius of two miles. Without predetermination, the writer grouped these samples into macroscopic textural divisions which conformed to Carr's as closely as possible. It was found that there is little correlation between a mapped unit and the textural descriptions of the rocks that the writer collected within its boundaries. Each unit as shown on Carr's map contains more rock types than the name applied to the unit. In several locations, especially in the porphyritic unit, there were as many as three different rock types from the same outcrop. The writer noted that if foliation is well-developed the texture of any particular sample can vary considerably depending on whether it is broken parallel or perpendicular to the foliation. Variable character of weathered surfaces can produce superficial differences in rock type that can lead to ambiguity in applying Carr's classification. Although Carr's regional mapping has provided much needed information and insight to the problems, the writer feels that further detailed work is required.

Other separate and possibly distinct quartz diorite bodies crop out in the area. A "Southern Quartz Diorite" occurs in the southwest corner of Carr's map about 2 miles below the pit. It is similar in appearance to the aforementioned units, but Carr suggests that the hornblende-biotite ratio is slightly different and that hornblende does not have the needle-like appearance commonly found in the units of the Brenda Stock. Ground cover obscures contact relations.

The Satellite quartz diorite is a fine-grained distinctively grey, small plug isolated in Nicola greywackes 2 miles north of the mine. Scattered small (1/2 cm) phenocrysts of plagioclase, hornblende and biotite appear in this unit. It also has a well-defined foliation.

Quartz monzonites appear in the southeastern part of Carr's map area and are similar in appearance to the quartz diorite units except that they contain more potash feldspar than the quartz diorites. These rock types are described more thoroughly in Carr's report to which the reader is referred.

Dikes in the region vary from aplites to basalts with several intermediate varieties. Most strike northwesterly and dip steeply. Carr dates some as being pre-ore and other as post-ore. He describes several structural belts as being defined by the presence or absence of aplite-pegmatite dikes of pre-ore age. Detailed data collected by the writer in and around the pit do not support these conclusions. A more detailed discussion of the dikes is presented in the following chapter.

A suggested age of the quartz diorite from unpublished potassium-argon age dating data (Harakal and White, personal communication, 1972) is about 176 million years. A detailed presentation and analysis of the data is located in the following chapter.

CHAPTER III

GEOLOGY OF BRENDA MINE - STRUCTURE

Primary structure features of the Speckled quartz diorite that contains the Brenda ore deposit have been referred to in an earlier section. Secondary structural features in their approximate order of relative age are from oldest to youngest: ore veins, intramineral dikes, shear zones, moly-slips, and joints. Ore veins are discussed in detail in a subsequent chapter.

FELSIC DIKES

Felsic dikes appear throughout the pit. They are divided for convenience into three textural divisions: aplite, pegmatite and granophyre dikes. As a group, they represent the earliest recognized geological event subsequent to development of the Speckled quartz diorite. Dikes range in width from 1/4 inch to a maximum of 12 inches. Wider dikes are more persistent laterally than ara small dikes, but observed strike lengths do not exceed one hundred feet. The dikes commonly occur in small swarms resembling filled, en echelon, tension fractures. Most dikes are a pale to medium pink color; some, however, are grey. Staining revealed that grey dikes contain less potash feldspar than do pink dikes.(Figure 4)

Aplites have a "sugary texture and consist of quartz, microcline, plagioclase, and minor amounts of green biotite with average grain diameters ranging from 0.05 to 0.3 millimeters....".

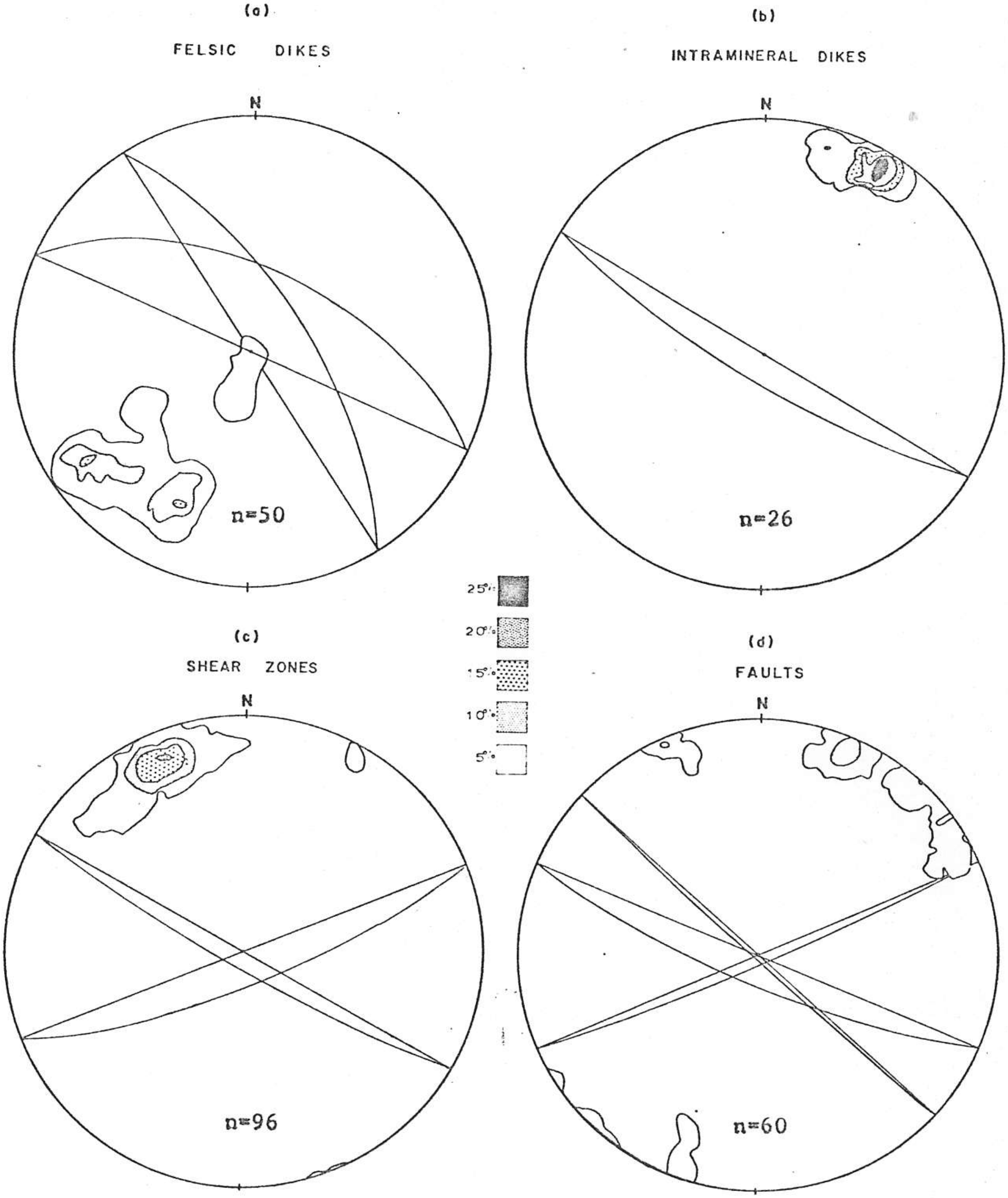


Figure 3. Contoured stereonets and major planes of orientation of secondary structures.

"Pegmatite consists almost exclusively of quartz and potash feldspar (mainly microcline)...."(Carr, 1967). Granophyre refers to dikes possessing irregular subgraphic intergrowths of quartz in feldspar. The subgraphic texture is formed between quartz and potash feldspar. Black tourmaline, brown biotite, and allanite have been identified in these dikes. Tourmaline occurs in pegmatites as rare anhedral masses up to 1/2 inch wide.

Most felsic dikes in the pit strike northwesterly. Two major attitudes are N66°W dip 61°NE and N33°W dip 71°NE (Figure 3a). A third minor concentration is nearly flat. Interestingly, two of the flat dikes observed were parallelled by nearby mineral segregation bands that locally formed faint gneissic textures. These were all thin 1/2 to 1 inch dikes with crystals varying from 1/8 to 1/4 inch in a slightly pegmatitic framework.

Although most dikes are unzoned mineralogically, a combination of textures generally occurs. The commonest zonal arrangement observed by the writer is a granophyric or pegmatitic core grading outwards into an aplitic border zone of varying width. These border zones probably represent chilled margins. Simple pegmatites with thin cores of coarse-grained quartz have also been found but are much rarer than other types. Another example of zoning which is uncommon but not rare is an apparent reverse zoning: aplite forms the central portion of the dike with pegmatite and less commonly granophyre in the border zones. In two such cases the aplite core zone was traced eventually to a separate later dike that had taken a course along the center of the previously emplaced pegmatite, and in other samples streaked remnants of the pegmatite indicate forceable intrusion of a later aplite (Figure 5). The pegmatite might have been refractured as further settling and cooling of the quartz diorite took place, or it provided a path of least resistance due to coarser crystallization and less interlocking of grains than the cooled intrusive possessed. Either explanation appears satisfactory.

It is possible that the wide range observed in the types and relationships of these felsic dikes result from an overlapping of more than one pulse or period of intrusion. Pegmatites and granophyres are both zoned and unzoned. The unzoned dikes might be considered the earliest of the dikes. Because of their coarse size and unchilled margin, they might have intruded an incompletely cooled magma. These are followed by later aplite dikes, probably genetically a part of the same system but slightly younger in age.

Aplite dikes cut granophyres and pegmatites. They also have intruded along the centers of previously emplaced dikes. Offsets of aplites by other aplites have also taken place. Possibly the last dikes to have formed are small grey aplitic dikes richer in quartz than feldspar. Some have been observed to intersect other aplites and pegmatites. Perhaps the aplites represent intrusion during a period when the quartz diorite had cooled sufficiently to chill the siliceous fluids forming the dikes. At several locations an en echelon arrangement of several dikes has been noted both by the writer and previously by Carr (1967). These lend support to the idea that such dikes filled tension fractures produced by contraction of the cooling mass of Speckled quartz diorite.

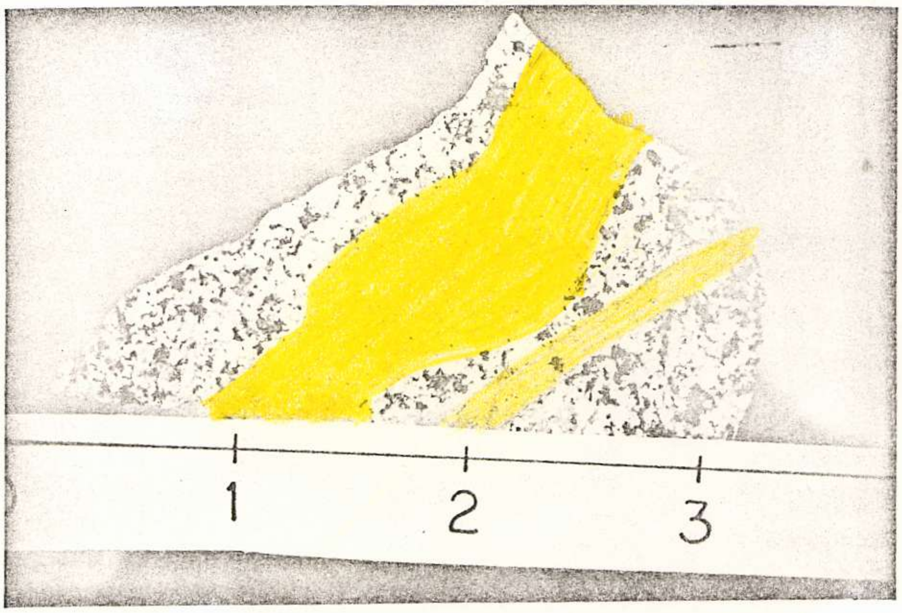


Figure 4. Two varieties of aplite dikes. Lighter colored dike contains less feldspar and is later than the other. Specimen has been stained.

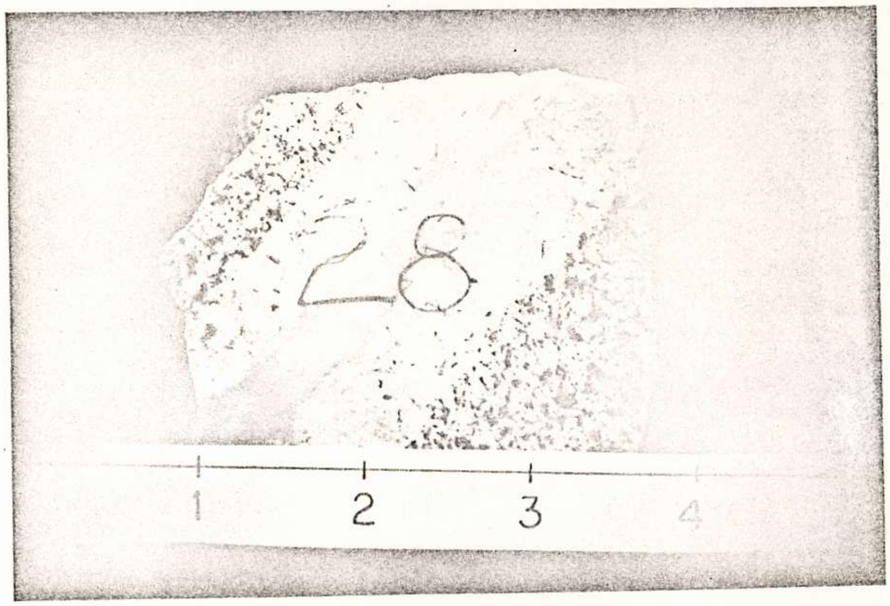


Figure 5. Small aplite intruding along center of pegmatite dike. Note streaked inclusion in center of dike.

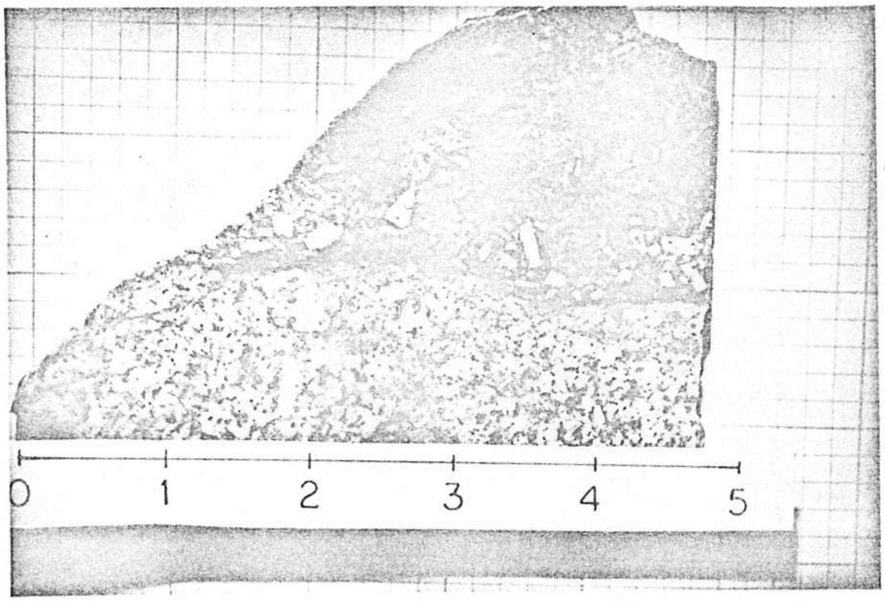


Figure 6. Intramineral dike (trachyte) cutting Stage II vein (outline with red dots).

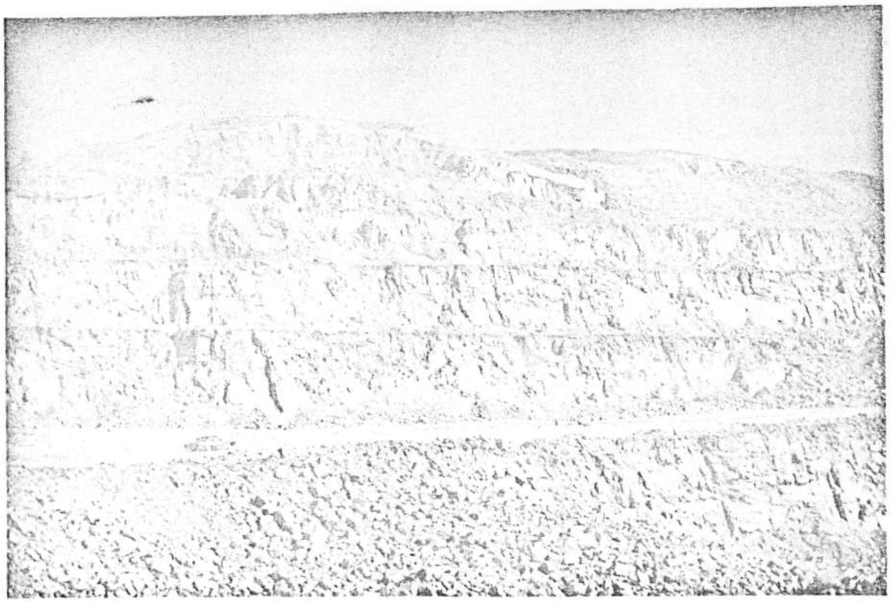


Figure 7. Jointing parallel to eroded surface. Other orientations appear at deeper levels. (Looking northwest).

Figure 8. Shear zone in argillic alteration. Black ribbon in center is a Stage III quartz-molybdenite vein that is sheared and partially decomposed.

At no time was the writer able to find evidence supporting Carr's suggestion that felsic dikes were contemporaneous with ore mineralization and fracturing. In every observable instance, felsic dikes were earlier than any other structural or mineralogical feature. Orientations of the dikes suggest also that their causes of formation were dissimilar.

INTRAMINERAL DIKES

Intramineral dikes are those emplaced between Stage III and Stage IV veins. (Kirkham, 1971; Wallace, 1967). They have variable compositions. All dikes in the pit area are in this category with the exception of two andesite dikes that predate Stage I veins. Many Stage IV veins intersect intramineral dikes. Despite their wide range of compositions, intramineral dikes as a whole have a strong preferred orientation averaging about N59°W/80°SW (Figure 3b). Slight differences in orientation are not related to textural or compositional differences. Average width of these dikes is approximately one foot. An exceptional trachyte dike is 20 feet wide. Dike lengths vary considerably in the pit, but none have been traced for over 1000 feet. Normally only lengths less than 100 feet have been measured.

Rarely a dike bifurcates and joins again surrounding an island (horse) of quartz diorite in the center. Rare changes in strike and dip take place on some dikes where they intersect earlier linear features such as veins.

All intramineral dikes have chilled contacts and show little if any zoning. No metamorphic affects in adjacent wall rock were noted.

One dike was observed that has a four inch marginal zone consisting of vessicles partially or completely filled with calcite, quartz, and rare chalcopyrite and pyrite. This dike strikes northwest and dips steeply to the southwest. The vessicles were on the hanging wall of the dike.

ZONES OF SHEARING

Shear zones are post ore zones of concentrated strike-slip movement in pre-weakened argillic alteration zones associated with Stage III veins. Both the amount of shearing and the width of the actual zone of movement are often obscurred by the intense alteration which so weakens the rock that it crumbles upon exposure to air and rain. In two cases shear zones proved to be only argillic alteration zones along which no movement at all had occurred. In each case felsic dikes (earliest feature) passed through the zones with no offset or movement.

The maximum width of these combined shear and argillic alteration zones within the pit is 35 feet. Average width is about 10 feet. A few have been traced for lengths up to one thousand feet.

As yet, an unexplained feature is that many of the shear zones appear to pinch out upwards and laterally. A zone ten feet wide at the base of a bench might thin to five or six feet at the top of the bench or laterally along strike. Although this feature has been noted frequently, it is not found in all shear zones. Indeed the opposite effect has been rarely seen when the width decreases downward instead of upward.

A few intramineral dikes have been observed both to intersect and be intersected by shear zones, indicating that the times of formation must overlap at least in part.

Some brecciation has been observed in at least two of the shear zones. In one sample angular to subrounded quartz fragments in a matrix of muscovite and minor clay containing up to 20 per cent euhedral magnetite and minor hematite have been refractured. Quartz has possibly been introduced in larger amounts than normally contained in the quartz diorite. Large (possibly annealed) grains up to one inch also occur. Some appatite is formed. The other consists of angular quartz and altered plagioclase fragments altered to clay and muscovite.

A few Stage III veins observed by the writer are unaffected by shearing in the argillic zones. Most, however, are sheared though not significantly offset.

Figure 3c displays the plots of the poles to the shear zones. Their orientations possess two distinct concentrations at N68°E/78°SE and N61°W/85°SW. The pattern of orientation is similar to those of Stage IV veins, as is expected since the argillic zones are intimately related to Stage III veining. Argillic alteration and Stage III vein structure are discussed separately in the following chapter.

MOLY-SLIPS

Black, shiny slip surfaces of slickensided molybdenite are found commonly in the pit. Generally they cover surfaces many tens of square feet wide or larger. A suggestion put forward in the early stages of development was that these surfaces "painted" with molybdenite constituted most of the molybdenum ore (Chapman, Wood, and Griswold, 1967). The writer disagrees. Most of these moly-slips observed by the writer are the result of post deposition movement along Stage II or III veins, having a high content of molybdenite along vein walls. Even minor movement of an inch or so in many cases would probably be sufficient to smear the molybdenite creating the obtrusive black, shiny surface. Only a few of these veins have had such movement, and by far the largest amount of molybdenum is present in Stage II and III veins that have not undergone subsequent movement.

BLACK CLAYS

A minor though widespread occurrence within and adjacent to highly argillized shear zones are dark, black zones containing a fine granular mixture of clays, calcite, molybdenite, chalcopyrite, pyrite, hematite and silica (Figure 8). They appear to be a result of deposition from ground water; and are, as such, distinctly separate from moly-slips discussed earlier. Most were found to be adjacent to Stage III quartz-molybdenite veins of various sizes. Apparently the alteration along the quartz-molybdenite veins provided a zone of permeability for percolation of ground water which might have broken down and/or dissolved the silica and physically transported finely granular molybdenite downwards along the sides of the veins until thick accumulations of molybdenite, fine clays and silica were deposited in varying amounts. Thicker accumulations were normally found lower in the pit. On freshly blasted benches, the writer was able to observe black muddy water transporting and depositing molybdenite, etc. down tbese zones of high permeability adjacent to the quartz-molybdenite veins.

Late movement on black molybdenite zones along which water was no longer flowing would produce slickensides superimposed on the hardened molybdenite clay mixture. The late slickensides probably represent late sporadic Tertiary movement along old ruptures, entirely unrelated to development of the ore body.

If most of the quartz in the quartz-molybdenite veins were removed in any one locality, these black zones might be mistaken for fault zones. It is the writer's opinion that this is what Carr mistakenly identified as "locally graphitic" faults (Carr, p. 201). Although several samples were analyzed by x-ray, none showed the presence of graphite nor has graphite been recognized macroscopically in the pit. Analysis of one of the clays revealed a high zinc content as well as high copper and molybdenum.

Deposition of the unaltered molybdenite and minor amounts of chalcopyrite apparently took place rapidly and below the zone of oxidation. Ferrimolybdite or limonite were not observed unless within 20 feet (rarely up to 90 feet) of the surface. Reddish oxidized hematite might also be present. The amount of molybdenite transported downward in this fashion is not calculable but in all probability is only a minor though noticeable amount.

FAULTS

Faults are not easily discernable. In many instances this is due to a lack of observable offset. Although few intersections with such linear features as dikes are available for every fault recognition, narrow envelopes of argillic alteration are normally indicative of fault movement.

At the present time data are insufficient for complete understanding of faults and their nature of occurrence. Based on the few reliable observations, however, the writer tentatively suggests that two types of faults developed successively or perhaps at distinctly separate times.

A set of strike-slip faults are perhaps represented by those that strike about N66°E and N66°W and dip southerly (Figure 3d). Due to their indicated relative movement and alteration affinities, they are probably directly related to shear zones. Indeed many of these were at first classified as very small shear zones but subsequently redefined for lack of evidence of an actual zone of shearing.

A possibly separate and/or later set of faults might be represented by normal faults striking N50° to 30°W and dipping more nearly vertical. These appear to have little associated alteration. Most appear to have an almost insignificant amount of throw. A maximum of 15 feet normal dip-slip was recorded on one fault striking N50°W and dipping steeply southwest.

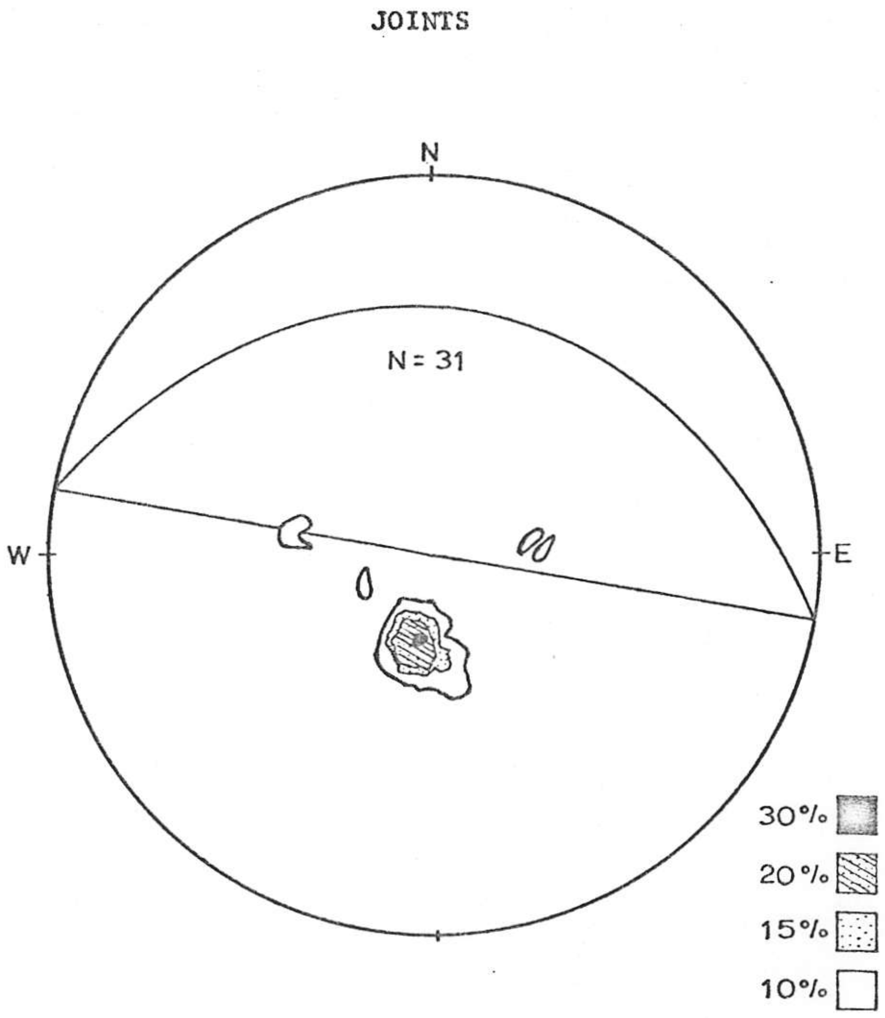


Figure 9. Poles of joint planes plotted on Schmidt net. Line indicates principal strike direction; N 80°East, dip 25° N.

JOINTS

Joints are a late feature believed to be an expression of pressure release related to surfaces of erosion (Figure 7). They are totally unmineralized. The joint density (joints per yard) is as high as six but normally is less than three. Conjugate pairs appear to form in some areas but were not observed at all locations. The major importance of these joints is their contribution to breakage of the rock for milling purposes and their possible effect on pit slope stability. The major orientation is N80°W/25°NE. Minor orientations occur at N8°E/40°E; N4°W/30°W; and N24°W/23°NE (Figure 9).

AGE DATING

Potassium-argon model ages were determined for eleven samples of quartz diorite from the Brenda mine and vicinity by W. H. White and J. E. Harakal (personal communication, 1972). Preliminary results for two samples have been published (White et. al., 1968), and those plus more recent data are reproduced with their permission. Sample locations are shown in Figure 2. Analytical data and model ages are listed in Table I, including duplicate and triplicate analyses. A histogram of model ages is shown in Figure 10.

Examinations of the model ages lead to the following generalizations:

(1) Hornblende ages group closely around 176 m.y.

(2) Biotite ages within the pit area group near 146 m.y.

(3) Biotite ages removed from the pit area give model ages in the range 131 to 174 m.y.

(4) Two intramineral dikes have whole rock K-Ar ages of about 130 m.y.

It seems reasonable to assume that the consistency of hornblende ages at 176 ± 8 m.y. represents the age of solidification of the Speckled quartz diorite and is, therefore, a reasonable estimate of the age of the entire Brenda stock. This is supported by concordant ages for biotite and hornblende of about 176 m.y. (Jh-5-68) from an area two miles north of Brenda pit.

Some doubt exists, however, concerning the interpretation of the model ages. Consider the following possible interpretations:

(1) Mineralization took place at about 176 m.y. and either
   a) a later thermal event unrelated to mineralization reset the biotite age at about 146 m.y., or
   b) the intrusion cooled slowly during an interval of about 30 m.y. gradually depleting the argon in biotite.

(2) Mineralization occurred about 146 m.y. followed by sequential structural events and late minor mineralization at about 130 m.y.

(3) Mineralization occurred at approximately 130 m.y.

Considering the third alternative, a possibility exists that some biotite ages were obtained on mixtures of rock biotite with an age of 177 m.y. and hydrothermal biotite (Stage IV) with an age of 130 m.y. The 146 m.y. ages might be a result of such a mixture of biotites. Hence, the age of actual mineralization might be about 130 m.y. Four biotite ages group about 146 m.y., three of which occur in or close to the pit. One biotite age occurs at 174 m.y., and two biotite ages from the similarily mineralized North Brenda vicinity have lower ages at 131 m.y. and 136 m.y. Such a wide range in ages between the two extremes would be expected from samples of varying proportions of different age biotites.

The second possibility is that ore mineralization occurred at 146 m.y., and ore related events continued intermittently perhaps until about 130 m.y. (age of the Intramineral dikes). The consistent grouping of the biotites near the pit at about 146 m.y. seem almost too coincidental to result from chance mixtures of different biotite ages. On the other hand, 16 million years is a long though not impossible time for mineralization to endure assuming that model ages for the intramineral dikes are correct.

The first alternative that mineralization quickly followed solidification of the intrusive necessitates a later thermal event to explain the anomalous biotite ages. Evidence supporting a later thermal event other than possible mineralization is lacking. Structural data, for instance, does not indicate the presence of a local underlying intrusive as a heat source. And the writer cannot find geological evidence necessarily relating mineralization and fracturing to the cooling history of the quartz diorite or immediately thereafter. That the intrusion cooled slowly over 30 million years and slowly reset the biotite seem quite unlikely. Unless the age determinations of the intramineral dikes are incorrect, they would indicate that a sequence of events directly and continuously related to ore mineralization proceeded until 130 m.y. - an interval of nearly 50 million years! Highly unlikely.

Until further selective potassium argon dating has been completed, the three interpretations remain. It seems likely,

TABLE 1 (Harakal - White, unpublished)

Sample Number	Material Analyzed	Rock Unit	K(%)	$^{*40}Ar / ^{40}$Total Ar	$^{*40}Ar$ (10^{-5} CC STP/g)	$^{*40}Ar / ^{40}K$	Age (my)
W-67-3	Hornblende	Medium	0.4%	0.57	6.486 x 10^{-1}	10.766 x 10^{-3}	176 ± 7
W-67-3	Hornblende	"	0.4%	0.85	6.298 x 10^{-1}	10.456 x 10^{-3}	171 ± 7
W-67-3	Hornblende	"	0.4%	0.41	6.334 x 10^{-1}	10.515 x 10^{-3}	172 ± 7
W-67-3	Biotite	"	1.0%	0.85	3.637	9.004 x 10^{-3}	148 ± 6
W-67-4	Hornblende	Speckled	0.7%	0.47	5.363 x 10^{-1}	11.239 x 10^{-3}	183 ± 8
W-67-4	Hornblende	"	0.7%	0.60	4.853 x 10^{-1}	10.170 x 10^{-3}	166 ± 7
W-67-4	Hornblende	"	0.7%	0.73	5.146 x 10^{-1}	10.784 x 10^{-3}	176 ± 8
W-67-4	Biotite	"	0.4%	0.68	4.510	9.033 x 10^{-3}	148 ± 5
JH-1-68	Hornblende	Speckled	0.2%	0.60	4.741 x 10^{-1}	10.961 x 10^{-3}	179 ± 7
JH-1-68	Biotite	"	1.1%	0.69	1.154	8.785 x 10^{-3}	145 ± 6
JH-2-68	Biotite	Porphyritic	0.2%	0.91	3.438	8.788 x 10^{-3}	145 ± 5
JH-2-68	Hornblende	"	0.6%	0.43	5.245 x 10^{-1}	10.930 x 10^{-3}	178 ± 8
JH-3-68	Whole Rock	Intramineral	0.4%	0.86	1.374	7.960 x 10^{-3}	131 ± 5
JH-3A-68	Whole Rock	"	0.3%	0.83	1.825	7.659 x 10^{-3}	127 ± 5
JH-4-68	Biotite	Satellite	0.4%	0.90	4.696	9.464 x 10^{-3}	155 ± 6
JH-4-68	Biotite	"	0.4%	0.69	4.615	9.303 x 10^{-3}	153 ± 6
JH-5-68	Biotite	Fine	0.3%	0.72	2.746	10.677 x 10^{-3}	174 ± 7
JH-5-68	Hornblende	"	0.4%	0.46	4.891 x 10^{-1}	10.876 x 10^{-3}	177 ± 7
JH-8-68	Biotite	Fine	0.5%	0.83	3.595	8.247 x 10^{-3}	136 ± 6
JH-9-68	Biotite	Porphyritic	0.6%	0.91	3.785	8.537 x 10^{-3}	141 ± 6
JH-11-68	Biotite	Medium	0.4%	0.92	2.759	7.978 x 10^{-3}	132 ± 6

Figure 10a. Histogram of potassium-argon dates (including error) for Brenda Mine and vicinity. Average ages were used for multiple analyses for the same concentrate.

Figure 10b. Diagram of model ages (without assigned errors). Whole rock analyses ○, Biotite ages □ , Hornblende ages △ . (From unpublished data by White and Harakal)

however, that mineralization was the agent that reset some biotite and precipitated hydrothermal biotite related to mineralization. If this were so, then the maximum age of mineralization is about 146 m.y. and could be as low as 130 m.y. if separate biotites were mixed for analyses.

The writer prefers the second hypothesis because the first hypothesis appears to be ruled out by all the data so far collected. And the third hypothesis requires extreme coincidence that several random samples would all contain the same relative proportions of separate biotites.

SUMMARY

The time of emplacement of the Speckled quartz diorite appears to be about 176 million years ago or lower Jurassic time as indicated by potassium-argon ages on hornblende by Dr. W. H. White of the University of British Columbia (Harakal and White, personal communication, 1972). This intrusion was followed by the introduction of aplite, pegmatite and granophyre dikes possibly related to late magmatic fluids resulting from cooling crystallization and settling of the magma. They strike predominently northwest and dip moderately to the southeast. Their orientation is significantly different than all other secondary structures, which leads the writer to believe that they are not contemporaneous with or even caused by the same conditions that formed later events as suggested by Carr (1967). Following these after some indeterminant time are the ore veins, intramineral dikes, shears and faults forming in overlapping sequence (Figure 11). Age dating indicates that mineralization probably commenced about 146 m.y.

Intramineral dikes are termed such for their occurrence in time with Stage IV veins and shears. They are overlapped by both but occur well after the formation of the ore veins. Orientations of intramineral dikes are remarkably consistent striking N59°W, dipping 89°SW; however, their compositions range between andesitic and basaltic. A few trachyte dikes are present that have been described previously by Carr (1967). Two dikes of andesitic composition are apparently of premineral origin. Their relation to the other dikes are unknown. The actual time of the sequence of alteration, mineralization and the formation of dikes and shears cannot as yet be determined absolutely. Two age determinations of mafic dikes have been carried out (Harakal and White, personal communication, 1972) and indicate an age of 130 million years. It appears possible that these dikes, though late in the sequence represent the final events with negligible but significant mineralization following emplacement of intramineral dikes.

Large shear zones averaging about 10 feet wide are predominant in the pit. Shears overlap the intrusion of the intramineral dikes and the end of the period of ore mineralization. Stage IV veins and a few Stage III veins in part intersect the shear zones. Argillic alteration has greatly extended the limits of shear zones and effectively weakens the rock for percolation of ground water and further decomposition of the rock.

Many faults are related to shearing whereas others appear unrelated. Movement direction and ages are difficult to determine and little can be said of them. Faults probably occur contemporaneously

Structural History at Brenda

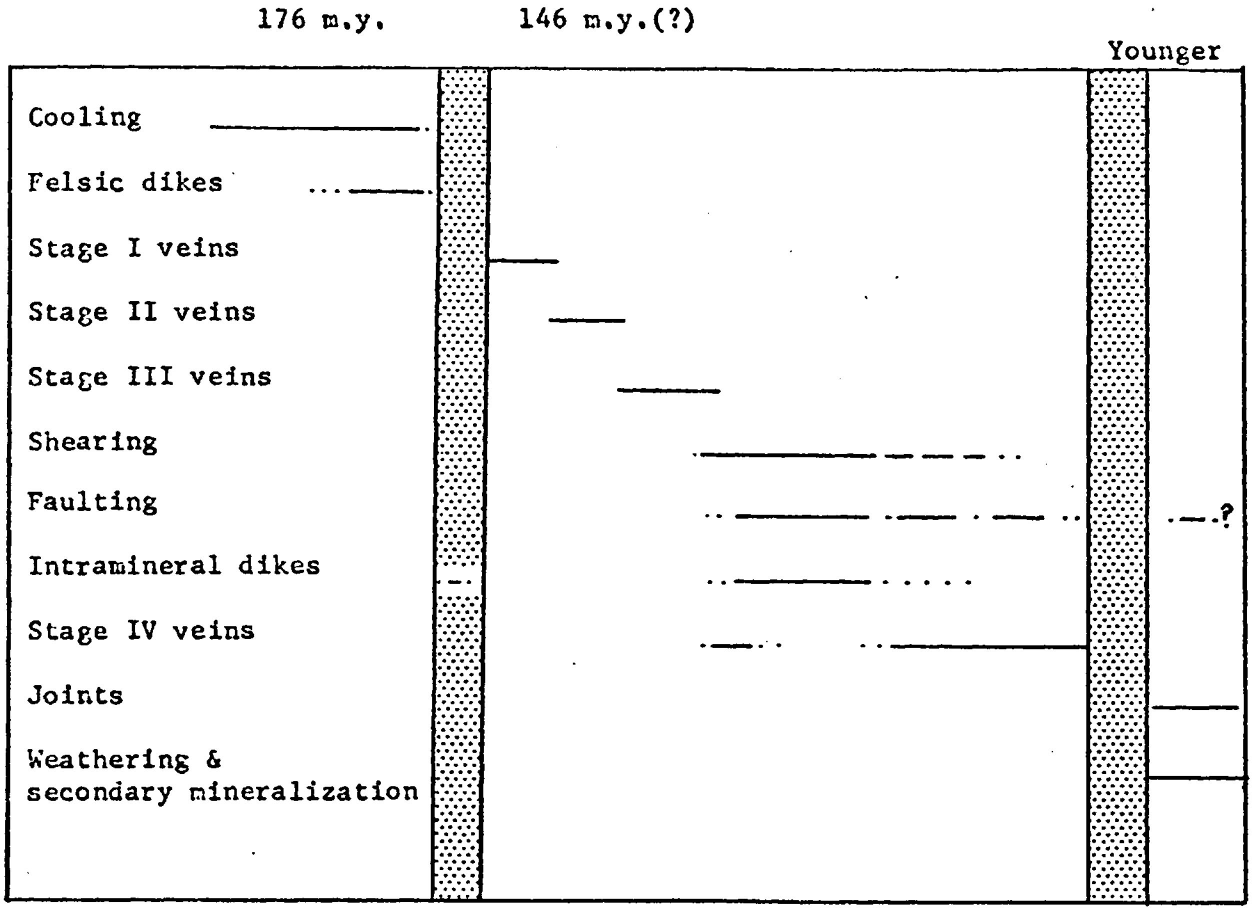


Figure 11. Sequence of events showing progressive overlap and relative ages. Stipled area indicates time gap.

with and/or slightly later than shear zones. Some faulting might be of Tertiary age. Orientation of both shears and faults are similar, striking about N68°E and dipping 75° to 85° southeast.

One of the most important conclusions is the apparent significance of the continuity of orientations of structural features of various ages. This suggests that the events were all in response to the same stress environment that existed with intermittent release over a protracted time period.

Joints are unmineralized late features possibly related to uplift and erosion. Their predominant orientation is N80°W/25°N. By comparing the orientation of these features (including mineralized veins discussed in the following chapter), a pattern can be observed with two predominant attitudes N60-68°E/75-85°SE and N60° to 70°W/80-85°SW. These orientations appear to be consistent throughout the pit barring gaps and slight differences due to inadequate exposure and few recorded observations.

CHAPTER IV

GEOLOGY OF BRENDA MINE - VEIN DESCRIPTIONS

INTRODUCTION

Chalcopyrite and molybdenite are the abundant ore minerals in the Brenda ore deposit. They occur in three paragenetically and mineralogically distinct vein systems. A fourth stage of veins are late and contain only infrequent sulfide occurrences.

	Time	Primary Opaques	Dominant Gangue
Ore veins	Stage I Veins	Chalcopyrite - Py	Biotite
	Stage II Veins	Cpy-Moly-Py	Quartz K-felspar
	Stage III Veins	Moly-Cpy-Py-Mag-Hem	Quartz Calcite
	Stage IV Veins	(Py, Spec, Hem, Cpy)	Various

Previously Soregaroli (1971), mapping within the pit in 1968, divided the veins into four types: 1) quartz-potash, feldspar-sulfide, 2) biotite-chalcopyrite, 3) quartz-molybdenite, and 4) epidote-magnetite-molybdenite veins, occurring in that order formation. The writer departs somewhat from this order. Biotite veins containing chalcopyrite are found to be consistently separated in time from barren biotite veins that crosscut all other veins except late calcite and epidote veins. Specific vein orientations are slightly more emphasized or de-emphasized by the writer than by Soregaroli. These are discussed in their appropriate order. Much of this work serves to confirm the excellent geology and mineralogy by Soregaroli with much fewer exposures than were available to the writer.

Average grade for the entire pit is 0.18 percent copper and 0.049 percent molybdenum, these metals being present almost entirely as chalcopyrite and molybdenite respectively. Computer calculated reserves are 177 million tons. Gold and silver assays in the copper concentrate average 0.056 oz./ton and 3.72 oz./ton respectively (D. F. Whitford, Brenda geologist, personal communication). Rhenium content in molybdenum concentrate ranges from 120 to 180 ppm (A. E. Soregaroli, personal communication). Ore minerals occur almost entirely in fractures, and fracture density is the dominant control of ore grade. Disseminations occur only rarely in areas where alteration is intense.

Other hypogene ore minerals are pyrite, magnetite, hematite, bornite, sphalerite, and galena. Galena has thus far not been observed in place or in polished sections by the writer. Sphalerite and bornite are rarely visible macroscopically but are in places apparent in polished sections examined by reflected light microscopy. Pyrite averages about one percent of vein sulfides. Amounts of the other ore minerals mentioned vary drastically from place to place but normally are found only in trace amounts.

Gangue minerals include quartz, potassium feldspar, calcite and clinozoisite. Barite was found in one location in the pit. Occurrences of the above minerals are discussed in detail in following paragraphs.

STAGE I VEINS

The earliest sulfide minerals in the intrusion were deposited in biotite-lined fractures, 1/32 to 1/16 inch wide. Soregaroli (1971) has considered the quartz-potash-feldspar veins to be older than biotite veins. The writer, however, has consistently observed quartz-potash-feldspar veins transecting sulfide bearing biotite veins. Equally consistently the writer has found a second class of biotite veins identical to the above mentioned biotite veins (excepting for a lack of visible sulfide content) that cut quartz-potash-feldspar veins as well as quartz-molybdenite veins and some intramineral dikes. The later biotite veins are grouped in the fourth stage of mineralization and are discussed separately in a later section of this chapter. The biotite is dark brown or black with a felted texture and normally covering the fracture walls completely. Chlorite is generally present, the amount depending on the extent of alteration. Chalcopyrite and minor amounts of pyrite are the dominant and almost exclusive ore minerals; molybdenite and bornite, occur much less abundantly. All biotite veins combined probably account for less than 5 percent of the ore due mostly to their small size and low sulfide content.

Mineralogy

Chalcopyrite appears as patchy, scattered blebs on the biotite walls, normally not covering more than 10 percent for the wall area. Aggregates of grains are generally less than 7 mm wide. Individual grains are as small as 0.1 mm.

Pyrite, the most abundant associated sulfide, appears to have

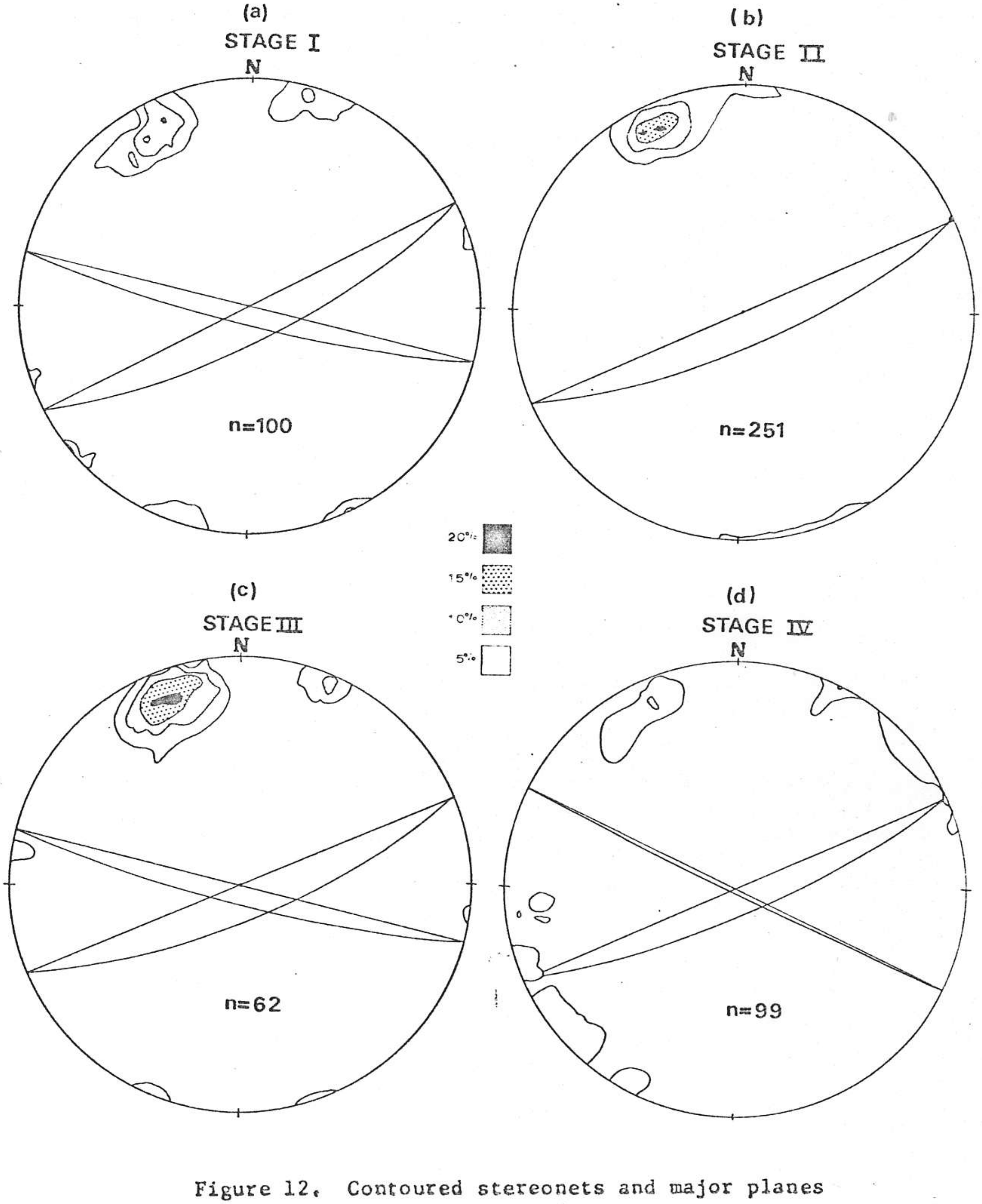


Figure 12. Contoured stereonets and major planes of orientation of veins.

been deposited either contemporaneously with or slightly later than chalcopyrite. Although grains or crystals are normally subhedral to anhedral, euhedral crystals are not uncommon. Most eubes and anhedral grains are 0.5 to 1 mm in diameter. Pyrite might form as much as 20 percent of the total sulfides, but normally is about 10 percent or less of total sulfides in Stage I veins. Although the percentage of pyrite versus chalcopyrite appears high in this system, it does not appear to seriously affect mill recovery because the veins are not important contributors to ore.

In the field bornite was identified in a single instance in a biotite vein by the writer but has not been observed in polished sections.

Macroscopic molybdenite is present in only a few biotite veins. Where it was observed, it is scattered as individual small plates or small groups of plates. Amounts are similar to the pyrite and in places equal to chalcopyrite. Although chalcopyrite-pyrite veins are earlier than second stage veins, most of the fractures bearing molybdenite were crosscutting and apparently later. It is suggested that these few veins, less than one percent of all biotite veins, are transitional to, or overlap in time the introduction of the second stage of minerals. Neither molybdenite nor bornite appear on a specific set of veins or in any particular orientation.

Structure

Although they represent 24 percent of all the ore veins measured (Stage I, II, and III), Stage I veins probably account for no more than five percent of the total sulfide ore due to the minor concentrations of chalcopyrite and almost total lack of molybdenite in the veins.

No offsets were observed where biotite veins intersected aplite or pegmatite veins. Lineations, i.e. streaking of the felted biotite, are minor but present on some of the larger veinlets. Most lineations, however, are felt to be very late, associated with uplift. Lineations are commonly vertically oriented showing normal dip-slip movement when observable. Some also displayed horizontal strike-slip motions with both right-lateral and left-lateral movement. Lineations are also more abundant near shear zones though not tremendously so.

There are two concentrations of biotite vein attitudes. By far the major concentration strikes about N62°E and dips 78°SE ± 2° (Figure 12a). It is outlined by two 15 percent concentrations out of 100 veins measured over the entire pit. The second high has an attitude of N76°W/dip 86°SW and was defined by visually centering the ten percent contour level. Orientation of veins are not found to change significantly from location to location (Figure 13). Preferred orientation for mineralogically distinct veins, i.e. molybdenite or bornite bearing veins, does not exist as far as present data allows. Soregaroli (1971) has described two orientations common to biotite-chalcopyrite veins: "a) 5-20°W/45°E to vertical" and "b) N40-60°W/15-30°N" (Soregaroli, 1971). Because the writer has subsequently divided biotite veins between two stages (I and IV), the patterns obtained are expectedly different. A minor occurrence of veins striking N25°E does exist, however, in the northeast section of the pit (Figure 13). Fracture densities,

Figure 13 Distribution of Stage I vein orientations within the Brenda pit. Strike and dip of major concentrations are heavy lines, and minor (questionable) concentrations are light lines. (Schmidt net used for construction)

Primary orientation is N62°E, dip 78°SE. N indicates the number of observations in each sector. Dotted line indicates approximate pit outline as of August, 1971.

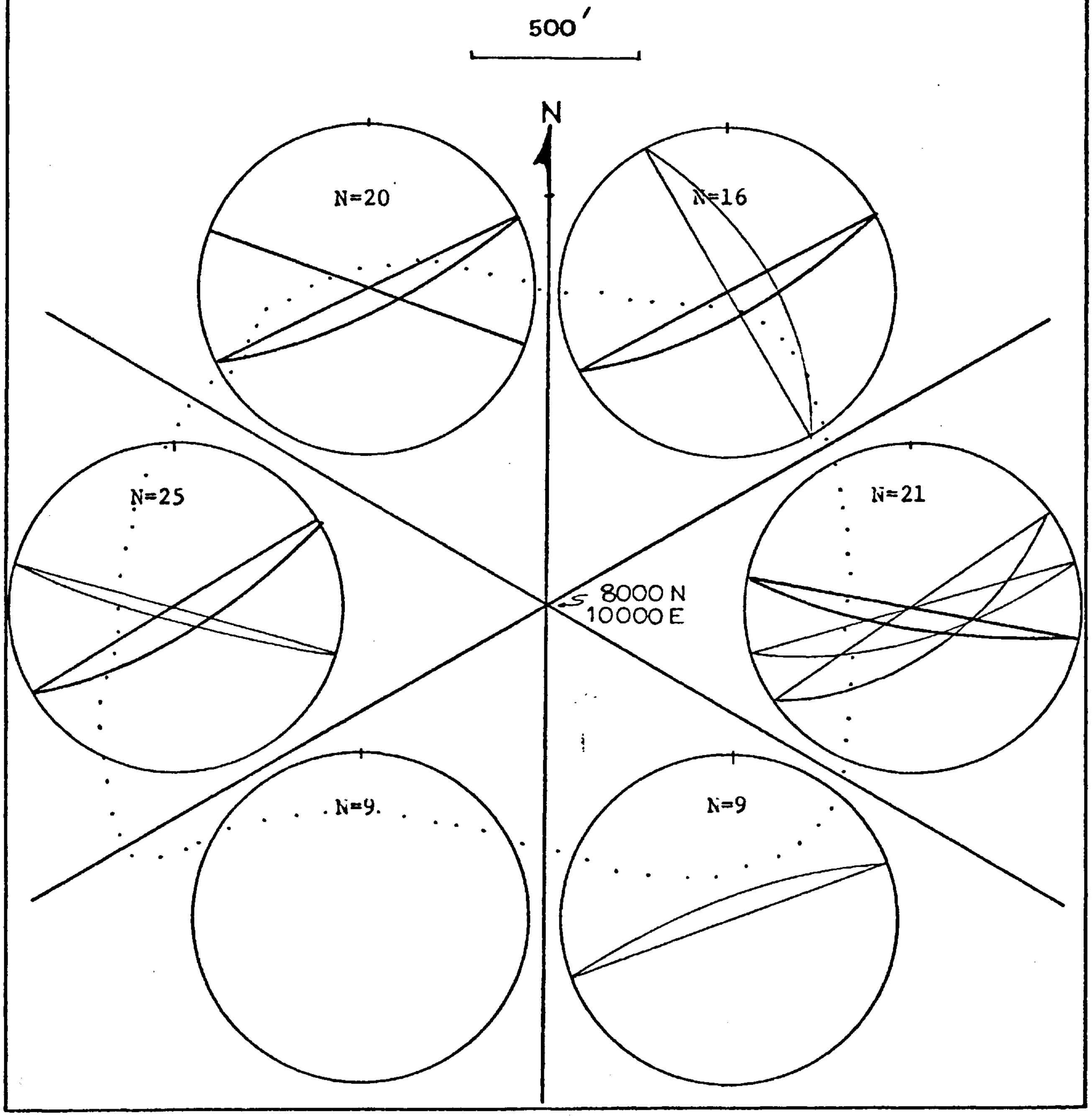


Figure 14. Stage I vein (biotite) offset by Stage II vein.

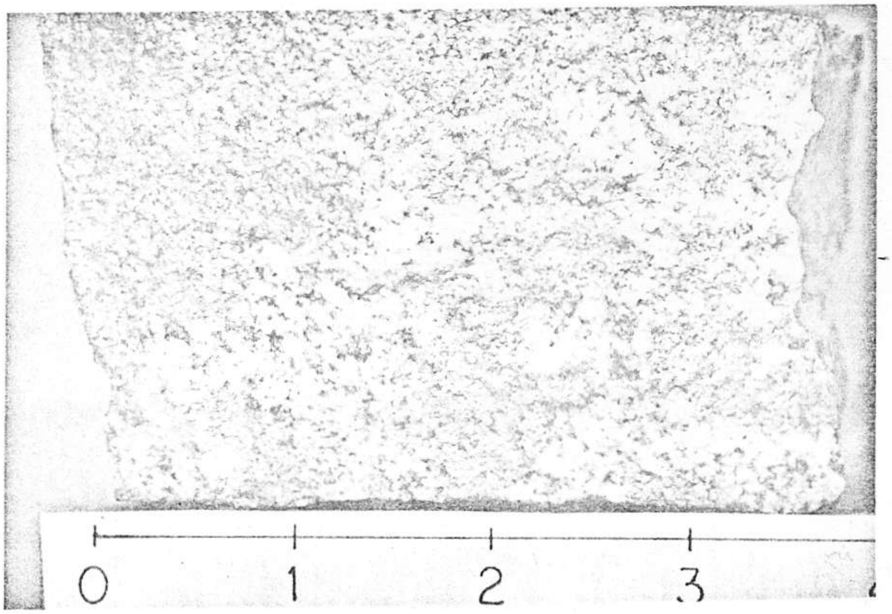


Figure 15. Surface of typical Stage II ore vein containing quartz, potassium-feldspar, chalcopyrite, molybdenite and pyrite.

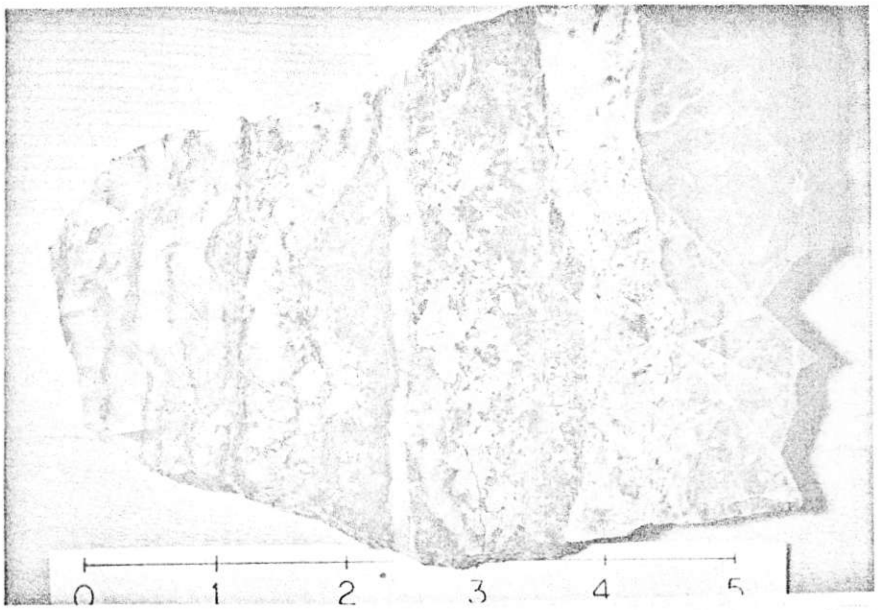


Figure 16. Large banded Stage III vein (quartz-molybdenite) chalcopyrite and pyrite stringers crosscut thin molybdenite bands. Calcite vein runs parallel to banding.

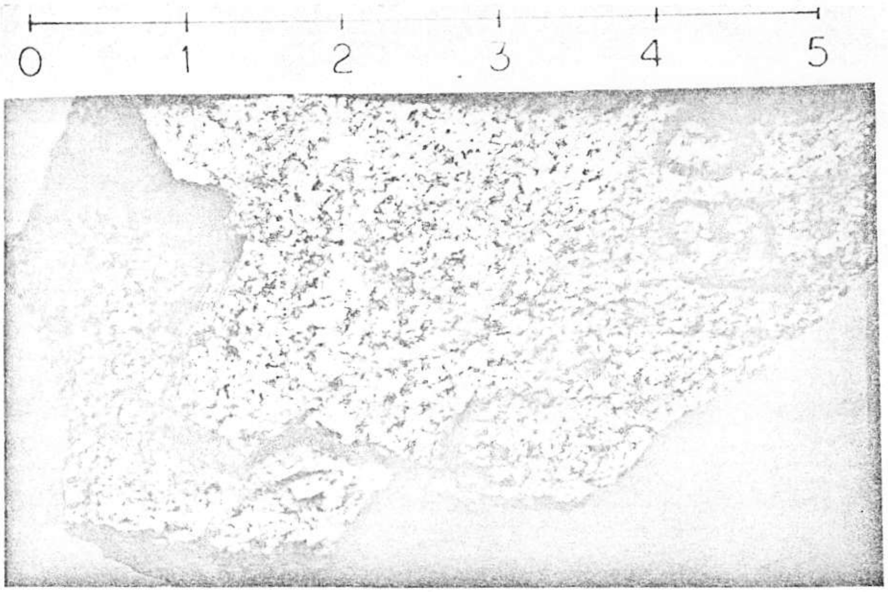
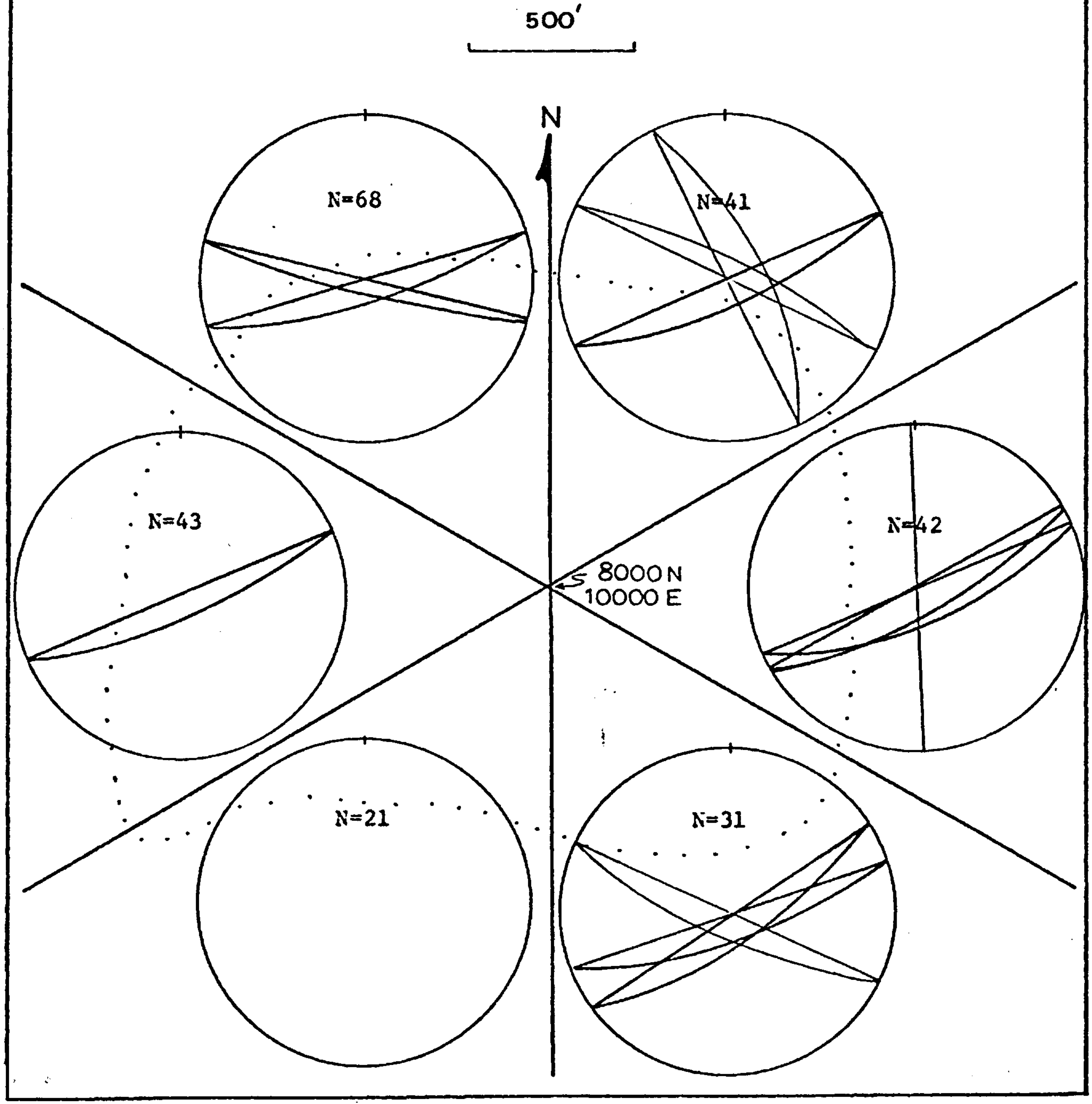


Figure 17. Irregular Stage IV vein (clinozoisite) intersecting Stage II vein.

Figure 18 Distribution of Stage II vein orientations within the Brenda pit. Strike and dip of major concentrations are heavy lines, and minor (questionable) concentrations are light lines. (Schmidt net used for construction)

Primary orientation is N66°E/78°SW. N indicates the number of observations in each sector. Dotted line indicates approximate pit outline as of August, 1971.



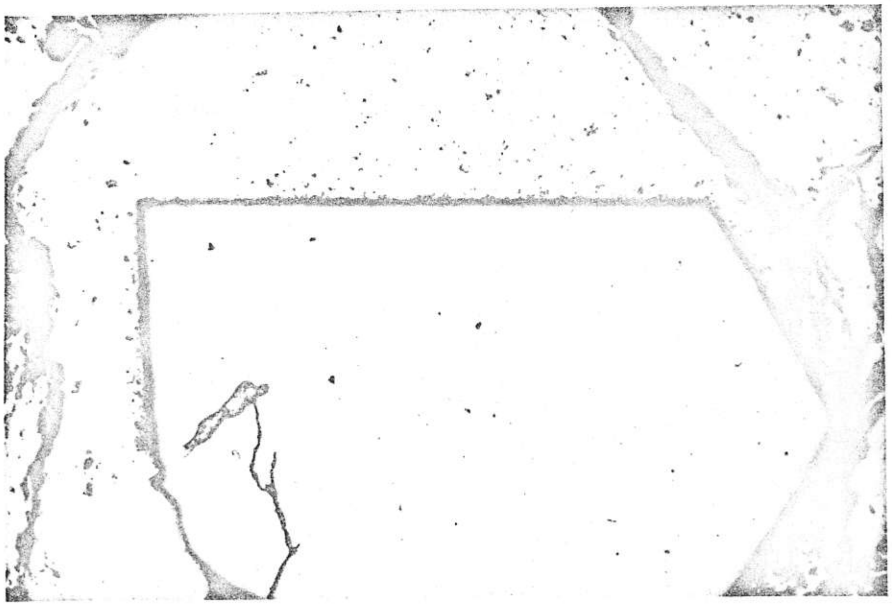


Figure 19. Euhedral pyrite in chalcopyrite. Stage II vein (X5).

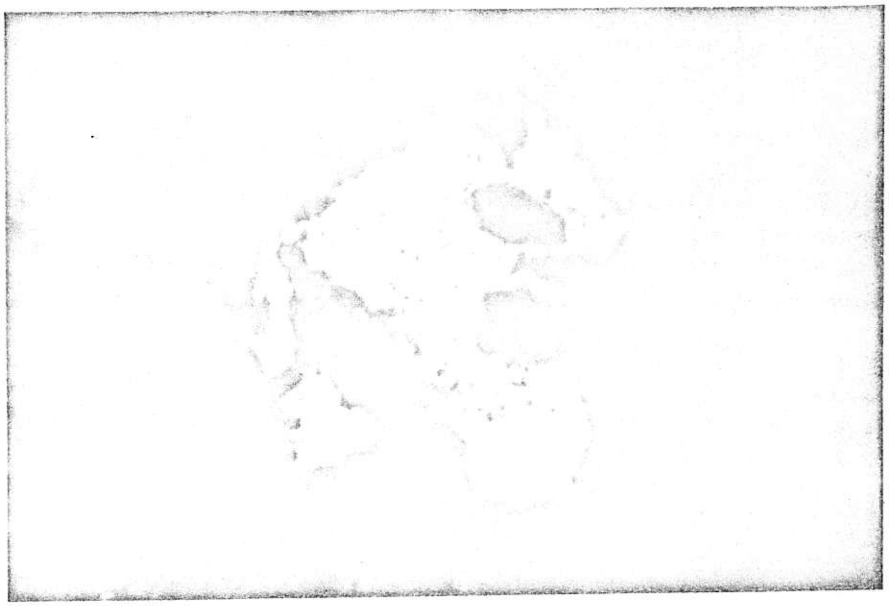


Figure 20. Bornite with chalcopyrite. Stage II vein (X40).

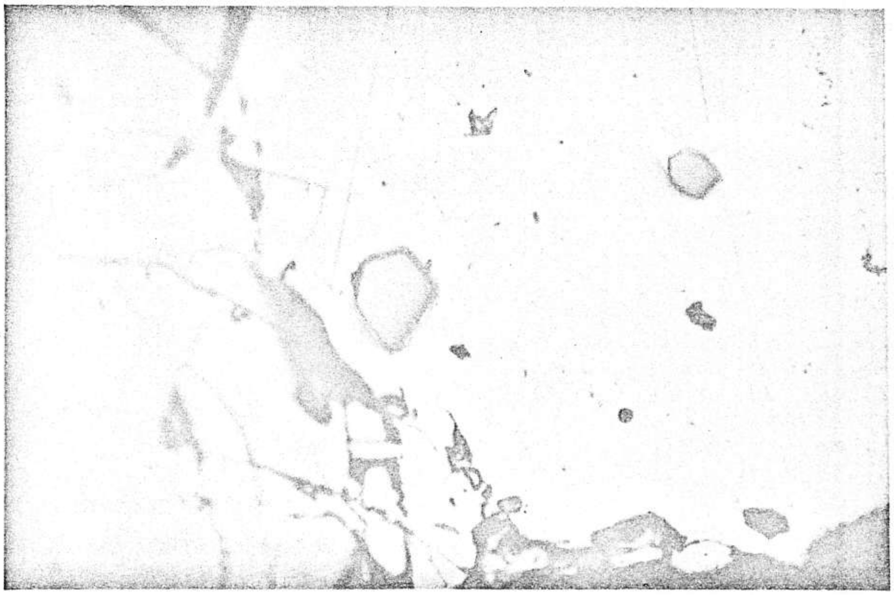


Figure 21. Euhedral magnetite crystals in chalcopyrite. Stage III vein (X20).

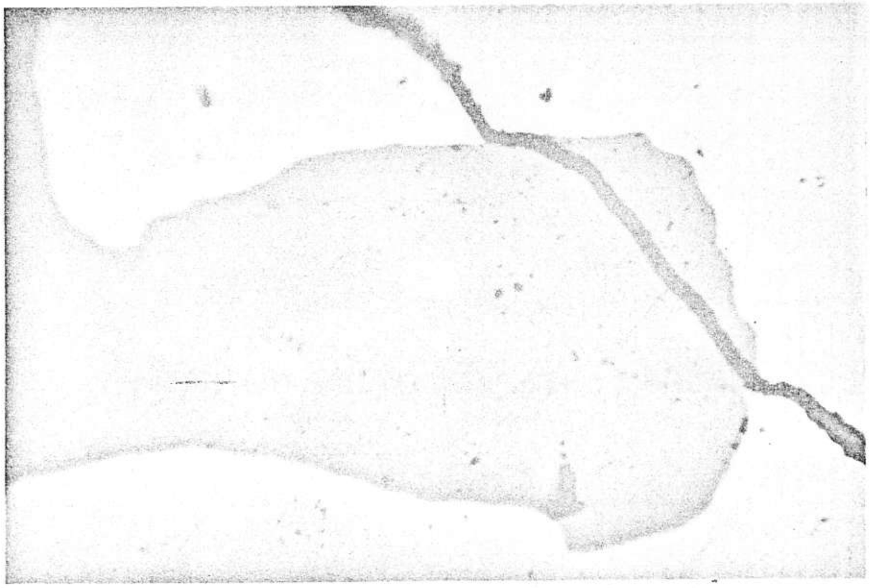


Figure 22. Sphalerite in chalcopyrite with possible exsolution of chalcopyrite within the sphalerite (X40).

23. Fracture pyrite of Stage III vein apparently infilled with chalcopyrite. Vein was located in a shear zone (X5).

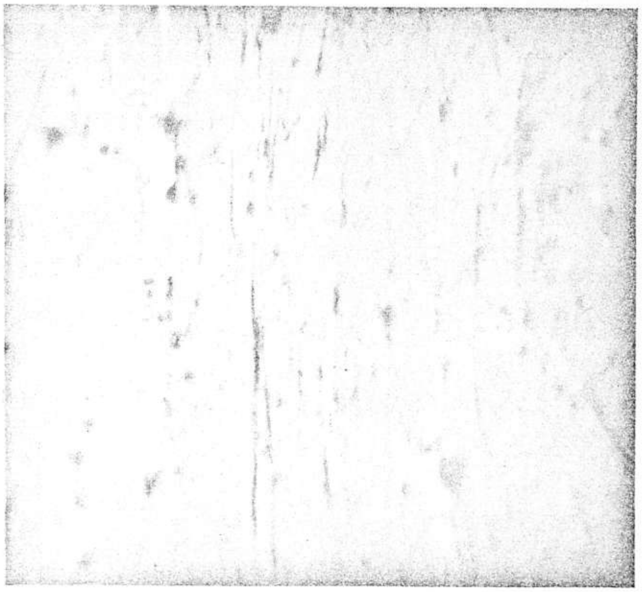


Figure 24. Molybdenite containing wedges of chalcopyrite (x40).

measured in terms of number of fractures per yard, are commonly high. Due to their extremely small size, many density counts were only best guesses based perhaps on a few inches or a foot of exposed rock. Even with good exposure, many were not visible unless accidentally broken along their plane. Blasting dust also obscurred veins making accurate counts and measurements difficult. Due to this difficulty, the writer cannot be certain if Stage I veins are more abundant in one locality than another in the mine.

STAGE II VEINS

Quartz-potash-feldspar veins are distinctly later than biotite veins and constitute a second separate phase of sulfide mineralization. They are the most important source of ore, probably accounting for close to 80 percent of all sulfides. The reasons are: larger size veins, greater amounts of chalcopyrite and molybdenite in individual veins, and greater abundance of the veins, especially near the core of the deposit.

Vein thickenesses range from 1/8 inch to rarely 1&1/2 inches wide. The average size is about 3/16 of an inch. Generally sulfides comprise 10 to 30 percent of the vein space, but locally reach 100 percent.

Mineralogy

Abundant hypogene sulfides are chalcopyrite and molybdenite. Magnetite, hematite, and bornite appear less commonly as hypogene minerals in Stage II veins. Most veins are closed. Open vuggy veins occur more commonly near the higher grade mineralized zones but possess exactly the same mineralogy and vein characteristics.

The bulk of the veins are filled with quartz unless sulfides are abnormally abundant. Early quartz is invariable anhedral . forming grains as large as 3/8 inch. Rarely quartz has formed doubly terminated crystals exceeding an inch in length and embedded in chalcopyrite.

Potash-feldspar forms euhedral to subhedral crystals up to 1 cm wide projecting into the quartz along the vein walls. It also forms as alteration of wall rock that will be considered in more detail in a subsequent chapter. Disseminated chalcopyrite and pyrite occur rarely where the potassium alteration is particularly intense.

Small euhedral crystal aggregates of clinozoisite (identified by x-ray) are found sporadically upon quartz or chalcopyrite. They rarely have lengths of one inch, although most are much less than a centimeter long, commonly with a very fine-grained, anhedral layering. They are for the most part very late in paragenetic sequence.

Molybdenite is generally the first mineral deposited, either along the walls or as scattered, small blades in the quartz. Locally small stringers of molybdenite cut chalcopyrite. Grain size depends to a large extent on the total amount of molybdenite in the vein. Most blades are less than 1 mm to 1 cm wide. Molybdenite might be found in contact with any of the other minerals; and contrary to previous thought, much of it contains intimately, admixed chalcopyrite, and less commonly pyrite and bornite. Disseminated molybdenite is uncommon but is found rarely in intense hydrothermal biotite halos adjacent to mineralized veins (Figure 29).

Chalcopyrite is equal to or in greater proportion than molybdenite. Normally it is paragenetically later than molybdenite, forming in the center of veins. Blebs of chalcopyrite occur scattered over the vein walls, not interconnecting unless unusually high grades of mineralization are present (Figure 15).

Where chalcopyrite and molybdenite are in contact, the molybdenite is replaced in part along (cleavages) planes or between individual plates. These small wedges or laths are intimately mixed with molybdenite and commonly are as small as one micron (Figure 24). Pyrite is in places corroded by chalcopyrite. Fractures within pyrite grains are generally filled with chalcopyrite. Small laths and wedges of pyrite in molybdenite also occur but with less frequency.

Other veins show opposite relations. Pyrite in some veins forms euhedral cubes and pyritohedrons in chalcopyrite, which are often found in associations with euhedral epidote and doubly terminated quartz crystals, all embedded in masses of chalcopyrite (Figure 19). No specific orientations for this latter association of euhedral crystals was found. However, all were found close to high grade mineralization.

Bornite and sphalerite are less abundant constituents. Bornite is seen only rarely in hand specimens, but mostly occurs as very minute replacements along fractures in and along grain boundaries of chalcopyrite. It is generally less than 1/10 to 1/50 mm. Sphalerite has been seen only in polished sections in association with chalcopyrite. It occurs as rounded blebs or stringers up to one mm in diameter on the margins or in the interior of chalcopyrite. Extremely minute dissiminated grains of chalcopyrite within sphalerite give the appearance of exsolution textures (Figure 22).

Pyrrhotite has been reported previously to occur in association with chalcopyrite and pyrite; presumably in Stage II veins (Vogan, 1966). The writer, however, has studied many polished sections and has failed to observe any pyrrhotite. As far as the writer knows, pyrrhotite has not been reported since 1966; and then it possibly was misidentified.

Structure

The predominant strike and dip of Stage II veins (taken from stereogram plots of poles to planes for 251 attitudes) is N66°E/78°SW, and remains relatively persistent throughout the mine (Figures 12b and 18). An exception is the young vuggy veins which strike mostly N0° to 10°W and dip vertically. These are few in number and occur mostly towards the center of the orebody. They have also been observed by Soregaroli (1971) who noted a second orientation about N30°-45°E15°-25°NW. The writer has not found a significant concentration in this range for the vuggy Stage II veins, however.

Densities of veining range from 5 to 15 fractures per yard along the periphyry to about 70 per yard and occasionally well over a hundred per yard near the center of the orebody. A definite zoning of the fracture density of quartz-potassium-feldspar veins is the main control of ore grade. This aspect is discussed further in the following chapter.

Minor offsets occur here and there, but most were observed in blast debris; hence, true offset is mostly indeterminable.

Because of the steep dips of all fractures, it is most probable that movements were strike-slip since a large amount of movement is required for the same throw if dip-slip movement occurred rather than strike-slip. Maximum offset is normally less than one inch.

STAGE III VEINS

The youngest ore veins at the mine are large quartz veins. Although not nearly abundant as earlier veins, they enhance the higher grade ore due to their larger widths and greater sulfide content. Size, properties of the quartz, and lack of potassium feldspar typically characterize and distinguish Stage III veins. Vein width averages one to two inches,although they can be as small as 1/2 an inch or rarely as large as 14 inches.

Mineralogy

Hypogene ore minerals include molybdenite, chalcopyrite, pyrite, magnetite and sphalerite. Bornite has not been observed in these veins to date. Gangue minerals are normally quartz and minor amounts of calcite. Hematite occurs in small amounts associated with calcite. Any of the sulfides can occur singly or in combination with others and in widely variable proportions. Banding of the quartz and sulfide(s) might or might not be present.

Banded quartz-molybdenite veins consist of 1/4 to 3/4 inch repetitious layers of quartz separated by thin lacy molybdenite covers (Figure 16). The quartz is generally greyish due to disseminated molybdenite, though this is less common. Books of subparallel molybdenite are as large as 1/8 inch, but normally do not exceed 1/16 of an inch in greatest dimension. Chalcopyrite and pyrite commonly are minor constituents forming irregular blebs of various sizes and tiny, locally-crosscutting veinlets, indicating they are probably paragenetically later than molybdenite. Pyrite forms both as striated euhedral cubes and anhedral grains. Cube edges commonly are less than 1/8 inch but can be as large as 1/4 inch.

Less commonly, the banded vein consists of chalcopyrite with molybdenite confined to the very earliest outer margin of the vein. Although there is a change in the predominant sulfide, the shape and structure is similar to the banded quartz-molybdenite veins.

A second type of Stage III veins is massive quartz-chalcopyrite or quartz-pyrite vein. The writer does not intend that a genetic difference be implied in this distinction - only a textural and mineralogical difference. All other features dictate the same system of mineralization. Chalcopyrite and pyrite occur as massive lodes in the vein or as smaller blebs scattered among the quartz. Molybdenite is normally missing or in subordinate amounts confined to the walls of the vein. Either chalcopyrite or pyrite can be the most abundant sulfide. Pyrite forms many euhedral, striated cubes with edges up to one inch long. Where present with chalcopyrite, most pyrite is situated along the margins of the vein. Locally, magnetite forms large veins with minor amounts of pyrite up to two inches wide. Euhedral magnetite grains massively packed together have maximum widths of 1/8 inch. Some of these veins have a larger amount of sphalerite (in the chalcopyrite) than previous stages. These veins are more rare and are grouped with Stage III veins due to their size and similarity of occurrence in the host rock. Most magnetite, where present, is less than one or two percent of the metallic content of the veins (Figure 21). Several samples of whitish "pyrite" were x-rayed to test the possibility they might be marcasite; all proved to be pyrite.

Structure

The predominant vein attitude is N67°E/77°SE - defined by a 20 percent concentration of poles to planes. A secondary concentration occurs at N76°W/86°SW (Figure 12c).

Stage III veins are never densely spaced unless directly adjacent to a shear zone. In the core of the pit, densities reach one to two per yard though not consistently. Shears have been observed to transect these quartz veins but also may be unaffected by some. Offsets resulting from the development of the shears have not been observed by the writer. Similarly, offsets have not been observed due to the formation of the quartz veins. However, in a few places lensing of the quartz veins forms a sigmoidal shape. The similarity in orientation between vein stages suggests a similar structural origin.

STAGE IV VEINS

The fourth stage of mineralization consists of numerous veins and fractures that fall into four convenient types; clinozoisite veins, biotite veins, quartz veins, and calcite veins. All except a few of the early clinozoisite veins are post ore and intersect all previously described veins and intramineral dikes. It is possible that a hiatus is present sometime after the ore veins and before the Stage IV veins except epidote. Biotite veins are the most numerous and were at first mistaken for Stage I biotite veins as discussed earlier. They are quite thin, often discontinuous, not persistent, and difficult to observe unless the rock was fortuitously broken along one of the fractures. Minor amounts of sulfides are present especially where the veins intersect mafic dikes. Chalcopyrite, pyrite and hematite have been observed in Stage IV veins in generally snbordinate amounts. Minor quantities of molybdenite have been observed in a few veins - especially clinozoisite veins.

Epidote veins (confirmed by x-ray to be clinozoisite) are for the most part insignificant in both number and sulfide content. Vein widths range from as small as 1/32 of an inch to 4 inches. Normally they are present as irregular 1/8 inch veins of finely granular anhedral clinozoisite (Figure 17). In the larger veins chalcopyrite, molybdenite, magnetite, (± hematite), and pyrite might be present in greatly varying amounts and grain sizes. The most common assemblages of the larger veins are chalcopyrite-pyrite, chalcopyrite-molybdenite-pyrite, magnetite-pyrite, and magnetite alone. All except chalcopyrite occur either as anhedral or euhedral crystals and crystal aggregates. Small anhedral grains of quartz can be interspersed among the epidote but never in amounts greater than 10 percent of the vein. Paragenesis of the sulfides is indeterminable by the writer, but it is likely that overall mineralization follows the pattern established for the preceeding two stages.

Only 23 epidote veins were measured in the pit, insufficient data to give any concentration when plotted on a stereogram. Offset along these veins has not been observed. Soregaroli (1971) has observed "Epidote-magnetite-molybdenite veins which strike N45-55°W with vertical dips".

Clinozoisite veins are grouped in the fourth stage of mineralization but are in part contemporaneous with earlier veins. The larger veins are thought to be concurrent with the last phases of Stage III mineralization because the sulfide assemblages are similar, and the rare large lenses of sulfides are associated in space with some late Stage III quartz veins. The larger veins also show strong hydrothermal biotite envelopes very similar to Stage III alteration. Field observation has shown that the smaller veins and veinlets are younger than mafic dikes and hence are post ore. A possible mineralization hiatus might be present between the third and fourth stages of mineralization, although other structural features tie them together.

Biotite veins similar to Stage I biotito veins are approximately 1/32 inch to 1/16 inch but do not contain sulfides. For the most part, they are merely coatings of a dark brown felted mass of hydrothermal biotite on fracture surfaces. They are by far the most numerous veins of this stage. Rarely pyrite and/or chalcopyrite occurs as isolated irregular blebs less than 2 mm long.

Small quartz veins, 1/4 inch or less in width, crosscut all previously mentioned mineralization. These are few in number and contain no related potash-feldspar, biotite or other alteration minerals. In places they contain euhedral pyrite or minor amounts of anhedral chalcopyrite. Sulfides are rare and were observed only where crossing post-ore dikes. They do not appear in any way related to ore veins. In one case a vuggy, though unmineralized quartz vein, was observed crosscutting the trachyte dike.

Calcite veins are numerous though small in size. They fill in most reopened fractures of all ages and form their own veins, commonly 1/8 inch wide and rarely two to three inches. Hematite is ordinarily the only opaque mineral in these veins. It is thought to be disseminated among the calcite, producing a black-brown to orange tinge. Positive identification of the calcite coloration was not possible due to the extremely fine-grained and dispersed nature. Rarely crystalline ferroan dolomite has been found to fill open fractures at a very late stage.

Specular hematite has, at rare localities, filled small 1/16 inch fractures. Their exact relation to other veins is unknown.

A single barite vein, one to one and one-half inches wide, occurs in the northwest margin of the pit. The margins of the veins were brecciated with quartz diorite fragments from 1/2 inch to one inch in size. This is the only observed occurrance of barite in the pit. It is in an area of hydrothermal biotite alteration, but the vein itself was found loose in the muck; and the writer was unable to locate its outcrop.

Structure

Fourth stage veins (dominantly biotite veins) are similar in attitude to the previous veins. High concentrations on the Schmidt net are N66°E/80°SE and N64°W/89°SW (Figure 12d). Greater scatter of attitudes exists among these veins than in other vein systems; possibly because they are late and formed in a more complicated environment than ore fractures. But a consistent change in attitudes relative to location in the pit cannot be determined. The fracture density of the biotite veins in places appears high, but a precise count was not always possible. Calcite and quartz veins are most numerous around dikes and peripheral to shear zones.

SECONDARY MINERALS

Secondary minerals observed include ferrimolybdite, limonite, malachite, azurite, chalcocite, native copper, powellite, cuprite, cupriferous manganese oxides, and ilsemanite. Tenorite and covellite have also been reported by earlier workers (Soregaroli, 1971).

Limonite is the predominant secondary mineral, forming in weathered rock that extend rarely to depths of 90 feet below the surface. The average weathered zone where limonite forms is less than 20 feet thick. Greater depths of weathering and hence of limonite formation are found locally in shear zones. Limonite forms as thin, brown coats and in some cases as boxwork replacement of pyrite and chalcopyrite. X-ray analyses did not reveal any goethite.

Ferrimolybdite, an alteration product of molybdenite, is uncommon at Brenda and has been identified by the writer in only two samples. Samples were, however, more easily observed when early stripping of the cap rock was taking place (Soregaroli, personal communication). One sample was found in a one inch quartz-chalcopyrite-pyrite vein located a mile northeast of the mine. The other was found at the tailings dam and was presumed to have been hauled from surface muck obtained at the pit. Favorable conditions for the formation of ferrimolybdite require a low pH on the order of 1.5 to 4. The absence of significant amounts of pyrite and a cold climate both could be responsible for the overall scarcity of this alteration product.

One small specimen of native copper was observed in a late vuggy calcite vein.

Malachite and azurite have been found as thin encrustations along joints or fractures in the uppermost exposed section near the surface. In places the encrustations are 1/8 inch thick, but normally they are much thinner. Malachite is more abundant than azurite.

Neglegible supergene enrichment is recorded in Brenda deposit. Admittedly, however, it is only a single occurrence. In a single location,sample #4-3 of bench 5060 located near the surface of the old stream which transversed through the center of the pit, sooty chalcocite was confirmed as a thin coating on pyrite and chalcopyrite grains along a Stage II vein. A layer of chalcocite one to three mm thick in places almost completely replaces 1/2 cm chalcopyrite and pyrite grains. The extent of this supergene enrichment is limited to only a few yards near the former streambed where this particular vein is exposed. Pyrite and magnetite, it should be noted, form as much as 20 percent of this vein; and

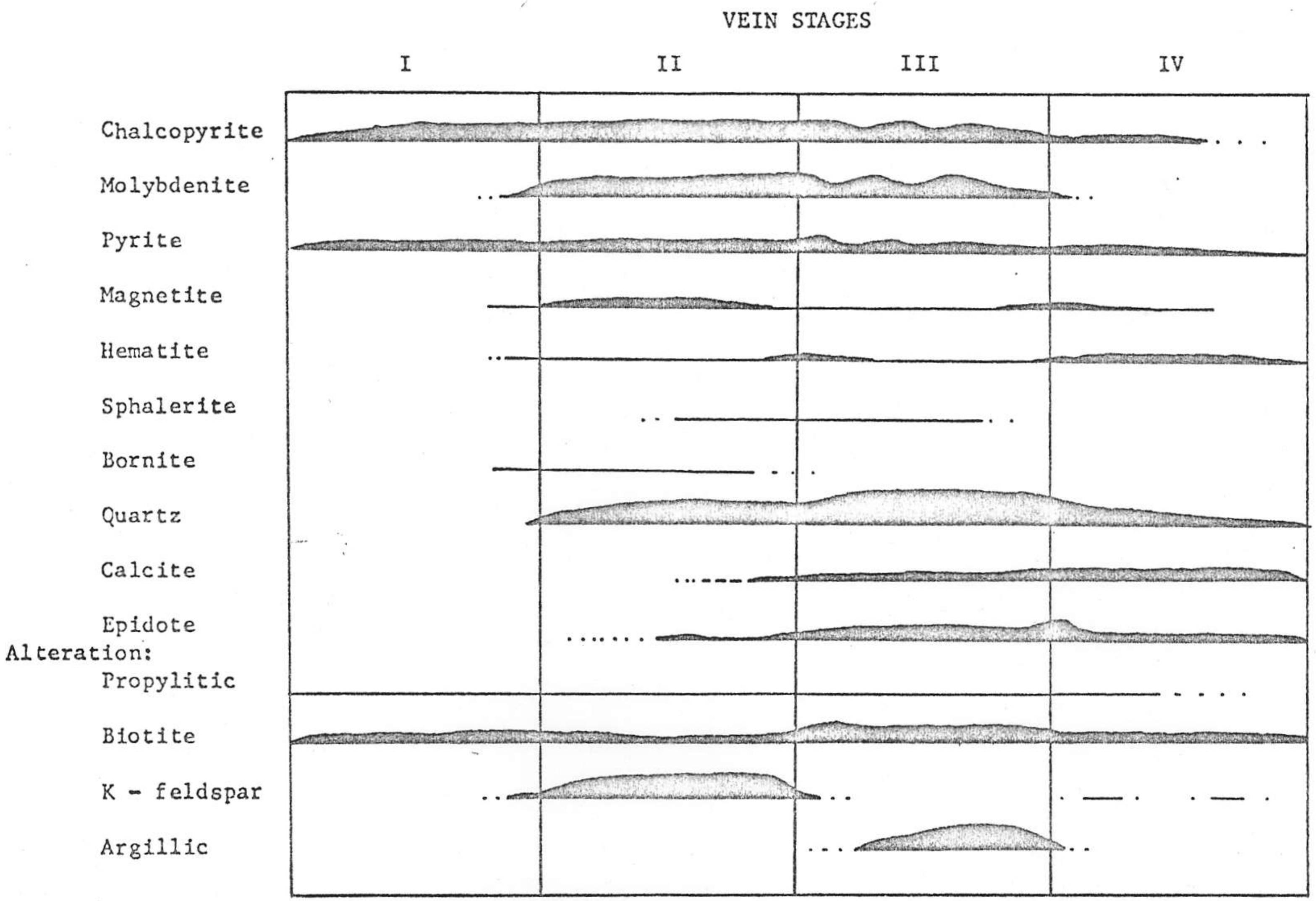


Figure 25. Line diagram of mineralogy of vein systems. The thickness of the lines indicates general relative abundance of the minerals.

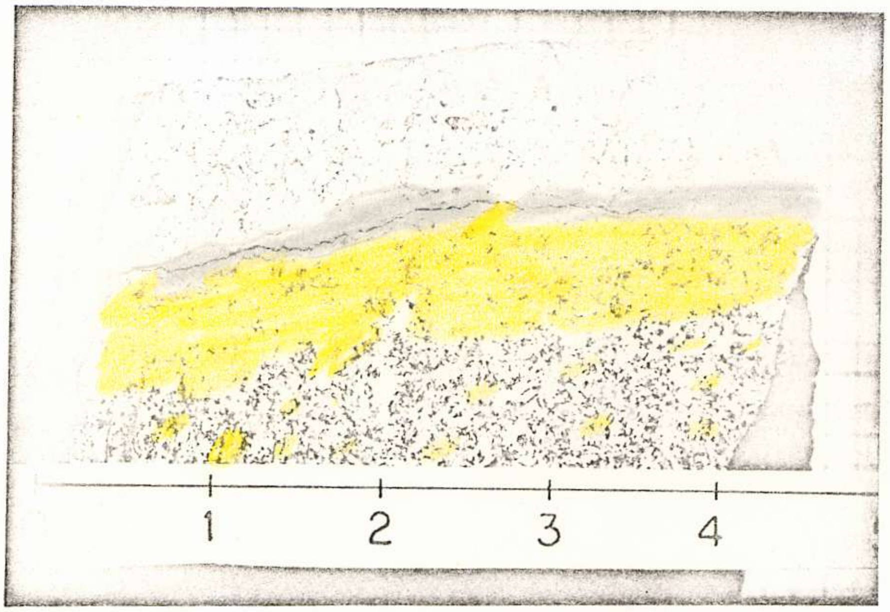


Figure 26. Extremely large Stage II vein showing potassium-feldspar alteration (stained).

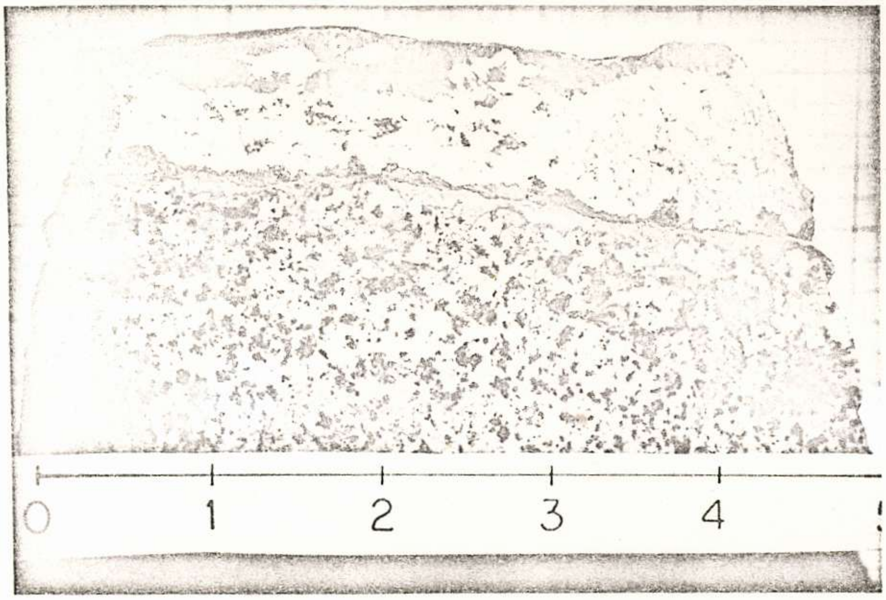


Figure 27. Same vein as Figure 26 although not stained. Note greenish propylitic aleration beyond potassium-feldspar envelope.

Figure 28. Stained Stage II vein showing euhedral potassium-feldspar along vein walls grading into wall rock potassium-feldspar alteration.

Figure 29. Biotite alteration along Stage III vein. Note the disseminated molybdenite in the biotite.

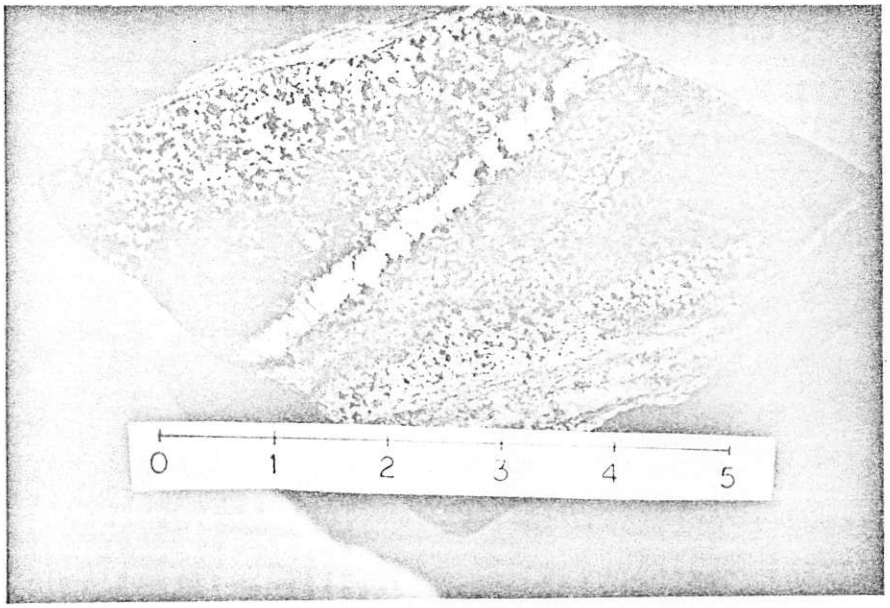


Figure 30. Biotite alteration along Stage III quartz-pyrite vein. Biotite envelope overlaps and destroys alteration of previously emplaced Stage II vein.

Figure 31. Potassium-feldspar and hydrothermal biotite alteration envelopes about a Stage II vein.

pyrite is in great abundance in an 8 inch quartz-pyrite vein immediately adjacent. Hence, many of the conditions appear to have been combined fortuitiously for this rare supergene occurrence.

HYDROTHERMAL ALTERATION

Hydrothermal alteration in the Brenda ore body has been described in more or less general terms by several previous workers (Vogan, 1966; Carr, 1967; and Soregaroli, 1968 and 1971). While differing significantly from the first two authors, the writer's alteration study is in agreement with the types of alteration presented by Soregaroli (1968 and 1971). These types are 1) potassium alteration, 2) propylitic alteration, and 3) argillic alteration. The first two types form as narrow envelopes about Stage I and II veins, while argillic alteration is associated with Stage III veins in zones up to 35 feet wide and several hundreds of feet long. Although searched for dilligently, a spatial pattern of alteration, other than the small envelopes about ore veins, could not be found. Concentric zoning of alteration types, for example, does not exist as far as the writer has been able to determine. Soregaroli (1971) indicates the presence of hydrothermal biotite in a zone extending to the northeast beyond the ore body.

Potassium alteration consists of two types: potassium feldspar (chiefly orthoclase) and hydrothermal biotite. Potassium feldspar mostly forms thin envelopes around Stage II veins (Figures 26, 27, 28, and 31). Generally the feldspar is confined to growth along vein walls but can form envelopes in the wall rock up to 8 inches wide replacing plagioclase in the host rock. Occasional mica and kaolinite have been seen replacing mafics and some feldspar.

Where large amounts of potassium feldspar are introduced, the hydrothermal biotite content also increases and forms plates up to 1/4 inch diameter admixed with the feldspar. A secondary envelope of hydrothermal biotite might also develop around the feldspar envelope before grading into propylitic alteration. Although hydrothermal potassium feldspar is associated with the most important ore veins (Stage II), the amount of potassium feldspar does not appear to be related to the amount of sulfides present.

Hydrothermal biotite, often a green biotite under the microscope, occurs in all stages of vein formation. Only in the second stage is it less developed. In the first stage of mineralization, it forms felted black coatings as described earlier. Rarely is it visibly developed into the wall rock adjacent to the vein. In second stage veins it is less developed but can form a thin envelope; generally less than 1/8 inch and difficult to observe. Macroscopically, it can be recognized by its greater abundance and its fine-grained nature compared to normal host rock biotite. It also may be admixed with orthoclase as mentioned earlier or form a secondary envelope about the potassium feldspar alteration (Figure 31).

Third stage veins also contain abundant biotite and generally little or no potassium feldspar. Commonly, alteration is so complete that hydrothermal biotite forms more than 50 percent of the rock. This envelope can be several feet wide in some places, while elsewhere it is less than one inch wide. Rarely dissiminated sulfides are present in the biotite envelope (Figure 29).

Stage IV alteration consists of biotite filled fractures similar to Stage I veins and envelopes of biotite a few inches wide around large epidote veins which are generally few in number. In all cases biotite and potassium feldspar grade outward into propylitic alteration.

Propylitic alteration is a term used to describe a weak alteration effect forming thin envelopes adjacent to potassium alteration along veins. Where vein densities are extremely high, pervasive propylitic alteration might be present, though not necessarily. Epidote and minor amounts of chlorite are characteristic alteration products of the propylitic zone. Epidote commonly forms in the cores of plagioclase crystals, and occassionally muscovite appears in the assemblege. Megascopically, the plagioclase appears slightly greenish and waxy textured.

Thin white albitized veinlets occur rarely, but their exact relationship to other alteration types has not yet been determined. Indeed, they are possibly late weathering alteration unrelated to ore vein alteration.

Argillic alteration occurs in large widely spaced planar zones, generally a light tan or brown in color (Figure 8). Stage III veins are always associated, and shearing is generally present. X-ray analyses of clay fraction of nine alteration zones of various widths and locations show identical assemblages of kaolinite, muscovite and montmorillonite. For an assemblage such as this, Meyer and Hemley (1967) suggest using the term "intermediate" argillic alteration to distinguish it from a more advanced argillic alteration which they also describe.

Although both biotite and argillic alteration are associated with Stage III veins, the writer could not find a consistent spatial

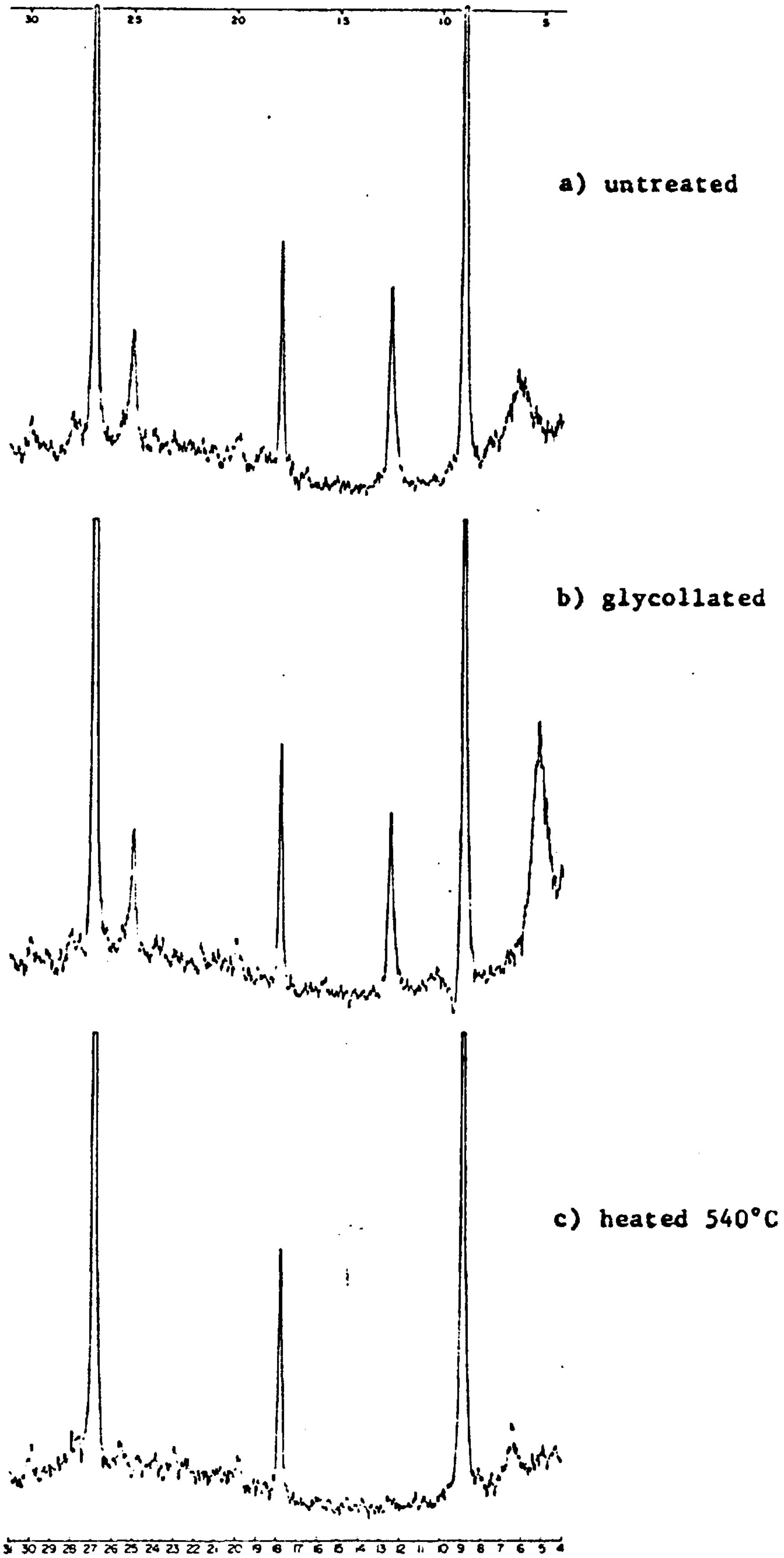


Figure 32. X-ray diffraction traces clay fraction of argillic alteration zone. Kaolinite, muscovite and montmorillonite are dominant constituents. Numbers indicate degrees 2θ. KV = 40, MA = 20.

relationship between biotite and argillic alteration. It appears that only certain Stage III veins (generally two or three per shear zone) are suitable for producing this alteration. Most of the veins in these zones were high in quartz and molybdenum; however, some quartz-molybdenum veins were observed which were not associated with argillic alteration.

Muscovite, much of it fine-grained, occurs throughout the shear zone. In places it might be termed "sericite" alteration; however, because of its extremely rare and inconsistent appearances, the writer believes it does not warrant a separate classification.

SUMMARY

Ore minerals occur almost exclusively in veins at the Brenda ore deposit. These veins have a specific paragenetic order. Ore forming veins are biotite, quartz-potassium-feldspar-sulfide, and quartz-sulfide veins.

Biotite veins are the earliest. They are thin veins containing minor yet consistent amounts of chalcopyrite. Predominant orientation of these veins is N62°E/78°S and N76°W/86°S.

Quartz-potassium-feldspar veins formed later, apparently without a significant time gap separating them from the earlier biotite veins. Concentrated orientations occur at an attitude of N66°E/78°SE. Vein densities increase toward the center of the pit and are the principle "raison d'etre" for high grade ore zones. Average vein width is 3/16 of an inch. Strike-slip offsets are abundant. The ore mineral paragenesis is molybdenite, chalcopyrite, pyrite, magnetite and hematite, although some reversals do occur. Potassium feldspar is the main alteration type usually grading into propylitic alteration. A thin envelope of hydrothermal biotite might also be present.

Stage III veins are large quartz veins containing various sulfides in several combinations. Banded molybdenite veins and massive chalcopyrite veins are the most common. Potassium feldspar is normally absent; however, biotite and argillic alteration are commonly associated. Primary orientations are N69°E/77°SE and N67°W/86°SW. They have in places the form of sigmoidal lenses.

Stage IV veins are post ore and contain no significant concentration of sulfides. They consist of clinzoisite veins, biotite-lined fractures, calcite and quartz veins. Large epidote (clinozoisite) veins overlap in time of formation with late Stage III veins. All other Stage IV veins and fractures are significantly later and probably distinctly separate from the third stage of mineralization. Attitudes are more widely scattered than in other stages of mineralization. A small 10 percent concentration occurs with an attitude of N66°E/80°SE and N64°W/89°SW. Offsets have not been observed by the writer.

All vein systems possess remarkably similar orientations that do not change significantly over the pit area. A slight progressive change in attitude is possibly indicated for Stage I to III veins inclusive; Stage I strike N62°E; Stage II - N66°E; Stage III - N69°E. These small differences, however, might not be real and could result from the relatively small amount of data available. Stage IV veins are more scattered and have smaller concentrations, possibly due to later structural influence in the system long after the ore forming environment had passed.

Hydrothermal alteration is limited to envelopes about veins, except for a few large zones of argillic alteration associated with large Stage III veins. Hydrothermal biotite and potassium feldspar (chiefly orthoclase) form about Stage II veins, while biotite alteration forms in varying degrees about veins in Stages I, II and IV. Propylitic alteration might accompany all stages of veining in varying amounts,although generally it too is limited to envelopes about veins.

CHAPTER V

ZONING

MINERAL ZONING

At Brenda mine it is possible to find a general systematic distribution for abundances of chalcopyrite, molybdenite, and galena, although no such patterns have been recognized for other minerals such as bornite, sphalerite and pyrite. Nor have patterns been found for the abrupt appearance or disappearance of any of the ore minerals. Chalcopyrite and molybdenite zoning results from a change in the density of veins across the ore body.

Copper and Molybdenum

The presence of a central zone of high copper and molybdenum percentages has long been recognized. Because the only significant primary copper and molybdenum minerals are chalcopyrite and molybdenite, the grade distribution is directly related to mineral distribution. Figures 33 and 34 display the zoning pattern for copper and molybdenum grades respectively on the 5210 bench. Cuttings from closely spaced 58 foot deep rotary drill holes were uniformly sampled and analyzed by atomic absorption at the mine. Lines of equal abundance were hand contoured. A distinct, though irregular central zone of higher grades, exists in the center of the ore body. To the west the amount of copper drops quickly in an almost linear zone that coincides roughly with the appearance of large xenoliths of Nicola Group hornfels mapped by the writer. Reductions in copper and molybdenum take place more gradually to

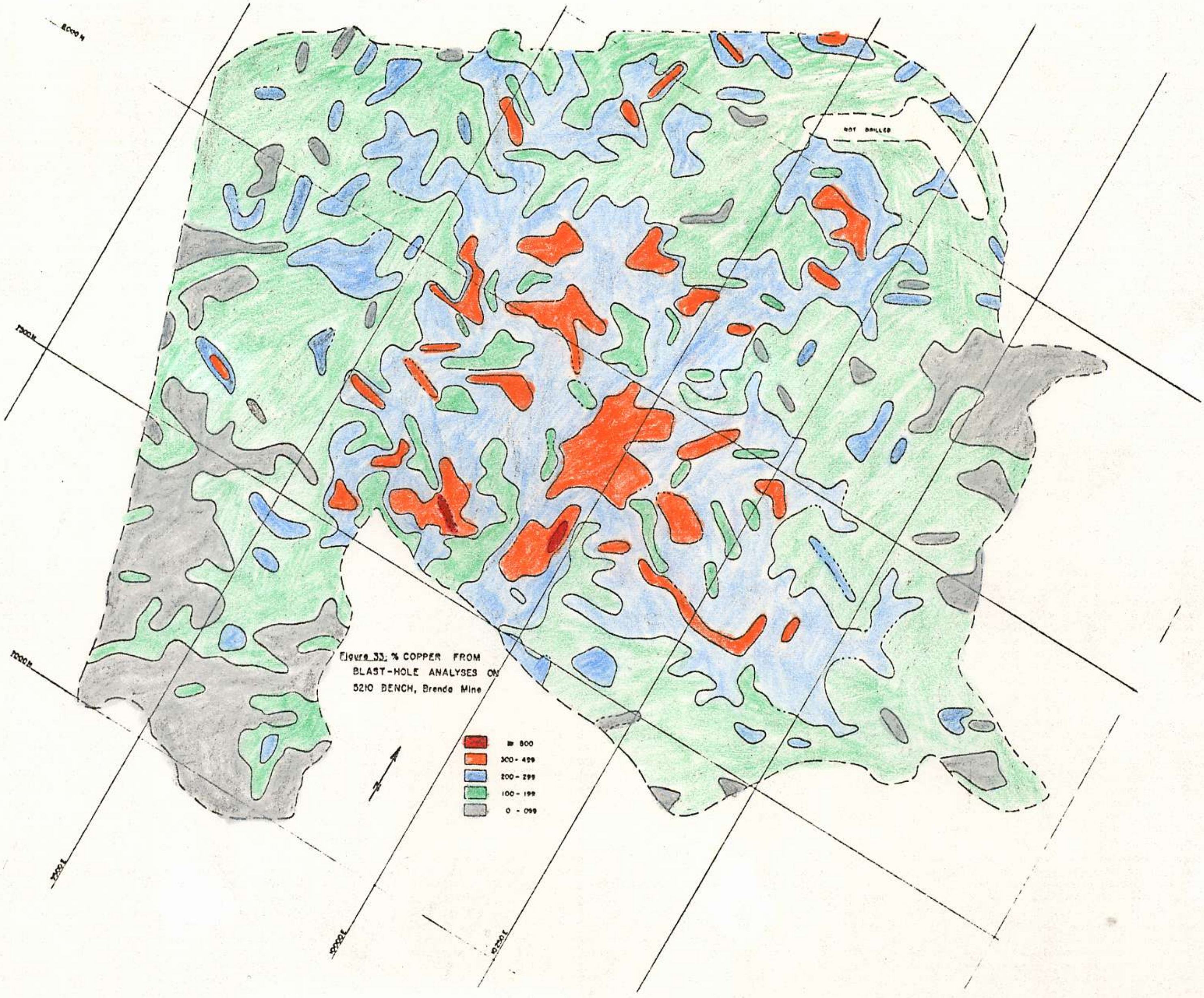


Figure 33: % COPPER FROM BLAST-HOLE ANALYSES ON 5210 BENCH, Brenda Mine

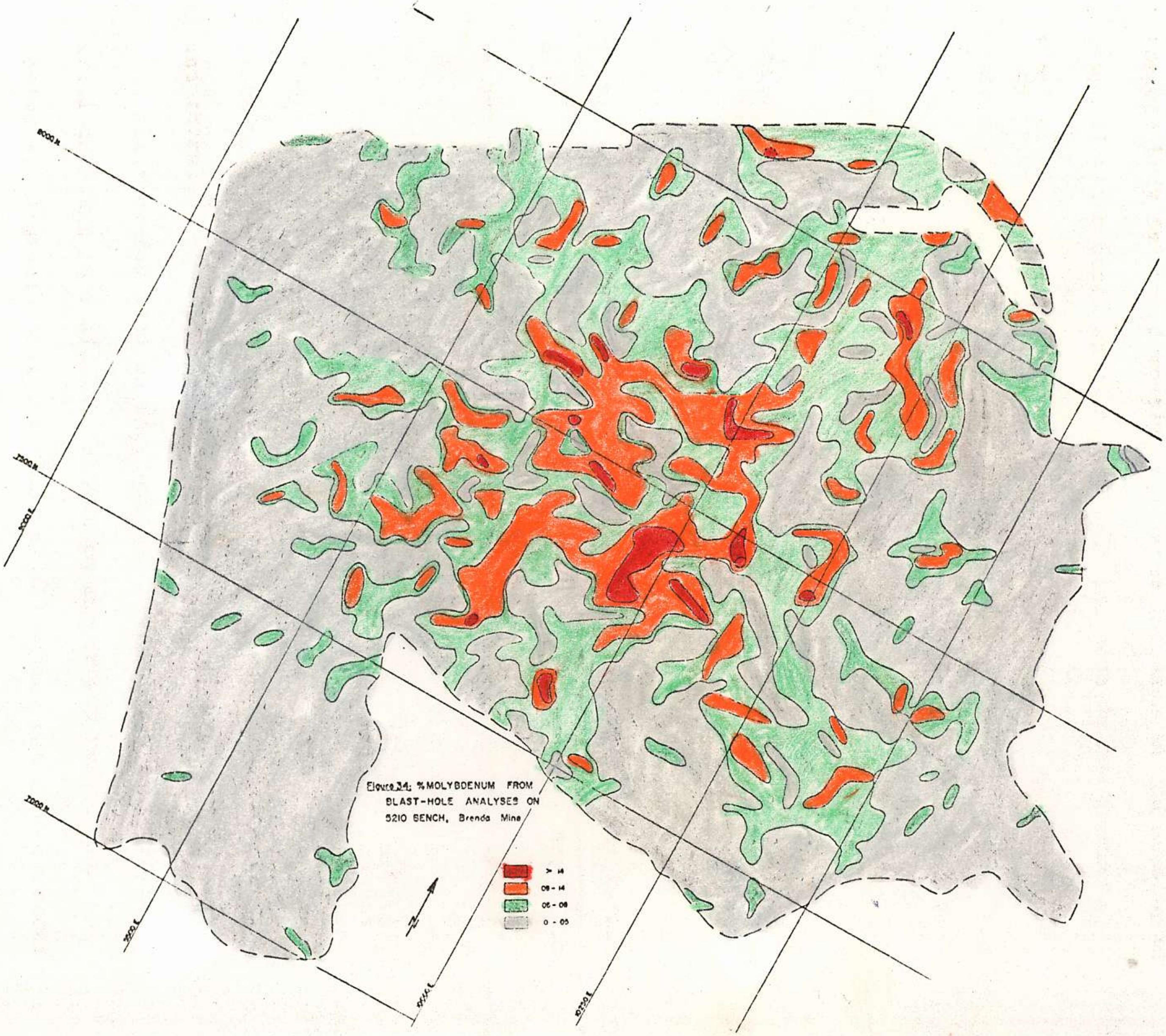


Figure 34: % MOLYBDENUM FROM BLAST-HOLE ANALYSES ON 5210 BENCH, Brenda Mine

the east. The limits of the present pit end in low grade ore on the eastern margin.

The increase of copper and molybdenum assays in the center of the ore body is caused mostly by a large increase in the density of Stage II veins accompanied by a slight increase in the average width of the veins. Stage II veins in the periphyry of the pit average from 5 to 15 per yard; while near the center of the pit, vein densities may be as high as 100 per yard or more in some localities.

In addition, a notable increased variation of attitudes of Stage II veins also occurs in the central part of the deposit. Veins with attitudes between N35°E to N40°W occur more often in areas of higher total grade. The contribution of Stage I and III veins appears to be relatively less important to the zoning in the pit. Indeed Stage I veins seem to decrease in number in the center of the deposit relative to the periphyry.

Lead

To date only a small part of the 5110 bench drill holes has been assayed for lead. Most lead in the mine is less than 0.005 percent, but small isolated patches up to 0.2 percent appear here and there.

Analyses for lead on the 5060 and 5110 bench were performed on drill cuttings in a similar fashion to copper and molybdenum analyses. A statistical treatment of 323 values was done in order to separate possibly distinct populations according to the methods of Tennant and White (1959), Lepeltier (1969), and Sinclair (1972). The cummulative percent frequencies were plotted on cummulative log probability. Examination of the resulting curve suggests that two lognormal populations are represented in the data. Population R forms 90 percent of the total, and Population S forms 10 percent (Figure 35). Recalculation of the values to 100 percent (for each population where not overlapping) defines the distinct end member population (Symbol ● in Figure 35). Because these are two interpreted lognormal populations, it is a useful check to mix the two in appropriate proportions for comparison with the real data. When mixed in the ratio 10 to 90 (for S and R respectively), the resulting curve (Symbol o in Figure 35) is seen to match closely the real data (Symbol X in Figure 35).

The R population, with a geometric mean of 32 ppm, can be interpreted as rock background values contained in K atomic sites in such minerals as potash-feldspar, biotite, and hornblende. The value compares with a world average of 15 ppm in intermediate intrusive rock (Krauskopf, 1967).

The S population probably represents sporadic localities of sulfide lead, for minor amounts of galena have been seen in the mine.

The distribution of these values is shown in Figure 36 . The S or assumed sulfide population occurs as isolated sporadic highs. Since only a limited area of the pit has yet been sampled, interpretation of a pattern is highly uncertain. Possibly fracture density might also relate directly to sulfide lead; and if so, an expected high in the center of the pit should exist. A second possibility is that galena increases away from the center of the deposit; however, present data is too limited to confirm or deny

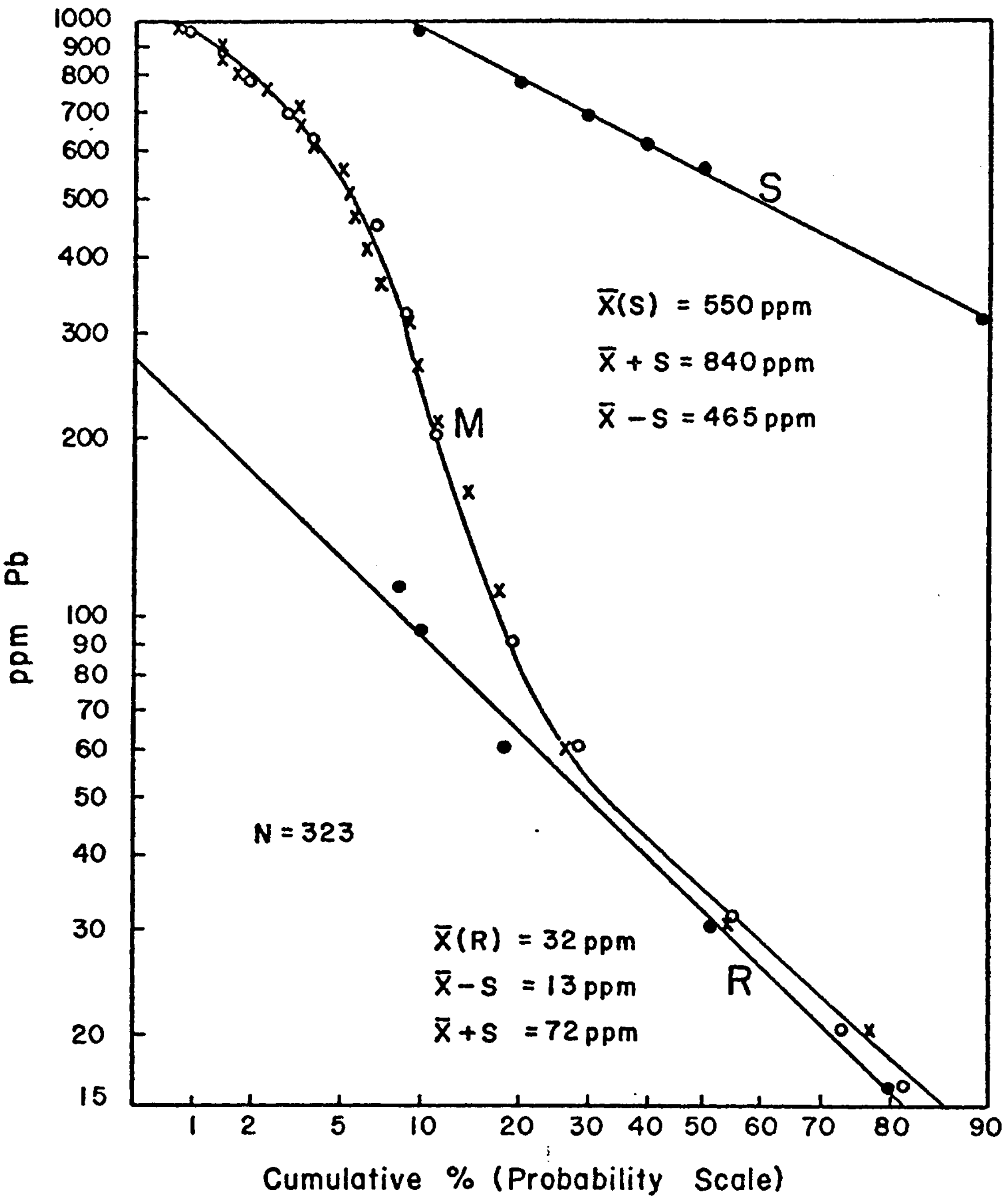


Figure 35. Cumulative probability plot (M) of 323 blasthole analyses of lead (ppm) from Brenda Mine. Lines R & S are the populations separated from M. Open circles represent ideal mixing points of R & S in the proportions 90% R and 10% S.

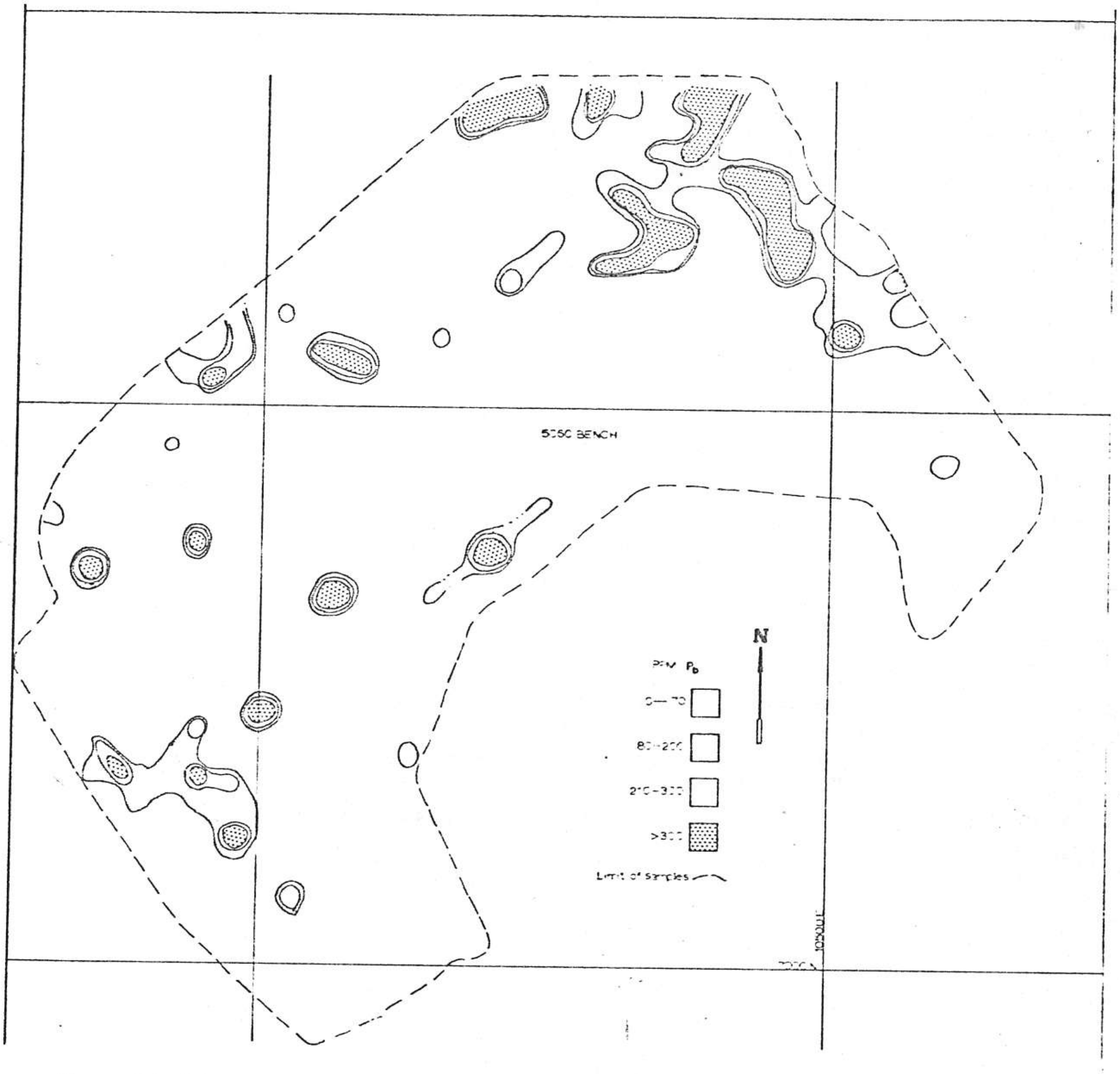


Figure36. Distribution of Lead in Brenda pit from blast-hole analyses.

this possibility. Additional analyses are underway at the mine to further examine the distribution of lead in the mine area. Other minerals common in and about the ore zone are bornite, magnetite, hematite and pyrite. Of these only pyrite appears to show even a vague systematic variation in abundance, apparently increasing in amount to the north and west.

MINOR ELEMENT ZONING

A study of minor element distribution in 50 chalcopyrite samples from Brenda mine has been undertaken by Dr. D. Brabec. Samples, provided by the writer, represented the veins of Stages II and III. Samples were analyzed for Se, Ni, Cd, Mn, Zn, and Ag. The latter five were analyzed by atomic absorption spectroscopy, whereas selenium was analyzed by x-ray fluorescence. Geometric means for these elements (lognormal distribution) were Cd - 31ppm; Mn - 87ppm; Ni - 16ppm; Ag - 79 ppm; Zn - 734ppm; and Se - 358ppm. Plotted results do not indicate the presence of lateral systematic variations (i.e. zoning). However, sample distribution was erratic; and the number of samples was relatively small compared to the size of the pit. Hence, a possibility of other perhaps complicated patterns cannot be ruled out. Significant positive correlations at a probability level of 0.05 were found with Cd and vein width; Cd and Cu/Fe ratio and Ni and Ag. Negative correlations were found for Ni and Cu/Fe ratio; Zn and Se; and Se and vein width. Although not all have been explained, cadmium apparently increases in thicker veins of Stage III type, whereas selenium decreases in these later veins compared to Stage II veins. Except for Cd and Ag, the elements show a biomodal distribution on lognormal probability plots (D. Brabec, personal communication, 1972).

CHAPTER VI

SUMMARY AND CONCLUSIONS

GENERAL GEOLOGICAL EVOLUTION OF THE BRENDA DEPOSIT

Several textural varieties of quartz diorites form the Brenda Stock that was emplaced in Nicola Group volcanic rocks about 176 m.y. ago. One phase, the Speckled quartz diorite, contains most of the Brenda copper-molybdenum ore body. Small aplite and pegmatite dikes formed shortly thereafter, probably during a late stage of the cooling history of the intrusion.

Contrary to Carr (1967), the writer found that these felsic dikes, although more abundant near the central part of the pit, formed in all areas of the ore body and are not confined to a structural belt as proposed by Carr (1967). Furthermore, these orientations do not correspond to ore veins or other younger planar features. Consequently, the writer is inclined to relate these felsic dikes genetically to the Brenda Stock as a late stage residium. This dissimilarity between felsic dikes and all younger features also supports the hypothesis (contrary to Carr, 1967) that a period of time, probably large, elapsed after the intrusion of aplite-pegmatite dikes and before fracturing and mineralization of the ore body began. Potassium-argon age dating data preferentially support (in the writer's view) the hypothesis that mineralization occurred at about 146 m.y. - well after the solidification of the intrusive quartz diorite at about 176 m.y. On this assumption it appears highly unlikely that this deposit is a paramagmatic type deposit, i.e., "an integral feature of a magmatic event." (White et. al., p. 9, 1968).

The Brenda ore body was formed by three separate but partially overlapping pulsating phases of mineralization. An increase in fracture density in the central part of the pit causes an irregular zoning of copper and molybdenum grades at Brenda. There is, however, an absence of symmetrical lateral zoning of minerals and elements in the classical sense and a scarcity of hydrothermal alteration, other than as thin envelopes about veins. Because vein orientations remain rather uniform throughout the deposit and because of their strongly preferred orientation and similarity to air photo lineament directions (Chapman, 1968), the writer believes that a regional rather than a local control caused fracturing that provided channelways for migrating ore fluids.

Although some movement along fractures occurred during mineralization as evidenced by minor offsets of veins, most movement began near the end of the third stage of mineralization. Shearing took place in weakened zones of argillic alteration and faulting, both dip-slip and strike-slip followed. The first minor epidote veining also took place at the end of the third stage of mineralization, but most Stage IV veins developed after the emplacement of the intramineral dikes. Whole rock analyses of two intramineral dikes indicate an age of about 130 m.y.

Late Tertiary events are largely speculative. Movement along shear zones and perhaps some faults probably continued during the Tertiary but did little to affect the ore body. A small patch of Tertiary (?) conglomerate possibly once extended over a large area but has been largely eroded. Glaciers might have eroded appreciable portions of the ore body. While at the surface and subjected to weathering and weathering processes, produced features such as the black clays developed from the combined breakdown of the argillized zones and the physical transport of fine clays, molybdenite and other opaques downward along accessable fractures. Ferrimolybdite, limonite, malachite, powellite, and other secondary minerals developed in a zone of weathering that averaged 20 feet deep, but locally attained depths of 90 feet.

UNUSUAL ASPECTS OF THE BRENDA DEPOSIT

The presence or absence of a number of features sets Brenda apart from other large tonnage, low grade copper and/or molybdenum deposits.

1) A well-defined spatial alteration and ore mineral sequence is virtually absent. Potassic and propylitic alteration is limited to thin envelopes around vein walls. Even the highest grade ore can have practically no visible alteration affects, whereas some almost barren veins have prominent envelopes up to six or eight inches wide. The greatest alteration effect, argillic alteration, occurs in widely spaced planar zones no wider than 35 feet and generally associated with a few third stage veins and shearing. What a contrast this is to the alteration at Climax or Bingham or most large tonnage deposits one can name. That the deposit also appears to lack a classical zonation of ore minerals (other than that related to density of fractures) compounds the disparity.

2) Unlike most similar deposits, disseminated ore mineral occurrences are extremely limited at Brenda. All occurrences of disseminated sulfides observed by the writer occur in zones of unusually intense potassic alteration, either hydrothermal biotite or potassium feldspar. It is probable that the lack of disseminated mineralization is related to the scarcity of alteration particularly potassic alteration.

3) Another unusual aspect of the deposit is the remarkable uniformity of orientation of structures with time. From the first phase of mineralization through shearing, faulting, and diking to the last phase of mineralization only two orientations persist. The dominant orientation strikes N60-70°E,and the second orientation strikes N55-65°W. Both have steep southerly dips.

4) Also differing from most "Porphyry Copper" or "Stockwork-moly" deposits is the approximately equal economic grades of copper and molybdenum at Brenda. Most deposits of this type predominate in either copper or molybdenum but rarely both. Rhenium values apparently support this "middle of the road" status of Brenda. The rhenium content of molybdenite concentrates are about 120 to 180 ppm at Brenda, whereas most porphyry copper deposits have high values (Ely - 1650 ppm, Chino - 800 ppm, Bingham Canyon - 360 ppm); and stockwork molybdenum deposits are generally quite low in rhenium content (Questa - 12 ppm, Climax - 3 ppm), (Sutulov, 1970).

PROBLEMS FOR FUTURE INVESTIGATION

A particularly important problem revealed by this thesis is the need for additional potassium-argon analyses for final determination of the ages of the quartz diorite host and ore mineralization. Present data indicates that mineralization occurred at a maximum of 146 m.y. and possibly as late as 130 m.y. It is critical to analyze biotite strictly related to ore mineralization (Stages I, II, or III) being careful not to include Stage IV biotite alteration that already is indicated to be 130 m.y. In addition, further samples from entirely unmineralized areas and from selected intramineral dikes are needed for confirmation.

Careful regional mapping is needed to tie the structural and petrographic history into a regional picture. Too little is known about the Brenda Stock. This vicinity has been termed by some to be part of the Pennask batholith (Schau, 1970) and by others to be part of the Similkameen batholith (Peto, 1970). Internal details such as phase relations and contacts need careful mapping, for the writer has found that the relations between varieties of quartz diorite might be much more complex than previously mapped. Careful attention should also be paid to secondary structural features such as veins, dikes faults, and shears in order to try to relate them to features observed within the Brenda ore body. In addition, the Nicola Group rocks are little understood in the vicinity of Brenda and deserve consideration.

A project for future consideration is an element zoning study from blast-hole data. Brenda is presently beginning to store copper and molybdenum concentrate from each blast hole (D. F. Whitford, Brenda Mines, personal communication). Considering the tight patterns of blast holes, it might be possible at a later date to study both lateral and vertical zoning with thousands of samples available for analyses by x-ray fluorescence.

It has been suggested by Dr. Soregaroli (personal communication) that because of the limited alteration present at Brenda mine, it might be much more ameniable for detailed study than deposits where alteration is pervasive and overlapping. The writer believes that a detailed study of the nature, chemistry, petrology and interdependence of the wall rock alteration assemblages would be a valuable contribution.

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APPENDIX

INDUCED POLARIZATION

The first successful Induced Polarization surveys in British Columbia were completed at the Brenda Mine in 1966. The results were published by Fountain in 1968. Although the estimated total sulfides were only 0.5 to 1 percent, significant anomalies outlining the ore body were found. The low consistent background of the quartz-diorite, probably due primarily to the confinement of alteration to narrow envelopes along veins, enabled the low but anomalous values to be recognized (Figure 37). Low overall pyrite content in the veins also meant that the anomalies might be correlated more specifically to ore-forming chalcopyrite and thus giving a more precise outline of the concentrated mineralization. Fountain (1968) presents a detailed description of procedure and analysis in his paper.

SOIL GEOCHEMISTRY

In conjunction with the Induced Polarization program, a soil geochemistry program was undertaken in 1966 to serve as a guide to drill exploration of the property (Chapman, Wood and Griswold, Ltd., 1967), (Soregaroli, 1968 and 1971).

Results show anomalous copper and molybdenum values ($\geqslant$200ppm copper and $\geqslant$ 20 ppm molybdenum) with similar distributions that outline in a general way the ore body (Figures 38 and 39) (Soregaroli, 1968 and 1971).

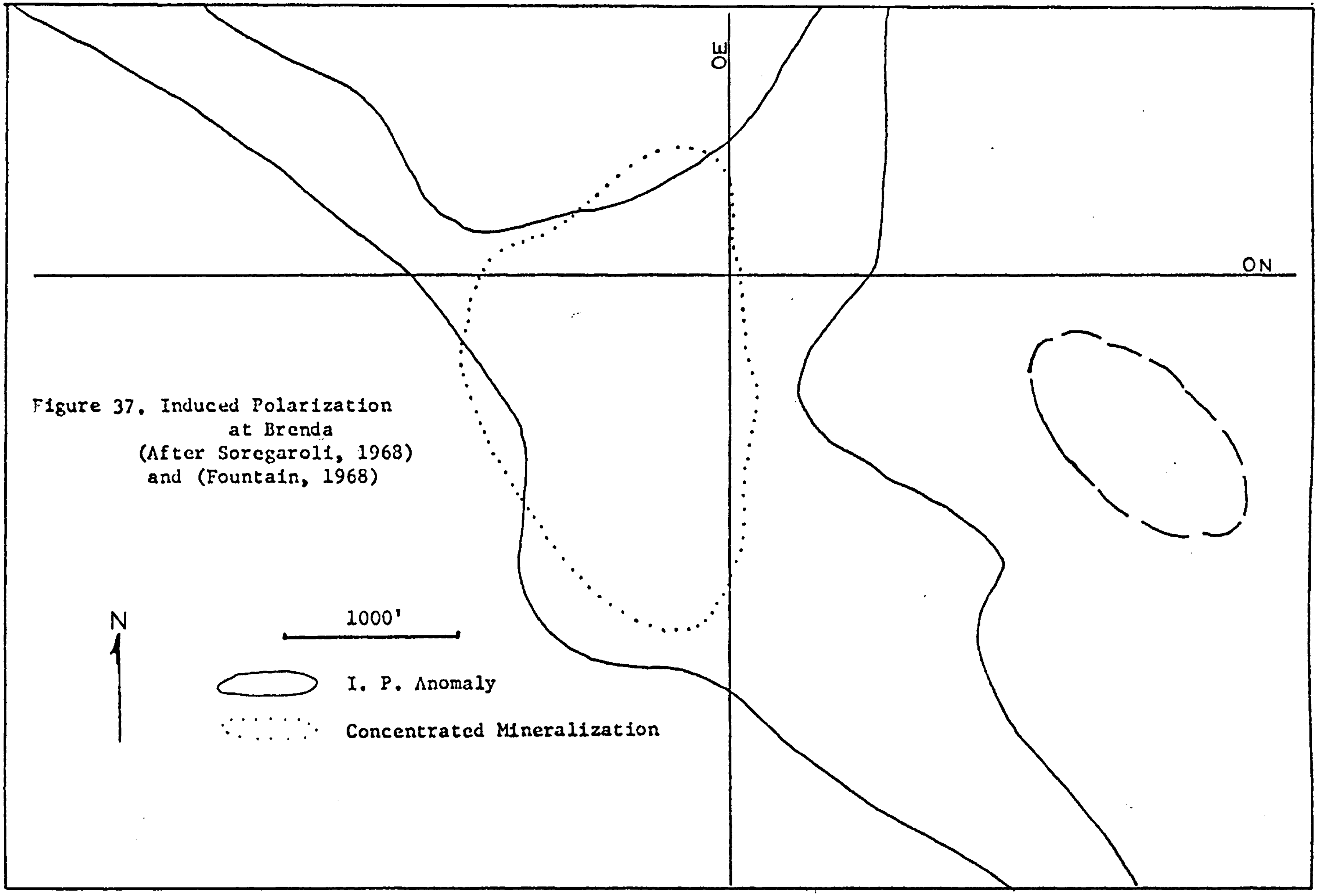

Figure 37. Induced Polarization at Brenda (After Soregaroli, 1968) and (Fountain, 1968)

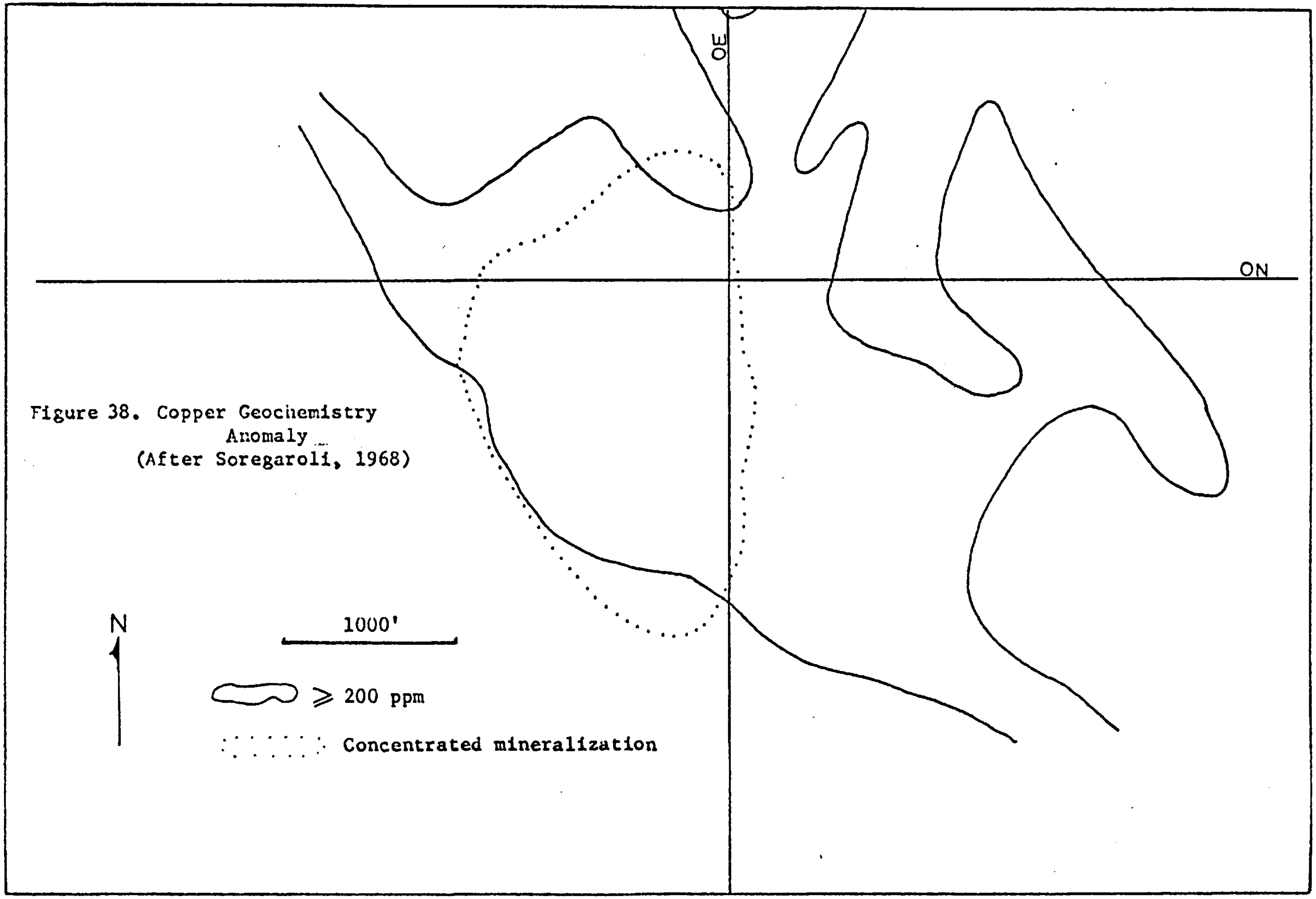

Figure 38. Copper Geochemistry Anomaly (After Soregaroli, 1968)

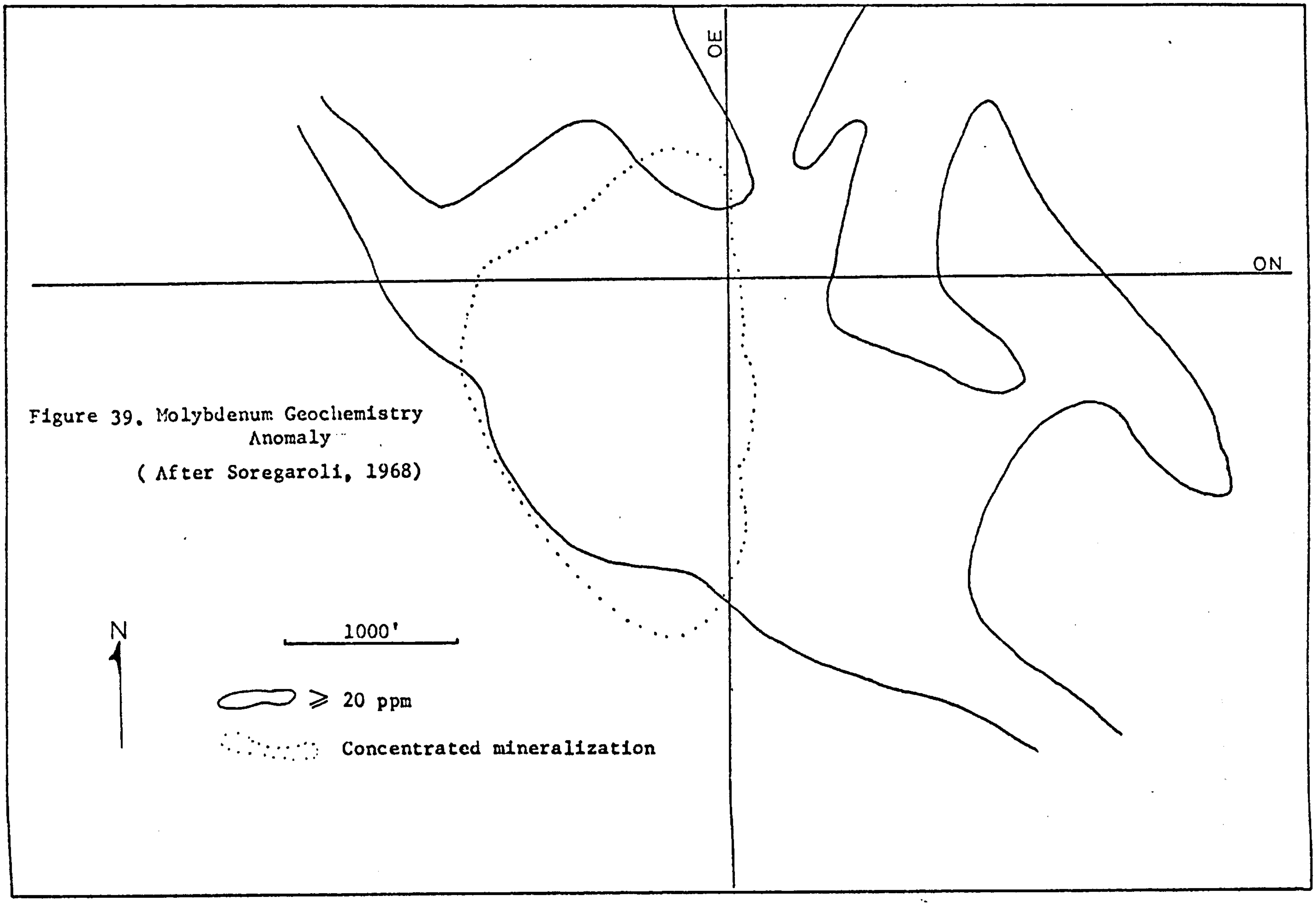

Figure 39. Molybdenum Geochemistry Anomaly

(After Soregaroli, 1968)