Brenda

008455

A. E. Soregaroli,*
Geological Survey of Canada,
Ottawa
D. F. Whitford,
Brenda Mines Limited,
Peachland, B.C.

Abstract

The Brenda copper-molybdenum deposit is within the Brenda stock, a composite quartz diorite/granodiorite body of Jurassic age which intrudes Upper Triassic sedimentary and volcanic rocks of the Nicola Group. Pre-ore and post-ore dykes with widely divergent compositions cut the stock.

Hypogene mineralization generally is confined to veins. Disseminated sulphides are rare. At least five chronological stages of veins, each with unique attitudes and mineralogy, were developed in fractures created by east-west regional compression. Grade of mineralization is a function of fracture density and mineralogy of the veins. Chalcopyrite and molybdenite, the most abundant sulphides, are accompanied by minor pyrite and magnetite in a gangue of quartz, potash feldspar, biotite and/or calcite.

Hydrothermal alteration is particularly weak in distribution. Potassic alteration (potash feldspar and biotite), which forms envelopes adjacent to some stages of mineralized veins, is directly related to sulphide mineralization. Propylitic alteration formed both before veining and accompanied some later-stage veins, but it is only of local significance. Argillic alteration is restricted to post-mineral fault zones.

Introduction

LOCATION

THE BRENDA MINE is 225 km east-northeast of Vancouver and 22.5 km west of the Okanagan Valley (Lat. 49°52′30″N, Long. 120°00′W, NTS 92H/16E). The area around the deposit is characterized by gently rolling, tree-covered upland, with scattered, glacially rounded outcrops. Elevations at the mine site range from 1450 to 1700 meters.

HISTORY

The first recorded prospecting on the Brenda deposit, then known as the Copper King Group, was by the Sandberg family of Kelowna during the late 1930's and early 1940's. The property was visited by H. M. A. Rice of the Geological Survey of Canada and, in spite of his recommendation (1947) that "...the widespread mineralization in the wallrock... suggests the possibility of a very considerable tonnage of low-grade ore, and deserves further considerations", work on the property was discontinued.

The property lay dormant until 1954, when a local prospector, Bob Bechtel of Penticton, rediscovered the showings and staked claims covering them. Bechtel contacted B. O. Brynelsen in Vancouver, then western manager for Noranda Exploration Company, Limited, and arranged an examination of the prospect. During the ensuing years, Brynelsen and his assistant, M. M. Menzies, took an active interest in the property, arranging several examinations and test drillings of the property between 1954 and 1964. The most comprehensive study during this time was a joint Noranda-Kennco program in 1957 under the supervision of C. S. Ney (Kennco). Under Ney's guidance, maps portraying geology, fracture density and biotite-hornblende percentages were prepared. Magnetic, induced polarization, self-potential and geochemical surveys were conducted and were followed by shallow X-ray drill holes in the mineralized area. Low assay values resulted in withdrawal of Noranda and Kennco from the property.

In 1964, under the direction of Brynelsen and Menzies, Brenda Mines Ltd. was formed with funds obtained from Nippon Mining Company and private individuals. Detailed exploration and feasibilty programs, commencing in 1965, consisted of geophysical surveys (IP), diamond and rotary percussion drilling, and underground exploration. During the feasibility study, 74 BQ wireline and 19 rotary percussion holes were drilled on a 400-ft grid. Two –63-degree holes were drilled at each drill site, one directed to the northwest and the other to the southeast. Underground exploration consisted of 563 meters of drifting and crosscutting and 288 meters of raising on four drill holes for comparison of assay values. Approximately 10,800 tonnes of mineralized rock from this underground development were treated in a 90-tonne-per-day mill to determine metallurgical characteristics of the ore.

Noranda Mines Limited began providing major financing in June 1966 and assumed management control in the spring of 1967. The decision to equip the property for production came in late 1967. Concentrator tuneup began in November 1969 and the rated capacity of 21,600 tonnes per day was achieved by April 1, 1970.

When production began, the Brenda orebody had proven reserves of 159,300,000 tonnes grading 0.183 per cent copper and 0.049 per cent molybdenum (0.082 MoS_2) at a cutoff of 0.300 per cent equivalent copper [eCu = % Cu + (5.45 x % Mo)]. Within this orebody was a higher-grade core of 25,200,000 tonnes grading 0.212 per cent copper and 0.063 per cent molybdenum. On January 1, 1975, reserves were 116,133,300 tonnes of 0.177 per cent copper and 0.046 per cent molybdenum. During 1974, a total of 8,494,809 tonnes of ore grading 0.186 per cent copper and 0.051 per cent molybdenum were treated in the concentrator and 6,445,440 tonnes were hauled to low-grade stockpile (0.2-0.3% eCu) and waste dumps.

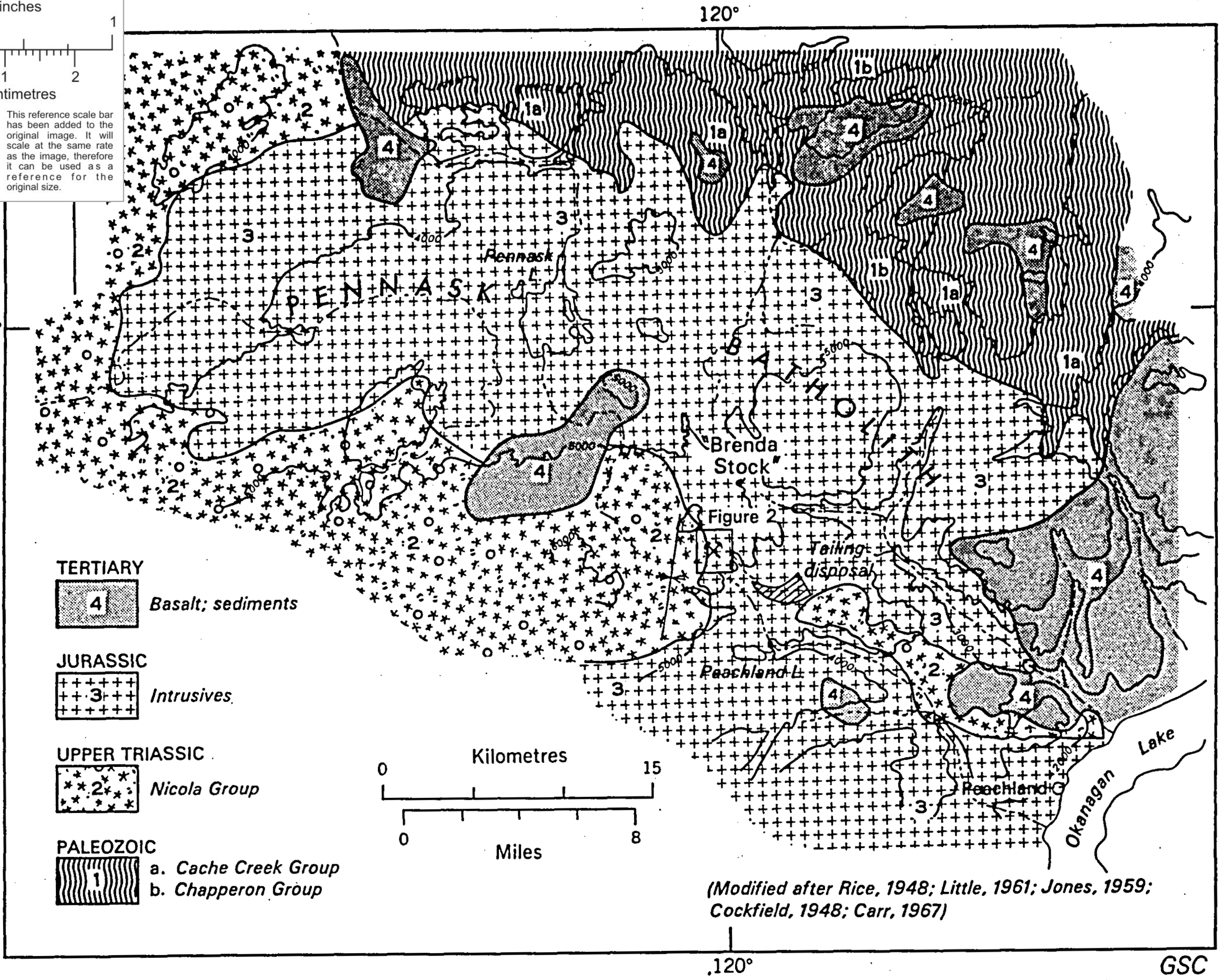
Geology

REGIONAL GEOLOGY

The Brenda copper-molybdenum deposit is within the Brenda stock, which was defined by Carr (1967, p. 184) as the "...zoned and composite quartz diorite body..." in the Brenda mine area. The "stock" is considered as part of the much larger Pennask batho-

---

*Dr. Soregaroli is now vice-president, exploration, with Western Mines Ltd., Vancouver, B.C.



(Modified after Rice, 1948; Little, 1961; Jones, 1959; Cockfield, 1948; Carr, 1967)

FIGURE 1 — Regional geology and location.

lith of Jurassic age (Gabrielse and Reesor, 1974), but field relations between these two bodies have not been established, so the name "Brenda stock" is retained for this paper.

The Pennask batholith, which is near the eastern margin of the Intermontane Tectonic Belt, was emplaced into rocks of the eugeosynclinal Upper Paleozoic Cache Creek and Chapperon groups on the north and east and into Upper Triassic Nicola Group sedimentary and volcanic rocks on the west (Fig. 1).

Several major linear features cut the Brenda stock and older rocks. Many of these are related directly to faults exposed during the excavation of the pit (Fig. 3). Others, such as the one which passes through MacDonald Lake and strikes northeasterly through Long Lake (Fig. 2), probably are the traces of faults. Quartz diorite units of the Brenda stock and an offset of a felsite dyke show clear evidence of right-lateral displacement along this fracture, which has been named the MacDonald Lake fault. Several other major linear zones occur in the rocks north of the area shown on Figure 2. Some strike northeasterly and others have northwesterly strikes.

PETROLOGY

The Brenda deposit is within the Brenda stock, approximately 390 meters from its contact with the Nicola Group (Figs. 2 and 3). Several ages and compositions of pre- and post-ore dykes cut the stock.

Nicola Group

Nicola Group tuffs, volcanic breccias and flows adjacent to the Brenda stock have been altered to "schistose hornfels" (Carr, 1967). This hornfels, which is as wide as 450 meters, is characterized by the development of bands and aligned lenses of felted brown to black biotite. Siliceous bands and matrix in the hornfels consist of quartz with minor plagioclase, potash feldspar and occasional euhedral brown garnet.

Schistosity, although somewhat irregular north of the MacDonald Lake fault, generally strikes roughly parallel to the intrusive contact and dips westerly at 30 to 70 degrees. The development of the schistose fabric suggests that some structural adjustment accompanied emplacement of the stock. North of the fault, the hornfels takes on a different character and becomes more schistose, with coarse biotite. Farther north in the greywacke, hornfelsing is weaker and is marked predominantly by the development of abundant pyrite.

The schistose hornfels grades westerly into recognizable westward-dipping volcanic rocks (Carr, 1968), and these in turn are overlain by greywacke, argillite and shales.

Brenda Stock

The Brenda stock is a composite, zoned quartz diorite to granodiorite body which is divided into two units, based on the composition and nature of the rock-forming minerals. Carr (1968) originally divided the stock into "... four gradational units of quartz diorite ... and a related partly discordant unit...". For purposes of field mapping and recognition, the authors found it more convenient to use only two subdivisions. These units are easily distinguished in hand specimen, because Unit 1 contains abundant mafic minerals (hornblende > biotite) and angular quartz grains, whereas Unit 2 contains fewer mafic minerals (biotite > hornblende), well-defined biotite phenocrysts and subhedral quartz grains. The contact between Units 1 and 2 is generally gradational, but locally sharp. At sharp contacts, Unit 2 is chilled against Unit 1.

Unit 1, which is of quartz diorite composition, shows a considerable variation in texture and composition. Near the contact with Nicola Group rocks, Unit 1 is somewhat foliated. The unit generally becomes increasingly more mesocratic with increasing distance from the contact. This gradation is not uniform in character and even in individual outcrops shows considerable inhomogeneity.

Modal composition ranges fall within the following boundaries: quartz, 10 to 25 per cent; potash feldspar, 10 to 20 per cent; plagioclase, 50 to 60 per cent; hornblende, 10 to 30 per cent; biotite, 1 to 15 per cent; and magnetite, sphene and apatite, 1-2 per cent. Quartz occurs as angular interstitial grains. Poikilitic potash feldspar encloses quartz and plagioclase. Plagioclase composition ranges from An_{36} to An_{48}.

The gradation from Unit 1 to Unit 2 generally is somewhat diffuse, with the contact defined as the first appearance of subhedral quartz and biotite (Figs. 2 and 3).

Unit 2 consists of porphyritic granodiorite and a chilled, finer grained phase. Both are characterized by subhedral quartz grains, which range from 2 to 6 mm in diameter, and by well-defined biotite phenocrysts (3-10 mm). The rocks, especially the porphyritic variety, are lighter coloured than those of Unit 1.

The ranges of modal composition are: quartz, 20 to 30 per cent; poikilitic potash feldspar, 10 to 20 per cent; plagioclase (An_{34-43}), 45 to 60 per cent; biotite, 5 to 15 per cent; hornblende, 2 to 10 per cent; and minor magnetite, apatite and sphene.

Dykes

Dykes of several ages and compositions cut the Brenda stock. At least four types, aplite-pegmatite, andesite, trachyte porphyry and basalt, have been identified in the Brenda orebody. Dykes with these compositions, as well as felsite, dacite and quartz diorite, have been mapped beyond the limits of economic mineralization. Because of its continuity, the trachyte porphyry dyke is the only dyke shown on Figure 3. All other dykes are too small or too short in strike length to be shown in the figure.

Aplite-Pegmatite — Pink to grey aplite-pegmatite dykes include bodies of essentially quartz and potash feldspar with aplitic, pegmatitic or granophyric textures. Plagioclase and biotite are minor constituents. Individual dykes may have one texture or any combination of the three textures. The dykes range in thickness

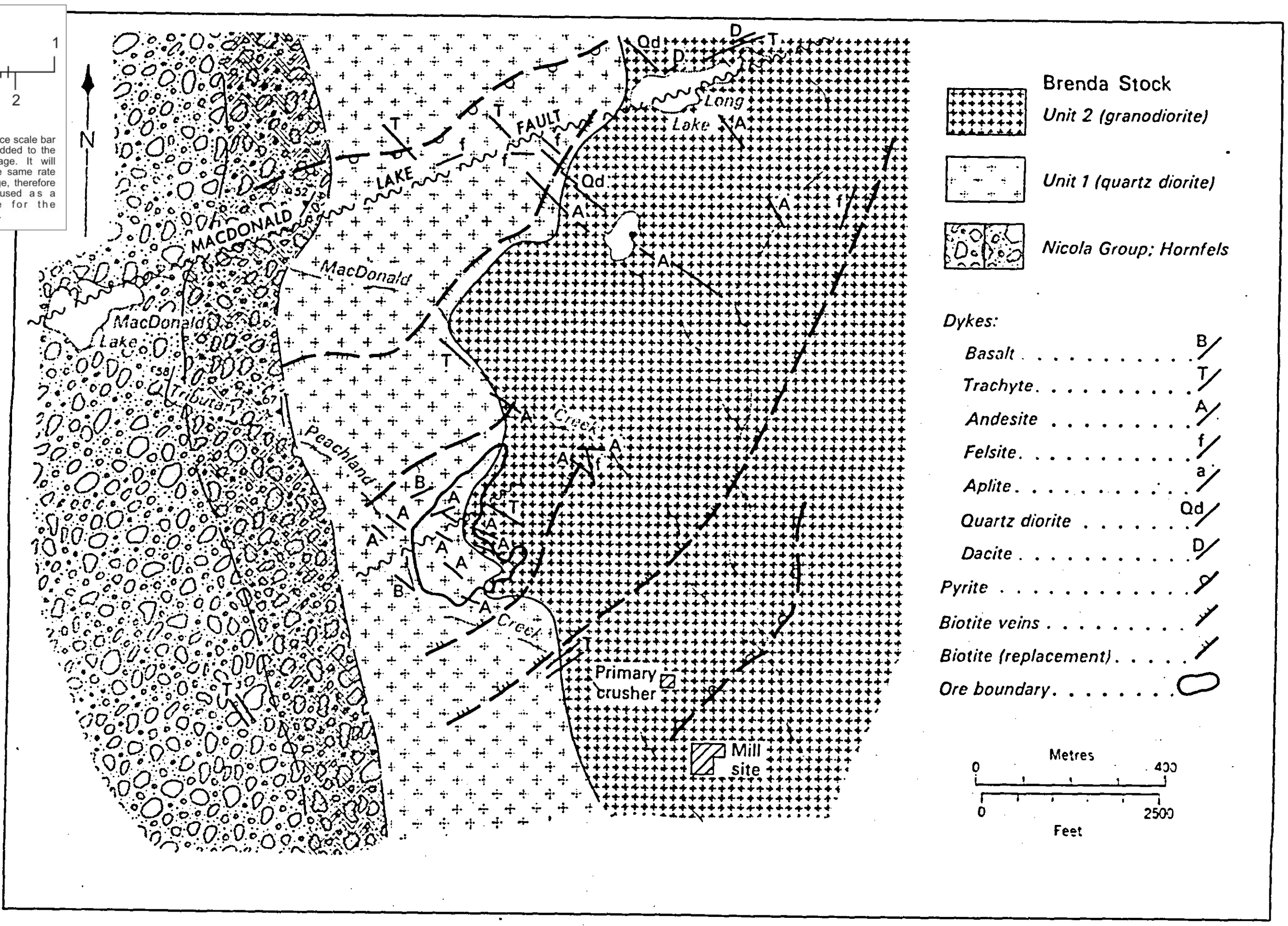


FIGURE 2 — Geology of the Brenda mine area (modified after Carr, 1968). Symbols for biotite and pyrite indicate their outer limits of occurrence.

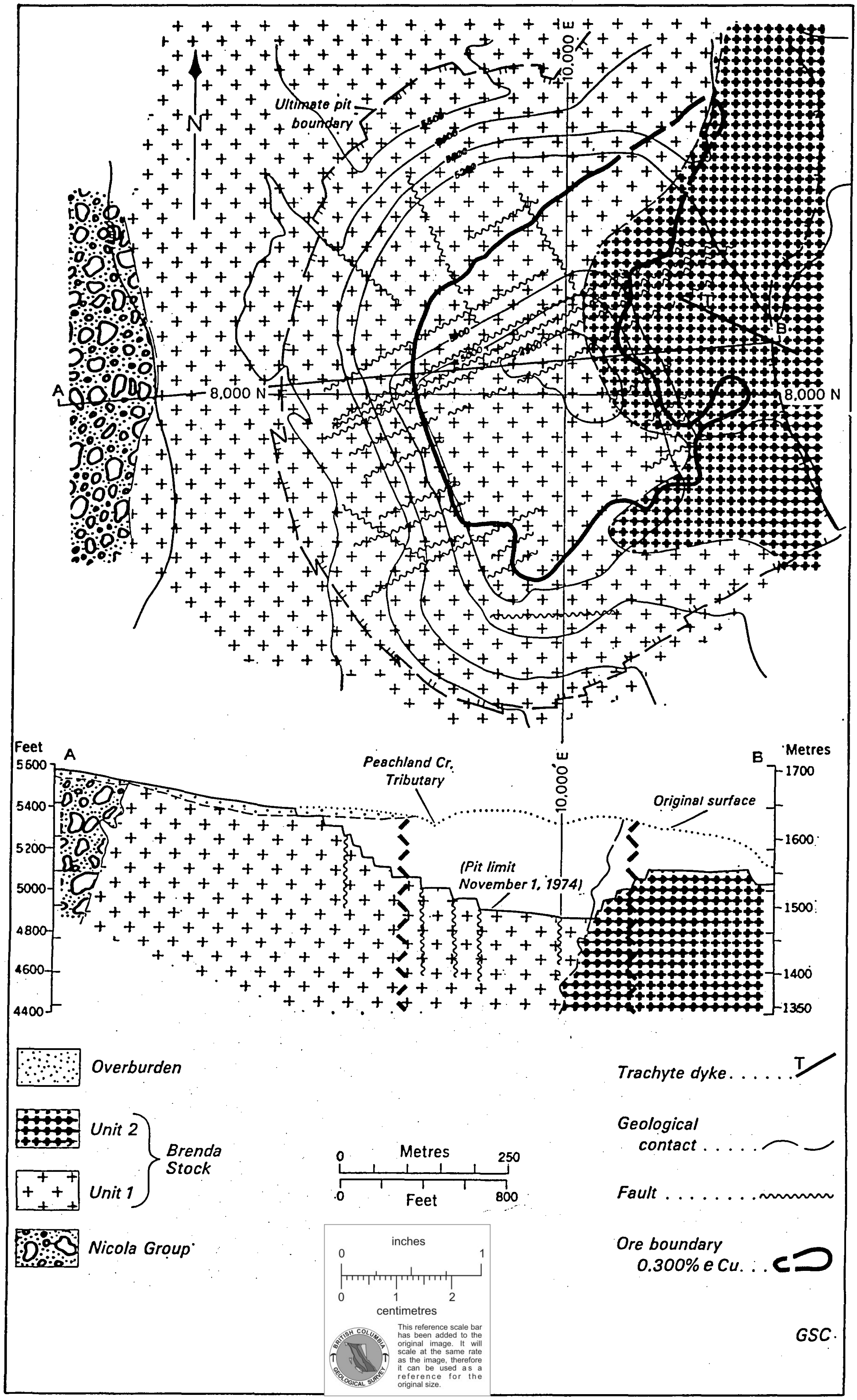


FIGURE 3 — Geology of the Brenda deposit.

from less than 1 cm to 60 cm and rarely persist for lengths exceeding a few meters.

Most dykes strike N 45° to 65°W and dip from 50 to 70 degrees northeast. Some strike easterly and dip 65 to 70 degrees south. Northerly striking, nearly vertical dykes are rare. Aplite-pegmatite dykes occur throughout the Brenda stock. A few have been observed in the hornfelsed Nicola Group. These dykes are cut by all other dykes and by all mineralized fractures.

Andesite — Andesite dykes up to 60 cm wide occur throughout the Brenda stock. They are dark greenish black, with scattered phenocrysts of hornblende. All dykes strike northwesterly, dip 65 degrees south to vertical, and have been altered and mineralized during ore formation.

Quartz Diorite — Two types of quartz diorite dykes are found in the mine area. Both types are cut by quartz-sulphide veins. The most prominent dykes occur in a northwesterly striking swarm southwest of Long Lake. These dark grey dykes range in width up to 4.5 meters and occur across a 60-meter-wide zone (Carr, 1967). Small crystals of plagioclase, biotite and hornblende are set in a dark grey matrix of plagioclase, potash feldspar and quartz, with accessory apatite, sphene and magnetite. The chilled, aphanitic margins resemble andesite dykes observed elsewhere in the area.

A second type of quartz diorite, which occurs north of Long Lake, was classified as one of the dacite dykes by Carr (1967), although he recognized its resemblance to the quartz diorite. The dark greenish grey dyke is composed of plagioclase, hornblende, biotite and interstitial plagioclase, potash feldspar, and quartz. Sphene, apatite and magnetite are accessory minerals. The rock has been chloritized and epidotized.

Dacite Porphyry — One dyke of dacite porphyry was observed about 100 meters north of Long Lake. The dyke contains abundant phenocrysts of plagioclase, hornblende, biotite and lesser quartz in a grey matrix of quartz, plagioclase and potash feldspar, with accessory sphene and apatite. The dyke strikes northeasterly and cuts across an earlier composite, trachyte porphyry - hornblendite dyke system. Primary hornblende and biotite are replaced by fine-grained, green biotite (Carr, 1967, p. 197). Quartz-sulphide veins cut the dyke.

Felsite — Grey to buff felsite dykes are scattered sparsely through the Brenda stock. Aphanitic varieties are locally cherty in appearance and may rarely contain small potash feldspar phenocrysts. Porphyritic felsite dykes contain quartz phenocrysts up to 2 mm in diameter and commonly have a subgraphic groundmass of intergrown quartz and potash feldspar. Pyrite is a common accessory mineral, especially in porphyritic varieties. Some dykes are cut by quartz-sulphide veins.

Most dykes are nearly vertical, with strikes ranging from northwesterly to northeasterly. One dyke has been disrupted by the MacDonald Lake fault, which caused the development of narrow, black mylonite zones within the dyke. Offset parts of the dyke show right-lateral displacement.

Trachyte Porphyry — Trachyte porphyry and related dykes intrude the Nicola Group and Brenda stock. Only one of these dykes has been observed in the Brenda pit. This dyke, which is characterized by aligned tabular phenocrysts of potash feldspar, is up to 4.5 meters wide and has been traced along strike for more than 300 meters (Figs. 2 and 3). Phenocrysts of potash feldspar, some of which exceed 2.5 cm in length, are pink to white in colour, with glassy, black turbid cores which enclose small laths of plagioclase. Such phenocrysts constitute up to 50 per cent of the rock and are smaller near the margins of the dyke, where they are accompanied by felted clots of biotite which have replaced magmatic hornblende. Accessory magnetite, sphene and apatite are disseminated through the rock. The magnetite content generally is high enough (up to 5%) that the rock is attracted to a magnet. Miarolitic cavities locally contain chalcopyrite.

Most trachyte porphyry dykes strike northwesterly with nearly vertical dips. A few, especially those of complex, composite character, strike east-northeast. The latter dykes may be simple dioritic dykes, as they are south of the Brenda deposit, or they may be intimately mixed, composite dykes with gabbro, hornblendite, hornblende-rich diorite and trachyte phases, as they are north of Long Lake. Trachyte phases cut all other phases, but the presence of xenoliths in many trachyte dykes of diorite and hornblendite suggests a genetic relationship.

One weakly mineralized vein was observed in the trachyte dyke in the pit, which suggested an intermineral age for the dyke (Soregaroli, 1974). Further evidence has clearly shown that the dykes cut all stages of mineralization, except some of the latest quartz veins. Carr (1967) recognized several post-mineral hornblende lamprophyre dykes within the Brenda orebody. These dykes probably are genetically related to the trachyte porphyry dykes.

Basalt — Irregular, branching basalt dykes, probably related to Tertiary volcanism, have been intruded along pre-existing fault zones. The dykes are dark greenish black, with chilled margins, and may rarely exhibit crude columnar jointing normal to dyke walls. Glassy margins commonly are sheared and devitrified.

Steeply dipping basalt dykes generally strike east, northeasterly or more rarely northwesterly. They cut all phases of mineralization and alteration and locally are themselves cut by calcite-filled fractures.

RADIOMETRIC DATING

Initial K/Ar dating of two samples from the Brenda Mine area (White *et al.*, 1968) resulted in different ages for hornblende (176 m y) and biotite (148 m y). Samples collected in the following two years failed to establish with certainty the age of mineralization. Interpretation of these results suggests that the Brenda stock crystallized about 176 million years ago. Biotite samples from the pit area have been dated at about 146 m y, which probably represents the age of mineralization.

Samples collected by one author in 1972 and 1973 should define more precisely the age of mineralization.

Structure

Structural features of the deposit include veins, faults and joints. Only veins and faults have been studied in detail. Veins are described in the section on Mineralization.

FAULTS

Faults in the Brenda pit are expressed as fractured zones in which the rock is intensely altered to clay minerals, sericite, epidote and chlorite. These fracture zones range in width from a few cm to 9 meters.

Most strike N 70°E and dip steeply southward. Northwesterly striking faults exhibit left-lateral movement. On Figure 3, the major faults exposed in the pit on November 1, 1974 are shown. The faults transect all mineralization, except some calcite veins. Sulphides, especially molybdenite, have been smeared along fault planes.

Shear zones are wider and more numerous in the north half of the pit, where they control bench limits (Fig. 3).

Mineralization

The Brenda orebody is part of a belt of copper-molybdenum mineralization that extends north-northeasterly from the Nicola Group - Brenda stock contact at least to Long Lake (Fig. 2). Mineralization of economic grade (0.300% copper equivalent) is confined to a somewhat irregular zone about 720 meters long and 360 meters wide (Fig. 3). Ore-grade mineralization extends more than 300 meters below the original surface and, although not explored in detail, all diamond drill holes in the ore zone bottomed in ore-grade mineralization. Lateral boundaries of ore-grade mineralization are gradational and appear to be nearly vertical.

Primary mineralization is confined almost entirely to veins, except in altered dyke-rocks and in local areas of intense hydrothermal alteration which may contain minor disseminations. The grade of the orebody is a function of fracture (vein) density and of the thickness and mineralogy of the filling material.

The average total sulphide content within the orebody is 1 per cent or less. Chalcopyrite and molybdenite, the principal sulphides, generally are accompanied by minor, but variable, quantities of pyrite and magnetite. Bornite, specular hematite, sphalerite and galena are rare constituents of the ore. Johnson (1973), in a study of 17 samples from the deposit, reported minor pyrrhotite, mackinawite, carrolite, cubanite, ilmenite, rutile and native gold (?), as well as several secondary sulphides.

Pyrite is most abundant in altered andesite dykes and in quartz-molydenite veins. The ratio of pyrite to chalcopyrite in the orebody is about 1:10, with the chalcopyrite content diminishing beyond the ore boundaries. Pyrite occurs throughout the north-northeasterly trending belt of mineralization, but within this belt the pyrite content of the rocks generally is less than 0.05 per cent and nowhere exceeds an estimated 0.1 per cent.

VEINS

Because mineralization is confined almost entirely to veins in relatively fresh homogeneous host rock, the veins are divided into separate stages (Soregaroli, 1968), based on cross-cutting relations and their mineralogy and alteration effects on the host rock. Oriel (1972) studied the veins in greater detail and showed that vein density within the orebody is not uniform. Ranges were recorded from less than 9 per meter near the periphery of the orebody to 63 per meter and occasionally 90 per meter near the center of the orebody (Oriel, 1972).

Some veins have very sharp contacts with wall rocks, but most contacts are irregular in detail where gangue and sulphide minerals replace the wall rock. A vein may show features characteristic of fracture filling in one part and of replacement in another.

TABLE 1 — Attitudes, Mineralogy and Alteration of Veins and Faults

Structural Feature	Vein Mineralogy	Attitude	Alteration
FAULTS: (Post-ore)		N 70°E; 82°S N58° W; 86°S	Argillic
VEINS: Stage 5	Biotite; Calcite; Quartz	N66° E; 80° SE N64° W; 89°S (after Oriel, 1972)	nil
Stage 4	Epidote-Sulphide-Magnetite	N51° W; vertical (minor)	Propylitic
Stage 3	Quartz-Molybdenite-Pyrite	N72° E; 86° S N76° W; vertical (minor)	Biotite (Potash Feldspar)
Stage 2	Quartz-Potash Feldspar-Sulphide	B. Late (Vuggy) N 22° W; vertical N 35° E; 20° NW (minor) A. Early N 68° E; 74° S N 70° W; vertical (minor) N 70° W; vertical (minor)	Potash Feldspar (Biotite)
Stage 1 (Oldest)	Biotite-Chalcopyrite	C. N 12° W; 58° E N 48° W; 18° N (minor) B. N 76° W; 86° S A. N 62° E; 78° S	nil
			Propylitic

Mineralizing solutions were introduced into fractures and, during development of the resultant veins, minor replacement of the wall rock ensued.

The following chronological stages of mineralization (veins) are based on the work of Oriel (1972) and Soregaroli (1968). Stages 1 through 4 are all genetically related to a single mineralizing episode, which was responsible for development of the Brenda orebody. Stage 5 represents a later, probably unrelated, event(s).

Stage 1. Biotite-chalcopyrite (oldest)
Stage 2. Quartz - potash feldspar - sulphide
Stage 3. Quartz-molybdenite-pyrite
Stage 4. Epidote-sulphide-magnetite
Stage 5. Biotite; calcite; quartz.

Veins of some stages exhibit more than one distinct attitude and are subdivided accordingly, as shown in Table 1. This subdivision contains more than one age within Stage 2 veins, but both are grouped together because of their similar features.

Stage 1: Biotite-Chalcopyrite

Most biotite-chalcopyrite veins do not exceed 1.5 mm in thickness and are difficult to recognize in undisturbed pit walls. Biotite-filled fractures contain disseminated patches and crystals of chalcopyrite and, more rarely, pyrite, molybdenite and potash feldspar. Quartz is notably absent. The dark brown to black biotite commonly shows evidence of slip along the fractures.

The most abundant biotite veins, Stage 1A, and the only ones found throughout the entire mineralized zone, were observed as far north as Long Lake (Fig.

4). Stage 1B veins occur only in the southwest half of the Brenda orebody, whereas the remaining veins (Stage 1C) of similar age have been observed only in the northeast part of the orebody and as far north as Long Lake. The density of biotite veining within this belt averages less than one per meter, but in very local areas may reach 11 per meter.

Biotite-chalcopyrite veins comprise about 20 per cent of the total number of veins within the orebody. However, because of their very narrow thickness and patchy mineralization, they probably contain less than 5 per cent of the total sulphides in the orebody.

Stage 2: Quartz - Potash Feldspar - Sulphide

Stage 2 veins form the bulk of the mineralization in the Brenda deposit, and are the most important source of ore. Two ages of veins with different characteristics have been recognized. Thickness ranges from 0.5 cm to 60 cm, but is usually 0.5 to 2.0 cm. Sulphide distribution within the veins is erratic.

Stage 2A veins are composed of quartz and potash feldspar, with highly variable quantities of chalcopyrite, molybdenite and pyrite. Quartz is the most abundant vein mineral. Potash feldspar content ranges from less than 1 per cent to as much as 25 per cent.

Sulphide distribution within the veins is erratic. They generally comprise 10 to 25 per cent of the vein space, but may locally exceed 80 per cent. Chalcopyrite is the most abundant sulphide. Molybdenite exhibits two different habits: (1) as single crystals and crystal groups; and (2) as veinlets which cut all other vein minerals. The single crystals and crystal groups were introduced with the veins, but the cross-cutting veinlets probably are related to a later stage (Stage 3) of mineralization.

Pyrite is a minor, but constant, accessory. Magnetite occurs as rare octahedra in chalcopyrite and more rarely as bands at vein walls. Bornite and sphalerite are occasional accessories.

Northeasterly striking Stage 2A veins (Table 1) are most abundant and are remarkably persistent throughout the deposit. Veins with this attitude include the original high-grade vein showing. They comprise 60 per cent of all veins mapped in the pit.

All other Stage 2A veins represent a combined 5 per cent of the total number of veins. They are very subordinate in number, rarely exceed 2 cm in thickness and are confined to the northeastern part of the orebody.

Stage 2B veins clearly cut the Stage 2A veins and have several distinctive characteristics. All Stage 2B veins are vuggy, with sulphides occurring as discrete crystals and crystal groups in interstices between subhedral quartz and potash feldspar crystals. Biotite occurs as a minor constituent of all veins, as does epidote. Chalcopyrite is the principal sulphide and is accompanied by minor quantities of molybdenite and pyrite.

Stage 3: Quartz-Molybdenite-Pyrite

Veins of quartz and molybdenite, with disseminated cubes of pyrite and chalcopyrite on fractures, range from 2.5 to 35 cm in thickness. Banding in some veins is caused by seams of molybdenite within the quartz. Calcite is a minor constituent.

Most Stage 3 veins strike N 72°E and dip 86°S (Table 1). They comprise only 2 per cent of all observed veins, but may be more important than this figure suggests. The attitude of these veins overlaps the attitude of some Stage 2A veins, and accordingly the Stage 3 period of mineralization may have provided much of the molybdenite found in the earlier veins. In addition, many post-mineral faults with attitudes subparallel to the Stage 3 veins contain abundant molybdenite on shear planes, suggesting that some veins were destroyed by these faults.

A very minor set of Stage 3 veins with a west-northwesterly strike was recorded by Oriel (1972).

Stage 4: Epidote-Sulphide-Magnetite

Veins of epidote and magnetite with minor molybdenite, chalcopyrite or pyrite occur throughout the area, but are nowhere abundant. The wall rock adjacent to the veins is irregularly replaced by epidote and chlorite.

Stage 5: Biotite; Calcite; Quartz

Several ages of veins, all of which are later than the mineralizing episode, are grouped in Stage 5. All are minor in occurrence.

Biotite veins are narrow and similar to Stage 1 veins, except that they rarely contain ore minerals and they cut all mineralized veins (Oriel, 1972).

Calcite veins appear to be of more than one age. Earlier veins are thicker, up to 7.5 cm, and may be accompanied by specular hematite, chlorite and epidote. Calcite in these veins commonly is salmon coloured. Later calcite veins, which cut all dykes and fill fractures in all orientations, may be related to Tertiary basalt dykes. These veins of white calcite rarely exceed 1.5 mm in thickness.

Quartz veins, which contain rare grains of pyrite or chalcopyrite, cut all mineralized veins and have been observed in trachyte dykes. The origin of these veins is unknown.

Gypsum was noted as veins and vug fillings in stage 2B veins at depths exceeding 270 meters (900 feet) below the ground surface, but has not been observed above this level.

Alteration

Hydrothermal alteration at the Brenda deposit generally is confined to narrow envelopes bordering veins. These alteration envelopes commonly grade outward into unaltered or weakly propylitized rock. Where veins are closely spaced, alteration envelopes on adjacent veins may coalesce to produce local areas of pervasive alteration. For the most part, hydrothermal alteration at the Brenda deposit is exceptionally weak for a porphyry copper system.

Four types of alteration are recognized in the Brenda deposit, three of which are related to the mineralizing process. Two of these are potassic (potash feldspar and biotite) and the other is propylitic. Later argillic alteration has been superimposed on the system along post-mineral faults.

POTASSIC ALTERATION

Potash feldspar and biotite alteration generally are separated in space, but locally occur together. Both types of alteration accompanied sulphide deposition.

Potash Feldspar

Pink to white potash feldspar, much of which is not visible without staining the rock with cobaltinitrate solution, replaced plagioclase adjacent to most Stage

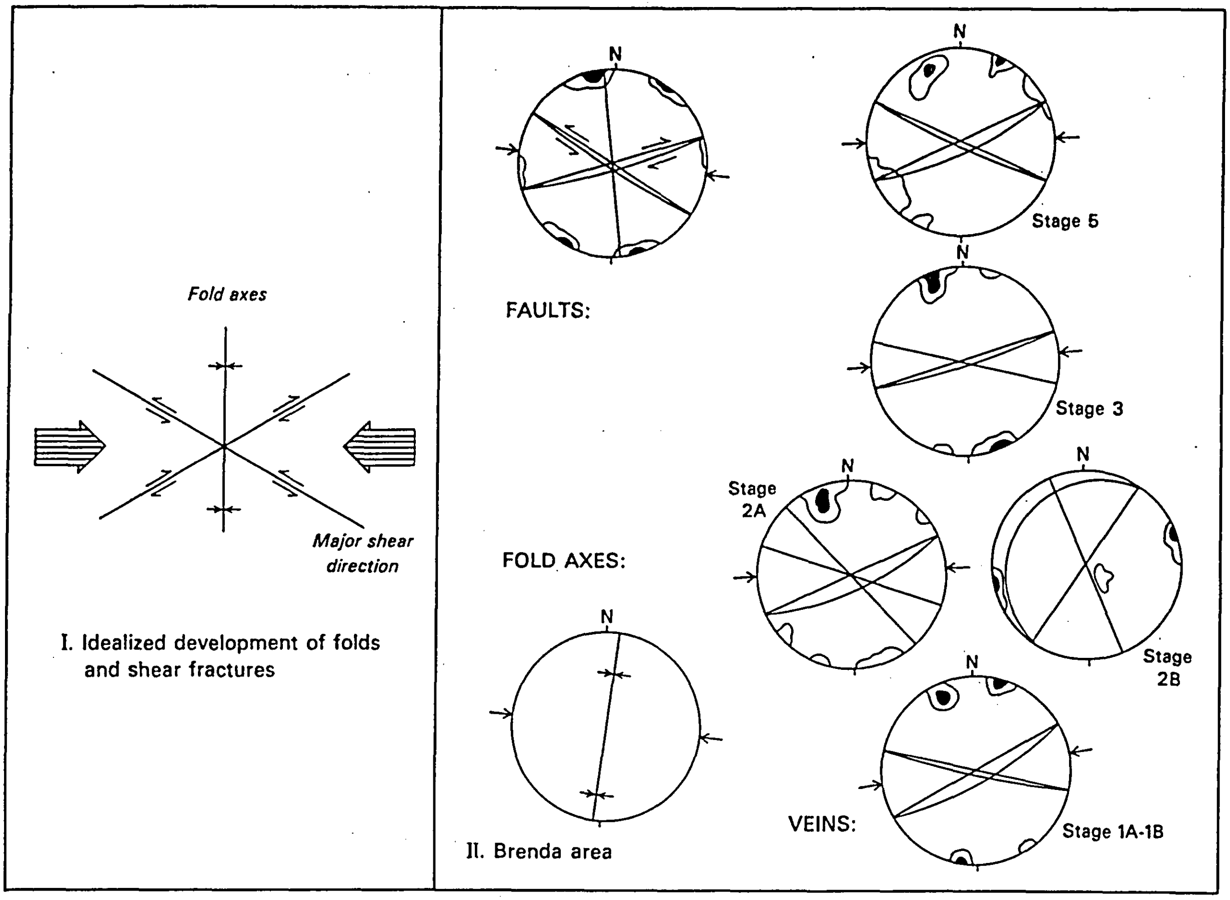


FIGURE 4 — Development of folds, faults and veins in the Brenda mine area.

2 and, to a lesser extent, Stage 3 veins. These irregular envelopes of potash feldspar range in width from a centimeter or less up to a meter, with an average of about 2 centimeters. Potash feldspar also occurs as a minor constituent of Stage 1 veins.

Biotite

Hydrothermal biotite replaced magmatic mafic minerals and, more rarely, plagioclase in host rocks adjacent to Stage 2 and especially Stage 3 veins. These envelopes of hydrothermal biotite range in width from less than 1 mm to several centimeters. In local, highly irregular areas, hydrothermal biotite may form up to 50 per cent of the rock.

Hydrothermal biotite is readily identified in hand specimens as veinlets and as felted black clots, which are pseudomorphs after magmatic hornblende and biotite. Replacement biotite occurs only in the Brenda orebody and adjacent to some Stage 2 and Stage 3 veins to the northeast (Fig. 2). Stage 1 veins of hydrothermal biotite occur throughout a north-northeasterly trending belt that extends at least as far as Long Lake.

PROPYLITIC ALTERATION

Weak to intense propylitic alteration, which is characterized by the development of chlorite and epidote, as well as less obvious microscopic sericite and carbonate, is sporadically distributed throughout the Brenda stock. Large areas within the orebody have not been propylitized and in these areas veins with potassic alteration envelopes clearly cut across propylitized quartz diorite, indicating an early hydrothermal or even a pre-ore origin for the propylitization.

A second period of propylitization accompanied the development of Stage 4 veins and is reflected as envelopes of epidote and chlorite. Because these veins are very minor in occurrence, this propylitization is restricted in distribution.

ARGILLIC ALTERATION

Locally intense argillic alteration is confined to post-mineral fault zones where the host rock has been highly shattered. Kaolinite, sericite and epidote, the characteristic alteration assemblage, have almost completely replaced the comminuted host rocks. Of the original magmatic minerals, only quartz has survived.

Weathering

Surface weathering, which is expressed predominantly by the development of limonite, extends as a highly irregular blanket over the mineralized zone for depths ranging from a few meters to greater than 30 meters. In this weathered area, limonite stains all fractures. Fault zones have been especially susceptible to surface weathering, and the argillic alteration of these zones may be primarily the result of groundwater action.

Limonite was especially visible in outcrops exposed along a tributary of Peachland Creek which cuts the orebody and in some areas of shallow soil cover. In glacially rounded outcrops, the only evidence of underlying mineralization was the presence of limonite stains in weathered "joints". The lack of a well-developed gossan probably is the result of glacial scouring and the relative paucity of pyrite in the deposit.

Secondary minerals developed during weathering, all highly subordinate in quantity to limonite, include malachite, azurite, hematite, ferrimolybdite, powellite and cupriferous manganese oxides. Cuprite, covellite, chalcocite, native copper, tenorite and ilsemannite are rare constituents.

Environmental Considerations

From the outset, environmental considerations have been important factors in the planning and development of the Brenda mine. The location at the headwaters of two drainage systems which provide domestic and irrigation water for orchards in the Okanagan Valley, and the importance of the tourist trade to the valley and its environs, were of prime consideration in establishing a source of fresh water and in the selection of tailing- and waste-disposal sites.

With approval from the Peachland Irrigation District and the Water Rights Branch of the Department of Lands and Forests, the level of Peachland Lake was raised about 15 meters. All land to be flooded by this rise in water level was first cleared of trees and easy access to the lake was established.

To prevent any downstream discharge of mill waste, a 120-meter-high dam is being constructed with the sand-sized portion of the mine tailing. Water and slimes are impounded behind this dam and the water is recycled for mine use. A small water-reclamation dam is located downstream to collect and recycle any water which may percolate through the dam.

On completion of mining, all disturbed and unseeded areas will be revegetated. Currently, tests are underway to determine the type of vegetation most suitable for various disturbed areas. Inactive areas are seeded on an annual basis.

Synthesis

Copper-molybdenum mineralization in the Brenda deposit was developed during several sequential stages, all of which constitute one mineralizing episode. Each stage occupies unique sets of fractures, which are filled with specific combinations of metallic and gangue minerals (Table 1, Fig. 4). Although the attitudes of veins in each stage are unique in detail, most stages include conjugate steeply dipping sets of northeasterly and northwesterly striking veins. If these veins occupy shear fractures, then it is obvious, from Figure 4, that the fractures were formed by generally east-west compressional forces.

Additional data concerning regional tectonics are gained by the examination of structures within the Nicola Group to the west and by the analysis of attitudes of existing shear zones. Folds in the Nicola Group have north-northeasterly axes (Fig. 1), again indicating generally east-west compression. East-west compressional forces folded the Nicola Group sedimentary and pyroclastic rocks into generally north-south-trending folds, whereas the more massive and competent rocks of the Brenda stock were extensively fractured by these forces.

Within the Brenda stock, the contact between quartz diorite (Unit 1) and granodiorite (Unit 2), although gradational, seems to have partly controlled the location of the Brenda orebody and related peripheral mineralization. Perhaps the subtle textural and compositional variations between these two units were sufficient to localize fracturing along this contact.

Although the source of the mineralizing fluids has not been defined, the authors suggest that intermittent east-west compressional forces intensely fractured the rocks of the Brenda stock during several stages of time and that these fractures tapped a hydrothermal source, either a later phase of the Brenda stock or a separate intrusive system. As each stage of fractures developed, hydrothermal fluids introduced vein material which healed the fractures. Renewed build-up of compressional forces again fractured the rocks, which were again healed. Repetition of this sequence can explain all stages of mineralization within the Brenda deposit, except Stages 1C and 2B (Table 1), which could have been introduced into fractures formed by activity at the source of the mineralizing solutions.

East-west compression continued after ore deposition ceased and produced prominent east-northeast and northwesterly striking shear zones.

Acknowledgments

The authors would like to thank the management and personnel of Brenda Mines Limited for their cooperation and help in the collection of data and preparation of this paper. Noranda Exploration Company, Limited provided financing for most of the early geological studies. We would also like to thank J. M. Carr for many enlightening discussions concerning the Brenda deposit.

Publication of this paper is by permission of Brenda Mines Limited and the Geological Survey of Canada.

References

Carr, J. M. (1967): Geology of the Brenda Lake area; B.C. Minister of Mines and Petroleum Resources, Ann. Rept., 1967, pp. 183-212.

Chapman, E. P. J. (1968): Geology of the Brenda molybdenum-copper prospect; CIM 70th Annual Mtg., Vancouver, preprint.

Cockfield, W. D. (1948): Geology and mineral deposits of Nicola map-area, British Columbia; Geol. Surv. Canada, Mem. 249.

Douglas, R. J. W., Gabrielse, H., Wheeler, J. O., Stott, D. F., and Belyea, H. R. (1970): Geology of Western Canada; Geol. Surv. Canada, Geology and Economic Minerals of Canada, Econ. Geol. Rept. No. 1.

Fountain, D. K. (1968): The application of the induced polarization method at Brenda Mines, British Columbia; CIM Bulletin, Vol. 61, pp. 153-157.

Gabrielse, H., and Reesor, J. E. (1974): The nature and setting of granitic plutons in the central and eastern parts of the Canadian Cordillera; Pacific Geol., Vol. 8, pp. 109-138.

Johnson, A. E. (1973): Mineralogical and textural study of the copper-molybdenum deposit of Brenda Mines Limited, south-central British Columbia; Energy, Mines and Resources, Canada, Mines Branch. Inf. Circ. IF302.

Jones, A. G. (1959): Vernon map-area, British Columbia; Geol. Surv. Canada, Mem. 296.

Little, H. W. (1961): Geology: Kettle River (west half), British Columbia; Geol. Surv. Canada, Map 15-1961.

Ney, C. S. (1957): Geological and geophysical report on the Brenda prospect, Osoyoos Mining Division, British Columbia; Assessment Rept. No. 189, B.C. Dept. Mines and Petroleum Resources.

Oriel, W. M. (1972): Detailed bedrock geology of the Brenda copper-molybdenum mine, Peachland, British Columbia; unpublished MSc thesis, UBC.

Rice, H. H. A. (1948): Geology and mineral deposits of the Princeton map-area, British Columbia; Geol. Surv. Canada, Mem. 243.

Roddick, J. C., Farrar, E., and Procyshyn, E. L. (1973): Potassium-argon ages of igneous rocks from the area near Hedley, southern British Columbia; Can. Jour. Earth Sci., Vol. 9, pp. 1632-1639.

Soregaroli, A. E. (1968): Preliminary report on geological studies at the Brenda Mine; unpublished report, Noranda Exploration Company, Limited.

Soregaroli, A. E. (1974): Geology of the Brenda copper-molybdenum deposit, British Columbia; CIM Bulletin, Vol. 67, No. 750, pp. 76-83.

White, W. H., Harakal, J. E., and Carter, N. C. (1968): Potassium-argon ages of some ore deposits in British Columbia; CIM Bulletin, Vol. 51, pp. 1326-1334.