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Mineral Zones in the Utah Copper Orebody

EDWARD C. JOHN

Abstract

Sulfide minerals of the Bingham mining district are distributed as concentric rings in plan view and inverted shells in cross section. Mineralization is centered on and drapes around and through the quartz monzonite porphyry phase of the Bingham stock. The dominant overlapping sulfide mineral zones, from the interior outward, are deep, low-grade core, molybdenite, bornite-chalcopyrite, chalcopyrite-pyrite, pyrite, and galena-sphalerite. Hydrothermal biotite distribution is concentric with the sulfide mineral zones in plan but crosscuts them in section. The controlling parameters for the sulfide and alteration mineral zones are: location relative to the quartz monzonite porphyry phase of the Bingham stock, rock type, degree of fracturing and permeability, and copper grade.

Introduction

THE concentric metal zones of the Bingham district were summarized previously by James et al., (1961). Magnetite-sulfide mineral zones were defined by Bray in 1969 and the cross section of the economic sulfide metal zones was described as a series of inverted shells by James in 1971.

Studies of geological details other than rock type, structure, copper and molybdenum grades, and gross alteration patterns are relatively recent at Bingham. The major emphasis of geological efforts has been and is the documentation of geologic parameters in production problems. The relationship of sulfide minerals to recoveries and concentrate grades at the concentrator and to recovery rates from dump leaching led to the study of sulfide mineral distribution. Hydrothermal biotite was early recognized as an important indicator of lateral and vertical extent of better grade mineralization and as such was noted during field mapping and core logging. Other parameters such as quartz veining, sericite, calcite, and hydrothermal potassium feldspar distribution were noted only as present, strong, moderate, or weak without sufficient detail to construct maps. Geological studies are becoming increasingly important in the solution of slope stability, concentrator, leaching, and smelter problems which arise as the characteristics of the mill feed change, the pit enlarges, and economic factors multiply. These conditions require continuing and more thorough geological studies of the Utah Copper orebody.

Study of the sulfide mineral distribution associated with the porphyry copper-molybdenum deposit was originally undertaken because of the correlation of sulfide minerology of mill feed with the recovery of copper and molybdenum and with the grade of copper concentrates. Estimates of the total sulfides and percentage of individual sulfide minerals of drill core were coupled with sulfide mineral determinations from 160 rotary drill holes made by examining heavy mineral concentrations using a binocular microscope. Hand lens estimates of sulfide content and mineralogy were made of the entire pit surface area. Copper assays were combined with the above data to significantly refine the estimates of sulfide content. Sulfur assays on diamond drill core were also used to confirm the estimates. The sulfide mineral distributions derived by the several methods outlined above are in essential agreement.

The five concentric overlapping sulfide mineral zones from the interior outward are: deep low-grade core, molybdenite, bornite-chalcopyrite, chalcopyrite-pyrite, pyrite, and galena-sphalerite (Figs. 1 and 7). Molybdenite occurs as stockworks. Chalcopyrite, bornite, primary chalcocite, and minor covellite occur as disseminations at sites formerly occupied by accessory magnetite and also in veinlets. The pyrite zone contains mainly pyrite with some hydrothermally deposited magnetite and hematite. Ore minerals in the galena-sphalerite zone are mainly vein and rock-type controlled and include abundant pyrite. Isolated and poorly studied occurrences of barite, manganese, and fluorite are found on the outer fringes of the lead-zinc zone.

The Utah Copper orebody has produced a total of 1.35 billion tons of copper ore which has yielded 11 million tons of copper, plus 320,000 tons of molybdenum and significant gold and silver. In addition, trace elements such as platinum, palladium, selenium, rhenium, and bismuth are recovered.

The lode mines surrounding the Bingham district produced a total of 45 million tons of lead, zinc, and copper, having a gross metal value of $800 million, during the productive years from 1870 to 1971. A good summary of the geology of these deposits is given by Rubright and Hart (1968). The major

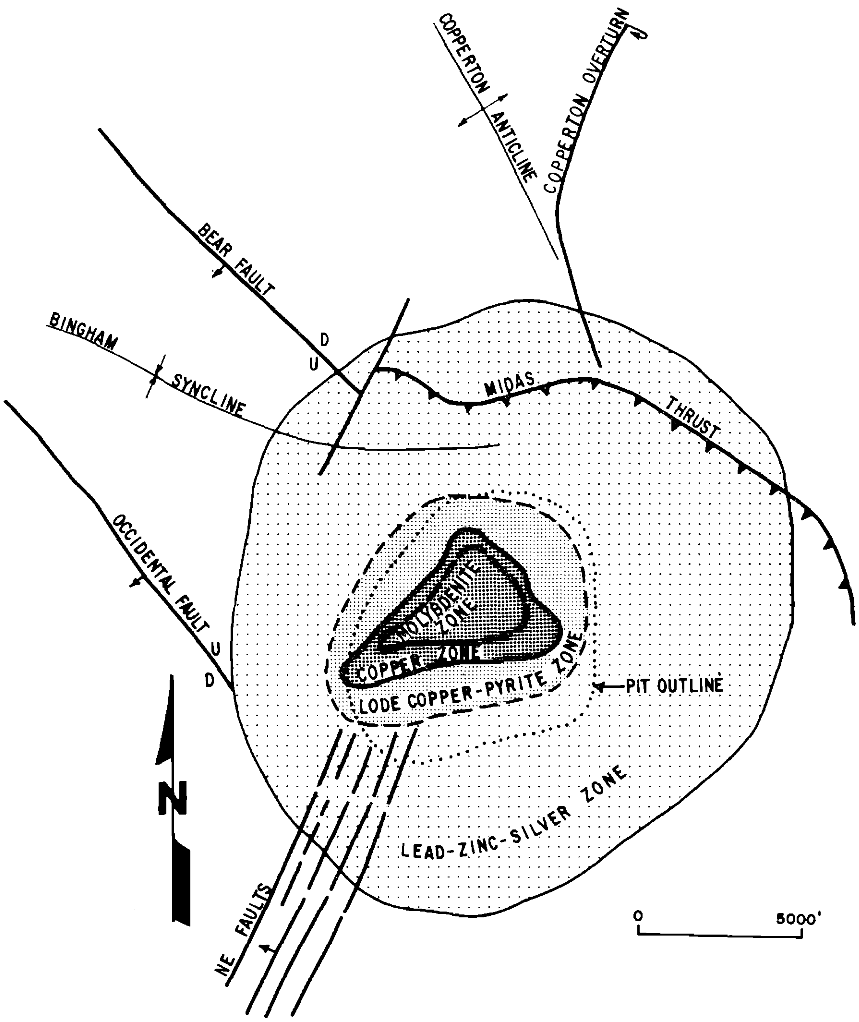


FIG. 1. Metal zone and principal structures of the Bingham mining district (after Peacock, 1948, and James et al., 1961).

controls on economic galena-sphalerite mineralization are host rock and/or fissure and location in the zoning envelope. Most economic deposits occur between 5,000 and 9,000 ft from the center of the copper deposit. The high-pyrite zone generally does not contain economic galena-sphalerite mineralization within 2,000 ft of the disseminated copper orebody. Galena and sphalerite deposits become restricted to a narrower zone with depth and are controlled by rock type and fissures (Figs. 1 and 7).

A study of the hydrothermal alteration products of silicate minerals, with emphasis on ferromagnesian minerals, was initiated in 1963. The geological mapping of the pit surface from 1966 to 1968 includes hand lens determinations of these alteration products. Many of the earlier diamond drill holes were relogged to determine the subsurface distribution of these minerals. The three-dimensional distribution of hydrothermal biotite is emphasized in this report. Quartz veining, sericite, secondary potassium feldspar, and clay minerals were also recorded in the field notes, but not in sufficient detail to render meaningful maps.

Although hydrothermal alteration minerals at Bingham were little noted by early workers, Boutwell (1905), Beeson (1917), and Butler (1920) offer clues to alteration at higher elevations. The distribution and type of many alteration features at the pit surface from 1947 to 1950 were discussed in considerable detail by Stringham (1953). The alteration of ferromagnesian minerals in the southwest quadrant of the mine was presented by Bray in 1969. Work completed by Field, Rose, Peters and others was summarized by Peters et al., (1966) and updated by Rose (1970) to include some data supplied by the author. Hydrothermal alteration was also

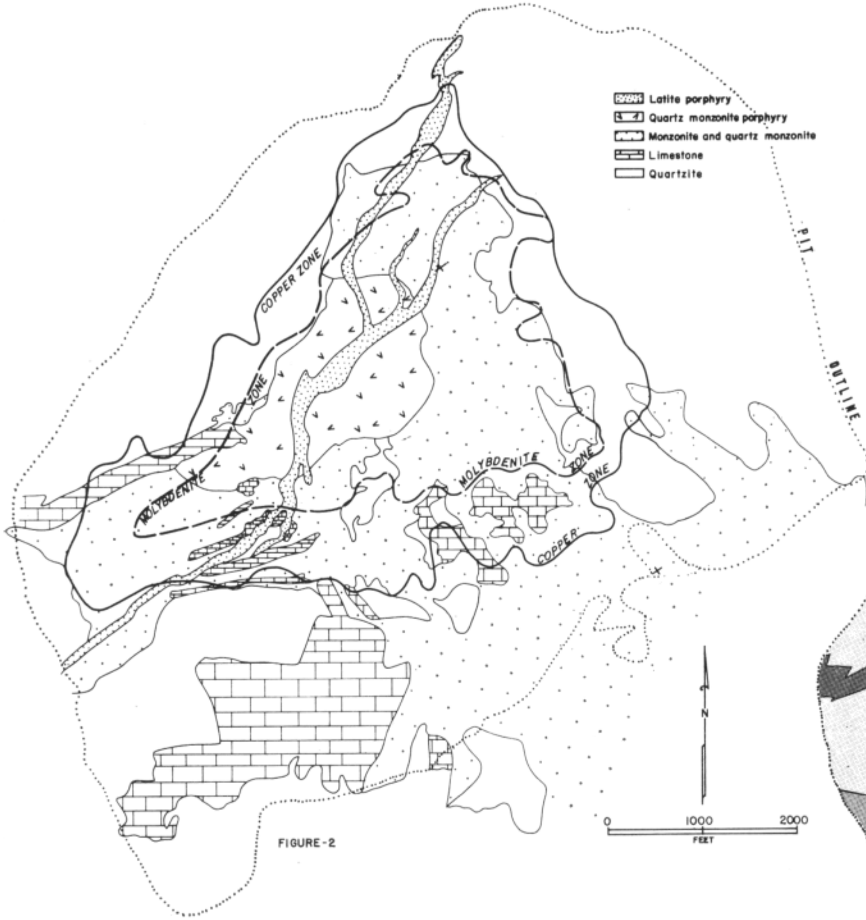


Fig. 2. Generalized geology map of Bingham mine.

Fig. 3. Plan map of pyrite distribution (numbers indicate weight percent).

discussed by Moore and Nash (1974) in their reexamination of Stringham's samples. These samples came almost entirely from the zone of complete replacement of ferromagnesian minerals by hydrothermal biotite and represent less than one-half the present pit area at a level 500 to 700 ft above the 1976 bottom of the pit.

Sulfide Mineral Distribution

The replacement of magnetite by sulfides at Bingham was reported by Boutwell (1905), Beeson (1916), Butler (1920), and Bray (1969). Much of the iron removed from the interior zones was apparently deposited in the pyrite zone. A zone of net iron removal shown in Figure 10 is suggested when assays for iron in mineralized rock are compared with assays of equivalent unaltered units found outside the deposit. The zone of iron depletion is reflected in the sulfide mineral distribution. Total copper-iron sulfide abundance is nearly constant at 2.5 percent in the inner portion of the copper deposit. Lateral changes of copper and iron grades are reflected in changes of sulfide ratios, but not total abundance. Thus, in the areas of higher copper grade, the sulfide minerals are bornite, chalcopyrite, and primary chalcocite, with no pyrite or magnetite. Outward, the decrease in copper and increase in iron are reflected by a lack of bornite and an increasing abundance of pyrite.

Although veinlet-controlled sulfides are important throughout the deposit, the sulfides are more disseminated in the interior and more veinlet controlled outward and downward in the deposit. Normally, the veinlet-controlled sulfide assemblage is more copper rich than that disseminated at the sites of primary magnetite. Thus, where pyrite is noted in the same rocks as is bornite, bornite usually occurs in veinlets and pyrite occurs at the former magnetite sites or remains as incompletely replaced blebs on the interior of a chalcopyrite-bornite grain. However, pyrite replacing chalcopyrite and pyrite veinlets cutting bornite-rich rock have been noted. Such veinlets are normally found at the outer edge of the bornite zone. This relationship suggests several stages of mineralization or slight changes in the mineralization pattern.

The intensity of fracturing and possibly that of mineralization is less in parts of the latite porphyry dikes and much less in the quartz latite porphyry dikes than in the quartz monzonite porphyry. Magnetite is common in the quartz latite porphyries that occur in the high-bornite zone. Also, several xenoliths of strongly mineralized rock have been found in these dikes. These data are thought to reflect intrusion of the dikes into the system after some mineralization had occurred. However, because the grade of molybdenum, and in many places the grade of copper, does not diminish across the contacts of the dikes, the difference in degree of fracturing and alteration may indicate parameters such as permeability rather than time of intrusion.

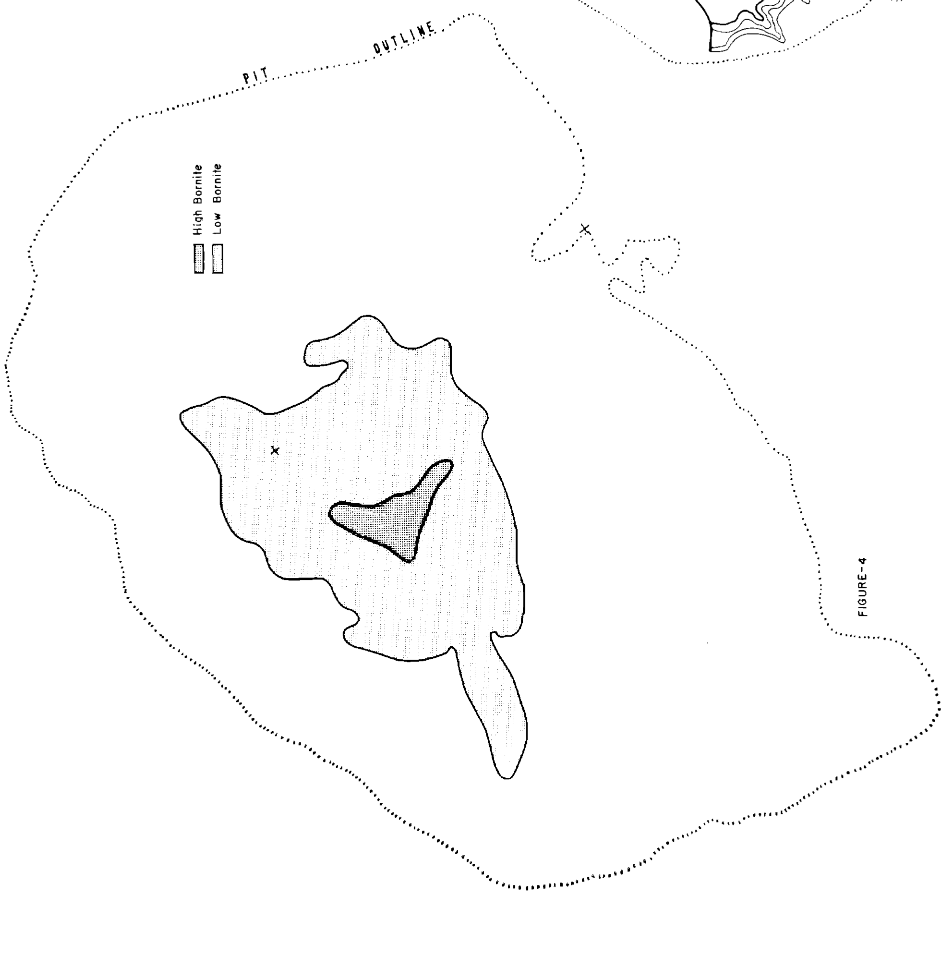
The width of all zones, as defined by sulfide mineral ratios, is narrower in sedimentary rocks than in igneous rocks. Quartzite is a poor host for copper compared to quartz monzonite at the same location in the zoning envelope. The iron content of the sulfide assemblage is usually much higher in quartzite at quartzite-igneous contacts. Limestones are even more iron rich, with two to five times higher pyrite-to-chalcopyrite ratios than adjacent igneous rock. Bornite is rarely found in the limestone skarns.

The low-grade core, which has much of the original igneous magnetite intact, contains less than 0.5 percent sulfides consisting of pyrite, chalcopyrite, bornite, and molybdenite. Although no truly barren rock has been drilled at Bingham, unmineralized rock probably does occur at greater depths.

The molybdenite zone is interior to the economic copper zone and extends into the copper zone slightly past the transition of bornite to pyrite-bearing rock. Molybdenite occurs as stockworks and does not appear to replace magnetite. Much of the primary magnetite remains in the interior of this zone but disappears where the zone merges with the bornite-chalcopyrite zone. Pyrite is present near the inner edge of the copper zone.

The bornite-chalcopyrite zone comprises the central high-grade portion of the primary copper deposit with bornite-chalcopyrite ratios commonly 1:1 in the highest grade zones (Figs. 4 and 9). Primary chalcocite occurs with and normally replaces the bornite. Bornite decreases, as does the grade of copper, outward and downward from the center of the orebody. Pyrite is absent where bornite is abundant, but present in minor amounts (0.1–0.5 wt %) at both the interior and exterior edges of the bornite-chalcopyrite zone. Some pyrite veinlets appear to be the last mineral event at the outer edges of the bornite zone and are interpreted as part of a late-stage inward and downward collapse of the alteration and mineralization zones as the hydrothermal system responsible for the Bingham Canyon deposit cooled. Data are not available to determine the original upper boundary of the bornite zone. Records of bornite in the concentrate indicated a marked increase from 4.23 to 10.95 percent of the concentrates between samples taken in 1929 and 1945. It is not known if this increase is due to primary zonation or secondary replacement of bornite at higher elevations (800–2,000 ft) above the present pit.

The pyrite-chalcopyrite zone of the copper orebody is the peripheral portion of the ore deposit. Chalcopyrite reaches 2.5 percent by weight near the



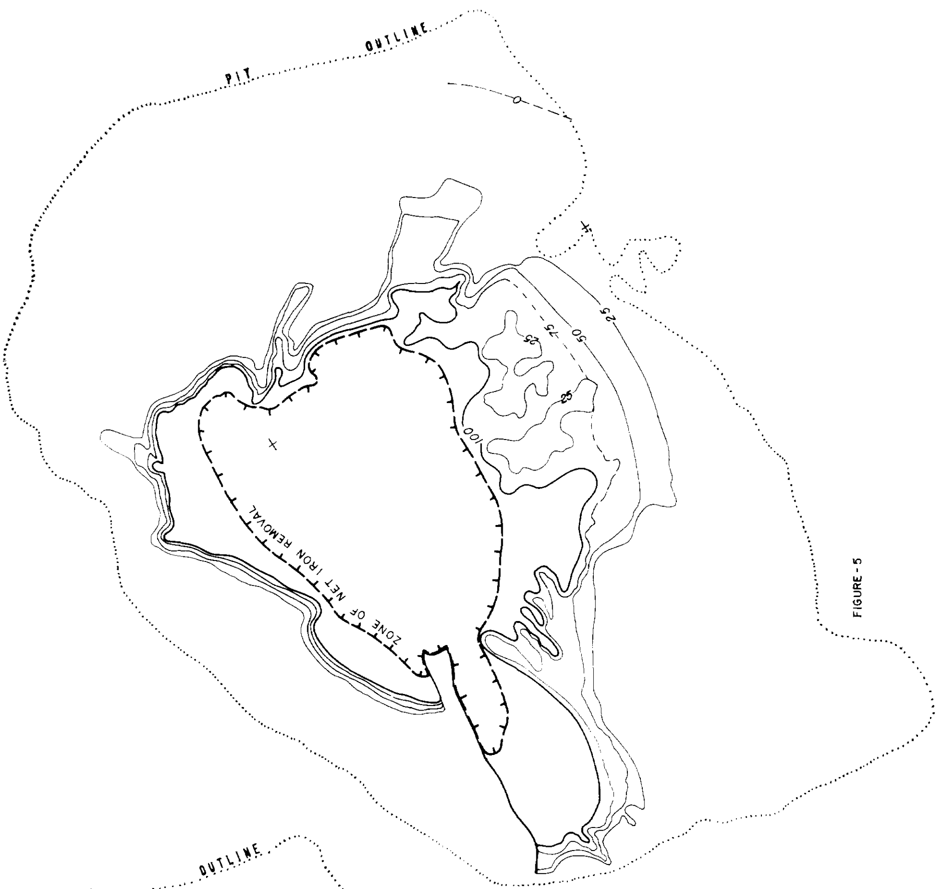


FIG. 4. Plan map of bornite distribution (numbers indicate weight percent).

FIG. 5. Plan map of hydrothermal biotite distribution (numbers indicate percentage of original ferromagnesian minerals replaced by hydrothermal biotite).

outer limit of the bornite occurrence and progressively decreases outward. Pyrite appears slightly interior to the outer limit of bornite. The pyrite-to-chalcopyrite ratio is 2:1 at the outer edge (0.35% Cu) of the disseminated copper orebody. Total sulfide content and copper grade decrease slowly downward.

The pyrite zone contains an average sulfide abundance of 3.5 percent (maximum 7%) in the igneous rocks and quartzites. Limestone skarns contain as much as 70 percent pyrite. Pyrite reaches a peak between 500 and 1,000 ft outside the disseminated copper orebody (see Figs. 3 and 8). Disseminated mineralization is not ore grade in this zone. However, lode copper, lead, and zinc deposits do occur in the pyrite zone as fissure fillings, limestone replacements, and skarns. At the outer edge of the zone nearly all of the pyrite occurs as fracture fillings.

Magnetite occurs at depth and on the periphery of the pyrite zone. Veinlets of pyrite change downward into magnetite veinlets. Veinlets of magnetite also occur sparsely in igneous rocks on the south side of the pit. Veinlets of specularite occur in quartzites on the east side of the pit near igneous rocks containing magnetite veinlets. Primary magnetite reappears about 1,000 ft outside the disseminated copper orebody on the 1968 pit surface.

Hydrothermal Biotite Zone

Bray (1969) documents the complete alteration of primary igneous ferromagnesian minerals to hydrothermal biotite in and near rocks of the high-grade copper mineralization at Bingham. Hydrothermal biotite is defined as the biotite formed by hydrothermal destruction of primary igneous ferromagnesian minerals or magnetite added to the rock as envelopes on veinlet and fracture surfaces. Relict magmatic biotite occurs as megascopic pseudohexagonal books, which are readily distinguished from hydrothermal biotite in all of the igneous rock. Hydrothermal biotite distribution shown in this report (Figs. 5 and 10) was mapped with a hand lens.

Hydrothermal actinolite is an intermediate step in the alteration of augite to biotite. Hydrothermal actinolite after augite at Bingham is discussed in detail by Bray (1969) and Lanier et al. (1975). Moore and Nash (1974) offer a different point of view in explaining the actinolite as magmatic and deuteric. Actinolite is felt by Kennecott geologists to be predominately of hydrothermal origin because: (1) no evidence has been found that hydrothermal biotite ever directly replaces augite; an intermediate step to actinolite always exists, (2) augite increases as hydrothermal biotite and actinolite decrease laterally outward from the orebody and with depth, and (3) intrusive contacts between the high-augite zone at the southern edge of the stock and the zone of high-hydrothermal biotite are lacking.

Hydrothermal biotite is pervasive in the highly fractured center of the deposit and becomes restricted to envelopes along sulfide-bearing veinlets outward and downward. Hydrothermal actinolite is also controlled by distance from sulfide-bearing veinlets.

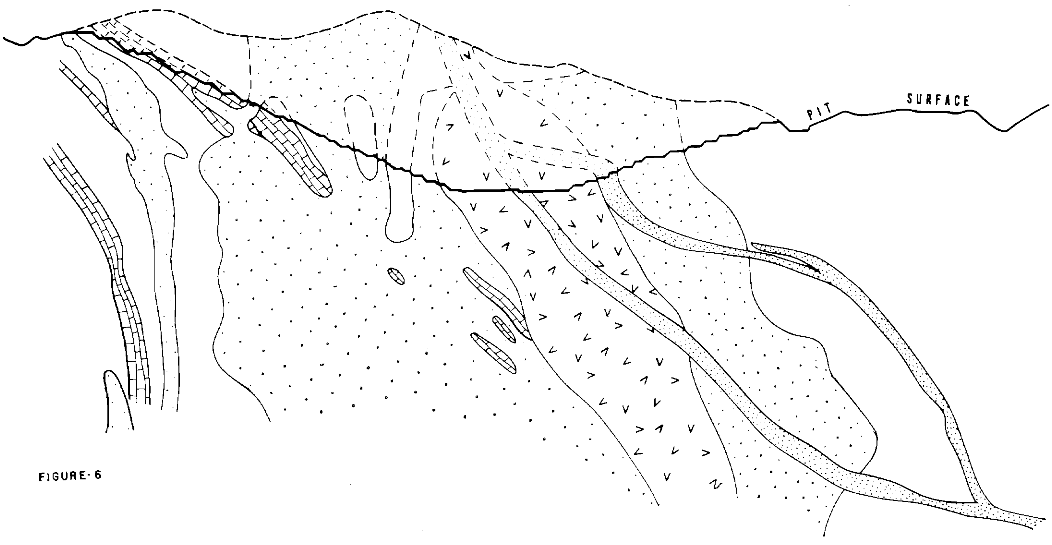
The degree of alteration of magmatic ferromagnesian minerals to hydrothermal biotite is dependent on location in the sulfide system. In plan view (Fig. 5) the zone of hydrothermal biotite is concentric around the quartz monzonite porphyry. The content of biotite decreases sharply at the edge of the chalcopyrite zone but extends outward as selvages around sulfide, mainly pyrite, veinlets for at least 3,000 ft from the disseminated copper orebody. In cross section (Fig. 10), the zone of total replacement of ferromagnesian minerals by hydrothermal biotite is an inverted cone, which crosscuts the sulfide mineral zones. This decrease in pervasive mineralization is related to the decrease in fracture density downward and outward. Sulfide veinlets have selvages of hydrothermal biotite throughout the copper- and iron-rich portions of the deposit. The abundance of hydrothermal biotite decreases downward and outward with the horizontal gradient steeper than the vertical gradient.

Hydrothermal biotite is strongly developed along the intrusive-quartzite contact on the north and east sides of the deposit (Figs. 5 and 10). Hydrothermal biotite is present in the quartzites along the contacts where it replaces actinolite and chlorite that formed earlier as a result of alteration of carbonate minerals to calc-silicate minerals. Biotite alteration decreases with depth in intrusive rocks. Reasons for the difference appear to be greater fluid flow along the contacts, higher grade mineralization, and possibly different chemical gradients.

The downward-converging cone shape of the zone of total alteration of ferromagnesian minerals to hydrothermal biotite in intrusive rock is largely constricted into the quartz monzonite porphyry at depth. In the quartz monzonite porphyry, total alteration of ferromagnesian minerals to biotite, even in rock with .0X percent copper and molybdenum values, is found as deep as drilling has penetrated. However, in the adjacent quartz monzonite the replacement becomes less intense with depth, decreasing to less than 50 percent biotite replacement less than 100 ft from the quartz monzonite porphyry contact in the deepest penetration.

Other Alteration Minerals

Pervasive quartz-sericite alteration that results in the nearly complete destruction of the primary minerals of the igneous host rocks is not common at Bingham. However, the rare samples retained from the first years of production indicate a greater abundance of this alteration type but do not define the distribution. As reported by Moore and Nash (1974),



FIGURE·6

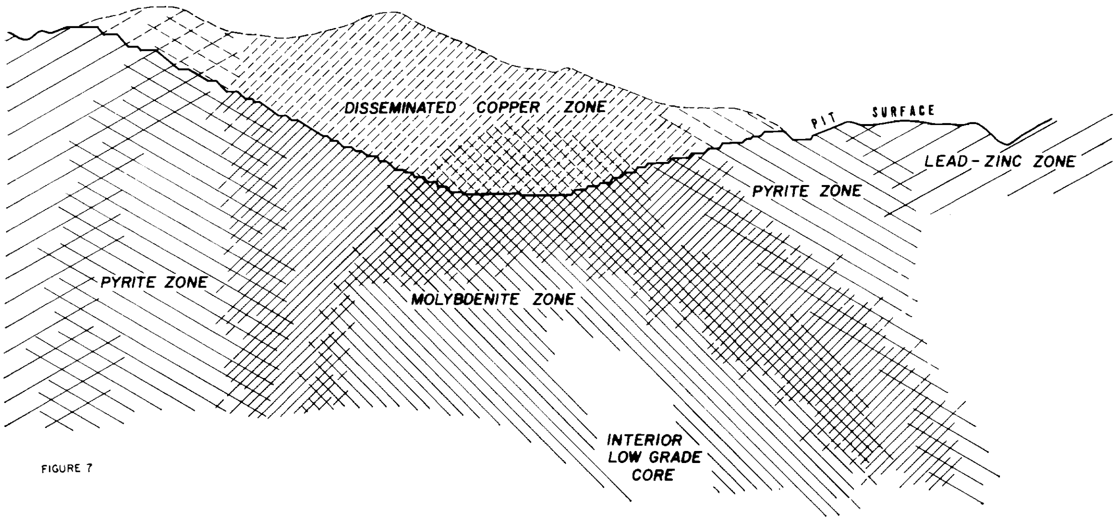


FIGURE 7

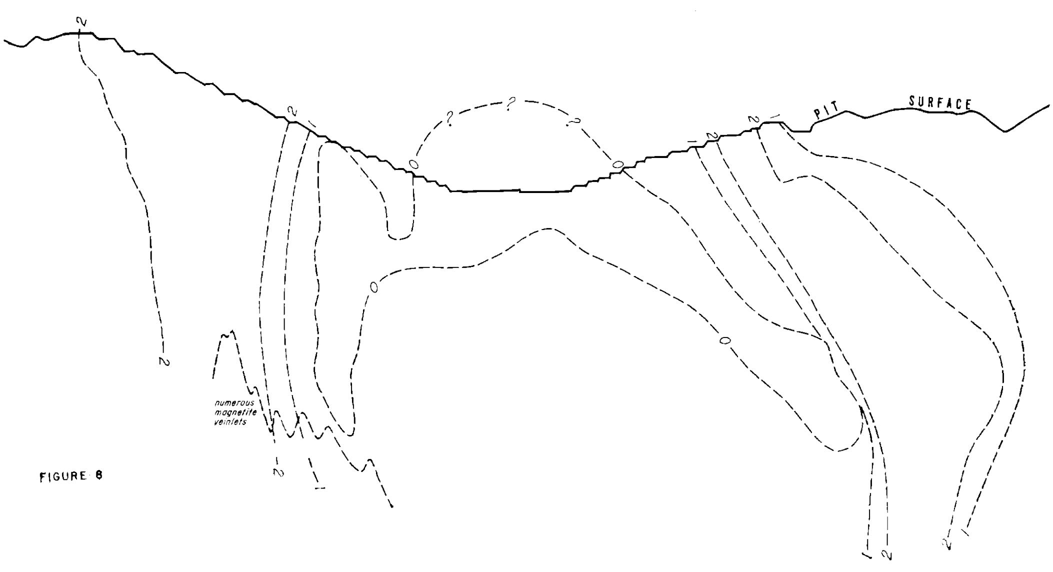
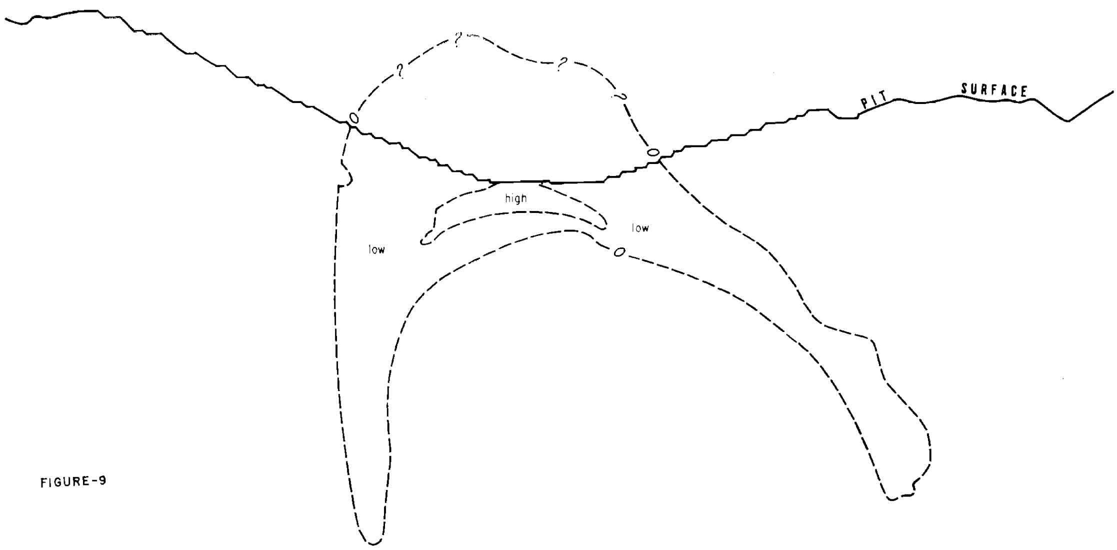


FIGURE 8



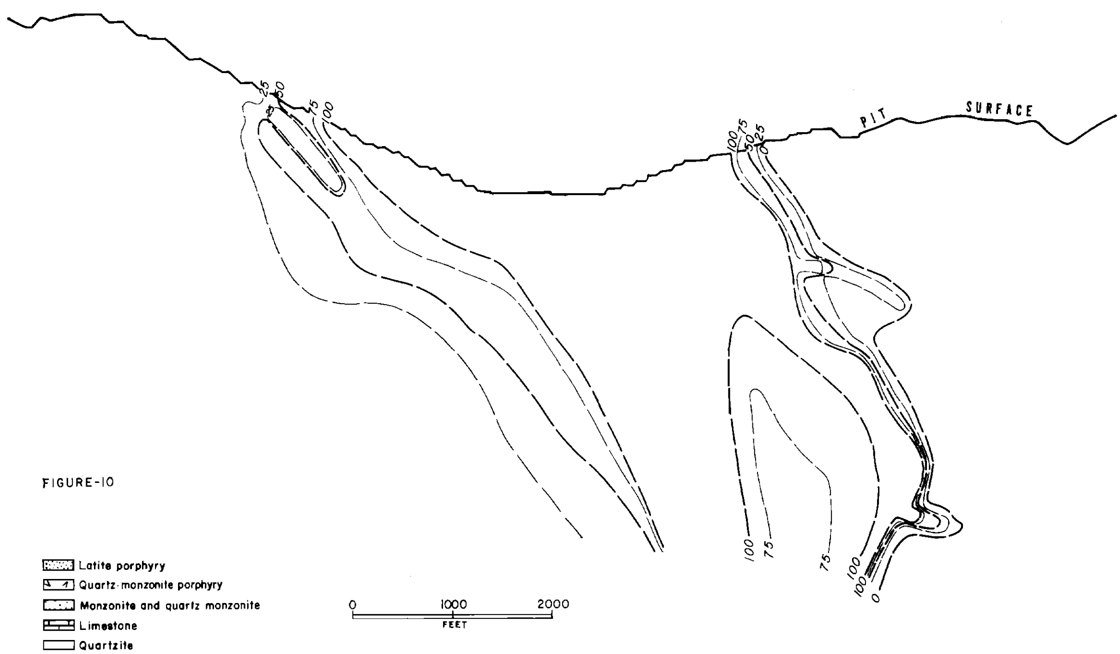


Fig. 9. Cross section showing bornite distribution.
Fig. 10. Cross section showing hydrothermal biotite distribution (numbers indicate percentage of original ferromagnesian minerals replaced by hydrothermal biotite).

sericite (6–10%) is present throughout the ore zone. Higher sericite and clay values are found in the rocks along the northwest edge of the orebody, paralleling, but mainly north of, the latite porphyry dikes. Prominent occurrences of sericite were mapped during this study on the high west side of the pit near the premine land surface.

Quartz-potash feldspar-calcite veinlets are common in the central part of the ore zone. Sericite, as envelopes along veinlets, becomes more common outward. Although study of these features has been minimal because their presence or absence causes few if any problems to the mining operation, several generalizations can be made. (1) The veins decrease in abundance away from the high-grade copper and molybdenum inward toward the barren core and outward through the ore shell. (2) Flooding of silica and potassium minerals into the rock around the

Fig. 6. North-south cross section through Utah Copper mine showing geology (looking west).
Fig. 7. Cross section showing sulfide mineral zones.
Fig. 8. Cross section showing pyrite distribution (numbers indicate weight percent).

quartz veinlets is strongest in the bornite zone. (3) Secondary potash feldspar is more extensive than the disseminated copper orebody (Lanier et al., 1975). (4) Strong quartz-potash feldspar-calcite veinlets continue below the deepest drill holes in the center of the quartz monzonite porphyry but diminish in other rock types, indicating that the porphyry constitutes the major plumbing system for the mineralizing solutions.

Fracturing must be considered an integral part of the rock alteration. In the area of strongest alteration and mineralization, the rock is shattered with fractures spaced less than an inch apart. Fracturing is coextensive with the biotite alteration, strongest in the highest grade mineralization, decreases in intensity toward unmineralized rock laterally outward, vertically downward, and inward from the ore shell. Some of the proposed mechanisms of fracturing include contraction with cooling during and after solidification, breaking by forceful intrusion of later rock types, violent boiling of water, reaction with hydrothermal solutions, and/or a combination of these or other methods. Whatever the mechanism, the rock was thoroughly shattered and rendered permeable in and near the zone of ore deposition.

Anhydrite, common in many porphyry copper deposits, has not been found other than in minute quantities at Bingham. Indeed, only a few sulfur assays of rocks on the periphery of the deposit indicate more sulfur than is required by the sulfides. Thus, anhydrite is not an important phase in the alteration-mineralization sequence at Bingham.

Discussion and Conclusions

Several inferences may be derived from the location, shape, and interrelationships of the general alteration and sulfide mineralization of the rocks of the Bingham deposit. District mineralization is zoned around the quartz monzonite porphyry phase of the Bingham stock (see Fig. 2). This small intrusion, 1,400 ft by 3,200 ft in plan, appears to have acted as a conduit for the residual fluids and heat escaping the magma chamber at depth. Fluid flow was also concentrated along the stock contacts with the sediments on the north and east sides of the deposit. Weaker flow is inferred in the equigranular quartz monzonite along the south side of the deposit. Mineralization is best developed at the top of the system, in limestones, and along the stock contacts.

The author feels that the evidence is strong that the major driving mechanism for the mineralization was heat and residual fluids escaping from a magma chamber through the conduit provided by the broken and crackled rock, in and around the quartz monzonite porphyry intrusion, along the contacts with the sediments, and along fissures extending outward into the fringes of the district. Zoning of both alteration and sulfide minerals is believed to be caused by gradients in heat, pressure, solution chemistry, and rock reactivity as the fluids moved upward and outward through the rocks in and adjacent to the conduit. Although several pulses of mineralization may have occurred, the overall boundaries of alteration and mineralization remained nearly constant throughout the sequence because slight overlap and mixing of zones is recognized.

Acknowledgments

This report is a summation of many years' work by many people. It is a statement of the broad understanding of the geology of the Utah Copper orebody stated from the author's point of view. Each geologist who has worked at Bingham has had a slightly different point of reference and each succeeding geologist has built upon and drawn from work previously done.

Early Kennecott mine geology work was conducted under the direction of James Marsh, Russell Anderson, and William Peters. The author was directed in the work by Herman L. Bauer, Jr., and Wilbur H. Smith, division geologists of the Utah Copper Division, Kennecott Copper Corporation. Many geologists have mapped and logged core, with major contributions during the author's tenure from R. Eldon Bray, Richard L. Brumbaugh, Ralph Green, Jeff Hulen, George Lanier, Paul Mogensen, A. Jaren Swensen, S. Blaine Willis, and many others to a lesser degree. R. M. Vodopich drafted the field sheets onto office compilations. J. D. Moore drafted most of the maps and cross sections. The author expresses his thanks to each of the people who have contributed to this effort. He also expresses his thanks to Kennecott for permission to publish this report.

KENNECOTT COPPER CORPORATION
METAL MINING DIVISION
P. O. Box 11299
SALT LAKE CITY, UTAH 84147
May 23, 1978

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