# THE ROOT-ZONE CHARACTERISTICS OF PORPHYRY COPPER DEPOSITS

by

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## Abstract

The root-zone characteristics of porphyry copper systems and their recognition is of considerable importance to the exploration geologist. Deep-level and root-zone alteration and mineralization features described by previous authors at San Manuel—Kalamazoo, Arizona; the Fortuna pluton and Los Loros, Chile; the Appalachian porphyry systems and the Cornelia pluton, Arizona, are summarized.

The Little Hill Mine area located 25 miles north-northwest of Tucson, Arizona is described in detail and is interpreted to be the exposed root zone of a porphyry copper system. The upper level, and potentially economic portion of this porphyry copper system, has been removed by erosion or faulting. The rocks at Little Hill are principally Precambrian schist and quartz monzonite intruded by a Laramide(?) quartz monzonite stock and postmineral dikes. The west-northwest-trending, south-dipping Mogul fault is the principal structure in the area. Alteration and mineralization at Little Hill cover an area approximately 8,000 x 4,500 feet. The alteration and mineralization can be divided into three zones: the inner, middle, and outer. These zones are defined by specific alteration suites which roughly correspond to copper grade and pyrite-chalcopyrite ratios. The alteration-mineralization zones form a nonconcentric pattern elongated along the Mogul fault and truncated by it to the south.

The geologic, alteration, and mineralization features identified at Little Hill when compared with well-known porphyry copper deposits suggest it is the root-zone of a porphyry copper system.

The importance of recognizing root-zone features at an early stage in an exploration program is discussed. A table is presented which outlines many of the features that characterize porphyry copper root zones and compares them with similar features of hood zones with which they are often confused.

## Introduction

Identification of the root-zone characteristics of porphyry copper deposits is of considerable importance to mineral exploration programs. The attributes of such deep-level alteration and mineralization have received little published attention, have remained inadequately characterized, and may be confused with hood-zone characteristics. A quote from Peter Joralemon (1975, p. 33) illustrates the problem. "The study of depth and mineralogic zoning as a tool for ore finding is perhaps also overvalued. I know of a possible porphyry copper occurrence that was turned down by two able geologists: one because erosion had clearly stripped the deposit down to its very roots, and the other, seeing the same evidence, because the ore body was still buried at a depth of over 5000 feet below the surface."

This paper presents the results of a detailed geological, geophysical, geochemical, and petrographic study of the Little Hill Mine area, Arizona. Particular attention is given to identifying those characteristics of deep-level alteration and mineralization in porphyry copper deposits that distinguish root-zone from hood-zone propylitization. The results are then discussed with respect to their application in mineral exploration programs.

## Previous Studies

Articles by Lowell (1968), Lowell and Guilbert (1970), Sillitoe (1973), Hollister, Potter, and Barker (1974), and Wadsworth (1968) make

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note of deep-level alteration and mineralization in the context of broader discussions.

## San Manuel–Kalamazoo Orebody, Arizona

Lowell (1968) and Lowell and Guilbert (1970) tentatively identified a deep-level alteration and mineralization assemblage in the Kalamazoo portion of the San Manuel–Kalamazoo orebody, Arizona. The outer portions of this deep-level zone are characterized by slight augmentation of quartz; minor alteration of K-feldspar to sericite; saussuritization of plagioclase by sericite, chlorite, and epidote; alteration of ferromagnesian silicate minerals to chlorite, epidote, carbonate, and magnetite; and by the augmentation of magnetite. The inner portions of this deep-level zone are transitional to a potassic alteration assemblage, as indicated by the appearance of secondary K-feldspar and biotite and by the pyritization of magnetite. Deep-level sulfide mineralization is characterized by Lowell (1968) as being bleblike, with a high ratio of chalcopyrite to pyrite but with overall low copper values owing to the low total sulfide content.

## Fortuna Pluton, Chile

Sillitoe (1973) suggests that the Fortuna granodiorite may be an upthrown, deep-level portion of the Chuquicamata porphyry copper system. The granodiorite contains pegmatitic areas and a stockwork of copper oxides. Alteration in the Fortuna granodiorite is weak, and the rock becomes less porphyritic and more equigranular with depth.

## Los Loros, Chile

Mineralization and alteration at Los Loros, Chile are described by Sillitoe (1973) as characteristic of a deeply eroded porphyry copper system within a large, equigranular, granite pluton. A central core of potassically altered rock changes laterally into propylitically altered rock, then into fresh granite. Deep-level potassic alteration consists of late magmatic to deuteric quartz, K-feldspar, sericite after plagioclase, and chlorite after primary biotite, with minor calcite and secondary biotite. Pyrite and secondary magnetite are the most conspicuous metallic minerals, and only minor amounts of chalcopyrite and molybdenite are present.

## Appalachian Porphyry Systems

Hollister and others (1974) discuss porphyry mineral deposits of the Appalachian orogen. These mineral deposits are much older (346-580 m.y.) than the southwestern porphyries and have apparently been eroded to a much deeper level.

Appalachian porphyry mineralization is associated with equigranular to porphyritic quartz monzonite intrusions. The cores of these intrusions may locally contain small amounts of disseminated pyrite, chalcopyrite, bornite, and molybdenite, but more commonly they are fresh and unmineralized. Enveloping this central core are concentric alteration zones: (1) potassic (K-feldspar, biotite, chlorite, and epidote); (2) phyllic (quartz, pyrite, and sericite); and (3) propylitic (chlorite and epidote). In the potassic zone, according to Hollister and others (1974), sulfides are more abundant as disseminations than as veinlet fillings; however, veinlets become dominant in the phyllic zone. Molybdenum assays increase and copper assays decrease with increasing depth.

## Cornelia Pluton, Arizona

Wadsworth (1968) concluded that a portion of the Cornelia pluton, exposed to the west of the New Cornelia mine, may be the eroded root zone of the New Cornelia porphyry copper deposit, which was downfaulted to the east. As described by Wadsworth, this portion of the composite quartz monzonite–granodiorite parent pluton has an equigranular texture, in contrast to the porphyritic texture of quartz monzonite and granodiorite within the mine. The proposed conduit rocks to the west of the mine show evidence of minor deuteric and retrograde propylitic hydrothermal alteration or mineralization and are related by Wadsworth to intrusive rocks exposed in the mine by structural relationships and corrosive textures.

# Little Hill Mine Area

The Little Hill Mine area is located on the northwest flank of the Santa Catalina Mountains, Pinal County, Arizona, about 12 miles southwest of the San Manuel–Kalamazoo orebody (Fig. 1). Elevations in the area range from 3,800 to 4,400 feet.

## Lithology

The oldest rocks in the vicinity of the Little Hill Mine area are Precambrian Pinal Schist, which crops out mostly south of the Mogul fault zone (Figs. 2 and 3). Precambrian Oracle quartz monzonite occupies most of the area north of the Mogul fault. Numerous aplite-pegmatite dikes are associated with the Oracle quartz monzonite. Near the Mogul fault, Oracle quartz monzonite has been cataclastically deformed and has been mapped as a unit here termed the "transition gneiss" (Durning, 1972). Apache Group sedimentary rocks of Younger Precambrian age (not shown on Fig. 2) lie unconformably on the Pinal Schist south of

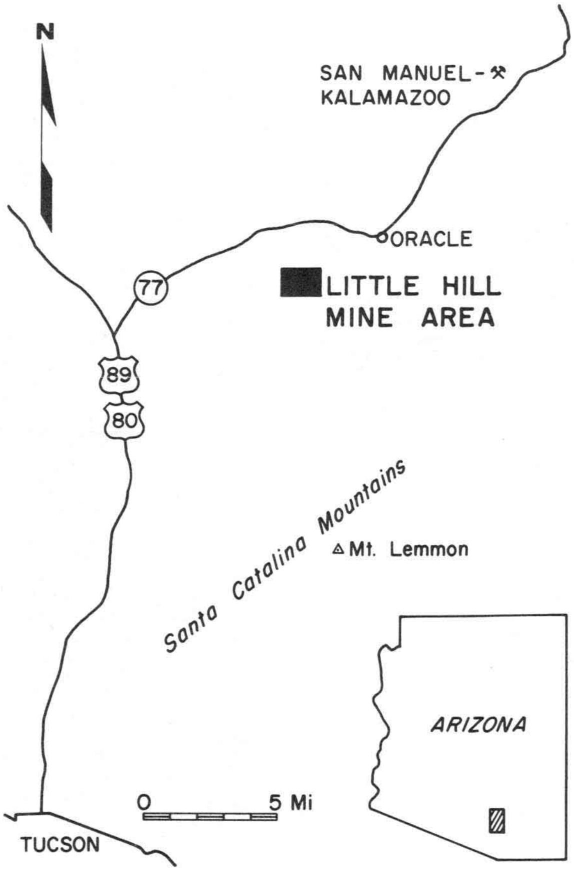

Fig. 1. Location map, Little Hill mine area, Pinal County, Arizona

the mapped area.

An intrusive body of coarse-grained, equigranular quartz monzonite has intruded the zone of deformation adjacent to the Mogul fault between the transition gneiss and Oracle quartz monzonite. This intrusive quartz monzonite has been dated by the Rb-Sr method at 163-303 m.y. The range is not unexpected because of the contamination of Laramide rocks which are intruded into this type of Precambrian environment, and the data actually favor a Laramide age for the quartz monzonite (D. E. Livingston, University of Arizona, oral communication, 1975).

The youngest rocks exposed in the vicinity of the Little Hill Mine are dikes of Tertiary age. Northwesterly trending rhyolite dikes that intrude the Oracle quartz monzonite are the most prominent and are possibly premineral. Latite, quartz latite, monzonite porphyry, and quartz porphyry dikes are also present but are of postmineral age.

### Structure

The west-northwest-trending Mogul fault is the major structural feature in the vicinity of the Little Hill Mine. Fifteen hundred feet of left-lateral displacement on the fault in the Little Hill Mine area is suggested by the offset of a monzonite porphyry dike (Fig. 2).

Estimates based on interpretation of aeromagnetic data (F. P. Fritz, AMAX Exploration, Inc., oral communication, 1975) suggest that the fault has a minimum throw of 4,500 feet.

### Alteration and Mineralization

At the surface in the vicinity of the Little Hill Mine, hydrothermal alteration and mineralization extend over an area roughly 8,000 x 4,500 feet. The alteration and mineralization are distributed among outer, middle, and inner zones (Figs. 4 and 5).

The inner, or core zone, is defined by the surface exposure of intrusive quartz monzonite. The core-zone alteration mineral assemblage consists of veinlet quartz, pervasive quartz, pervasive late-magmatic to hydrothermal veinlet-related sericite, and K-feldspar. Much sericite and secondary K-feldspar occur as envelopes adjacent to veinlets of hydrothermal quartz. Conspicuous K-feldspar occurs additionally as late-magmatic reaction rims between quartz and sericitized plagioclase. Retrograde chlorite alteration partially destroys primary and secondary biotite, and clay minerals commonly coat fracture surfaces.

Mineralization in the core zone consists mostly of pyrite, magnetite, and minor chalcopyrite associated with narrow quartz veinlets and as disseminations. Magnetite appears to be locally replaced by sulfides. Although quartz veinlets are abundant in the core zone, the average sulfide content is low, ranging from a trace to 0.75%. The range in copper values is 0.02–0.07%, and pyrite-chalcopyrite ratios range from 1:1 to 5:1. Molybdenite is present both in quartz veinlets and as disseminations in trace amounts.

Middle-zone alteration and mineralization are elongate in plan view, 5,000 x 2,000 feet, and extend easterly from the eastern exposed end of the Little Hill quartz monzonite (Figs. 4 and 5). The middle zone is well defined at the surface by rock-chip geochemical values for copper of more than 600 ppm.

The middle-zone alteration assemblage includes quartz, sericite, secondary K-feldspar, biotite, chlorite with leucoxene, minor epidote, carbonate and clay, and magnetite. Hydrothermal quartz occurs in veins and as a pervasive

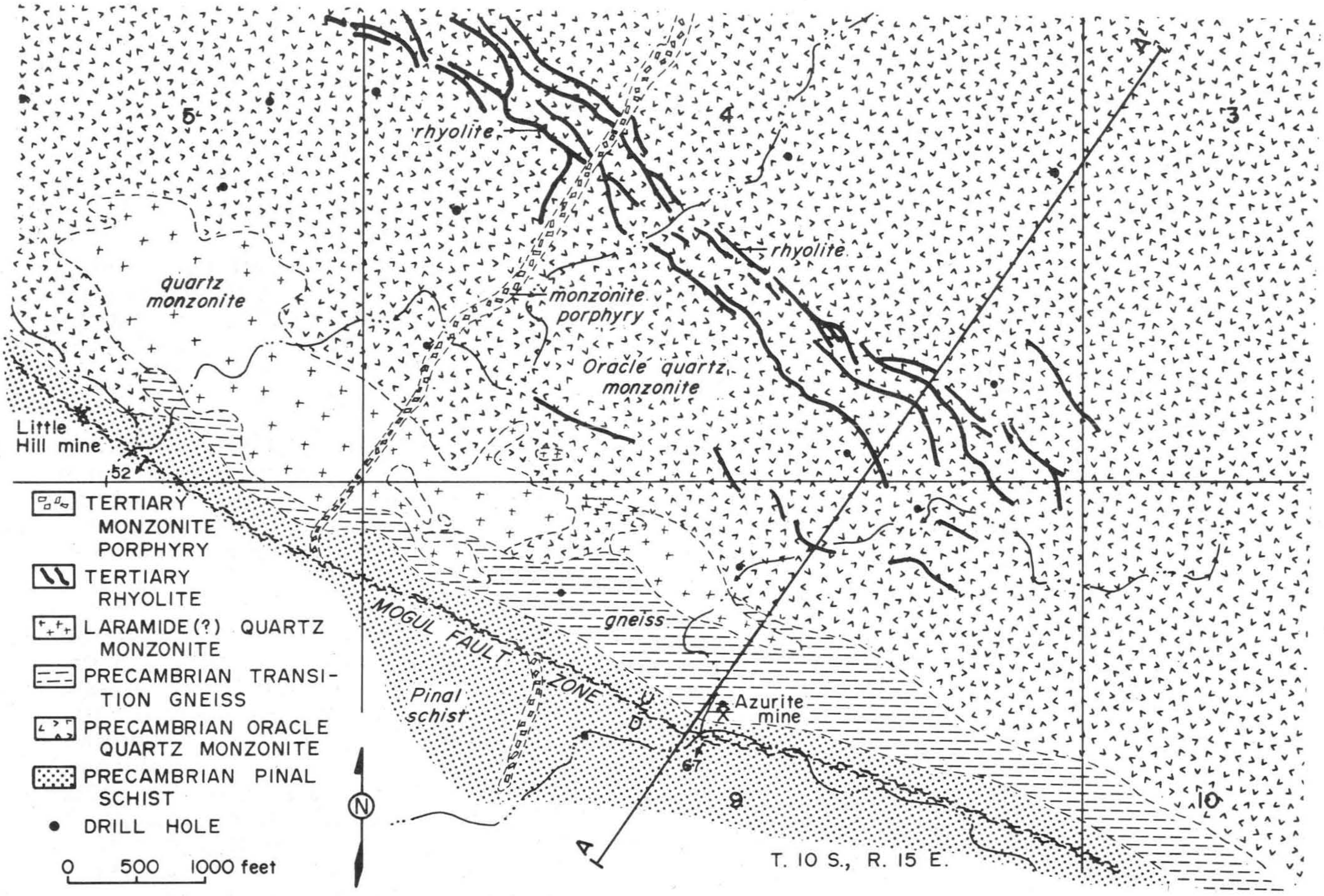

Fig. 2. Generalized geologic map, Little Hill mine area

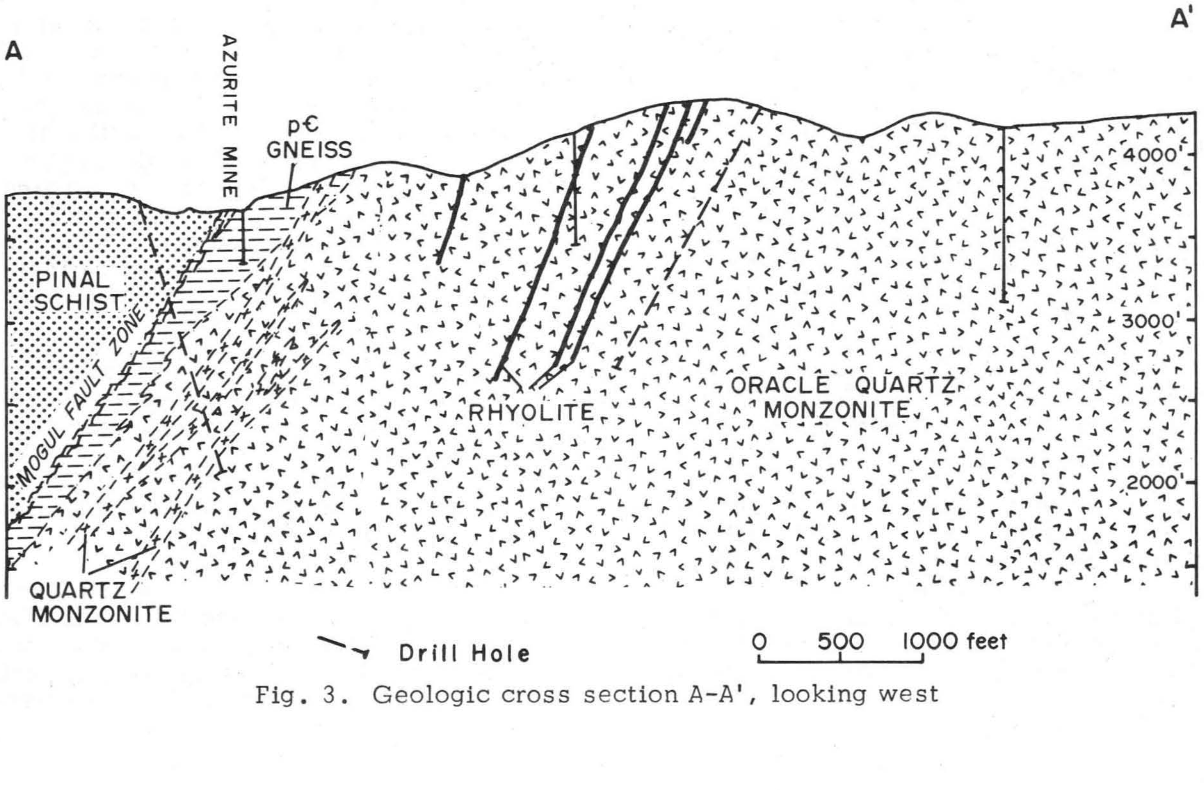

Fig. 3. Geologic cross section A-A', looking west

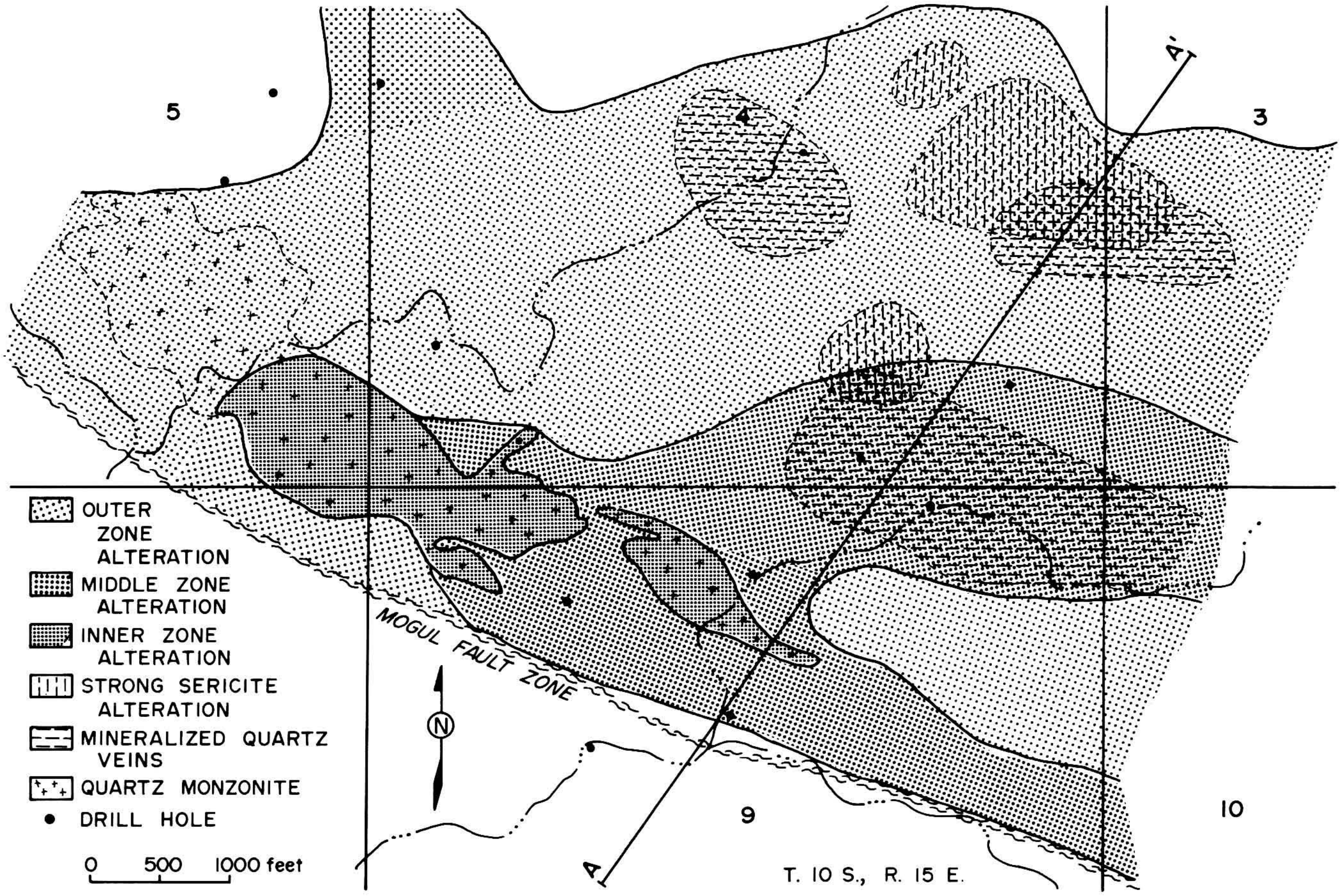

Fig. 4. Generalized alteration map, Little Hill mine area

flooding. Sericite commonly dusts plagioclase and envelops quartz veinlets. Secondary K-feldspar occurs in veins, as envelopes to quartz veins, and as local flooding. Fine-grained secondary biotite of late-magmatic to deuteric origin forms clotlike masses replacing plates of primary biotite and commonly is itself partially altered retrogressively to chlorite. Magnetite occurs with quartz in veinlets and with quartz and alkali feldspar in pegmatitic pods and lenses. Epidote, carbonate, and clay are not abundant and are mostly restricted to small, relatively late veinlets and fracture coatings.

Mineralization in the middle zone consists of spottily distributed pyrite, chalcopyrite, molybdenite, and magnetite. Copper values are highest in the middle zone. Seventy to eighty percent of the copper and molybdenum sulfide mineralization is fracture and veinlet associated; the remaining sulfides are disseminated. In the middle zone, pyrite-chalcopyrite ratios average 1:1 at the surface and increase with increasing depth to 4:1. Both copper and molybdenum values decrease with increasing depth, even though the quartz veinlets persist (Fig. 6). Magnetite fills microfractures and occurs in association with sulfide minerals in the quartz veinlets. Middle-zone copper values range from 0.10% to 0.25%; molybdenum values range from 10 to 50 ppm.

Outer-zone alteration and mineralization form a broad, diffuse, poorly defined envelope around the core and middle zones. Prominent alteration minerals in the outer zone include chlorite, epidote, sericite, quartz, magnetite, clay, and carbonate. Chlorite, locally accompanied by leucoxene, is the most conspicuous of these minerals and replaces a large percentage of the primary biotite. Epidote occurs both in hydrothermal veinlets and as a pervasive alteration product of primary biotite. Light, pervasive, probably deuteric sericitization of plagioclase is common. Relatively extensive development of sericite occurs adjacent to disseminated sulfides and as envelopes adjacent to hydrothermal quartz veins. Secondary quartz occurs mostly in veinlets and is often accompanied by finely divided magnetite. Clay and carbonate locally fill fractures.

Mineralization in the outer zone is dominated by pyrite, with minor amounts of magnetite, molybdenite, and chalcopyrite. Sulfide

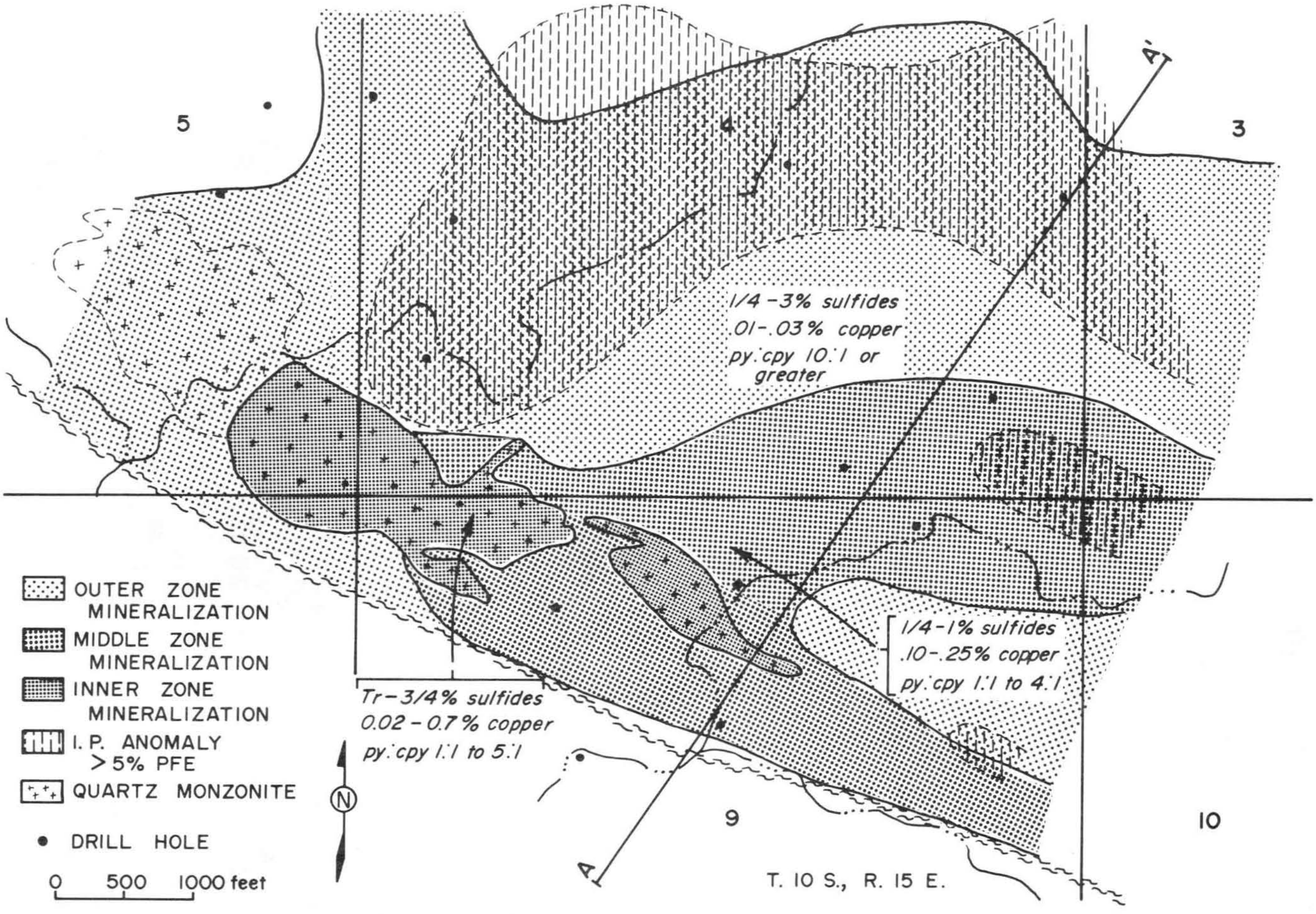

Fig. 5. Generalized mineralization map, Little Hill mine area

minerals are abundant as granules distributed throughout veinlet envelopes rather than as components of the quartz veins. Within the area of the induced-polarization anomaly (Figs. 5 and 6), total sulfide content of the rock averages 2-3 volume percent. Outside of the anomaly, the sulfide content is typically 0.5–1%. In the outer alteration-mineralization zone, pyrite-chalcopyrite ratios average 10:1 or greater. Copper concentrations range from 0.01% to 0.03%, and molybdenum in the outer alteration zone ranges from 10 to 50 ppm. Sulfide mineralization in the outer zone typically has an erratic distribution. A successive, retrograde onlap of outer, upon middle, upon inner alteration-zone mineral assemblages is apparent in the Little Hill Mine area. A similar retrogressive inward collapse of alteration-zone assemblages has been noted elsewhere (Davis, 1974) and seems to reflect the transition from late-magmatic to hydrothermal conditions.

## Discussion

Several features of the Little Hill Mine area, when compared with well-known porphyry copper deposits, suggest that mineralization and alteration associated with the quartz monzonite intrusion along the Mogul fault may represent deep-level exposure of a porphyry copper system:

1. The intrusive quartz monzonite with which mineralization is associated has a phaneritic, equigranular texture suggestive of deep-level emplacement rather than a porphyritic texture indicative of hypabyssal emplacement.

2. The assemblage of alteration minerals —chlorite, magnetite, carbonate, quartz, epidote, sericite, and K-feldspar—is compatible with deep-level exposure of the system.

3. A low overall percentage of sulfides at the Little Hill prospect and the relatively high ratio of chalcopyrite to pyrite are consistent with an interpretation of deep-level exposure.

4. An absence of Pb-Zn-Au-Ag zoning, as determined from geochemical surveys in the vicinity of Little Hill Mine, is more typical of deep-seated or submarginal mineralization than of shallow porphyry system exposure.

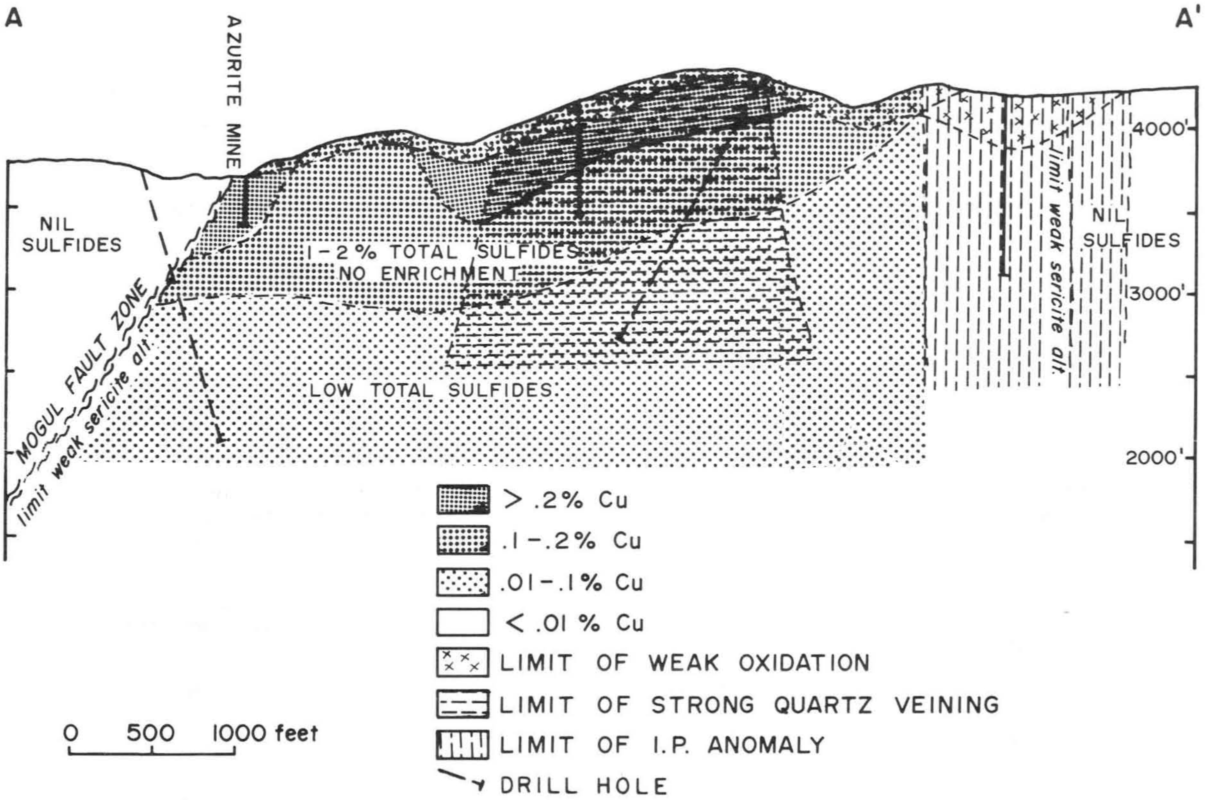

Fig. 6. Mineralization cross section A-A', looking west

At the Little Hill Mine, displacement along the Mogul fault and subsequent erosion have provided a deep, root-level exposure of a porphyry copper system. It must be stated, however, that evidence is lacking that would distinguish Little Hill as the root zone of an economically viable porphyry copper system from that of a submarginal porphyry copper system because the upper part of the Little Hill system has not been found. In the Little Hill porphyry system, crudely concentric shells of alteration and mineralization are centered around an intrusive body of quartz monzonite. With increasing depth, the intrusive rock appears to become more equigranular and alteration envelopes progressively diminish in size, extensiveness, and intensity. Concomitantly, the distinction between alteration envelopes becomes less well defined at greater depths owing to the merging of alteration assemblages. Mineralization is widely but irregularly distributed and diminishes with increasing depth. Secondary magnetite, in contrast, appears to be augmented with increasing depth.

## Recognition of Root Zones of Porphyry Copper Systems

Superficial similarity of alteration and mineralization in hood-and root-level exposures of porphyry copper systems often permit their confusion. Specifically, root zones may be confused with the peripheral zone as described by Lowell and Guilbert (1970) at San Manuel—Kalamazoo or the weak potassic zone described by Corn (1975) at Red Mountain, Arizona. Ability to distinguish between root and hood exposures is of considerable importance in mineral exploration programs. If the surface or near-surface expression of a porphyry copper system is consistent with exposure of a root zone, the following conclusions may be inferred:

1. There is minimal justification for deep testing of the exposed mineralization.

2. Significant secondary enrichment is unlikely because of the low total sulfide content at deep levels of exposure.

3. If the root-zone exposure is related to uplift along a major fault, a portion of the productive part of the system may be preserved on the downthrown side of the fault.

4. Significant amounts of copper oxides may occur in the vicinity of the root zone because of the low initial pyrite-chalcopyrite ratios and the low overall sulfide content.

Table 1 enumerates comparative characteristics, both permissive and definitive, which

Table 1. Comparative characteristics of hood-level and root-level exposure of porphyry copper systems

| Root Zone | Hood Zone |
|---|---|
| Texture and Structure | |
| 1. Mineralization frequently associated with phaneritic equigranular intrusive rock | 1. Mineralization associated with porphyritic intrusive rock |
| 2. High proportion of disseminated sulfides have a bleblike, commonly syngenetic appearance | 2. High proportion of sulfides occur in crosscutting, epigenetic textural modes |
| 3. Veinlets relatively free of vugs | 3. Veinlets commonly vuggy |
| 4. Breccia pipes absent; relatively wide-spaced fracturing; sympathetic veining related to master faults | 4. Breccia pipes may be present; abundant, closely spaced fractures; stockwork veining |
| 5. Limited number of dikes associated with mineralizing intrusion | 5. Abundant crosscutting dikes may be associated with mineralizing intrusion |
| Mineralization | |
| 1. Mineralizing intrusion barren to weakly mineralized with sulfides | 1. Mineralizing intrusion barren to well pyritized |
| 2. Low overall sulfide content (generally less than 1% in the middle and inner zones; 1-3% in the outer zone); spotty distribution of higher sulfide values | 2. Moderate to high total sulfide content (2-10%); widely distributed |
| 3. Sulfide population dominated by pyrite in the outer zone; chalcopyrite/pyrite relatively high in the middle and core zones; molybdenite commonly present | 3. Sulfide population dominated by pyrite; molybdenite typically absent |
| 4. Copper mineralization decreases with increasing depth, although veinlets persist; molybdenum mineralization persists or in-increases with increasing depth | 4. Copper and molybdenum mineralization typically increases with increasing depth |
| 5. Original magnetite content of intrusive rock augmented by introduction of secondary magnetite in veinlets and as pervasive replacement product of ferromagnesian silicates; magnetite commonly replaces sulfides; relatively high magnetite-sulfide ratio | 5. Secondary magnetite locally present, but overall augmentation of magnetite in the mineralizing intrusive rock is not pronounced; magnetite is replaced by sulfides; magnetite-sulfide ratio comparatively low |
| 6. Pb-Zn-Au-Ag zoning typically absent or poorly developed | 6. Pb-Zn-Au-Ag zoning commonly well developed |
| Alteration | |
| 1. Alteration zoning is not well defined; core-zone assemblage consists of flood and veinlet quartz, reaction rim K-feldspar after particially sericitized plagioclase, veinlet K-feldspar, and epidote, chlorite and carbonate after biotite and hornblende; core zone transitional into middle and outer zones with gradual diminution of potassium metasomatism | 1. Exposed alteration commonly consists of a single, dominantly propylitic mineral assemblage or of an inner phyllic assemblage enveloped by a propylitic assemblage; reaction rim K-feldspar absent; secondary alkali feldspar absent, or if present, albitic and veinlet related; plagioclase replaced by illite-sericite, carbonate, and epidote; ferromagnesian sillicates replaced by epidote, chlorite, and carbonate |
| 2. Most extensively developed metasomatic alteration occurs immediately adjacent to veinlets; pervasively distributed alteration not strongly developed | 2. Alteration distribution notably pervasive as well as veinlet related |
| 3. Podlike, pegmatitic masses of quartz and K-feldspar with accompanying magnetite and sulfide commonly present | 3. Pegmatitic mineralization absent |

permit distinction between hood- and root-level exposures of porphyry copper systems. Not all characteristics are present in each deposit, but identification of several of these features is generally sufficient to permit confident distinction between root- and hood-zone exposure.

## Conclusions

Study of alteration and mineralization exposed in the vicinity of the Little Hill Mine in southern Arizona suggests that it represents deep-level exposure of a porphyry copper system. An assemblage of attributes common to exposures of deep-level alteration and mineralization in porphyry copper deposits is identified. Recognition of these characteristics commonly permits distinction between the superficially similar appearance of hood-zone and root-zone exposures of porphyry copper systems.

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## References

Corn, R. M., 1975, Alteration-mineralization zoning, Red Mountain, Arizona: Econ. Geol., v. 70, p. 1437-1447.

Davis, J. D., 1974, Geothermometry, geochemistry and alteration at the San Manuel porphyry copper orebody, San Manuel, Arizona: unpublished Ph.D. dissertation, University of Arizona, Tucson, 269 p.

Durning, W. P., 1972, Geology and mineralization of Little Hill Mines area, northern Catalina Mountains, Pinal County, Arizona: unpublished M.S. thesis, University of Arizona, 91 p.

Hollister, V. F., Potter, R. R., and Barker, A. C., 1974, Porphyry-type deposits of the Appalachian orogen: Econ. Geol., v. 69, p. 618-630.

Joralemon, Peter, 1975, The ore finders: Mining Eng., v. 27, no. 12, p. 32-35.

Lowell, J. D., 1968, Geology of the Kalamazoo orebody, San Manuel district, Arizona: Econ. Geol., v. 63, p. 645-654.

Lowell, J. D., and Guilbert, J. M., 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373-408.

Sillitoe, R. H., 1973, The tops and bottoms of porphyry copper deposits: Econ. Geol., v. 68, p. 799-815.

Wadsworth, W. B., 1968, The Cornelia pluton, Ajo, Arizona: Econ. Geol., v. 63, p. 101-115.