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GEOLOGICAL ASSESSMENT OF THE LITTLE HILLS COPPER PROPERTY

By

William A. Rehrig

August 1993

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SUMMARY AND CONCLUSIONS

1. Copper mineralization at the Little Hills prospect is believed due to a sill-like(?) intrusive mass or masses of leucocratic quartz monzonite or alaskite. Although there are scattered dikes of dioritic to rhyolite composition on the property, their distribution does not correlate with overall copper mineralization. The alaskite pluton may be controlled by elements of the Mogul fault; however, in detail alaskite is present as a series of west and south dipping dikes, many of which strike NNE to NE, or NW to WNW sub-parallel to the attitude of the Mogul fault zone.

2. Curiously, the alaskite is relatively barren of copper. Instead, copper is enhanced in country rocks of Precambrian Oracle Granite adjacent to the alaskite. Mineralization appears stronger, where an abundance of small sills/dikes of alaskite have invaded transition gneiss, along the southern edge of the alaskite body and at its narrowing eastern end. In these areas the gneiss is enriched(?) in recrystallized biotite and has been structurally prepared by intense low-angle shearing and general fracturing near the Mogul fault. In addition, the gneiss hosts disseminated, intercrystalline sulfides. Ingress of pyrite and chalcopyrite here and throughout the property are directly tied to quartz mineralization, presumably from the alaskite.

As such, a zone of disseminated and fairly strong copper mineralization is formed along the southern margin of the alaskite in the transition gneiss and mylonite. The zone is structurally characterized by an abundance of low- to moderately west to south dipping structure hosting mineralization. In addition, steeply dipping quartz veins and mineralized fractures are present striking WNW and ~EW. This southern contact zone between alaskite and transition gneiss should receive focused exploration to determine copper grade and thickness of oxidation. One AMAX drill hole encountered over 100 ft of ~0.3% Cu from along this zone.

In the slaty, fine-grained mylonites, original copper mineralization may have been further dispersed by superimposed mylonitic deformation along the Mogul fault. It is uncertain if this mechanical dissemination has upgraded or diminished the copper content of mylonite compared to that in transition gneiss.

3. A broad zone of roughly EW-trending quartz veins forms the northern branch of a sideways y-shaped geochemical copper anomaly. Although veins are numerous and fairly close spaced (i.e., 1 or 2/ft), they are narrow (1-4") and there is no evidence of alteration or dissemination of sulfides between veins.

Nevertheless, because of the length of the zone (4,000 ft plus) and the fact that copper oxides have permeated host rocks, some exploration should be devoted to ascertain depth of oxidation and grade across this zone. Visual estimates would suggest grades of <0.3% copper for any appreciable volume of rock.

4. Copper concentrations would appear to vary substantially along the relatively narrow but long mylonite zone adjacent to the Mogul fault. Some areas are dominantly pyritic, others are deficient in quartz veining, others are pervasively copper stained. West of the aggregate mine site, copper appears severely diminished. Fairly extensive drilling will be required to establish economic volumes and grades of solvent extractable copper mineralization.

5. One anomalous area just east of McGee's aggregate site appears to have a limonite capping reflecting oxidation of chalcocite. The area extends to a major, NNW-striking, west-dipping normal fault which may have something to do with copper enrichment. The area should definitely be drilled

to test for higher grades of subsurface copper, either immediately beneath or down the dip of the Mogul fault zone.

6. I find no compelling evidence for a classic type (i.e., San Manuel) porphyry copper system at Little Hills. No pluton of intermediate composition is present, and the mineral-associated alaskite is unfavorably barren of copper. Most importantly, there is no pervasive or continuous alteration zoning present, as has been suggested by previous workers. Biotite-stable mineralogy, without evidence for potassic alteration, appears everywhere with only localized superposition of chlorite, epidote or coarsely crystalline sericite.

Quartz-sericite alteration with very low sulfide associations is dominant within the alaskite; however, I would certainly not call it a porphyry copper related phyllic zone.

Previous drilling on the property also failed to encounter indications of any San Manuel or Florence type porphyry copper system.

7. A number of phases of quartz veining may be present. The narrow veins of the EW-trending northern copper zone carry low sulfide contents but a high cp/py ratio. Conversely, the prominent, thick, and strike-continuous white quartz veins appear to be mainly pyritic. Veins in the alaskite carry very low sulfides as pyrite, yet veins in the adjacent Oracle granite are richer in copper.

MEMORANDUM

To: Mr. Mike Gustin, Exploration Manager
CAMBIOR USA., INC.

From: Dr. William A. Rehrig
AGS INC.

Date: August 10, 1993

SUBJECT: REPORT ON GEOLOGICAL EVALUATION OF THE LITTLE HILLS COPPER PROSPECT

Introduction

At your request, I have spent 4.5 field days in early August inspecting the Little Hills copper prospect which is located some 25 miles north of the town of Tucson, on the back side of the Catalina Mountains. The property has belonged for many years to a Mr. Dave McGee who lives on the property. It received much attention as a porphyry copper play during the early 1970's.

Because of having past experience and data on the prospect, I was asked to focus on aspects of a possible porphyry copper model at Little Hills, paying particular attention to possible Laramide intrusion, alteration zoning and structure and their relationships with copper mineralization.

The following report summarizes my findings. Appendices found at the end of this report contain earlier Conoco data and my field notes (keyed to Fig. 1, Geologic sketch map).

Geology

Lithologies:

To the north of the Mogul fault on its footwall side, rocks consist exclusively of crystalline plutonic and gneissic types which include Precambrian Oracle Granite, foliate and mylonitic equivalents, and Phanerozoic intrusive rocks as dikes and a possible stock.

The predominant rock belongs to the Precambrian basement complex of this part of Arizona and consists of the 1.4 Ga Oracle Granite. This plutonic rock is actually a quartz monzonite porphyry and its type locality is the town of Oracle, located just northeast of the Little Hills prospect. At the property, the Oracle Granite is generally a medium- to coarse-grained, holocrystalline quartz monzonite, with ~10% biotite and quite variable amounts of K-spar phenocrysts.

The Oracle Granite becomes foliate with well-developed mineral lineation near the Mogul fault, the major shear zone that passes through the property. Biotite crystals in the granite become recrystallized into an abundance of clots and mattes of medium- to fine-grained multiple crystals (Refer to discussion of "Structure", below). Further southward, this gneissic rock becomes overprinted with mylonitic deformation along the fault zone. This deformation has resulted in progressive destruction of original plutonic crystalline textures in the rock, resulting in a fine-grained, schistose mylonite.

Intrusive into the Oracle basement are a variety of plutonic rocks. Precambrian types may be present; however, most are considered to be of Laramide or Tertiary age. The most common intrusion, and the one most important to mineralization, consists of a light-colored, fine- to medium-grained, equigranular quartz-monzonite or alaskite. This rock is nearly everywhere altered to some degree, the typical alteration consisting of sericitization (i.e., coarsely crystalline muscovite). Consequently, the rock is usually devoid of dark-colored ferromagnesian minerals. In rare unaltered exposures, original euhedra of fresh biotite compose approximately 5% of the rock.

A variety of dike rocks are noted in the Little Hills area. Rarely, elongate bodies of diabase are found in the Oracle Granite. They probably represent Late Precambrian intrusion so widespread in the basement of Arizona. Finely flow-banded rhyolite dikes are common trending northwest. Dikes of latite or quartz latite may be related to the rhyolites (See Conoco geologic map in pocket of report). Occasional aplite-micropegmatite dikes are noted, which may be related either to the alaskite intrusion or to the Oracle Granite. Rarely, a gray, fine-grained, porphyritic monzonite(?) or moans-diorite was mapped in several dikes striking to the northeast. One prominent dike of this type is noted on the map of Durning and Davis (1978) and Conoco's geologic map (See Map pocket). It is post-mineral with respect to the alaskite and associated quartz-sulfide mineralization. I encountered another dike of this type (See Fig. 1), which cuts mineralized quartz veins, yet carries disseminated chalcopyrite.

At specific localities (i.e., Hill 4444, west of McGee's aggregate mine, and as isolate dikes throughout the property; Fig. 1), a coarser grained granite is mapped. The granite is ferromag-poor, consisting only of orthoclase and abundant quartz. Some of this granite, especially that mapped on Hill 4444, is believed related to the alaskite intrusion, because fine-grained alaskite also abounds in the area. The granite west of the aggregate mine is pervasively affected by mylonitization, and may be a separate intrusion possibly of Precambrian origin.

South of the Mogul fault, hanging wall rocks consist of Pinal Schist, unconformably overlain by sedimentary rocks of the Late Precambrian Apache Group which are intruded by diabase sills. I did not venture into this area during my work.

Structure:

By far the dominant and most important structure of the prospect area is the WNW-striking Mogul fault. This fault is part of the package of major shear zones crossing southern Arizona known as the Texas Lineament. The Mogul fault or fault zone is believed to project many miles out of the Catalina Mountain area to the east and west.

In the Little Hills area, the fault is marked by a wide zone of deformed basement rocks as has been well described by Durning and Davis (1978), by Conoco (See Appendix 2), and other workers. A point of clarification is warranted here with respect to fault-zone units designated by these previous workers. Both Durning/Davis and Conoco refer to a "Transition Gneiss" unit mapped north of the fault trace.

This nomenclature refers to what I would call foliated Oracle Granite. Significant textural changes and perhaps minor compositional modifications have occurred to the granite because of concurrent (i.e., Precambrian, ~1.4 GA) fault-induced deformation. Feldspar and biotite are recrystallized and become finer-grained. Quartz grains are deformed and strung out. Manifest mainly in biotite and quartz is a pronounced mineral lineation. The Oracle granite has become mylonitically deformed; however, the original plutonic protolith is still recognizable. So although referred to as a transition gneiss, it should be realized that the unit is still Oracle Granite. With that understanding, I will continue to refer to it as "transition gneiss", because it has an identity important to mineralization.

Nearer the Mogul fault, transition gneiss is transformed by fault-generated stresses into a progressively darker-colored, finer-grained, and schistose mylonite with further recrystallization and physical grain milling and/or fragmentation. Biotite is commonly shredded and altered to a very fine matte of chlorite. Ultimately, discrete mineral components become indistinguishable. Commonly the mylonite is very thinly laminated with a well-developed slickenside-like lineation. Light-colored mylonite units, believed to be felsic or granitic sills or dikes, are interleaved with the dark ones. Intricate, small-scale inter-folio, sheared out chevron folds are common in the finer-grained mylonite sequences.

The schistose mylonitic rocks have been mistakenly mapped by previous workers as Pinal Schist (See Conoco geologic map).

The actual trace of the Mogul fault is recognized by a sudden and erratic change from schistose mylonite to cataclastic rocks and breccias, mainly of ferruginous character. Just east of the McGee's aggregate site, an interval of exotic blocks of quartzite breccia may represent drag material of Late Precambrian sedimentary rocks from the hanging wall.

The geometry of fault-related structures is as follows. Along the fault zone, deformational foliation strikes NW to WNW, parallel or subparallel to the trace of the controlling Mogul fault. It was noted in field work that commonly the strike of transitional gneiss is about N40-50W, only sub-parallel to the fault. Closer to the Mogul fault, this crystalline foliation appears to gradationally change to or become superimposed by more intense mylonitic foliation striking about N70W. Foliation of gneiss and mylonite dips consistently from about 40 to 60 degrees SW to south.

Pervasive lineations occur on mylonitic foliation planes. Mineral lineation of the transitional gneiss trends south to about S10W. Slickensiding lineation of the mylonite and ultramylonite consistently plunges S10-20E. These directions would indicate a dominant dip-slip component of slip along the Mogul structure.

An abundance of shallow to moderately dipping structural elements are present in mineralized ground north of the Mogul fault trace, for distances of up to about 2,000 ft. These shallower dipping features are not evident farther north and east in relatively barren Oracle Granite. The elements consist generally of quartz veins and altered zones containing quartz, hydrothermal muscovite, chlorite, epidote, and sulfides, and dikes of alaskite. The attitudes of these low-angle mineralized elements vary significantly; many parallel the Mogul fault, others do not. Common directions of strike include: N60-80W, N40-50W, N15-25E, all with 20 to 50 degrees west or southerly dips (See Fig. 1). The absence of low-angle structures with dip to the north or east is striking and must relate to specific stress trajectories along the Mogul fault.

Regardless of the strike direction of low- to moderate-dipping mineralized structures, they persistently exhibit slickensided lineation bearing from ~N10E to N20W, generally parallel to that found along mylonitic foliation paralleling the Mogul fault.

In addition to low-angle mineralized zones and dikes, there is the widespread presence of steeply dipping (i.e., >60 degrees) veins, and mineralized fractures and shear zones. The strike on these structures varies only between about N80E and N70W, and a great deal of EW-striking structures are present (Fig. 1). Veins of quartz spatially associated with and commonly surrounded by envelopes of sericite (muscovite) and sulfides (pyrite>>chalcopyrite) vary in width from as much as 50 ft to mere veinlets and fracture coatings. The wide veins can be traced for considerable distances along strike (Fig. 1), but in detail are commonly broken and offset short distances by cross faults. Nearer the Mogul fault, these veins dip steeply south. For the great majority of thinner veins, especially those farther to the north, the dip is consistently 60-80 degrees to the north.

Although the overall map shape of the alaskite intrusion is WNW, subparallel to the Mogul fault, close inspection of alaskite masses show that the pluton is commonly represented by sill/dike bodies of relatively low-angle dip. Like the quartz-sericite-sulfide zones, these sills strike most commonly WNW, N40W, and especially N20 to 50E; all with westerly to southerly dip.

Intrusion of the mineral-related alaskite appears to be syn-deformational, at least with respect to deformation along the Mogul fault. In places, sills are far less mylonitic or foliated than enclosing Oracle Granite. Nearer the fault trace, the alaskite dikes and sills show more intense mylonitic deformation.

A few high-angle normal(?) faults striking NNW may represent Tertiary extensional structures. The faults cut across Mogul-related structures and dip 50 to 70 degrees west. The most prominent of these faults is mapped just east of McGee's aggregate site (Fig. 1). It consists of a broad 50 ft-wide zone of fault splays, brecciated zones, clay gouge, and strong argillic alteration.

Mineralization:

Weak but relatively continuous copper mineralization is observed along the Mogul fault zone from the aggregate site eastward at least to Margaret Wash (Fig. 1). The area of copper north of the fault broadens significantly through the north part of section 9 and into section 4 (T10S, R15E) (Fig. 2). This broad zone narrows eastward but continues several thousand feet straddling the boundary between sections 3 and 10.

In more detail, the distribution of anomalous copper is controlled by three geologic elements or settings.

1. Mogul fault mylonite/breccia zone: Copper occurs immediately adjacent to the outcrop trace of the fault in rocks that have been intensely mylonitized, shattered, and partially brecciated. These host rocks are the dark-colored, slaty, schistose mylonites that have minute quartz laminae and hydrothermal veinlets contained in the foliation and cross-cutting it as near-vertical veinlets. A certain amount of true dissemination may also occur in these rocks, with intergranular sulfide replacement and deformational redistribution or dissemination of former sulfides. From the relatively high ratio between copper and iron oxides, a relatively high cp/py ratio is inferred. Locally, (i.e., traverse site #42, Fig. 1), pyrite greatly exceeds chalcopyrite. There has been sufficient shattering and local brecciation of these rocks by renewed fault movement to widely disperse secondary copper oxide mineralization.

2. Transition gneiss mineralization adjacent to alaskite intrusion: At all scales, copper is enhanced adjacent to the alaskite intrusion(s). A good part of the broadening of copper through sections 9 and 4 is owed to mineralization fringing the alaskite (See Fig. 2). Although the alaskite itself is unusually barren of copper, the surrounding transition gneiss formed an excellent host for disseminated sulfides and for veining associated with both low- and high-angle structures. Tiny sulfide aggregates are pervasive through the gneiss associated with small quartz pockets, deformed quartz veinlets and in crystal clusters of biotite. Whereas many of the larger white quartz-sericite veins appear to have contained mostly pyrite, the sulfide disseminations appear to have higher cp/py ratio. Estimate of overall sulfide content in transitional gneiss is from about 1/4 to 2%.

3. EW-trending quartz vein zone: Running along the common boundary of sections 4 and 9 and sections 3 and 10 is a broad EW zone (Fig. 1) of multiple quartz veins which carry low total sulfide but relatively high copper. Veins of the zone define small dihedral angle strikes of EW to N80E and N70-80W, with from vertical to 60 degree north dips. They vary from about 1" to 4" in thickness, with a distribution perpendicular to strike of about 1 to 2 veins per foot of rock (Figs. 3 & 4). Original copper sulfides are completely confined to the veins with no dissemination outward into the

wall rocks. Wall rocks of relatively undeformed Oracle Granite show no effects of hydrothermal alteration (i.e., fresh biotite). Only secondary copper oxides have permeated into the Oracle granite host rocks.

It should be noted that although copper diminishes suddenly to the immediate north of the copper/quartz vein zone, quartz veins and a persistent set of N70W, steep north-dipping hydrofractures do carry pyrite and extend for at least several thousand feet farther north (Fig. 1).

In the SE corner of section 5, a small area extending from the aggregate mine eastward to the major N20W-trending normal(?) fault features mineralization marked by dark red/maroon-colored iron oxides with traces of copper oxide minerals. This "capping" is distinct from the yellow-orange-brown iron oxides elsewhere on the property which were derived from pyrite and chalcopyrite. Both color and texture of hematitic oxides after sulfides suggest former supergene chalcocite. Some of the more pervasive ocherous red limonites may be secondarily derived from localized capping possibly after chalcocite.

Since this area of possible chalcocite (enriched copper at depth?) appears confined to the immediate hanging wall of the N20W normal fault, supergene processes may have been controlled in some way by this structure which cuts obliquely across the Mogul fault zone.

Tracing this hematite capping to the west is difficult because of the cover created by McGee's aggregate operations. West of the aggregate site, mineralization, at least as exposed in low hills north of the Mogul fault, seems significantly diminished. There is no alaskite in this area, and a peculiar, mylonitic, coarse-grained leuco-granite is cut by barren, white-gray quartz veins.

Alteration and Alteration Zoning:

During the early 1970's the Little Hills area was comprehensively explored as a porphyry copper prospect. Drilling was done by Magma Copper Co., AMAX Inc., and CONOCO. Also during this era, the prospect was geologically studied by Durning (1972) and Durning and Davis (1978). From personal experience, I know that CONOCO considered the prospect to be the periferal part of a buried porphyry system of the San Manuel or Florence type (See appendicized data).

This concept was based on what was thought to be a wide zone of propylitic alteration, obvious anomalous copper, and favorable structural setting in the footwall of the Mogul fault (Refer to data in Appendix 2). CONOCO'S drilling was focused in the hanging wall of the fault and probed the footwall at considerable depths.

Work by Durning and Davis (1978) delineated alteration zones defined as Inner (in the alaskite), Middle, and Outer. The zones generally can be described as follows: Inner (core) = potassic and quartz/sericite; Middle = mixed potassic-sericitic-propylitic; and Outer = propylitic. These workers concluded from this zoning and other geological evidence that the Little Hills copper occurrence represented the deep root zones of a classic porphyry system.

Some 20 years later, my renewed field interpretation of the alteration differs substantially from that of earlier workers, including myself. The new interpretation can be introduced by this statement: With the exception of alteration in the alaskite, there is no continuous or pervasive alteration zoning present in the Little Hills area.

The Oracle Granite is an ideal homogeneous host rock for reflecting effects of significant hydrothermal alteration caused by any hypothetical porphyry copper system. Careful search in the granite failed to document any pervasive hydrothermal alteration, other than that expressed locally along discrete structures. Except for these localized occurrences (See discussion below), biotite is fresh and unaltered, and commonly occurs that way even when intimately associated with disseminated sulfides.

This lack of alteration also applies to the strong zone of EW quartz-copper veins which form the northern branch of the Y-shaped geochemical anomaly (Fig. 2). Fresh biotite, without signs of potassic alteration, occurs right up to vein contacts.

As noted above, evidence for significant potassic alteration in the Oracle Granite are also lacking. No obvious secondary biotite is observed, except for what has occurred in the transition gneiss by processes of mylonitization and recrytallization. In rare localized outcrops or road cuts, the Oracle Granite where well mineralized and/or where intensely intruded by alaskite, takes on a somewhat lightened or pale pink color, possibly due to feldspar replacement. Some of this may be owed to contact metasomatic effects; regardless, such alteration is not sufficiently extensive to represent any potassic zone of a porphyry copper deposit.

The following kinds of localized alteration were observed in the Oracle Granite.

1. Pervasive coarsely crystalline sericite (muscovite) within and as selvages to quartz and quartz-sulfide veins. Adjacent to major (5-50 ft-wide) veins, sericite selvages attain substantial widths (up to 50 ft); with small veins and veinlets, sericitization is correspondingly diminished.

2. "Disseminated" chlorite (after biotite) and muscovite in close spatial association with sulfide/quartz mineralization localized in disseminations and hairline fractures. This alteration occurs on a very small scale with unaltered biotite also present, even in hand-sized samples.

3. Restricted areas of more pervasive propylitization where biotite is altered to chlorite, and epidote appears replacing plagioclase and on fracture surfaces. This alteration was noted, affecting perhaps up to 50% of the rock at traverse sites 6, 13, & 18 (Fig. 1).

4. Propylitic selvages to pyritic hydrofractures. Biotite has been chloritized adjacent to pyrite veinlets, affecting up to 50% of the Oracle Granite, through a wide area north of the copper mineralized zone in section 4 (Fig. 1). This alteration is rigidly structurally controlled as selvages to WNW-striking joints. Where jointing becomes wider spaced, fresh biotite occurs between the hydrofractures.

Within the alaskite, alteration is more consistent and pervasive (Durning's core or Inner zone), and consists of coarsely crystalline sericite (muscovite), closely associated with an abundance of quartz veins cutting the pluton(s). The sericite occurs in the veins and as alteration envelopes adjacent to veins. Veining is sufficiently intense to effectively result in most of the host rock being sericitized or bleached to some extent.

Secondary feldspar alteration noted by Durning and Davis (1978) may be present; however, I believe some or all of it is related to late stage magmatic quartz/feldspar diking and not hydrothermal processes associated with sulfide mineralization.

In only two localities, was fresh biotite noted in the alaskite. This occurred in small several meter-sized areas along traverse intervals 14 and 31 (Fig. 1).

FIGURE 1

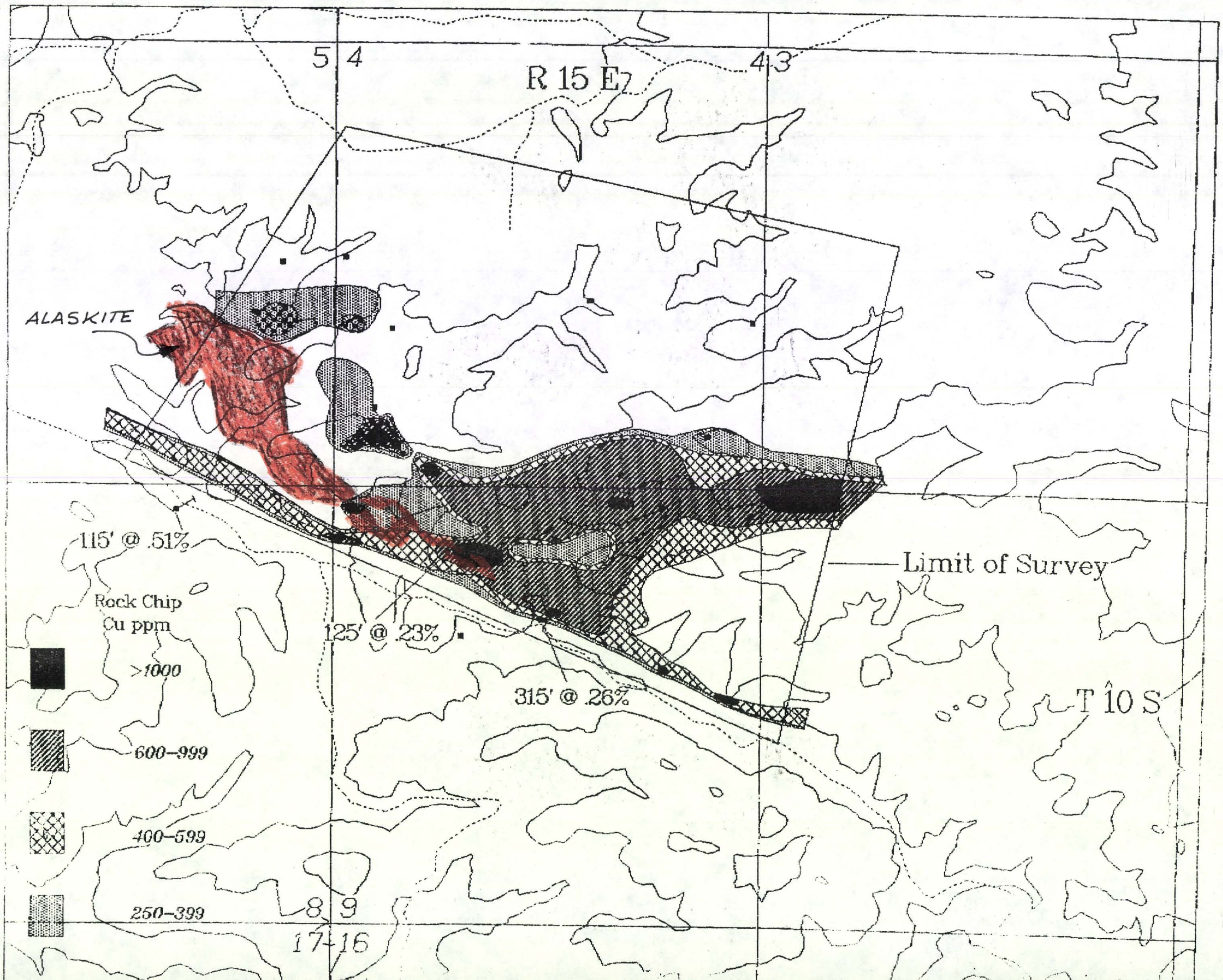
SKETCH MAP OF LITTLE HILLS PROSPECT AREA SHOWING RECORDED FIELD DATA. Traverse numbers are circled and correspond to field notes contained in Appendix I. Principal litholigy contained in mapped area consists of Precambrian Oracle Granite which has been left uncolored. Alaskite intrusions are shown in purple. Dikes of rhyolite, latite or quartz latite are shown in orange. Dikes of fine-grained, porphyritic monzonite(?) which cut sulfide/quartz veins are shown in dark green. Quartz veining is shown by red lines. Multiple hydrofractures containing pyrite, chalcopyrite and/or quartrz are indicated by the following symbol:

Fault or shear zones are colored blue. Mylonitic foliation is shown by standard symbol along with direction of lineation or slickensiding. The trace of the Mogul fault occupies the major WNW-trending drainage with road along it.

The EW-trending zone of steeply north dipping quartz-copper veins is shown in pink. The area of possible chalcocite mineralization, as suggested from limonitic capping, is demarked in yellow.

FIGURE 2

GEOCHEMICAL MAP OF COPPER OVER THE LITTLE HILLS PROPERTY . Data supplied by Cambior. In orange is shown generalized outcrop of alaskite with highly anomalous copper fringing this intrusion in Precambrian Oracle Granite.


5 4
4 3
R 15 E
ALASKITE
115' @ .51%
125' @ .23%
315' @ .26%
Limit of Survey
T 10 S
Rock Chip
Cu ppm
>1000
600–999
400–599
250–399
8 9
17 16

APPENDIX 1

FIELD NOTES TAKEN DURING PROPERTY EXAMINATION

Aug. 2 '93 · LITTLE HILLS, AZ · JOB FOR CAMBIOR USA INC. CU-PROSPECT

Ogr = Oracle Granite
bio = biotite
$S^=$ = sulfide

(1) Ogr · Extr.-mod. mylonitic; deformed f.gr. musc? granite s/1s occsly. 30% zones of strg. propylit. assoc. w/ qtz-$S^=$ vning. 70% releft. fresh rexliz. (clots of f.gr.) bio. Mod. qtz vns/vnlets ∥/subparallel to fol. Most non-sulfidic; larger ones w/ Feox/Cuox. Qtz syn-late deformat. Cu = < .1% (prob. 100-500 ppm) Some thinner vnlets ~ vert w/ N50-60E.

propy = propylitic
vns = veins

(2) (To major qtz vein - (2A)) Ogr. sl. mylonitic; moderately mylonitic in narrow zones which are minor in interval) Gen. non-propy.; bio in f.gr. clusters & mattes. Intense qtz-ser (c.gr.) pyrite adj. to major qtz vns. (2A) Minor qtz vns w/o much $S^=$ or Cu sub-∥ to weak foliat. & syn-late deformation. No visible Cu in this interval; except traces w/ large qtz vns.

Some qtz (white) w/ Ksper + muscov. as pegmatoidal zones.

(2A) Major qtz vein + qtz-ser-$S^=$ 50' wide. On one side is f.gr. gd. (sl. def.?) dike w/ Cuox. Sample ____

(3) Ogr intruded by felsite & assoc. qtz-musc. vns. No signif. $S^=$ or Cu. Ogr. non-propy.

sl = slightly
def = definitely
cp = chalcopy

(4) Ogr. non-mylonitic, only sl. foliate. From EW - 50' qtz. vein, interv. is of Ogr. intruded by 2-10" dikes of f.gr. bio-bearing granite or alaskite (SAMP 4) Alask. def. assoc. w/ Cu + Cu-qtz. Ogr in interval is cut by qtz-$S^=$ (cp) veinlets 1-2/' EW-N80E, 90° Bio. vnlt. in & adj. to vnlets. Possible bio + Ksper in some veinlets w/ qtz. Cuox weak (500-1000 ppm) but pervasive. estimate

(5) mass = massive

Ogr. mass. uniform; sl. foliate xlike (non-mylonitic. 80% bio fresh as f-m-gr mattes, 10-20% dark chl. - not pervas. Sev. flow-lamin. rhy. dikes w/ intense qtz. lamanae ∥ to contacts & swirling. 1-2' grey dacite dike w/ hrnbl. pheno. strikes N55E. 0.1"-4" (avg. 2-4") qtz veins - EW & WNW (70-60) occslly - not intense - wide spaced. Some epidote showings. Granite very blocky & poorly fractured. No signif. Cu noted.

(6) chl = chlorite

Ogr. - sl. foliated but massive, distinctly coarser-grained clots of bio. ~10-15% to chl. Generally fresh. Cut by numerous 2-6" qtz. veins w/ Feox & traces of Cuox. Veins persist. ~1/1-2' (occslly more). Not much alt. assoc. w/ veins. Traces of epidote/chl. & occsl. c.gr. sericite. NW-rhyolite-alaskite dikes cut by qtz. veins.

Note: 1-5-10' wide monz. dike SAMP. LH-6 (grey) N50E contains dissem. cp + Cuox. More Cu noted in Ogr. near dike.

Note: qtz. veins do not cut dike. This interval fairly well mineraliz. w/ Cu (est.) 500-1000 ppm overall. Veins strike N70E - EW; 60-80° N.

(7) wk = weak
obv = obvious

Ogr not very megacrystic. Same for (6). c. gr. bio. clusters abdt. Only traces to 10% chloritic along fract. Chl. very poor overall.

Abdt qtz. veins w/ low $S^=$ but perves. wk. Cuox. Veins EW ± 10 60-70° N. Also N70-75W ~ vert. No obv. alteration in wallrocks. Veins 1-3/ft 1"-6" width. No dikes, except at start of inter. where 1-2 mica-garnet granite dike stks N70°W.

(8) Ogr. unalt. fresh c.g. bio. Signif less qtz. vns. except 1-2 3-10' wide ones. 1-200' area of N60E 20NE 1-10" vns. w/ S= & tr. Cuox.

(9) Large wht qtz vein (5-10') in zone of qtz-sericite-py. On south side of vein Ogr is bleached & propylitiz. for 50-200'.

(10) Ogr- Generally unalt & unveined (several N65-70W, 2-4' qtz-S= veins). Ogr. not very megacrystic Bio. as c. gr. xls & mattes. (Some N20E flow fol.?)

(11) Rather sudden change to mylonitic Ogr. Foliation seems to swing from N30W gradually to N70W.
Myl. Ogr picks up Feox + qtz veins, but no Cuox seen until near road.

(12) Mylonite - ultramyl. Extr. drag isoclines & multiple shears; tight & some siliceous sections, other f. gr. grey mylonite - 2ndary deform. qtz. is intense but w/o mineraliz. N20W linect. pervasive. poss. mylonitic gd. f.g. sill?
Interfolio shear folds w/ axes S40-55W, 30°

(13) From mylonitic Ogr to sl foliate Ogr. weak but perv. S= + Cuox. S= dissem. in rock & a few veins. SAMP 13

SAMP 13A — Part farther N intensely intruded by dikes/sills of leucogranite - some foliate other not. leucogr. mineraliz. w/ S= + qtz veins. Enclosing

Ogr. is intensely propylitic (chl.) + Cu-bearing Qtz vnlets + veins up to 4" carry Cu. Dikes appear to trend sub-ll to foliat. + shearing of Magul flt. but in detail stk. NS to N40W & dip 30-40° W. Intrus. believed cause of mineraliz. *

Section est. Cu = 500 ppm overall 1000-5000 locally. Dike sample

Excell. exposures of N50-70W low-∠ shears & slips w/ excell slicks N15-20W.

* Alaskite (micro-granite) carries dissem cp + py + dissem cp in biotite (chl. in places); foliate (slight) Ogr. is the host rock.

(14) Alaskite (nearly completely - starting southward as sills (6"-2') & then totally Alaskite. In part cut by deformed zone sev. hundred ft. (on horizontal) w/ intense shearing & alteration (qtz-seric). Zone stks NW-WNW w/ 30-40° S. dip.
Abdt qtz. clots & veins but they carry only rare Feox after S= No Cu-ox seen in this interval. Veins w/ common c. gr. sericite.
One small area in Alaskite has coarser xline texture & ~5% euhedral biotite. SAMP. LH-14

(15) Change back to mainly Org. Org. ~10-20% is of Alaskite sills & dikes assoc. w/ qtz veining. Ogr. mainly w/ fresh med. xl clots & mattes of biotite.
<10% overall — Chl. & muscovite v. locally assoc. w/ spotty sulfides. (Feox). Former S= may average 1/4-1/2% on fract. (low) dissem (mod) & w/ qtz veining & assoc musc-py? alt. halos. No Cu-ox seen. Note bio & muscov. coexist locally w/ S= in pockets, dissemnat. & veins.
ions

O gr. generally only weakly foliated. (northerly [illegible] lineation?) but there are v. common platy low-∠ fracturing & low-∠ qtz-filled, foliated shear(?) zones invaded by Alaskite + qtz. Trends = N20E, 30°W.; N40W 30-40° S. Vertical qtz veins + vnlets also present (EW to N75E & N75W) but 60°N dip not signif. abdt. Qtz is white & gen w/ low S= to nil S=. Other qtz has more common S=. No dikes, other than Alaskite.

(16) Road skirting top of NE-ridge to top.
Alask. + Ogr. veins + dikes N20°E 40°W w/ slicks + striae on veins = N20E to NS.
Common qtz cuts Alask. N70-75W, 60°N. 1 or 2 2-3' qtz. w/ much FeOx. Still not Cu ox. Overall S= ½%?
Most common fracturing + qtz. veining on ridge = N20E to N20W, 40-50° W dip. cut both Ogr + Alask. Fairly strong FeOx but no CuOx.

(17) 80% Ogr 10-20% Alask. sills. Ogr is 80% fresh, 20% chloritic. Qtz (± S=) veins strike N20E 20-30°W. Also direct. of Alask. sills. 1 or 2 WNW-EW, 40-60°N veins.
Traces of CuOx at drill site cuts.
Still note dissem. S= (FeOx after py & cp) in Ogr. where more chloritized.
No signif. high-∠ veining or mineralz.
~drill site { Fairly pervas. wk diss + hairline fract. FeOx after S= w/w/o qtz. Some epidote present.

(18) Ogr. Pervasive alteration as follows:
~10-50% of biotite gone to chlorite w/ signif. occurr. of epidote, also. Epidote on numerous fractures. Some areas locally have 50%-70% epidote-chl. of bio.

18 cont. Pervasive qtz. vnlet, vein & fracture mineralz. w/ traces of CuOx. << FeOx.
Min. structure = 1/ft to 1/2" Occsly several/ft. Rock shows pervasive, partial alteration. Chl/epid, S= (FeOx) w/ qtz. on fractures.
Cu - est. 200-500 ppm overall.

Veins stk EW - N80W & N80E. Dip is ~vert. but mostly 60-70° N. Occsl N60-70E structure. Flat shear zones & veins appear to have disappeared or are not as evident.

(19) Abdt alaskite - granite intrusion into Ogr. Ogr appears to have been granitized. Less biotite - more qtz + Kspar. Thought I was into a separate QM. granite intrusion.
Alaskite bodies appear to trend down ridges (NNW), but there's alot of irreg. coalescing.
Have def. lost Chl-epidote w/ 90% + large xls of biotite. Tendency to be single xls. Samp ______. Qtz veins continue EW ± 10° but are not so frequent as (18). They come in bunches w/ wide spaced between. Cu ox in weathered Kspar is very weak but present where qtz. vns are more common.
Very little to Nil FeOx in interval.
Traces of dissem S=, but rare overall.
Not nearly as many qtz veins as in valley to the south.

(20) Largely cov. but Ogr w/ fresh c. gr xls. bio.
20% Alaskite + gr. A few N60-70E-stking. 1-3' qtz veins. MnOx - Not much thin veining or FeOx after S? present in veins.

(21) Ogr. Fairly barren w/o much veining & w/ fresh biotite.

(22) Grey monz. dike & qtz. vein. Dike looks like one at (6). Quite a bit of Cu ox assoc. w/ dike & 3-5' vein. Can't tell if dike cuts qtz. vn or vice versa.

(23) Ogr. Well fract 2/1' w/ ll qtz. veins: EW ± 10, 70-80° N dip. More vein population than elsewhere. (See photos). Traces of Cuox but v. low overall. Feox after S=. Ogr. is unalt except for c.gr. musc. along some veins. No chloritiz of bio. Poss. 2ndary Kspar addition to Ogr. (See samples). Veins vary from 1-4" (avg = 2"). No evid. of dissem mineraliz. between veins.

(24) Decidedly grey barren Ogr. No hydro-fract. or small veins. Only 3-4 1-5' bull qtz veins. Bio unaltered in granite. V. poor unsystem. wide-sp. fracturing. No Alaskite as dikes.

(25) Well developed, mineral. (c.gr.) foliation w/ lineation N40-50W 60°S. Lineat. is strong, N20W trending.

Aug. 5 '93

(26) Ogr & Alaskite intrusions. Ogr. foliate w/ bio. rexliz. to f.-m. gr. clots-mattes. Biotite non-chloritiz. Intruded by Alaskite sills - dikes subll to foliation. 2-3 large qtz veins at end of road. N40W 50S & N70W 60°S & sub-vert. Veins + dikes ~~suspect~~ S = mineraliz + IMPART

Cuox into foliate granite. Dissem of oxid. S = w/ high cp/py & w/ biotite & in hairline cracks & in hairline qtz veinlets - ~~some~~ some are deformed. Traces of Cu ox present. Crystalloblastic foliation = N40°W, 45°S w/ xl. lineation NS-N10E. Alask. dikes generally not deformed here.

Smaller qtz-seric. shears = N40-50W, 45°S dip.

Alask. makes up 20% of interval. Farther north along road Ogr. becomes less foliate w/ corresp. increase in xl. size. Numerous S= fract. + qtz veins strike N70W w/ 60-40° dips to S. Ogr. ~~...~~ looks fresh. (except local argilliz. of Kspar) but still has traces of dissem. S= (Feox, tr. Cuox).

(27) Below switchback ~200' of road-cut is sill of Alask. - Not deformed. Below Alask. is sudden change to mylonite - f. gr. - med gr. Finer-grained my. has all biotite converted to f. gr. chlorite. Elongate, lenzoidal S= (Feox) dissem. + hairline fract. S=. Rare to nil Cuox. ~~on surface~~. Mineraliz. best in areas of Felsite intrus. Felsite (Alaskite) is partly mylonitic; occsly is not.

my. = mylonite.

NOTE - Structure: Myl. fol. = N70 ± 10 W, 40°S w/ lineat. N15-20W. Same in deformed Alaskite. Myl. is cut by Qtz veins (deformed) + qtz + S= along foliation. S= content quite variable from Nil to 1%.

(28) Alaskite mainly in form of several sill/dike tabular bodies. Main direction of dikes ≈ N40-50E w/ 40-60° W dip. Some silling also is sub parallel to foliation in Ogr.

Dikes have dissem. v. weak S= & qtz veining.

Dominant alt. along qtz-shears of c. gr. muscovite.

Also a dark green f. gr. chl. w/ Feox after S= & qtz on many fractures in one locality. Dikes vary in gr. size from f. to med. gr. - c. gr. granitic locally. Qtz very dominant in dikes as veins.

Generally however, S= is very low.

(29) Ogr. From mylonitic to only sl. foliate. Definitely biotite-stable the whole way. Finely re-xliz to the southwest to m. xline multiple x/s northeast along traverse. Only minor chl. - v. locally.

Same for musc. along qtz. shears. Best S= + Cuox wdy. to Alask. dikes, where 1/2 - 2% S=.

In rest, dissem. + hairline fract. S= ≈ weak discont. but persist.

Cuox. Est. S= 1/4 - 1/2 % Est. Cu 200 - 500 ppm.

Common vein-alt.-deformed zones N70-80W, 60°S; N40W & (N20-30E), ∥ w/ west or S dips.

Ogr. is well broken, diked & veined & w/ fair perss. Feox on outcrops.

(30) Sl. foliate Ogr. - Bio - fresh. Cut by common 1-3' qtz-seric.-py zones - N10-30E 30-40° west dips - Also a few N70W qtz vein, 60°S. Traces of (but not much) dissem. py (Feox) in Ogr.

(31) Alaskite - Abdt. N70W - EW - N80E, 2-15' thk white qtz. veins cutting qtz-seric + low py. alteration borders. Structures dip 40-70°S.

Alask. w/ c. gr. musc (alt.) & rare areas of fresh, euhedral biotite. More pervasive J-1 jointing + smaller white qtz veinlets = N60-70°E - subvert.

Alask. w/ traces of py - but v. low S=. NO CU.

(32) Alaskite (w/ EW + N60-70E seric. hydrofract. & traces of py along them) to major X-flt. trending N30W w/ NS splays & west dip ~60°. Much clay gouge f. gr. sericite.

West of flt zone bio-stable (10% chl)

gneissic - Ogr is badly sheared, well iron-stained, and w/ fair Cu-ox stain.

(33) v. f. gr. schistose, siliceous mylonite. N30-60W 45°S. Toward south, gets quite reddish. Qtz-S= veinlets may have been chalcocite w/ Feox hematite after S=. Tr. of Cuox but mainly sample — hematite - indig + transported. Red interval ends suddenly against or overlain by drab coarser-grained gry. mylonite zone which goes to breccia right along fault.

(34) Mylonitic Ogr. Bio. strung out & rexliz. to f. gr. mattes. Common qtz. vnlets up to 6" N70W-EW steep; N40-60W 50°S. Some veins (1-2') show hematite in py (large) casts. Veins + dissem. in gneiss possibly after chalcocite.

fav: favorable-looking — dark fav. hematite casts. SAMPLE.

Gneiss stks N50-60W 55° SW dip.
Cuox sparingly w/ hematite (peross.) staining.

(35) Intrusive contact NE w/ SW dip of Alask w/ bio-bearing Ogr. Alask. cut by EW ~V hydrofract w/ seriate.
Also N40-50W, 60 SW qtz shears w/ some having hem. Feox after S=. (after chalcocite?).
hematitic

(36) Ogr. - wide sp fract. grey; sl. to non-foliate - bio - no chl. EW 60-70°N qtz veins + min. (Feox after S=) fract. wide-spaced 1/1' max 1/2-3' avg. | tr. with Cu-ox, but only rarely seen.

(37) 50-70' thick dioritic dike complex N70-80W 50° S. Ogr. adj. w/ S= + traces of Cuox. Some locally areas w/ strg. Feox after S=. Ogr = unalt. Dike may be along large shear zone because of shearing in & adj. to dike.

(38) Unalt. Ogr uniform cut by Feox (after S=) (pyritic) 1/1' avg. N75W-N80W 60-75° N. Epid. + chl. on fract. w/ Feox. Qtz as vns in some of fractures (up to 2").

(39) Ogr. w/ rare dike of rhy. or Alaskite. Cut by pervasive hydrofract. w/ chlorite & pyrite. Rocked into N70-75W 60-80° N. 1/ft average commonly w/ 2/ft or 1/2'. Chloritic alt. of bio. outward from fract. ~80-70% chl. 1-5 amp. of fresh of rock gone to

euhed. bio. taken. Note-py only; no qtz. veins; ∴ prob no Cu. NO Cuox seen.

(40) C. gr. leucogranite (seriate) (variably mylonitic) lower ferromags. Seriate large qtz grains. Minor ferromags gone to lt. grn. chl-seric.
Abdt. grey-white qtz veins-veinlets to 6" all directions, but N75W prefered.
Qtz has rare traces of py. (hematitic Feox) but no signif. mineraliz.
BARREN. Only the rarest Cuox seen in 1 ~5 x 5' area.
Foliation EW - N80W 40° S.

(41) F. gr. dark siliceous tight mylonite (i.e. Ogr.) to ultramyl. Some c. gr. lenses look like plutonic protolith. Dark chloritic on parting surfaces. Foliat. EW to N70W, 35-50° S.
Note - Although qtz ribbons & veins conform. to foliation, no sign of S= or mineraliz. noted.
NOTE - NO slicks or lineation obvious on these mylonites.

(42) Highly pyritic myl. + myl. Ogr. 1-5% S= indicated. NO CuOX. Orange spongy Feox poss. cp. S= → dissem. + hairline fractures. No sig. qtz. veins noted.
significant

APPENDIX 2

COPIES OF CONOCO DATA ON THE LITTLE HILLS PROPERTY

Tucson, Arizona
August 1, 1972

B. F. Kern, R. C. Barkley

Little Hills Prospect: Phase I proposal: Joint agreement with Amax and Drilling

Background Data

To evaluate the merits of joining Amax Exploration Inc. in exploration of the Little Hills prospect located 4 miles WSW of Oracle, Arizona, Conoco has devoted several weeks to geologic mapping, IP, and re-appraisal of Amax data. Major results of new and original mapping, etc. are outlined below.

(1) The prospect lies at an important and field verified structural intersection between the Mogul Fault zone (WNW premineral structure) and an ENE concentration of Laramide dikes. The dike swarm passes through and is colinear with the San Manuel-Kalamazoo prophyry copper orebodies located some 8 miles to the northeast.

(2) A wide area of weak propylitic alteration and highly anomalous copper geochemistry (>400 PPM) is located in the general area of the structural intersection in Precambrian Oracle granite cut by Laramide(?) dikes. Alteration and geochem anomalies are not wholly coincident but may arise from the same source, namely a buried porphyry copper deposit of the San Manuel type. Both are abruptly cut off by the Mogul fault. This truncation may be to an extent not yet determined, due to post-mineral movement on the fault, however, the fault did exert a primary influence on the hydrothermal activity.

(3) For third dimension control, shallow drilling by Amax supports propylitic alteration and anomalous copper (hundreds to several thousand PPM) to depths of around 200 to 500 feet. The deeper holes 6-1 and 6-2 (860' and 1056') were outside the area of better copper mineralization. Holes were not drilled deep enough to be sure of any decreasing or increasing alteration gradients.

(4) The areas of IP, air mag. and molybdenum geochem anomalies located to the north in the 6-1 - 6-2 region are less attributable to copper mineralization and propylitic alteration than to a strong local zone of quartz, pyrite (+ moly) veining which trends WNW. The PFE high centered about DDH 4-2, appears to correlate with stronger pyritization in propylitically altered Oracle granite. The higher grade copper minerlization (high Cu/Fe sulfide ratio) near the fault is poorly expressed by IP effects.

(5) Copper occurs in three slightly different modes. Each constitutes a particular exploration target on its own merits. These occurrences are:

(a) Disseminated chalcopyrite associated with propylitization of Oracle granite and a hybrid gneissic variety of the granite. This mineralization which is present through the bulk of the rock mass appears to increase inward toward the Mogul fault. (TARGET 1).

(b) A near surface swarm of subparallel quartz-chalcopyrite veins trending ENE-E out of the area of propylitic alteration. (TARGET 2).

(c) As copper oxide or mixed oxide-sulfide in a narrow (200-500+ feet) surface zone along the Mogul fault zone. (TARGET 3).

Our work continues to support a viable multiple prospect objective at Little Hills which requires additional drilling to adequately test. Provided that an existing land problem can be resolved, it is recommended that we negotiate a joint venture contract with Amax and proceed with the drill program to be described in this memo.

The land problem is one of renegotiating presently untenable option terms with McGee (10 patented and 17 unpatended claims along the Mogul fault) and Kowalewski (SW$\frac{1}{4}$ of section 4). McGee's claims are indispensable in testing Targets 2 and 3. Kowalewski's $\frac{1}{4}$ section is less critical and would be needed only if a deep test of outcropping propylitic alteration north of the fault becomes justified.

Exploration Targets

The specific targets, 1, 2 and 3, are discussed in more detail below.

Target 1: The arcuate-shaped zone of propylitic alteration (based on >50% chloritization of ferromag minerals) centered on DDH-11 and which includes DDH 7, 8, 9, 6-1 and 4-2 is generally pervasive in three dimensions. Mineralogically this alteration closely resembles propylitization surrounding the Florence orebody. Similarities in copper content, magnetite, chlorite, epidote, pyrite, sericitization of plagioclase and carbonate are striking. The lack of secondary K-spar or biotite indicates that the alteration cannot be confused with extraneous deuteric effects or the deep hydrothermal lateration corresponding to relatively barren root zones of prophyry deposits.

The alteration is best developed in Oracle quartz monzonite and a hybrid gneiss. Within the altered zone, however, propylitization is weak to absent in a slice of Pinal schist against the fault and in a body of PG alaskite just to the north. (Note: the alaskite does bear sericite and disseminated pyrite).. These rock types may not have been favorable chemically for receiving alteration and disseminated copper mineralization equivalent to that developed in the Oracle rocks.

Target one is based on the assumption that the propylitic alteration is marginal to a major copper porphyry deposit at depth. If our interpretation of local-regional structure and geologic history is correct, some degree of eastward tilt is present. Such tilting would result in a vertical element (i.e., a porphyry copper body) having a plunge toward the southwest. Provided the envisioned porphyry body were emplaced along the pre-existing Mogul fault zone at its intersection with the ENE San Manuel-Kalamazoo intrusive zone, a concept somewhere between the two extremes shown in Figure

1 would result. For either concept, a deep drill hole (± 3000') just south of the Mogul fault to test the footwall is called for.

Target 2: The ENE-E trending zone of quartz-chalcopyrite veins produced the high geochem anomaly passing through DDH 9, 10 and 13 and probably also contributes some to the values in holes 7 and 8. The veins vary from about 6 inches to mere silica coated joint surfaces. The average is about 4 inches. They are high in chalcopyrite relative to pyrite but the distribution of sulfide is often erratic along the vein. The vein swarm measures perhaps 1000 feet by 3000+ feet on the surface. Vein density in this zone is around 1 vein per foot, however, in places (i.e. around DDH 13 and just south and north of DDH 9)it attains 1 per 6". The veins dip moderately to steeply north near hole 13. They are vertical to south dipping from north of hole 9 toward the Mogul fault.

It is significant that the vein zone passes from propylitically altered rock near the fault through unaltered Oracle granite to the east. In unaltered rocks, sulfides are largely confined to the quartz veins themselves. Thus the vein swarm may represent a zone of primary hydrothermal leakage from the buried porphyry of Target 1.

The short angle hole 13 (T.D. 125') yielded 0.3 to 0.5+% copper for 60 feet. It cut across the dipping veins. More and deeper drilling is justified in this zone to see if a decent tonnage of surface mineralization (amenable to open pit mining) can be proved up which approaches 0.5% Cu. To achieve this grade the estimated vein density should be less than 1 per 1 foot. Mapping to date would tentatively indicate at least one zone of about 2000 by 500 feet with this vein density.

Target 3: Copper oxide and sulfide mineralization in a narrow zone along the Mogul fault has been mined at the Little Hills and Azurite mines. At the Little Hills mine a figure of 6 million tons of 0.44% Cu. as oxide comes from McGee. Amax feels this to be a maximum figure at best. Nevertheless, Magma Copper Company's angle holes probing the footwall beneath the hanging wall of the Mogul fault did encounter mixed sulfide-oxide mineralization. The copper was adjacent to the fault in the Little Hills-Azurite mine area at depths of 250 to 650 feet.

Considering the future acid surplus and thus the increasing favorability of oxide (plus sulfide?) copper ore, one exploration objective should be a short hole evaluation of the Mogul fault zone. This objective is considered especially attractive provided either or both targets 1 and 2 materialize. The implementation of exploration (i.e., drilling) to test Target 3 is therefore not considered vital until after work on the first two targets is well underway and evaluated. Should targets 1 and 2 not pan out, a final action plan for exploring for leachable ore can be made.

Phase I Recommendations

Provided the McGee and Kowalewski options can be extended and a feasable joint-venture agreement worked out with Amax, the following Phase I program is suggested.

I. Geology

A. Further mapping is required in the area around DDH 6-1, 4-2, K-1, 4-1 in order to establish with greater certainty the >50% chloritization boundary across the north and west parts of the prospect.

B. A bit more work is justified in the eastern extreme of the mapped area to determine what happens to the quartz-chalcopyrite zone.

C. Considering that faulting of the deep porphyry target may have displaced it deep in the hanging wall to the south, geologic mapping and geochem sampling should be carried at least a mile south of the Mogul shear zone (see Figure 1).

II. Geophysics

A. More IP may be necessary south of the Mogul fault. This necessity will depend on results of Phase I drilling.

B. Downhole IP could prove useful in any deep hole (i.e., ± 3000') in conjunction with alteration towards locating a second deep test.

III. Additional Claim Staking

More ground is needed south of the Mogul fault. A mile strip south of the structure should be covered through sections 8 and 9.

IV. Drilling

The following 4 holes are recommended. The drill plan is to first probe deeper along the Mogul fault in the high copper area before positioning a deep (3000') test of Target 1. Concurrently, 2 holes in the Target 2 area can be scheduled.

A. Deepen DDH #8 from ~300 feet to 1500 feet, to test the continuation of 0.2±% Cu mineralization and search for higher grade alteration at depth.

B. DDH #14: In the vicinity of DDH 12 approximately 500-1000' south of the trace of the Mogul fault, drill ~1500 feet to penetrate the fault and probe footwall mineralization in the transition gneiss and Oracle granite.

C. DDH #15: With encouragement in hole 14, move to the WNW in the hanging wall (500-1000' south of fault) and drill 1500 feet prepared to carry hole to 3000 feet if necessary. This hole would test Target 1 beneath the fault in the center (based on present exposure) of the pervasive propylitic halo. Positioning of this hole is contingent upon prior Phase I drill results and surface and IP data.

D. DDH 16 and 17: Two 1000 foot angle holes in the quartz vein zone to test Target 2. These would cut across the dip of the mineralised structures and be placed perhaps in the areas of high and moderate vein density.

Cost Estimate

1.	Geophysics - 7 days	$ 3,000.00
2.	Geochemistry	800.00
3.	Drilling (Based on the following costs):	

0 - 500'	8.00/ft.	1500 - 2000'	9.50/ft.
500 - 1000'	8.50/ft.	2000 - 2500'	10.00/ft.
1000 - 1500'	9.00/ft.	2500 - 3000'	10.50/ft.

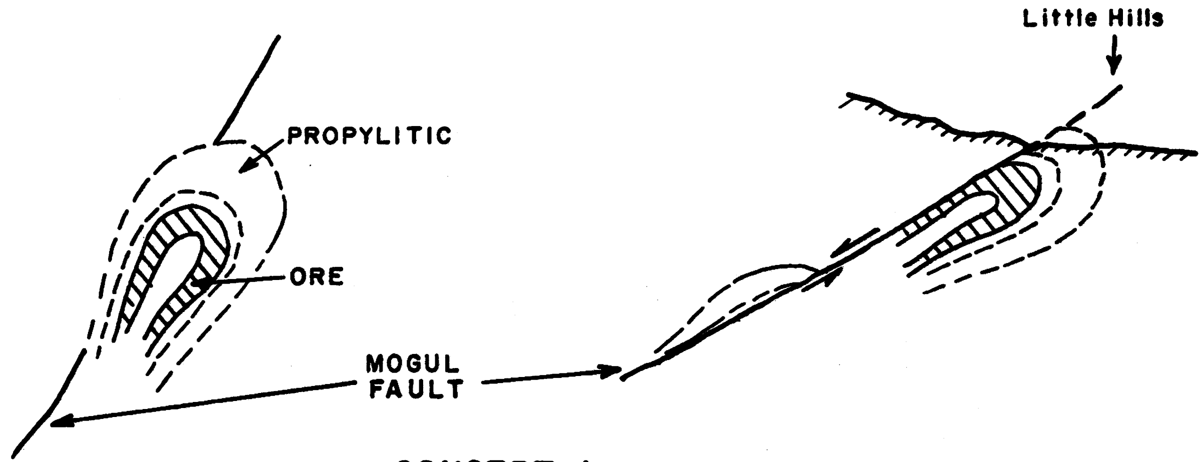
Hole #8 (1200')		$10,350.00
Hole #14 (1500')		12,750.00
Hole #15 (3000')		27,750.00
Hole #16 (1000')		9,250.00
Hole #17 (1000')		9,250.00
	Direct drilling costs	$69,350.00
Water truck		1,000.00
Dozer		1,200.00
Assaying		5,000.00
Mud		2,000.00
4. Contingencies @ 10% (environmental expenses, etc.)		8,235.00
	Grand total	$90,585.00*

*Note: This figure compares with an estimate of approximately $64,000.00 (excluding land costs) spent thus far on the Little Hills prospect by Amax.

W. A. Rehrig
Geologist

pv

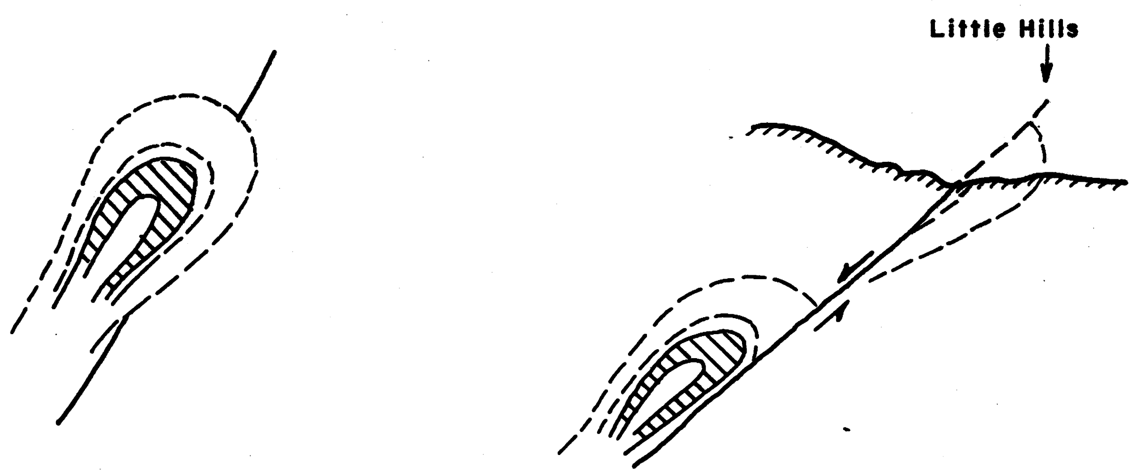
Enclosure



CONCEPT 1

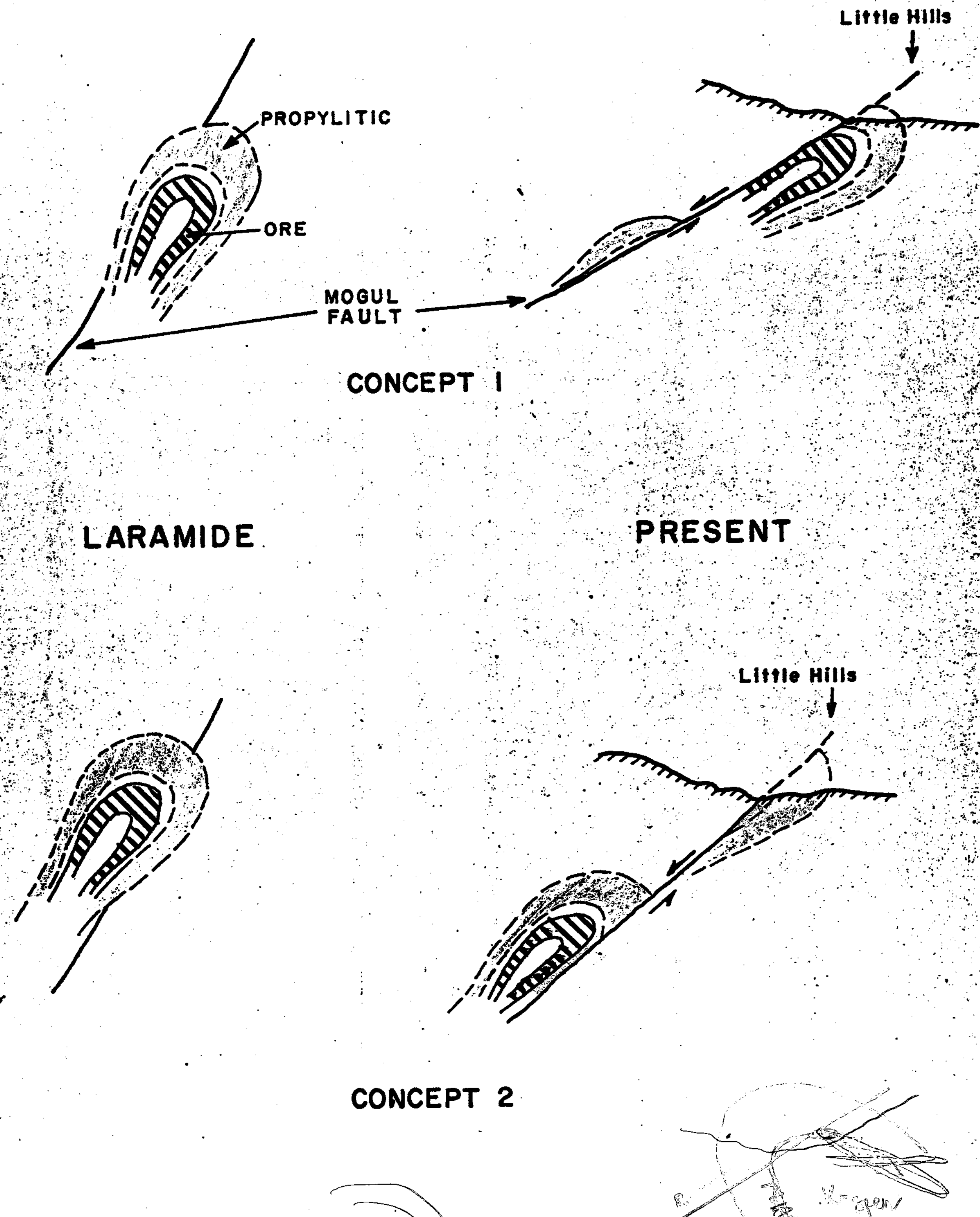
LARAMIDE

PRESENT



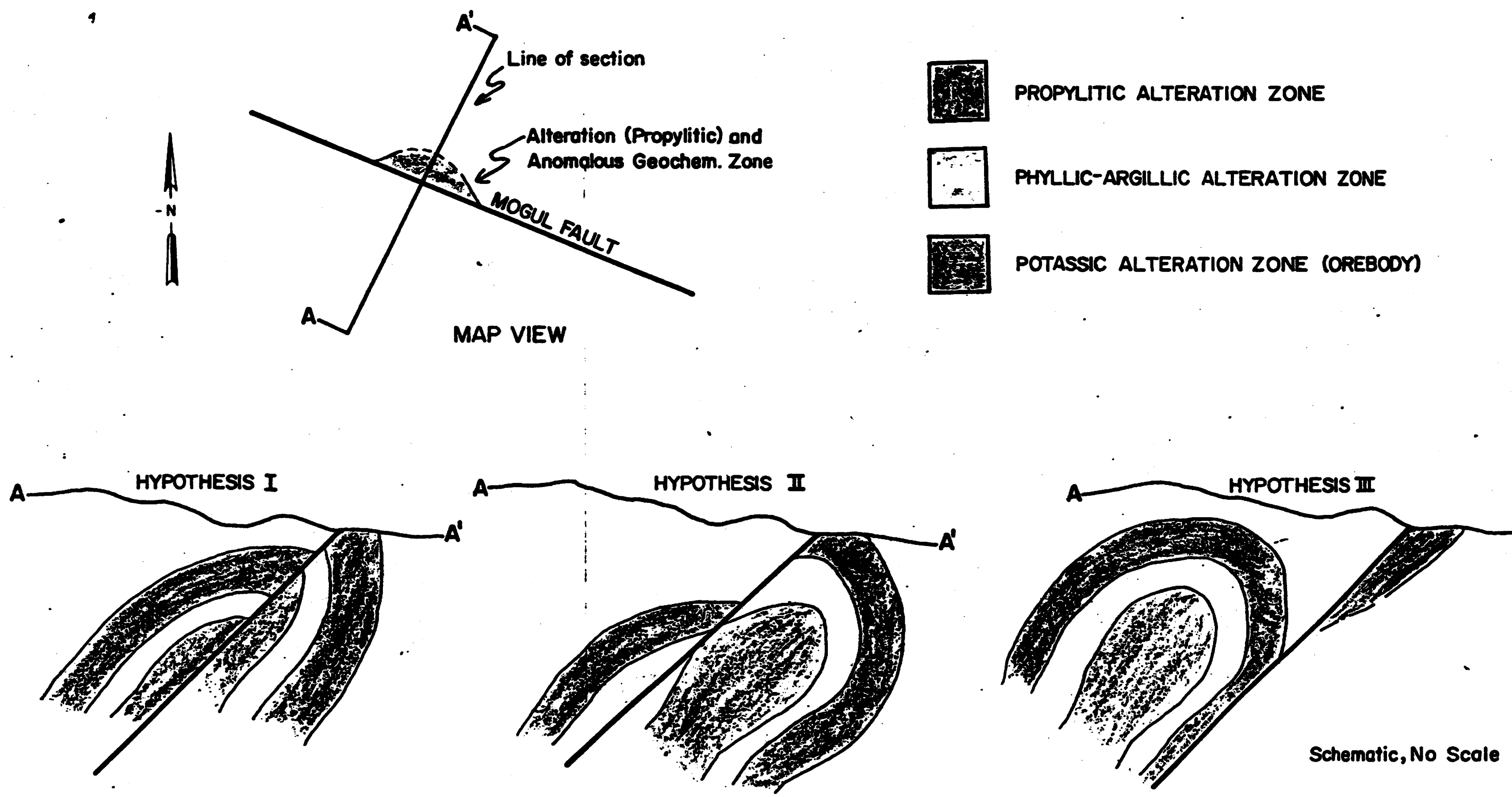
CONCEPT 2

Fig. 1



Little Hills
PROPYLITIC
ORE
MOGUL
FAULT
CONCEPT I
LARAMIDE
PRESENT
Little Hills
CONCEPT 2

Fig. 1



SCHEMATIC CROSS SECTION LITTLE HILLS AREA

FIGURE I

Tucson, Arizona
October 10, 1972

R. C. Barkley & B. F. Kern

Petrology of Propylitic Alteration: Discussion with Dr. Sidney Williams, Consultant

To follow up his petrographic report of September 13, (previously sent to you), Dr. Williams was contacted for a more in-depth discussion of his findings. The thin section suite sent to him consisted of four unidentified sections from propylitically altered QMP at Florence and four similarly altered slides from the Little Hills prospect. The objectives of Williams' work were (1) to compare the alteration between the two areas and (2) to determine whether any subtle mineralogical clues were present in the altered rocks which indicated the proximity of a porphyry copper deposit.

First and most significantly, Dr. Williams stressed that propylitic types of alteration are not just restricted to the margins of porphyry copper deposits. In fact, more commonly propylitic mineral sequences are developed merely as a consequence of low temperature hydrothermal fluids of weak intensity which never were associated with economic sulfide mineralization. Apparently the key then, to discerning productive propylitization is in identifying unique exotic or volatile minerals in the characteristic propylitic suite of chlorite, epidote, pyrite and carbonate. Secondary minerals such as tourmaline, fluorite, zircon, and apatite are examples.

Williams considered the Little Hills samples more favorable altered than the Flor suite due largely to slide 8-314 which contained fluorite and a stronger intensity of calcite, epidote and chlorite.

The "reservations" about favorability of the Little Hills alteration consisted mainly in the fact that relatively few of the diagnostic exotic minerals were present in the slides. Sid has a suite of samples from San Manuel-Kalamazoo and he notices abundant evidence of exotic hyperfusible mineral additions in the Oracle granite over distances up to 3000 feet from the orebody. These are coupled with weak propylitic alteration in the outer zone. Both alteration and hyperfusibles disappear rather suddenly, suggesting an alteration front at around 3000 feet.

Another unfavorable factor was the presence of green biotite. This type of biotite is secondary (hydrothermal) and has a high ferrous to ferric ratio. The green mica recognized at both Florence and Little Hills, represents the end result of the process; original biotite to chlorite and back to green biotite by the addition of potassium ions. The relatively high ferrous component indicates a low oxygen fugacity which, according to Williams is not overly typical of porphyry copper deposits.

To summarize, Sid did recognize considerable amounts of weak hydrothermal alteration from both the Flor and Little Hills suites. He was, however, less optimistic about the possibility of nearby copper ore. If a porphyry deposit were associated with the propylitization, it would probably be one that formed under deeply buried, poorly differentiated, hot and fairly dry conditions.

The kicker in this petrographic analysis is Williams' belief that the Little Hills samples looked more favorable than even those at the Florence deposit. Of the four Flor sections, Sid thought perhaps slide 12E-730 (DDH 12) was the most favorable of the Flor samples. Hole 12 does in fact lie closest to the orebody. Significantly, however, even in this hole, as in the others, the exotic minerals Williams looks for around porphyry orebodies were not recognized. This tells me that we have an untypical porphyry copper deposit at Florence.

Nevertheless, untypical though it may be, it is still an orebody and because the correlation between the Florence and Little Hills samples is so close, it may mean that a Florence type target is a good possibility if not probability at Little Hills. This target would contrast with San Manuel in that it is less differentiated and formed deeper. If this is the case, should we succeed in the deal with AMAX, exploration should be geared toward looking for a buried Laramide intrusion (granodiorite or quartz diorite) and the zone of potash silicate alteration.

W. A. Rehrig
Geologist

pv

CONOCO

Interoffice Communication

To R. C. Barkley

From Gordon L. Pine

Date November 26, 1973

Subject Evaluation of the Little Hills Area

Introduction

The Little Hills area is approximately 25 miles north-northeast of Tucson, Arizona. The area occurs at the intersection of the mineralized north-westerly Mogul Fault Zone and a southeasterly dike swarm related to the San Manual-Kalamazoo porphyry copper deposit. CONOCO controls approximately 2800 acres of land; most of the land is south of the Mogul Fault.

Geology

The north-northwest striking Mogul Fault separates areas of contrasting rock types (see Geologic Map). Outcrops north of the fault consist mainly of Precambrian Oracle Granite with minor amounts of Precambrian alaskite and Pinal Schist. South of the fault outcrops consist mainly of Precambrian Apache Group sedimentary clastic rocks with associated diabase sills. Minor amounts of Pinal Schist and Teriary (?) Gila Conglomerate also crop out. Laramide and/or Tertiary dikes occur north of the Mogul Fault; dikes and sills of similar intrusive rocks occur south of the fault.

Target

A conceptual model for an orebody was developed using similarities between the Little Hills and San Manuel-Kalamazoo areas. These similarities include rock type, fault attitude, relative movement of faults and orientation of dikes.

Three hypotheses (See Figure 1) were developed based on possible offset of the hypothesized orebody by the Mogul Fault. All hypotheses have two common assumptions.

1. Post-mineralization lateral movement along the Mogul Fault is minimal (only dip slip movementsexists, south side down)
2. The propylitic alteration and anomalous geochem zones which are terminated at the Mogul Fault are the surface indications of an altered zone fringing a major porphyry copper deposit (See Cu-Mo Anomalous Zones and Alteration Map).

Amax Exploration, Inc. controls the ground north of the Mogul Fault; they also control a strip approximately 1500 feet wide which is south of and parallel to the Mogul Fault (See Land Map). CONOCO acquired available ground south of the Mogul Fault.

Geologic mapping south of the fault revealed some mineralized shear - fault zones; dominant direction is northeast to east, but all directions exist. No significant widespread hydrothermal alteration was observed in the hanging wall outcrops. Rock chip samples taken in conjunction with geologic mapping were assayed for Cu and Mo content. Assay values are generally low. Single point high assays occur, but no trends or anomalous zones exist, except along the Mogul Fault (See Rock Chip Cu and Mo Geochem Values Map).

An IP survey using 1000 foot dipole spacing was run about 1500 feet south of and parallel to the Mogul Fault. Heinrichs Geoexploration Company concluded that in the main area of interest (section 8 and 9, south of the fault terminated alteration and anomalous geochem zone) no significant sulfide existed within the resolvable penetration limit of the IP system. They concluded that the penetration could be as much as 2000 feet below the surface. Their definition of significant sulfide mineralization is a block at least 1000 feet on a side containing at least one percent sulfide (by volume). The IP survey did show a shallow anomalous zone in section 15.

Drilling

To test for the existence of the hypothesized orebody, CONOCO has drilled four deep core holes in the area. The location of the holes is shown on the geologic map (See also Geologic Cross Sections). A brief summary of the holes is given below.

Hole Number	Interval	Remarks
MO-10	0-676'	Precambrian Apache Group sedimentary rocks and diabase sills; no significant hydrothermal alteration or mineralization; no anomalous assay values.
	676'-700'	Fault zone (not Mogul)
	700'-1822'TD	Precambrian Pinal Schist; no significant hydrothermal alteration or mineralization; assay values increasing slightly with depth, but still less than 100 ppm Cu; hole abandoned because of drilling problems.

Hole Number	Interval	Remarks
MO-11	0-1049'	Precambrian Apache Group sedimentary rocks and diabase sills; no significant hydrothermal alteration or mineralization; no anomalous assay values.
	1049'-1059'	Mogul Fault.
	1059'-1169'	Gneiss; moderate chloritization of biotite; ½% disseminated pyrite; ½% chalcopyrite associated with 1"-2" quartz veins; Cu av. 627 ppm; Mo av. 19 ppm.
	1169'-1240';	Gneissic quartz monzonite; medium to coarse grained; moderate-strong chloritization of biotite; weak to strong sericitization of plagioclase; alteration stronger along shear zones; ½% disseminated pyrite; Cu av. 385 ppm; Mo av. 14 ppm.
	1240'-1410'	Gneissic quartz monzonite; similar to interval above; slightly weaker alteration; scattered quartz veins, both cross cutting and parallel to foliation; Cu av. 126 ppm, Mo av. 9 ppm.
	1410'-1440'	Gneissic quartz monzonite; similar to above; locally highly deformed: quartz-muscovite-sulfide veins common; 1-2% total sulfide; Cu av. 1284 ppm; Mo av 10 ppm.
	1440'-1514'TD	Gneissic quartz monzonite; similar to above; fewer quartz-muscovite-sulfide veins and less sulfide; Cu av. 234 ppm; Mo av. 21 ppm.

MO-13A	0-1145'	Precambrian Apache Group sedimentary rocks and diabase sills; no significant hydrothermal alteration or mineralization; no anomalous assay values.
	1445-1454'	Mogul Fault.
	1454-1716'TD	Precambrian Pinal Schist; quartz-mica-chlorite schist; occasional gouge and breccia zones; no significant hydrothermal alteration or mineralization; no anomalous assay values.
MO-14	0-584'	Precambrian Apache Group sedimentary rocks and diabase sills; no significant hydrothermal alteration or mineralization; no anomalous assay values.
	584-590'	Fault breccia zone (not Mogul)
	590-1746'TD	Precambrian Pinal Schist; similar to MO-13A; hole abandoned because of drilling problems.

MO-13A was drilled to check the shallow IP anomaly obtained by Heinrichs Geoexploration Company. Drilling revealed significant quantities of authigenic pyrite in the upper portion of the Precambrian Dripping Spring Quartzite. Pyrite and limonite after pyrite existed in the interval from 285 to 595 feet. Sufficient amounts of pyrite are present to have caused the IP anomaly.

Two holes (MO-11 and MO-13A) cut the Mogul Fault. In both holes footwall mineralization, alteration and rock type are similar to that observed in the footwall north of the drill holes. Two holes (MO-10 and MO-14) had to be abandoned because of drilling problems before encountering the Mogul Fault.

Mapping indicated the dip of the Mogul Fault to be approximately 45° in the central part of the area. Drilling has revealed that the fault dips approximately 70° in the eastern portion of the Little Hills area and gradually steepens with depth in the western portion of the area.(See Geologic Cross Sections). The steepening of the Mogul Fault has made Conoco's position quite unattractive because of the land situation (See Section A-A' and B-B'). Conoco would only have a small "sliver" of any footwall mineralization; depth to the "sliver" would be approximately 4000 feet.

Land and Commitments

Conoco's land and commitments are listed below:

Land Description	Remarks
MO Claims (89)	Good until September 1, 1974, must due assessment work for 1974-1975.
MOLY Claims (18)	End price $1,000,000.00 on 3-1-78. Work commitments as follows: 1973-1974 $20,000.00, 1974-1975 $40,000.00, 1975-1976 $60,000.00, 1976-1977 $80,000.00, 1977-1978 $100,000.00. Conoco has satisfied 1973-1974 work commitment, but must do assessment work for 1974-1975 ($1,800.00)
SSP on Section 9 (152 acres)	Renewal due 1-22-73. Work done and given to W. Pokluda for filing.
SSP on Section 10 (400 acres)	Renewal due 1-22-73. Approximately $1000.00 more work required. Do not renew.
SSP on Section 17 (320 acres)	Renewal due 1-22-73. No work done. Do not renew.

Conoco would have to spend approximately $11,000 for assessment work to keep a land position beyond September 1, 1974.

Amax Exploration, Inc. controls the ground north of Conoco. Although exact terms of their commitments are not known, they are probably close to what is shown below based on Conoco-Amax negotiations prior to the disagreement.

Land Description	Remarks
Kowaleski	End price $81,000.00 on 1-20-76, must do assessment work and work for state prospecting permit.
McGee	End price $3,000,000.00 on 3-24-76; $2,000,000.00 advance royalty. Work commitments of $50,000.00 prior to 3-24-74; total of $125,000.00 prior to 3-24-75, total of $225,000.00 prior to 3-23-76.

Conclusions

Geologic mapping, drilling and IP surveying suggests no significant mineralization at reasonable depth in the hanging wall of the Mogul Fault (Hypothesis #III incorrect, see Figure 1). Either hypothesis I or II could be correct. If I is correct, displacement is so large that the mineralization is too deep to be a viable target. If mineralization does occur in the footwall (I & II) the steepening of the Mogul Fault with depth indicates only a small portion would be on Conoco ground. Hypotheses I & II could be checked by drilling vertical holes in approximately the same east-west position relative to the alteration-anomalous geochem zones as MO-10 and MO-14, but the holes should be about 500 feet south of the Mogul Fault. Such drilling is impossible to accomplish now since Amax controls the ground.

The possibility of lateral movement along the Mogul Fault can not be ignored. Post-mineralization movement may have laterally offset mineralization that occurred in the hanging wall.

Recommendations

Conoco's ground at Little Hills does not appear to contain any significant mineralization. The best hole (MO-11) contained one 30 foot interval that averaged 0.13% Cu; the rest of the footwall rocks averaged less than 0.06% Cu. The only reason for doing any additional work on the claims, etc. would be strictly for a land position. It is possible that an orebody could exist on Amax's ground, then Conoco's ground would be needed to develop the orebody.

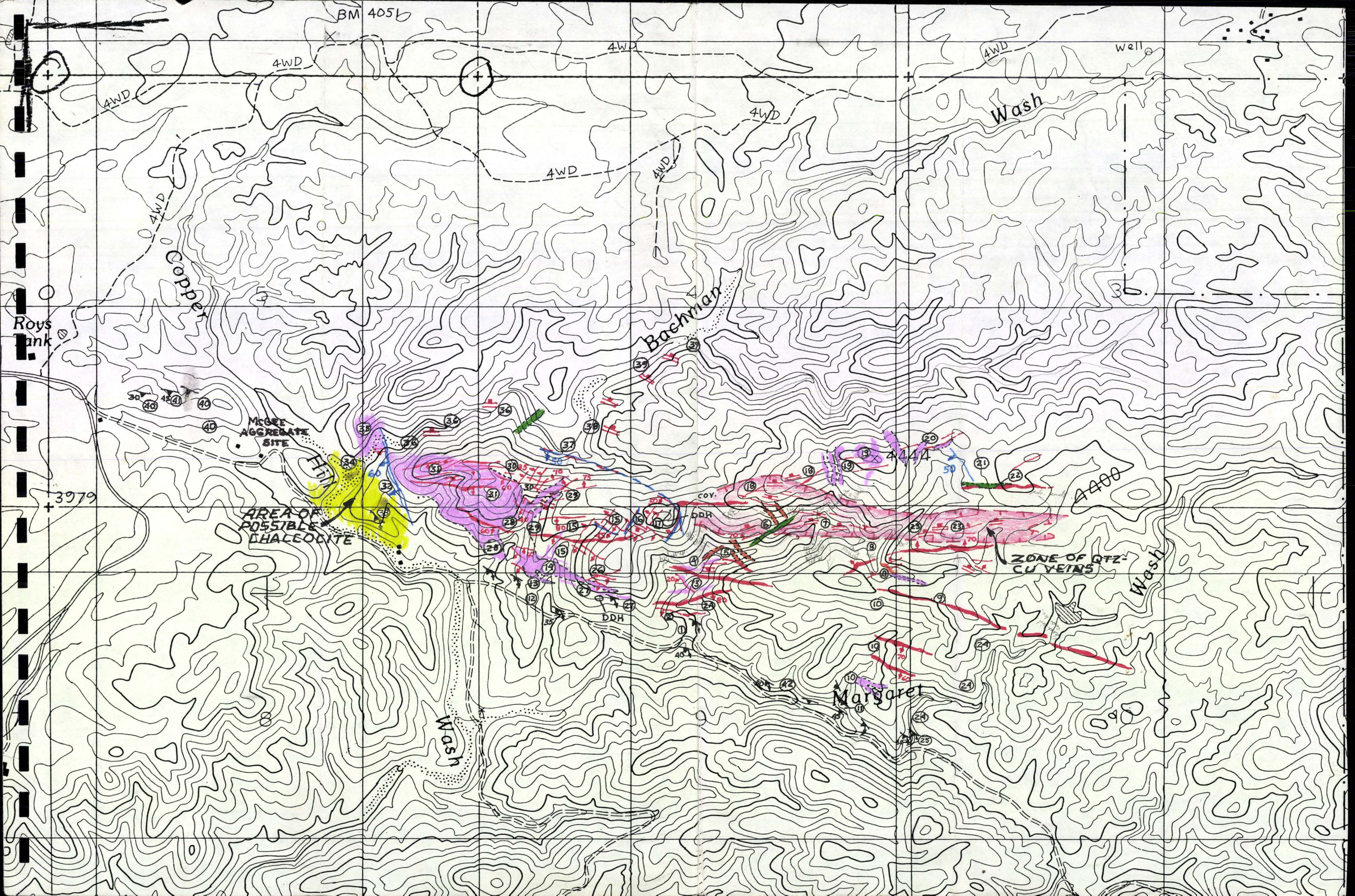
A drill hole to check footwall mineralization would be highly desirable, but as stated before, such a hole would have to be placed on Amax controlled ground. A joint venture between Amax and Conoco does not seem likely because of the original conflict in the area.

Conoco appears to be in a little better position than Amax as far as expenditures and commitments are concerned. Perhaps Amax will abandon their ground and Conoco could acquire it. The critical ground (now Amax) is owned by Dave McGee. McGee is not known for his "easy" deals. He would probably want too "tough" a deal when one considers the depth and geology of the proposed target. If Amax does drop the ground, Conoco should talk to McGee about an option.

Some library-regional work should be done on the Mogul Fault. The Pirate Fault (post mineral) shows apparent left lateral offset just west of the Little Hills area. Additional post-mineral offset is feasible, therefore the possibility of hanging wall mineralization should be checked along the Mogul Fault.

Gordon L. Pine

Gordon L. Pine
Project Geologist



BM 4051
4WD
Well
Wash
Copper
Roys Tank
3979
Bachman
McGEE AGGREGATE SITE
Hill
AREA OF POSSIBLE CHALCOCITE
COV.
DDH
4444
4400
ZONE OF QTZ-CU VEINS
Wash
Wash
Margaret

GEOLOGY AND MINERALIZATION
OF
LITTLE HILL MINES AREA,
NORTHEN SANTA CATALINA MOUNTAINS,
PINAL COUNTY, ARIZONA

by

William Perry Durning

M.S. Thesis 1972

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by

William Perry Durning

A Thesis Submitted to the Faculty of the

DEPARTMENT OF GEOSCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN GEOLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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STATEMENT BY AUTHOR

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SIGNED: William Perry Durning

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

John M. Guilbert
JOHN M. GUILBERT
Associate Professor of Geosciences

May 5, 1972
Date

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ABSTRACT

The Little Hill Mines area is about 25 miles north-northeast of Tucson, Arizona. It occupies a terrain of primarily older Precambrian Pinal Schist, Oracle quartz monzonite, transition gneiss, alaskite, and aplite-pegmatite dikes. These rocks have been intruded sequentially by rhyolite, latite, quartz latite, and monzonite porphyry dikes of Tertiary age. The west-northwest-trending Mogul fault, the main structure in the area, has been intermittently active since Cretaceous time. Most of the small faults, the foliation, and joints show a dominant trend parallel or subparallel to the Mogul fault. A zircon study suggests that the Oracle quartz monzonite is metasomatic rather than intrusive in origin.

Propylitic alteration and weak sericite alteration of plagioclase cover an area of roughly 1 3/4 square miles. The alteration is hydrothermal and may represent either the upper extent or the deeply eroded roots of a porphyry copper deposit.

Low-grade copper and molybdenum mineralization occurs as disseminations in Precambrian rock types and in quartz veins. The mineralization roughly coincides with the weak sericite alteration. Rock chip geochemical sampling outlines a >250 ppm copper anomaly which occupies the southeastern quarter of the area and a >6 ppm molybdenum anomaly which is U-shaped and nearly surrounds the copper anomaly. Copper oxide mineralization at the Little Hill mine is transported from areas to the north.

INTRODUCTION

Purpose and Scope of Study

The purpose of this work is to conduct a study of the economic geology and the economic potential of the Little Hill Mines area, Pinal County, Arizona. An effort is made to determine the origin of the copper-oxide mineralization along the Mogul fault at the Little Hill Mines. Details on the abundant sulfide-bearing quartz veins in the Oracle quartz monzonite and other rocks north of the Mogul fault in the area are reported in order to determine the possible influence of the Mogul fault zone.

A zircon study to evaluate the conclusion of an earlier investigation, that Oracle quartz monzonite is metasomatized Pinal Schist, is reported. Also, the western portion of the Mogul fault zone is investigated for evidence of displacement in the Little Hill area.

All pertinent available information on the structural geology and petrography is incorporated into the thesis in order to tie these features in with the detailed mapping of mineralization, alteration, geology, and structure of the area.

Methods of Study

Field work consisting of surface mapping and a geochemical survey of the area was accomplished from February through August, 1969. The mapping was done at a scale of one inch equals 500 feet on enlarged U.S. Forest Service aerial photographs and later transferred to a photographic enlargement of the U.S. Geological Survey seven and one-half minute preliminary topographic map of the Winkelman three southeast quadrangle.

Thirty thin sections were studied petrographically to obtain descriptions of newly reported rock types in the area and verification of former descriptions. Heavy mineral separations were performed so that a zircon study could be made of the Precambrian rock types. A Schmidt net analysis was done to determine preferred orientations and trends of mineralized and unmineralized joints and quartz veins and so deduce the influence of the Mogul fault zone on these trends.

Location

The Little Hill Mines area is located about 25 airline miles north-northeast of Tucson, Arizona, in the northwestern part of the Santa Catalina Mountains, Pinal County, Arizona (Fig. 1). The mapped area encompasses approximately one and three-quarters square miles and includes portions of secs. 3, 4, 5, 8, 9, and 10, T. 10 S., R. 15 E., Oracle, Arizona, 15 minute quadrangle. The area is 4 miles south-southwest of Oracle, Arizona, midway between Oracle and Oracle Junction. It is reached by driving north from Tucson 25 miles to Oracle Junction, then east on State Highway 77 to the Little Hill Mines access road. One and one-half miles from the highway the access road divides, and approximately half a mile further on the left fork is the southwest boundary of the Little Hill area.

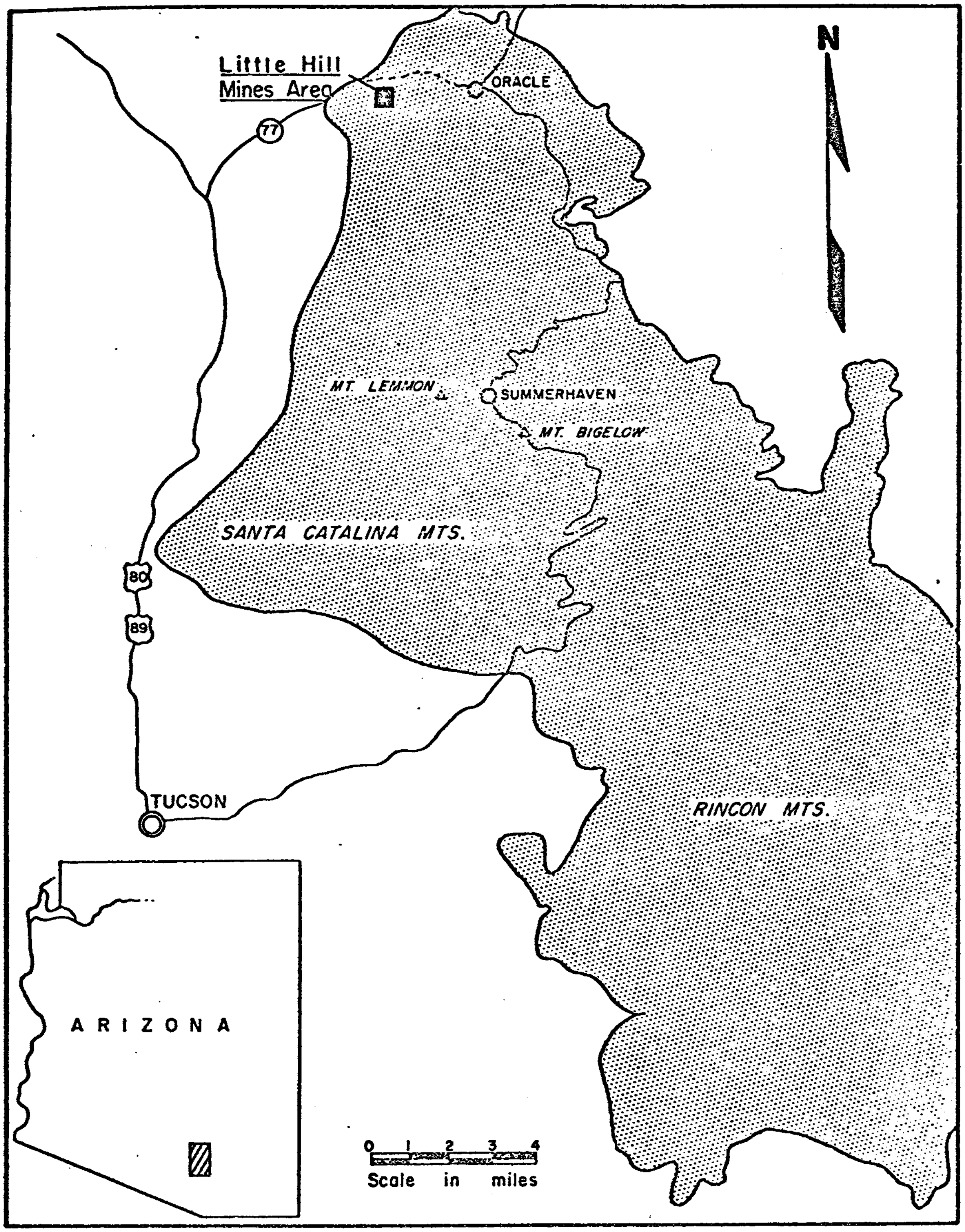


Figure 1. Location Map, Little Hill Mines Area, Pinal County, Arizona

Topography and Accessibility

Topographic relief in the study area is 760 feet, with the highest point having an altitude of 4,444 feet. Although the relief is not great, the slopes are steep, commonly between 25 and 35 degrees. Geologic contact are often covered by talus on the steep slopes. Rock types do not appear to have a significant influence on the topography. The tops of hills are developed at surprisingly uniform altitudes, leading to the possible conclusion that this area was once a continuation of the plain of low relief immediately to the north.

Moderate vegetation on the south-facing slopes consists mostly of saguaro, ocotillo, cholla, and grasses. The north-facing slopes are heavily covered with grasses, local dense growths of scrub oak, yucca, poison oak, and catclaw. Abundant mesquite and catclaw line the sides of the washes.

The southern part of the area is easily accessible by passenger car from the Little Hill Mines road, which connects the main pit on the west with the Azurite mine on the east. The western and north-central parts of the area are accessible with a four-wheel-drive vehicle by way of Bachman Wash and other arroyos.

History, Production, and Previous Work

The early history of the Little Hill Mines area is sketchy. No written information was found on the area. All the historical information was obtained through personal communication with Dave McGee, owner and operator of the Little Hill Mines. The first claims in the area were staked in the 1880's, probably for gold and silver. At some later time, the Copper Hill Consolidated Mining Company took control of eleven and a fraction claims patented prior to 1904. The work done by this company consisted of several short adits, a shallow shaft, and some prospect pits. Copper Hill Consolidated became defunct in 1928, and title to the claims was given over to the George S. Wilson family. The Wilsons paid taxes until 1958, when Wilson sold much of his land. Since taxes on the claims were not paid in 1958, the Allison Land Company was able to acquire the claims.

At that time McGee became interested in the area. Thomas H. Wilson II repurchased the property from Allison and at McGee's request sued for quiet title from every stockholder in the old Copper Hill Consolidated Mining Company. No one claimed stock in the property, so clear title was decreed to Wilson. McGee then bought the property from him in 1962. McGee began mining at the Little Hill Mines in February 1960 in a small open pit operation on the east side of Bachman Wash. The high-silica, low-alumina ore was shipped as flux to the ASARCO smelter in Hayden. The open pit operation uncovered the top of a high-grade ore zone which necessitated underground mining. Underground workings consisted of a one and one-half compartment, 51-degree inclined shaft, which reached a depth of 225 feet. The shaft was in ore for nearly this entire length. The ore body extended 155 feet downdip, was about 200 feet long, 50 feet wide, and averaged about 1.5 percent copper. At peak production McGee employed eight men and shipped 70 tons a day from the underground operations.

The underground working closed down in 1964, and McGee began shipping larger tonnages of 0.4 to 0.5 percent copper ore from several small pits. His main pit is now on the west side of Bachman Wash, directly across from the old underground workings. Ore shipments fluctuate from 60 to 300 tons a day, depending on the demands of the smelter for silica flux ore. In 1969, McGee began development work at the Azurite mine, about one and one-half miles east of the Little Hill mine, from which he ships a high-alumina flux ore upon request from the smelter. To date, McGee has shipped about 250,000 tons of copper-bearing flux ore to ASARCO, and he has about 6,000,000 tons of probable reserves.

Published accounts of the geology of the Little Hill area are limited. Damon, Erickson, and Livingston (1963) make brief mention of the Mogul fault and transition gneiss in the area, and the Little Hill area is mentioned in a field trip guide book (Committee on Arid Lands, 1969). Unpublished reports include two Ph.D. theses and one Master's thesis. Wallace (1954) discusses the stratigraphy and structural geology of the area and briefly notes the mineralization at the Copper Hill mine. Banerjee (1957) details the petrography and the structural geology of the Oracle quartz monzonite in the Little Hill area and also mentions the evidence of copper mineralization. Jinks (1961) mapped the structure of the Pinal Schist and transition gneiss on both sides of the Mogul fault in detail and related the structure to fault movement.

GEOLOGIC SETTING

The Little Hill area is located in the northwestern portion of the Santa Catalina-Rincon mountain block (Fig. 2). It is separated from the main mountain mass by the west-northwest-trending Mogul fault. The Santa Catalina-Rincon block is part of a larger entity consisting of the Santa Catalina, Rincon, and Tortolita Mountains. Structurally, the ranges form a large west-northwest-oriented dome. Internal structure reveals that intrusive emplacement into Precambrian and Paleozoic rocks occurred as a series of lobes of igneous material, each of which rose independently of the others. The fracture pattern seems to indicate that the relief of the Santa Catalina Mountains is not due to faulting. The Pirate fault on the west side of the range appears to be part of a graben structure between the Tortolita and Santa Catalina Mountains. The Mogul fault, the Geesman fault, and the Romero Pass zone, all trending west-northwest, are apparently related to the doming but are not responsible for the development of significant relief (Committee on Arid Lands, 1969). Banerjee (1957) postulates that the Mogul fault may be an important strand of the Texas Lineament and may extend eastward across the southern portion of the Galiuro Mountains to the northern part of the Chiricahua range.

Potassium-argon dates by Damon et al. (1963) show the Oracle quartz monzonite to be about 1,420 m.y. old. Near the Mogul fault severe loss of argon apparently has occurred, and an age date of only 49.2 m.y. was obtained. Other granitoid and gneissic rocks in the

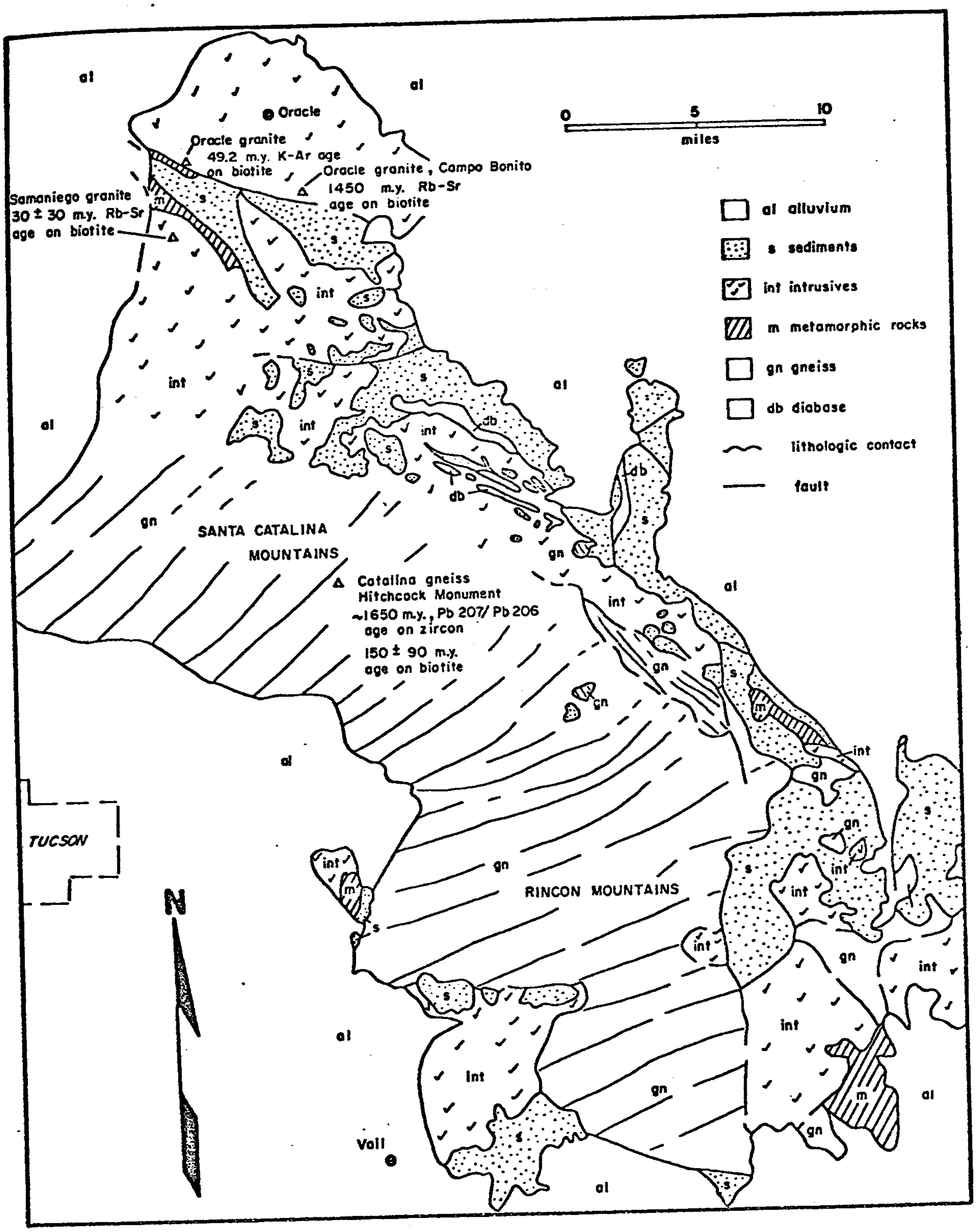


Figure 2. Generalized Geologic Map of the Santa Catalina and Rincon Mountains, Pima and Pinal Gounties, Arizona.--After Committee on Arid Lands (1969)

Santa Catalina-Rincon block yield young age dates, ranging from 48.2 to 24.0 m.y. Severe effects of Basin and Range tectonics on potassium-argon content are assumed responsible for the relatively recent dates obtained (Damon et al., 1963). This orogenesis apparently did not affect the dates derived for the Oracle quartz monzonite north of the Mogul fault.

GEOLOGY

Eleven distinct rock types crop out in the Little Hill area (Fig. 3, in pocket). The oldest is the older Precambrian Pinal Schist, which occurs primarily on the hanging-wall side of the Mogul fault. Other Precambrian rocks, beginning from the older rocks, are the Oracle quartz monzonite, transition gneiss, and aplite pegmatite dikes shown on the geologic map. The age of the remaining igneous rocks is unknown, but their sequential relationships are clear. The intrusion of the alaskite is followed in succession by the profusion of rhyolite dikes, latite dikes, quartz latite dikes, and finally by the intrusion of a large monzonite porphyry dike shown in Figure 3. Quaternary colluvium and alluvium mantle hillsides and fill washes throughout the area.

The west-northwest-trending Mogul fault (Figs. 3 and 4) is the dominant structural feature in the area. North of the fault are hundreds of parallel and subparallel synthetic faults of small displacement. Synthetic faults, as defined by Cloos (1936), are subsidiary faults parallel to a master fault. Late faults trend in northeast and north-northeast directions. A well-developed west-northwest to east-northeast joint pattern is in evidence, as well as a less pronounced north-northeast to north-northwest pattern. Foliation in the Pinal Schist has a preferred west-northwest trend with local fluctuations and a pronounced southerly dip.

Figure 4. Aerial Photograph of the Little Hill Mines Area

The Azurite mine is in the foreground and the Little Hill mine is in the background. Looking west along the Mogul fault zone.

Rocks

Precambrian Rocks

Pinal Schist. The Pinal Schist occurs in a fairly narrow band parallel to the Mogul fault in the southern part of the Little Hills area (Fig. 3, in pocket). It has a gradational contact just north of the Mogul fault with the transition gneiss and a sharp contact with the alaskite. South of the fault, beyond the Little Hill area, the Pinal Schist is buried beneath younger sedimentary rocks of the Precambrian Apache Group. The Pinal Schist also occurs as large inclusions within the Oracle quartz monzonite. One inclusion is more than 100 feet long and about 50 feet wide. The Pinal Schist ranges from a gray-white quartzite to a reddish-brown meta-arkose to a gray-green phyllite. The phyllite and meta-arkose are the most common rock types and are irregularly distributed in the area.

The quartzite units are generally fine grained, well foliated, and locally micaceous. Some units might better be called meta-sandstones, since they are quite friable. The arkose is a foliated, dense, well-indurated unit with locally abundant micas. The phyllite is a very fissile, very well foliated unit which contains fine mica. Chlorite is the most abundant mineral. The Pinal Schist generally shows very pronounced foliation trending west-northwest with a distinct southerly dip. The foliation is commonly characterized by tight crinkle folds on a local scale, especially near the Mogul fault.

For a detailed description of the Pinal Schist in the Little Hill area, Banerjee (1957), Wallace (1954), or Jinks (1961) may be consulted.

Oracle Quartz Monzonite. The northern two-thirds of the Little Hill area is primarily Oracle quartz monzonite (Fig. 3). This Oracle quartz monzonite is the same unit which was called Oracle Granite after the town of Oracle by Peterson (1938). The unit was found by Banerjee (1957) to be for the most part a quartz monzonite which grades locally and irregularly into a granodiorite or granite. This unit will be referred to in the present report as the Oracle quartz monzonite. The Oracle quartz monzonite has been dated by potassium-argon methods and shows an age of 1,420 ± 20 m.y. (Damon et al., 1963).

The Oracle quartz monzonite in the area of study is a very coarse grained, pinkish-white to gray porphyritic rock in which textural variations are common. The quartz monzonite contains abundant large phenocrysts of microcline up to two inches long, occurring in a coarse matrix of quartz, plagioclase, and biotite (Fig. 5). Nearly all specimens in the area show evidence of sericitic alteration of the plagioclase and chloritic alteration of the biotite (Fig. 6). Locally, especially along quartz veins and in shear zones, the rock is altered to a mass of quartz, clay, and sericite. The Oracle quartz monzonite commonly contains disseminated accessory magnetite and pyrite, and often shows a brownish iron stain. The recognized heavy minerals are biotite, chlorite, magnetite, apatite, clinozoisite, epidote, zircon, sphene, ilmenite, and pyrite; these minerals make up about 10 percent of the rock (Banerjee, 1957).

The Oracle quartz monzonite in the Little Hill area is weathered to brownish iron-stained decomposed suboutcrops. The best outcrops

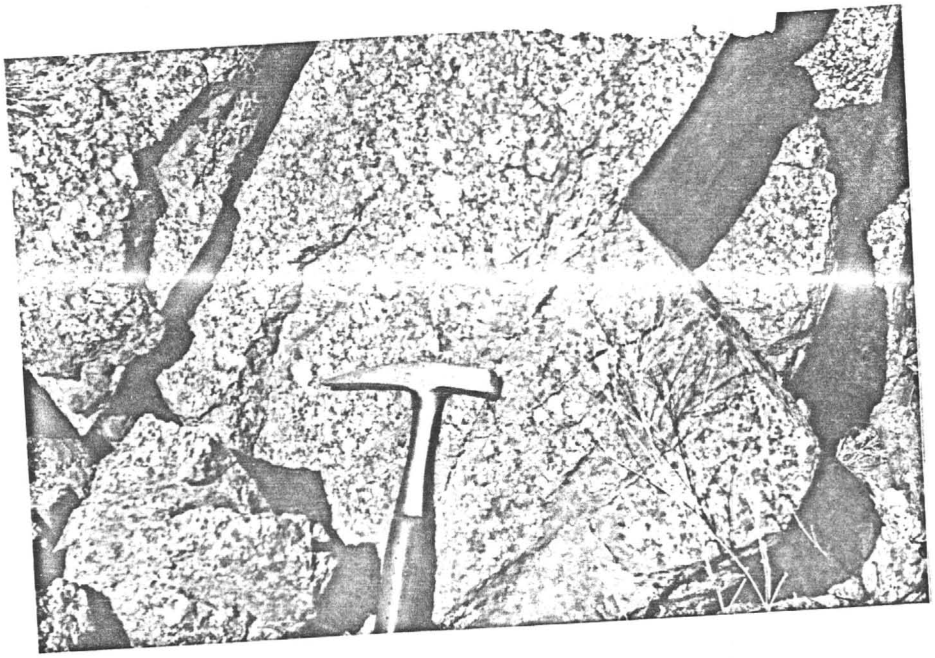


Figure 5. Outcrops of Oracle Quartz Monzonite

Rock is coarse grained with abundant large potassium feldspar phenocrysts.

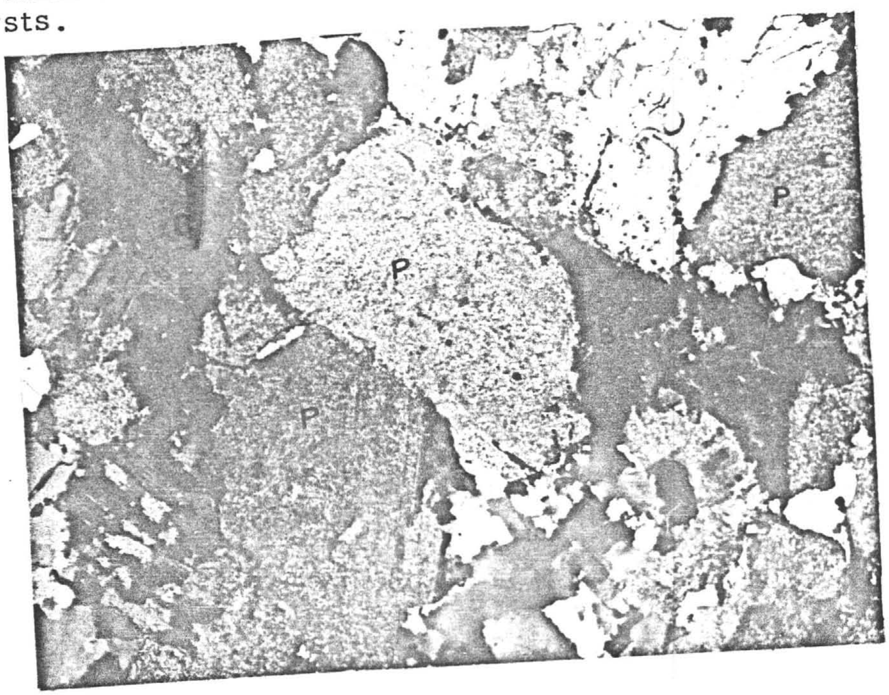


Figure 6. Photomicrograph of a Thin Section of Oracle Quartz Monzonite

The plagioclase crystals (P) show a light dusting of sericite while the biotite crystals (B) are altered to chlorite. Crossed nicols, X9.

a found in washes or in areas of silicification. The quartz monzonite, where fresh and unaltered, is weathered into large rounded boulders.

A zircon study made during the present investigation showed a high percentage of rounded zircons in the Oracle quartz monzonite, indicating probable sedimentary transport. This information is consistent with the petrographic findings of Banerjee (1957) and Wallace (1954), which showed that the Oracle quartz monzonite was probably metasomatized Pinal Schist.

The reader is referred to Banerjee (1957), Schwartz (1953), and Creasey (1967) for a detailed petrographic description of the Oracle quartz monzonite. Lowell and Guilbert (1970) describe alteration of the Oracle unit and present several photomicrographs of fresh and altered materials.

Transition Gneiss. The transition gneiss lies between the Pinal Schist and the Oracle quartz monzonite or alaskite (Fig. 3) on the northern side of the Mogul fault. The gneiss was recognized by Wallace (1954), Banerjee (1957), and Jinks (1961). The unit forms a sharp contact with the alaskite, a gradational contact with the Pinal Schist, and a gradational and interfingering contact with the Oracle quartz monzonite. The transition gneiss attains a maximum width of about 700 feet near the Azurite mine, becoming progressively thinner to the west. The gneiss yields an apparent potassium-argon age of 49.2 m.y. (Damon et al., 1963). These workers speculate that the gneiss has suffered severe argon loss due to movement along the fault and that this loss accounts for the apparently recent date of this rock.

The transition gneiss is a coarse-grained granitic gneiss, except near its contact with the Pinal Schist where it may be finer grained. The gneiss is characterized by well-developed foliation and distinctive coarse grain size. The unit commonly contains large inclusions of Pinal Schist. Petrographically, there are alternating bands of three distinct types of material: (1) almost pure quartz, (2) chlorite, sericite, and (3) quartz, feldspar (Fig. 7). The bands range in width from a fraction of an inch to more than half an inch.

The quartz bands make up 30 percent of the rock and consist of crushed elongate quartz grains oriented parallel to the foliation. Chlorite sericite grains oriented parallel to the foliation account for another 20 percent of the rock. Some quartz and feldspar grains are present in these chlorite-sericite bands, and pyrite, hematite, and magnetite are common accessories. The feldspar-quartz bands average about 50 percent of the rock, and the bands contain almost no chlorite or opaque minerals. The feldspar is commonly altered to sericite and clay, with the sericite often oriented parallel to the foliation. The segregations into well-defined mineralogical bands become obscure near the contact with the Oracle quartz monzonite. The quartz and feldspar grains are up to three-quarters of an inch in length, and the chlorite and sericite grains reach lengths of one-quarter of an inch.

From thin-section study, the transition gneiss appears to be sheared and mylonitized Oracle quartz monzonite (Wallace, 1954) and is thus a tectonic feature related to movement along the Mogul fault. The mylonitic texture of the gneiss is conspicuous near the fault,

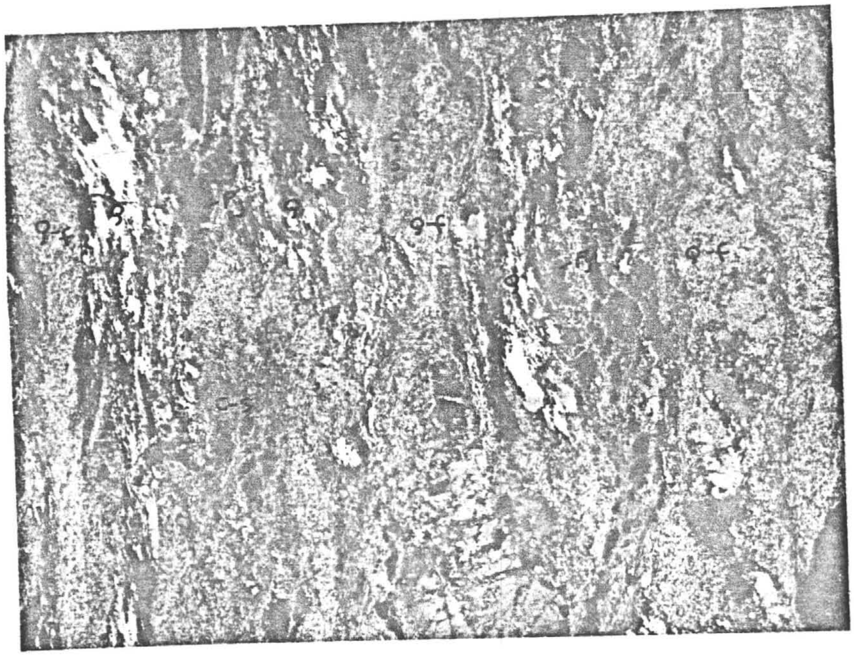


Figure 7. Photomicrograph of a Thin Section of Transition Gneiss

The gneiss shows well-developed foliation expressed by alternating bands of quartz (Q), chlorite-sericite (C-S), and a quartz-feldspar (Q-F). The opaque minerals are pyrite (Py). Crossed nicols, X4.

becoming less visible to the north. Structural controls of localization of the gneiss in the Little Hill area are not known.

Aplite-pegmatite. Aplite-pegmatite dikes occur throughout the Oracle quartz monzonite. The dikes are especially abundant in the northeast part of the Little Hill area. Only large bodies of aplite-pegmatite were mapped. An age date of 1,420 ± 40 m.y. was obtained by Damon et al. (1963) on a pegmatite dike in the Oracle quartz monzonite near Oracle, Arizona. The aplite dikes are white, fine- to medium-grained rocks of quartz, potassium feldspar, and muscovite, with a saccharoidal texture. The pegmatite dikes contain large crystals of quartz and potassium feldspar, with local concentrations of tourmaline. Many textural gradations between aplite and the pegmatite occur in the area.

Rocks of Unknown Age

Little Hill Alaskite. The Little Hill alaskite was evidently classified as a fine-grained facies of the Oracle quartz monzonite by previous investigators and therefore not mapped as a separate unit. In the present study, this unit, a sill-like mass intruded along the Oracle quartz monzonite-transition gneiss contact, was considered distinctive enough to merit mapping as a separate igneous rock. This alaskite occurs in a swath about one mile long and up to 1,000 feet in width (Fig. 3).

Several features indicate that the Little Hill alaskite is a unit which should be distinguished from the Oracle quartz monzonite. At the sharp contact between the alaskite and quartz monzonite, changes in

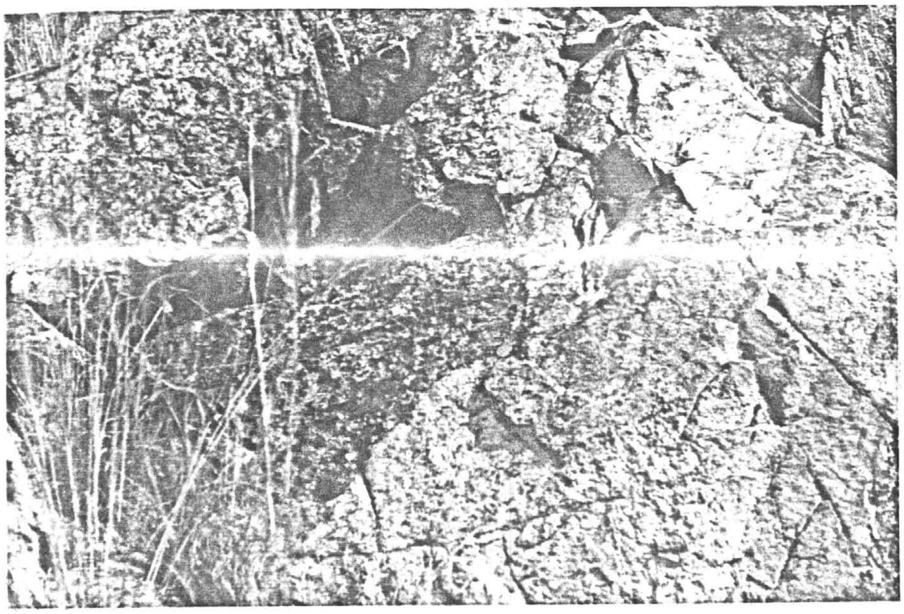


Figure 8. Contact between Little Hill Alaskite and Oracle Quartz Monzonite

The photograph shows the sharp nontransitional contact which is typical of contact of these two rocks.

Figure 9. Inclusion of Oracle Quartz Monzonite in Little Hill Alaskite

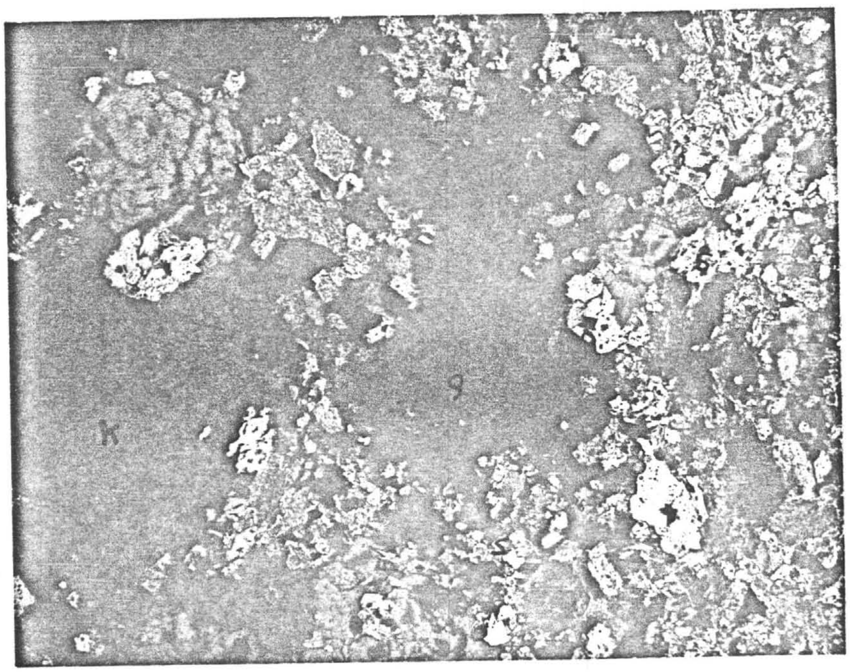


Figure 10. Photomicrograph of a Thin Section of Little Hill Alaskite

The alaskite consists of quartz (Q) and K-feldspar (K) phenocrysts, surrounded by a matrix of coarse sericite and muscovite (S). Crossed nicols, X41.

Point counts were made of two thin sections, one of "fresh" alaskite and one of altered alaskite. Results are summarized in Table 1.

Table 1. Point Count Percentages of the Little Hill Alaskite

Mineral	"Fresh" Alaskite Point Count Percentages	Altered Alaskite Point Count Percentages
Quartz	44.2	40.0
Potassium feldspar	23.0	14.6
Plagioclase	18.8	0.0
Muscovite	13.6	13.6
Hematite, magnetite, pyrite	0.4	0.8
Sericite and clay	0.0	27.8
Biotite	0.0	0.6
Zircon, rhodochrosite, epidote, and other	0.0	2.6
	100.0	100.0

In both thin sections the amount of quartz is about equal, but percentages of potassium feldspar and mica differ greatly between the "fresh" and the altered rock. It is interesting to note, however, that the combined percentages of potassium feldspar, plagioclase, and sericite and clay are 41.8 percent for the "fresh" alaskite and 42.4 percent for the altered alaskite. It might therefore be assumed that the change in composition from the "fresh" to the altered sample is due to sericitic alteration of the feldspars.

Strong potassium metasomatism of the mafic minerals of the Little Hill alaskite is shown by the introduction of abundant sericite and the formation of magnetite and local rhodochrosite. The latter two minerals were possibly derived from the iron and manganese released by the mafic minerals during alteration.

The alaskite, like the Oracle quartz monzonite, forms subdued outcrops, which are covered by blocky, weathered alaskite. However, the alaskite does form very steep hills. Abundant sericite and muscovite are characteristic of alaskite outcrops. A poorly defined lineation can be seen in the quartz grains, and locally the micas show a crude foliation.

Tertiary Rocks

Rhyolite. Five to six rhyolite dikes in a zone about 750 feet wide enter the Little Hill area in the northwest corner, trending S. 50° E. The dikes cross to the east-central boundary of the area, diminishing in size and number, and leave it trending S. 30° E. (Fig. 3). The dikes range in width from a few feet to 50 feet, with an average width of about 15 feet. The rhyolite dikes are quite resistant and form pronounced ridges (Fig. 11).

The rhyolite is a light-gray aphanitic non-porphyritic rock. Only rarely is a grain of quartz, potassium feldspar, or muscovite visible. The dikes are highly jointed and generally form fist-size pieces of blocky, weathered rock. The rhyolite is locally silicified, and quartz veins commonly fill the joints (Fig. 12). Fine disseminations of specularite and pyrite are widespread. The dikes locally show deep reddish-brown iron stains on bleached white outcrops where pyrite concentrations were unusually high. Rhyolite dikes are found only in the

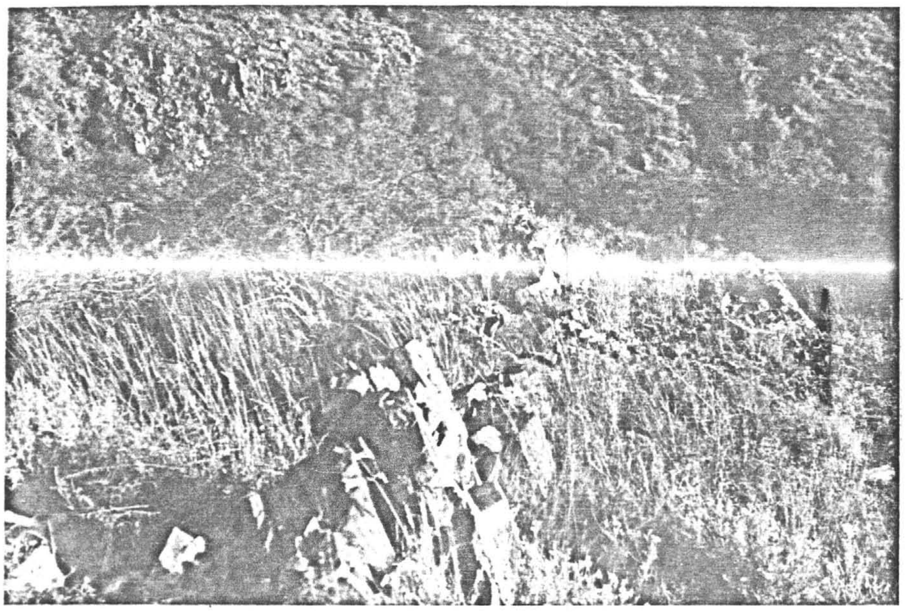


Figure 11. Rhyolite Dike Forming Bold Outcrop in Oracle Quartz Monzonite

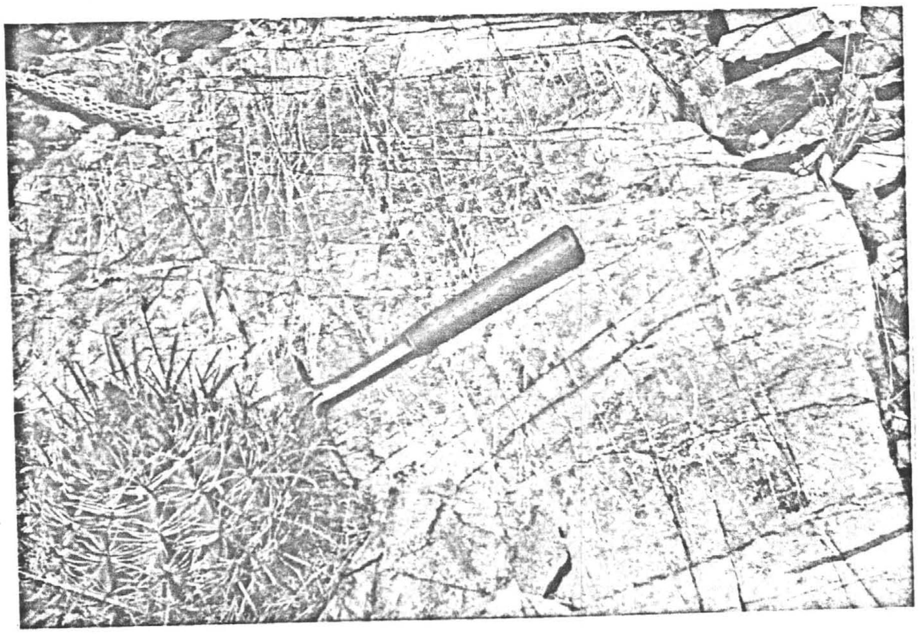


Figure 12. Thin Quartz Veins Filling Joints in Rhyolite Dikes

Oracle quartz monzonite. Some dikes show poorly developed flow banding, and some have a distinctive spotted appearance due to high concentrations of an unidentified opaque mineral disseminated in small circular masses with fine quartz and feldspar (Fig. 13). Pyrite, magnetite, and specularite constitute less than 5 percent of the rock. Minor sericite alteration is present in the few feldspar phenocrysts seen under the microscope.

Latite and Quartz Latite. The latite and quartz latite dikes in the Little Hill area (Fig. 3) have preferred north-northeast to east-northeast trends. The sequential relationships between the latites and quartz latites are not known. The dikes crosscut all the older rock types and are most abundant in the northern and eastern portions of the area of study. The dikes average about 10 feet in width and are traceable for several hundred feet along strike. The latite dikes are gray to green and contain local segregations of chlorite up to one-quarter of an inch in width. The ground mass consists of fine plagioclase, orthoclase, and minor quartz. Chlorite and other mafic minerals make up about 20 percent of the rock. The latite in thin section shows poorly defined crystal boundaries (Fig. 14).

The quartz latite dikes are gray-green micaceous rocks. The dikes show a very pronounced flow banding due to the parallel orientation of the micas and elongation of quartz and feldspar grains. The schistlike rock is comprised of quartz and feldspar phenocrysts held in a fine-grained matrix of quartz, feldspar, and mafic minerals (Fig. 15).

Monzonite Porphyry. The monzonite porphyry dike is 50 to 100 feet in width and trends approximately N. 35° E. throughout the Little

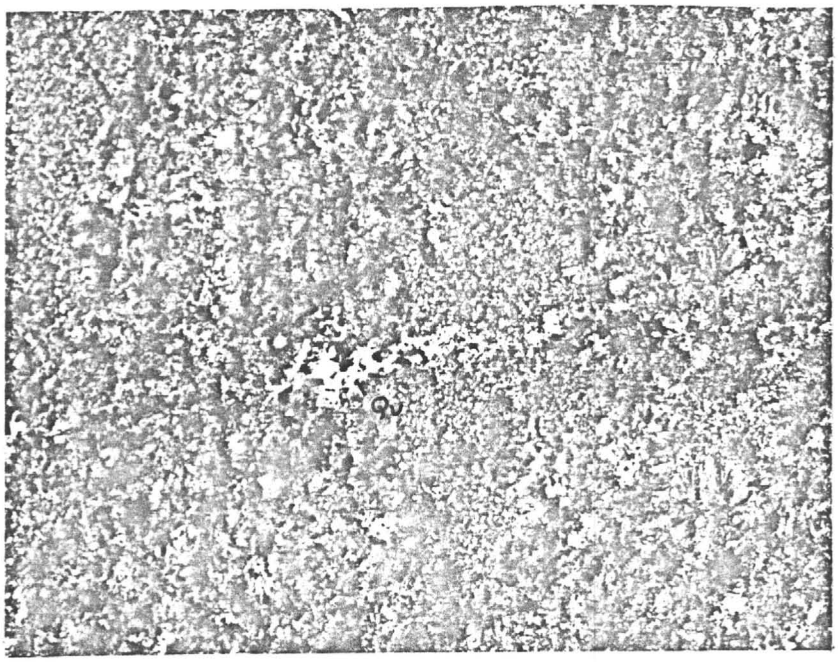


Figure 13. Photomicrograph of a Thin Section of Rhyolite

A thin quartz vein (Qv) cuts the weakly flow-banded rhyolite. Crossed nicols, X9.

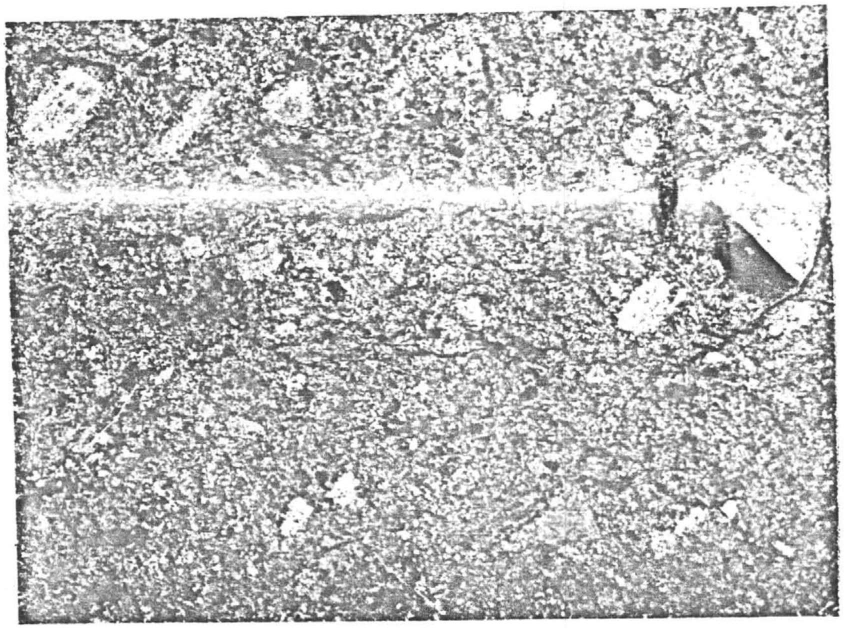


Figure 14. Photomicrograph of a Thin Section of Latite

Small (1/16") phenocrysts of plagioclase are held in a matrix of fine-grained feldspar, chlorite, and minor quartz. Crossed nicols, X9.

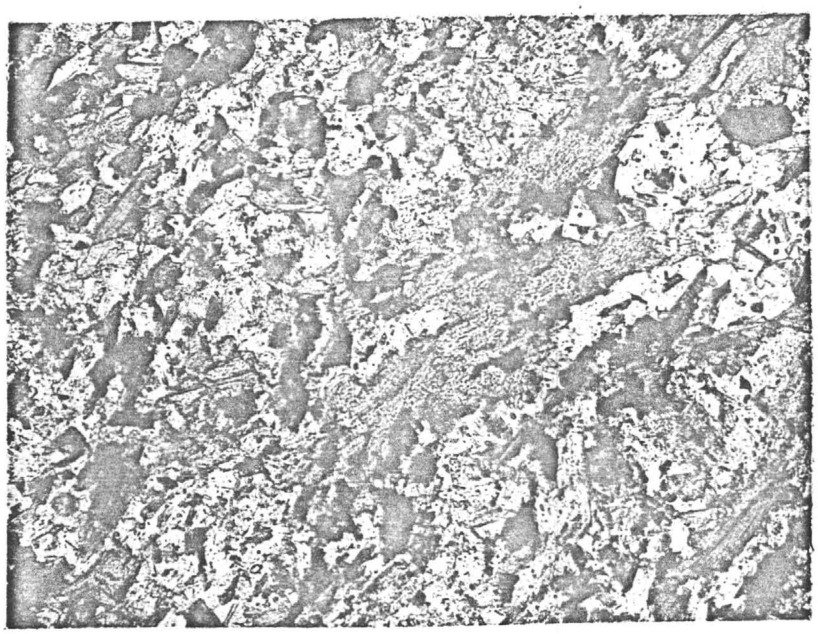


Figure 15. Photomicrograph of a Thin Section of Quartz Latite

Crudely developed flow banding is expressed by elongation of chlorite crystals. The other minerals are mostly quartz, feldspar, and magnetite. Plain light, X100.

Hill area (Fig. 3). A similar dike found on the south side of the Mogul fault probably represents an offset portion of the same monzonite porphyry unit. The monzonite is very resistant and forms bold but rounded outcrops (Fig. 16).

The monzonite porphyry contains phenocrysts of potassium feldspar and plagioclase set in a gray-green matrix of plagioclase, chlorite, biotite, and rare quartz (Fig. 17). The dike is conspicuously porphyritic at the center and has a chilled margin on either side which varies from a few inches to several feet in width. The effects of the contact on the intruded rock are minor except for minor brecciation along the contact due to forceful(?) intrusion. The rock locally contains masses of epidote filling cavities up to half an inch in diameter. Clasts of all older rock types are found as inclusions in the dike.

Quaternary Rocks

Colluvium. The colluvium is primarily a recent cover of deep soil or slump material and has sufficiently buried outcrops over enough area to make mapping of the older rocks inaccurate. All colluvium material is of local derivation.

Alluvium. Alluvium is found in all the washes in the Little Hill area. It consists primarily of sand-size material with concentrations of gravel and cobbles. The alluvium is composed chiefly of decomposed Oracle quartz monzonite, with lesser amounts of other Precambrian and dike rocks. Minor amounts of quartz vein material and copper oxides are also present.

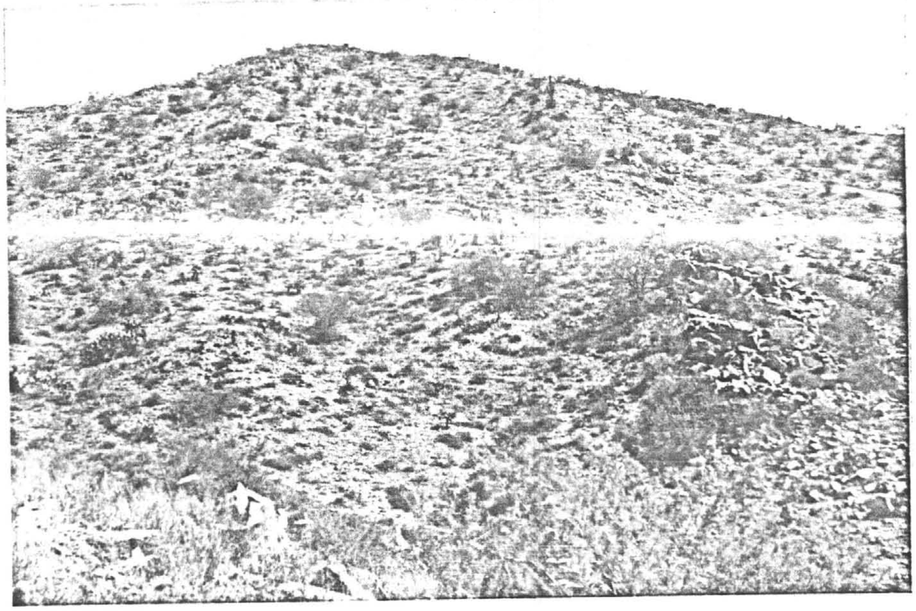


Figure 16. Boldly Outcropping Monzonite Porphyry Dike

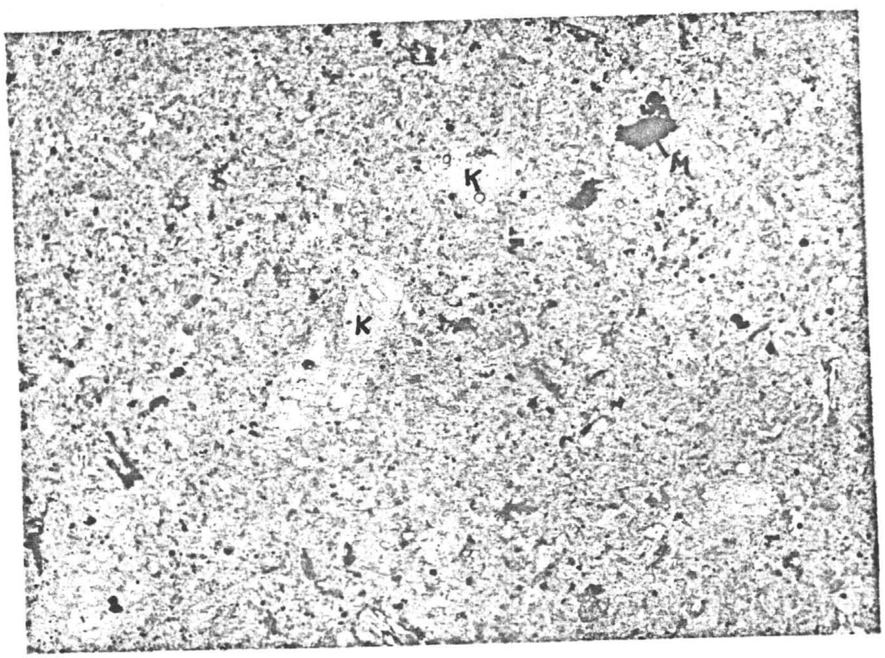


Figure 17. Photomicrograph of a Thin Section of Monzonite Porphyry

K-feldspar phenocrysts (K) and magnetite (M) held in a fine-grained matrix of feldspar, chlorite, biotite, and quartz. Plain light, X9.

Structure

There have been several studies of the structural geology of the Little Hill area. Banerjee (1957) was concerned with the structure in the Oracle quartz monzonite. Wallace (1954) did a detailed structural study of the Precambrian, Paleozoic, and Mesozoic rocks in the northern part of the Santa Catalina Mountains. Jinks (1961) mapped in detail the structures in the Pinal Schist adjacent to the Mogul fault.

Faulting

The Mogul fault is the dominant structural feature in the Little Hill area (Fig. 3, in pocket; Fig. 18). It trends west-northwest, dips 40° to 60° S., and has a large displacement. The Mogul fault is thought by some to be a strand of the Texas Lineament (Banerjee, 1957; Mayo, 1958; and Jinks, 1961). Creasey (1967), after mapping the Mammoth quadrangle east of the Little Hill area, stated that the Mogul fault may have as much as 10 miles of right lateral displacement. The present study found a monzonite porphyry dike cut by the fault which indicated 1,500 feet of left lateral displacement since the intrusion of the dike. F. P. Fritz (personal communication, 1971) calculated 4,500 feet of throw on the fault from aeromagnetic data. The north side is the up-thrown block.

Creasey (1967) suggested that the Mogul fault may have been active since Cretaceous time. Damon et al. (1963) obtained an apparent age of 49.2 m.y. in dating the Oracle quartz monzonite just north of the fault. This age indicates a severe loss of argon from the biotites, possibly due to thermal effects caused by movement along the fault.

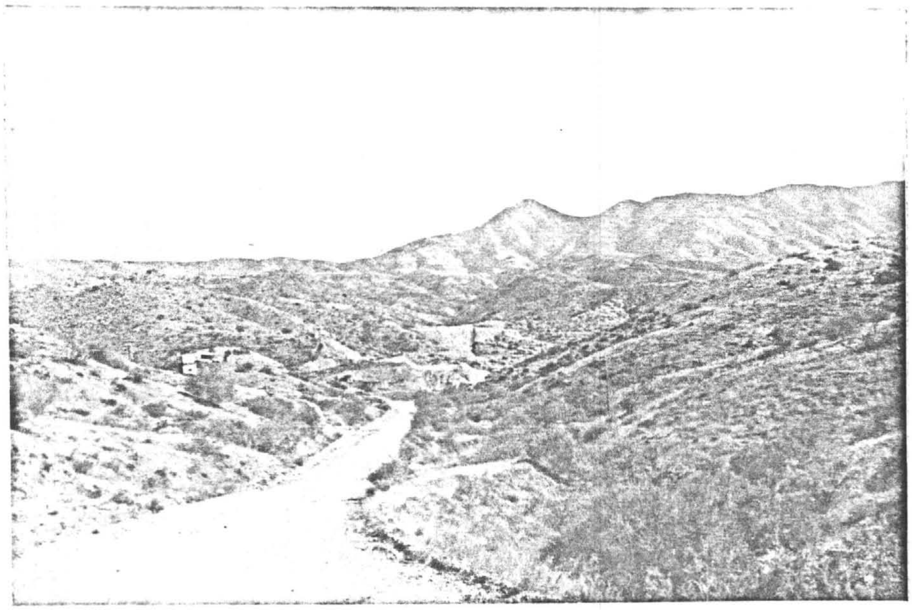


Figure 18. Surface Trace of the Mogul Fault Zone

Photograph was taken looking east along the fault zone. The Little Hill mine is in the center.

The young age obtained may be an indication of the date of the latest severe movements along the fault. Movement prior to mineralization is evidenced by brecciation of a quartzite unit at the Little Hill mine. Brecciation of the mineralized quartz veins north of the Mogul fault indicates post-mineralization movement along the fault.

The Mogul fault in the Little Hill area tends to follow the boundary between the Pinal Schist on the hanging wall and younger rock units on the footwall. The zone of brecciation along the fault ranges from a few feet in width, as seen in drill core from the Azurite mine, to several tens of feet at the Little Hill mine. Shearing parallel and subparallel to the Mogul fault exists more than a mile north of the fault in the Little Hill area (Fig. 3). Most of the shears are of small displacement and would not be detectable in the igneous rock except that many are filled with quartz veins. Some of these quartz veins are up to 15 feet wide and can be traced for more than 2,000 feet. These small synthetic faults are best developed and most abundant near the Mogul fault, decreasing in size and number to the north. Some of the small faults show recurrent movement, as indicated by many brecciated quartz veins. Few synthetic structures were detected south of the fault. The shear zones near the Mogul fault dip at moderate to steep angles to the south. Beyond about 2,500 feet north of the Mogul fault, most of the small synthetic faults dip north.

Other faults in the area trend north-northeast to northeast. Some contain quartz veins, but most are barren. The unmineralized faults are most evident in the central part of the Little Hill area where they have caused small offsets of rhyolite dikes.

Another late set of faults trend west-northwest and offset the post-mineral monzonite porphyry, latite, and quartz latite dikes. These faults show no mineralization (Fig. 3).

Foliation

The Pinal Schist and transition gneiss are conspicuously foliated in the Little Hill area. The Oracle quartz monzonite and alaskite show weakly developed but widespread foliation. The foliation strikes west-northwest and dips at moderate to steep angles to the south. Foliation in the Pinal Schist is represented by alignment of micas in the phyllite. In the transition gneiss, foliation consists of alternating bands of micas and elongate grains of quartz and feldspar. Foliation in the Oracle quartz monzonite results from the alignment of biotite and chlorite, while the alaskite contains crudely elongated quartz and feldspar grains.

Wallace (1954) and Banerjee (1957) mapped foliation in all rock types that trend west-northwest near the Mogul fault. Progressing northward from the fault, the foliation curves to the northeast. The change in the attitude of the foliation is probably due to drag along the Mogul fault.

Jointing

All rock types in the Little Hill area exhibit two principal joint trends: the first occupies a 20-degree range between N. 80° E. to east-west and N. 80° W. to east-west, and the second trend is northwest to northeast. The joints in general dip steeply. The density of joints ranges from 1 or 2 per foot for most of the Oracle quartz monzonite to

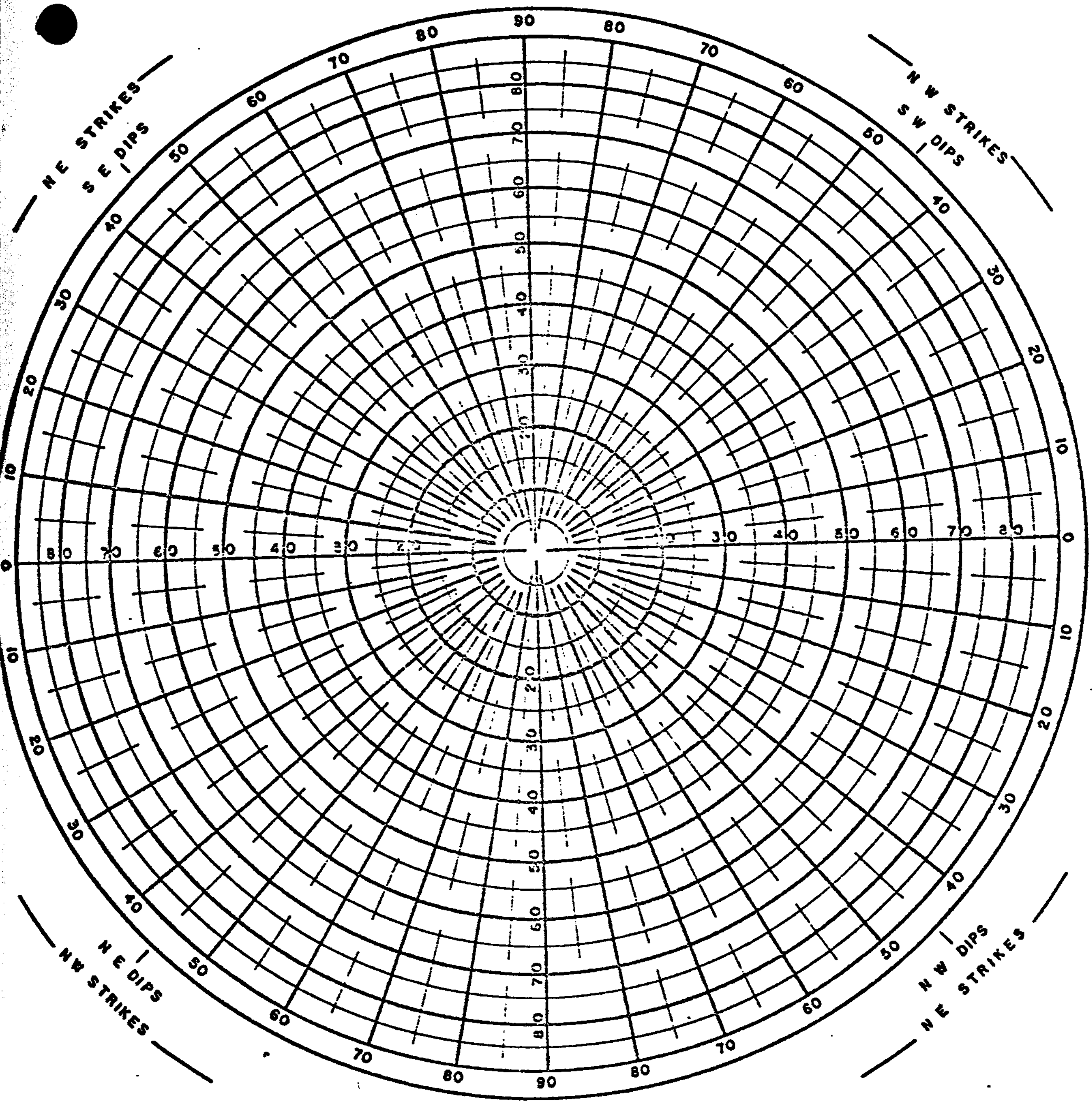
6 or 8 per foot in the Pinal Schist and transition gneiss near the Mogul fault. The west-northwest to east-northeast joint sets are preferentially mineralized. Schmidt net analyses were made of the joint attitudes.

Schmidt Net Analyses

Schmidt net analysis provided the best method by which to visualize joint and vein attitudes in the Little Hill area. Rehrig (1969, p. 27-30) gives a concise description of the procedure.

> . . . The method is somewhat difficult to visualize and has not been well understood by laymen or even some geologists. The difficulty is partially overcome by use of a net graduated directly in terms of strike and dip /Fig. 19/.
>
> The orientations of planes in space are plotted in terms of their poles on the /Schmidt/ equal-area net. The net represents a plan view of a graduated lower hemisphere. The poles represent the projections of lines normal to the planes.
>
> As illustrated . . . /Fig. 20/, the pole of a horizontal plane would plot at the center of the net. A vertical plane would plot on the circumference. Graduations on the net emphasize that points representing planes of equal strike but varying dip form lines radiating outward from the center of the projection. Points representing planes of equal dip but varying strike form concentric circles.
>
> After initial plotting of poles, the statistical density is evaluated by counting over a prescribed grid the number of points which fall in a small circle, the area of which is 1% of the entire projection. The counting circle is centered on each intersection of the orthogonal grid. At this point the net consists of about 320 gridded numbers which can either be the number of counted points or a percentage of counted points to total points. These values are then contoured, and the area between contours colored to facilitate interpretation. Spatial patterns of anomalous density are observed directly as shown by the example /Fig. 20D/.

Attitudes in several hundred veins and joint sets in all pre-mineral rock types in the Little Hill area were measured. Joint measurements were taken at sample sites spaced approximately 200 feet apart.



EQUAL AREA NET

Graduated for poles of planar elements (lower hemisphere)

Figure 19. Schmidt Equal Area Net.--From Rehrig (1969, p. 28)

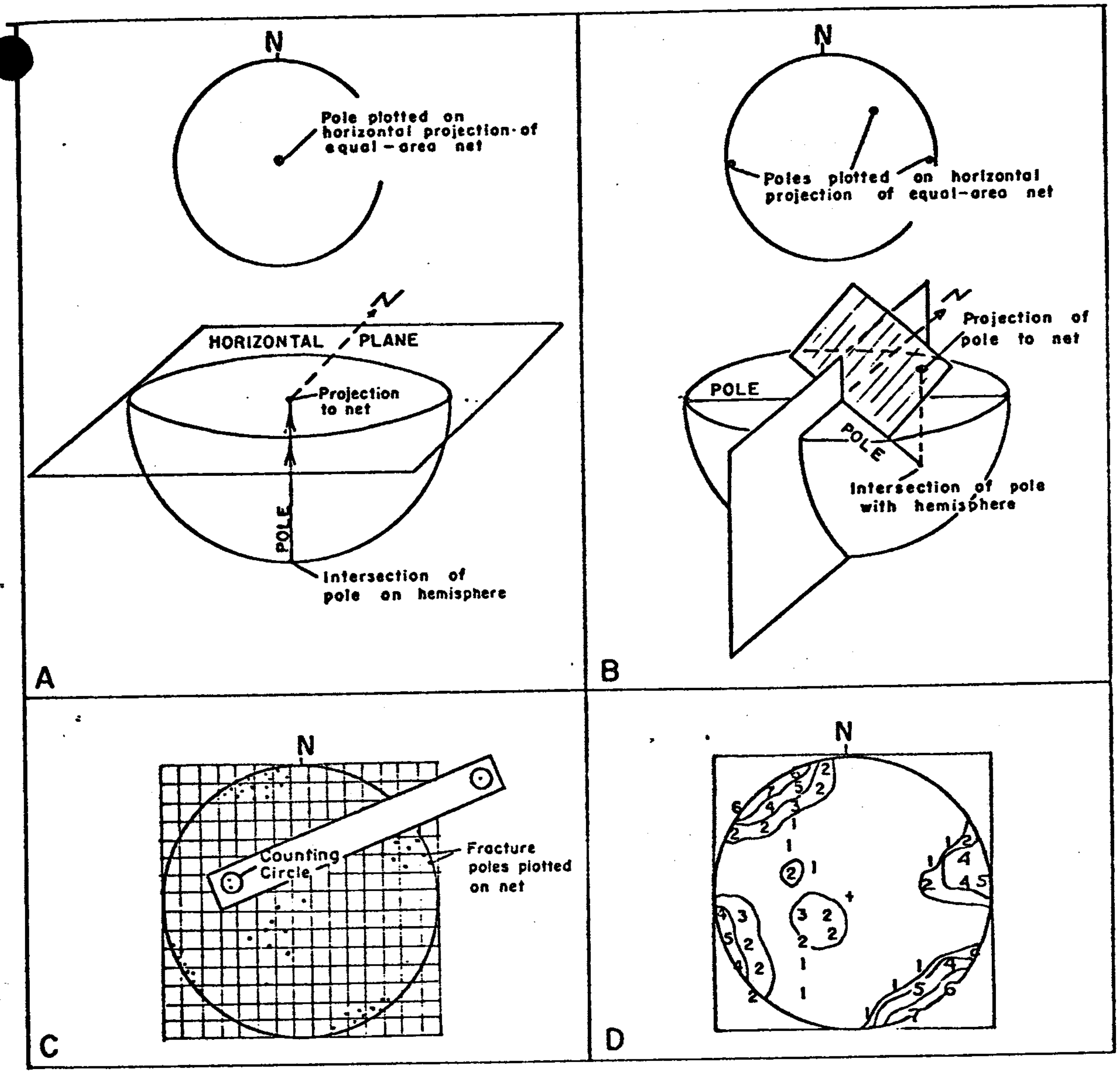


Figure 20. Construction of the Equal-area Net Plot, Lower Hemisphere

(A) The plotting of a horizontal plane. (B) The plotting of a north-striking, vertical plane and a N. 45° W., 45°S. plane. (C) The net with poles of planes plotted and overlain by counting grid. The standard counting circle whose area is 1% of the entire net is shown. This circle is centered at points on the grid and the pole points are counted. (D) Final overlay of pole density and contours. Numbers recorded are either number of poles or the percent of poles per 1% counting circle to the total number of poles.--From Rehrig (1969, p. 29).

Two or three prominent joint sets, consisting of at least three parallel joints each, were measured per sample site, and note was made of mineralization. Mineralized joints are defined as those that show evidence of hydrothermal activity, such as quartz, epidote or chlorite veining, or sulfide casts and sericite. Attitudes were taken and mineralization was noted on veins of 6 or more inches in width. Most veins were quartz filled and commonly showed evidence of sulfide mineralization (Fig. 21, in pocket).

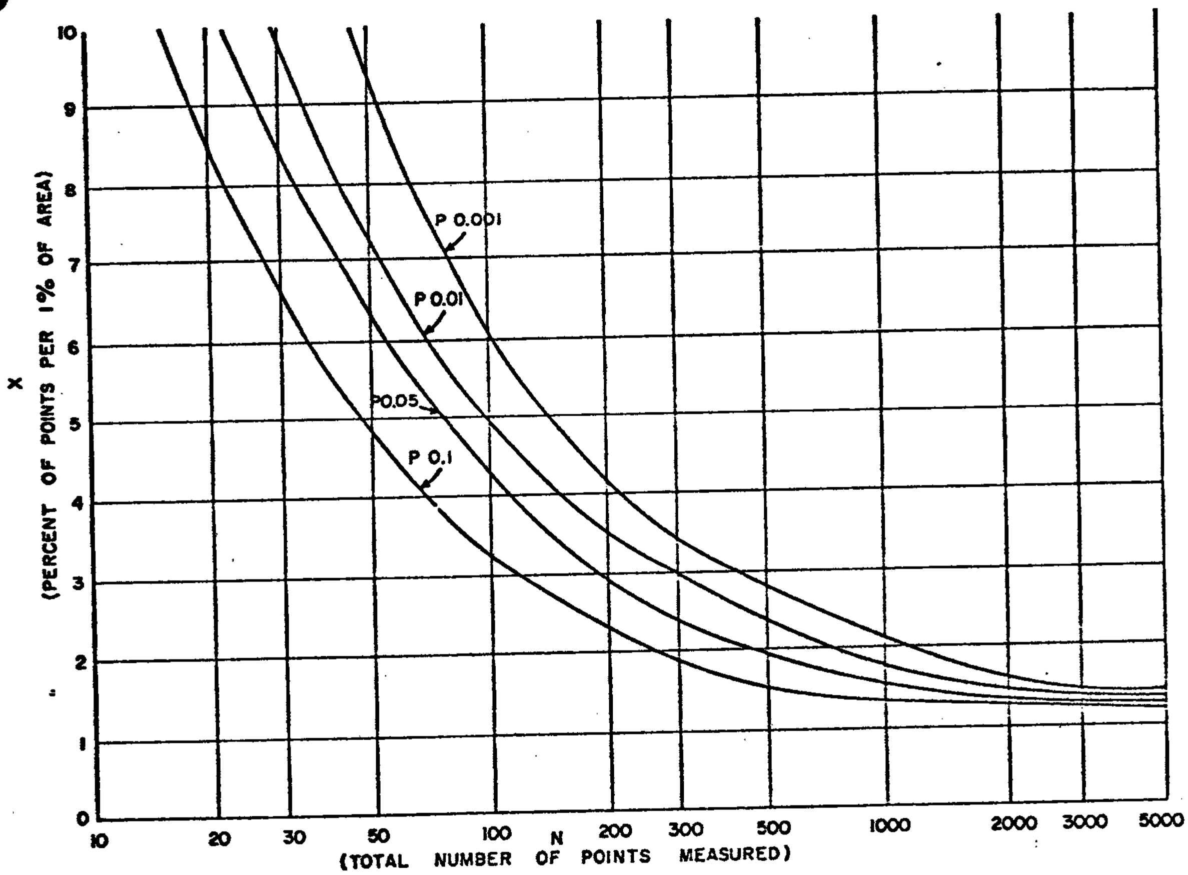
The joint and vein attitudes were evaluated by a lower hemisphere Schmidt-net Fortran computer program (R. D. Call, personal communication, 1970). The Little Hill area was divided into five domains, each of which was analyzed separately. Each domain was determined primarily on the basis of rock type. From south to north, they are as follows: (1) the Pinal Schist, restricted mainly to the Mogul fault zone; (2) the transition gneiss north of the fault zone; (3) the alaskite further north of the fault; (4) the southern portion of Oracle quartz monzonite, distinguishable by quartz veins with a distinct southerly dip; and (5) the northern portion of the Oracle quartz monzonite, characterized by quartz veins dipping to the north. The boundary between the southern and northern Oracle quartz monzonite approximately parallels the Mogul fault. The delineation is apparent on the mineralization map (Fig. 21).

Attitudes from the Schmidt net diagrams were evaluated for significance by the Poisson exponential binomial limit. The use of this formula is discussed by Friedman (1964) and Rehrig (1969). The probability of randomly attaining at least some set number of points in any one percent counting circle of an equal area projection is given by the equation

$$P = \sum_{x=x^1}^{x=\infty} \frac{e^{-N/K}(N/K)^x}{x!}$$

where P is the probability, e is 2.7183..., N the total number of points, and x the number of points per one percent counting circle. The symbol K relates to the size of the counting circle and is equal to 100 for a counter which is one percent of the net. A graph constructed by Trent (1971) was used for determining the 0.05 level of significance for each net (Fig. 22). The graph is used by finding the total number of points in the projection on the abscissa and then proceeding upward to the curve representing the 0.05 level of significance; the corresponding value of the ordinate is the maximum percentage that can exist in any one percent of the projection due to random causes. Table 2 shows the number of measurements for each domain of the Little Hill area and the percentage necessary to obtain the 0.05 level of significance. These significant percentages are indicated on the Schmidt net diagrams. Only significant attitudes are noted in the following discussion.

Unmineralized Joints. A total of 949 unmineralized joints were measured in the Little Hill area. These measurements were separated into the five domains described above. The joints show a strong northwest trend for the Pinal Schist and transition gneiss and an east-west trend for the alaskite and Oracle quartz monzonite (Figs. 23 to 27; Table 2). The change from the preferred northwest direction near the Mogul fault to a more nearly east-west direction, the principal joint trend in the Precambrian basement, is probably a function of distance from the fault.



$$P = \sum_{X = X'}^{X = \infty} \frac{e^{-N/K} (N/K)}{X!}$$

where P = probability, N = total number of points measured, K = 100, and e = 2.7183.. for probabilities of 0.001, 0.01, 0.05, and 0.10.

Figure 22. Curves Representing the Poisson Exponential Binomial Limit.--After Trent (1971)

Table 2. Summary of Schmidt Net Results of Unmineralized and Mineralized Joints and Quartz Veins

Rock Type	Type of Measurement	Number of Measurements	Critical Percentage (P = 0.05)	Main Trend		Secondary Trend		Tertiary Trend	
				Strike	Dip	Strike	Dip	Strike	Dip
Pinal Schist	Total joints	58	5.8	NW	40°-70° SW	NW	40°-70° NE	NE	50°-90° NW
	Mineralized joints	--	--		--		--		--
	Quartz veins	--	--		--		--		--
Transition gneiss	Total joints	35	7.6	NW	50°-90° NE	NE	80°-90° SE		--
	Mineralized joints	--	--		--		--		--
	Quartz veins	30	8.4	WNW	60°-80° SW		--		--
Alaskite	Total joints	110	3.9	E-W	70°-90° N&S		--		--
	Mineralized joints	27	8.8	E-W	70°-90° S		--		--
	Quartz veins	66	5.4	WNW	60°-80° S		--		--
South Oracle quartz monzonite	Total joints	317	2.4	E-W	50°-90° N	NE	70°-90° SE	NNW	70°-90° SW
	Mineralized joints	91	4.4	E-W	50°-90° N&S		--		--
	Quartz veins	124	3.8	WNW	70°-90° S	ENE	70°-90° N	NE	40°-60° NW
North Oracle quartz monzonite	Total joints	429	2.1	E-W	60°-90° N	N-S	70°-90° W	NNW	70°-90° SW
	Mineralized joints	134	3.6	E-W	60°-90° N&S		--		--
	Quartz veins	137	3.6	WNW	50°-90° W		--		--

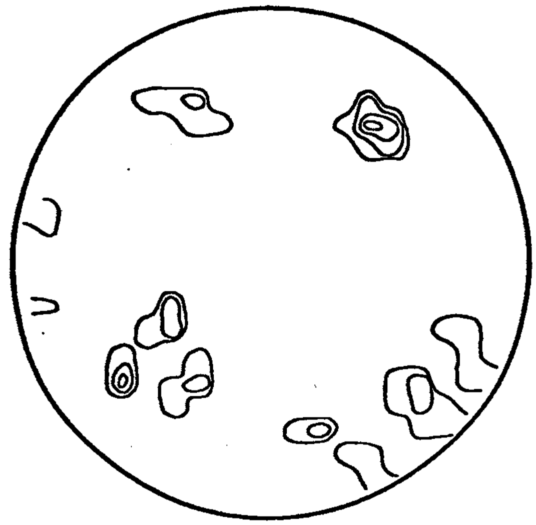


Figure 23. Schmidt Equal Area Net of Unmineralized Joints in Pinal Schist

P = 0.05 achieved when 5.8 percent of measurements occur per 1 percent area; contour interval is 3 percent; 58 points.

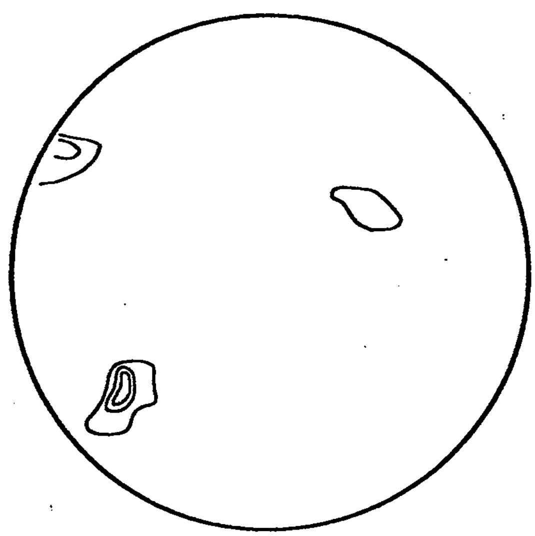


Figure 24. Schmidt Equal Net of Unmineralized Joints in Transition Gneiss

P = 0.05 achieved when 7.6 percent of measurements occur per 1 percent area; contour interval is 4 percent; 35 points.

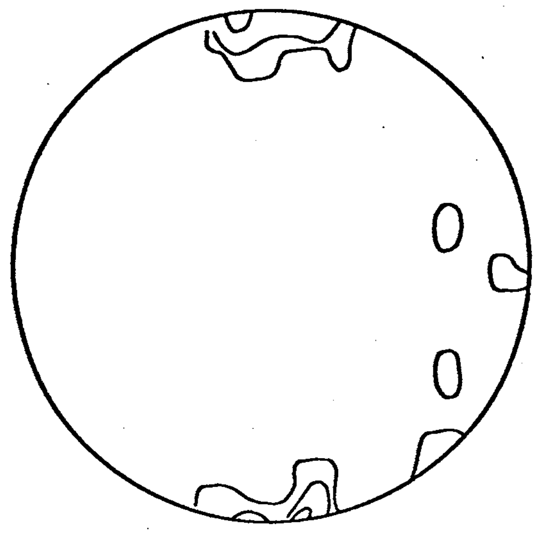


Figure 25. Schmidt Equal Area Net of Unmineralized Joints in Little Hill Alaskite

P = 0.05 achieved when 3.9 percent of measurements occur per 1 percent area; contour interval is 2.0 percent; 110 points.

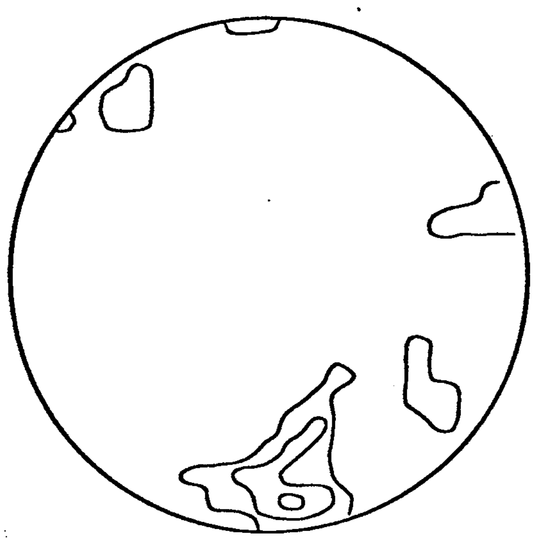


Figure 26. Schmidt Equal Area Net of Unmineralized Joints in South Oracle Quartz Monzonite

P = 0.05 achieved when 2.4 percent of measurements occur per 1 percent area; contour interval is 2 percent; 317 points.

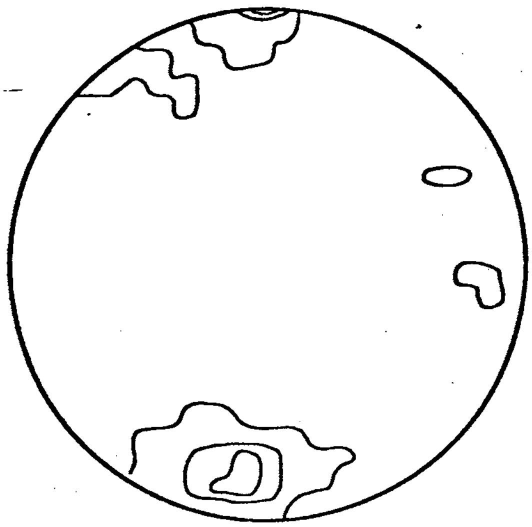


Figure 27. Schmidt Equal Area Net of Unmineralized Joints in North Oracle Quartz Monzonite

P = 0.05 achieved when 2.1 percent of measurements occur per 1 percent area; contour interval is 2 percent; 429 points.

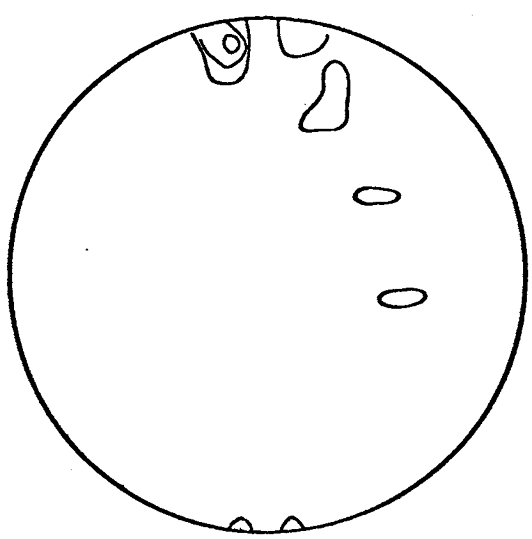


Figure 28. Schmidt Equal Area Net of Mineralized Joints in Little Hill Alaskite

P = 0.05 achieved when 8.8 percent of measurements occur per 1 percent area; contour interval is 3 percent; 27 points.

The northwest direction may be a result of drag near the fault. Most of the joints dip between 50° and 90° N. No strong orthogonal joint trends are developed in the area. Most of the strong secondary trends are northeast, northwest, and north-northwest with steep dips both to the north and south.

Mineralized Joints. Two hundred fifty-two mineralized joints were measured in the Little Hill area. There were too few mineralized joints in the Pinal Schist and transition gneiss to provide accurate Schmidt net diagrams. Joints in the alaskite show an east-west trend with strong 70° to 90° S. dips (Fig. 28; Table 2). Joints of both the north and south Oracle quartz monzonite show strong east-west strikes, and most of these joints dip 60° to 90° to the north, although a small fraction dip to the south (Figs. 29 and 30; Table 2). The number of south-dipping mineralized joints decreases from the south Oracle quartz monzonite to the north Oracle quartz monzonite. No secondary trends are developed.

The proximity of the alaskite to the Mogul fault may account for the predominant southerly dip of the mineralized joints in the alaskite. As one progresses northward from the fault, the number of south-dipping mineralized joints decreases noticeably. The strong east-west trend of the mineralized joints was influenced by movement along the Mogul fault. Conceivably the direction was strongly expressed in the Precambrian basement and later enhanced and opened during mineralization by movement along the west-northwest-trending Mogul fault. Dip-slip fault movement may have caused joints near the fault, originally dipping to the north, to be rotated southward. This would explain the gradual

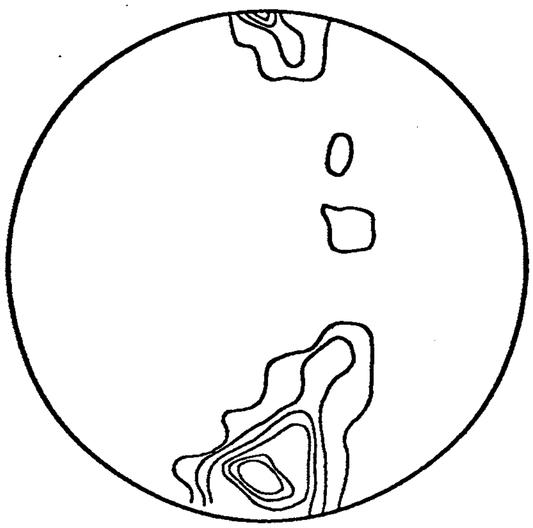


Figure 29. Schmidt Equal Area Net of Mineralized Joints in South Oracle Quartz Monzonite

P = 0.05 achieved when 4.4 percent of measurements occur per 1 percent area; contour interval is 2 percent; 91 points.

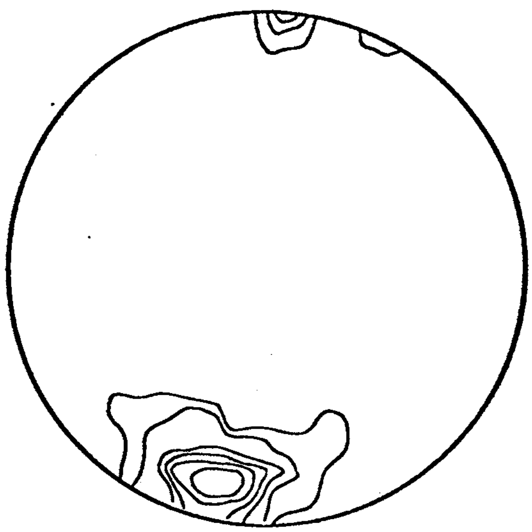


Figure 30. Schmidt Equal Area Net of Mineralized Joints in North Oracle Quartz Monzonite

P = 0.05 achieved when 3.6 percent of measurements occur per 1 percent area; contour interval is 2 percent; 134 points.

change from mineralized joints that dip predominantly to the south near the fault to those which dip predominantly to the north a mile north of the fault.

The rotation in the Little Hill area may be similar to the well-documented rotation in the San Manuel area a few miles to the northeast (Lowell and Guilbert, 1970). The San Manuel-Kalamazoo ore body experienced at least three separate episodes of tilting due to vertical uplift along a major fault since Laramide time. The ore body at San Manuel is tilted about 70 degrees from the vertical. Though not as severe as at San Manuel, the rotation at Little Hill probably occurred similarly in several phases, as evidenced by recurrent movement along the Mogul fault since Cretaceous time.

Quartz Veins. Previous discussion noted that quartz veins are greater than 6 inches in width and are not obviously emplaced along joints in the Little Hill area. A total of 357 quartz veins was measured (Fig. 21, in pocket). No Schmidt net analysis was done for the Pinal Schist, because it contains insufficient quartz veins.

Quartz veins in transition gneiss and alaskite show a very strong west-northwest strike and a strong southerly dip (Figs. 31 and 32; Table 2). Quartz veins in the south Oracle quartz monzonite show two predominant trends: west-northwest with a strong southerly dip and east-northeast with a steep northerly dip (Fig. 33). The veins from the north Oracle quartz monzonite trend west-northwest and dip to the north (Fig. 34). Only the west-northwest to east-northeast quartz vein trends are well developed in the Little Hill area.

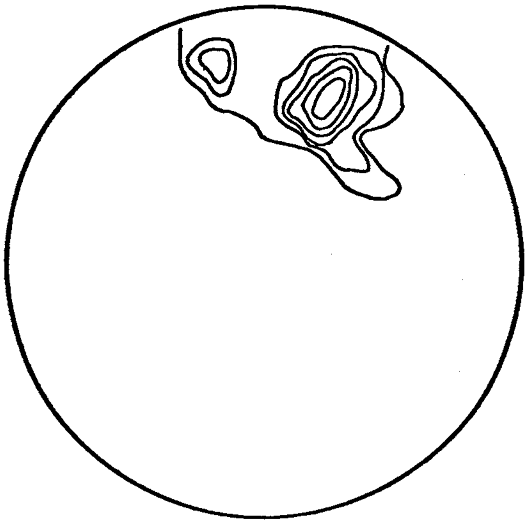


Figure 31. Schmidt Equal Area Net of Quartz Veins in Transition Gneiss

P = 0.05 achieved when 8.4 percent of measurements occur per 1 percent area; contour interval is 3 percent; 30 points.

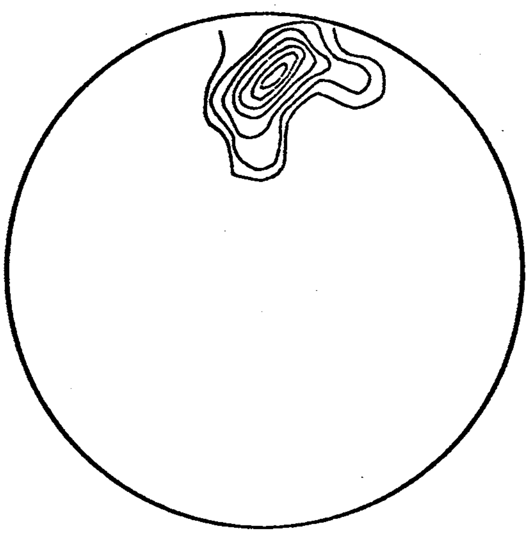


Figure 32. Schmidt Equal Area Net of Quartz Veins in Little Hill Alaskite

P = 0.05 achieved when 5.4 percent of measurements occur per 1 percent area; contour interval is 2 percent; 66 points.

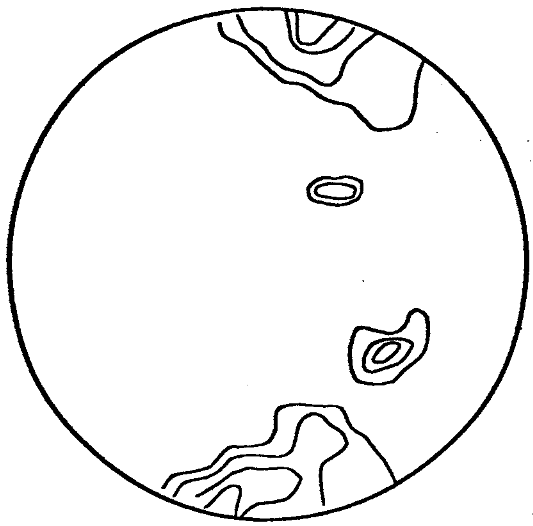


Figure 33. Schmidt Equal Area Net of Quartz Veins in South Oracle Quartz Monzonite

$P = 0.05$ achieved when 3.8 percent of measurements occur per 1 percent area; contour interval is 2 percent; 124 points.

Figure 34. Schmidt Equal Area Net of Quartz Veins in North Oracle Quartz Monzonite

$P = 0.05$ achieved when 3.6 percent of measurements occur per 1 percent area; contour interval is 2 percent; 137 points.

The Mogul fault has exerted a profound effect on the directions open to quartz vein mineralization. It appears that west-northwest synthetic faults may have provided the channels for mineralization. The quartz veins and faults decrease progressively in number and strength with distance north of the Mogul fault. The lack of quartz veins in the Pinal Schist may be due to its incompetence, which prevented shears from remaining open during mineralization. The quartz veins nearest the Mogul fault have a pronounced southerly dip. Progressing northward from the fault, the Schmidt nets show that the veins dip vertically and then to the north. The change in direction of dip may be related to rotation caused by dip-slip movement along the fault, as discussed above with reference to mineralized joints.

Summary. It is evident from the Schmidt net analyses that the Mogul fault has had a strong influence on the preferred west-northwest to east-northeast directions for the unmineralized and mineralized joints and quartz veins. The fault was influential in opening the east-west joints which were preferentially mineralized. West-northwest to east-northeast synthetic faults were developed for a distance of more than a mile north of the Mogul fault and were open during episodes of quartz vein mineralization.

ZIRCON STUDY

The zircon study was conducted in an attempt to cast light upon the origin of the Oracle quartz monzonite. Is the Oracle quartz monzonite largely the result of metasomatism of the Pinal Schist, as proposed by Wallace (1954) and Banerjee (1957), or is it truly intrusive?

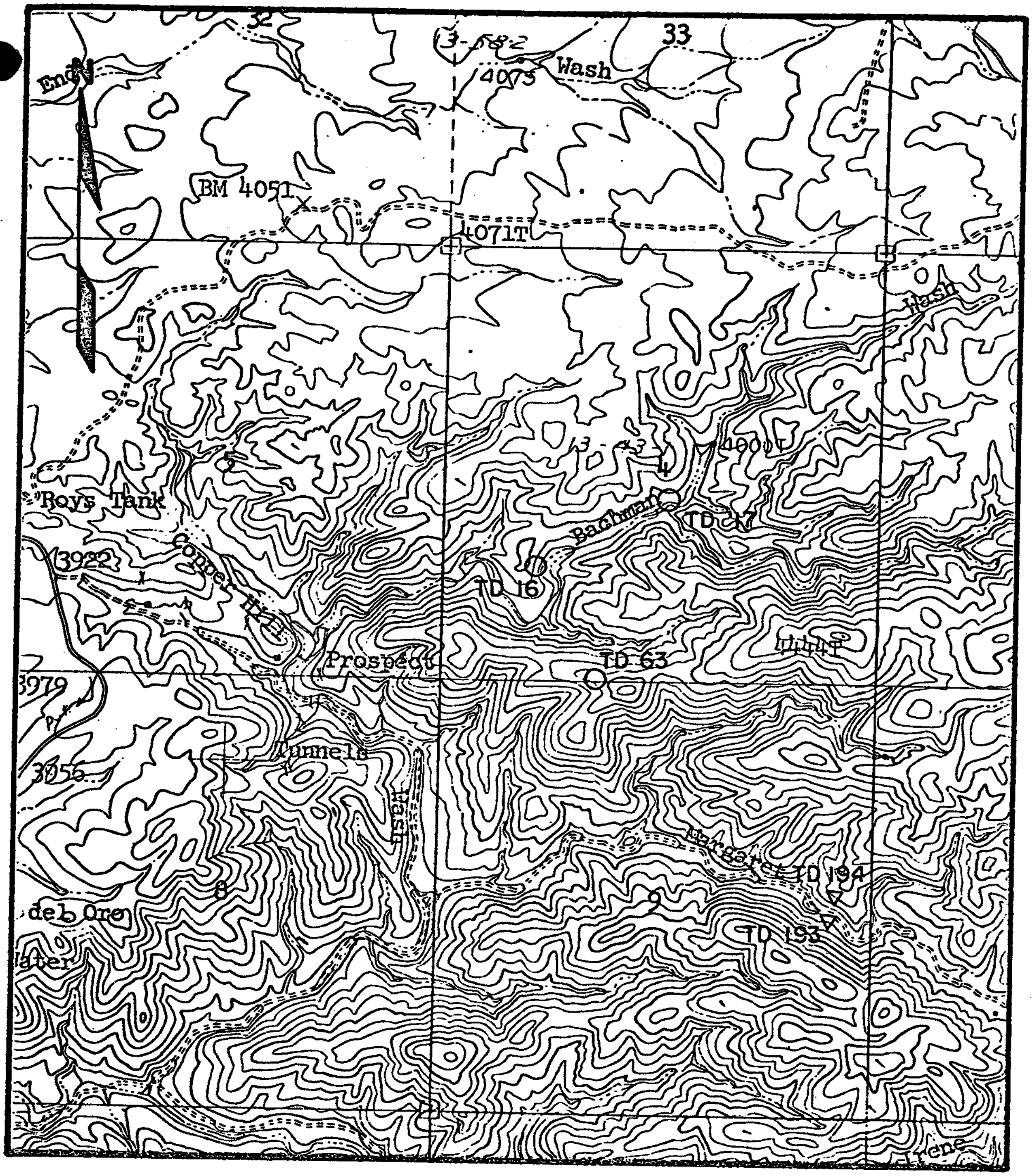
The study of zircons in possible igneous and metamorphic terrains may give evidence as to the origin of the rocks. It has been shown that zircons become rounded during sedimentary transportation (Armstrong, 1922; and Poldervaart, 1950). The majority of the zircons in felsic to intermediate igneous rocks are euhedral (Eckelman and Kulp, 1956), except when corroded by magmatic or hydrothermal fluids (Poldervaart, 1956; Spotts, 1962; and Armstrong, 1922). Such corrosion is, however, much more common in extrusive than intrusive rocks (Poldervaart, 1956). Zircons will not easily recrystallize during metamorphism (Poldervaart and von Backström, 1949; Poldervaart, 1950).

It has been demonstrated from the tabulation of many elongation frequency curves that zircons from an igneous terrain commonly have elongation ratios greater than 2.0, while those from sedimentary terrains generally average ratios less than 2.0 (Poldervaart and von Backström, 1949; Poldervaart, 1950). Curves with two maxima indicate a mixture of sedimentary and igneous zircons in metamorphic rocks. A high rounding index indicates that crystals have been abraded to a great extent, as for example in the generation of sandstone. Lesser rounding indices indicate shorter distances of transport. Spotts (1962) states that elongation frequency curves for samples of a single phase of an intrusion are statistically similar. Radically different curves may indicate that the intrusion occurred in more than one phase or that the rock is possibly of metasomatized sedimentary origin.

Alper and Poldervaart (1957) and Spotts (1962) have shown that within a given intrusion the reduced major axis of zircons may be regarded as the relative crystal growth trend of the zircon samples. The slopes of reduced major axes of samples drawn from a single phase of an intrusion will not differ statistically. A sample taken from a different intrusive unit a short distance away, even though it may have the same chemical and mineralogical composition as the first intrusive unit, will show a significantly different slope. If then two samples from what appears to be a single intrusive phase were to show statistically different slopes for the reduced major axis calculations, one might conclude that there was either more than one intrusive phase or that the supposed igneous rocks were actually of metasomatized or granitized sedimentary origin. If the latter conclusion is correct, evidence from elongation frequency graphs and rounding index calculations should concur with the reduced major axis calculations in indicating a non-igneous origin.

Method and Calculations

Several representative geochemical pulps of Oracle quartz monzonite and Pinal Schist were used in the zircon study (Fig. 35). Each sample was treated with tetrobromoethane to separate light from heavy



Scale: 1 inch = 2000 feet

▽ Pinal schist samples

O Oracle quartz monzonite samples

Figure 35. Location Map of Samples Used for Zircon Study

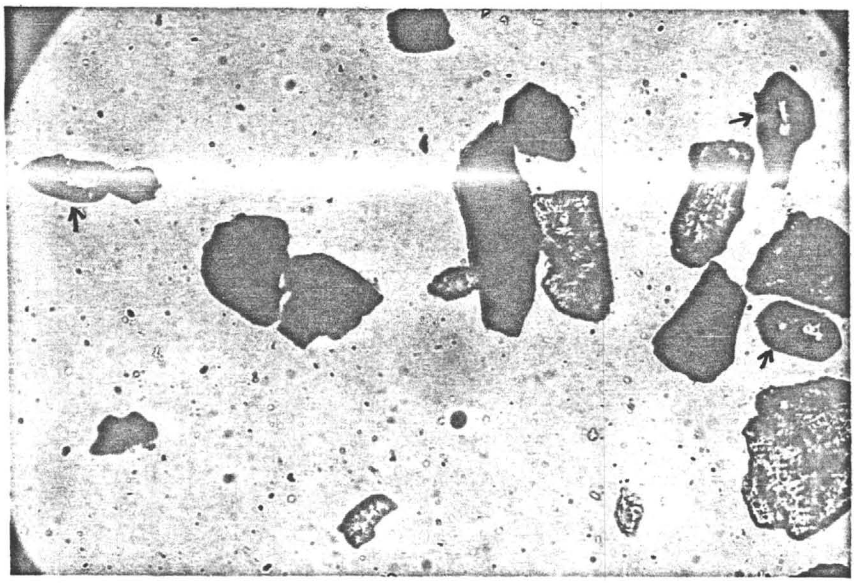
fractions. The heavy portions were dried and the magnetic material was separated from the nonmagnetic. The resulting concentrates were sufficiently pure despite that the use of a small magnet did not remove the biotite or ilmenite. The concentrates were mounted with cadex on glass slides and viewed under medium power with an ocular micrometer. The length and breadth of each unbroken zircon were measured and the degree of rounding for each zircon was noted. The zircon was classified according to the following scheme: euhedral if all crystal faces were sharp; subhedral if the pyramids of the crystals showed rounding; subrounded if the pyramids and the corners of the prism were rounded; rounded if all edges of the zircon showed rounding and no crystal faces remained; and well rounded if the crystal was approximately equidimensional with all edges and crystal faces completely rounded (Fig. 36). The number of zircons measured per sample ranged from 33 to 81. The elongation ratio was determined by dividing the length of each zircon by its width. Ratios were then plotted on an elongation frequency graph. The rounding index of a sample was based on the percentage of crystals showing any evidence of rounding in that sample.

Results and Conclusions

Elongation Frequency Graphs

The elongation frequency curves for three samples of Oracle quartz monzonite are presented in Figure 37. The curves for the three samples show maxima between 1.65 and 1.85. By inspection, the three curves are markedly different in form. These differences are treated statistically below.

A



B

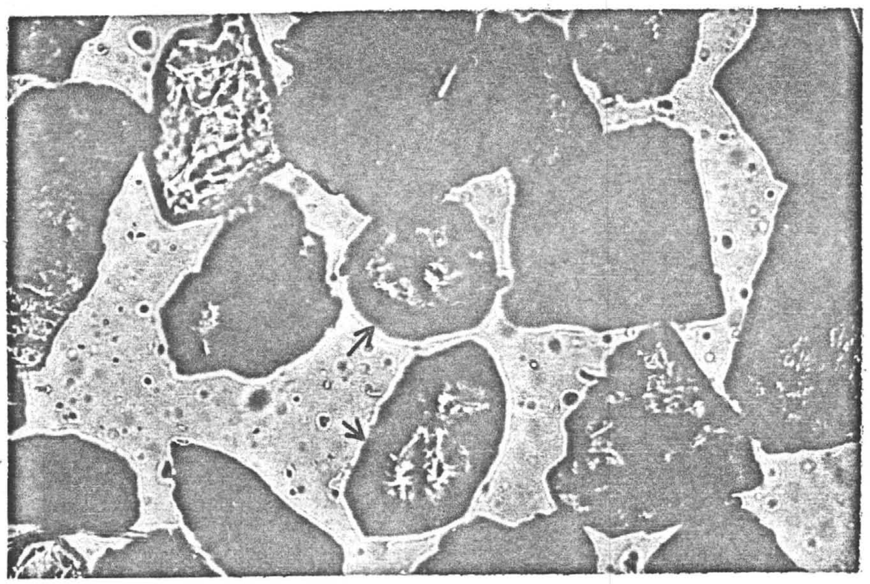


Figure 36. Photomicrographs of Zircon Crystals from Oracle Quartz Monzonite

A: Three zircon crystals from sample TD-17 show subrounded to rounded outlines. Plain light, X85. B: Two zircon crystals from sample TD-17 show subhedral to well-rounded forms. Plain light, X161.

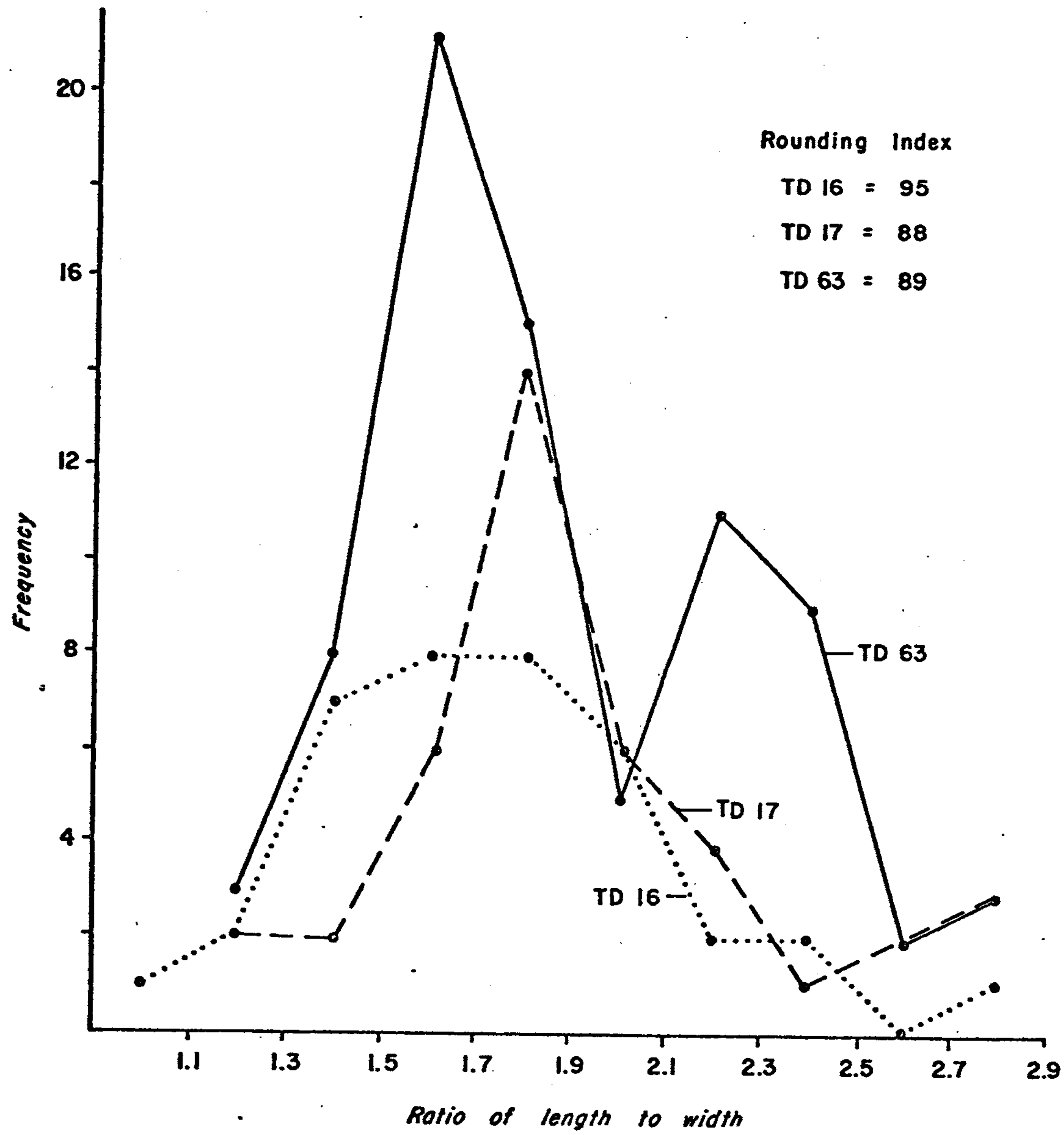


Figure 37. Elongation Frequency Graph and Rounding Index of Three Samples of Zircon from the Oracle Quartz Monzonite

The elongation frequency curves for the Oracle quartz monzonite show peaks that indicate ratios less than those expected for most igneous rock. Further, the differences in form of the curves imply that the Oracle quartz monzonite is either non-igneous or that, if igneous, its intrusion in the Little Hill area did not occur in a single phase (Spotts, 1962).

The Pinal Schist elongation frequency graph (Fig. 38) is presented for comparison with that of the Oracle quartz monzonite. The two samples of Pinal Schist, a rock of known sedimentary origin, show elongation ratio maxima between 1.45 and 1.85. The values for the schist cover the range of values obtained for the Oracle quartz monzonite.

Rounding Indices

The rounding index for each sample of the Oracle quartz monzonite is indicated in Figure 37. For sample TD-16, 95 percent of the zircon crystals show rounding. For sample TD-17, the rounding index is 88 percent, and for TD-63, 89 percent. Eckelman and Kulp (1956) state that most zircon crystals in felsic or intermediate rocks are euhedral. This is clearly not true for the above samples. The high rounding indices might indicate strong hydrothermal corrosion of the crystals or abrasion of the zircon crystals during sedimentary transport.

The two samples of Pinal Schist give rounding indices of 97 percent and 94 percent (Fig. 38). These values are comparable to those obtained from samples of the quartz monzonite.

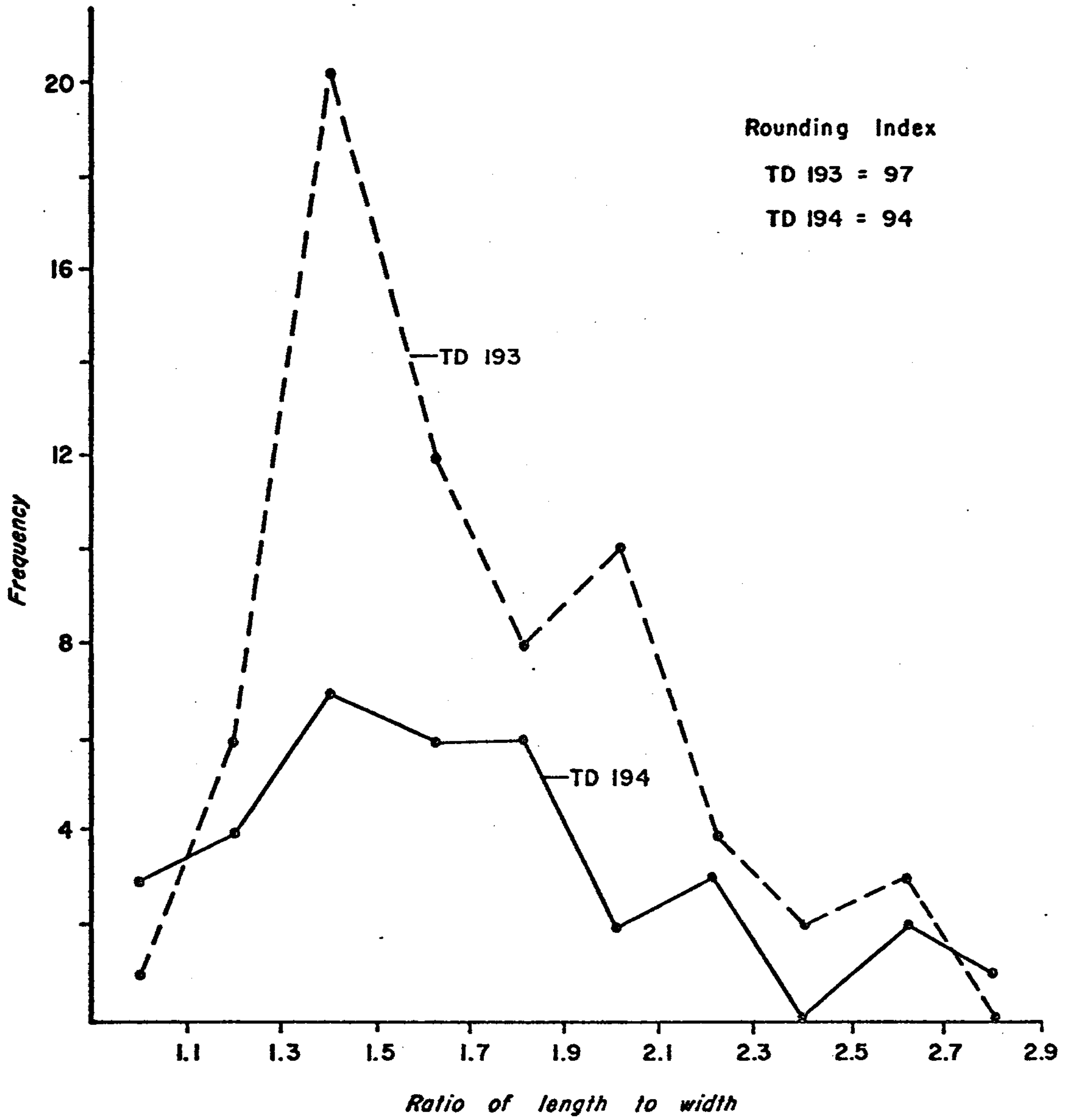


Figure 38. Elongation Frequency Graph and Rounding Index of Two Samples of Zircon from the Pinal Schist

The implication is that the zircons in the Oracle quartz monzonite may have been derived from a rock that was originally sedimentary.

Reduced Major Axes

Sample TD-16, taken from the central region of the Oracle quartz monzonite in the Little Hill area (Fig. 35), was used as a reference in the reduced major axes comparisons. Sample TD-17, from a point north of TD-16 in the Oracle quartz monzonite, and sample TD-63, from an area to the south in the same rock type, were compared to TD-16.

Reduced major axes for each of the three samples were calculated from the zircon length-width data according to the formula provided by Alper and Poldervaart (1957):

$$a = s_w / s_l$$

where a is the slope, s_w the standard deviation of the width, and s_l the standard deviation of the length.

If length is plotted against width, the reduced major axis of a sample is drawn through the point of the mean length (L), mean width (W) at an angle whose tangent is equal to the slope, a. The line represents the best geometric fit to the scatterplot of the two parameters, length and width. A graph of the reduced major axes of samples TD-16, TD-17, and TD-63 is presented in Figure 39.

To determine the significance of the difference between two reduced major axes, the standard error of slope (σ_a) for each sample

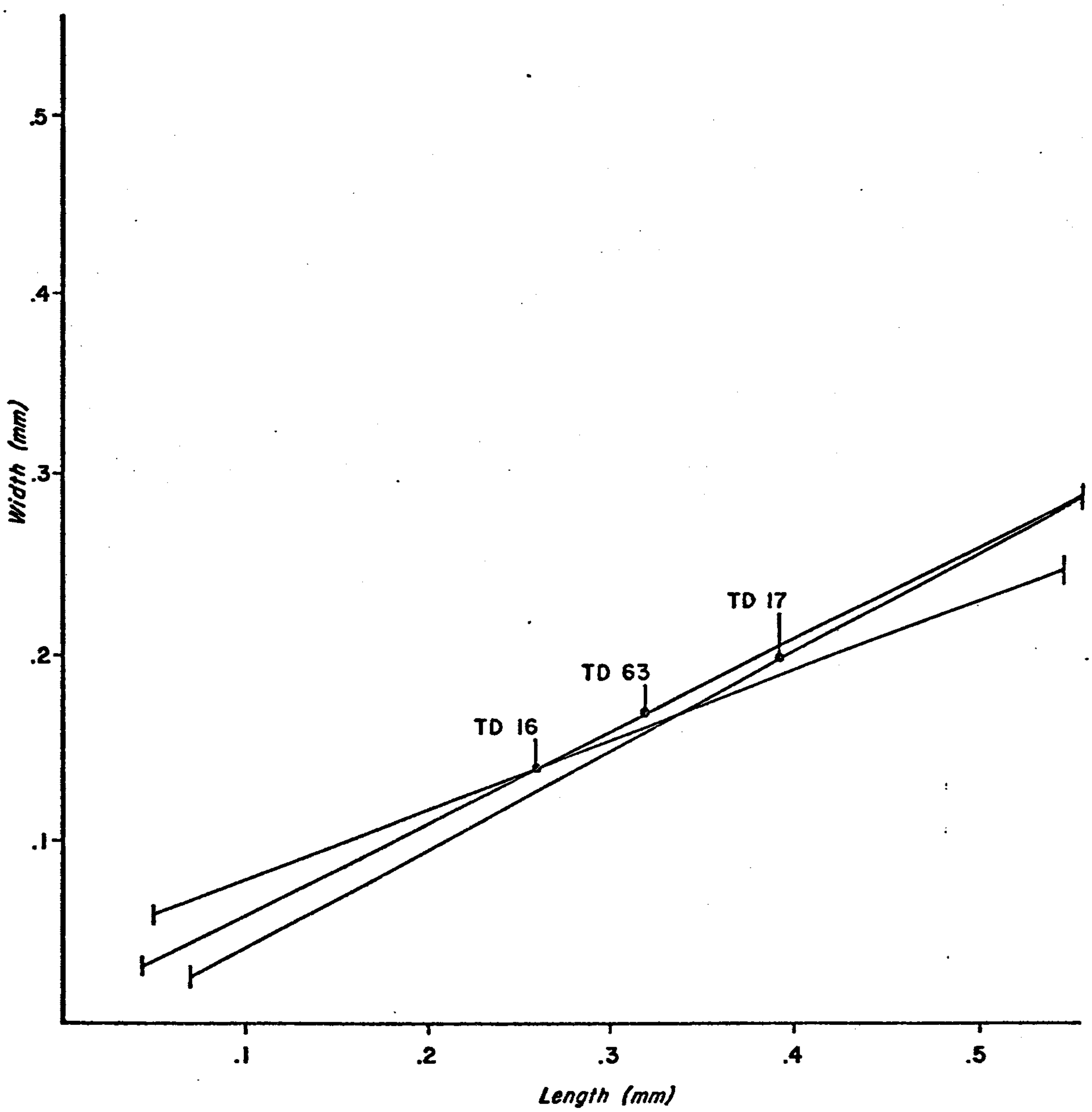


Figure 39. Reduced Major Axes for Three Zircon Samples from the Oracle Quartz Monzonite

is determined and a z value calculated (Alper and Poldervaart, 1957):

$$\sigma_a = \sqrt{\frac{1 - r^2}{N}}$$

where r is the product-moment correlation coefficient between length and width, and N is the number of zircons in the sample; and

$$z = \frac{a_1 - a_2}{\sqrt{\sigma_{a_1}{}^2 + \sigma_{a_2}{}^2}} .$$

The z score is then evaluated by a table of the normal curve. The probability of a $z \geq 1.96$ occurring by chance is 0.05. The 0.05 confidence level is arbitrarily chosen as reflecting a non-chance difference between reduce major axes of two samples.

The results of the comparisons of the reduced major axes are presented in Table 3.

Table 3. Comparisons of Reduced Major Axes of Three Samples from the Oracle Quartz Monzonite

(N--number of zircons measured; a--slope; r--product-moment correlation coefficient; σ_a--standard error of slope.)

Samples of Comparison	N	a	r	σ_a	Difference (z value)
TD-17 TD-16	41 40	.520 .361	.647 .705	.062 .041	2.146*
TD-63 TD-16	81 40	.483 .361	.755 .705	.035 .041	2.272*
TD-17 TD-63	41 81	.520 .483	.647 .755	.062 .035	0.521

* Significant at $P \leq 0.05$.

The z values of the comparisons of TD-17 to TD-16 and TD-63 to TD-16 exceed the critical level of P = 0.05. The slopes of reduced major axes of the two samples drawn from the northern and southern Oracle quartz monzonite do differ significantly from the reference sample TD-16, although TD-17 and TD-63 do not differ significantly from each other.

The significant differences obtained from the statistical comparisons of reduced major axes concur with data presented above in indicating that if the Oracle quartz monzonite is a Precambrian intrusive rock, it was emplaced in two or more phases and the zircons were strongly corroded by hydrothermal solutions in the Little Hill area. Alternatively, the zircons may have been derived originally from sedimentary rocks.

Petrographic evidence from the thesis studies of Banerjee (1957) and Wallace (1954) indicates that the Oracle quartz monzonite, at least locally, is actually metasomatized Pinal Schist. Although small in scale, the present zircon study shows that the zircons of the Oracle quartz monzonite have probably experienced some sedimentary transport. Thus, the zircon data lend credence to the hypothesis of Banerjee and Wallace that the Oracle quartz monzonite in the Little Hill area is metasomatized Pinal Schist. Further study is needed over a much larger area in the Oracle quartz monzonite to resolve this problem.

GEOCHEMISTRY

A total of 336 rock chip samples for geochemical analysis were collected in the Little Hill area. Geochemical results and sample locations are shown in Figures 40 and 41 (in pocket). All rock types older than the rhyolite are mineralized.

Most samples were collected on traverse lines trending N. 10° E. to N. 25° E. originating south of the Mogul fault and cutting completely across the zone of weak sericite alteration. Each sample consisted of 10 or more rock chips collected at the end of a taped interval which varied from 100 to 400 feet.

The geochemical results for the rock chip samples show a large percentage of the copper values to be anomalous with respect to the regional background of 20 to 30 parts per million (ppm) copper which has been established for the Oracle quartz monzonite by a reconnaissance survey conducted by AMAX Exploration, Inc. The copper values obtained in the present study, also analyzed by AMAX, ranged from 5 to 2,800 ppm. Background and anomalous values for the Little Hill area were determined by an arithmetic frequency plot (Fig. 42). Raw data were contoured on a logarithmic basis. Due to the general high background for the area, only the 306 samples from premineralized rocks were used for the frequency plot. This yielded the clearest picture of the anomalous area. The frequency graph with a class interval of 25 ppm shows a distinct break at 250 ppm. This value is taken to be the lower limit of

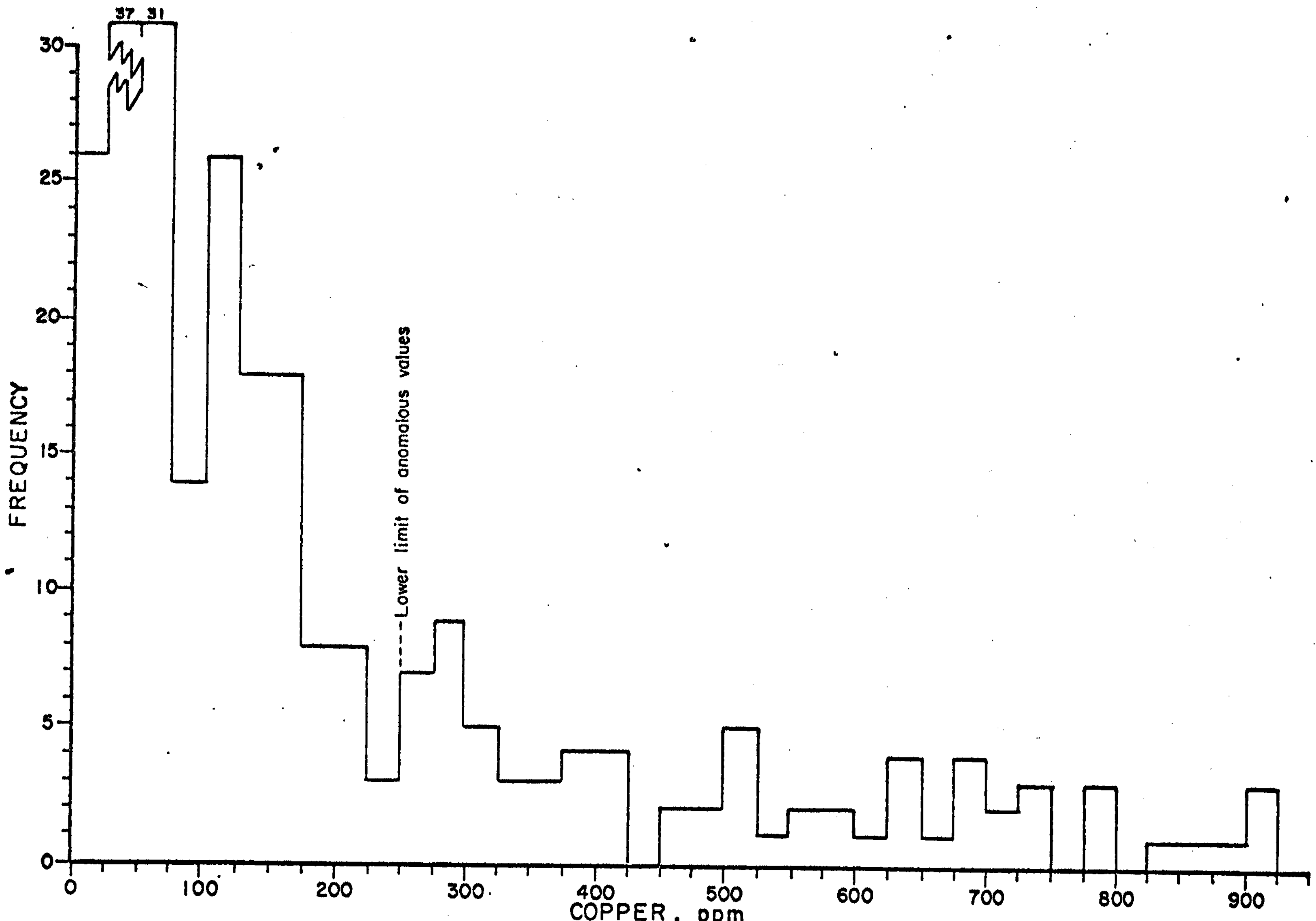


Figure 42. Histogram of Copper Geochemical Values from Rock Chip Samples, Little Hill Area

anomalous values within the broad anomalous zone which encompasses the Little Hill area.

The logarithmic contours of the geochemical copper values (Fig. 40) were the most informative. A logarithmic scale was used in contouring the wide range of geochemical values which would have necessitated an excessive number of arithmetic contours. By the logarithmic method, a broad but weakly anomalous zone for the Little Hill area on a regional basis is indicated to be at greater than 100 ppm copper. This zone nearly corresponds with the area of weak alteration. Values of greater than 250 ppm copper define both a highly anomalous area on a regional basis and a zone considered anomalous for the local Little Hill area. This latter zone, the main copper anomaly, covers the southeast quarter of the Little Hill area. It is nearly trapezoidal and about 6,000 feet long and 2,000 to 3,500 feet in width. The anomaly shows a sharp boundary on the south at the Mogul fault, decreasing gradually in strength in all other directions.

The copper anomaly defines the zone of copper mineralization visible on the surface in the form of chalcopyrite in quartz veins and disseminated chalcopyrite casts, malachite, azurite, and chrysocolla.

The molybdenum geochemical values were analyzed by the same method as the copper values. A frequency plot (Fig. 43) was used to determine the background and anomalous molybdenum values. Background values for molybdenum average about 1 ppm, and the lower limit of anomalous values occurs at 5 ppm. The class interval for the frequency plot is 2 ppm.

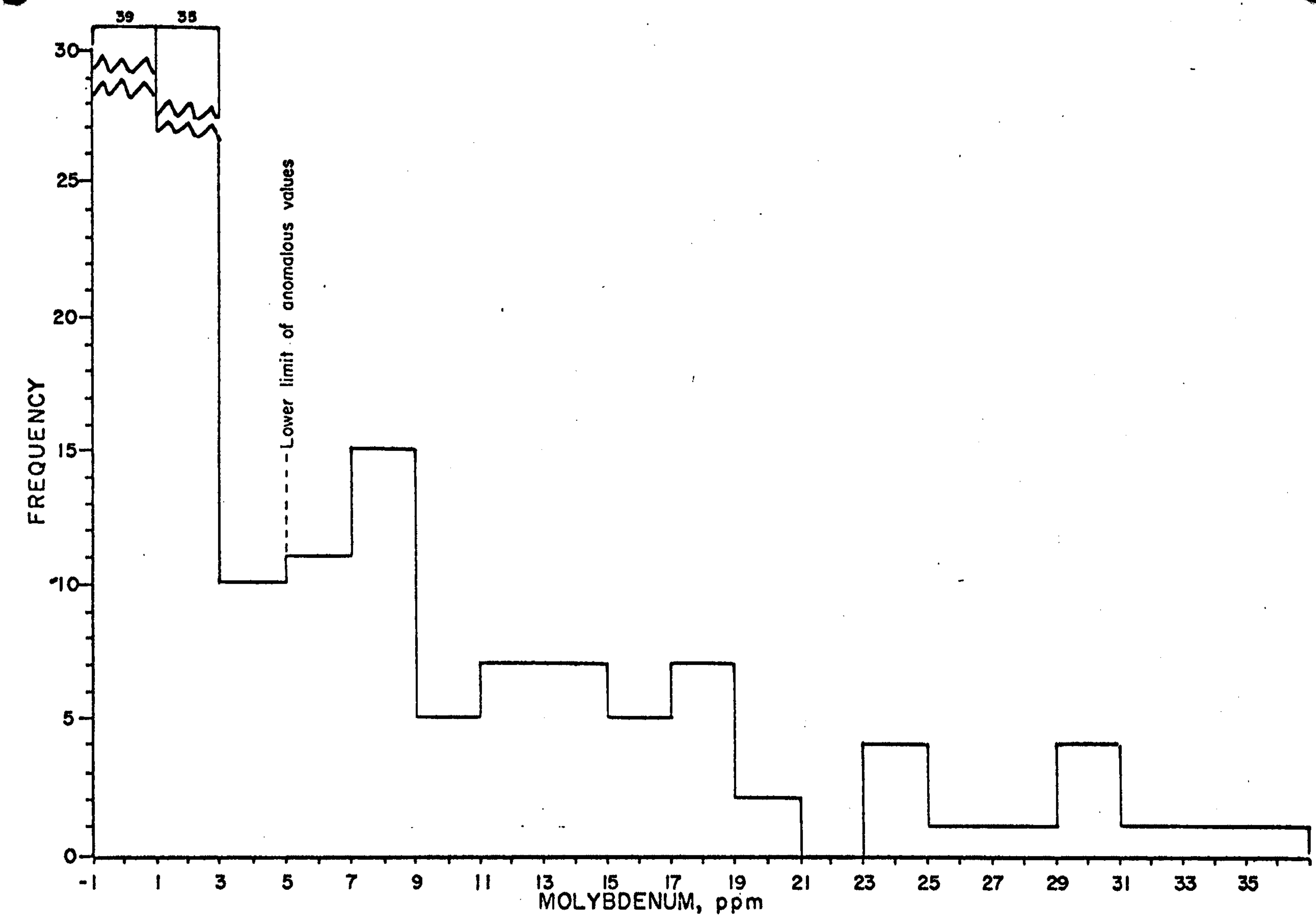


Figure 43. Histogram of Molybdenum Geochemical Values from Rock Chip Samples, Little Hill Area,

The molybdenum anomaly outlined by values of greater than 5 ppm is clearly defined when the data are contoured on a logarithmic basis (Fig. 41). Molybdenum values range from less than 1 to 690 ppm. The molybdenum anomaly is in the shape of a large "U" more than 8,000 feet long and 5,000 feet wide. The anomaly trends almost parallel to the Mogul fault. The limbs of the "U" are 300 to 1,500 feet in width. The area between the limbs shows low molybdenum values. The anomaly is cut off sharply on the south by the Mogul fault, and values decline across a steep gradient at all other boundaries. The molybdenum and copper anomalies are largely exclusive of one another, except near the Mogul fault where they cross. Surface evidence indicates a relationship between the molybdenum anomaly and the molybdenum-rich quartz veins and molybdenum paint on joints. The molybdenum has probably not migrated far, because the anomaly is well defined.

Reconnaissance surveys in all directions from the Little Hill area revealed no additional anomalies. It is concluded that the geochemical data of the Little Hill area define a unique zone of mineralization in the Precambrian rocks at the west end of the Mogul fault.

ALTERATION

Alteration in the Oracle quartz monzonite has been discussed by Schwartz (1953), Creasey (1965), and Lowell and Guilbert (1970). Their work dealt exclusively with rock specimens seen underground and in drill core. The purpose of the present discussion is to describe the alteration as seen in weathered surface outcrops. The present observations will be compared with those made by Lowell and Guilbert at the San Manuel-Kalamazoo deposit a few miles northeast of Little Hill.

The Little Hill area displays weak but pervasive chloritic alteration and a broad zone of weak sericite alteration of plagioclase (Fig. 3, in pocket). The zone of sericite alteration extends more than a mile north of the Mogul fault, running for a length of about one and three-quarters miles parallel to the fault. The alteration decreases in pervasiveness fairly abruptly north of this zone, where alteration is only weak and local. Epidote alteration is present throughout the area as local joint and fracture filling and as disseminations in the rock.

Sericitic alteration is present in all premineral rock types. It is best developed in the alaskite, transition gneiss, and Oracle quartz monzonite. Each of the 336 rock chip geochemical samples, taken at regular intervals across the entire area, was described with attention to the sericitic alteration extensiveness. From this information, a zone of weak sericitic alteration was outlined. Within this zone two distinct zones of stronger alteration were defined (Fig. 44).

SCALE: 1 inch = 2000 feet

LIMIT OF SERICITIC ALTERATION OF PLAGIOCLASE

AREAS OF STRONG SERICITE ALTERATION

AREAS OF ABUNDANT MINERALIZED QUARTZ VEINS ALONG JOINTS

Figure 44. Alteration Map of the Little Hill Area, Pinal County, Arizona

The classification which follows was used during the field mapping to categorize sericitic alteration by degree of extensiveness.

1. Alteration was termed weak to very weak if the plagioclase showed some evidence of sericitic alteration with the aid of a hand lens.
2. Alteration was judged moderate if the plagioclase was completely sericitized, the potassium feldspars showed some sericite, and the sericite was visible with the unaided eye.
3. Strong alteration was the description applied if both the plagioclase and potassium feldspar had largely been altered to sericite. Introduced quartz was sometimes present. This altered rock was generally vuggy, almost always showed evidence of sulfide mineralization, and revealed destruction of all the mafic minerals. The sericite was fine to coarse. The strong alteration commonly occurred adjacent to quartz veins.
4. Alteration was termed very strong if the rock had been altered to a vuggy mass of quartz and sericite (the phyllic alteration assemblage of Lowell and Guilbert, 1970). In these very strongly altered rocks, all the feldspars and mafic minerals have been completely replaced. A few grains of quartz were all that remained of the original rock. The sericite was generally coarse grained. This very strong alteration is most commonly, although not exclusively, found adjacent to quartz veins (Fig. 45). The outcropping rock is yellow brown and full of sulfide casts.

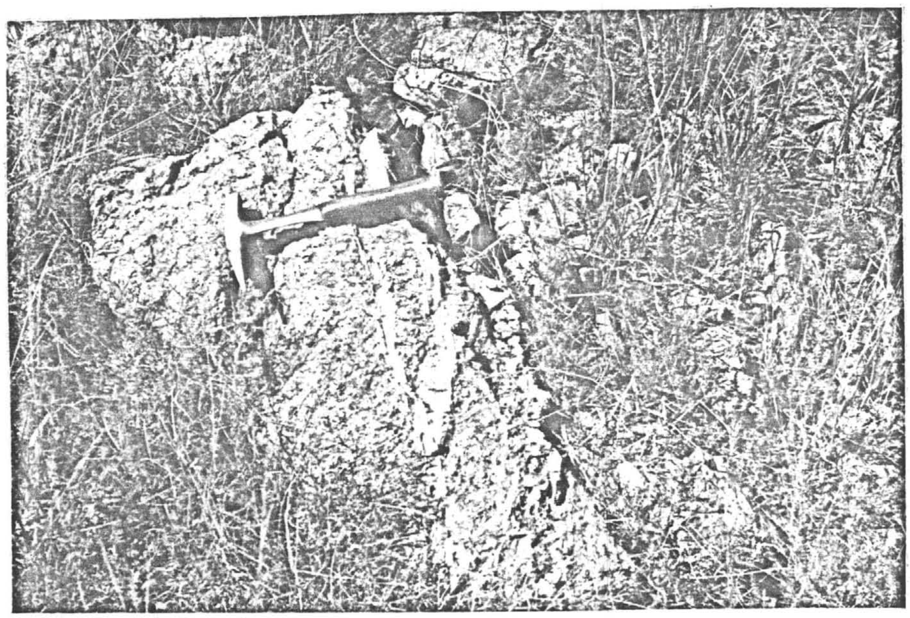


Figure 45. Very Strongly Altered Oracle Quartz Monzonite Adjacent to Quartz Veins

Sericitic alteration varies to some extent for the various pre-mineral rock types. The Oracle quartz monzonite in the Little Hill area shows weak but general sericite alteration. However, locally along quartz veins and adjacent to shear zones the quartz monzonite is strongly to very strongly altered. These strongly altered zones range from a few inches to a few feet in width and locally contain up to 10 percent sulfide casts. In the northeastern part of the Little Hill area abundant quartz veins, each less than one foot wide, occupy a northwest-trending zone 1,500 to 2,000 feet wide and several thousand feet long (Fig. 44). These quartz veins have intensely altered margins which nearly merge with one another, yielding Oracle quartz monzonite that is 20 to 30 percent strongly altered.

Alteration in the alaskite consists of moderate sericitic alteration which affects both plagioclase and potassium feldspar. The sericite, which is fine to coarse, is commonly accompanied by silicification, and locally the rock is altered to a mass of quartz and sericite.

The Pinal Schist, transition gneiss, and other rock types seldom show more than moderate sericitic alteration. In these rocks few of the areas adjacent to the quartz veins show the strong alteration characteristic of such areas in the Oracle quartz monzonite.

Chlorite, which may represent propylitic alteration, is most pronounced in the Oracle quartz monzonite, where it occasionally replaces all the mafic minerals. The chlorite is erratically distributed over a wide area and is apparently not related to economic mineralization. The Pinal Schist, transition gneiss, and dike rocks also show this chlorite alteration.

The Oracle quartz monzonite and the monzonite porphyry dike rocks are the only rock types that show significant amounts of epidote alteration. Epidote occurs as joint filling and as small disseminated masses within the host rock. The monzonite porphyry contains masses of epidote up to half an inch in width which have replaced feldspars. Epidote and epidote-chlorite alteration show no apparent relationship to mineralization in the Little Hill area.

Alteration in outcrops at the Little Hill area fits best into the propylitic alteration zone described by Lowell and Guilbert (1970), but with stronger sericite and a phyllic assemblage developed as vein and veinlet envelopes. There is no evidence for development of an extensive phyllic zone.

According to Lowell and Guilbert (1970), mineralization in the propylitic zone involves pyrite with only trace amounts of copper, while in the phyllic zone strong pyrite occurs commonly with marginal grade copper. At Little Hill, the pyrite content averages about one percent with local areas of much higher pyrite content in altered zones adjacent to quartz veins. Overall, the pyrite content is approximately what would be expected in the propylitic alteration zone. Copper over the large copper anomaly is 0.1 to 0.2 percent, as evidenced by sulfide casts and geochemical results. This grade of copper mineralization is higher than that expected for a propylitic zone but appropriate to that of a phyllic zone.

If the alteration picture at Little Hill has been interpreted correctly, it is conceivable that the surface outcrops represent the outer fringes of a weak alteration zone of a buried porphyry copper deposit. The present surface may be in excess of 2,000 feet above such a deposit. However, the absence of a Laramide dike or stock in the area is discouraging. An alternative hypothesis is that the Little Hill area represents the root zone of a porphyry copper system which has been deeply eroded due to vertical uplift along the Mogul fault. The propylitic alteration and low-grade copper mineralization might be expected in such a root zone. However, the lack of a Laramide intrusion makes this hypothesis difficult to prove.

MINERALIZATION

A broad zone of low-grade mineralization, roughly coinciding with the sericite alteration zone described previously, occurs in the Little Hill area north of the Mogul fault. The zone extends from the western boundary of the Little Hill mine to the center of secs. 3 and 10 and northward from the Mogul fault for about 6,000 feet to the center of secs. 3, 4, and 5 (Figs. 3 and 21, in pocket).

Within this zone, disseminated mineralization consists primarily of pyrite which constitutes about one percent by volume of the rock. Local concentrations of pyrite may reach 10 percent, however. Copper oxides, consisting of chrysocolla, malachite, and azurite, occur as coatings along joints and fractures and as disseminations within the rock. Copper oxides are especially abundant along the Mogul fault at the Little Hill and Azurite mines. Concentrations of chalcopyrite and molybdenite are locally present in quartz veins. The only economic mineralization, discussed below, occurs along the Mogul fault at the Little Hill and Azurite mines.

Within the broad zone of low-grade mineralization, abundant quartz veins contain visible pyrite, chalcopyrite, molybdenite, and copper oxides. North of the Mogul fault, particularly near the Azurite mine, the Oracle quartz monzonite and transition gneiss contain coatings of malachite on surface outcrops.

Between the Little Hill and Azurite mines, north of the Mogul fault, hundreds of sparsely mineralized quartz veins crop out (Figs. 21

nd 46). The northern limit of the area of abundant quartz veining falls at about the center of secs. 3, 4, and 5. The quartz veins range in width from a fraction of an inch to 15 to 20 feet. The veins are of three basic types. Near the Mogul fault the veins are intensely sheared and brecciated. These veins show abundant copper oxides but seldom carry sulfide mineralization at the surface. A second type of vein is composed of weakly mineralized banded quartz. A third variety of quartz veins is white to gray massive quartz with copper oxides and copper and iron sulfide minerals.

The quartz veins are very irregular and have a tendency to pinch, swell, and horsetail erratically over short distances. This is especially true in the alaskite, where in one example a single vein changes in width from 6 inches to nearly 10 feet over a distance of 20 feet. The quartz veins in the northern part of the area are narrow and maintain a fairly constant thickness along strike. Most have a wide zone of strong alteration adjacent to them. Some of the large veins are quite persistent and may be traced for more than 2,000 feet along strike (Fig. 47).

The major quartz vein trend is east-northeast to west-northwest. Minor vein trends are northwest, northeast, and north-south (Figs. 32 to 35). The veins in the southern portion of the area dip moderately to the south approximately parallel to the foliation in the transition gneiss and Pinal Schist. In the center of the Little Hill area, the veins dip steeply both north and south. In the northern section of the area the veins dip steeply to the north. In order of abundance, the veins contain pyrite, pper oxides (malachite, azurite, and chrysocolla), chalcopyrite,

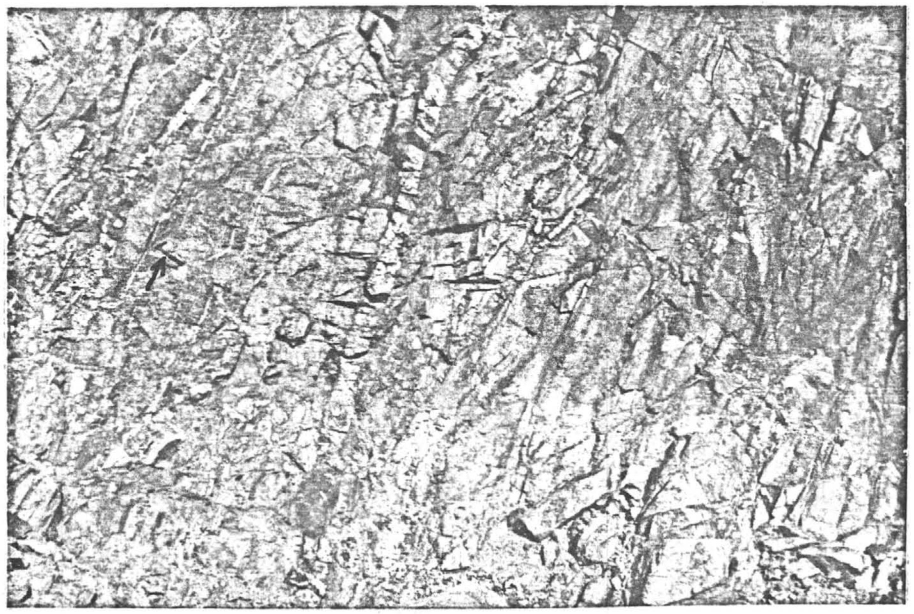


Figure 46. Mineralized Quartz Veins with Copper Oxide Stain on Oracle Quartz Monzonite Host Rock

The veins vary from a fraction of an inch to about 6 inches in width (note rock hammer in left center of photograph for scale). These veins occur in the east-central portion of the area, and the host rock is only weakly altered adjacent to them.

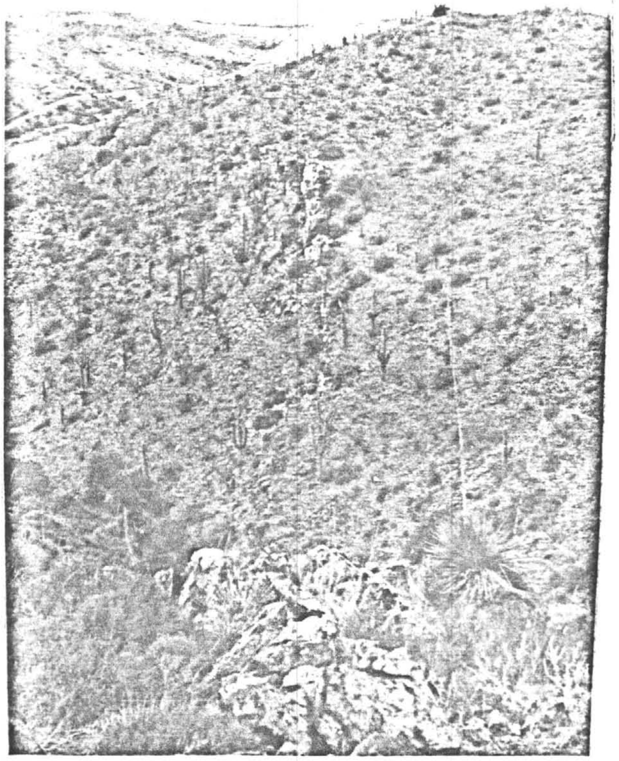


Figure 47. Ten-foot-wide Quartz Vein Cutting the Oracle Quartz Monzonite

The vein strikes west-northwest and is traceable for several hundred feet along strike.

molybdenite, secondary chalcocite, secondary covellite, magnetite, hematite, and traces of galena and sphalerite. Quartz and sericite are generally the only gangue minerals. Mineralization is erratically distributed within the quartz veins.

There are two ages of mineralization of quartz veins. For example, at one location in the north-central part of the area an older foot-wide quartz vein is cut and slightly offset by a rhyolite dike. A few tens of feet further along strike this same rhyolite dike is cut by a 6-inch-wide younger quartz vein. Early and late quartz veins both follow the preferred west-northwest to east-northeast vein directions. The early quartz veins, those cut by rhyolite dikes, carry sulfide minerals and commonly have zones of sericite alteration adjacent to them. The late quartz veins cut the rhyolite dikes, and many carry sulfide mineralization, but most lack the zone of hydrothermal alteration that is characteristic of many of the early quartz veins.

In some areas joints trending west-northwest to east-northeast show pronounced mineralization. Locally, mineralized joints trending north-northwest and north-northeast are also present. This mineralization is in the form of thin quartz veins, fractions of an inch in width, which occur two to three per foot along the joints. Mineralization may also take the form of a thin veneer of sulfide mineralization unrelated to quartz. The quartz veins occurring along the joints carry pyrite, copper oxides, chalcopyrite, and minor molybdenite. The small veins show little evidence of hydrothermal alteration of the host rock. The sulfide-bearing joints contain pyrite and iron oxides which have zones of iron staining one-half to three inches wide adjacent to them (Fig. 48).

Figure 48. Joints in Oracle Quartz Monzonite Filled with Thin Sulfide Veinlets

Iron stains due to oxidation of the sulfide minerals extend one to two inches beyond the veinlets into Oracle quartz monzonite.

The northwest-trending rhyolite dikes contain up to 2 to 3 percent pyrite and specularite and traces of chalcopyrite. However, the dikes do not appear to be related to the main copper mineralization.

Structural Controls of Mineralization

Much of the mineralization in the Little Hill area is controlled by shearing parallel and subparallel to the Mogul fault zone. The Little Hill area is the only area along the Mogul fault where mineralization extends for a substantial distance beyond the fault. The mineralization is also restricted laterally. The Oracle quartz monzonite and Pinal Schist are in contact for nearly the entire length of the Mogul fault. A reconnaissance survey for several miles along the Mogul fault east of the Little Hill area revealed similar rock types, but there was a decided lack of mineralization north of the fault. One feasible explanation for the unique mineralization in the Little Hill area may be that the Mogul fault widens and horsetails in the area of study because of the proximity of its intersection with the Pirate fault less than a mile to the west. An alternative solution is the possibility that the Little Hill area was tectonically more active than other areas along the Mogul fault. Evidence for the latter interpretation might include the transition gneiss, a wide zone of cataclastically deformed Oracle quartz monzonite that is only found in the Little Hill area.

The quartz vein mineralization seems related to synthetic faulting north of the Mogul fault. This synthetic faulting was also responsible for breaking and preparing the ground for the altering and mineralizing hydrothermal solutions which yielded the widespread disseminated sulfide mineralization. However, this ground preparation was not sufficiently strong to provide adequate channels for ore-grade copper mineralization.

Origin of Mineralization

The sulfide mineralization described previously has definite hydrothermal characteristics. The most notable are the banded and bull quartz veins, open-space filling, the broad but weak zone of sericite and chlorite alteration, and the distinct zones of hydrothermal alteration adjacent to quartz veins in the northern part of the area. The restriction of quartz veining and mineralization indicates that the hydrothermal solutions emanated from a moderately restricted source or that ground preparation was suitable in only certain areas. The strong hydrothermal alteration adjacent to quartz veins in the northern portion of the Little Hill area may signify that higher temperature or more abundant solutions were active in that area. Such solutions might also account for the molybdenum anomaly in the northern portion of the Little Hill area and the higher copper concentrations to the south. Possibly the northern portion of the area with its zone of strong alteration was closer to the source of the fluids than the area to the south. Another feasible explanation of alteration adjacent to quartz veins in the northern part of the area is that hydrothermal solutions may have been derived from two different sources in the Little Hill area, and the Oracle quartz monzonite was in a state of greater disequilibrium when contacted by solution than were the rocks further to the south.

There are three possible sources of mineralizing fluids. Fluids may have been derived from a deeply buried mineralized intrusion which has no surface expression in the form of diking, bending, or doming of foliation in the granite. Alternatively, a deeply penetrating shear zone parallel or subparallel to the Mogul fault may have tapped mineral-bearing fluids from depth. Finally, silica, copper, molybdenum, and other elements may have been drawn from the host rock by metamorphic or secretional reconstitution and deposited in shear zones or fractures. The process by which this redistribution might have occurred in the area remains unclear. The copper oxide mineralization at the Little Hill Mines seems related to copper-bearing ground waters and will be discussed below.

Age of Mineralization

The age of the copper and molybdenum mineralization in the Little Hill area can only be estimated within broad limits. Mineralization along the Mogul fault and along synthetic faults took place after the initial movement of the Mogul fault. This movement is thought by Creasey (1967) to have occurred during the Cretaceous Period. The main-stage mineralization was also prior to the intrusion of the rhyolite dikes, which are thought to be Tertiary in age. A minor episode of quartz veining and copper and molybdenum mineralization occurred after the rhyolite dikes but prior to the intrusion of the latite dikes.

ORE DEPOSITS AND MINING

At the present time, the Little Hill mine is the only producing mine in the area of study. The Azurite mine, about one and one-half miles east of the Little Hill mine, is worked intermittently. Both mines are in the Mogul fault zone.

Geology of the Ore Deposits

The ore currently being mined at the Little Hill mine is from a zone of brecciated quartz vein and quartzite 50 feet wide. The ore averages about 0.4 percent copper, in the form of copper oxides, but local zones of much higher grade material are common. The ore minerals coat fractures and permeate the brecciated rock, which is weakly cemented by quartz. The principal ore mineral is chrysocolla. Minor amounts of malachite, azurite, and melaconite are also present. The only abundant gangue minerals are quartz, calcite, and sericite. No sulfide minerals have been found in the high-silica fault zone at the Little Hill mine, in the open cut, in the 225-foot shaft, or in diamond drill holes. Pyrite is found in small amounts adjacent to the breccia zone and in the Pinal Schist and transition gneiss. Copper sulfide casts in the rocks adjacent to the fault zone are not abundant enough to have been the primary source of copper oxide mineralization.

Diamond drill holes, which have penetrated the Mogul fault zone at depths ranging from 10 to 400 feet, show no copper mineralization below 100 feet at the Little Hill mine. The material of the Mogul fault zone in the drill holes ranges from a hard, silicified breccia to a clayey fault gouge. In the schist and gneiss on either side of the fault zone, small quantities of sulfides are found, nominal amounts of which are chalcopyrite.

Apparently the copper oxides in the Mogul fault zone at the Little Hill mine resulted from percolation of copper-bearing ground waters through the quartz breccia, a favorable host for ore deposition. The Little Hill area is the only area observed along the Mogul fault where such a wide, open breccia zone occurs. This shallow origin for the ore is evidenced by the fact that the Mogul fault zone at the Little Hill mine is barren where intersected by drill holes at depths greater than 100 feet. The copper in solution may have been derived from copper sulfide-bearing quartz veins and disseminated sulfides north and east of the mine. Beane (1968) proposed that some copper oxide-type minerals may be hydrothermal in origin. He based this hypothesis on differential thermal analysis and infrared and thermochemical analyses of selected copper oxides and on the presence of barite, a typical hydrothermal gangue mineral, which is found at some copper oxide occurrences. Barite, as well as other geologic attributes found at hydrothermal copper oxide deposits, is absent at the Little Hill area. The copper oxide minerals are therefore not considered to be hydrothermal in origin.

Mineable silica flux ore is traceable over a distance of several hundred feet. The ore maintains a width of more than 20 feet and continues from 100 to 200 feet in depth. At the Azurite mine, the ore occurs in brecciated Pinal Schist and transition gneiss, which contain some disseminated copper mineralization. The ore consists of melaconite, urite, malachite, and chrysocolla and contains about 0.4 percent copper. The ore coats joints and fractures, although some is disseminated throughout the rock. Disseminated chalcopyrite was intersected at a depth of 15 feet in a diamond drill hole, where it occurred as small, thin, elongate blebs parallel to the foliation in the schist and gneiss. The disseminated chalcopyrite is the source of the copper oxides at the Azurite mine. Sulfide casts make up about 2 percent of the total rock.

The ore at the Azurite mine, unlike Little Hill ore, is not in high-silica material. The Azurite mine ore occurs in a broken zone along the fault. The zone is 70 to 80 feet wide and several hundred feet long. The ore is a high-alumina flux ore.

The Mogul fault zone between the Little Hill mine and the Azurite mine also contains copper oxide mineralization. This mineralization is generally restricted to broken zones less than 10 feet wide which cannot be mined economically at the present time.

Mining at the Little Hill Mines

Dave McGee first began work on the Little Hill property in 1960, and he has been shipping ore steadily since. First production came from an open cut and from underground workings just east of the present Little Hill mine (Figs. 49 and 50). The underground workings tapped a 50,000- to 75,000-ton ore body which averaged 1.5 percent copper. Malachite and chrysocolla were the main ore minerals. The ore was in a 50-foot-wide breccia zone of quartzite mixed with quartz vein material along the Mogul fault. The zone extends for about 200 feet along strike and 150 feet downdip.

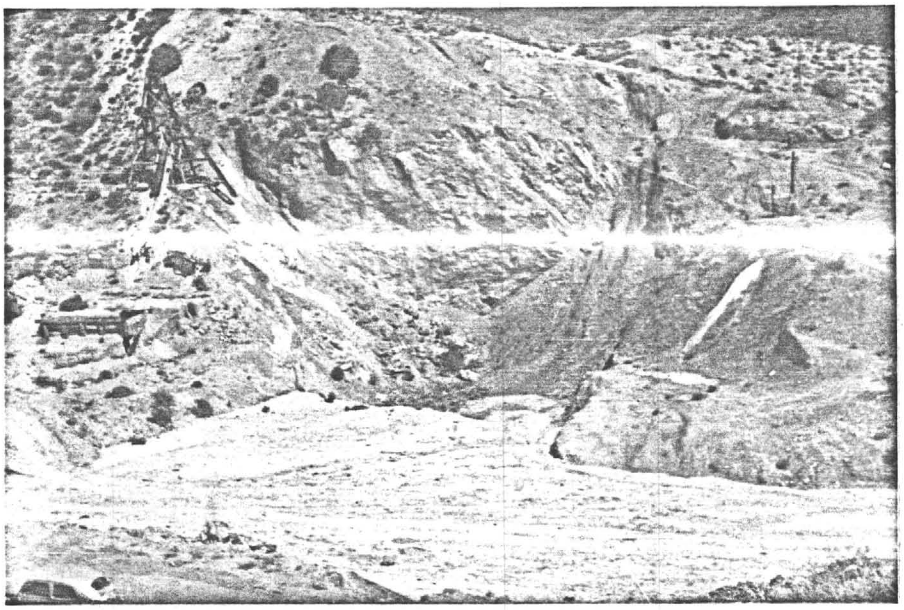


Figure 49. Original Little Hill Mine, Looking East

Open cut and headframe for inclined shaft and underground workings in the Mogul fault zone are shown.

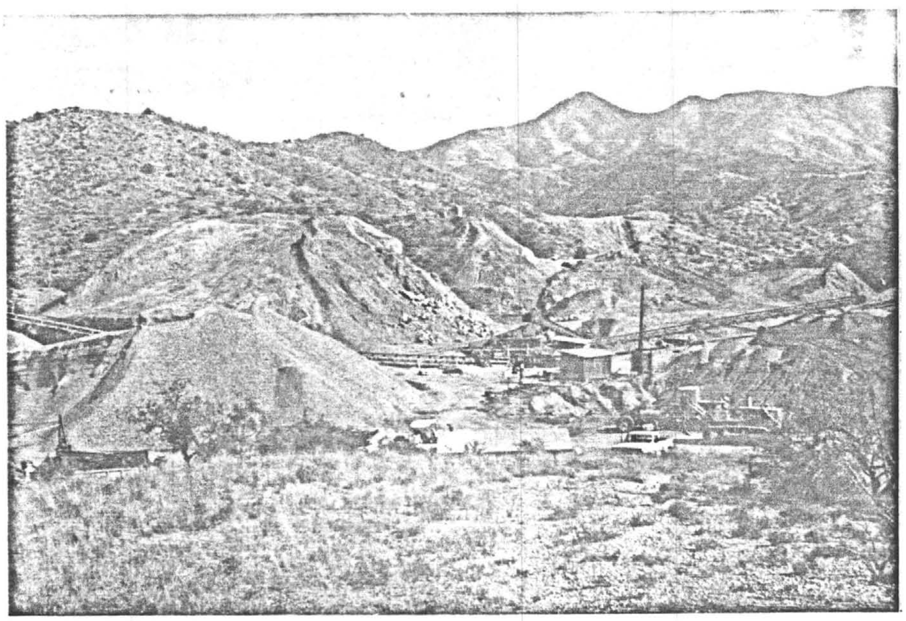


Figure 50. Little Hill Mine, September 1971, Looking East

Ore is mined from the open cut, transported to the crusher (center), and the sized material taken by conveyor belt to the ore pile on the left. The fines are taken to the waste dump to the right.

Ore is presently being produced from a 50-foot-wide high-silica zone at the Little Hill pit and is mined, crushed, and shipped by McGee to the American Smelting and Refining Company smelter at Hayden, Arizona. Mining is a simple process. Ore at the Little Hill and Azurite mines is badly broken and only weakly cemented by quartz. A D-8 Caterpillar equipped with hydraulic rippers is able to break the ore well enough to allow it to be loaded into a 12-ton Dodge ore truck by either a 3-cubic-yard 44-A or a 1 3/4-cubic-yard 995 Caterpillar skip loader. The ore is transported to a 14 by 36-inch coarse ore jaw crusher at the Little Hill mine, which can handle 4,800 tons of ore per day (Fig. 50). The ore is crushed to pieces ranging from 1/4 to 1 3/4 inches in diameter. The remainder of the ore is conveyed to the ore pile where the larger fraction is recycled through a second 10 by 24-inch jaw crusher. The crushed ore is loaded by skip loader into one of three 20-cubic-yard semitrailer trucks for shipment to the smelter. The peak production of sized ore is 500 tons per 5- to 6-hour day.

McGee presently employs four mine workers and a truck driver. In addition to the equipment described, McGee owns a 12-cubic-yard earth mover used for stripping small amounts of overburden and stock-piling ore. Blasting is necessary every 6 to 8 months when occasional hard siliceous areas are encountered.

The current average production is a steady 200 tons per day, but it may fluctuate from 60 to 300 tons per day, depending upon requests from the smelter.

CONCLUSIONS

This study clarifies several issues in the Little Hill area, such as the origin of the Oracle quartz monzonite, the displacement of the Mogul fault in the area, the significance of the alteration and mineralization north of the Mogul fault, and the origin of the copper oxide mineralization at the Little Hill Mines.

The zircon study on samples of the Oracle quartz monzonite supports the hypothesis of Wallace (1954) and Banerjee (1957) that the Oracle quartz monzonite is actually metasomatized Pinal Schist. The zircon rounding indices and elongation frequency curves are also consistent with the supposition of the sedimentary origin of the Oracle quartz monzonite.

Detailed geologic mapping along the Mogul fault in the Little Hill area shows that the fault has had approximately 1,500 feet of left lateral displacement since the emplacement of the Tertiary(?) monzonite porphyry. This contrasts significantly with Creasey's (1967) mapping in the Mammoth quadrangle east of Little Hill, which indicated about 10 miles of right-lateral displacement on the fault. Aeromagnetic data indicate about 4,500 feet of throw on the fault in the Little Hill area.

The alteration in the Little Hill area is hydrothermal and fits into the propylitic alteration zone discussed by Lowell and Guilbert (1970). The broad but weak alteration zone outlines an area of unique mineralization along the Mogul fault. Copper and molybdenum rock-chip geochemical results define restricted anomalies for these metals within the alteration zone. Geologic mapping shows that disseminated sulfides and sulfide-bearing quartz veins occur within the altered zone.

The mineralization in the Little Hill area is hydrothermal and may indicate the possibility of porphyry copper type mineralization at depth. In this study, neither the mineralization nor the alteration could be related to Laramide igneous activity. All igneous rocks in the area are either Precambrian or Tertiary, and the Tertiary rocks are unmineralized.

If economic mineralization exists, the alteration implies that the present surface may be 2,000 feet or more above such mineralization. A Laramide intrusion might be encountered by deep drilling. An alternative suggestion is that the alteration and mineralization represent the root zone of a porphyry copper system which has been deeply eroded due to vertical movement along the Mogul fault.

The copper oxide mineralization at the Little Hill mine is related to percolation of copper-bearing ground waters which found the quartz breccia of the Mogul fault zone a favorable host for ore deposition. Since there is no significant copper sulfide mineralization at the Little Hill mine, it is probable that the copper-bearing waters obtained their mineral content by leaching copper from a mineralized area to the north.

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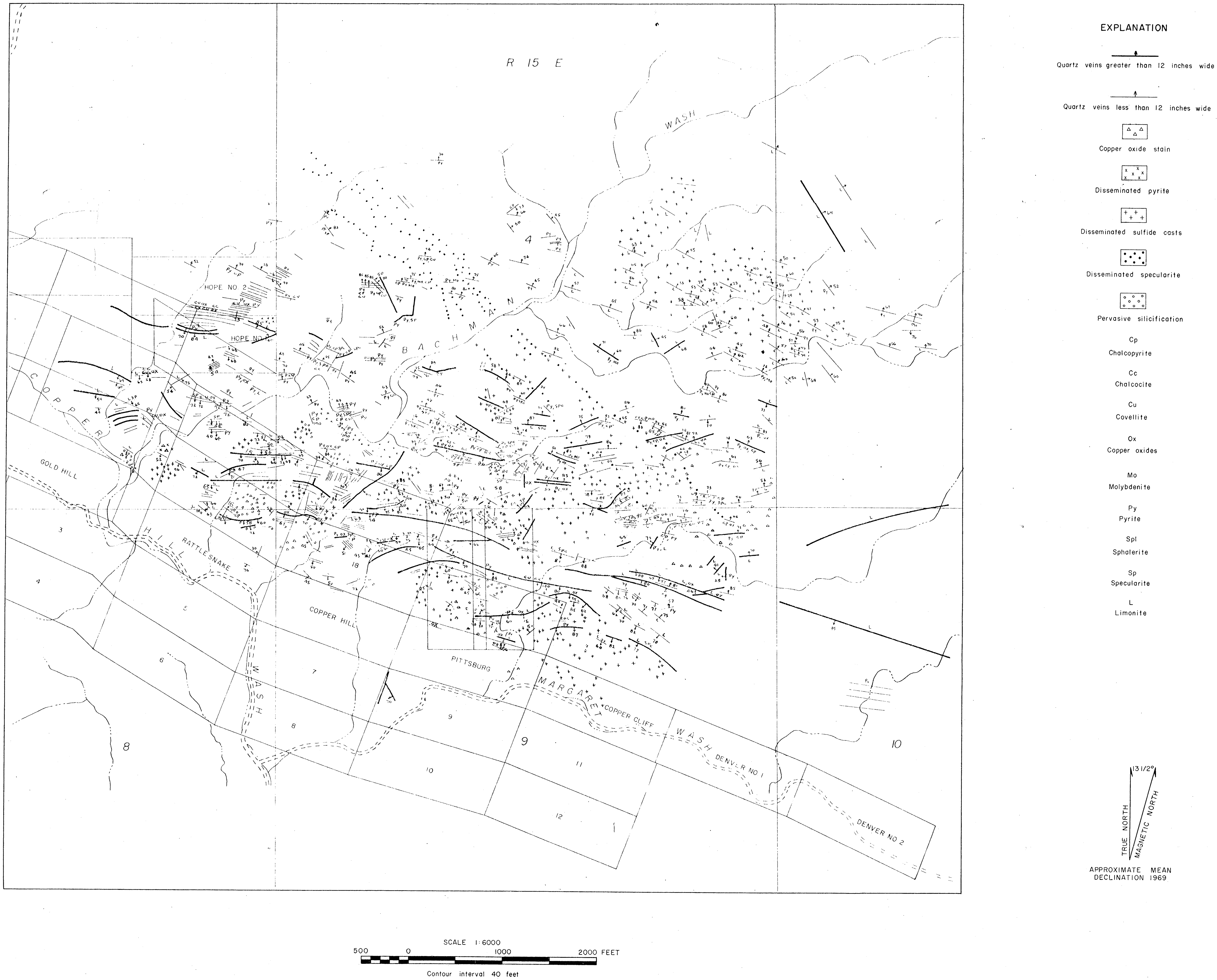

FIGURE 21. MINERALIZATION MAP, LITTLE HILL MINES AREA, PINAL COUNTY, ARIZONA

WILLIAM PERRY DURNING, GEOLOGY THESIS 1972

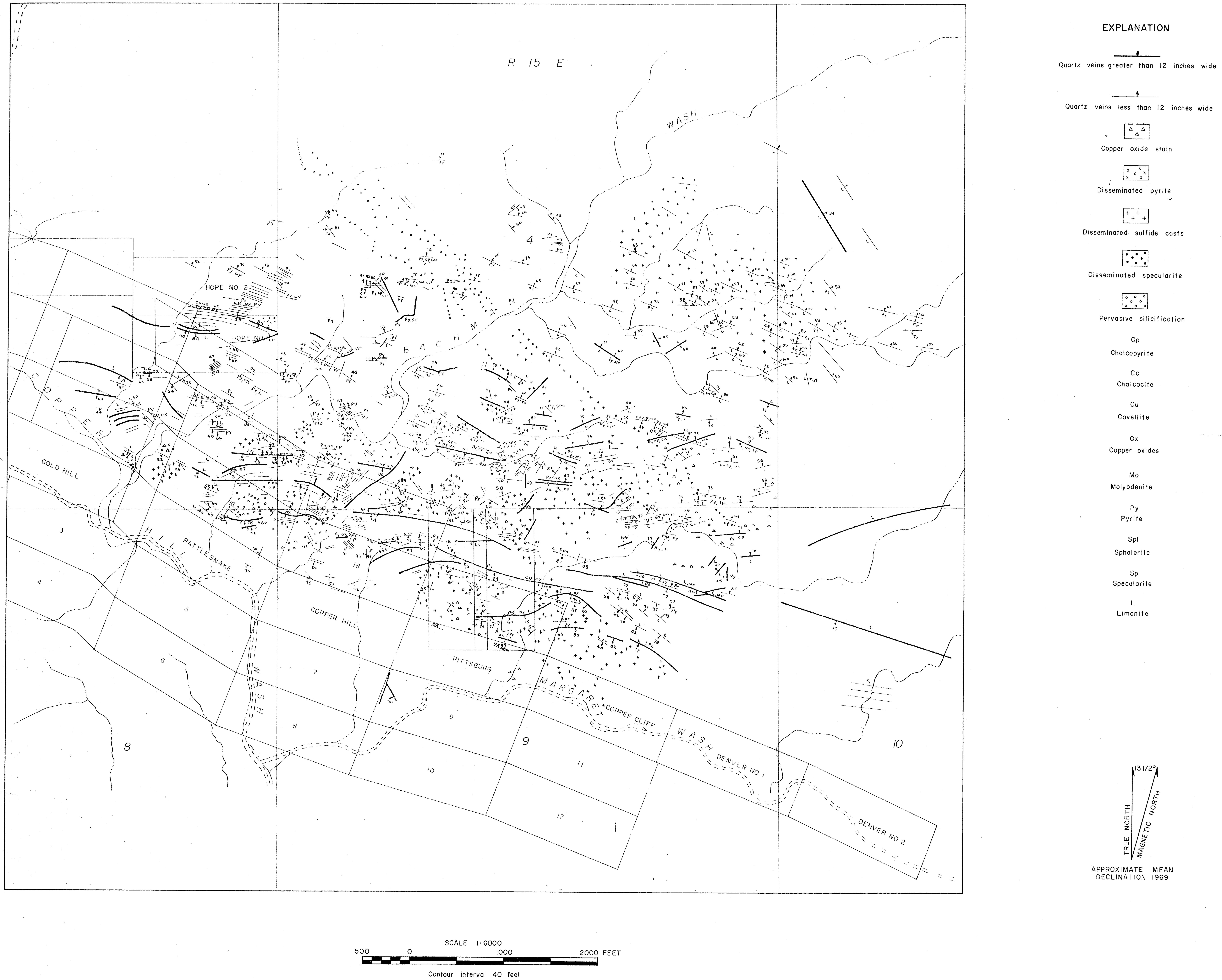

FIGURE 19. MINERALIZATION MAP, LITTLE HILL MINE AREA, PINAL COUNTY, ARIZONA

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