GEOLOGY, ALTERATION, AND MINERALIZATION
OF THE COPPER BASIN PORPHYRY COPPER DEPOSIT,
YAVAPAI COUNTY, ARIZONA

by
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STATEMENT BY AUTHOR

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ABSTRACT

The Copper Basin porphyry copper deposit occurs in a multiple-phase stock of Laramide age emplaced in Precambrian wall rocks. In order of emplacement, the stock includes granodiorite-quartz diorite-meladiorite, granodiorite-quartz monzonite, older quartz latite porphyry, and younger quartz latite porphyry. K-Ar dating shows that these rocks were intruded from about 75 to 72 m.y. ago. Breccia, thought to be the result of collapse of a large vapor-filled chamber, forms a large part of the deposit.

Hydrothermal alteration and mineralization zoning is recognized as rough annular zones centered on the most abundantly fractured portion of the stock. The alteration zones from the center of the deposit outward are a poorly-developed core of phyllic alteration surrounded by a potassic zone which grades outward to a halo of propylitic alteration. The potassic zone is divided into secondary biotite and secondary orthoclase subzones. Sulfide mineralization zoning is characterized by the variability of pyrite and pyrite: chalcopyrite ratios. The sulfides occur as veinlets and disseminated grains and blebs.

Both the alteration and mineralization zoning are attributed to convective flow of saline hydrothermal fluids. These fluids were probably a combination of meteoric and magmatic solutions. The available fluid inclusion data suggests the fluids ranged between 200 and 500°C. The fluids circulated at hydrostatic pressures of
200 bars or less which are compatible with a maximum depth of 1.8 km. The hydrothermal fluids are believed to have boiled intermittantly.
INTRODUCTION

Purpose

This study investigates the geology, alteration, and mineralization of the Copper Basin porphyry copper deposit. Primary emphasis is on the alteration petrography, alteration-mineralization zoning, and the temporal relationships among alteration-mineralization products.

Methods

Geology and alteration-mineralization level maps of the Copper Basin deposit are depicted on horizontal and vertical sections. These sections were prepared using drill hole data acquired by the author while employed by the Phelps Dodge Corporation from 1970 to 1973. The drill holes were on a 400-foot (122 meters) orthogonal grid which covered an area of about 3/4 square miles (1.2 square kilometers). Except for three 45° angle holes, all drill holes were vertical.

To study mineral assemblages and paragenesis, 185 thin sections were stained for potassium feldspar. A hand-held reflected-light source was used to identify opaque sulfide and oxide minerals in thin section.

Alteration maps were constructed by contouring areas characterized by suites of alteration minerals. Sulfide mineralization zoning was defined by contouring values of both similar pyrite abundances and pyrite:chalcopyrite ratios. Contour intervals for the pyrite were chosen using natural breaks in the sample population. Calculated
sulfide abundances were found by first converting copper, molybdenum, and sulfur analyses averaged over a 50-foot (15.24 meter) interval into chalcopyrite and molybdenite, and then using the excess sulfur to determine the amount of pyrite. These values were determined for the top (5200 level), middle (4750 level), and bottom (4300 level) of each drill hole. This permitted a vertical and horizontal sample spacing of 450' and 400', respectively. Although minor sulfur may have been contributed by anhydrite, the resulted error is believed to be negligible.

Samples for age dating were collected December, 1975 and in March, 1976, from both altered and unaltered rocks in Copper Basin. Hornblende and biotite from the unaltered rocks, and sericite from the altered rock, were dated to establish the ages of intrusion and alteration, respectively. In all, four previously unpublished dates are presented in this report. All rocks were dated by the potassium-argon method by Dr. M. Shafiqullah at the University of Arizona's Laboratory of Isotope Geochemistry.

**Location and Access**

The Copper Basin deposit (Fig. 1) is about 10 airline kilometers southwest of Prescott, Arizona in T.13N., R.3W., Secs. 16, 17, 20, and 21. Good access is provided by Copper Basin Road, a graded dirt road maintained by Yavapai County, that runs from Prescott to Skull Valley via Copper Basin. A rougher route is via jeep trail from Wilhoit, 8 airline kilometers south of the deposit.
Figure 1. Location map of the Copper Basin deposit, Arizona.
The deposit (Fig. 2) lies along the southwestern flank of the Sierra Prieta Mountains in an erosional depression from which the area is in part named. Local relief is moderate with a few hills of silicified breccia extending 61 meters above an average elevation of about 1615 meters. The mountains to the northeast, however, rise 305 to 475 meters above the basin floor.

**History and Previous Work**

Gold-seeking prospectors who invaded the Bradshaw Mountains in the early 1860's were soon attracted to both the leached capping over the Copper Basin deposit and to gold-bearing gravels of Copper Basin Wash (Granger, 1960). The estimated value of placer gold mined through 1933 is $50,000 (Elsing and Heinemann, 1936), while production from 1931 to 1949 totaled $60,000 (Wilson, 1961). Modern-day prospectors still dig placer gold along Copper Basin Wash, but production does not exceed a few ounces in the best of years (Witcher, 1976).

The Copper Basin District has had sporadic minor production of lead, zinc, and silver; but high-silica copper oxide ore has accounted for the bulk of production which is valued at less than $3,000,000 (Anderson, 1968; Johnston, 1955). The most recent mining was by McFarland and Hullinger Company from 1965 to 1967 under a lease from the Phelps Dodge Corporation.

The copper deposits of the district were described by Wheeler (1876) and Blake (1889), whereas, Lausen and Gardner (1927) studied mercury mineralization associated with rhyolite dikes. Gambell (1973) studied heavy mineral analysis of Copper Basin Wash. The most
Figure 2. Westward view showing the outline of the Copper Basin deposit.
comprehensive references to date are by Johnston (1955) and Johnston and Lowell (1961).
GENERAL GEOLOGY

The Copper Basin porphyry copper deposit occurs near the center of a 9 by 3 kilometer composite Laramide stock. Rocks in the deposit proper includes several phases of the stock, a Precambrian quartz diorite, and Tertiary rhyolite dikes (Fig. 3). This report has established that the Laramide rocks range in age from 75.5 ± 1.6 m.y. to 72.8 ± 1.5 m.y. old, whereas the Tertiary rocks are 14.94 ± 0.33 m.y. old. Porphyry copper alteration and mineralization are developed only in the Precambrian and Laramide rocks. The subsurface distribution of these rocks is shown in Figures 4, 5, 6 and 7.

Precambrian Rocks

Quartz Diorite

Precambrian quartz diorite is a light- to dark-gray or greenish gray rock with a medium- to coarse-grained hypidiomorphic-granular texture. It is composed of 1 to 10 mm plagioclase, hornblende, and orthoclase grains enclosing 0.5 to 1.5 mm grains of interstitial quartz. The hornblende is largely replaced by secondary biotite within the deposit. Near the margins of the deposit, chlorite and epidote more commonly replace hornblende. Plagioclase is altered to 10 to 40 percent sericite within the deposit, but contains less than 5 percent sericite where chlorite and epidote are common. The Precambrian quartz diorite is distinguished from all other rocks in the deposit by its pronounced
Figure 3. Generalized surface geology of the Copper Basin deposit (modified after Johnston and Lowell, 1961).
Figure 3. Generalized surface geology of the Copper Basin deposit (modified after Johnston and Lowell, 1961).
Figure 4. Subsurface lithology of the 5200 level as interpreted from diamond drill core.

EXPLANATION

Laramide

- Breccia
- Older quartz latite porphyry
- Granodiorite-quartz monzonite
- Granodiorite-quartz diorite-meladiorite

Precambrian

- Quartz diorite
Figure 4. Subsurface lithology of the 5200 level as interpreted from diamond drill core.
Figure 5. Subsurface lithology of the 4750 level as interpreted from diamond drill core. See Figure 4 for explanation of symbols.
Figure 6. Subsurface lithology of the 4300 level as interpreted from diamond drill core. See Figure 4 for explanation of symbols.
Figure 7. Lithology of the Copper Basin deposit along cross-section A-A’ (Figs. 4, 5, and 6). See Figure 4 for explanation of symbols.
gneissic texture. This texture comprises segregations of mafic minerals (Fig. 8) which appear in thin section as discontinuous stringers of hornblende and biotite among larger feldspar phenocrysts. The texture probably resulted from Precambrian deformational events (Johnston, 1955).

Laramide Rocks

Granodiorite-Quartz Diorite-Meladiorite

Intrusives that range from granodiorite, quartz diorite to meladiorite form the eastern margin of the Copper Basin deposit. These rocks are extensive along the outer margins of the Copper Basin stock and will be collectively referred to as the border facies rocks. The border facies rocks were the earliest Laramide rocks to crystallize as the Copper Basin stock intruded cooler Precambrian wall rocks. This conclusion is based on intrusive relationships and is consistent with K-Ar dating to be discussed in a later section.

The border facies rocks from a medium gray to nearly black equigranular mass composed of 0.1 to 0.3 mm grains of plagioclase, quartz, biotite, and actinolitic hornblende. Clinopyroxene rimmed by hornblende is occasionally present in the meladiorite. Anhedral quartz and orthoclase occur interstitial to the plagioclase. Magnetite comprises up to 12 percent of the border facies rocks. A partial chemical analysis of a drill core passing through 2000 feet of border facies rocks shows that SiO₂ and K₂O decreases, and CaO, Na₂O, and MgO increases with depth (Table 1). Although a gradual change in rock type was noted in the core with depth, no sharp contacts were observed.
Figure 8. Foliated texture developed in Precambrian quartz diorite. Hornblende (H), plagioclase (P), and quartz (Q). X1.3
Table 1. Partial chemical analyses of border facies rocks in a drill hole containing less than 1 volume percent propylitic alteration minerals (Values in weight percent).

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<th>Interval of composite samples (below surface)</th>
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<th>1815-1915'</th>
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<tr>
<td>$\text{SiO}_2$</td>
<td>62.30</td>
<td>51.20</td>
</tr>
<tr>
<td>$\text{CaO}$</td>
<td>3.12</td>
<td>9.40</td>
</tr>
<tr>
<td>$\text{Na}_2\text{O}$</td>
<td>2.76</td>
<td>3.72</td>
</tr>
<tr>
<td>$\text{K}_2\text{O}$</td>
<td>4.84</td>
<td>2.18</td>
</tr>
<tr>
<td>$\text{MgO}$</td>
<td>1.57</td>
<td>4.72</td>
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Petrographic examination of the analyzed core clearly indicates that the core changes from granodiorite to meladiorite between the intervals 308-408' and 1815-1915', respectively. This gradual change in rock types can be attributed to normal fractional crystallization of the border facies magma. The compositional relationships suggest that as crystallization of the magma proceeded, residual silica-rich magma was squeezed upward from the meladiorite mass. However, the absence of a sharp contact between the granodiorite formed from the residual magma and the meladiorite demonstrates that the process occurred slowly at near equilibrium conditions.

The contacts between border facies rocks and the Precambrian quartz diorite vary from sharp to gradational. Where the contacts are gradational, the border facies rocks contain abundant mafic minerals and "wispy" streaks of plagioclase and quartz. These border facies rocks are here termed "contaminated". These "contaminated" rocks contain isolated crystals of plagioclase that are texturally and compositionally similar to the plagioclase observed in the Precambrian quartz diorite. These crystals of plagioclase indicate that some assimilation of the Precambrian wall rocks has taken place. An additional feature suggesting assimilation is that micro-crystalline "filaments" of quartz and plagioclase crosscut the Precambrian rock along border facies contacts.

Hydrothermal alteration and mineralization has produced minor changes in the border facies rocks which include partial conversion of biotite to chlorite and epidote and accounts for the presence of sericite in plagioclase. Pyrite is present along fractures.
Granodiorite-Quartz Monzonite

The bulk of the Copper Basin stock is composed of a light- to dark-gray rock that is transitional from granodiorite to quartz monzonite. The gradational contacts of these phases suggest derivation from a single intrusion. This rock intrudes the border facies rocks and has produced isolated contact breccias within its margins. Generally, the contacts between the granodiorite-quartz monzonite and the border facies rocks are sharp, as are the contacts between granodiorite-quartz monzonite and the Precambrian wall rocks. The presence of a large Precambrian xenolith (Fig. 4) within the granodiorite-quartz monzonite suggests that the former is a roof pendant engulfed during intrusion of the granodiorite-quartz monzonite. No chilling of the stock in contact with this xenolith was observed. Furthermore, no features indicative of assimilation were observed along the contact. These observations and the presence of marginal contact breccias suggest that the granodiorite-quartz monzonite was intruded at near-solidus temperatures.

Three textural varieties of granodiorite-quartz monzonite are recognized in the deposit area: a medium-grained seriate variety, a medium-grained equigranular variety, and a porphyritic variety. The seriate variety is the most common, while the porphyritic variety is the least.

Older Quartz Latite Porphyry

The older quartz latite porphyry is texturally distinct from all other rock units shown in Figure 4 and is restricted to the center
of the deposit area. It is characterized by large, euhedral plagioclase and biotite phenocrysts up to 4 mm and 2 mm across, respectively. The groundmass is composed of light- to medium-gray mass of aphanitic quartz and orthoclase. Scattered throughout the groundmass are smaller (0.2 to 0.5 mm) crystals of plagioclase and deeply embayed quartz crystals (Fig. 9) up to 6 mm. Both the embayment of the quartz and the aphanitic groundmass may be the result of quenching when the rock still contained an appreciable amount of magmatic fluid. The quenching is most likely due to rapid intrusion or a venting of magmatic fluids from the melt along faults in the wall rocks.

Alteration of the older quartz latite porphyry consists of irregular zones of potassic and phyllic mineral suites that appear to be superimposed on earlier chlorite, epidote, and calcite replacing biotite and occasionally hornblende. The pervasive nature of the chlorite, epidote, and calcite and their lack of a spatial association with sulfides suggests a deuteric origin. The potassic and phyllic alteration will be treated in a later section. Sulfide mineralization consists of sparse pyrite, chalcopyrite, and molybdenite.

Younger Quartz Latite Porphyry

Although dikes of younger quartz latite porphyry are too small and discontinuous to show in Figures 4, 5, 6, and 7, they are present throughout the deposit. These rocks are similar in texture, color, and composition to the older quartz latite porphyry. Surface exposures suggest that the younger quartz latite porphyry dikes are late relatives of the older quartz latite porphyry. They appear to
Figure 9. Embayed quartz phenocryst (Q) in older quartz latite porphyry. Polarized light, X35.

Corrosion rim is composed of fine-grained orthoclase and quartz groundmass (GM).
intrude outward from the older quartz latite porphyry along radial and concentric fractures. Apparently the dikes were emplaced near the end of the alteration-mineralization processes as they are relatively fresh. However, K-Ar dating cannot distinguish between the very similar ages of phyllic alteration in the older quartz latite porphyry and the age of the younger quartz latite porphyry.

Breccia

The Copper Basin breccias (Fig. 10) were first described by Johnston (1955) and later by Johnston and Lowell (1961) as "pipes" formed by the action of corrosive magmatic fluids moving upwards along intersecting faults and rock contacts. These authors concluded that at least one period of breccia fragment movement in the "pipes" was downward. This study found that nearly all evidence favored downward movement in the breccias. Furthermore, correlation of breccia between drill holes shows that the breccia "pipes" coalesce at depth to form a single body of breccia (Fig. 7).

Rock types observed in the breccia include Precambrian quartz diorite, granodiorite-quartz monzonite, and older quartz latite porphyry. Two varieties of the older quartz latite porphyry occur as breccia fragments. The more common variety is typical of the older quartz latite porphyry previously described. The other variety is nearly devoid of phenocrysts. This latter variety is uncommon in the older quartz latite porphyry intrusion except where chilling has occurred. Thus, the breccia fragments of older quartz latite porphyry which are low in phenocrysts quite likely were chilled prior to being
Figure 10. Outcrop of Copper Basin breccia.

Fragments in outcrop are composed mostly of older quartz latite porphyry cemented together by quartz. Outcrop in area of a collapsed stope at the Commercial mine.
brecciated. For logging purposes, these fragments were termed phenocryst-deficient older quartz latite porphyry. The phenocryst-deficient fragments will be referred to in a later discussion of a possible origin of the Copper Basin breccia.

Most of the breccia is composed of a mixture of two or more of the above rock types. The most thoroughly mixed areas of the breccia occur near the center of the deposit around the periphery of the older quartz latite porphyry. Outward, toward the margins of the deposit, the heterogeneous composition of the breccia decreases until the breccia is composed of only one rock type. Breccia in these areas is almost always composed of the adjacent wall rock. The size of fragments ranges from less than a centimeter to a few meters. No gradation in fragment shape was recognized, but angular to sub-angular fragments are dominant near the outer margins of the breccia, whereas sub-rounded to sub-angular fragments are prevalent near the inner margins.

The breccia forms an irregularly-shaped but continuous shell around much of the older quartz latite porphyry. This shell extends from the surface to a depth of at least 350 meters. In plan view, the walls of this shell are 125 to 200 meters thick, and 1000 to 1300 meters long. Contacts of the breccia with wall rocks vary from sharp to gradational. The contact between the Precambrian quartz diorite and the breccia is sharp and dips toward the center of the deposit at an average angle of 70 degrees. The contact with the granodiorite-quartz monzonite is generally more gradational and is nearly vertical. Contacts between the older quartz latite porphyry and the breccia are sharp. It was found that the breccia contains clasts of older quartz
latite porphyry which, in turn, intrudes the breccia (Fig. 11). Since the breccia extends away from the older quartz latite porphyry for great distances, it does not appear to be a contact breccia.

The breccia is an important host for copper and molybdenum mineralization and is cemented and partially replaced by quartz, secondary orthoclase, and sulfides. A later section will give details on these aspects of the breccia.

**Tertiary Rocks**

**Rhyolite**

A series of northwest-trending rhyolite dikes are a prominent feature of the Copper Basin district (Fig. 3). These dikes postdate all alteration and mineralization associated with the stock. Although the dikes are intersected in drill holes, they are too discontinuous to trace in the subsurface. However, they are not uncommon in the deposit proper. Contacts between the rhyolite and wall rocks are sharp and regular. Drilling shows that the rhyolite dikes dip steeply toward the center of the deposit.

The rhyolite is composed of biotite, quartz, and sanidine phenocrysts set in an aphanitic groundmass of quartz, orthoclase, and biotite. The quartz phenocrysts show rounding by development of overgrowth rims of groundmass material.
Figure 11. Older quartz latite porphyry (QLP) cross-cutting silicified breccia (SBX) and containing a clast of breccia (BX).
Structure

Johnston and Lowell (1961) believe that a N 10-20 E regional fault was important during emplacement of the Copper Basin stock. These workers propose fault trends of lesser importance to N 10-30 W, N 10-30 E, and N 60-80 W. Reber (1945) has shown apparent movement along faults to be present in both the right-lateral and left-lateral directions along the southern margins of the deposit.

Fractures are the most dominant structure within the Copper Basin deposit. The continuity of the fractures range from a few tens of meters in length, down to stockwork fractures less than a centimeter long. Fracture frequencies range from less than 3 per meter of drill core to about 50 per meter. The zone of most frequent fracturing forms a northeast-trending ellipse centered on the granodiorite-quartz monzonite phase of the stock. The area of highest copper and molybdenum mineralization roughly coincides with the ellipse. The area of less frequent fracturing occurs within the older quartz latite porphyry. These fractures are generally shallow dipping, contain 0.5-1.5 weight percent sulfides, and may have formed during the relatively late stages of copper mineralization.

Major faults are not obvious on the surface in the study area but have been detected in drill holes. Although structural interpretation is difficult, persistent steeply-dipping fault breccia zones show that northeast-striking faults are present along the northwest side of the mineralized zone. Granulated sulfides and fragmented quartz in veinlets show that some faults had post-mineral movement.
zones encountered in drill holes east of Copper Basin Wash indicate that steeply-dipping faults striking northerly, bound the eastern portion of the deposit as well.
The term "alteration" as used in this report refers to the formation of silicate, oxide, and carbonate minerals as the result of the reaction between hydrothermal fluids and host rocks. The use of "mineralization" is restricted to the deposition of sulfide minerals.

The alteration in Copper Basin can be divided into three principal zones—potassic, phyllic, and propylitic (Table 2). The potassic zone is further divided into secondary biotite and secondary orthoclase subzones (Table 2). The distribution of these alteration zones in the deposit is shown in Figures 12, 13, 14, and 15. Mineralization from the center of the deposit outward (Figs. 12, 13, 14 and 15) can be divided into three zones:

1. 1.5 or less weight percent pyrite with a pyrite:chalcopyrite ratio of greater than 6:1,
2. 3 to 5 weight percent pyrite with pyrite:chalcopyrite ratios between 5:1 and 10:1, and
3. 1.6-2.9 weight percent pyrite with pyrite:chalcopyrite ratios of 1.5:1 to 2:1.

Completely surrounding these three zones is a poorly-defined region of variable pyrite content (0.1 to 3 weight percent) and very high pyrite:chalcopyrite ratios (greater than 10:1). For discussion, this area will be referred to as the "marginal pyrite zone". Figure 16 is a cross-sectional view of the Copper Basin deposit showing some of
<table>
<thead>
<tr>
<th>Alteration Zones</th>
<th>*Essential Minerals</th>
<th>*Accessory Minerals</th>
<th>Mode of Alteration</th>
<th>Principal Mineralization Zones</th>
<th>Principal Host Rock(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROPYLITIC</td>
<td>4% chl</td>
<td>tr-1.5% ser</td>
<td>chl, p&gt;v</td>
<td>4</td>
<td>bf, grd-qm, qd</td>
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<tr>
<td></td>
<td>1% ep</td>
<td>ep, p&gt;v</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tr-0.5% ser</td>
<td>cal, p&gt;v</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POTASSIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotite Subzone</td>
<td>5-15% sbt</td>
<td>3-15% ser</td>
<td>sbt, p</td>
<td>3 to 2</td>
<td>grd-qm, oqlp</td>
</tr>
<tr>
<td></td>
<td>tr-10% sor</td>
<td>1-10% qtz</td>
<td>sor, v&gt;p</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1-5% cal</td>
<td>qtz, bxf</td>
<td></td>
<td>bx</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5% dol</td>
<td>ad-cal-dol-ahn, bxf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orthoclase Subzone</td>
<td>10-40% sor</td>
<td>1-5% cal</td>
<td>cal, p&gt; v</td>
<td>1</td>
<td>oqlp</td>
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<tr>
<td></td>
<td>20-50% qtz</td>
<td>leu, p</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>PHYLLIC</td>
<td>10-50% ser</td>
<td>tr-1% cal</td>
<td>ser, p=v</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>tr-1% leu</td>
<td>qtz, v&gt;p</td>
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<tr>
<td></td>
<td>10-50% qtz</td>
<td>cal, p</td>
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<tr>
<td></td>
<td></td>
<td>leu, p</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: ad=adularia
abr=anhydrite
bfr=border facies rocks
bbr=breccia
bfl=breccia filling
cal=calcite
ch=chlorite
cp=chalcopyrite
dol=dolomite	ep=epidote
grd=q=granodiorite=quartz monzonite
leu=leucoxene
mg=magnetite
old=older quartz latite porphyry
py=pyrite
py=py
q=quartz
r=rutile
sbt=secondary biotite
sor=sericite
sph=sphene
tr=trace, less than 0.5 volume %
v=veinlet-controlled

*reported as volume %
Figure 12. Alteration and mineralization zoning of the 5200 level.

**EXPLANATION**

<table>
<thead>
<tr>
<th>Alteration Zones</th>
<th>Mineralization Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phyllic</td>
<td>1.5 or less weight percent pyrite, pyrite:chalcopyrite greater than 6:1</td>
</tr>
<tr>
<td>Secondary biotite subzone</td>
<td>1.6 to 2.9 weight percent pyrite, pyrite:chalcopyrite=1.5: to 2:1</td>
</tr>
<tr>
<td>Secondary orthoclase subzone</td>
<td>3.0 to 5.0 weight percent pyrite, pyrite:chalcopyrite greater than 6:1, but less than 10:1</td>
</tr>
<tr>
<td>Propylitic</td>
<td>&quot;marginal pyrite zone&quot;, pyrite:chalcopyrite greater than 10:1</td>
</tr>
</tbody>
</table>
Figure 12. Alteration and mineralization zoning of the 5200 level.
Figure 13. Alteration and mineralization zoning of the 4750 level. See Figure 12 for explanation of symbols.
Figure 14. Alteration and mineralization zoning of the 4300 level. See Figure 12 for explanation of symbols.
Figure 15. Alteration and mineralization zoning along cross section A-A' (Figs. 12, 13, and 14). See Figure 12 for explanation of symbols.
Figure 16. Pyrite distribution along cross section A-A' (Fig. 15).

Black dots are at base of sample interval; values represent average pyrite content over a 50-foot (15.24 m) interval. Dashed lines show outlines of sulfide zones discussed in text. Scale 1 inch (2.54 cm) = 500 feet (153.4 m). *No Data.
the pyrite values used to determine sulfide zoning. Locally, pyrite over intervals of a couple tens of meters may exceed the values in a mineralization zone by a factor of about two. The mineralization zones are correlated with alteration zones as shown in Table 2.

Potassic Alteration Zone

Secondary Orthoclase Subzone

The essential minerals of the secondary orthoclase subzone are secondary orthoclase and quartz. The accessory minerals in the order of decreasing abundance are calcite, secondary biotite, dolomite, adularia, and anhydrite. This subzone is restricted to the Copper Basin breccia. Secondary orthoclase subzone alteration forms the matrix material between breccia fragments and locally replaces the fragments. The contacts between secondary orthoclase and secondary biotite subzones are irregular because of the variable nature of the breccia. Drill holes along the contact often penetrate through tens of meters in which the subzones alternate.

Areas subject to secondary orthoclase alteration often contain numerous cavities which are unfilled spaces between breccia fragments. These cavities often contain terminated quartz crystals up to 3 centimeters long with calcite coatings. On rare occasions, pyrite, chalcopyrite, and pink wedge-shaped adularia crystals occur with the quartz. Massive quartz has filled all cavities locally. This massive quartz imparts a banded appearance to drill cores and is up to 3 meters thick. Figure 17 shows an exposure of a massive quartz "band".
Figure 17. Photograph of a massive quartz "band" (Q) in the Copper Basin breccia (BX). Sledge hammer for scale.

Dashed line shows the contact between the quartz "band" and the breccia.
In thin section, secondary orthoclase subzone alteration appears as mosaics of quartz, secondary orthoclase, calcite, and lesser amounts of secondary biotite, adularia, anhydrite, and dolomite. The sequence of deposition of these minerals was complex. It began with secondary orthoclase and very minor secondary biotite, probably followed closely by quartz and calcite. In many cases, all of the above minerals appear to be contemporaneous. The sequence was completed by adularia, a second generation of calcite, anhydrite, and dolomite. Adularia occurs as euhedral to subhedral rhombic crystals replacing quartz and secondary orthoclase (Fig. 18). The second generation of calcite and dolomite occurs as drusy masses deposited on older minerals in the vugs.

Mineralization in the secondary orthoclase subzone is distinctly characterized by the clot- to bleb-like occurrence of pyrite, chalcopyrite, and molybdenite, although molybdenite also occurs as fine-grained disseminations. These sulfides typically replace quartz and secondary orthoclase of the breccia matrix.

The intensity of mineralization varies greatly within the secondary orthoclase subzone (Fig. 15). The 1.6 to 2.9 percent pyrite zone makes up the bulk of the mineralization, although it appears to pinch out on the 4300 level. Concomitantly, the two inner chalcopryite-poor sulfide zones expand outward toward the periphery of the deposit (Fig. 15). These changes are accompanied by an overall reduction in the potassic alteration zone at the 4300 level.
Figure 18. Photomicrograph of a thin section of breccia showing secondary orthoclase alteration. Polarized light, X50.

A=adularia, C=calcite, Q=quartz, and SB=secondary biotite.
Secondary Biotite Subzone

The secondary biotite subzone is defined by the presence of abundant secondary biotite with or without secondary orthoclase veinlets. In general, the secondary orthoclase veinlets only occur in the Laramide granodiorite-quartz monzonite, whereas secondary biotite is ubiquitous throughout the subzone. Accessory minerals in the order of decreasing abundance are sericite, quartz, rutile, and leucoxene.

Secondary biotite occurs as pale- to medium-brown to greenish-brown flakes and "felty" clots scattered throughout the host rocks of the secondary biotite subzone. The pale brown to greenish-brown colors suggest a phlogopitic composition and a Mg:Fe ratio of 1 or greater (Neilsen, 1968). Secondary biotite flakes also occur as replacements of plagioclase along cleavages (Fig. 19), and along minute, discontinuous fractures (Fig. 20). Relict textures indicate that the felty clots of secondary biotite are replacements of primary biotite and hornblende. The intimate relationship of rutile and leucoxene with secondary biotite probably resulted from the expulsion and recombination of titanium from primary biotite (Roberts, 1973). The rutile occurs both as well-defined crystals and anhedral granules. The crystals form criss-crossed "webs" in the basal sections of primary biotite (Fig. 21). "Flame-like" bodies of leucoxene also form along biotite cleavage surfaces.

Secondary orthoclase veinlets range from 1 to 8 mm in width and up to a few meters in length. Under the microscope, secondary orthoclase appears as colorless grains (up to 2 mm in diameter) which
Figure 19. Photomicrograph of a plagioclase phenocryst (P) partly replaced by secondary biotite (SB). Polarized light, X50.
Figure 20. Photomicrograph of a thin section of granodiorite. Polarized light, X50.

Plagioclase phenocryst (P) cross-cut by a secondary biotite veinlet (SB), both of which are cross-cut by a secondary orthoclase veinlet (K).
Figure 21. Photomicrograph of a primary biotite phenocryst (B) showing an acicular mat of rutile crystals (R). Polarized light, X50.

Sample taken from the secondary biotite subzone.
usually occur near the center of veinlets. It may also form veinlet selvages up to a few millimeters wide. Frequently, the veinlets consist of less than 50 percent secondary orthoclase with quartz and sulfides composing the rest.

Secondary biotite is uniformly distributed throughout the secondary biotite subzone. However, along the western margin of the deposit, secondary biotite is slightly more abundant in the Precambrian host rocks than in the Laramide host rocks. This difference can be explained by the higher hornblende content of the Precambrian wall rocks, which is more readily altered to secondary biotite. Near the interface with the propylitic zone, secondary biotite decreases. In addition, some secondary biotite has been altered to chlorite, although secondary orthoclase veinlets are free of any retrograde alteration effects. This phenomenon may be attributed to the chloritization of secondary biotite which tends to stabilize potassium feldspar (Rose, 1970).

Sericite is a common accessory mineral throughout the secondary biotite subzone. Sericite in this subzone is not related to the phyllic alteration which will be discussed later. Sericite accompanying and contemporaneous with potassic alteration is very common (Lowell and Guilbert, 1970; Himes, 1973). Davis (1974) noted that in the Kalamazoo deposit, sericite in the potassic zone is locally as abundant as sericite in the phyllic zone.

Sericite occurring as fine-grained flakes (up to 0.05 mm in length) replaces plagioclase both randomly and/or selectively, the
latter along cleavage and growth zones. Occasionally, traces of very fine-grained clay or calcite are intergrown with sericite. Sericite replacing primary orthoclase is insignificant and occurs only as sparse, very fine-grained flakes. Poikilitic patches of unsericitized primary orthoclase are commonly seen surrounding moderately sericitized plagioclase crystals (Fig. 22). The conversion of plagioclase to sericite ranges from 10 to 40 volume percent.

Mineralization within the secondary biotite subzone occurs as both veinlets and disseminations. A study of paragenetic relationships among veinlet sulfides indicates that the veinlets change through time from pyrite-rich to chalcopyrite- and molybdenite-rich to molybdenite-rich. Disseminations of sulfides occur in groundmass and also as replacements of biotite phenocrysts (Fig. 23). Some drill core intercepts show that up to 20 percent of the biotite has been replaced by pyrite and chalcopyrite. At least a portion of the Cu, Fe, and S in these sulfides may have been released from the biotite during alteration (Banks, 1973; Graybeal, 1973; and Roberts, 1973). The abundance of sulfides associated with the secondary biotite subzone is quite variable. As shown in Figure 15, all four mineralization zones occur in the secondary biotite subzone. Of these zones, the 1.6 to 2.9 percent pyrite zone makes up the bulk of the mineralization.

Phyllic Alteration Zone

Phyllic alteration is composed of a network of widely-spaced quartz-sericite veinlets and pervasive replacement sericite. In detail, this zone is highly irregular and contains areas of non-phylllic
Figure 22. Photomicrograph of a thin section of granodiorite-quartz monzonite. Polarized light, X50.

Unsericitized primary orthoclase (K) poikilitically engulfing sericitized plagioclase (P).
Figure 23. Photomicrograph of a thin section of granodiorite-quartz monzonite showing primary biotite (B) partly replaced by pyrite (P). Plane light, X50.
alteration where biotite and hornblende are replaced by chlorite, epidote, and calcite (Fig. 24). Although too small to show on the alteration-mineralization maps, phyllic alteration extends beyond the phyllic zone typically as replacements of veins.

Phyllic alteration imparts a bleached appearance to both surface and drill core samples. In some examples, the bleaching is due to overlapping sericite selvages between closely-spaced quartz-sericite veinlets. In other areas, the sericite is formed solely by pervasive replacement. In all cases, this alteration is at the expense of biotite and feldspars. Sericitization of biotite occurs pseudomorphically (Fig. 25), whereas the feldspars are replaced by coarse-grained sericite flakes up to 0.4 mm long. In exceedingly altered core samples, the rock is reduced to a mass of quartz and sericite (Fig. 26). Groundmass quartz in these samples may be recrystallized.

Accessory minerals formed as the result of phyllic alteration include calcite and leucoxene. Calcite occurs as minute grains intermixed with sericite in plagioclase. Calcite probably formed when Ca, released during plagioclase alteration, combined with CO₂ in the hydrothermal fluid. Leucoxene is generally observed along cleavages of altered biotite. As in the potassic alteration zone, Ti is probably derived from the biotite.

Two zones with different pyrite content characterize the area of phyllic alteration. However, both zones are low in copper. As shown in Figures 12, 13, and 14, these zones are arranged as such that the zone of 1.5 or less percent pyrite is somewhat enclosed by the zone
Figure 24. Photomicrograph of a thin section of older quartz latite porphyry. Polarized light, X50.

Primary biotite (B) is partly replaced by chlorite (C) and epidote (E).
Figure 25. Photomicrograph of a thin section of older quartz latite porphyry showing the alteration of biotite to sericite (S). Polarized light, X50.
Figure 26. Photomicrograph of phyllic zone alteration. Polarized light, X50.

Q=recrystallized quartz, S=sericite, and dark area is relict primary quartz.
of 3 to 5 percent pyrite. Sulfides of the 1.5 or less percent pyrite zone occur typically as disseminated grains and veinlets, whereas the sulfides in the 3 to 5 percent zone occur as blebs and veinlets.

**Propylitic Alteration Zone**

The propylitic minerals, chlorite, epidote, and calcite form a one to two thousand meter alteration halo around much of the Copper Basin deposit. At its most distal points outside of the deposit, propylitic alteration is characterized by the incipient chloritization of biotite. Initially, chlorite replaces biotite along cleavage surfaces, but approaching the deposit progressively more biotite is altered. Within a distance of 150 to 500 meters from the deposit, epidote and calcite become prominent phases. Epidote occurs as small green granules replacing chlorite (Fig. 27) and plagioclase, or as clusters of larger yellowish green grains. Calcite is less abundant than epidote and is absent in some samples. Calcite usually occurs as a replacement of biotite and hornblende, although some calcite also replaces plagioclase.

Veinlets in the propylitic zone are composed of chlorite, epidote, calcite, and pyrite. These veinlets occasionally show a bleached rind of sericite-kaolinite(?) along their margins. This bleaching is generally developed near grains of pyrite (Fig. 28).

Sphene, although not clearly a product of hydrothermal alteration, occurs as a replacement of biotite and hornblende. Chemically, sphene in the propylitic zone may be analogous to rutile and leucoxene
Figure 27. Photomicrograph of a thin section of granodiorite from the propylitic alteration zone. Polarized light, X50.

Lath of primary biotite altered pseudomorphically to chlorite (C) and anhedral epidote (E).
Figure 28. Photomicrograph of a thin section of a border facies rock (granodiorite) showing veinlet-controlled propylitic alteration. Polarized light, X50.

Veinlet is composed of pyrite (PY) and epidote (E) with a narrow selvage of sporadic sericite (S) with minor clay. Hornblende (H) is partly altered to epidote.
in the secondary biotite subzone. Where sphene is observed near the inner margin of the propylitic zone, it is often altered to leucoxene, magnetite-ilmenite(?), and pyrite. The conversion of sphene to leucoxene and ilmenite at El Salvador has been attributed to incipient potassic alteration (Gustafson and Hunt, 1975).

Mineralization within the zone of propylitic alteration is almost entirely restricted to pyrite along fractures. Propylitic alteration coincides with the "marginal pyrite zone" in which pyrite never exceeds 3 percent and is generally less than 1 percent. Copper ranges from about 1500 ppm to usually less than 500 ppm.
GEOCHRONOLOGY

Four rock samples from Copper Basin were dated by K-Ar methods during this study (Tables 3 and 4). These dates established the Copper Basin stock and the hydrothermal alteration as being of Laramide age. The post-mineral rhyolite dikes were found to be Miocene in age. Inexplicably, the ages determined for the Copper Basin stock in the study are older than a previously published age of 64 m.y. (Anderson, 1968).

Laramide Ages

Based on geological observations, the oldest and youngest rocks genetically associated with alteration and mineralization in the Copper Basin stock are the border facies rocks and the younger quartz latite porphyry dikes, respectively. The border facies rocks were dated using primary biotite collected from an outcrop over a thousand meters from the deposit proper. Primary biotite is identified by its euhedral to subhedral form and dark brown color. Primary biotite from the border facies rocks gave an age of 75.5 ± 1.6 m.y. This date establishes a maximum age for the deposit. Primary biotite and hornblende from the younger quartz latite porphyry gave ages of 72.8 ± 1.5 and 72.9 ± 1.6 m.y., respectively. Since the younger quartz latite porphyry is altered and mineralized in the deposit, these ages provide an upper time boundary for intrusive events related to alteration and mineralization. An age of 72.6 ± 1.5 m.y. was determined for sericite.
Table 3. Potassium-argon analyses of Copper Basin rocks.

<table>
<thead>
<tr>
<th>Rock type and Sample No.</th>
<th>Mineral</th>
<th>K(%)</th>
<th>Ar x 10</th>
<th>Ar (%)</th>
<th>Age(10 yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granodiorite border facies (UAKA 75-117)</td>
<td>Biotite</td>
<td>6.789 ±0.049</td>
<td>9.104</td>
<td>95.0</td>
<td>75.5 ± 1.6</td>
</tr>
<tr>
<td>Younger quartz latite porphyry (UAKA 76-1)</td>
<td>Biotite</td>
<td>6.691 ±0.090</td>
<td>8.691</td>
<td>96.2</td>
<td>72.8 ± 1.5</td>
</tr>
<tr>
<td></td>
<td>Hornblende</td>
<td>0.6505 ±0.0051</td>
<td>0.845</td>
<td>80.8</td>
<td>72.9 ± 1.6</td>
</tr>
<tr>
<td>Granodiorite-quartz monzonite (UAKA 76-25)</td>
<td>Sericite</td>
<td>8.113 ±0.099</td>
<td>10.46</td>
<td>94.7</td>
<td>72.6 ± 1.5</td>
</tr>
<tr>
<td>Rhyolite (UAKA 76-26)</td>
<td>Biotite</td>
<td>7.567 ±0.054</td>
<td>1.974</td>
<td>74.1</td>
<td>14.94 ± 0.33</td>
</tr>
<tr>
<td>Sample No.</td>
<td>Latitude(N)</td>
<td>Longitude(W)</td>
<td>Locality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAKA 75-117</td>
<td>34 28'28.78&quot;</td>
<td>112 35'15.50&quot;</td>
<td>1 km southwest of Hill 5642 in Copper Basin Wash, Kirkland Quadrangle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAKA 76-1</td>
<td>34 29'03.35&quot;</td>
<td>112 35'34.02&quot;</td>
<td>Arroyo west of Copper Basin Wash, 0.6 km northeast of Hill 5497, Kirkland Quadrangle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAKA 76-25</td>
<td>34 29'45.64&quot;</td>
<td>112 35'5.77&quot;</td>
<td>North side of arroyo north of Aztec Hill and west of Copper Basin Wash, Wilhoit Quadrangle.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UAKA 76-26</td>
<td>34 29'39.29&quot;</td>
<td>112 29'54.42&quot;</td>
<td>Northeast of Gabarina Hill and west of Copper Basin Wash, Wilhoit Quadrangle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
from the phyllic alteration zone. Veinlets of phyllic alteration cross-cutting potassic alteration demonstrated that the age of the sericite is the upper age limit of hydrothermal alteration. The similarity in ages between the intrusion of the Copper Basin stock and the hydrothermal alteration is independent verification of the genetic relationship between these two events.

The ages of intrusion and alteration of the Copper Basin stock are significant in that they denote the earlier stage of Laramide orogeny in Arizona and show that Copper Basin is one of the oldest Laramide porphyry copper deposits in Arizona. The only other deposits of similar age are the Bagdad and Mineral Park porphyry copper deposits (Livingston, Mauger, and Damon, 1968) which occur near Copper Basin and in similar geologic environments. The possible significance of the Bagdad deposit to the Copper Basin deposit is discussed in a later section.

**Tertiary Ages**

The post-mineral rhyolite dikes which intrude the Copper Basin deposit were determined to be 14.94 ± 0.33 m.y. old (Miocene). This date verifies a previous inference by Johnston (1955) that these rocks were Tertiary in age. The age of these rhyolite dikes correlates closely with the period of 14.8 to 10.1 m.y. before present when minor latite and widespread basaltic volcanism occurred in north-central Arizona (McKee and Anderson, 1971).
DISCUSSION

Petrogenesis of the Copper Basin Stock

The preceding discussion has shown that the Copper Basin stock was emplaced by multiple intrusions from about 75 to 72 m.y. ago. Cross-cutting relationships show that the border facies rocks were intruded before other parts of the stock. Compositional differences of the border facies are thought to be attributable to differential cooling of the border facies magma. As cooling progressed, the more mobile quartz- and orthoclase-rich residual portions of the border facies rocks were intruded higher in the stock. Marginal contact breccias of the granodiorite-quartz monzonite show that it intruded the border facies rocks in a semi-crystallized state. Seriate to equigranular to porphyritic rock textures show that the granodiorite-quartz monzonite probably cooled under a range of pressures and temperatures. The last intrusive phases of the stock were the older and younger quartz latite porphyries. Aphanitic-porphyritic rock textures show that both of these rocks were emplaced very quickly and cooled rapidly. Spatial relationships indicate the younger quartz latite porphyry dikes were relatives to the larger mass of older quartz latite porphyry. The progressively more quartz- and orthoclase-rich compositions of the stock rocks correlate with a trend established by Bowen (1928) as being indicative of fractional crystallization. Thus, it is here postulated that the sequence of the Copper Basin stock rocks can
be explained by fractional crystallization of a parent magma much deeper in the crust. Radiometric dating shows the unaltered rhyolite dikes which crosscut the deposit to be a much younger (Tertiary) intrusive event.

The depth at which the Copper Basin deposit formed cannot be determined from geological evidence now available. However, Lowell (1974) estimates that the Copper Basin deposit has undergone an amount of erosion equal to or somewhat less than the nearby Bagdad deposit. Fluid inclusion studies (Nash and Cunningham, 1974) show that about 1.8 Km of material has been eroded from the Bagdad deposit. Thus, if the Lowell (1974) postulation is correct, then no more than about 1.8 Km of burial depth can be estimated for the Copper Basin deposit.

The contacts of the border facies rocks suggest that they were emplaced by magmatic stoping of stope blocks of wall rock. Textures indicative of assimilation suggest that magma temperatures of the border facies rocks were well above their solidus temperature. However, the granodiorite-quartz monzonite appears to have been emplaced at near-solidus temperatures. At an estimated maximum emplacement depth of 1.8 km and assuming equilibrium of the magma with water vapor, the granodiorite-quartz monzonite would have crystallized completely at about 700 to 775°C. Quenching textures in the older quartz latite porphyry suggest crystallization at low pressures, but fairly high temperatures.

As noted previously, Johnston and Lowell (1961) proposed that the Copper Basin breccia formed during corrosion and collapse of wall rocks. Observations during this study found that that model is
inconsistent with the large-scale nature of the breccia and does not explain how two texturally distinct varieties of older quartz latite porphyry were incorporated into the breccia. Nor does it explain the cross-cutting relationship of the older quartz latite porphyry to the breccia.

The author feels that the Norton and Cathles (1973) model can explain all of the above features and relationships. Their model proposes that solidified "roof" rocks of cooling intrusives can trap magmatic gases. These gases collect to form a large gas-filled chamber at depth. As the chamber grows, the gases must maintain mechanical equilibrium with the overlying rocks. When major breaks occur in the chilled "roof" rocks, the gases escape and the equilibrium is upset. Without the buoyant effect of the trapped gases, the chamber ceiling and the overlying rocks collapse downward. Integration of this model with the features of the Copper Basin breccia allows the following interpretation.

1. At some unknown depth, chilling formed a phenocryst-deficient seal over a magma of older quartz latite porphyry. Relicts of this seal occur in the breccia as the fragments of phenocryst-deficient older quartz latite porphyry described earlier.

2. Pore fluid pressure or tectonic activity caused the seal to crack and allowed the trapped gases to escape.

3. When the lithostatic load pressures exceeded the strength of "roof" rocks, the overlying rocks and ceiling of the chamber collapsed downward.
4. An increase in magmatic pressure forced the older quartz latite porphyry to ascend through the breccia.

**Pressure, Temperature, and Source of the Hydrothermal Fluids**

The maximum estimate of 1.8 km of post-mineral cover over the Copper Basin deposit allows an estimate of maximum confining pressure to be made. Assuming that lithostatic conditions prevailed during alteration and mineralization, the confining pressure would have been about 500 bars. If hydrostatic conditions are assumed over a depth of 1.8 km, the maximum pressure would have been about 175 bars for a static column of water of constant temperature, density, and composition. Density values of saline hydrothermal fluids (Haas, 1971) would raise this latter value to a maximum of about 200 bars. Interspersed gas-rich and fluid-rich fluid inclusions in the areas of the breccia (secondary orthoclase subzone) indicate that the hydrothermal fluids boiled intermittently. As will be shown later, temperatures of the hydrothermal fluids were probably too low to cause boiling at 500 bars pressure (lithostatic conditions), but were sufficient to cause boiling under hydrostatic conditions (200 bars or less). Outside of the breccia, no fluids inclusions indicative of boiling were observed. Therefore, much higher lithostatic conditions may have prevailed in the unbrecciated wallrocks.

Temperatures of hydrothermal fluids can be estimated from homogenization temperatures of fluid inclusions (Roedder, 1967). Although this study did not measure homogenization temperatures, the criteria of Nash and Theodore (1971) and Nash (1976) permit visual estimates to
be made. These estimates (Table 5) are based on the proportion of vapor to liquid and the type of daughter crystals in the fluid inclusions.

Three compositional types of fluid inclusions were observed during this study. The terminology to be used conforms to that of Nash (1976). About 90 percent of the inclusions observed are Type I inclusions. Type I inclusions consist of liquid and a small vapor bubble. The vapor bubble occupies between 10 and 40 percent of the inclusion. Work by Roedder (1971) indicates the Type I inclusions are of low to moderate salinity (3 to 20 percent NaCl equivalent) and generally homogenize at less than 300°C (Nash, 1976). The liquid phase is mainly water with dissolved sodium, potassium, and chlorine, whereas the vapor phase is mainly water (Roedder, 1972). Type III inclusions compose about 7 percent of the fluid inclusion population. These inclusions contain a vapor bubble of similar proportions as in Type I inclusions, but they also contain a daughter mineral. The euhedral, cubic habit of the daughter mineral suggests it is halite. Type III inclusions represent very high salinity fluids, i.e., near 40 weight percent and homogenize between 225 and 725°C (Nash, 1976). The high NaCl content of Type III inclusions makes estimation of filling temperatures uncertain, however, Nash (1976) found that most porphyry copper deposits form at about 400 ± 100°C. Therefore, a temperature of 500°C seems to be a reasonable upper limit to be expected for the filling temperature of Type III inclusions, and for Copper Basin hydrothermal fluids in general. The least commonly observed inclusions
Table 5. Fluid inclusion data for the Copper Basin deposit.

<table>
<thead>
<tr>
<th>Inclusion Type</th>
<th>*Estimated Salinity</th>
<th>Vapor/Liquid Ratio</th>
<th>Estimated Homogenization Temperature °C</th>
<th>Daughter Minerals</th>
<th>Location(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>20</td>
<td>1:1.5 to 1:9</td>
<td>300</td>
<td>None</td>
<td>SOS, SBS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PhZ</td>
</tr>
<tr>
<td>II</td>
<td>0.4-7</td>
<td>1:1 to 4:1</td>
<td>N.E</td>
<td>None</td>
<td>SOS, SBS</td>
</tr>
<tr>
<td>III</td>
<td>40</td>
<td>1:2 to 1:9</td>
<td>300-500</td>
<td>Halite</td>
<td>SOS, SBS</td>
</tr>
</tbody>
</table>

Abbreviations: N.E.=Not estimated, probably same range as Type III inclusions. PhZ=Phyllic Zone SOS=Secondary Orthoclase Subzone SBS=Secondary Biotite Subzone

* =reported as weight percent NaCl equivalent.
were Type II inclusions. The inclusions are vapor-rich with the vapor occupying over 50 percent of the inclusion. Type II inclusions often coexist with Type III inclusions, a relationship which can be explained as contemporaneous trapping of a boiling parent fluid (Nash and Theodore, 1971). Type II inclusions generally contain between 0.4 and 7 weight percent NaCl equivalent and contain variable amounts of CO$_2$ (Roedder, 1971).

In areas of the breccia where boiling cannot be demonstrated, the homogenization temperatures require a pressure correction to attain the true original homogenization temperature of a fluid inclusion. On the basis of a range of maximum pressures from 175 to 200 bars, a correction of only about +15 to 20°C is needed in the above estimates. Calculated boiling curves for various concentrations of water and NaCl (Haas, 1971) clearly demonstrate the above temperatures are too low to cause boiling at depth of 1.8 km and under lithostatic conditions. Therefore, the Copper Basin deposit probably formed under hydrostatic conditions and at a depth somewhat shallower than 1.8 km.

Two major models have been postulated to explain the formation of hydrothermal fluids associated with porphyry copper deposits, i.e., the orthomagmatic model (Burnham, 1967; Neilsen, 1968; Lowell and Guilbert, 1970) and the connate-meteoric, i.e., ground water model (White, 1968). Isotopic studies (Sheppard, Neilson, and Taylor, 1971) show that many characteristics of porphyry copper deposits can be explained by both theories. The following evolutionary trend of events is suggested to account for the source of hydrothermal fluids at Copper Basin:
1. A short early stage of magmatic fluids released by crystallization of the Copper Basin stock. Magmatic fluids are believed responsible for the metals, sulfur and saline character of hydrothermal fluids (Burnham, 1967, Kilinic and Burnham, 1972; Whitney, 1975). At least the initial formation of potassic alteration is attributed to this stage of hydrothermal fluids (Rose, 1970; Sheppard et al., 1971).

2. A long intermediate stage of meteoric fluids driven under the influence of thermal gradients in the fractured stock. These fluids convect through the deposit area (Cathles and Norton, 1974) and mix with the magmatic fluids (Whitney, 1975). This mixing increases the activity of $H^+$ through oxidation of magmatic $H_2S$ (Hemley and Jones, 1964) and scavenges metals (Cathles, 1977) by means of chloride-complexing (Helgeson, 1970). In striving for equilibrium, the convecting fluids undergo changes in temperature, pressure, and composition in which various elements are deposited or taken into solution (Holland, 1972; Crerar and Barnes, 1976). The abundance of low to moderate salinity fluid inclusions and relatively low temperature of the hydrothermal fluids suggest that meteoric fluids were an important component of the hydrothermal fluid.

3. A short late stage of dominantly meteoric fluids. Although speculative, it is believed that these fluids overwhelmed older hydrothermal fluids at equilibrium with potassic
alteration and shifted them into equilibrium with phyllic alteration. Stable isotope studies of sericite at other deposits show that this is a reasonable assumption (Sheppard et al., 1971; Sheppard and Taylor, 1974). Radiometric dating and cross-cutting relationships show that the phyllic alteration is temporally related to the older quartz latite porphyry and occurred late in the formation of the deposit. An explanation for these features is that intrusion of the older quartz latite porphyry occurred when the stock was fairly cool. Fracturing accompanying this intrusion allowed meteoric fluids to migrate downward and flow around and through the older quartz porphyry. Duration of fluid flow around plutons is a function of the size and permeability of the pluton (Norton and Knight, 1977). Since the older quartz latite porphyry is a relatively small intrusive and poorly fractured, the duration of flow of meteoric fluids was probably brief. Thus, cooling produced by the meteoric fluids caused very restricted phyllic alteration.

Generalized compositions of the hydrothermal fluids during the periods of potassic and phyllic alteration are shown in Figure 29. Point B (Fig. 29) depicts possible equilibrium conditions in the secondary orthoclase subzone. The location of point A is consistent with the vein mineralogy of the secondary biotite subzone. Widespread development of sericite in the secondary biotite subzone shows that the hydrothermal fluids were probably at, or near point A. Sericitization of plagioclase which consumes more $H^+$ than $K^+$, and concomitant cooling
Figure 29. Hypothetical hydrothermal fluid compositions during alteration of the Copper Basin deposit (after Montoya and Hemley, 1975).
of the hydrothermal fluids would have tended to maintain the fluids on this two-phase boundary. Thus, it is likely that with time, the fluid composition moved from point A down the two-phase boundary to some new point C. However, it is also possible that some of the fluids at point A were moved along pressure gradients into the breccia (secondary orthoclase subzone). This process is shown by line A-B. At some later time, the influx of meteoric fluids shifted the hydrothermal fluids into equilibrium with phyllic alteration (sericite) at point D.

**Paragenesis of Mineralization**

Several writers (Stringham, 1953; Lowell, 1968, Rose, 1970) have shown that the highest copper grades in porphyry copper deposits are usually associated with potassic alteration. A similar relationship exists in the Copper Basin deposit. An important determinant governing this relationship may be the saturation of the hydrothermal fluid with biotite (Helgeson, 1970). Figure 30 diagrammatically depicts this relationship. At point 1, the host rock and the hydrothermal fluid are interacting. This interaction is a hydrolytic reaction in which H⁺ are consumed, but the activity of Fe²⁺ increases as biotite dissolves. As shown, pyrite is a stable phase and is being precipitated. As the reaction continues, the reaction path changes along line 1-2. At point 2, when sufficient K⁺, Fe²⁺, and other mineral-forming species have been increased in the hydrothermal fluids, biotite equilibrates and begins to precipitate (Helgeson, 1970). The buffering of Fe²⁺ by the deposition of biotite and the concomitant consumption of H⁺ causes a direction change of the reaction path horizontally to the right. If
Figure 30. System Cu₂S - FeS - H₂S - H₂SO₄ - HCl - H₂O.

A reaction path a hydrothermal fluid may take leading to the deposition of chalcopyrite (from Norton, Titley, Gerlach, and Knight, 1975).

Temperature = 300°C  Pressure = 1 bar
Log a(H₂S) = -2.00  a(H₂O) = 1.0
the reaction path continues along this new direction, chalcopyrite is eventually deposited.

Norton et al. (1975) notes that biotite equilibration may not by itself be sufficient to cause chalcopyrite deposition. He states that chloride complexing of Cu$^+$ could cause a decrease in the a(Cu$^+$) and thus move the reaction path 1-2 towards the left and thus prevent chalcopyrite deposition. Under this condition, Norton suggests a requirement of deposition may be:

1. a shift of the hydrothermal fluid's pH toward neutrality, or

2. a decrease in the temperature of the hydrothermal fluid.

In general changes in hydrothermal fluid pH are related to host rock reactions that consume H$^+$. Cooling of hydrothermal fluids may be associated with many phenomena (Toulmin and Clark, 1967), and the most significant of these are:

1. boiling,

2. irreversible adiabatic expansion, and

3. mixing of ground water with hydrothermal fluids.

Observations in this study indicate that an important cooling process in the Copper Basin deposit was boiling. Evidence of boiling includes the gas-rich fluid inclusions described earlier. Crystal-lined vugs and massive silicate alteration assemblages in the breccia (secondary orthoclase subzone) are also indicative of boiling (Jahns and Burnham, 1969). Evidence that boiling had a substantial effect on cooling is based on the occurrence of adularia in and near the breccia vugs. Thermodynamic calculations (Robie and Waldbaum, 1968) indicate that
adularia is stable over the range 85 to 380°C, although it more likely forms in hydrothermal deposits between 200 to 300°C (Weissberg, 1969; Nash, 1972; O'Neil, Silberman, Fabbi, and Chesterman, 1973). Based on the above data and observations, it appears reasonable to believe that the adularia precipitated between 200 and 300°C as the result of boiling.

The reason that reducing temperature of an ore fluid is such a significant way of precipitating chalcopyrite was discussed by Helgeson (1970), who showed that with decreasing temperature, the stability field of chalcopyrite is greatly enlarged. Thus, the size of the chalcopyrite field may become so large that deposition must occur at low temperatures, regardless of the precise ore fluid composition.
The main observations of this study show:

1. The K-Ar ages of 75.5 ± 1.6 to 72.8 ± 1.5 m.y. show that the Copper Basin stock is much older than previously thought. The only other igneous activity within the deposit occurred when rhyolite dikes were intruded 14.99 ± 0.33 m.y. ago.

2. Alteration and mineralization were clearly related to crystallization and cooling of the Copper Basin stock. K-Ar dating shows that the alteration and stock are the same age within the precision of error.

3. Alteration and mineralization show concentric zoning. The earliest alteration is composed of a broad zone of potassic alteration. This zone is fringed by a diffuse zone of propylitic alteration. Subsequently, a small zone of phyllic alteration was superimposed on the older quartz latite porphyry near the center of the deposit. In general, sulfide zoning correlates to the pattern of alteration zoning. As in many deposits, the highest grade of copper is contained within the potassic zone.

4. Chalcopryite deposition was governed by a decrease in pH, equilibration of biotite with hydrothermal fluids, and cooling of the hydrothermal fluids.
5. Hydrothermal fluids probably evolved in three separate, but closely related stages. In the earliest stage, the fluids were probably magmatic and carried both metals and sulfur. During an intermediate stage, meteoric fluids mixed with the magmatic fluids. The meteoric fluids scavenged metals from the magmatic fluids and carried them upward in the stock. A later stage of hydrothermal fluids was probably composed of largely meteoric fluids. These fluids encroached downward, as the upward flow of older hydrothermal fluids diminished.

6. Breccia in the Copper Basin deposit is much more pervasive than previously recognized. The breccia appears to be a collapse structure complexly related to intrusion of the older quartz latite porphyry.
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