CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
520-770-3500
http://www.azgs.az.gov
inquiries@azgs.az.gov

The following file is part of the

James Doyle Sell Mining Collection

ACCESS STATEMENT

These digitized collections are accessible for purposes of education and research. We have indicated what we know about copyright and rights of privacy, publicity, or trademark. Due to the nature of archival collections, we are not always able to identify this information. We are eager to hear from any rights owners, so that we may obtain accurate information. Upon request, we will remove material from public view while we address a rights issue.

CONSTRAINTS STATEMENT

The Arizona Geological Survey does not claim to control all rights for all materials in its collection. These rights include, but are not limited to: copyright, privacy rights, and cultural protection rights. The User hereby assumes all responsibility for obtaining any rights to use the material in excess of "fair use."

The Survey makes no intellectual property claims to the products created by individual authors in the manuscript collections, except when the author deeded those rights to the Survey or when those authors were employed by the State of Arizona and created intellectual products as a function of their official duties. The Survey does maintain property rights to the physical and digital representations of the works.

QUALITY STATEMENT

The Arizona Geological Survey is not responsible for the accuracy of the records, information, or opinions that may be contained in the files. The Survey collects, catalogs, and archives data on mineral properties regardless of its views of the veracity or accuracy of those data.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

MAR 2 1972
J. H. C.

March 1, 1972

FILE MEMORANDUM

Safford
Kennecott Deposit

Reference is made to Mr. Davis' Memorandum of February 11, 1972 concerning the recent deep drilling by Kennecott on the west side of their deposit.

In questioning John Wilson as to why KCC started deep drilling here, he stated that it was based on surface geology, relogging the old core (none of which was deep), and ground geophysics. The area being drilled is in andesite with quartz-sericite-pyrite alteration and a thin (2'-20') chalcocite blanket. This area is also immediately west of the volcanic vent as mapped by KCC. Thus, the factors that led to the deep drilling probably were:

1. vertical zoning interpretation,
2. testing at depth the west side of volcanic vent,
3. "different" I.P. response at depth than near surface.

It is rumored that KCC has intersected 1,000 feet of primary ore grading 0.6% copper.

W. L. Kurtz

WLK:lad

cc: JHCourtright
SRDavis

SOCIETY OF

not related to principal intrusive
1949 - 51 - CCC - 7 holes
Bear Cr - started drilling 1956

? Safford
Lone Star
Bear Cr.

I. INTRODUCTION

During 1955 Bear Creek Mining Company -- the exploration subsidiary of Kennecott Copper Corporation -- commenced geological reconnaissance in the Gila Mountains, Graham County, Arizona. As a result of this work the Lone Star Mining District was selected for intensive exploration because of the presence of a series of Cretaceous (?) andesitic volcanic rocks (named the "Older Volcanic Series") that were found to be strongly sheared by northeast fault zones. Plutonic rocks in the form of small stocks -- ranging from quartz-monzonite through granodiorite -- were also known to intrude the Older Volcanics. Still later dikes and sills -- and one plug-shaped mass -- of acid to intermediate composition, intersected all the older rocks. While the areas in and around some of these intrusives were hydrothermally altered and mineralized, known copper mineralization was usually confined to shear zones a few feet in width. intrusive - 58 my -

A later Tertiary volcanic sequence, the Intermediate Series (consisting of andesites, latite-flows, flow breccias and tuffs, with some basalt) and another Younger Volcanic Series (consisting of basalt, agglomerate and tuff) were also known to overlie and largely cover the mineralized Older Volcanic Series. Neither of these upper series of volcanic rocks is mineralized, but the possibility existed that they might overlie a hidden orebody.

In 1949 Consolidated Coppermines Corporation and the American Metal Company entered the District and commenced drilling a sheared, altered limonite-stained plug of rhyolite-latite, overlain on its northern side by basalt of the Younger Volcanic Series. Drilling

andesite flow 2000' lowest unit
older - 0 - 3000
upper vol - 0 to 1000 - to 800'
inter me - 0 - to 2600 - one ore 700'

results showed that strongly sericitized and silicified outcrops were essentially only mineralized with pyrite. Other holes collared in the Younger or Intermediate Series to the north of the crest of the mountains, showed the presence of disseminated oxide and sulfide copper mineralization at depth in the Older Volcanic Series. Values were too low to be of interest at the time and the property was abandoned.

No details of what had been found in these drillholes were available to Bear Creek at the time the area was selected as one worth further prospecting. It was felt, however, that there was still enough area unexplored to contain a sizeable copper deposit. ?

A. Location

Kennecott's Safford copper deposit is located in the Lone Star Mining District, nine miles northeast of the town of Safford, county seat of Graham County, Arizona. The orebody lies in the rugged Gila Mountains, mainly in Section 5, Township 6 South, Range 27 East. Surface elevations over the ore vary from 4,500 feet to 5,500 feet above sea level, though Webber Peak, the highest point in the immediate vicinity, reaches an elevation of 6,111 feet. Safford itself adjoins the Gila River at an elevation of 2,920 feet.

B. History & Production

Recorded production from the Lone Star District from its initiation in 1886, through 1907 (and also to date) is only 110,000 pounds of copper. Several small shafts were sunk on some of the shear zones to a maximum depth of about 500 feet. No ore of any consequence,

however, was ever found from the limited amount of drifting done. Later geological mapping by Bear Creek demonstrated that most of the old mine workings were located on small copper veins in the pyritized halo adjoining the orebody.

The next work done on the property was from 1949 to 1951 when Consolidated Coppermines Corporation and the American Metal Company entered the district. Bear Creek's reconnaissance project was initiated in 1955, geological mapping being done on aerial photographs on a scale of 1" = 1/2 mile. In 1956 several groups of claims owned by local residents were optioned. By the end of 1958 over 76,000 feet of diamond and rotary drilling had been completed and early in 1959 the options on two properties were exercised. Development work was also commenced during this year and by the end of 1962 a development shaft had been sunk to a depth of 804 feet and 1,500 feet of crosscutting and 1,500 feet of drifting had been completed on the 3900-foot level. Additional surface and underground drilling (totalling 118,000 feet) was also done to further outline the orebody.

C. Previous Work

Apart from a brief reference in 1928 by Tenney (16) to the Lone Star District, no details of the geology of the area were ever published until 1962. During this year the authors of this paper wrote a brief summary of the deposit for the Thirteenth Annual Guidebook of the New Mexico Geological Society (5).

II. GENERAL GEOLOGY (Figs. 1, 2, and 3)

A. Regional Setting

The deposit lies in the Gila Mountains -- one of the several

northwesterly trending ranges characteristic of the Basin-Range province of southeastern Arizona. This range lies on the eastern side of the Mountain Region or Mexican Highland, that separates the Colorado Plateau from the Sonoran Desert. Tertiary basalts and andesites, overlying Cretaceous (?) andesites and flow breccias, making up the range, were subjected to Basin-Range faulting. As a result of this faulting (which may have caused displacement as much as 2,000 feet) and subsequent erosion, the present-day outline of the range was formed.

The highest parts of the range consist of the Tertiary Younger and Intermediate Series of volcanic rocks which dip to the north and northeast from 10°-12°. On the southern flanks of the mountains, except where covered by terrace gravels and basin fill, the Cretaceous (?) Older Volcanic Series crops out with its attendant intrusive plutonic and volcanic rocks. Windows in the Tertiary volcanics may expose the Older Volcanics in places, but on the Kennecott property these are scarce and are limited to an area of a few square feet over the orebody.

Because of the northwesterly trending Basin and Range faulting, the predominant and obvious structural trend in the area parallels this direction. In the Older Volcanics of the Lone Star District, however, strong northeast faulting and shearing -- that appear to have controlled mineralization -- is evident. Dikes follow this trend and stocks and plugs appear to have their longer axes elongated in this direction.

Apart from Phelps Dodge Corporation's large disseminated porphyry copper deposit at Morenci -- located 19 airline miles to the northeast -- there are no active mines in the immediate area. During 1960 Phelps Dodge acquired a deeply buried porphyry-type deposit -- located 4 1/2 miles west-northwest from the Kennecott orebody. No plans have, however, been announced for bringing this into production.

Lying between the Phelps Dodge and the Kennecott deposits is the property from which most of the early copper production of the district came -- the San Juan Mine. Most of the mineralization is confined to veins or fractures in quartz-monzonite porphyry, although some disseminated sulfides are known to be present (Figs. 1, 3, 4, 5, 6, 10 and 11).

B. Rock Types

The sequence of rocks exposed in the area is shown in the following tabulation:

SEDIMENTARY AND VOLCANIC ROCKS

Formation	Rock Types	Thickness	Age
Alluvium, terrace gravels, basin fill	Sands, gravels, siltstone, conglomerates.	0' - 2,500'+	Pliocene-Recent
	- - UNCONFORMITY - -		
Younger Volcanic Series	Upper unit -- basalt flows and tuffs.	0' - 1,000'	Later Tertiary (?)
	Lower unit -- basalt flows, agglomerates and tuffs.		
	- - UNCONFORMITY TO DISCONFORMITY - -		
Intermediate Volcanic Series	Upper unit -- andesite, latite flows, flow breccia and tuffs.	0' - 2,000'	Earlier Tertiary (?)
	Lower unit -- basalt flows.	0' - 600'	
	- - UNCONFORMITY A - -		Post mineral / Pre "
Older Volcanic Series	Lithic tuff, pyroclastics, sandy grits.	2,700'+	Cretaceous (?)
	Upper unit -- andesite flow breccia and mud flow.		
	Lower unit -- porphyritic andesite and flow breccia.		
	- - UNCONFORMITY - -		
Quartzite	Quartzite	Xenoliths (?)	Cambrian (?)

INTRUSIVE ROCKS

Formation	Age
Basalt, rhyolite dikes	Post-mineral
Rhyolite, quartz-latite, latite, dacite and quartz-diorite dikes and plugs	Pre-mineral -- older than Unconformity A (intrusive into Older Volcanic Series and Lone Star Pluton)
San Juan Stock - quartz-monzonite porphyry, grano-diorite	Eocene and older than Unconformity A. (58 m.y. by K-A determination)
Lone Star Pluton - quartz-diorite, quartz-monzonite	Eocene and older than Unconformity A. (58 m.y. by K-A determination)

(1) Sedimentary

The oldest rocks exposed consist of small xenoliths of quartzite -- up to 250 feet in length and width -- in the Lone Star quartz-diorite stock. The rock resembles the Cambrian Coronado quartzite at Morenci. The only other sedimentary rocks -- terrace gravels and basin fill -- constitute the youngest formation present. These sediments are interbedded with the so-called Gila Conglomerate a few miles east of the property (8).

(2) Igneous

(a) Extrusive Rocks - The Older Volcanic Series, in which the orebody occurs, is overlain by two later volcanic units -- the Younger and the Intermediate Volcanic Series. On the basis of potassium-argon age determinations (58 m.y. or Eocene) made on two stocks (17) -- the San Juan and Lone Star -- intruding only the Older Volcanic Series, both of these later units are believed to be of Middle or Late Tertiary Age.

The Older Volcanic Series consists of dark grey massive porphyritic andesite and fine-textured flow breccia with intercalated tuff beds. South of the Lone Star Fault and north of the San Juan Shear Zone they are overlain by several hundred feet of flow breccia. Near the orebody they are also overlain by a thin series of grits, sandstones and conglomerates 10-60 feet thick, which appear to be associated in origin with a series of rhyolitic and tuffaceous rocks occurring in a vent-like structure described below.

The Older Volcanics are overlain unconformably by the Intermediate Volcanic Series consisting of andesites, latite flows, flow breccias and tuffs. They range in thickness from 0-820' over the orebody.

The Younger Volcanic Series, consisting of basalt flows, tuffs and agglomerates, overlies the Intermediate Volcanic Series disconformably. This unit may reach a thickness of 750 feet over the orebody.

(b) Intrusive Rocks - All the known intrusive rocks, on and adjoining the property, penetrate only the Older Volcanic Series. While a few basalt and rhyolite dikes, a few feet in width, are post-mineral, the bulk of them are pre-mineral in age.

Rhyolite, quartz-latite, latite, dacite and quartz-diorite - Rocks varying in composition from acid to intermediate, occur in a dike swarm within the Lone Star Shear Zone. Some of the dikes probably emanate from a rhyolitic plug which, together with pyroclastics, crystalline tuff and tuff breccia, fill a steep sided,

deep seated vent at least 2,000 x 1,500 feet in area. Because of its cylindrical shape, steep sides and associated explosive-type debris, this feature is considered to be a near surface portion of a volcanic vent.

While varying in width from a few inches to 200 feet, individual dikes may be traced for distances of 2,000 to 4,000 feet. Some are found as much as 10,000 feet southwest of this possible source. To the northeast, both the plug and dikes continue under the Younger and Intermediate Volcanics. On the 3900-foot level, for instance, the orebody lies in porphyritic andesite traversed by 14 to 20 of these dikes. About 25 percent of the area on this level is thus made up of intrusives.

Quartz-monzonite porphyry stock - A quartz-monzonite porphyry stock, Eocene in age, intrudes the porphyritic andesites at the San Juan Mine. Oval in outcrop, the dimensions are 1,500 by 1,000 feet, the longer axis being in a northeasterly direction.

Quartz-diorite, granodiorite - The Lone Star Pluton, also Eocene in age, is an elongated composite stock-like mass composed mainly of quartz-diorite, quartz-monzonite and granodiorite at least 8,000 by 4,000 feet in size.

Breccia pipes and pebble dikes - While none of these igneous structures are found near the orebody, three intrusive pipes, up to 50 feet in diameter, occur in the Lone Star Stock near the At Ease Fault. Several pebble dikes -- a foot or less in width -- also extend away from one of these pipes. On the northwest side of the San Juan Stock another breccia pipe, 400 feet in diameter, is surrounded by a narrow dacite porphyry ring dike.

C. Structure (Fig. 4)

(1) Regional

The regional structural picture, already partly described, is represented by the northwest trending Gila Mountains and the associated southwesterly dipping Butte Fault. Based on the difference in elevation of the unconformable surface between the Older and Younger Volcanics on both sides of the fault, the throw might be as much as 2,000 feet. As a result of this major structural disturbance, the Gila Range was tilted 10-12 degrees to the northeast.

(2) Local

Both the Kennecott deposit and the San Juan Mine are localized in extensive sheared zones several thousand feet wide, named respectively the Lone Star and San Juan Shear Zones. The Lone Star Shear Zone lies between the Lone Star and the At Ease Faults on the northeast flank of the Lone Star Pluton and is approximately 6,000 feet wide. The strike length is at least 16,000 feet -- 5,000 feet of which is covered by the Tertiary Volcanics. Its strike varies from N50°-65°E while the dip is essentially vertical or steep to the north. The zone, which contains the orebody, appears to constitute an upthrown block and is characterized by a large number of shears, faults, fractures and sheeted zones, generally striking in the same direction. While the exact amount of displacement along the Lone Star and San Juan Shear Zone is unknown, it could be as much as 800 feet -- based on outcrops of the upper mud flow-flow breccia unit of the Older Series exposed on both the footwall of the Lone Star Fault and the north side of the San Juan Shear, but

missing in the intervening area.

Parallel to the Lone Star Fault and 3,000 feet to the south, is the Trojan Fault. This break is a normal fault that displaces the Tertiary Younger Volcanic Series with the southeast side dropped 170 feet with respect to the northwest.

Around the San Juan Mine, the San Juan Shear Zone has a width of 3,000 feet and a strike length of 9,000-10,000 feet. Separated from the Lone Star Shear Zone by 3,000 to 4,000 feet of relatively less sheared ground, the San Juan Shear Zone strikes and dips in similar fashion. Shearing is strongest in the vicinity of the quartz-monzonite porphyry stock which intrudes the zone. Shear zones of lesser intensity, striking northwest, east-west and north-northeast intersect the San Juan Shear at the stock and may have helped localize its intrusion.

III. OREBODY GEOLOGY (Figs. 6, 7, 8 and 9)

A. Nature of Orebody

(1) General - The Safford orebody occurs in the Older Volcanic Series where northeast shears and faults in the porphyritic andesite were intruded by the acid-intermediate series of dikes, plugs and the volcanic vent. Because the shear zone was also superimposed on the volcanic vent and associated bedded vent debris -- near surface phenomena -- shallow depth of burial and relatively low pressure and temperature conditions of ore formation are postulated.

This disturbed zone was then strongly hydrothermally altered and mineralized with iron and copper sulfides over an area of 12,000 by 6,000 feet. While most of this area was pyritized, the maximum

plan limits of the ore cover an area one fourth this size. The greater thickness of the ore shown on Figure 8, Section G-G', is 1,600 feet.

After mineralization the orebody was exposed to oxidation, leaching and enrichment. Because the resulting leached capping is thick (ranging from 0-950 feet and averaging 440 feet) the chalcopyrite-pyrite ratio was probably favorable for the removal of copper. In the primary ore zone this ratio is approximately 2:1 by volume -- 2% chalcopyrite and 1% pyrite. In the capping, however, more pyrite may have been present -- because of some vertical primary zoning -- resulting in more favorable conditions for leaching.

The copper removed from the leached capping formed a chalcocite blanket on the primary zone, where the chalcopyrite-pyrite ratio was higher. Because of the relatively low pyrite content of this zone, little of either the secondary or the primary copper was removed during later periods of uplift associated with movement along the Butte Fault. Only remnants of the enriched secondary zone now exist, however, because of additional deep oxidation resulting from these uplifts. As a result, three types of ore are present -- oxide, mixed oxide-sulfide and sulfide.

Chrysocolla, the silicate and brochantite, the basic sulfate, were the main minerals developed during this time. In the mixed zone these overlap with and replace chalcocite and covellite, while in the primary zone chalcopyrite, pyrite and molybdenite are present. Oxidation and enrichment is known to have commenced before the later Tertiary volcanic rocks covered the mineral deposit, because frag-

ments of oxidized ore are found in some of the overlying pre-volcanic basal conglomerates. Although no water table has been found to be present in the area of the deposit, one must have existed during the time of the formation of the chalcocite blanket.

(2) Leached Capping - Apart from a few square feet of leached capping exposed in a window in the Younger Volcanics, the orebody does not crop out. Most of the adjoining pyritized area is, however, exposed on the southern slopes of the Gila Mountains. Although largely leached and oxidized, sulfides are known to occur at surface in a few instances. Leaching and oxidation of the buried ore zone has, however, taken place to great depths. The sub-outcrop -- consisting predominantly of brown-red-maroon (and occasionally black) "limonite" stained andesites or intrusives, with minor green (mainly chrysocolla) staining -- averages 0.17% total copper over the first 10 feet. Overall average grade of the leached zone is slightly less and averages 0.13% total copper. The ferric iron minerals present are goethite or hematite, with rarer jarosite, distributed abundantly in veinlets, fractures, or leached cavities throughout the cap rock.

B. Mineralization (3, 4, 10 and 11)

(1) Primary Minerals - Primary minerals consist mainly of pyrite and chalcopyrite with lesser amounts of bornite and molybdenite and rare tetrahedrite, galena and sphalerite.

Pyrite is the most abundant sulfide present. Content of the primary ore varies from 0.2-1.0% by volume while in the adjoining pyritic halo zone it ranges from 4-8%. Occurring in veins and

disseminations, pyrite is more resistant to replacement by chalcocite and covellite and to oxidation to "limonite," than chalcopyrite.

Chalcopyrite also occurs in veins and disseminations and is the most abundant primary copper mineral. In the primary ore the chalcopyrite content approaches 2%. In the protore, only 0.7% is present while the pyritic halo averages 0.4% chalcopyrite.

Bornite occurs in veins and disseminations but is much less common than chalcopyrite. Molybdenite occurs in quartz veinlets and is more abundant in the deeper sulfide zones.

Magnetite is also fairly common in quartz veins carrying sulfides. Tetrahedrite, galena and sphalerite have been identified within the pyritic halo in veins. Gold has not been identified in the orebody but is known to occur in small fractures in a 5-foot shear zone in propylitic andesite, 2,000 feet to the southeast. No silver-bearing minerals were ever found to be present.

(2) Secondary Minerals - Secondary minerals include the sulfides chalcocite and covellite. Chalcocite may completely replace chalcopyrite, bornite or covellite -- the latter derived from these two primary sulfides; pyrite is usually only coated. Both the "steely" and "sooty" varieties are present. Covellite replaces chalcopyrite and bornite and is itself replaced by chalcocite.

(3) Oxide Minerals

Chrysocolla is the most abundant copper mineral present in the deposit and makes up 50-85% of all the oxide mineralization. It occurs as veins, blebs or coatings on fractures, or as intergrowths with kaolinite or kaolinite-halloysite.

Malachite is much less abundant than chrysocolla but usually occurs in close association with chrysocolla.

Brochantite is less abundant than chrysocolla and constitutes 5-45% of the oxidized minerals. It appears generally to be later than the chrysocolla and perhaps replaces it.

Cuprite, tenorite and chrysocolla usually replace chalcocite.

Native copper occurs erratically along thin veinlets or fractures and is usually associated with cuprite or chalcotrichite. Minor amounts of pseudomalachite (a copper phosphate), chalcanthite, antlerite and turquoise are also known to occur.

Goethite and hematite occur in the rock replacing original sulfides and primary iron-bearing minerals. An orange-red transported limonite is also found filling fractures and superficially coating the rocks yellow to brown.

Jarosite occurs in fractures and veins replacing primary minerals, fault gouge and clay and is closely associated with turquoise and alunite.

Alunite occurs as a white to green mineral in fractures and shears.

C. Alteration

(1) Hydrothermal Alteration (Fig. 5 and 3, 4, 7, 10, 11, 12, 13 and 14)

(a) Zones & Distribution - As already described, an area 12,000 by 6,000 feet was subject to extensive hydrothermal alteration. Half of this area is exposed, while the balance is covered by the later Tertiary volcanics and was outlined by drilling and underground de-

velopment. The orebody occurs mostly in the buried portion of the altered area.

A central area of intense alteration is composed of a strongly developed quartz-sericite zone on the southwest which adjoins and is partially superimposed upon a large area of pervasive secondary biotitization on the northeast. The orebody lies within these two zones, around which are arranged the chloritic and propylitic zones in a roughly concentric pattern. Part of the quartz-sericite and the chloritized zones lie within essentially pyritized areas. The propylitic zone is, however, unmineralized except where traversed by shear zones, veins or dikes that may be accompanied by sulfides (pyrite and/or chalcopyrite). Alteration boundaries are rather arbitrary, in that mineralogical changes are transitional and overlapping, particularly in the porphyritic andesite host rock. The influence of rock type and structure is also important because the quartz-sericite zone corresponds mainly with the post-andesite intrusive complex and also with the pyroclastic lithic tuff and volcanic vent debris. Sericitic alteration not only occurs in all the dikes but also along their contact zones with the porphyritic andesite -- in both the chloritic and propylitic zones -- as much as 10,000 feet southwest of the orebody. Sericitization is clearly later than biotitization in gross field pattern -- wherein the biotitized rock contains sheaves of sericitized rock along veins, shears and contacts. Microscopically it is clear that biotite is also altered to sericite along these zones.

In most of the intrusives K feldspar, probably primary, makes up 15-20% of the groundmass. In some cases, however, there is a

concentration of K feldspar along veins, indicating either addition to the rock or possible segregation of primary K feldspar during alteration. In the andesites secondary K feldspar, with associated quartz and sericite, is abundant along veins.

Prior to the development of sericite, the plagioclase in the andesites -- andesine -- had largely been altered to oligoclase or albite. In the intrusives, albitization had also taken place at an early stage.

Quartz-sericite zone - Rocks which have undergone this type of alteration (occurring mainly over an area 7,000 x 5,000 feet) are characteristically bleached to a white or light grey color. This alteration stage appears to have been later than the other stages. The rocks of acidic to intermediate composition composing the dikes, plugs and volcanic vent debris were the most severely affected. Both plagioclase phenocrysts and plagioclase in the groundmass were thoroughly converted to sericite and quartz -- largely along veinlets. Mafic minerals were similarly affected. The biotitized andesite, where adjacent to faults, veins, intrusive contacts and shears, was also altered by conversion of mafics and plagioclase to sericite, quartz and minor sphene. Those zones are relatively narrow and exhibit gradational boundaries from pervasive sericitic content into the biotitized andesite. The superimposition of the quartz-sericite zone on the biotitized zone is thus clearly demonstrated. A similar relationship of this type of alteration to the chloritic and propylitic zones is also apparent. At the San Juan Mine the quartz-monzonite porphyry stock is similarly altered.

It is of interest to note that the potassium-argon age dating of the sericite is 53 m.y. (17) -- or slightly younger than the San Juan and Lone Star Stocks.

Biotite zone - The rocks mainly affected by this type of alteration are the porphyritic andesites. Hornblende and augite were replaced by brown biotite in flakes, clots and more rarely, in veinlets carrying sulfides. The strongest biotitization (10-50% and averaging about 20%) is developed around the intrusive plugs and dikes in and adjoining the orebody. The acidic to intermediate intrusive rocks have secondary biotite developed in only minor amounts (a few percent) along quartz veinlets. Other occurrences in these intrusives, if ever present, were probably destroyed by the later sericitic alteration phase. At the San Juan Mine a zone of biotitized porphyritic andesite -- 2,000 feet wide -- also surrounds the intrusive stock.

Chlorite zone - Chlorite is the most widely distributed alteration mineral and occurs in all stages of alteration. However, as shown on the map, a predominantly chloritic zone (1,000-2,000 feet wide) surrounds and overlaps the biotitized and sericitized zones on the southwest of the orebody. A similar zone occurs around the biotitized zone on the San Juan. The boundaries of the chloritic zone are arbitrarily drawn when mafics are more predominantly replaced by chlorite than by secondary biotite.

Propylitic zone - This is the most widespread zone and represents the area of lowest alteration intensity. Epidote, and to a lesser extent chlorite, are the common secondary minerals. The relationship of this zone to mineralization and other alteration

processes is not clear but it appears to have been very early and possibly deuteric in origin.

(b) Chemical Aspects - It is apparent that the rocks underwent considerable chemical changes during hydrothermal alteration and mineralization. Almost all of the sulfur present was introduced at this time. Chemical analyses of fresh and altered porphyritic andesite and dike rocks show that the potash content was almost doubled while small quantities of silica were added. Losses include calcium, small amounts of sodium, magnesium and aluminum. While there appears to have been a small loss of iron, a gain in ferrous iron almost balances a loss in ferric iron. Similar changes are described by Creasey in a paper in which nine porphyries are discussed (7).

(2) Supergene Alteration

As already mentioned, alteration of the outcrop and sub-Tertiary volcanic outcrop has produced a typically conspicuous colored cap rock over the orebody as well as over the mineralized veins and shear zones. The color of the rock is related in intensity directly to the amount of former sulfide content and to the degree of oxidation and weathering to which it has been subjected.

The dikes and plugs which have undergone sericitic hydrothermal alteration, are inherently bleached. Weathering of the sulfides has also produced oxidized compounds which have stained these light-colored rocks various hues of yellow-brown-red-maroon and black. The biotitized and chloritized porphyritic andesites tend to be relatively darker in color, although oxidation of the iron compounds

together with leaching, has actually produced a lighter colored rock in the zone of weathering. This grades into dark grey, black or green rock in the primary zone below. While some of the micaceous minerals in the weathered biotite zone may actually be sericite, it is thought that most of this material is biotite from which the iron has been leached by weathering.

The minerals which create the conspicuous color in the leached rock over the orebody are predominantly the ferric iron compounds goethite and hematite. Jarosite and alunite are more abundant over the pyritic halo.

Kaolin, alunite and montmorillonite are developed to the greatest extent along larger shears, faults and selvages on contacts where movement has occurred. Apparently the sheared, fractured and crushed rock was extensively converted to kaolin along the channels followed by acid-charged groundwater. Beyond these channels kaolin is developed to only a minor degree.

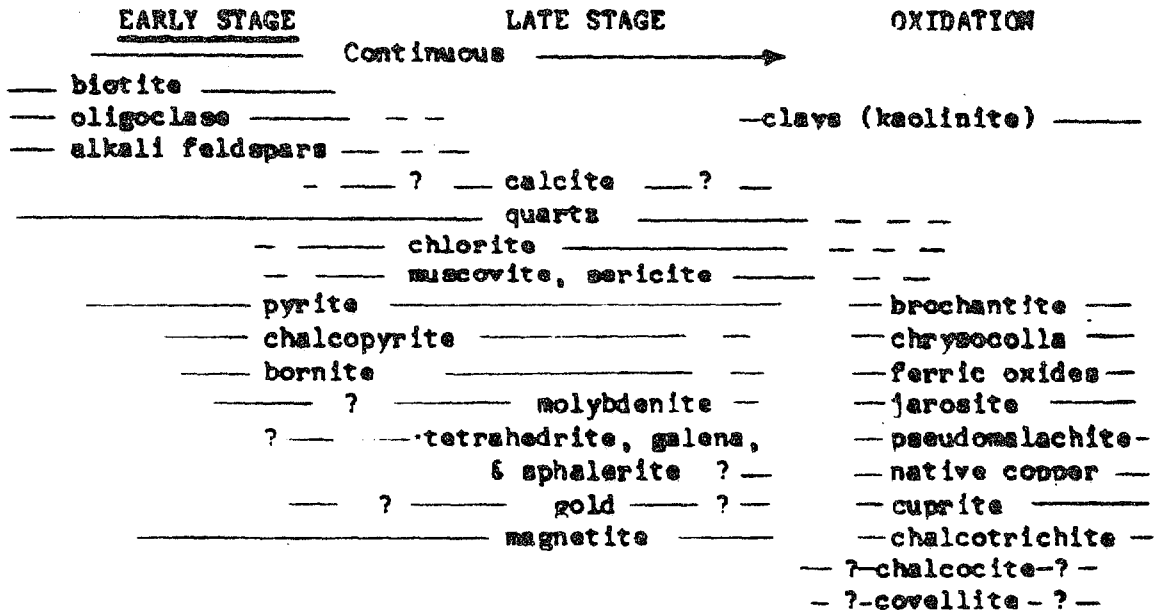
Supergene alteration over the buried orebody has taken place to an average depth of about 440 feet, although numerous oxidized channels have been encountered at depths of 2,000 feet below the surface. These do not exhibit bleached or leached haloes similar to those accompanying the hydrothermal channels. In the exposed pyritized area supergene effects are much shallower -- averaging only about 280 feet in depth.

or, oxidation & leaching

D. Mineral Processes & Paragenesis (4)

The andesite and the intrusive complex were altered in three

stages: (1) an early additive stage of intense hydrothermal alteration (2) a later lower temperature stage of hydrothermal alteration (3) a stage of oxidation and leaching. The first two stages were continuous and have been divided arbitrarily at that point when biotite was altered grossly to chlorite and sericite. These stages of alteration were accompanied by mineralizing solutions which deposited metallic sulfides in a sequence which varied with the changes in composition of the hydrothermal solutions. In contrast with some deposits, the ore exhibits abundant evidence of the close association of sulfide mineralization with hydrothermal alteration. The relative stages of these alterations, showing the mineral stability ranges in time, is shown below:



The primary minerals, pyrite, magnetite (?), chalcopyrite and bornite were deposited in that order, but some overlap in deposition is indicated by polished section study. Pyrite was both the earliest and latest primary sulfide to be emplaced. The relation of gold, sphalerite, galena and tetrahedrite to the magnetite and earlier formed sulfides has not been directly observed but probably, as elsewhere, they were deposited later. The whole range of sulfide deposition was accompanied by quartz and calcite gangue -- with the latter starting a little later than the quartz and terminating at an earlier time.

The earliest mode of sulfide emplacement was as disseminations and in thin, irregular quartz veinlets. It appears that the highest percentage of disseminated chalcopyrite, bornite -- and possibly pyrite -- was deposited at this time, particularly in the biotitized andesite. A close spatial association with clots and blebs of

secondary biotite and the disseminated sulfide is evident. This feature has also been reported at the Bagdad copper deposit by C. A. Anderson and others (1 and 2).

In a later period closely associated with quartz-sericite alteration, sulfide emplacement was primarily in larger veinlets and fracture fillings with quartz and carbonate gangue. At this time pyrite was deposited in greater amounts than the copper sulfides. In this later stage molybdenite -- with or without magnetite -- also occurs in quartz-carbonate veinlets and replaces chalcopyrite.

The relationship of the hydrothermal alteration zones and primary mineral zoning can be noted by comparing Figures 5 and 6. The central copper zone containing the +0.4% copper orebody occurs astride the contact between the zones of pervasive sericitization and biotitization. Most of it lies in the porphyritic andesites that have been extensively intruded by sericitized dikes and plugs of acid to intermediate composition. In this central zone chalcopyrite and pyrite are concentrated in the ratio of about 2:1 and the total sulfide content ranges from 1.5 to 3.0 percent by volume. At depth -- in the protore -- the chalcopyrite/pyrite ratio drops to 1:1 -- the total sulfide content averaging about 1.5% and the grade of copper dropping off to 0.2% and less. The bulk of the molybdenite also occurs within the central copper zone. ≥0.7%

Outward from this central zone, the pyritic haloes (with very low copper values) embrace the major part of the sericitic and chloritic zones. Within these zones the total sulfide content by

volume ranges between 4 and 8 percent and the pyrite/chalcopyrite ratio varies between 10 and 21:1. Within the sericitic, chloritic and surrounding propylitic zones small amounts of gold, galena and tetrahedrite (or their oxidized equivalents) are found to occur.

The secondary sulfides chalcocite and covellite were probably emplaced before the first uplift of the Gila Range along the Butte Fault. In thin and polished section chalcocite is seen to replace covellite. Chalcocite also preferentially replaces chalcopyrite and bornite and to a lesser extent, pyrite. In the pyritic halo on the west slope -- more recently exposed by uplift, tilting and erosion -- oxidation has been renewed and thin, incipient chalcocite coatings are forming on pyrite beneath the shallow leached zone.

The paragenetic relationships of the oxide minerals are complex and at the present not clearly understood. The reason for this is because the former chalcocite blanket -- as well as the primary sulfide zone -- was affected by one or more subsequent uplifts. Oxidation of both these zones may then have taken place simultaneously. Chrysocolla and cuprite are commonly noted to replace chalcocite, but the primary sulfide minerals are not observed to be directly replaced by the oxide zone minerals. Brochantite, chrysocolla, iron oxides, jarosite, pseudomalachite, chalcotrichite and native copper may have formed essentially contemporaneously.

E. Ore Controls

(1) Primary (Figs. 3 and 4)

The northeast shearing of the Cretaceous (?) Older Volcanics --

most intense in the Lone Star and San Juan Shear Zones -- provided deep channels for the emplacement of the Lone Star and San Juan Stocks. Following this the volcanic vent -- with accompanying dike swarm -- intruded the Older Volcanics mainly in the Lone Star Shear Zone. Renewed stresses reactivated these shear zones and the same fracture system was superimposed upon the volcanic vent debris and dike swarm.

In contrast to the majority of the porphyry copper deposits, the principle intrusive mass at Safford -- the Lone Star Pluton -- is not closely related to the hydrothermal or mineralizing processes. Apparently this intrusion resisted stresses associated with alteration and mineralization and remained impervious to the accompanying fluids at the critical period, while the shear zones on both flanks were being rendered highly permeable.

Hydrothermal fluids followed the shear zones and contacts of the San Juan Stock and the later intrusions in the Lone Star Shear Zone, altered the host rocks and deposited iron, copper and molybdenum sulfides in variable quantities. At the San Juan Mine, the most favorable area was the shattered contact zone of the stock and the adjoining andesite. On the Kennecott property the most favorable zone was where the volcanic plug, vent and associated dike swarm zone penetrated the strongly sheared andesites.

(2) Secondary

As already mentioned, several stages of uplift probably took place along the Butte Fault, with consequential periodic lowering

of the water table and resulting oxidation of the original chalcocite blanket in place. Where the relict pyrite content was low, secondary sulfides were oxidised to chrysocolla, brochantite, etc. in place. Where sufficient pyrite and primary sulfides remained in the blanket, an additional secondary zone probably formed at a lower elevation. The scattered chalcocite zones, interfingering with oxide and primary zones, are thus probably due to sporadic uplifts and tilting of the Gila Mountains. It is interesting to note that no water table has ever been encountered in any of the drilling.

F. Geologic History

The Pre-Cambrian rocks of Arizona have developed a regional northeasterly grain. After the Cretaceous (?) andesites and agglomerates were extruded in the Safford area, the northeast shearing and faulting that took place in Early Tertiary times -- along the Lone Star and San Juan Shear Zones -- was probably a continuation of movement along this old direction of weakness. In the Eocene period both the Lone Star and the San Juan Stocks were intruded in the strongly sheared volcanic rocks in both these zones. As the northeast shearing continued, plugs and dikes were intruded along the same direction and the formation of a volcanic vent took place. Reoccurring adjustment also resulted in the shearing of the intrusive bodies and volcanic vent. Later, some of the dikes and plugs and adjoining porphyritic andesites were altered and mineralized by ore-forming solutions. The Lone Star Stock itself was not, however, appreciably sheared, fractured, altered or mineralized by these crustal adjust-

ments.

Oxidation, leaching and enrichment then took place -- to be followed again by one or more periods of uplift and oxidation of the enriched zones. The major part of the uplift is considered to have taken place along the northwesterly trending Basin-Range type Butte Fault. During one of these periods of adjustment the Intermediate Volcanic Series were extruded. The progressive overlap and pinching out of this unit against the present east flank of the mountains suggests that at this time the top of the Gila Range lay west of the present crest.

A slight disconformity between the Intermediate Volcanic Series and the overlying Younger Series, suggests a slight period of erosion between the extrusion of these two units. The large area of the Younger Series along the west flank of the range also indicates that the old crest of the range was covered during the last period of extrusion.

Following these two periods of volcanic activity the major movement along the Butte Fault took place, resulting in a possible downthrow of 2,000' on the southwest, or hangingwall side.

Further erosion then took place and the highest existing pediment of the valley was formed. Minor northeast faulting -- that displaces the Younger Volcanic Series -- continued, and was followed by more periods of uplift and erosion that formed the present day topography.

V. COMPARISON WITH SIMILAR DEPOSITS

Exploration and development of the Safford copper deposit has shown the existence of a very large low to medium grade porphyry-type copper deposit occurring in porphyritic andesites intruded by acid to intermediate volcanic dikes and plugs. It is of particular interest geologically because, although volcanic rocks adjacent to some porphyry deposits have been mineralized (e.g. at Cananea, Sonora, Mexico and Ajo, Arizona), it is the only known porphyry-type copper deposit in North America that occurs entirely in volcanic rocks. In South America, however, the orebodies at Braden and El Salvador in Chile are associated with andesitic volcanics and both these properties have marked similarities with Safford.

also Silver Bell, Esperanza, etc.

At Braden the principal host rock of the orebody consists of an Early Tertiary extrusive andesite or andesite flow-breccia, in places intruded by quartz-diorite (9). Both these rock types adjoin the Braden breccia pipe which forms the most spectacular structural feature of the area. The andesite is flooded with secondary biotite while the quartz-diorite is largely altered to a fine-grained aggregate of sericite and secondary quartz. At El Salvador copper mineralization is more concentrated in the peripheral areas of acid intrusive porphyries and in Cretaceous (?) andesites marginal to the contacts (15). As at Safford and Braden, alteration of the original mafics to biotite is widespread in the andesites in the vicinity of the orebody. Sericite is also formed in the intrusives adjacent to younger sulfide-quartz veinlets which grade out through narrow bands of argillic alteration into fresh rock.

Quartz-sericite is a common alteration product of almost all the mineralized intrusives that occur in porphyry copper deposits, so its occurrence at Safford is not in any way unusual. Secondary biotite is also known to occur at Bingham (14) and Bagdad (1 and 2), but never in the volume developed when one of the host rocks is an andesite -- as at Safford, Braden or El Salvador.

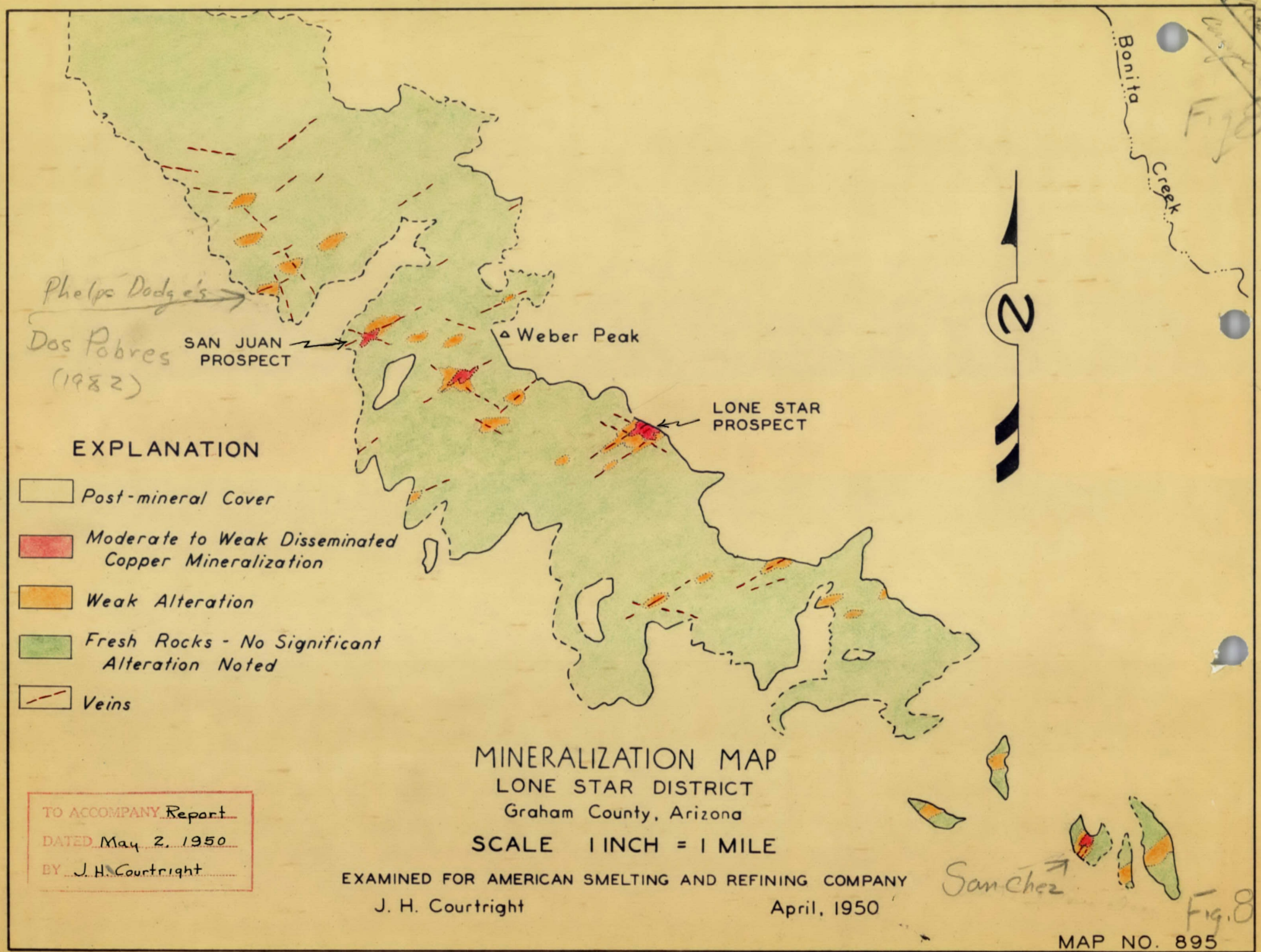
VI. ACKNOWLEDGMENTS

In addition to the work done on the property during the exploration and development stages by the two authors, much of the data contained in this paper are based on geological mapping done by Bear Creek geologists: A. T. Stone, Keith Martin, W. Mahrholz, D. Maltzahn, W. Kurtz, L. Bryner, D. Lobiondo, C. Hall, R. McColly, J. Brown, D. Hackins and A. W. Rose and for engineering data assembled by Sam Smyth. Detailed petrological and alteration studies were originally made by A. Banerjee and later, by A. W. Rose. Geochemical work on the property was done mainly by H. Jacobson.

In the exploratory stage Dr. Colin Hutton of Stanford University, Dr. R. L. DuBois, University of Arizona, and Dr. R. Lyon and Dr. James Stephens, both of the Kennecott Research Center, assisted greatly in mineral and rock identification. More recently Dr. Robert Compton, Stanford University, has rendered very valuable assistance with similar problems, including alteration studies.

Thanks for map preparation are due to Messrs. W. Reedy, A. Cuellar of the Safford Project and to Travis Mayhall and John Kelly of the Southwest District, Bear Creek Mining Company.

Thanks are also due to the Management of Kennecott Copper Corporation for permission to publish this paper.



ATTACHMENT C