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EVIDENCE INDICATING THE HYDROTHERMAL ORIGIN OF A "CONTACT METASOMATIC" MINERAL SUITE, MISSION COPPER DEPOSIT, ARIZONA

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INTRODUCTION

The Mission mine, located in southern Arizona near Tucson, is a recently developed open pit which produces 15,000 tons per day of copper ore. The mine lies on a wide and gently sloping bajada sweeping northeasterly from the Sierrita mountains. It derives its name from the nearby Mission San Xavier del Bac, built circa 1700.

The ore body is everywhere covered by about 200 feet of alluvium, as are the adjacent Pima and Palo Verde mines. The geology of the Mission deposit is known principally through the study of diamond drill holes spaced 150 to 300 feet apart. The open pit is in an infant stage and has not yet revealed much of the deposit, although information obtained there by the operating staff, and from a few thousand feet of exploratory underground workings, has added significantly to the general fund of knowledge.

Permission to publish was granted by the American Smelting and Refining Company. I am indebted to Kenyon Richard and J. H. Courtright for criticism of this paper and for their direction during the several years in which I studied the Mission deposit. Acknowledgment is given to consultant in petrography, Robert L. DuBois of the University of Arizona.

The only previous publication pertaining directly to the geology of the Mission deposit appeared in 1959 (Richard and Courtright), and may not be everywhere readily available. Cooper (1960) has published a short paper on the district.

SUMMARY

In the close vicinity of the Mission ore deposit, the principal rocks are sediments and small bodies of intrusive igneous porphyries, all of which are pre-ore in age. The bedrock surface is a buried pediment, and only a few small outcrops protrude from the alluvial plain. These small and isolated knobs, which are the tops of bedrock hills, lie within a large area of pervasive alteration and constituted one of the principal exploration leads. The very simplified geologic sketch in Figure 1 shows these features.

Alteration --- the formation of new minerals or textures and the destruction of the original rock character --- is pervasive within the Mission ore deposit, and extends a considerable distance beyond the principal area of copper concentration. The limits of the Mission altered zone, although

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gradational and by no means sharply defined, are shown approximately in Figure 1. The altered zone is roughly 3 x 2 miles in areal dimension, whereas ore or possible ore appears to be limited to an area not much larger than 1½ by 1 mile.

Copper and iron sulphides are disseminated throughout all rocks within the altered zone, and conversely, there are no epigenetic sulphides disseminated outside of the altered zone This relationship is so singularly conspicuous and without exception, that one is of necessity obliged to regard rock alteration and sulphide impregnation as a process which was integrated in time as well as space. The Mission ore body represents only that portion in which the copper concentration is sufficiently great and which occurs in such position that it may be mined by an open pit operation. The average ore grade is typical of southwestern disseminated copper deposits.

Alteration of the feldspathic sediments and igneous rocks produced sericite, clay and intergrowths of metasomatic quartz-orthoclase, whereas the alteration of limestones has formed an assemblage of lime silicates, such as garnet and diopside. Both types of alterations occur in a mutual environment, and all are veined and impregnated with sulphide minerals. The environment as a whole is so typical of porphyry copper deposits throughout the Cordilleran region that the occurrence of the commercial ore bodies within silicated sediments instead of within the porphyry itself should offer no detraction from the classification of the Mission ore deposit as a "porphyry copper."

GENERAL GEOLOGY

In brief summary, the geologic history has been as follows. Paleozoic sediments totaling an estimated 5000 feet were deposited on pre-Cambrian granite. These formations are dominantly limestones or marls, with the exception of Cambrian and Permian quartzite layers. A thick sequence (5000' plus) of clastic sediments -- arkose and siltstones -- of Cretaceous (?) age disconformably overlies the Paleozoic rocks. Following or during Laramide folding, thick sequences of unsorted and very poorly bedded silts and volcanic-pebble conglomerates were deposited on an eroded surface of Paleozoic and Cretaceous (?) strata. A second period of major erosion separated these rocks from an overlying formation composed of andesitic breccia and welded rhyolites. Volcanism was followed by the intrusion of a large plug of biotite-bearing rhyolite packed with foreign inclusions. Large granitoid plutons of "Laramide" age form the core of the nearby Sierrita mountains, and are separable into pre- and post- volcanic units. The youngest pre-ore intrusive is a quartz monzonite porphyry which is emplaced, generally, as sills along bedding and structurally weak zones.

Folding and thrust faulting are the dominant pre-ore structures. Major post-ore structural dislocations are also evident.

ROCKS OF THE ALTERED ZONE

Not all of the sedimentary formations known to occur in the Mission vicinity are found within the altered zone. Those which are recognized (and

this is with some uncertainty due to alteration effects) are as follows:

Paleozoic: Silicated limestones, marble, and altered marl, silt, and quartzite are the dominant host rocks for copper sulphide ore. These rocks most probably represent the Pennsylvanian and Permian section.

Cretaceous(?): Interbedded arkose and siltstone crop out in two isolated hills south of the Mission pit, and most likely are of Cretaceous age.

Tertiary: Two units which consist of unsorted silt and volcanic-pebble conglomerate are present within the Mission ore body. These rocks are dense and flint-like in character, and are referred to as argillite or conglomerate for purposes of mine mapping. The oldest, the Papago formation, consists dominantly of argillite, while the younger Kino formation, which consists dominantly of conglomerate, lies beneath a pre-ore thrust fault. Both are assigned tentatively to the early Tertiary on the basis of district and regional geologic mapping.

The youngest pre-ore igneous rock within the altered zone is a quartz monzonite porphyry of Stringham's (1960, p. 1623) "aphanitic porphyry" class -- a type almost universally present in prophyry copper districts. This rock may originally have more closely approximated a dacite porphyry, for its present mineral composition includes much introduced orthoclase.

The porphyry is seen to form sill-like bodies which have intruded the unconformable contact between the Paleozoic rocks and the overlying Papago formation, and also have intruded in a horizontal fashion above and below this contact. The sills are thickest near the west margin of the porphyry mass, and widely-spaced drill hole information suggests that they may merge into a thick dike or plug, which may be inferred to be the principal source, or magma vent.

A large mass of intrusive biotite rhyolite forms the host for the southern part of the altered zone. Regional mapping suggests this rock to be most closely allied to early Tertiary volcanism.

Narrow dikes of post-ore andesite are present.

A breccia dike crosses the pit in a northerly direction. The dike consists of various rock fragments set in a matrix of finely-ground rock particles, the whole of which has been altered. It differs from the surrounding rock in that it contains less chalcopyrite and locally contains much galena, sphalerite, and argentiferous tetrahedrite.

ALTERATION

Pervasive alteration may be here grouped broadly in two categories. The first, causing the most obvious changes in the rock bulk, involves the formation

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of new silicate minerals -- either lime or potassium types depending on the host. The second is the formation of copper and iron sulphides. An exception is the large area of marble in the Mission pit area, in which the only evidence of alteration is the coarse-grain size of the calcite crystals, representing recrystallization with traces of sulphide impregnation. The general distribution of alteration in the pit vicinity is diagrammatically shown in Figure 2, which also shows the principal structural features.

Feldspathic Rocks:

Alteration products in the feldspathic rocks are sericite, orthoclase, quartz, biotite, and clay. The rocks so altered are monzonite porphyry, argillite, and quartzite.

The monzonite porphyry consists of euhedral to subhedral phenocrysts of plagioclase and resorbed quartz phenocrysts, set in a recrystallized matrix of fine-grained quartz-feldspar. Ragged wisps of biotite are usually present. The rock is flooded by irregular blebs and replacement veinlets of pink orthoclase and quartz. The plagioclase phenocrysts are replaced by sericite in variable degrees, and to a lesser extent by clay minerals. The metasomatic intergrowths of quartz and orthoclase replace both the matrix and plagioclase phenocrysts. Pyrite, chalcopyrite, and rarely molybdenite occur as discrete grains scattered through the rock, and also in veinlets associated with borders of quartz and/or orthoclase. The tenor of copper is typical of chalcopyrite protore in many porphyry copper mines. There is only a few feet of chalcocite enrichment beneath a thin-leached zone.

Argillite, both that of the Papago formation and the thin beds within the Paleozoic rocks, is almost totally altered to a very fine-grained aggregate of sericite and/or a recrystallized mosaic of quartz-feldspar. Sulphide veinlets bordered by a narrow zone of quartz and feldspar give way at the outer edges, first to sericite and then to fine-grained biotite. Pyrite and chalcopyrite occur both as disseminated grains and in veinlets. The conglomerate of the Kino formation, which consists of pebbles in a matrix of argillite, has been similarly altered, although chalcopyrite is virtually absent, and pyrite is the principal sulphide.

Quartzites in the Paleozoic section were generally quite pure quartz sands. Their alteration is evidenced by nearly complete recrystallization of the quartz grains, together with the formation of sericite from a minor silt fraction. Sulphides are sparsely disseminated, and also occur as widely-spaced veinlets. In certain areas, however, chalcopyrite in disseminated form grades up to 0.6% Cu.

The arkose of Cretaceous(?) age has been altered so that the clastic quartz grains are set in a soft white matrix of sericite and clay, and the fabric is transected by sulphide veinlets bordered by glistening white halos of quartz and sericite. Pyrite and chalcopyrite are both disseminated and concentrated in the little veins.

The biotite rhyolite in the southern part of the altered zone is altered to clay, sericite, and minor carbonate. The biotite is destroyed to form sericite. Feldspar phenocrysts are less altered than the matrix, which was originally glassy, and also less altered than most of the foreign inclusions. Pyrite is disseminated throughout, principally as discrete grains, and chalcopyrite occurs in minor amounts. Assays show that small amounts of lead, zinc,

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and silver are there widespread.

Limy Rocks:

The Paleozoic sediments, which are principally cherty limestone, pure limestone, and marl, have been converted within the Mission altered zone to various lime silicate minerals. Two general groups are dominent: These are (1) tactite, which consists chiefly of garnet, and (2) hornfels, which consists of diopside and calcite. In the western portion of the ore body a silicate zone separating two quartzites is almost entirely of the diopside hornfels type, suggesting the rock was originally a dolomite. Elsewhere both sharp contacts and broad gradational zones between the two types suggest a more complex history, possibly involving migration of Mg. A third variety, which I consider to represent weak alteration, is represented by white coarse-grained marble with merely traces of disseminated sulphide grains. This type possibly has formed from black thick-bedded Permian limestone, as suggested by residuals of black limestone of that type. The contact between marble and tactite/hornfels is commonly sharp; but in places is marked by the presence of wollastonite.

The tactite type consists megascopically of massive structureless yellow-brown garnet, of yellow or brown euhedral friable masses, or of red-brown garnet. Spectrographic analysis and refractive index place all the types of garnet so far tested in the andradite group. A few garnets showed small amounts of alumina in the spectrograph. Soft white material commonly admixed with the garnet was in early stages of exploration mistaken for a clay alteration of what was, at that time, thought to be grossularite. The alumina content of the tactite appears too low to allow the presence of much clay as an alteration product, and the soft white mineral has been identified, in numerous samples in thin-section, as fine-grained diopside. Sulphides occur as small disseminated grains, in thin irregular veinlets, in narrow replacement fissures, and as large pods of massive sulphides which locally assay 5 to 15% Cu.

The hornfels type is commonly composed of a hard or soft, white fine-grained aggregate, which in thin-section proves to be equi-granular diopside with variable amounts of calcite (up to 20%). A variation is a hard greenish variety which in thin-section is seen to be composed of stubby prismatic crystals of diopside. The refractive index of the white granular variety is slightly higher than that of pure diopside, and the prismatic crystals range about midway between the indices of hedenbergite and diopside. Thus iron metasomatism is obviously a major factor in the formation of both the hornfels and the andradite-tactite described previously.

In the western portion of the ore body a characteristic feature of the hornfels is the presence of small veinlets of blue-green actinolite, 1/16 to 1 inch in width, most commonly, but not everywhere, having a medially disposed stringer of pyrite and chalcopyrite. The actinolite is commonly altered slightly to chlorite. Sulphides are distributed in the hornfels in the same manner as in tactite.

As a group, the limy rocks - tactite and hornfels - constitute the main source of copper and have a higher average grade than ore in argillite, which is the second principal copper host rock.

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Sulphide Impregnation:

A discussion of hypogene sulphide mineralization is included here under the general heading of alteration, because it is from an economic viewpoint the most important change, or alteration, of the host rocks.

Figure 3 shows the distribution of copper grading plus 0.4%, as a diagrammatic illustration of copper-grade variation. When viewing the figure, bear in mind that the white areas (with the exception of marble units) may contain about as much total sulphide as do the shaded (plus 0.4% Cu) areas and only slightly less copper. The reduction in copper content, in some cases, represents a slight decrease in the total sulphide content, but more generally it reflects an increase in the pyrite:chalcopyrite ratio, or a combination of both.

Total sulphide content obtained by calculations based on chemical analysis of composite samples of drill core is shown in Figure 4. It will be noted that: (1) the total sulphide content is higher in the east part of the pit area. (2) In any one sample location, the total sulphide content is about the same in the argillite of the Papago formation, as in the tactite and hornfels zones below. The volumetric percentage is given (Figure 4) because the difference in specific gravity between tactite and argillite introduces an error when comparing weight percentage to the degree of sulphide replacement. (3) There is no pattern of total sulphide content with respect to the area of porphyry sills.

There is a paucity of published analytical information on the total sulphide content of porphyry copper ore bodies as a group. Spencer (1917, p. 110) reports the sulphide content of three samples from the Ely district, based on chemical analysis, which appears to represent sulphides by weight. Some assumptions and calculations of mine yield the rough figures of 2.8, 4.0, and 4.9 per cent sulphides by volume for the three samples, which is comparable to the sulphide content at Mission (Figure 4).

ORE CONTROLS

All rocks within the Mission altered zone are recrystallized and/or metasomatized to various silicate minerals, and all are impregnated with sulphides. The ultimate source, or feeders, is not yet known. Within this altered mass, the Mission ore zone displays a few local ore concentrating structures, but for the bulk of copper and iron sulphides the method of implacement clearly did not depend on open channels of circulating hydrothermal solutions.

Referring again to Figures 2 and 3, the unconformable contact between the Papago formation and the underlying silicated sediments of the Paleozoic section has served as a localizing feature. Sulphides follow this contact in greater quantity and more uniformly grade in excess of 0.4% Cu than is the case at distances above or below the contact. Even the quartzite beds are well mineralized where they abut this surface. Similarly, the bottom sides of quartzite beds act as local controls. A high-angle fault is seen to cause even the unfavorable marble unit to become converted to tactite and hornfels and charged with sulphides.

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In the eastern portion of the ore body certain low-angle faults of thrust aspect contain thick (10-40 feet) bands of 1 to 6% Cu above them. The vertical fault on the far east terminates the ore body (but not sulphide dissemination), and along this fault are concentrations of massive sulphides. Certain pods up to several feet in diameter seem to be related to mineralized fissures. And throughout the ore zones thin fissures of northeast strike contain sulphides, but there is no concentration of disseminated sulphides adjacent to these fissures.

That all of these structural features are local sulphide concentrators is undisputed; however, the great bulk of copper and iron sulphides lie at great distances from these structures. From this, I draw the conclusion that the metasomatism which introduced great quantities of iron to form iron-lime silicates and iron sulphides, along with sulphur, possibly magnesium, copper and other minor metals, involved ionic diffusion as a principal process. Conduits of open circulation are widely spaced and are regarded as features which were important only in their local environment, and not necessarily as principal ore feeders.

The porphyry, rather than being the direct source of mineralizing solutions, is itself most obviously a host rock, for it was altered and impregnated with sulphides after solidification. The porphyry may have a genetic relationship to mineralization to the extent that it may have been intruded from a deeper source of magma, which later furnished the elements which were introduced into the altered zone.

CONCLUSION

The Mission altered zone is a zone of porphyry copper-type pervasive alteration and sulphide dissemination. The proposals presented in preceeding sections of this paper are that sulphide mineralization and alteration were all, broadly speaking, a contemporaneous process. The mineralized monzonite porphyry does not show a spatial relationship to the altered zone as a whole or to the copper ore deposits.

Pervasive alteration of the porphyry especially, and also of the altered clastic sediments (arkose and argillite) and of the rhyolite at the southern end of the altered zone, is of a type which few geologists would classify as other than hydrothermal. To go further, the minerals sericite, clay; carbonate, and pyrite-chalcopyrite, are commonly placed in Lindgren's mesothermal category. But at Mission the host for most of the copper mineralization is a complex of andradite garnet and diopside-hedenbergite, along with minor amounts of actinolite and wollastonite. These minerals, which are traditionally placed in a separate category such as "contact metamorphic", "contact metasomatic", or "pyrometasomatic", are generally thought of as forming at high temperatures and under special conditions, and of being related spatially to an igneous intrusive contact, from whence the mineralizing fluids came. A commonly stated assumption is that, since the sulphides in such deposits are seen to replace the silicates, the sulphides may be of some later phase, being formed at lower temperatures compatible with the Lindgren classification. The silicates, it then is held, formed early and at high temperatures.

At Mission, as stated under <u>summary</u> in this paper, the intimate spatial

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relationship of silicated limestones with sericitized feldspathic rocks, and their associations with sulphide mineralization, admits of no other conclusion than that all rock alteration including sulphide impregnation was more or less contemporaneous. The temperatures existing in all rocks must have been similar. At Mission the sulphides, as might be expected, replace silicates -- both potassic and lime varieties. There is no evidence, such as pre-sulphide, post-silicate brecciation, to suggest that any appreciable time gap existed. As a comparison, the sulphides at Butte, although they clearly replace the altered rock, are the result of a continuous and contemporaneous process, as so excellently proven by Sales and Meyer (1948).

I suggest that the criteria of geologic temperature indicators involving lime silicate minerals requires reappraisal. The inescapable conclusion at Mission is that either lime silicates form at lower temperatures than commonly believed, or else the temperature range of sericite-pyrite-chalcopyrite must be considerable higher than generally admitted.

Similar conclusions were reached many years ago by Spencer (1917) in his study at Ely, Nevada, which is a porphyry copper deposit more similar to Mission than most others, in that extensive mineralization in sediments is there present.

In the Ely district an altered zone about 7 miles long and a mile wide contains numerous separate porphyry masses which have intruded a sedimentary series. The following quotes are representative of Spencer's conclusions:

> "The changes in the limestones comprise (1) loss of color and recrystallization to white fine-grained marble; (2) silicification with the formation of jasperoid usually carrying large amounts of pyrite; and (3) the development of silicate minerals, including garnet, tremolite, pyroxene, and scapolite."
>
> "The alterations of the porphyry . comprise, in different stages, the progressive destruction of hornblend, of plagioclase, and of magnetite, and the formation in their stead of .... sericite and a brown variety (of mica) allied to biotite; the deposition of pyrite and chalcopyrite, and of calcite."
>
> "The distribution of the altered sedimentary rocks is so definitely limited to a zone comprising the medially disposed intrusive masses that no extended argument is required to support the conclusion that the metamorphism is causally related to these igneous rocks. However, ..., the relation is not a direct one as regards the bodies of porphyry which appear at the present surface, for it is held that the alterations were effected by hot solutions expelled from deep-seated masses of igneous material, of which the observed intrusive bodies are off-shoots."
>
> "Though the different rocks have yielded to chemical reorganization and to metasomatic replacement, each in a manner depending primarily on its original composition, yet the resulting products are all heavily charged with pyrite, and in the main this mineral is accompanied by minor amounts of chalcopyrite."

Another comparison may be made with the Linchburg mine, New Mexico (Titley, 1961). Here a zone of lime-silicate minerals of classical "pyrometasomatic" or "contact" type, occurs along the Linchburg fault, well away from a known igneous mass.

He states, in part:

> "Neither of the alteration stages can be fixed in time. There is no direct evidence to indicate either continuity of deposition or a time break in the depositional process. Certain arguments, however, suggest that a time break, if one existed, was of such short duration as to be insignificant."
>
> "The alteration, therefore, is considered as a continuing process in which the ore-bearing fluids, although changing slightly in their chemical properties, were more influenced by the nature of their environment of deposition than by any gross change in composition."

Titley attributes zoning halos of alteration and sulphides in the Linchburg mine to continuing growth of each alteration halo away from feeder-veins, with the inner halos expanding and replacing the halo adjacent. Note the similarity to the Sales-Meyer proposals for the formation of sericite-clay "envelopes" at Butte. Titley's careful work indicates another lime-silicate assemblage in which, contrary to common assumptions of early silication followed by fracturing and sulphide replacement, the silication and sulphide formation are contemporaneous, and are all the result of a normal hydrothermal process.

To recapitulate my major conclusions:

1. The monzonite porphyry within the altered area has no specific spatial relationship to either ore or alteration.

2. Alteration and sulphide impregnation were more or less contemporaneous. Alteration, as used here, includes the silication of large masses of limy host rocks.

3. Diffusion was a process of major importance. Major channels for open circulation of hydrothermal fluids were widely spaced.

4. The Mission mine is a "porphyry copper" deposit.

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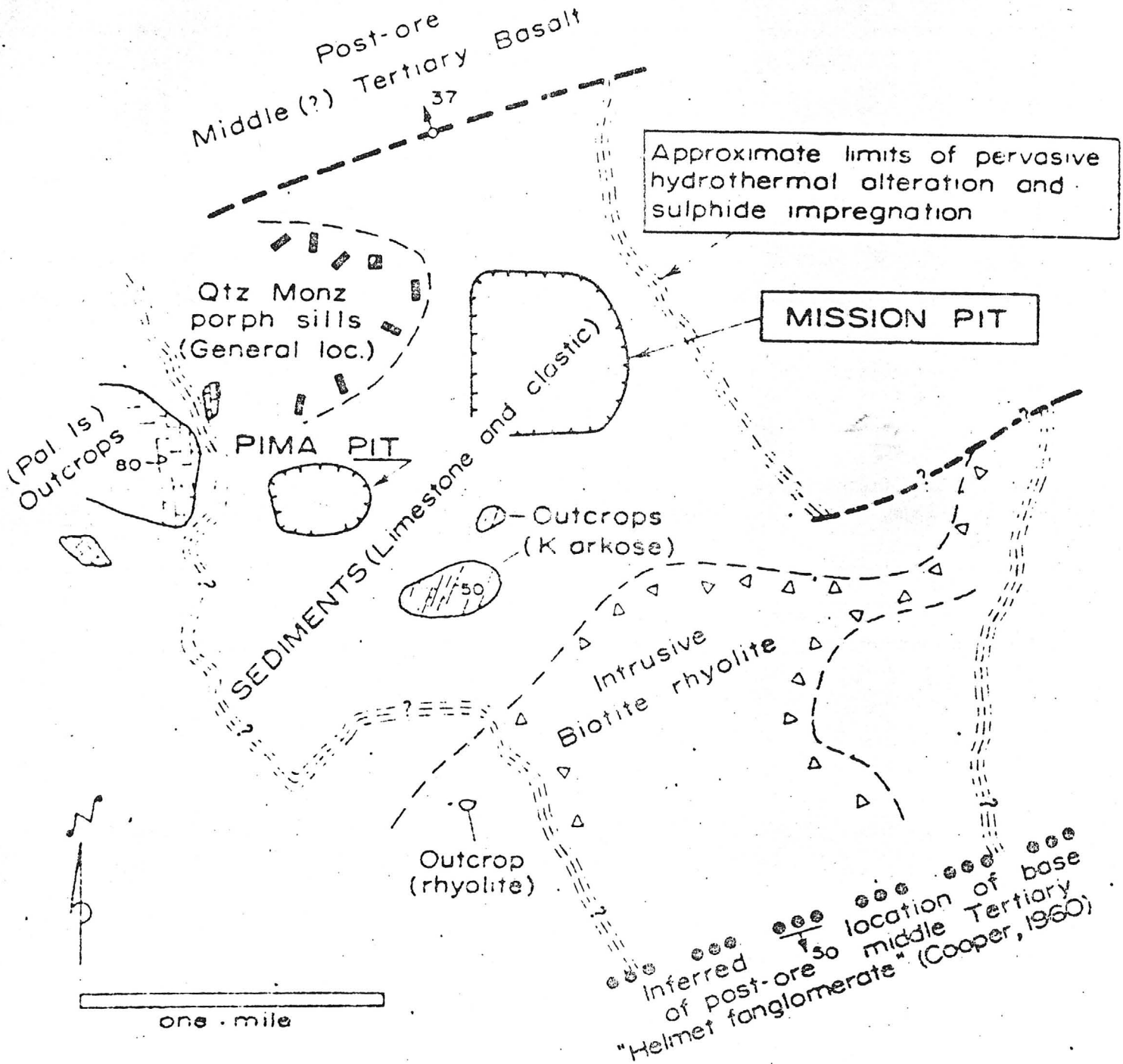

GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 1 J.E. Kinnison

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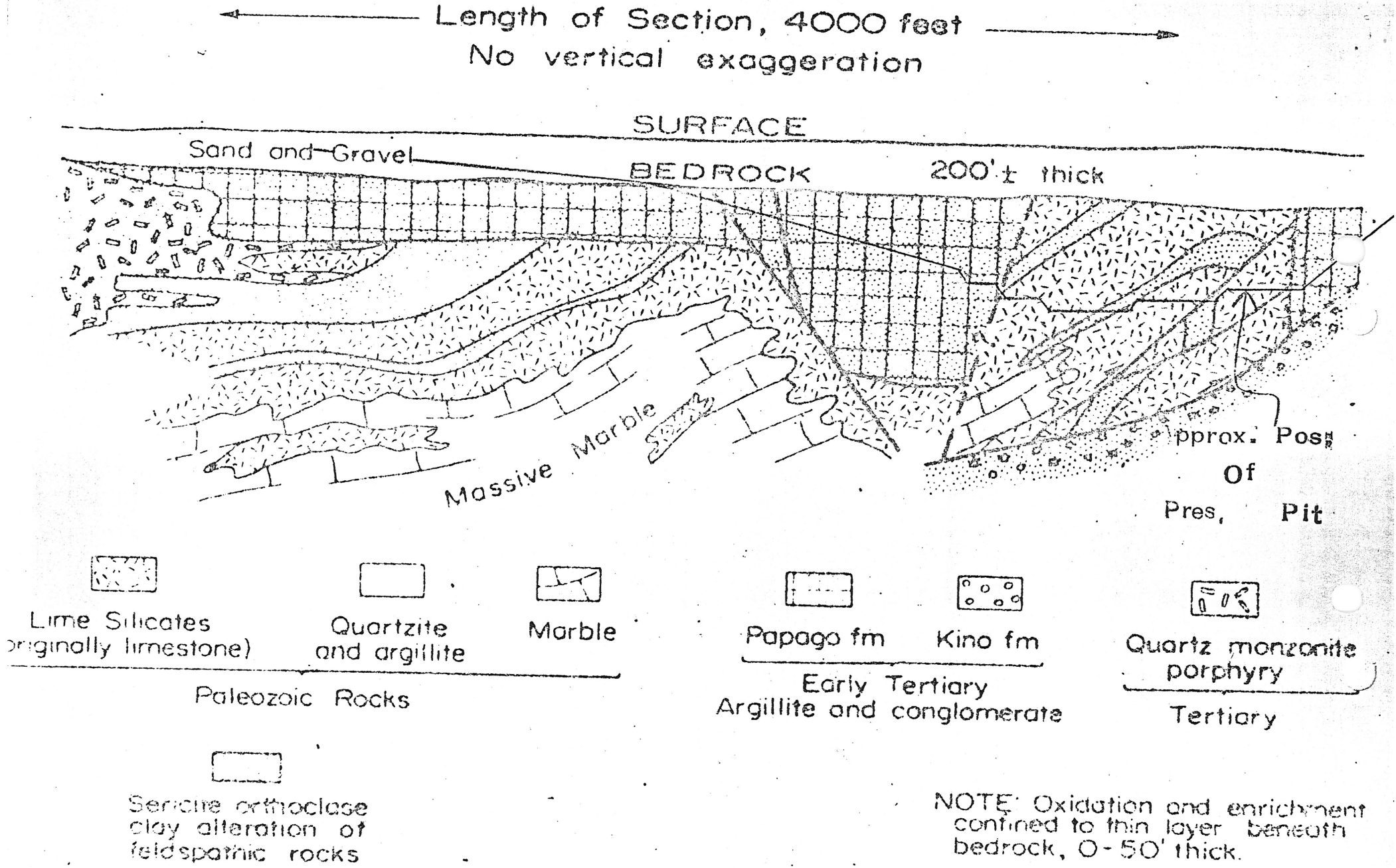

DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 2

J.F. Kinnison

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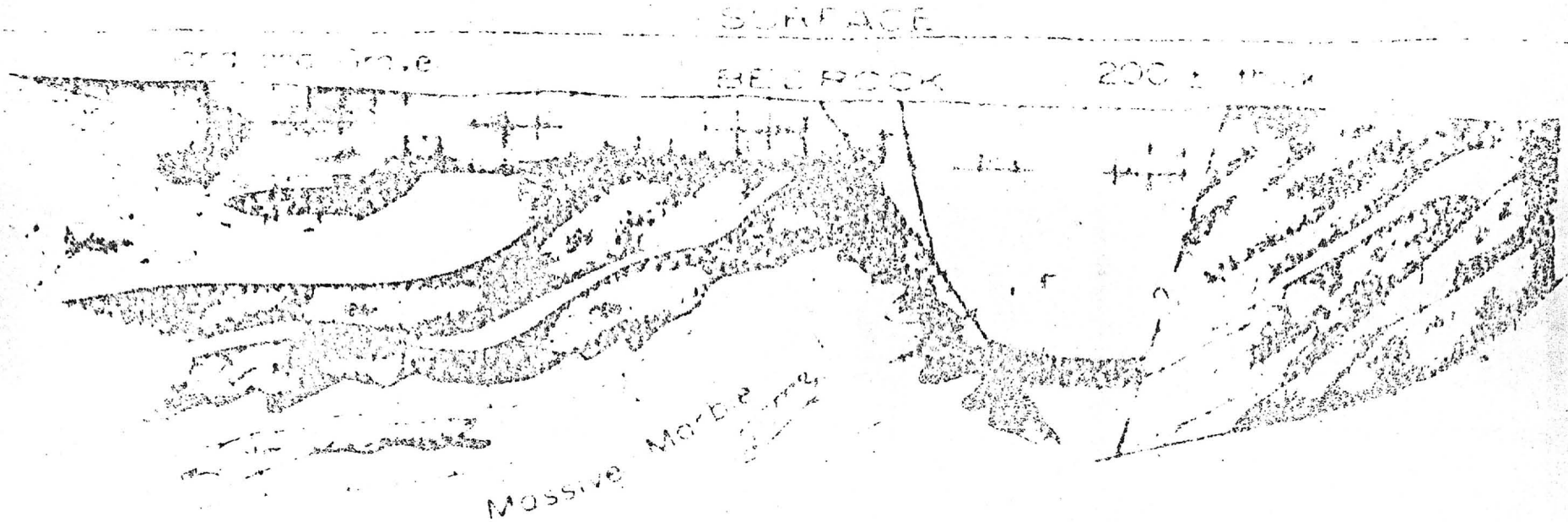
Length of Section, 4000 feet
No vertical exaggeration



Lime Silicates (originally limestone) | Quartzite and argillite | Marble

Paleozoic Rocks

Papago fm | Kino fm

Early Tertiary
Argillite and conglomerate

Quartz monzo porphyry

Tertiary

Plus 0.4% Cu

NOTE Oxidation and enrichment confined to thin cover beneath bedrock, 0-50 thick

DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 3

J.F. Kennison

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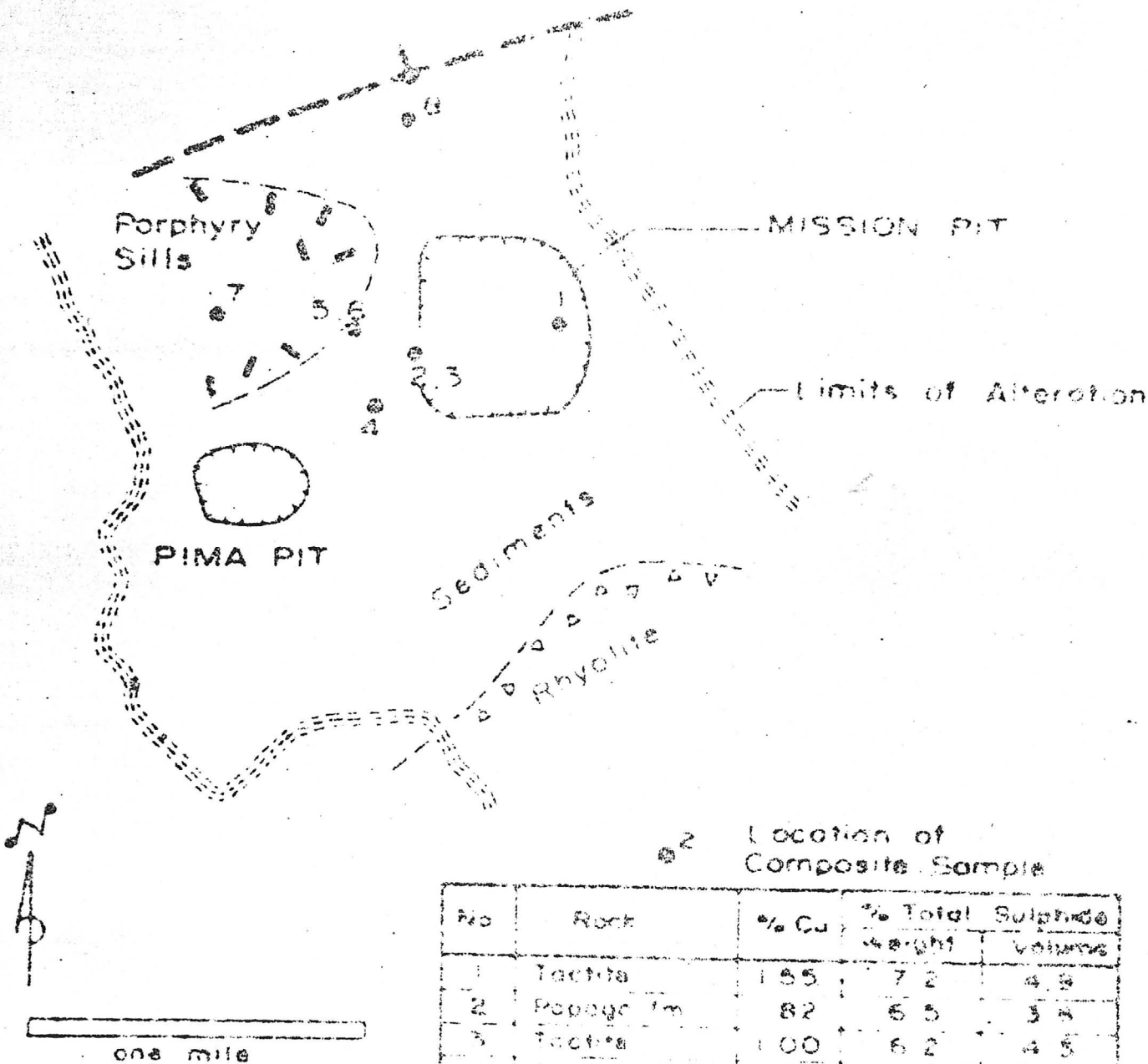

Location of Composite Sample

No	Rock	% Cu	% Total Sulphide Weight	% Total Sulphide Volume
1	Tactite	1.55	7.2	4.9
2	Papago fm	.82	6.5	3.8
3	Tactite	1.00	6.2	4.5
4	Papago fm	.63	4.7	2.8
5	Papago fm	.94	4.5	2.7
6	Tactite	.87	4.5	3.0
7	Porphyry	.30	2.7	.5
8	Papago fm	.20	3.4	.3

Note: All samples contain pyrite and chalcopyrite as the dominant sulphides, except No 8 which is enriched by chalcocite.

TOTAL SULPHIDE CONTENT - MISSION MINE

Figure 4

J E K[illegible]son

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(Mission Mine file)
Pima County

COPPER AND ZINC OCCURRENCES IN A FINAL TAILS SAMPLE FROM ASARCO'S MISSION UNIT

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April 28, 1992

Received by facsimile December 9, 1993
Arizona Department of Mines and Mineral Resources

Arizona Department of Mines and Minearl Resources Library Entry 12/21/93

Authors: Coe, Jennie E.

Pub. Date: 1992

Title: Copper and zinc occurrences in a final tails sample from Asarco's Mission Unit; American Cyanamid, Inc., Chemical Research Division, unpublished report, 8p.

Area/County: Pima
Latitude: 31943333 Longtitude: 111070000 (Dec. Equiv.)

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INTRODUCTION

The purpose of this study was to determine the copper and zinc occurrences in a 1991 five month composite final tails sample from ASARCO's Mission Unit. This sample contained 0.11% copper and 0.19% zinc.

SUMMARY

Chalcopyrite was the major copper mineral observed in the ASARCO final tails sample. The chalcopyrite observed in the +200 mesh fractions was predominantly locked with greater amounts of non-copper minerals, the most common occurrence being chalcopyrite locked with greater amounts of siliceous gangue.

The chalcopyrite was predominantly locked with greater amounts of non-copper minerals in the -200/+400 mesh fractions. As the particle size decreased in the -200 mesh fractions, the amount of free chalcopyrite increased. In the -400 mesh fraction the chalcopyrite was predominantly both free and locked with greater amounts of non-copper minerals.

Sphalerite was the zinc mineral observed in the final tails sample. The sphalerite observed in the final tails screen fractions was predominantly observed to be locked with lesser amounts of chalcopyrite, the chalcopyrite occurring as minute blebs and attachments.

No free sphalerite was observed in the +65 mesh fractions. The amount of free sphalerite fluctuated in the -65 mesh fractions. The most free sphalerite, approximately 26%, was observed in the -400 mesh fraction.

SAMPLE PREPARATION

A representative split of the final tails sample was screened on 65, 100, 200, 325 and 400 mesh U.S. Standard sieves. The screen analyses are listed in Table 1.

Representative splits of the head sample and the +65, -65/+100, -100/+200, -200/+400 and -400 mesh fractions of the final tails were submitted for copper and zinc assays. Acid soluble copper, iron and sulfur assays were also done for the head sample. These metallurgical results are listed in Table 1.

Also listed in Table 1 are the screen and metallurgical analyses for the ASARCO Mission flotation feed sample. No mineralogical study will be done on the flotation feed at this time.

Representative splits of the -100 mesh final tails screen fractions were run on a Haultain Superpanner in order to produce heavy mineral concentrates. Heavy mineral concentrates were not produced for the +100 mesh fractions because for the coarser sizes, the size of the particles interferes with the heavy mineral separations.

Representative splits of the final tails +100 mesh fractions and -100 mesh heavy mineral concentrates were mixed with epoxy to form grain mounts. The polished grain mounts were examined under an ore microscope in axially reflected light.

The non-opaque minerals were identified using X-ray diffraction analyses and refractive index oils.

MINERALOGY

The non-opaque gangue in this final tails fraction consisted of major amounts of quartz and potassium feldspar, minor amounts of calcite, dolomite, plagioclase, pyroxene, and mica and trace amounts of clays (undifferentiated).
In the chalcopyrite occurrences' descriptions, the non-opaque gangue predominantly locked with the chalcopyrite was quartz.

Chalcopyrite was the major copper mineral observed in the final tails sample. The chalcopyrite occurrences are described in detail in this section. Cuprite, bornite, chalcocite, covellite, digenite and native copper were observed in trace amounts in one or more of the screen fractions.

In the +65 mesh fraction, the chalcopyrite was predominantly both fully and partially locked. In the -65 mesh fractions, all of the locked chalcopyrite, except for that locked with sphalerite, was predominantly partially locked. In all of the -65 mesh fractions, the chalcopyrite that was observed to be locked with sphalerite was predominantly fully locked as minute blebs.

It should be noted that particles referred to as "free" particles are those which appear to be free in the polished cross section examined. Statistically, the proportion of truly free mineral grains in any sample is generally smaller than the proportion observed as "free" particles in polished section.

It should also be noted that very few particles containing sphalerite and/or chalcopyrite were observed in the +65 mesh fraction and therefore the observations may not be statistically representative of that fraction.

Chalcopyrite

Screen Fraction	Percent	Occurrences
+65 Mesh	65%	chalcopyrite locked with greater non-opaque gangue (pred. quartz)
	12%	chalcopyrite locked with greater amounts of non-opaque gangue/rutile
	5%	chalcopyrite locked with greater non-opaque gangue/hematite
	3%	free
	3%	chalcopyrite locked with greater non-opaque gangue/pyrite/rutile
	12%	chalcopyrite locked with greater sphalerite, chalcopyrite/bornite locked with greater non-opaque gangue, locked with greater sphalerite, locked with greater molybdenite/non-opaque gangue, locked with greater pyrite/non-opaque gangue, locked with greater cuprite/non-opaque gangue/pyrite, locked with lesser non-opaque gangue/hematite, locked with lesser pyrite, locked with bornite/digenite/covellite/non-opaque gangue and locked with bornite/non-opaque gangue
-65/+100 Mesh	70%	chalcopyrite locked with greater amounts of non-opaque gangue
	8%	free
	8%	chalcopyrite locked with greater amounts of sphalerite
	2%	chalcopyrite locked with greater amounts of rutile/non-opaque gangue
	2%	chalcopyrite locked with greater amounts of hematite/non-opaque gangue
	10%	chalcopyrite locked with greater amounts of magnetite/hematite/pyrite, magnetite/non-opaque gangue, pyrite/non-opaque gangue, magnetite/hematite/non-opaque gangue, non-opaque gangue, pyrite and magnetite
-100/+200 Mesh	30%	chalcopyrite locked with greater amounts of non-opaque gangue
	20%	chalcopyrite locked with greater amounts of sphalerite
	10%	chalcopyrite locked with greater amounts of pyrite
	8%	free
	5%	chalcopyrite locked with greater amounts of hematite/non-opaque gangue
	2%	chalcopyrite locked with greater amounts of pyrrhotite/pyrite

Screen Fraction	Percent	Occurrences
-100/+200 Mesh (Cont.)	2%	chalcopyrite locked with greater amounts of hematite/magnetite/non-opaque gangue
	23%	chalcopyrite locked with greater amounts of sphalerite/hematite, pyrite/magnetite/non-opaque gangue, magnetite/non-opaque gangue, rutile/non-opaque gangue, covellite/non-opaque gangue, pyrite/hematite, pyrite/non-opaque gangue, non-opaque gangue and sphalerite/non-opaque gangue
-200/+325 Mesh	25%	free
	20%	chalcopyrite locked with greater amounts of sphalerite
	18%	chalcopyrite locked with greater amounts of non-opaque gangue
	12%	chalcopyrite locked with greater amounts of pyrite
	8%	chalcopyrite locked with greater amounts of hematite/non-opaque gangue
	3%	chalcopyrite locked with greater amounts of pyrrhotite/pyrite
	14%	chalcopyrite locked with greater amounts of pyrite/non-opaque gangue, magnetite, pyrite/hematite/non-opaque gangue, sphalerite/non-opaque gangue and rutile/magnetite/non-opaque gangue
-325/+400 Mesh	35%	free
	15%	chalcopyrite locked with greater amounts of non-opaque gangue
	15%	chalcopyrite locked with greater amounts of pyrite
	15%	chalcopyrite locked with greater amounts of sphalerite
	8%	chalcopyrite locked with greater amounts of hematite/non-opaque gangue
	3%	chalcopyrite locked with lesser amounts of non-opaque gangue
	9%	chalcopyrite locked with greater amounts of pyrite/hematite/non-opaque gangue, pyrite/hematite/magnetite, magnetite/hematite, hematite, galena/sphalerite/non-opaque gangue, pyrite/pyrrhotite and galena

Screen Fraction	Percent	Occurrences
-400 Mesh	45%	free
	20%	chalcopyrite locked with greater amounts of sphalerite
	15%	chalcopyrite locked with greater amounts of non-opaque gangue
	5%	chalcopyrite locked with greater amounts of pyrite
	5%	chalcopyrite locked with lesser amounts of pyrite
	5%	chalcopyrite locked with lesser amounts of non-opaque gangue
	5%	chalcopyrite locked with greater amounts of sphalerite/non-opaque gangue, hematite, pyrite/non-opaque gangue, hematite/magnetite, hematite/non-opaque gangue, pyrite/hematite/non-opaque gangue, bornite/digenite, galena/sphalerite and locked with lesser amounts of sphalerite
Sphalerite		
+65 Mesh	66%	sphalerite locked with lesser amounts of chalcopyrite
	34%	sphalerite locked with lesser amounts of non-opaque gangue/chalcopyrite
-65/+100 Mesh	74%	sphalerite locked with lesser amounts of chalcopyrite
	16%	free
	7%	sphalerite locked with lesser and greater amounts of non-opaque gangue
	3%	sphalerite locked with greater amounts of chalcopyrite
-100/+200 Mesh	80%	sphalerite locked with lesser amounts of chalcopyrite
	8%	free
	5%	locked with lesser and greater amounts of non-opaque gangue/chalcopyrite
	5%	locked with lesser amounts of hematite/chalcopyrite
	2%	locked with greater amounts of chalcopyrite
-200/+325 Mesh	80%	sphalerite locked with lesser amounts of chalcopyrite
	18%	free
	2%	sphalerite locked with lesser amounts of pyrite/chalcopyrite and chalcopyrite/non-opaque gangue

Screen Fraction	Percent	Occurrences
-325/+400 Mesh	78%	sphalerite locked with lesser amounts of chalcopyrite
	16%	free
	4%	sphalerite locked with lesser amounts of non-opaque gangue/chalcopyrite
	2%	sphalerite locked with lesser amounts of galena/chalcopyrite/non-opaque gangue
-400 Mesh	70%	sphalerite locked with lesser amounts of chalcopyrite
	26%	free
	4%	sphalerite locked with lesser amounts of galena, chalcopyrite/non-opaque gangue or with greater amounts of chalcopyrite

PHOTOMICROGRAPHS

Mineral identification was conducted by direct microscopic examination, not by photomicrography. The colors of the minerals in the photomicrographs can deviate from their true colors due to the degree of reflectivity, abundance of light or dark particles, magnification and/or printing. The dark brown to olive-colored background between the grains is the thermoplastic mounting material.

The size of the particles in the photomicrographs is dependent on the plane of the section polished and photomicrographed.

Some of the major particles and their inclusions have been labeled on the photomicrographs to identify the various minerals. If the majority of particles in a photomicrograph are the same mineral, only a few have been labeled. The abbreviations are as follows:

cpy - chalcopyrite
gan - non-opaque gangue
hem - hematite
py - pyrite
qtz - quartz
spl - sphalerite

CONCLUSIONS

Approximately 50% of the total weight in the ASARCO Mission final tails sample was in the +200 mesh fractions. Approximately 74% of the copper was present in the +200 mesh fractions. The chalcopyrite observed in the +65 mesh fraction was predominantly both fully and partially locked. In the -65/+200 mesh fractions the chalcopyrite was predominantly partially locked. It appeared that a finer grind would free up a significant amount of chalcopyrite in the +200 mesh fractions. It appeared, however, that finer grinding would not liberate much, if any, of the chalcopyrite associated with the sphalerite in any of the screen fractions.

Approximately 26% of the copper in the final tails was present in the -200 mesh fractions. The -200 mesh fractions made up approximately 50% of the total weight. A significant amount of free chalcopyrite was observed in the -200 mesh fractions, especially in the -400 mesh fraction where 45% of the chalcopyrite in that fraction occurred as free particles.

The sphalerite observed in the final tails fractions was predominantly locked in particles with lesser amounts of chalcopyrite, the chalcopyrite occurring predominantly as minute blebs. The success of liberating the chalcopyrite from the sphalerite appeared unlikely.

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Table 1. ASARCO Mission Screen and Metallurgical Analyses

ASARCO Mission Final Tails

Screen Size	Weight (g)	Weight Cum.(g)	Weight %	Weight % Cum	Cu%	Zn%	Acid Sol Cu%	Fe%	S%
+65 Mesh	129.9	129.9	16.9	16.9	0.20	0.10			
-65/+100 Mesh	89.8	219.7	11.7	28.5	0.15	0.18			
-100/+200 Mesh	165.4	385.1	21.5	50.0	0.09	0.27			
-200/+400 Mesh	120.6	505.7	15.7	65.7	0.05	0.29			
-400 Mesh	264.3	770.0	34.3	100.0	0.05	0.16			
Calc. Head	770.0		100.0		0.10	0.20			
Assay Head					0.11	0.19	0.01	4.36	1.57

DISTRIBUTIONS

Screen Size	Cu	Cu Cum	Zn	Zn Cum
+65 Mesh	35.3	35.3	8.6	8.6
-65/+100 Mesh	18.3	53.6	10.7	19.3
-100/+200 Mesh	20.2	73.8	29.6	48.9
-200/+400 Mesh	8.2	82.0	23.2	72.0
-400 Mesh	18.0	100.0	28.0	100.0
Calc. Head	100.0		100.0	

ASARCO Mission Flotation Feed

Screen Size	Weight (g)	Weight Cum.(g)	Weight %	Weight % Cum	Cu%	Zn%	Acid Sol Cu%	Fe%	S%
+65 Mesh	81.1	81.1	14.3	14.3	0.32	0.09			
-65/+100 Mesh	78.6	159.7	13.9	28.2	0.57	0.19			
-100/+200 Mesh	126.4	286.1	22.3	50.6	0.82	0.31			
-200/+325 Mesh	59.6	345.7	10.5	61.1	0.95	0.36			
-325/+400 Mesh	26.2	371.9	4.6	65.7	0.97	0.36			
-400 Mesh	194.0	565.9	34.3	100.0	0.76	0.27			
Calc. Head	565.9		100.0		0.71	0.26			
Head					0.70	0.25	0.02	4.76	2.46

DISTRIBUTIONS

	Total Cu	Cum.	Zn	Cum.
+65 Mesh	6.4	6.4	5.0	5.0
-65/+100 Mesh	11.1	17.5	10.3	15.4
-100/+200 Mesh	25.7	43.2	27.1	42.4
-200/+325 Mesh	14.0	57.2	14.8	57.3
-325/+400 Mesh	6.3	63.5	6.5	63.8
-400 Mesh	36.5	100.0	36.2	100.0
Calc. Head	100.0		100.0	