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FEB 18 1963

AMERICAN SMELTING AND REFINING COMPANY
SOUTHWESTERN EXPLORATION DEPARTMENT
813 VALLEY NATIONAL BLDG., TUCSON, ARIZONA

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November 12, 1962

Mr. Allan James
Bear Creek Mining Company
802 Tribune Building
Salt Lake City 11, Utah

Dear Mr. James:

Enclosed is a draft of my paper on Mission for the coming AIME meeting in Dallas. I use the word "draft" in the sense that I have not yet received Company clearance, as the paper has just been finished; however, I do not anticipate any changes.

The paper will appear, then, in this form as a pre-print, although in delivering the talk I will use notes and will probably omit the long quotes from Spencer's Professional Paper, particularly inasmuch as that district will be covered by Herman Bauer. However, Spencer's work is, I believe, important both historically and geologically, and for that reason it is included for pre-print purposes.

I am also sending a copy to Mr. Bauer.

Yours very truly,

John E. Kinnison

JOHN E. KINNISON

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

John E. Kinnison
Geologist
American Smelting and Refining Company
Southwestern Exploration Department

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

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 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, 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 dominant: 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.

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.

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 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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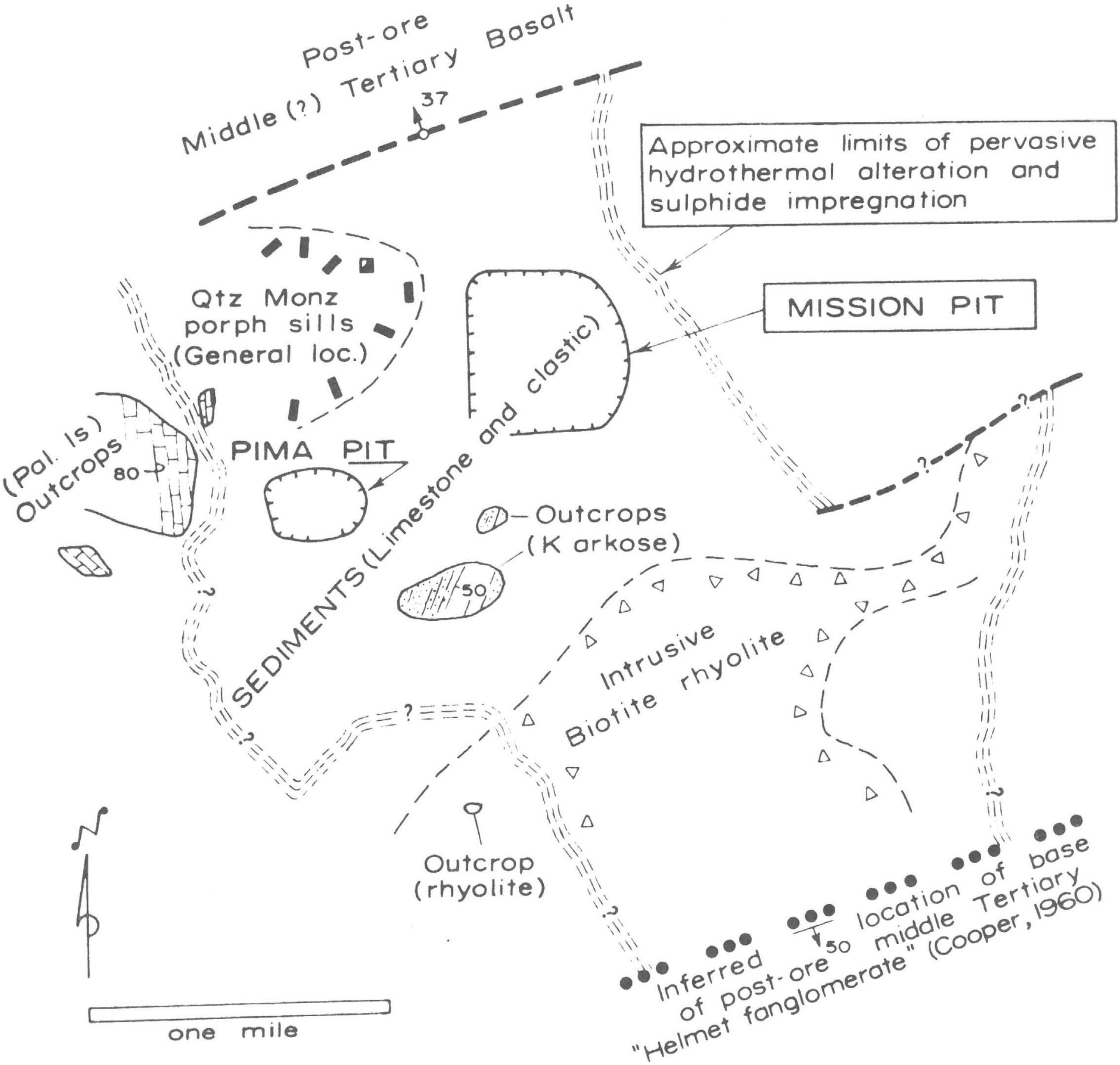
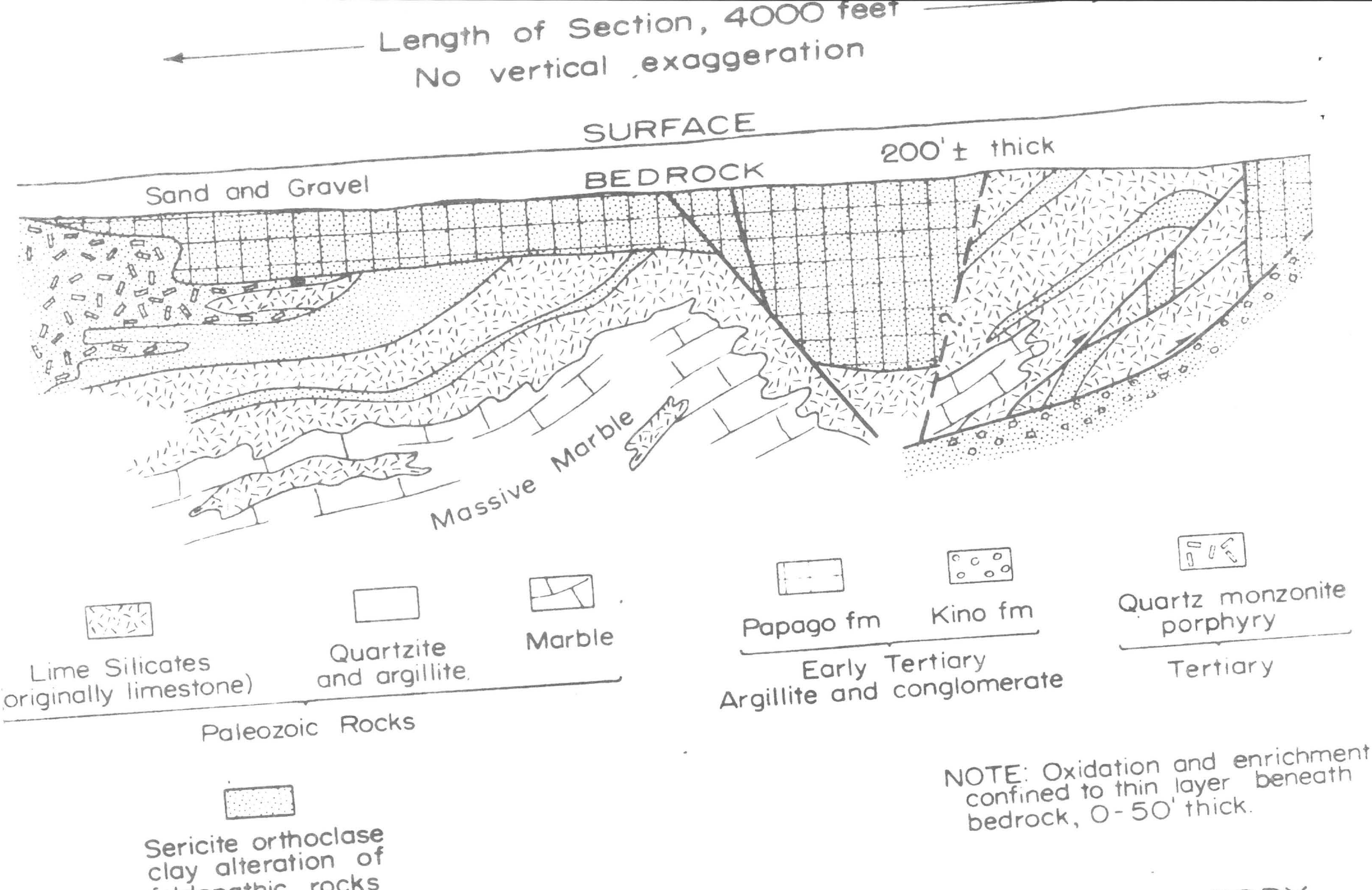


GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 1

J.E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY LOOKING NORTH

J.E. Kinnison

Figure 2

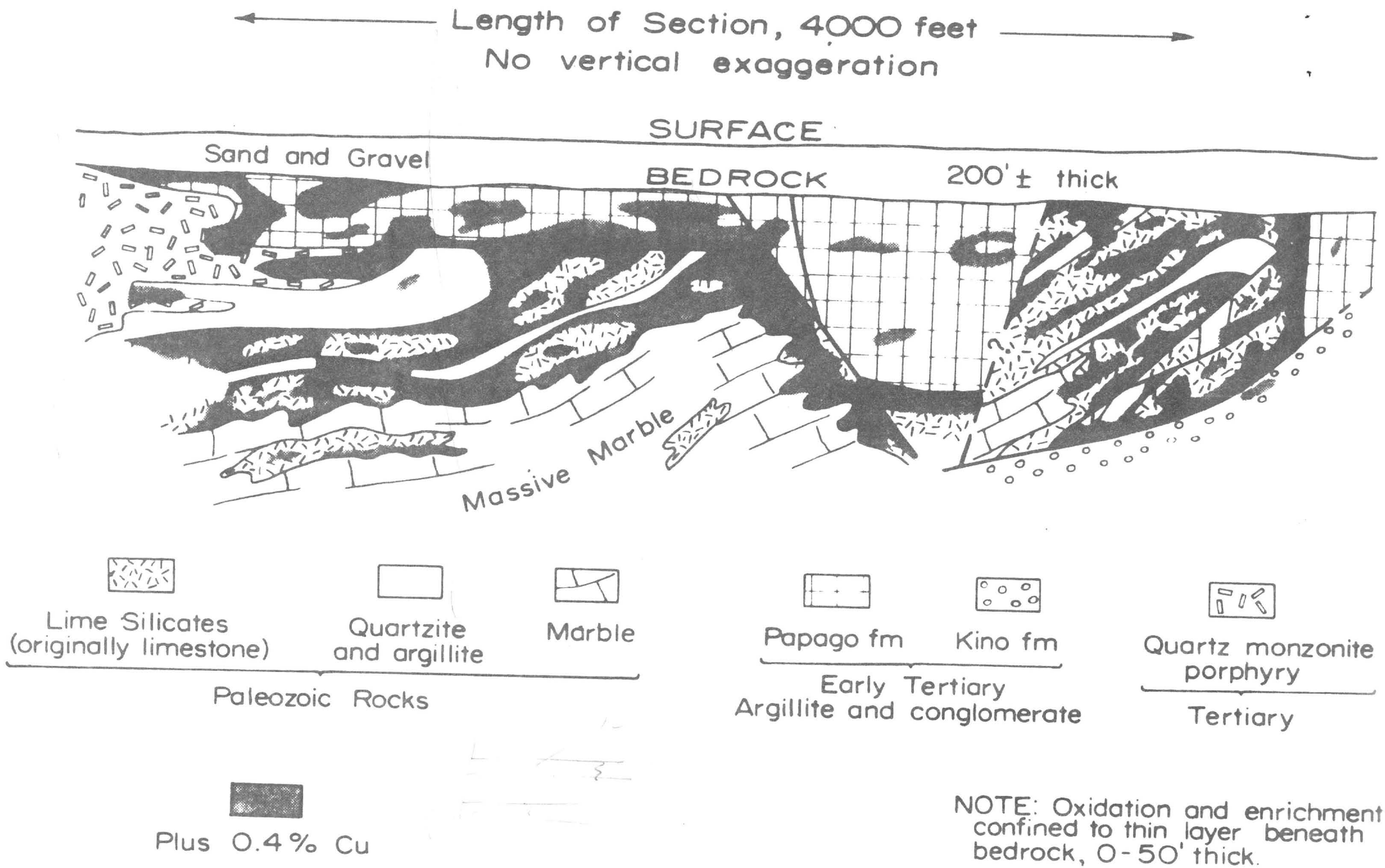


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Figure 3

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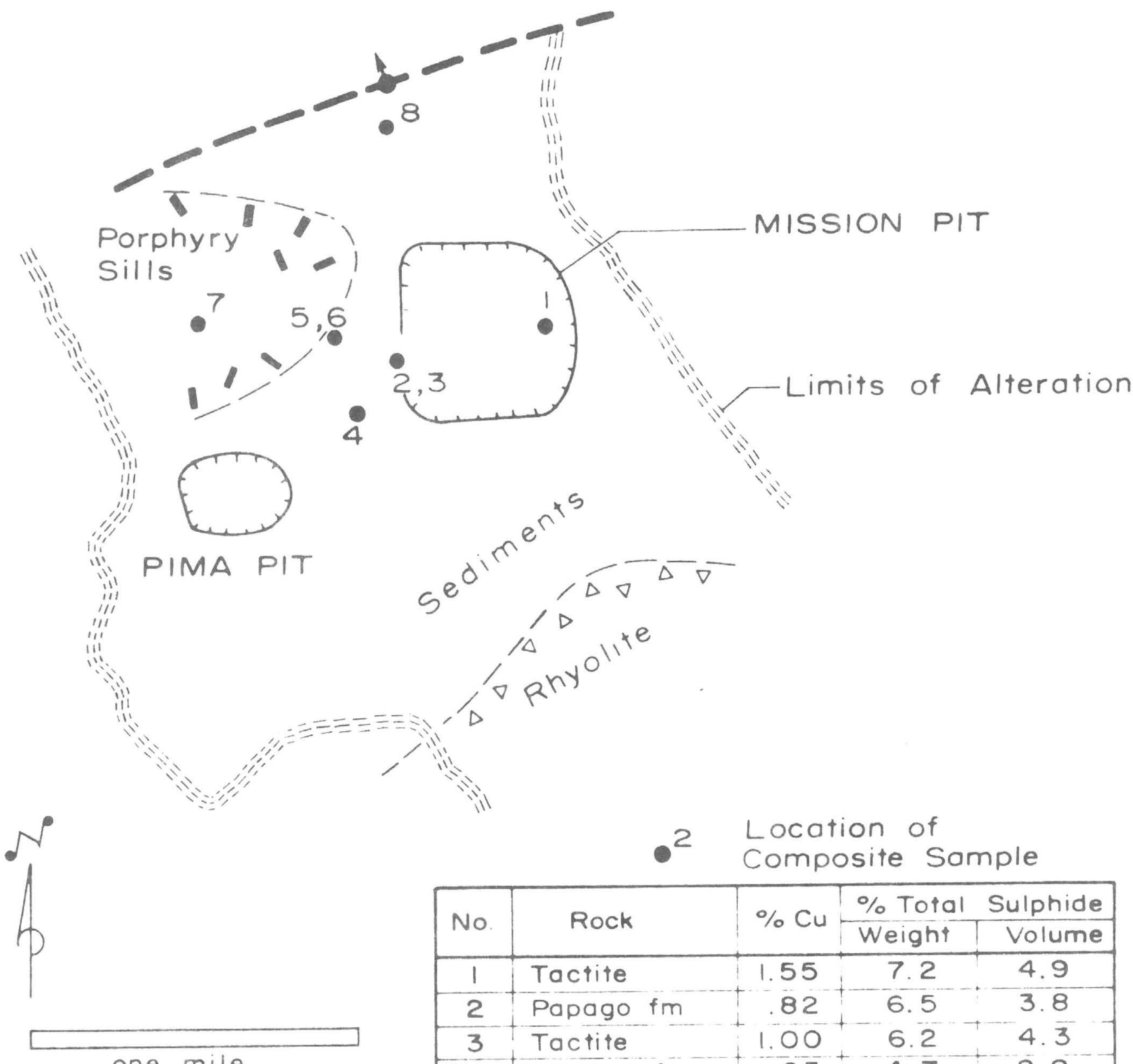

●2 Location of Composite Sample

No.	Rock	% Cu	% Total Sulphide	
			Weight	Volume
1	Tactite	1.55	7.2	4.9
2	Papago fm	.82	6.5	3.8
3	Tactite	1.00	6.2	4.3
4	Papago fm	.65	4.7	2.8
5	Papago fm	.94	4.5	2.7
6	Tactite	.87	4.5	3.0
7	Porphyry	.30	2.7	1.5
8	Papago fm	1.20	3.4	1.9

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. Kinnison

Roland Mulchay

Mulchay

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November 12, 1962

Rolland - please note

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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

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 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, 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 dominant: 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.

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 [illegible] and charged with sulphides.

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 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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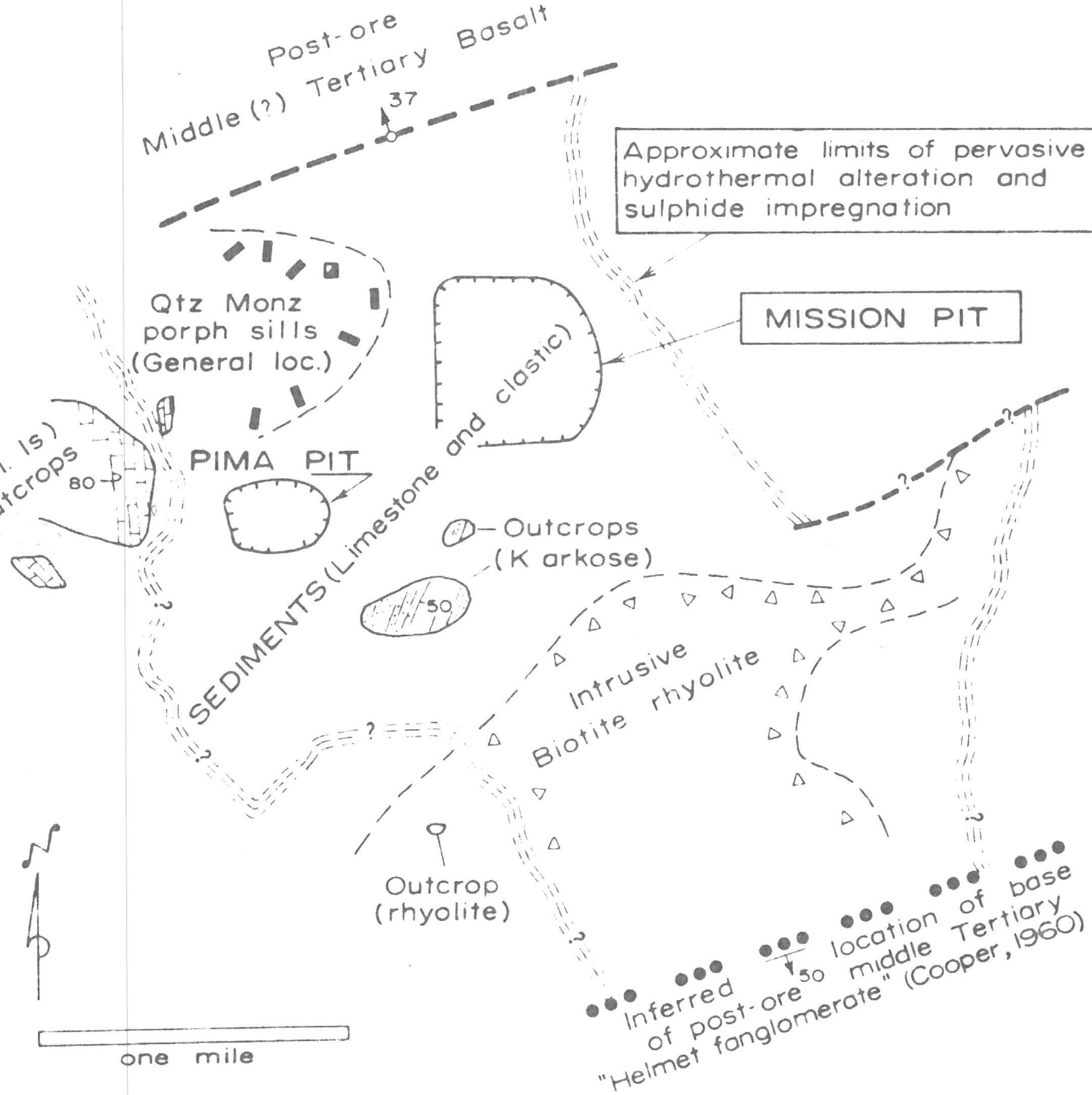
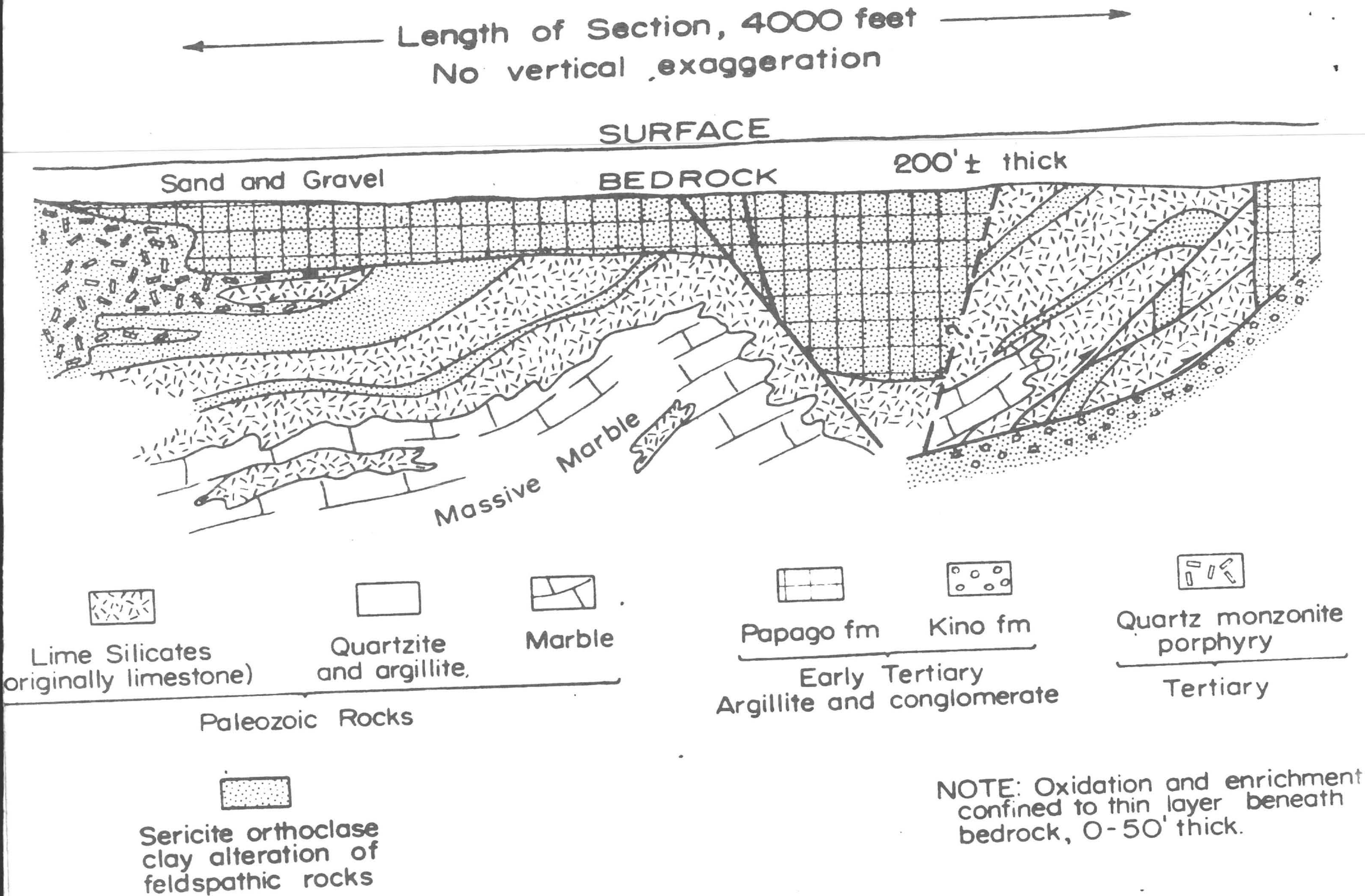


GENERALIZED MAP SHOWING DISTRIBUTION OF SEDIMENTS, IGNEOUS ROCKS AND ALTERATION BENEATH THE ALLUVIAL PLAIN AS KNOWN THROUGH DRILL DATA

Figure 1

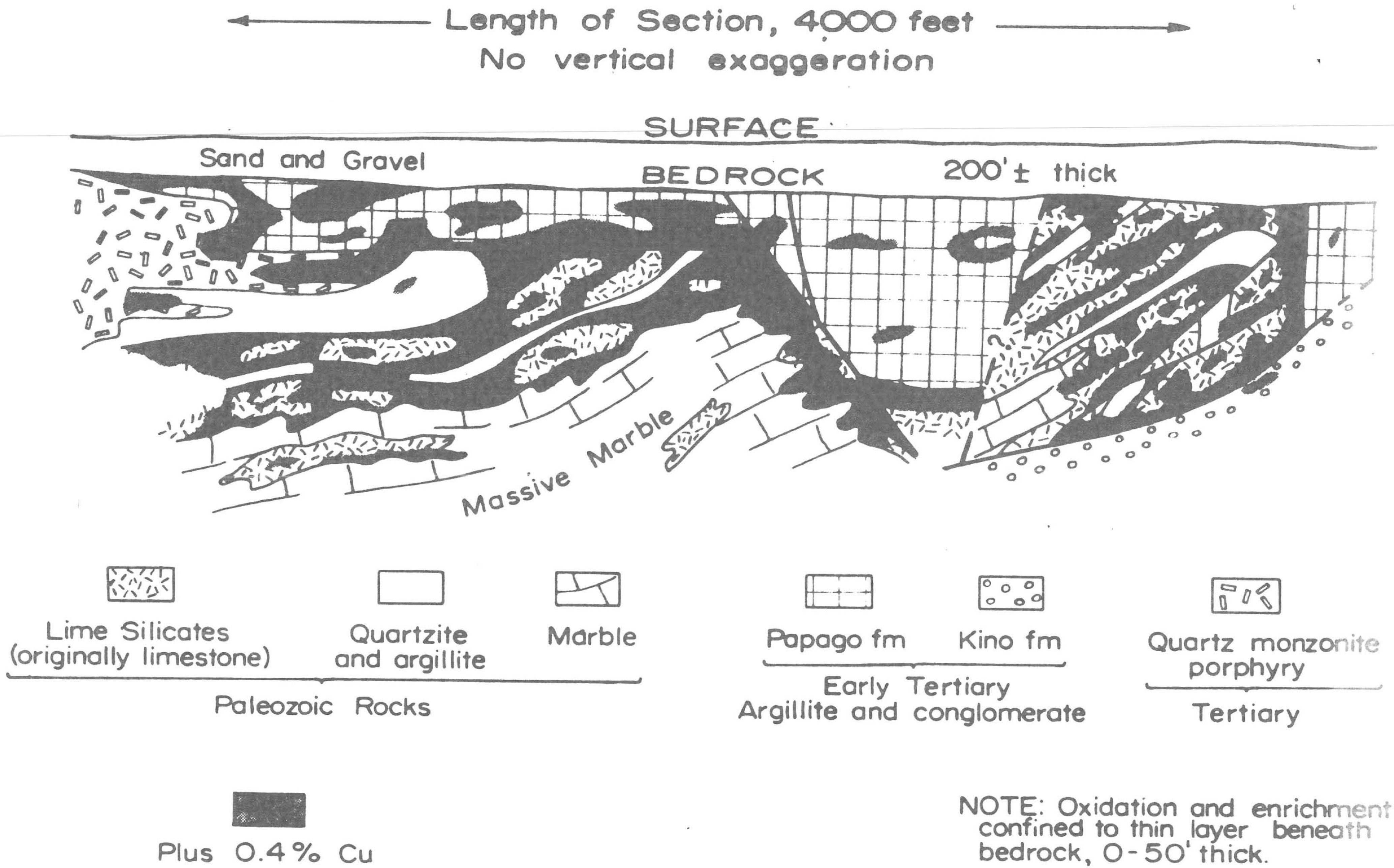
J. E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 2

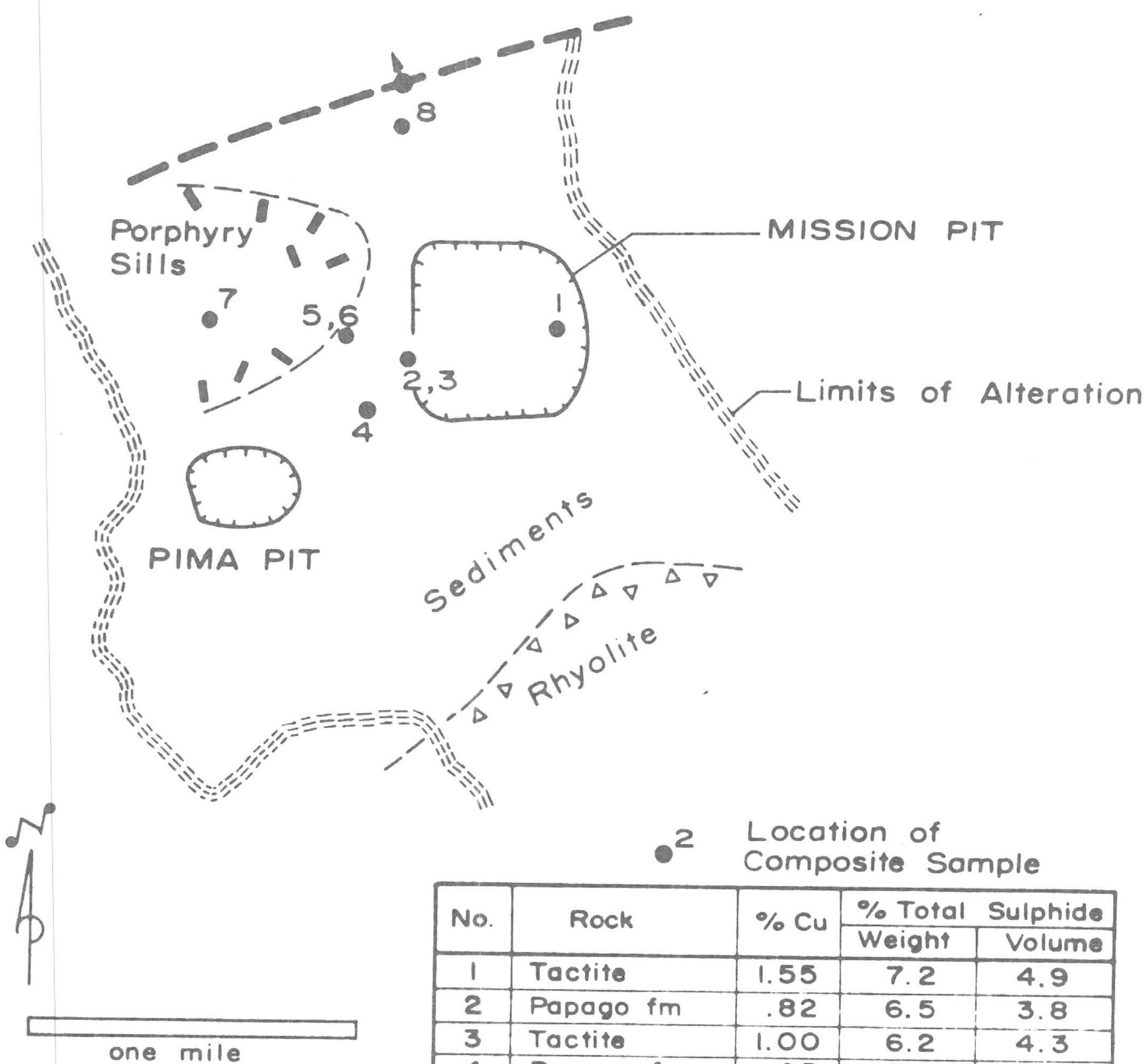
J. E. Kinnison



DIAGRAMMATIC CROSS SECTION THROUGH MISSION ORE BODY
LOOKING NORTH

Figure 3

J.E. Kinnison



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	4.3
4	Papago fm	.65	4.7	2.8
5	Papago fm	.94	4.5	2.7
6	Tactite	.87	4.5	3.0
7	Porphyry	.30	2.7	1.5
8	Papago fm	1.20	3.4	1.9

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. Kinnison

PAY DIRT
No. 322, December 17, 1965