CONTACT INFORMATION
Mining Records Curator
Arizona Geological Survey
3550 N. Central Ave, 2nd floor
Phoenix, AZ, 85012
602-771-1601
http://www.azgs.az.gov
inquiries@azgs.az.gov

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EXPLORATION REVIEW
SAN XAVIER INDIAN RESERVATION

J. E. Kinnison 11/10/66

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

November 10, 1966

Mr. K. E. Richard, Chief Geologist
American Smelting and Refining Company
120 Broadway
New York, N. Y. 10005

Dear Sir:

Enclosed is Mr. Kinnison's Exploration Review, San Xavier Indian Reservation, covering the period 1957 through 1960. The purpose of this paper is to provide for all concerned information which may be useful in dealing with problems which have arisen.

The Review, accompanied by maps, outlines (1) the general geologic environment of San Xavier Tracts I, II, and III, (2) the exploration objectives, and (3) the interpretation of results on which conclusions were based.

Included is an Appendix describing features which characterize porphyry copper deposits, with emphasis on those of importance in exploration.

Yours very truly,

J. H. Courtright

J. H. COURTRIGHT

JHC/kw
Enclosure
cc: RRichter (2), w/encls.
TASnedden, w/encl.
RBMeen, w/encl.
JEKinnison

Note to Mr. Richard:
Only original letter and your copy of report enclosed herewith. The two extra copies will be forwarded to Mr. Richter early next week.
JHC

NOV 21 1966
J.E.K.

AMERICAN SMELTING AND REFINING COMPANY
Tucson Arizona

November 10, 1966

TO: J. H. COURTRIGHT

FROM: J. E. KINNISON

EXPLORATION REVIEW
SAN XAVIER INDIAN RESERVATION

At your request I have reviewed the exploration information pertaining to the subject area. The following is a summary of this review. Because this memorandum may be read by officials of the Bureau of Indian Affairs, or other persons outside the Company, I have included a general discussion of those geologic features of porphyry copper deposits which influence exploration methods (appendix).

Three tracts of land, northerly from the Mission Mine, were obtained by Asarco for the purpose of mineral exploration. The region is a broad, gently sloping alluvial plain. Bedrock hills protrude from this surface in a few places only, and comprise less than 10% of the surface within the exploration tracts.

CONCLUSIONS

I conclude that these three tracts (designated I, II, III) were thoroughly tested for mineral bodies by an integrated combination of 1) drill penetrations, 2) multiple types of geophysical traverses, and by 3) regional geologic mapping. Two areas of mineral bearing rock which contain sufficient copper to be potentially classified as ore were drilled on a moderately close-spaced grid prior to the end of exploration in 1959. The southern of these two areas is in Tract II and is an extension of the Mission mineral deposit. The second is two miles northwesterly from Mission, in Tract I. This report, by intent, will deal principally with the mineral deposit in Tract I, which is termed the "North San Xavier" in Company correspondence.

Mineral leases for mining have been obtained for those parts of Tract I and II which contain mineral bodies that might be ore deposits under favorable circumstances. Beyond the area contained by the mining leases, the ground has been evaluated by widely spaced drill hole penetrations, and by geologic projections. Geophysical surveys throughout all three tracts have aided the geologic interpretation and have allowed us to place confidence in the interpretations based on these widely spaced drill holes. The geophysical work included airborne and ground magnetometer surveys, electrical conductivity traverses, and gravity surveys. During

1960 induced polarization geophysical surveys were made over the North San Xavier mineral zone, and then this survey was extended northwesterly to the north boundary of the San Xavier Indian Reservation. Induced polarization surveys, combined with widely spaced drill holes, clearly indicate the northern limit of mineralization in Tract I. The induced polarization survey also confirmed the earlier interpretations made by myself and others in the company, based largely on drill hole information, in all other directions surrounding the "North San Xavier".

John E. Kinnison

JOHN E. KINNISON

JEK:pjc

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APPENDIX

Porphyry Copper Deposits, Geology

MAPS

Attachment A	Geology of the Porphyry Copper Belt: Mission Area and San Xavier Reservation 1 mile = 2 inches
Attachment B	Bedrock Geology: San Xavier Project 1 inch = 1000 feet

MAPS

Two geologic maps (Attachments A and B) accompany this report. Their purpose is to show the distribution of rocks and also of mineralization. The report is written so that the maps may be referred to, and thereby obtain a better picture. These maps were prepared during 1960, following termination of drilling on the San Xavier Reservation. Attachment A is a regional map which illustrates the geology of the area around the Mission and Pima mines, and extends from there northward to the north edge of the Indian Reservation. The entire column of rocks, as known from mapping in the Sierrita and Tucson Mountains as well as from the immediate area about the Mission mine, is illustrated on this map. There is also included on it a diagrammatic cross-section which illustrates a composite of all rocks and their relationships to one another. That area covered by alluvium, but which is known from drill holes, is colored as though it were an outcrop. Attachment B is a geologic map of the bedrock surface on the San Xavier Reservation near the mineralized zone, as known from drill hole data. This map illustrates, in greater detail, certain features of mineralization, and the position of drill holes.

POST-MINERAL ROCKS

Post-mineral rocks in the San Xavier region may be divided into two principal categories. The oldest is a series of Mid-Tertiary conglomerate beds with an interbedded basalt flow. The younger group is a combination of Quaternary sand, gravel, and conglomerate which are generally grouped as a single division and termed "alluvium". In San Xavier Tracts I, II, III, alluvium overlies both pre-mineral rock and also the Mid-Tertiary, post-mineral formations.

Many faults, some of them large, displace the Mid-Tertiary sequence. However, no faults are known to cut alluvium. There are certain linear fissures near the northern edge of the Reservation which appear to be compaction cracks.

Note should be taken that the word "overburden" is commonly used to describe the post-ore formations (mostly alluvium) and that this term is not (or should not be) used for the leached capping which also must be removed from an open-pit. The term "bedrock" is used for all rocks older than alluvium.

PRE-MINERAL ROCKS

The columnar section shown on Attachment A illustrates the pre-mineral rocks, and their proper sequence. The entire span of geologic time since Precambrian is represented on the regional map. Within the exploration tracts some of this sequence is not present. These rocks--principally sedimentary--are described in many published articles in the geologic literature. Therefore, no detailed description is given here.

MINERALIZATION

The zone of pervasive alteration at Mission-San Xavier strikes northwest. It gradually weakens at both ends and becomes dominantly pyritic with a decreasing amount of copper. The sides of the zone are also gradational, from intense alteration in the central part of the zone which fades first into pyritic alteration and finally into unaltered rock. The width of this zone varies somewhat but averages about 1-1/2 miles. The strike length is about seven miles. The limits of pervasive alteration have been determined by drill penetration into pre-mineral rocks.

Geophysics which were done prior to and concurrently with drilling on the reservation proved to have a limited use other than to outline the area in which we might expect thick basalt. Induced polarization, however, which was conducted in 1960, brings out in sharp detail the zone of alteration and pervasive sulfide impregnation. Although induced polarization was done after drilling, it served to confirm the interpretation of the shape of the zone of alteration at the North San Xavier area in Tract I. Wide-spaced drill holes northwest of the "North San Xavier" copper deposit indicated that the alteration zone had faded to a weak and spotty pyritic type. It could be theorized that this represented a local decrease in the intensity of alteration and not necessarily the termination of the alteration zone. Induced polarization surveys which traversed this area--from the North San Xavier to the north edge of the reservation--confirmed the interpretation that the zone faded and ended.

ROCKS OF THE ALTERED ZONE

At the Mission mine and in the southern part of Tract II, the Paleozoic section lies within the altered zone. These rocks are pervasively altered and contain a large tonnage of copper as chalcopyrite--with grades typical of open-pit copper ore--in an altered rock which consists of lime silicate minerals. Where the Paleozoic limestones lie beyond the zone of pervasive alteration, there are only small tonnages of copper or other metal sulfides, in a form typical of limestone placement deposits. The rocks of Cretaceous and Tertiary ages within the altered zone are typified by quartz and sericitic alteration, and are impregnated with pyrite and chalcopyrite. Portions of the Tertiary Papago formation (Attachment A) constitute open-pit ore. Monzonite porphyry, where it is within the zone of alteration at Mission, is mineralized only to an average of about 0.15% copper and is not enriched by secondary chalcocite.[1] The possible orebody in Tract I--North San Xavier--is an enriched chalcocite zone in arkose and porphyry.

PALEOZOIC FORMATIONS ABSENT, TRACT I

The "Possible" ore deposit in Tract I (North San Xavier) consists mainly of: 1) a partly oxidized zone of secondary chalcocite enrichment, and, 2) of lower grade copper values in primary chalcopyrite. Portions of this primary copper which grades plus 0.4% lie within the proposed open-pit area, and will be included in the ore reserve.

---

[1]A small tonnage of chalcocite in southern Tract II, partly in porphyry and partly in argillite, represents "possible ore".

The fact that part of the primary chalcopyrite in arkose and porphyry grades higher than most porphyry copper protore naturally leads to the conjecture that the Paleozoic limestones, if present within the pervasive altered zone, might contain primary copper values comparable to other disseminated copper mines in the southwest. If this were the case, then additional reserves would be available.

To test this possibility a specific search, by drilling deep holes, was made prior to termination of exploration in 1959. None of these deep holes located the Paleozoic formations (the deepest was X-120, 1638' total depth).

Recent drill holes in this area, sunk principally to establish data for a firm reserve estimate, also confirmed the absence of the Paleozoic in the "North San Xavier" deposit. One of these more recent diamond drill holes (2SX-18 Ext.) passed through a post-mineral fault at 2012' (fault breccia zone 2012-2031), and then penetrated unmineralized granite beneath the fault. This particular fault, known in Asarco reports as the "Basement fault" and described by J. R. Cooper (his "San Xavier thrust", Bull. 1112-C, 1960) is a post-ore, low angle structure. It effects a great displacement. The upper plate, which contains the Mission-San Xavier altered zone, has moved north along the fault surface, and has placed these upper plate rocks above granite. It has been cored in many drill holes, and I have mapped its surface outcrop. The northern part of the surface outcrop is shown on Attachment "A". The lower plate of granite is not known to contain mineral values anywhere in the Mission-San Xavier region. The relationship of this to exploration is obvious--there can be no expectation to find an ore deposit beneath the fault on the San Xavier exploration tracts.

Geologic deduction also may be used to indicate the improbability that the Paleozoic formations exist anywhere in Tracts I, II, or III. Careful geologic mapping which I have done in the Tucson Mountains, to the north, reveals a four-fold division of the Cretaceous sequence of arkose and shale (Amole group). Although the total thickness of these strata is not precisely known, I conservatively estimate a minimum of 5000 feet. Beginning at the base, where the Cretaceous lies upon the Paleozoic, these formations are:

1. Braun formation (1000' plus)
2. Dead Cow formation (2000' approx.)
3. Mouse House formation (300' plus)
4. Echo Valley formation (1000' plus)

The Dead Cow formation is easily recognized. A projection of strike and dip in the Tucson Mountains, southeast into Tract I, indicates that the arkose of the North San Xavier is a correlative of that formation. The characteristic features of the Dead Cow furnish direct evidence for this correlation. A small hill made of Dead Cow strata, northwest of Black Mountain (Attachment A), further supports projection from the Tucson Mountains. These strata dip 45 to 70 degrees northeast. Their general strike is northwest.

Giving allowance for the probable thickness of the Cretaceous strata, and for their strike and dip, the Paleozoic strata might be present westerly beyond Tract I. Drill hole data near the west line of Tract I indicates that the entire pre-mineral rock sequence has been faulted out, and gravity surveys indicate that a deep erosional basin, filled with alluvium, occurs westerly from Tract I.

APPENDIX FOR:
EXPLORATION REVIEW
SAN XAVIER INDIAN RESERVATION

APPENDIX

Porphyry Copper Deposits, Geology

There are many variations in the details of those mineral deposits which are known, as a group, as "the porphyry copper deposits". Certain features of the "porphyry coppers" are so pronounced, however, that on these principal points there is no dispute among those geologists who have practical working experience with this type of mineral deposit. Of these characteristic features--where there is general agreement within the mining profession--I would list the most important as follows:

1. The porphyry copper deposits were initiated when hypogene (primary) fluids, from whatever source, permeated the host formations and deposited there, in a diffused pattern, copper and iron sulfides, together with other minor metallic sulfide minerals.

2. This aggregate of sulfides, which generally does not exceed 10% of the rock weight, is always accompanied by changes (or alteration) of the original rock minerals.

3. That area in which the metal sulfides are disseminated--as individual grains, veins, or both in combination--is essentially the same space in which the rock minerals are altered. The reverse of the above relationship also holds; no hypogene (primary) sulfides occur beyond the area of rock alteration in a porphyry copper deposit. Also, alteration without the deposition of sulfides, by whatever type of solutions this is effected, will fail to place that alteration into the same category as a porphyry copper deposit.

4. Ore is generally but a small part of the altered zone. The grade of copper and also the intensity of rock alteration generally decreases laterally toward the outside edge of the altered zone.

5. The primary copper sulfides in most deposits do not constitute ore at today's prices. The term "Protore" frequently is used for these low-grade copper values. The majority of porphyry copper mines are dependent upon a process of enrichment, which occurred in a previous geologic time. Ground water solutions circulating downward are assumed to have formed a condition where the low copper values were leached, taken into solution, and carried downward to a ground water level where they were then deposited as chalcocite to enrich the low-grade sulfides. This process forms a leached

"capping", which lies above a generally tabular and horizontal copper zone of ore grade. A few deposits, for example Mission and Ajo, contain no chalcocite, and ore is derived from higher grades of primary copper sulfide minerals.

6. The zone of alteration associated with a porphyry copper deposit, discussed and defined above, occupies a large area--a mile or more. The aggregate of altered rock and sulfides, or of altered rock and the residue left from leached sulfides in a leached capping, is readily recognizable. Because alteration and sulfides are distributed in a more or less uniform manner throughout a large area, this type of alteration is commonly termed "pervasive". A characteristic of many deposits is the tendency for alteration to be elongated. For example, the Silver Bell alteration zone is about 7 miles long and 1 mile wide. The projection of a partly explored and elongated altered zone is important, and is used by most mining companies as a guide for exploration of those deposits which are covered by post-mineral formations (such as alluvium).

7. Another feature, and which is well known, is that no <u>disseminated orebody</u> has ever been found beyond the limits of the zone of pervasive alteration.

8. These deposits, as known through mining and drilling at many properties, have a rather uniform and long vertical extent. The grade of hypogene (primary) copper sulfide (the protore of most mines) may vary locally in vertical dimension, but there may be no reasonable exception that the grade will noticeably improve or decline in depth unless some quite different host rock is present at greater depth. And even where the altered rock changes from a type which might be inferred to be less favorable for copper concentration, to one at depth which might be inferred to be more favorable, the change in copper value is not always great. The importance of this in exploration is that a deposit of low value in copper is not likely to improve to ore grade at a depth which may be reached by any type of mining.

Those basic geologic features which I have listed above are used in the practice of porphyry copper exploration. They lie at the root of, and lead directly up to exploration procedures. The risk of exploration may be analyzed in a logical manner by keeping them in mind, and costly errors may be minimized or avoided. The following discussion is intended to illustrate that use more specifically.

The chronology of pre-ore formations, both sediments and layered volcanics, and igneous intrusive rocks, forms the base. Large pre-mineral structural features, as well as unconformities in the rock

sequence, bring about a displacement in the geological succession of rocks. Although the pervasive alteration zone is usually independent of the host rocks, any large displacement usually has at least some effect on it, and thus the major pre-mineral structures and unconformities often have some influence on the shape of the alteration zone. Pre-mineral structures of small magnitude may be important to the genesis of a mineral deposit, but they are usually not relevant to exploration and development. The large zone of pervasive alteration is the principal feature which guides exploration of a porphyry copper deposit.

Most of those deposits now being mined were exposed at the surface, with little or no younger formations to conceal them. If the zone of alteration is exposed, then a correct interpretation of the limonite in the leached capping is a refinement which aids in deciding which part of the altered zone to drill first.

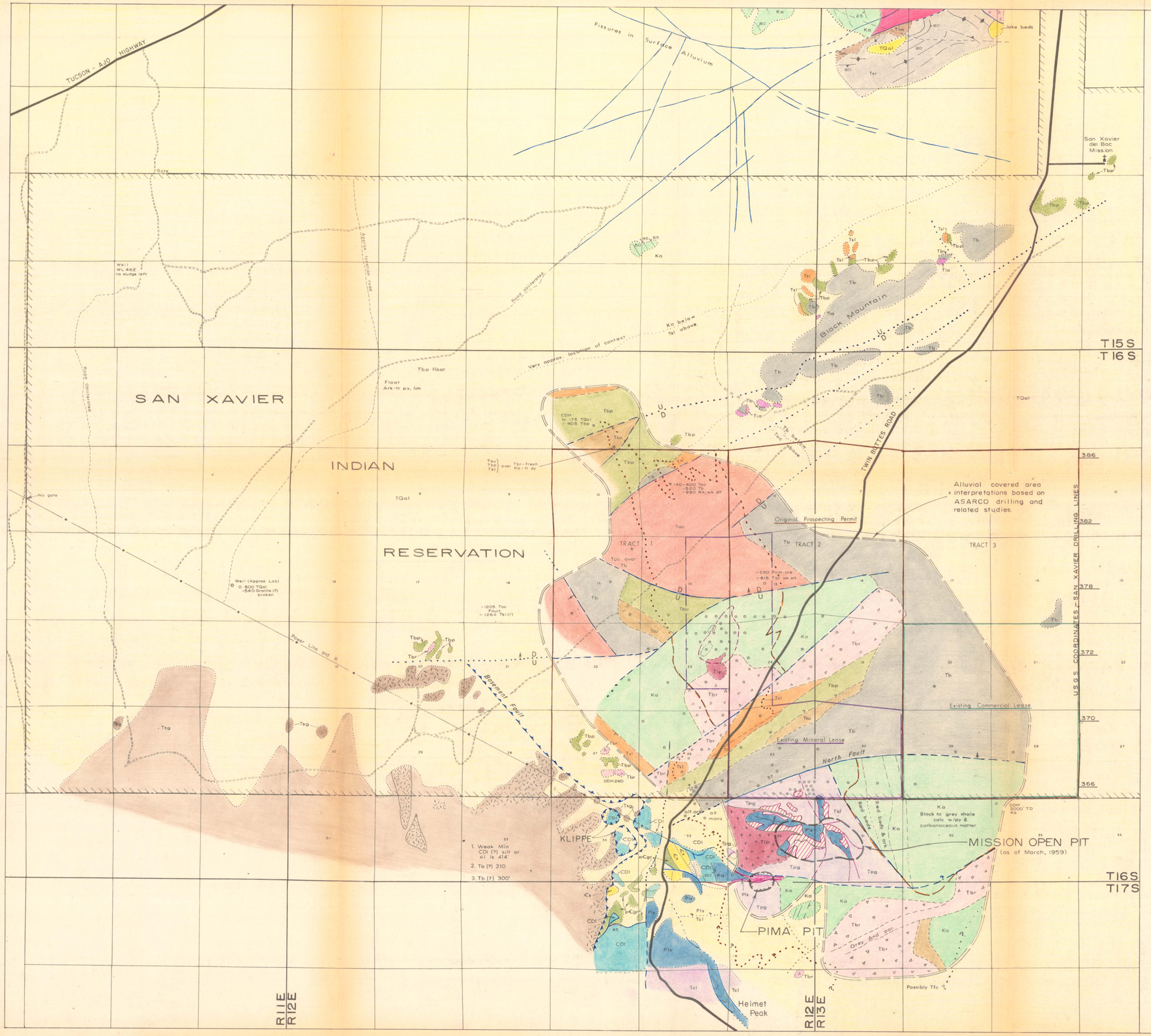
Post-mineral faults of large displacement which affect the geometry of the altered zone are important in the exploration for ore. Post-mineral formations, if present, may lie above and conceal the altered zone. Moreover, these younger formations will never contain ore, or alteration which is directly related to a porphyry copper deposit.

In summary then, there are two different types of exploration programs, although either may be directed toward the same type of ore deposit. The first is one where pre-mineral rocks are fully exposed at the present surface, and the limits of alteration and the nature of the leached capping may be mapped geologically prior to drilling. Secondly, is the one which is almost entirely covered by alluvium or other post-mineral rocks. For this second type--such as the San Xavier--the risk is always greater because very little direct information is gained prior to drilling. Exploration for the "concealed" porphyry copper deposits necessarily calls for the best geologic interpretations which may be had from the few outcrops which are present, for more emphasis on geologic projection, and for geophysical surveys.

John E. Kinnison

JOHN E. KINNISON

JEK:pjc
Attachments
cc: JHCourtright, 6 extra



COLUMNAR SECTION

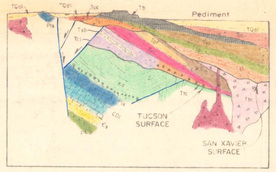
TO SCALE

1 inch = 1 mile

DIAGRAMATIC STRUCTURE

STRATIGRAPHIC COLUMN

NOT TO SCALE



As reference for structural disturbance, note that these strata were approx. horizontal when deposited:

Ꞓs, CDI, Pls, Ka
Tcl, Tcr, Taf
Tbp (?)
Tb

OTHER SYMBOLS

- Maintained road
- Desert auto trail
- Drill hole (not all ASARCO holes shown, within ore zone proper)
- Outline of ASARCO drilling area; geology within, under alluvium, colored as though it were outcrop
- Mine

LAYERED ROCKS
SEDIMENTARY AND EFFUSIVE

TERTIARY QUATERNARY

- TQal — Valley gravels, surficial alluvium and talus
- Major Erosion
- Tbp — Older conglomerate. Overlies Tb
- erosion
- Tb — Black Mountain basalt
- erosion

LOWER MIOCENE (?) - UPPER (?) TERTIARY

- Tsu, Tbp, Tsl — San Xavier formation: Upper conglomerate beds; Basalt porphyry flows (locally dikes); Lower conglomerate beds

POST-ORE / PRE-ORE — Major erosion — SAN XAVIER SURFACE

LOWER TERTIARY

- Tlm — Ivy May andesite (sills)
- Taf — Anklam formation
- Tpr — Cat Mountain rhyolite

Tsb, Tcl, Tkf, Tpg, Tfc, Tb — Pima Group: Tucson Mountain chaos; Tsb Silver Bell formation; Tcl Claflin Ranch fm. (mapped to include Recreation redbeds); Tkf Kino formation; Tpg Papago fm (below Kino ?); Tpu Undifferentiated — Mission Ore Zone = Claflin ?

- Major erosion — TUCSON SURFACE

PALEOZOIC CRETACEOUS

- Ka — Amole group
- Pls — Permian limestone. Includes Earp fm., Andrada fm., Scherrer fm., Concha ls
- CDI — Carboniferous and Devonian limestone. Includes Martin ls., Escabrosa ls., Horquilla ls
- Ꞓs — Cambrian Sediments. Includes Balsa qtzt., Cochise fm., Abrigo fm.

INTRUSIVE IGNEOUS ROCKS

- Tlg — Andesite, intrusive as dikes and small bodies. Several ages included together, some of which may be pre-ore.

POST-ORE / PRE-ORE

LOWER TERTIARY

- Tsg — Sierrita granite
- Tcl — Sierrita granite Coarse-grained type
- May be post-Cat Mtn rhyolite
- Tpr — Porphyry intrusive qtz-monz, monz
- Tbr — Biotite rhyolite
- Ts — Spherulitic rhyolite
- Tsr — Short's Ranch andesite
- Post-Cat Mtn rhyolite

PRE-CAMBRIAN

- pCgr — Mineral Hill granite

STRUCTURE

- Fault
- Contact
- Low angle fault. Thrust or gravity block
- Strike and dip of sediments
- Strike and dip of igneous flow layering
- Axis of Anticline
- Axis of Syncline
- Generalized bedding structure

NOTE: Structures dashed where obscure, dotted where covered. In the area of ASARCO drilling, structures shown solid where determined by substantial drilling data; dashed where only approx. known.

MINERALIZATION

- Vein, or mineralized fault
- Disseminated Cu bodies, >0.4 % Cu
- Limits of hypogene alteration. Dotted where uncertain.

American Smelting and Refining Company

GEOLOGY
of the
Porphyry Copper Belt

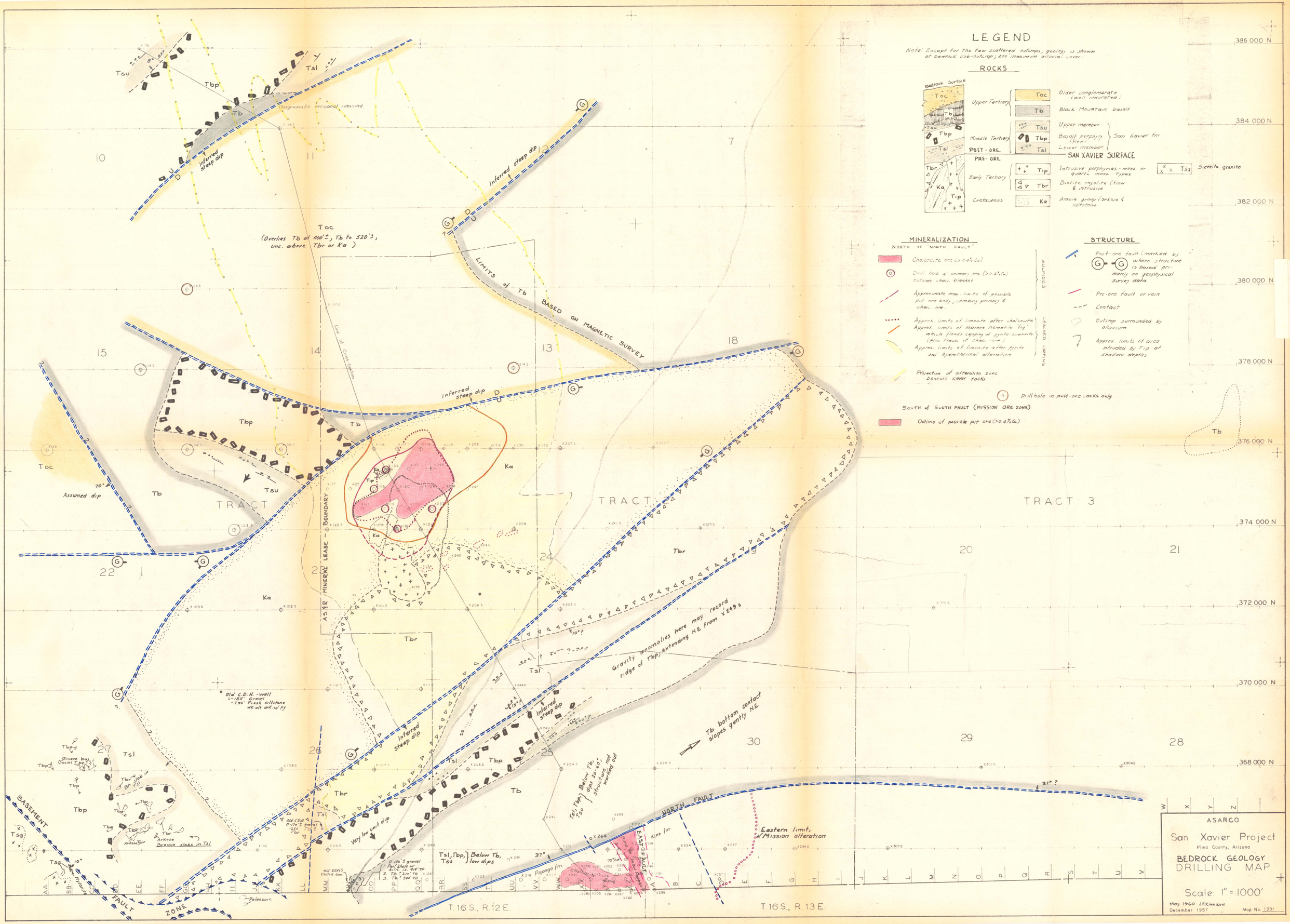
SAN XAVIER - MISSION

Pima County, Arizona

Approx. Scale: 1 inch = 1/2 mile

Compiled April, 1960
J.E. Kinnison

ATTACHMENT A


LEGEND
Note: Except for the few scattered outcrops, geology is shown at bedrock sub-outcrop, 200 maximum alluvial cover.
ROCKS
Bedrock Surface
Upper Tertiary
Toc Older conglomerate (well indurated)
Tb Black Mountain basalt
Middle Tertiary
Tsu Upper member
Tbp Basalt porphyry (flows)
Tsl Lower member
San Xavier fm
POST-ORE
SAN XAVIER SURFACE
PRE-ORE
Early Tertiary
Tip Intrusive porphyries - monz. or quartz monz. types
Tbr Biotite rhyolite (flow & intrusive)
Cretaceous
Ka Amole group (arkose & siltstone)
Tsg Sierrita granite
MINERALIZATION
NORTH OF "NORTH FAULT"
Chalcocite ore (>0.4% Cu)
Drill hole w primary ore (>0.4% Cu) outside chalc. blanket
Approximate max. limits of possible pit ore body, combing primary & chalc. ore.
SULFIDES
Approx. limits of limonite after chalcocite
Approx. limits of maroon hematite "cap" which floods capping of pyrite-limonite (Also traces of chalc. ore)
Approx. limits of limonite after pyrite and hydrothermal alteration
LEACHED CAPPING
Projection of alteration zone beneath cover rocks
Drill hole in post-ore rocks only
SOUTH OF SOUTH FAULT (MISSION ORE ZONE)
Outline of possible pit ore (>0.4% Cu)
STRUCTURE
Post-ore fault (marked by G where structure is based primarily on geophysical survey data.
Pre-ore fault or vein
Contact
Outcrop surrounded by alluvium
Approx. limits of area intruded by Tip at shallow depths
Diagramatic erosional remnant
Inferred steep dip
LIMITS of Tb BASED ON MAGNETIC SURVEY
Toc (Overlies Tb at 400'±, Tb to 520'±, unc. above Tbr or Ka)
Line of Cross section
Assumed dip
TRACT
TRACT 3
ASARCO MINERAL LEASE BOUNDARY
Gravity anomalies here may record ridge of Tbp extending NE from X249S
Tb bottom contact slopes gently NE
Old C.D.H. - well
Olivene bas (facies Tbp)
Arkose
Breccia slabs in Tsl
Old CDH
Very low unit dip
Tsl, Tbp, Tsu } Below Tb, low dips
Tsl, Tbp, Tsu } Below Tb dips 20-60°, structure not worked out
Papago fm.
Chalcocite
Kino fm.
Eastern limits of Mission alteration
NORTH FAULT
EAST FAULT
BASEMENT
FAULT ZONE
Paleozoic
T. 16 S., R. 12 E.
T. 16 S., R. 13 E.
386 000 N
384 000 N
382 000 N
380 000 N
378 000 N
376 000 N
374 000 N
372 000 N
370 000 N
368 000 N
ASARCO
San Xavier Project
Pima County, Arizona
BEDROCK GEOLOGY
DRILLING MAP
Scale: 1" = 1000'
May 1960 JEKinnison
December 1957
Map No. 1391