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Mining Records Curator
Arizona Geological Survey
416 W. Congress St., Suite 100
Tucson, Arizona 85701
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J. H. C.
OCT 27 1966

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

October 26, 1966

MR. WES
READ AND RETURN
PREPARE ANSWERS ____ HANDLE ____
FILE ____ INITIALS ____

Mr. R. B. Meen, Manager
Southwestern Mining Department
American Smelting and Refining Company
P. O. Box 5795
Tucson, Arizona 85703

SILVER BELL UNIT
GEOLOGY OF WILD HOG-COPPER
BUTTE AREA WEST OF OXIDE
PIT, by J. A. Briscoe

Dear Sir:

Attached for your files is a memorandum by James A. Briscoe, Geologist, on a study of the area west of Oxide pit.

The purpose of the study was to correlate the geologic information found in the Wild Hog-Copper Butte area with the North Butte area for the proposed diamond drilling in North Butte. The diamond drilling is now in progress.

Very truly yours,

Original Signed By
D. R. JAMESON

D. R. JAMESON
Superintendent

DRJ:jca

cc: TASnedden
KRichards

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL UNIT
Silver Bell, Arizona

August 25, 1966

MEMORANDUM TO: Mr. D. R. Jameson, Superintendent

Subject: THE RELATION OF PRIMARY PYRITE AND CHALCOPYRITE CONCENTRATION TO THE DEPOSITION OF ORE GRADE CHALCOCITE, AND THE DEVELOPMENT OF ATYPICAL LEACHED CAPPING IN THE WILD HOG-COPPER BUTTE AREA WEST OF OXIDE PIT.

Drilling in the Wild Hog-Copper Butte area, which has outlined a possible orebody of some 11,500,000 tons, has also revealed some interesting and possibly important relationships between rock type, grade of primary chalcopyrite, percent of pyrite, and the locus of ore grade chalcocite enrichment. The pyrite-chalcopyrite ratio in this area also has marked effects on the appearance of leached capping overlying ore.

The first thing noted during the drilling was that rock type appears to have considerable effect on ore grade, although in the Oxide Pit area ore grade has always been considered to be independent of rock type.

The following is an average of the primary chalcopyrite grade encountered in the various rock types during the drilling.

Rock Type	No. of Holes in which Primary Mineral was encountered	Average Grade of Protore
Syenoediorite Porphyry	8	0.23
Alaskite	29	.16
Monzonite Porphyry	25	.11
Dacite Porphyry	3	.04

It should be noted that the above order of favorability will not invariably hold for every assay intercept, ie: In places (particularly on the ridge to the south of Wild Hog-Copper Butte) monzonite porphyry appeared more favorable than alaskite. Generally however these relations appear valid.

Wild Hog-Copper Buttes area has been considered a poor drilling risk in the past because of the strong copper oxide staining in the alaskite, and lack of live limonite. It was assumed that all the copper, because of insufficient strength of the leaching solutions, had remained in the capping, and no chalcocite blanket could be expected. In addition weak brown limonite stain indicated that the rock had been poorly mineralized to start with.

Drilling in the alaskite revealed ore grade chalcocite on chalcopyrite finely disseminated along crystal boundary and quartz veinlets. The unusual aspect of the rock was its extremely low pyrite content ranging from barely a

trace to sparse amounts. The total sulfide content in this area amounts to less than 2% (possibly less than 1% in places), accounting for the weak limonite staining of the alaskite, and prominent green copper oxide in the capping.

On the ridge southeast of the Buttes (see Plate 4) green copper oxide stain diminishes and disappears and red hematite stain, limonite and live limonite increase. Drilling in this area shows that protore grade is somewhat lower but pyrite content is substantially higher (Plates 2 & 3), with total sulfide content being about 3-5% or about equal to that in Oxide Pit.

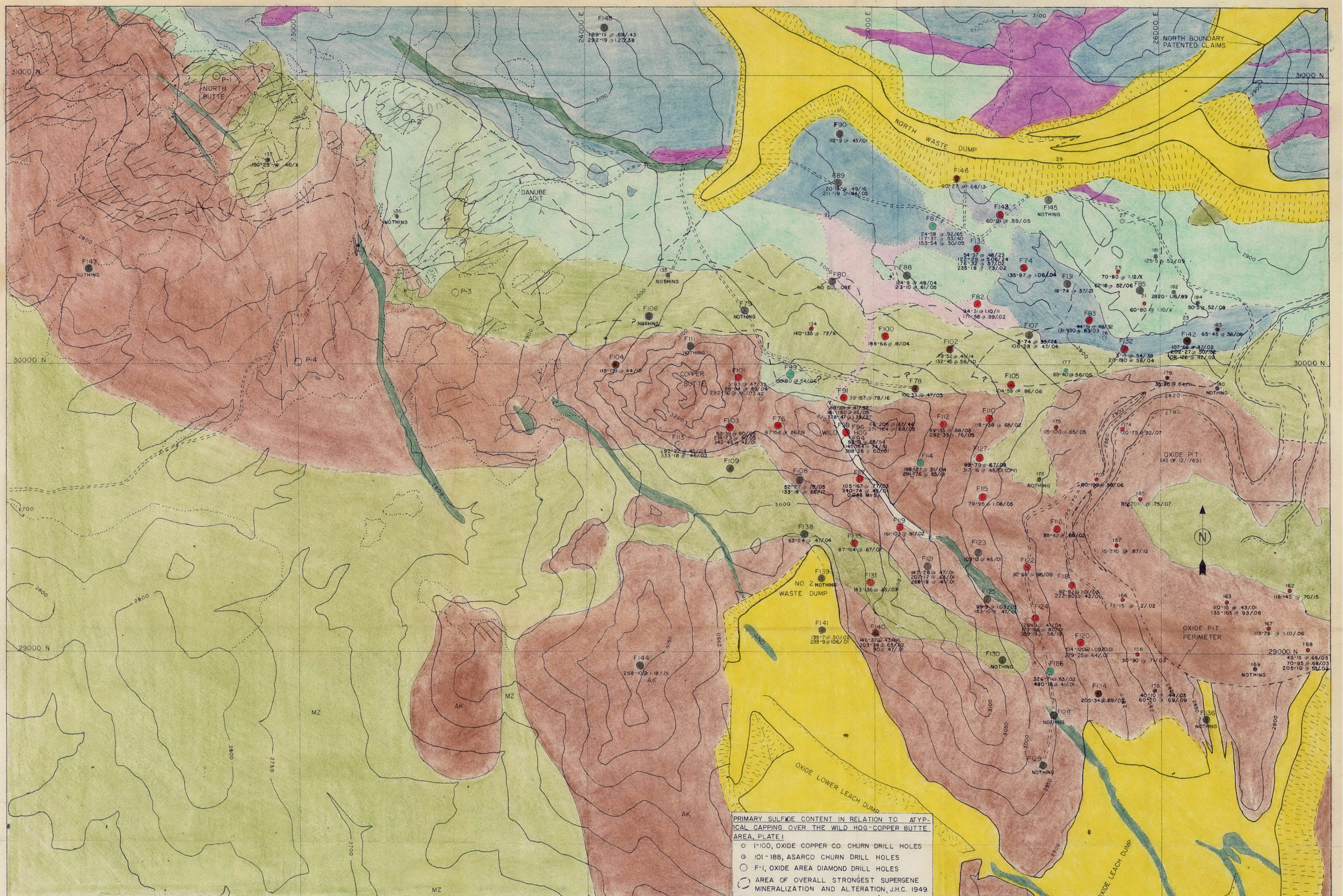
CONCLUSION:

The apparent reason for the presence of ore under the Wild Hog-Copper Butte area is the higher grade of the chalcopyrite protore, being in places little more than a tenth of a percent below cut-off grade of 0.40% copper. There is also a possibility that enrichment didn't come from above the Wild Hog-Copper Butte area, but was from lateral migration of copper solutions from the Oxide Pit or other areas. This is important because of the presence of similar capping over the North Butte area. If the ore in the Wild Hog-Copper Butte area was dervied from downward moving solutions then ore can be expected under similar capping in the North Butte area. If, however, the ore was derived from laterally moving solutions then ore may or may not be found under similar capping in the North Butte area depending on whether or not similar conditions prevailed. The drilling program planned for the near future in the North Butte area should show which of the hypotheses is correct. If the downward movement idea is indicated then there is a chance of a possible commercial connection of the two areas.

The initial drilling program proposed for the North Butte area consists of holes P-1 through P-5. Hole P-1 is located over good typical live-limonite capping in alaskite. Holes P-2 and P-3 are located on molybdenum geochemical anomolies. Hole P-4 is located on alaskite with oxide capping similar to that of the Wild Hog-Copper Buttes area. If P-4 hits ore then the Wild Hog-Copper Butte capping can be considered a valid indicator of low grade copper mineralization and more holes can be drilled in similar rock around P-4.

James A. Briscoe
Geologist

JAB:jca



PRIMARY SULFIDE CONTENT IN RELATION TO ATYPICAL CAPPING OVER THE WILD HOG-COPPER BUTTE AREA, PLATE I

- 1-100, OXIDE COPPER CO. CHURN DRILL HOLES
- 101-188, ASARCO CHURN DRILL HOLES
- F-1, OXIDE AREA DIAMOND DRILL HOLES
- AREA OF OVERALL STRONGEST SUPERGENE MINERALIZATION AND ALTERATION, J.H.C. 1949.

- ANDESITE DIKES (POST MINERAL)
- DIKE ROCKS (DIORITE, ANDESITE, PORPHYRY, ETC.) PRE-MINERAL
- MZ QUARTZ MONZONITE. PRE-MINERAL
- SP SYENODIORITE PORPHYRY " " "
- DP DACITE PORPHYRY " " "
- AK ALASKITE. PRE-MINERAL
- PALEOZOIC SEDIMENTARIES, CHIEFLY LIMESTONE. " " "
- OBSERVED CONTACT
- INFERRED CONTACT
- CONCEALED CONTACT

MINERALIZED FAULTS OR SHEETED ZONES

- FISSURE HAVING VERTICAL OR NEARLY VERTICAL DIP
- 60° TO 80° DIP.
- 60° TO 40° DIP.

AFTER J.H. COURTRIGHT, 1949
SYENODIORITE PORPHYRY ADDED BY J.A. BRISCOE, SEPT. 1966.

- ORE HOLE, 40' OR MORE FEET OF +0.40% COPPER, ENOUGH TO CARRY THE OVERBURDEN. TOTAL COPPER OVER OXIDE COPPER, F-119, 161-103 @ .91/.02.
- MARGINAL HOLE, 40' OR MORE FEET OF +0.40% COPPER, BUT NOT ENOUGH TO CARRY THE OVERBURDEN.
- LESS THAN 40' OF +0.40% COPPER.
- NONE TO SHORT RUNS OF +0.40% COPPER.

AMERICAN SMELTING & REFINING CO.
SILVER BELL UNIT

WEST OXIDE AREA

SCALE	DRAWN	DATE	FILE NO.
1" = 200'	T.B.A.	8-24-66	S-6-17D

PLATE I

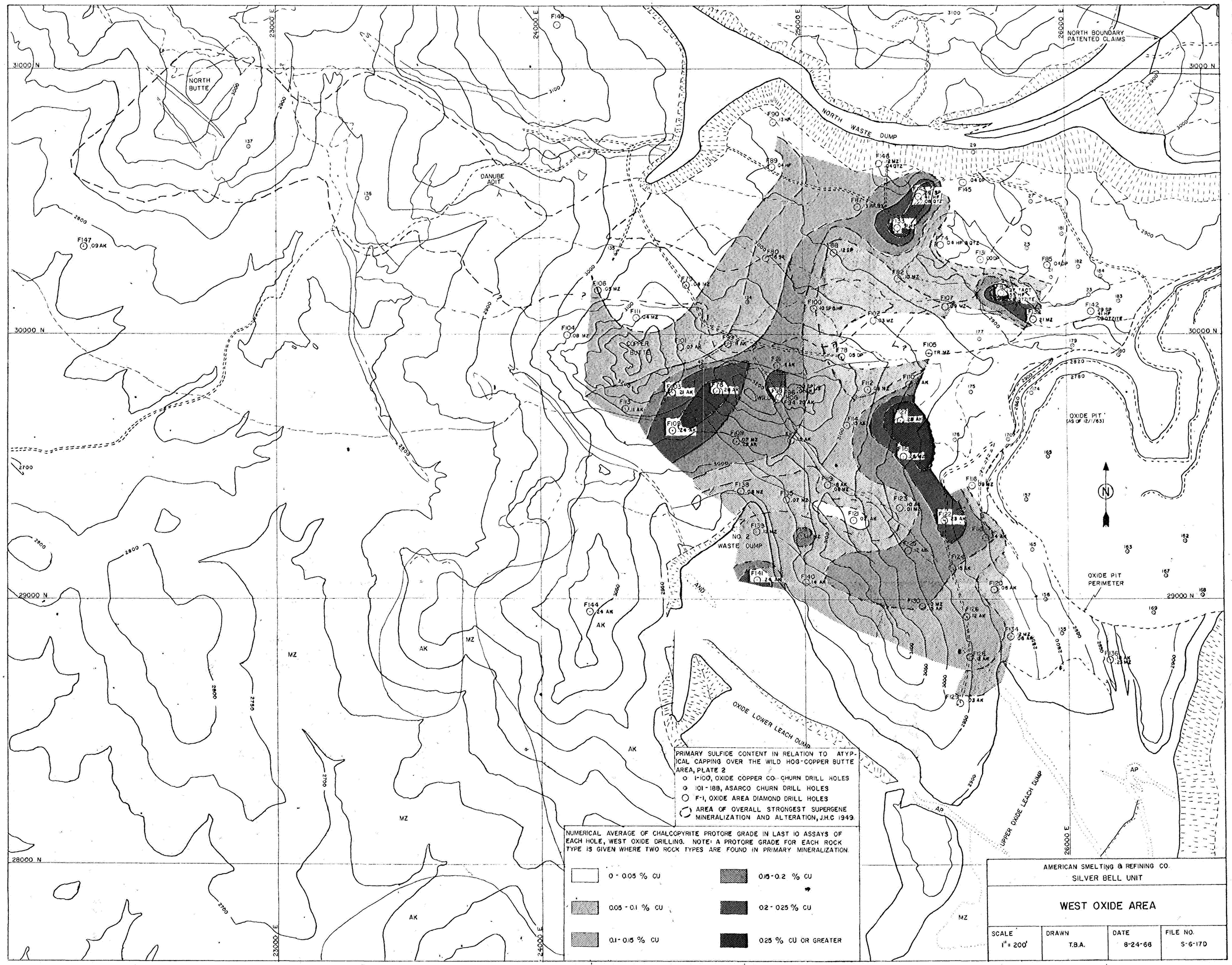

NORTH BUTTE
DANUBE ADIT
NORTH WASTE DUMP
NORTH BOUNDARY PATENTED CLAIMS
COPPER PIT
NO. 2 WASTE DUMP
OXIDE PIT (AS OF 12/1/63)
OXIDE PIT PERIMETER
OXIDE LOWER LEACH DUMP
UPPER OXIDE LEACH DUMP
31000 N
30000 N
29000 N
28000 N
23000 E
24000 E
25000 E
26000 E
PRIMARY SULFIDE CONTENT IN RELATION TO ATYPICAL CAPPING OVER THE WILD HOG-COPPER BUTTE AREA, PLATE 2
1-100, OXIDE COPPER CO. CHURN DRILL HOLES
101-188, ASARCO CHURN DRILL HOLES
F-1, OXIDE AREA DIAMOND DRILL HOLES
AREA OF OVERALL STRONGEST SUPERGENE MINERALIZATION AND ALTERATION, J.H.C 1949.
NUMERICAL AVERAGE OF CHALCOPYRITE PROTORE GRADE IN LAST 10 ASSAYS OF EACH HOLE, WEST OXIDE DRILLING. NOTE: A PROTORE GRADE FOR EACH ROCK TYPE IS GIVEN WHERE TWO ROCK TYPES ARE FOUND IN PRIMARY MINERALIZATION.
0 - 0.05 % CU
0.05 - 0.1 % CU
0.1 - 0.15 % CU
0.15 - 0.2 % CU
0.2 - 0.25 % CU
0.25 % CU OR GREATER
AMERICAN SMELTING & REFINING CO.
SILVER BELL UNIT
WEST OXIDE AREA
SCALE 1" = 200'
DRAWN T.B.A.
DATE 8-24-66
FILE NO. S-6-17D

PLATE 2

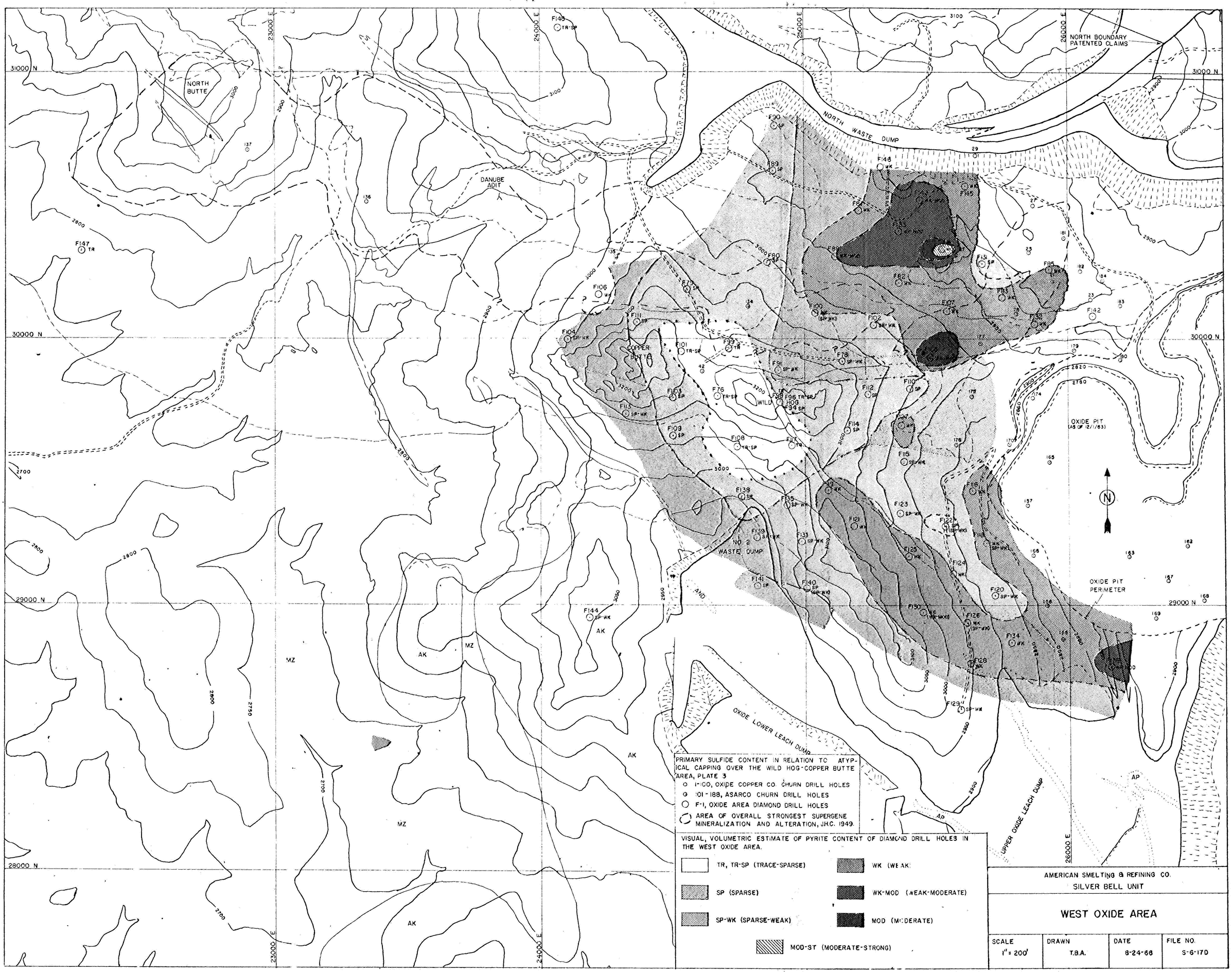

NORTH BUTTE
DANUBE ADIT
NORTH WASTE DUMP
NORTH BOUNDARY PATENTED CLAIMS
COPPER BUTTE
WILD HOG
NO 2 WASTE DUMP
OXIDE PIT (AS OF 12/1/63)
OXIDE PIT PERIMETER
OXIDE LOWER LEACH DUMP
UPPER OXIDE LEACH DUMP
MZ
AK
AP
31000 N
30000 N
29000 N
28000 N
23000 E
24000 E
25000 E
26000 E
PRIMARY SULFIDE CONTENT IN RELATION TO ATYPICAL CAPPING OVER THE WILD HOG-COPPER BUTTE AREA, PLATE 3
1-100, OXIDE COPPER CO. CHURN DRILL HOLES
101-188, ASARCO CHURN DRILL HOLES
F-1, OXIDE AREA DIAMOND DRILL HOLES
AREA OF OVERALL STRONGEST SUPERGENE MINERALIZATION AND ALTERATION, J.H.C. 1949.
VISUAL, VOLUMETRIC ESTIMATE OF PYRITE CONTENT OF DIAMOND DRILL HOLES IN THE WEST OXIDE AREA.
TR, TR-SP (TRACE-SPARSE)
SP (SPARSE)
SP-WK (SPARSE-WEAK)
WK (WEAK)
WK-MOD (WEAK-MODERATE)
MOD (MODERATE)
MOD-ST (MODERATE-STRONG)
AMERICAN SMELTING & REFINING CO.
SILVER BELL UNIT
WEST OXIDE AREA
SCALE 1" = 200'
DRAWN T.B.A.
DATE 8-24-68
FILE NO. S-6-17D

PLATE 3

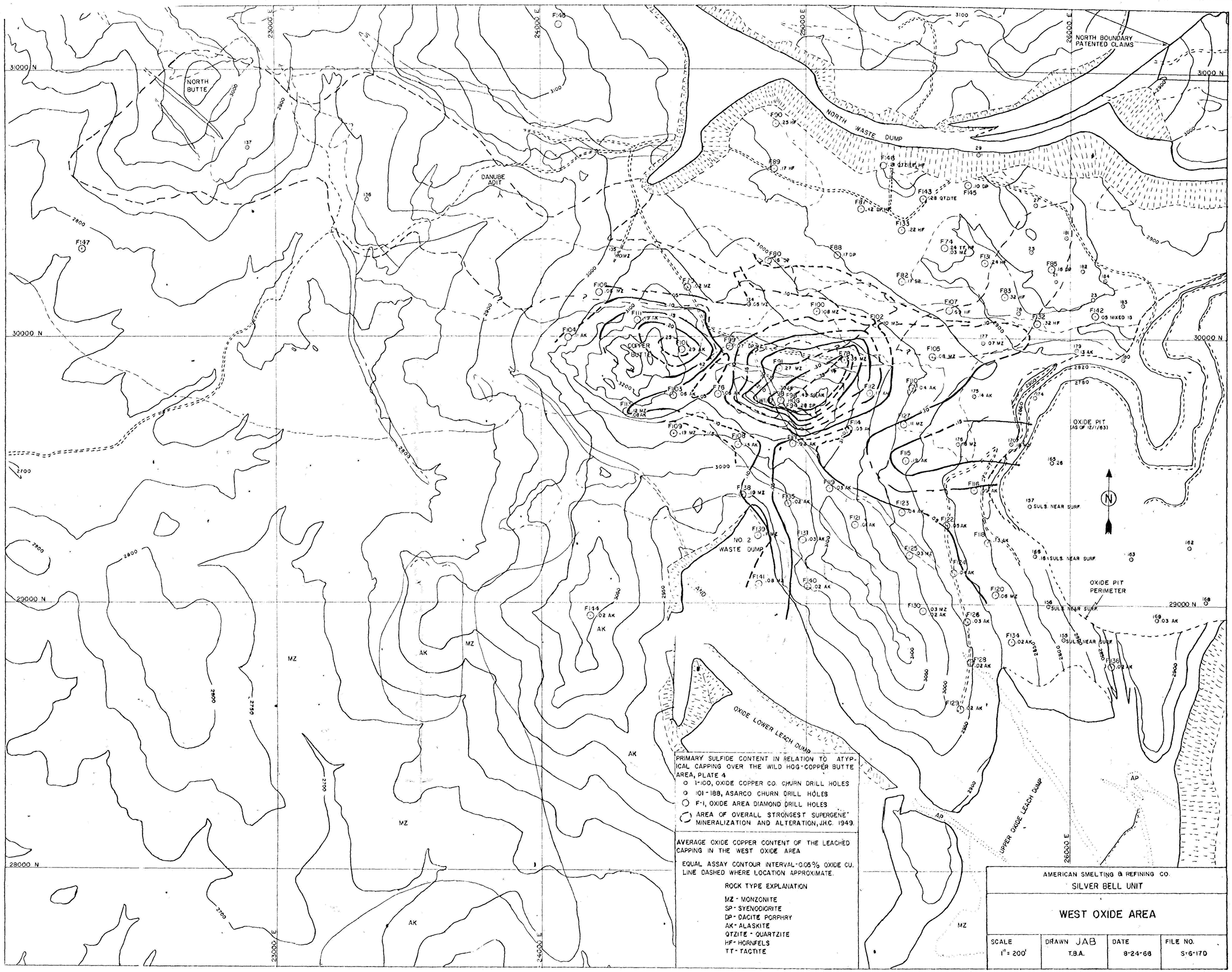
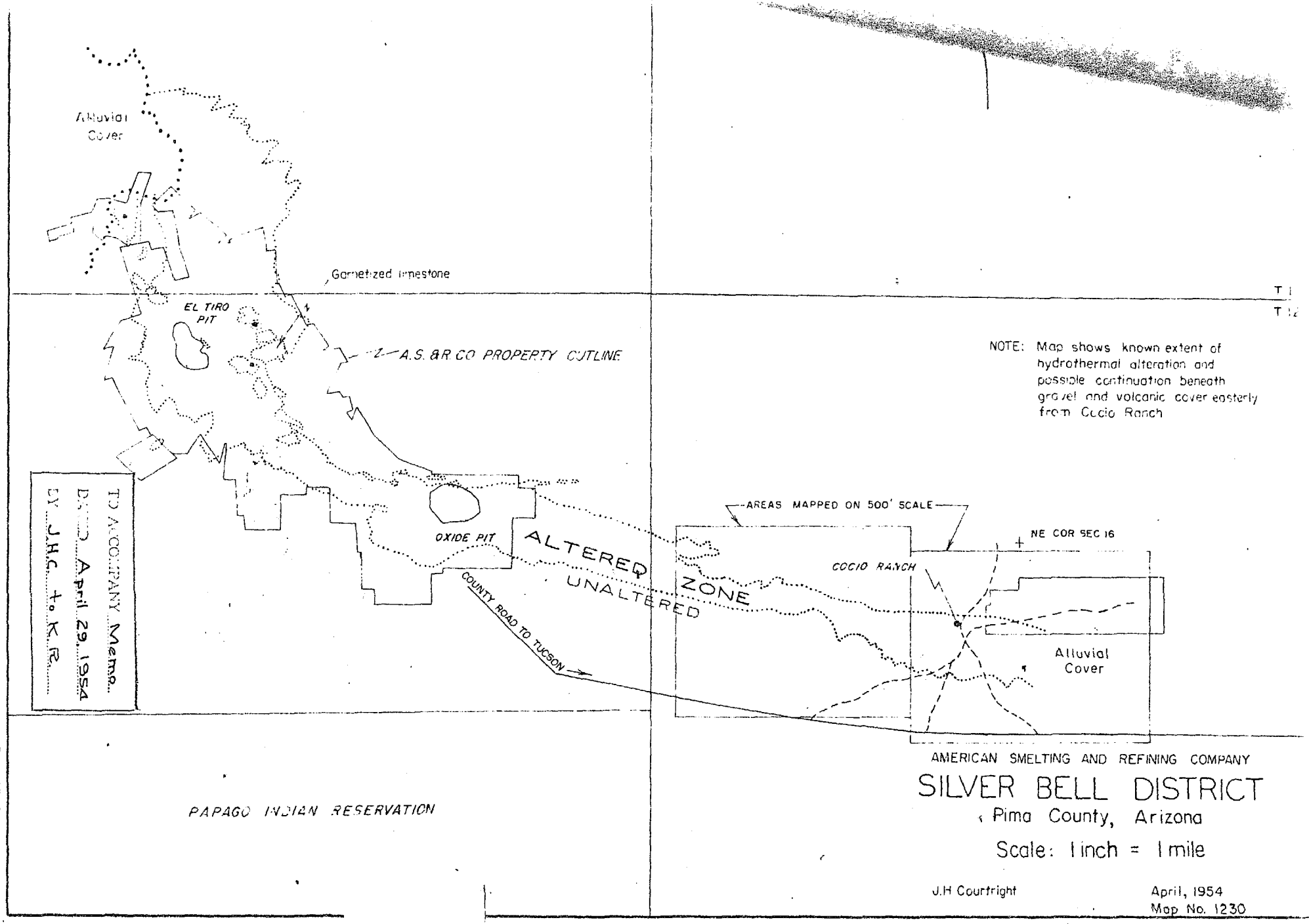

NORTH BUTTE
DANUBE ADIT
COPPER BUTTE
WILD HOG
NORTH WASTE DUMP
NO. 2 WASTE DUMP
OXIDE PIT (AS OF 12/1/63)
OXIDE PIT PERIMETER
OXIDE LOWER LEACH DUMP
UPPER OXIDE LEACH DUMP
NORTH BOUNDARY PATENTED CLAIMS
31000 N
30000 N
29000 N
28000 N
23000 E
24000 E
25000 E
26000 E
MZ
AK
AP
PRIMARY SULFIDE CONTENT IN RELATION TO ATYPICAL CAPPING OVER THE WILD HOG-COPPER BUTTE AREA, PLATE 4
1-100, OXIDE COPPER CO. CHURN DRILL HOLES
101-188, ASARCO CHURN DRILL HOLES
F-1, OXIDE AREA DIAMOND DRILL HOLES
AREA OF OVERALL STRONGEST SUPERGENE MINERALIZATION AND ALTERATION, J.H.C. 1949.
AVERAGE OXIDE COPPER CONTENT OF THE LEACHED CAPPING IN THE WEST OXIDE AREA
EQUAL ASSAY CONTOUR INTERVAL-0.05% OXIDE CU. LINE DASHED WHERE LOCATION APPROXIMATE.
ROCK TYPE EXPLANATION
MZ - MONZONITE
SP - SYENODIORITE
DP - DACITE PORPHRY
AK - ALASKITE
QTZITE - QUARTZITE
HF - HORNFELS
TT - TACTITE
AMERICAN SMELTING & REFINING CO.
SILVER BELL UNIT
WEST OXIDE AREA
SCALE 1" = 200'
DRAWN JAB T.B.A.
DATE 8-24-68
FILE NO. S-6-17D

PLATE 4



TO ACCOMPANY Memo.
DATED April 29, 1954
BY J.H.C. to K.R.

ATTACHMENT A

ATTACHMENT A

◇ ◇ ◇ STRUCTURE AND MINERALIZATION AT SILVER BELL, ARIZONA

BY KENYON RICHARD AND JAMES H. COURTRIGHT

INTRODUCTION

This material was originally published (12) in November 1954. Exploration and mining during subsequent years have provided additional information; accordingly, a number of revisions of text and figures are included herein. Basic concepts, however, remain essentially the same as originally presented.

Watson (oral communication, 1962) has prepared a doctoral dissertation based on detailed mapping in the Silver Bell Mountains. Mauger et al. (9) are making potassium-argon age determinations of most of the igneous rocks in the district. These two lines of research should, among other things, materially improve upon the knowledge of certain age relations that are noted only briefly herein.

Silver Bell is 35 airline miles northwest of Tucson, Arizona, in a small rugged range rising above the extensive alluvial plains of this desert region. Its geographical relation to other porphyry copper deposits of the Southwest is shown on the inset map in the lower left corner of figure 1. The climate is semiarid. Altitudes range from 2,000 to 4,000 feet.

Opening of the Boot mine, later known as the Mammoth, in 1865, was the first event of note in the district's history. Oxidized copper ores containing minor silver-lead values were mined from replacement deposits in garnetized limestone and treated in local smelters. Copper production had approached 45 million pounds by 1909 when the disseminated copper possibilities in igneous rocks were recognized. Extensive churn-drill exploration was carried out during the next 3 years and resulted in the partial delineation of two copper sulfide deposits—the Oxide and El Tiro. Although the then submarginal tenor discouraged exploitation of these disseminated deposits, selective mining of ore bodies in the sedimentary rocks continued intermittently until 1930, providing a production total of about 100 million pounds of copper.

The American Smelting and Refining Co. began exploratory and check drilling in 1948 and subsequently made plans for mining and milling the Oxide and El Tiro ore bodies at the rate of 7,500 tons per day. Production began in 1954 and has been maintained at a rate of about 18,000 tons of copper annually.

GENERAL GEOLOGY

Formations ranging in age from Precambrian to Recent are exposed near Silver Bell. The more erosion-resistant of these—Paleozoic limestone and Tertiary(?) volcanics—predominate in the scattered peaks and ridges comprising the Silver Bell Mountains. Porphyry copper mineralization occurs along the southwest flank of these mountains in hydrothermally altered igneous rocks. These are principally intrusives which cut Tertiary(?), Cretaceous, and older sediments and are considered to be components of the Laramide Revolution.

For three-fourths of its length, the zone of alteration strikes west-northwest (fig. 1). There now is no single structure that accounts for this alignment. However, indirect evidence suggests that a fault representing a line of profound structural weakness existed in this position prior to the advent of Laramide intrusive activity. This line will hereafter be referred to as the "major structure." It was largely obliterated by the Laramide intrusive bodies, but it effected a degree of control on their emplacement, as evidenced by their shapes and positions. The influence of fault structures on the shapes of intrusives in other porphyry copper districts has been noted by Butler and Wilson (2).

As shown on the inset map on figure 2, a fault of parallel trend and considerable displacement lies to the north. This fault is now marked by a line of small intrusive bodies. To the south is a third fault of large displacement. Evidence of its age in relation to the Laramide intrusions and mineralization is not recognized, but its conformance in strike with the other two major faults is significant. These three breaks establish a pronounced trend of regional faulting, and it has been suggested (11) that they be named, from south to north, the Waterman thrust, the Silver Bell fault zone, and the Ragged Mountains fault. The two northerly ones are high angle, and the southerly one may be

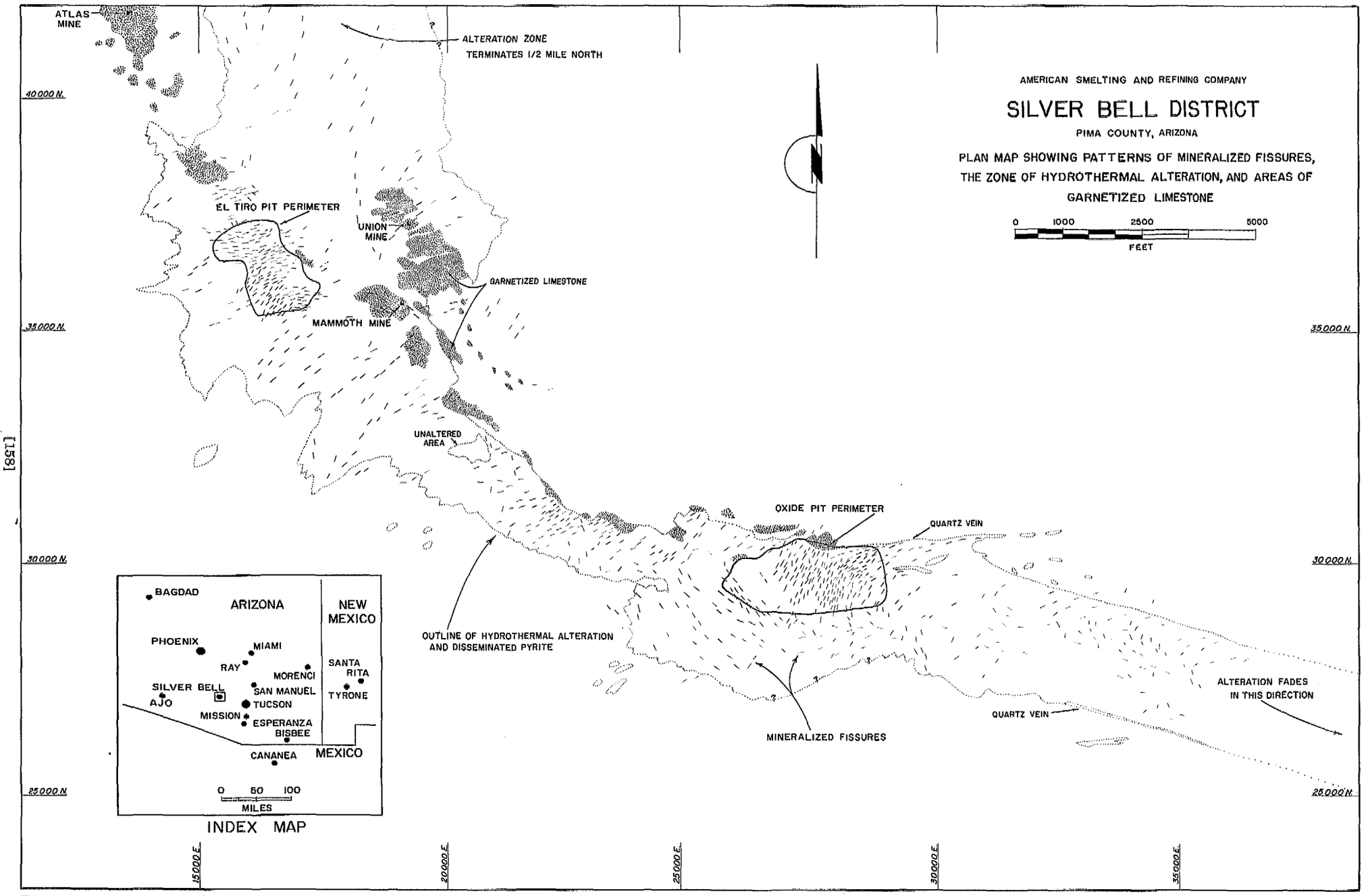

AMERICAN SMELTING AND REFINING COMPANY
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA
PLAN MAP SHOWING PATTERNS OF MINERALIZED FISSURES, THE ZONE OF HYDROTHERMAL ALTERATION, AND AREAS OF GARNETIZED LIMESTONE
0 1000 2500 5000
FEET
ATLAS MINE
ALTERATION ZONE TERMINATES 1/2 MILE NORTH
EL TIRO PIT PERIMETER
UNION MINE
GARNETIZED LIMESTONE
MAMMOTH MINE
UNALTERED AREA
OXIDE PIT PERIMETER
QUARTZ VEIN
OUTLINE OF HYDROTHERMAL ALTERATION AND DISSEMINATED PYRITE
MINERALIZED FISSURES
QUARTZ VEIN
ALTERATION FADES IN THIS DIRECTION
40000 N.
35000 N.
30000 N.
25000 N.
15000 E.
20000 E.
25000 E.
30000 E.
35000 E.
BAGDAD
ARIZONA
NEW MEXICO
PHOENIX
MIAMI
RAY
MORENCI
SANTA RITA
SILVER BELL
AJO
SAN MANUEL
TUCSON
TYRONE
MISSION
ESPERANZA
BISBEE
CANANEA
MEXICO
0 50 100
MILES
INDEX MAP

FIGURE 1.

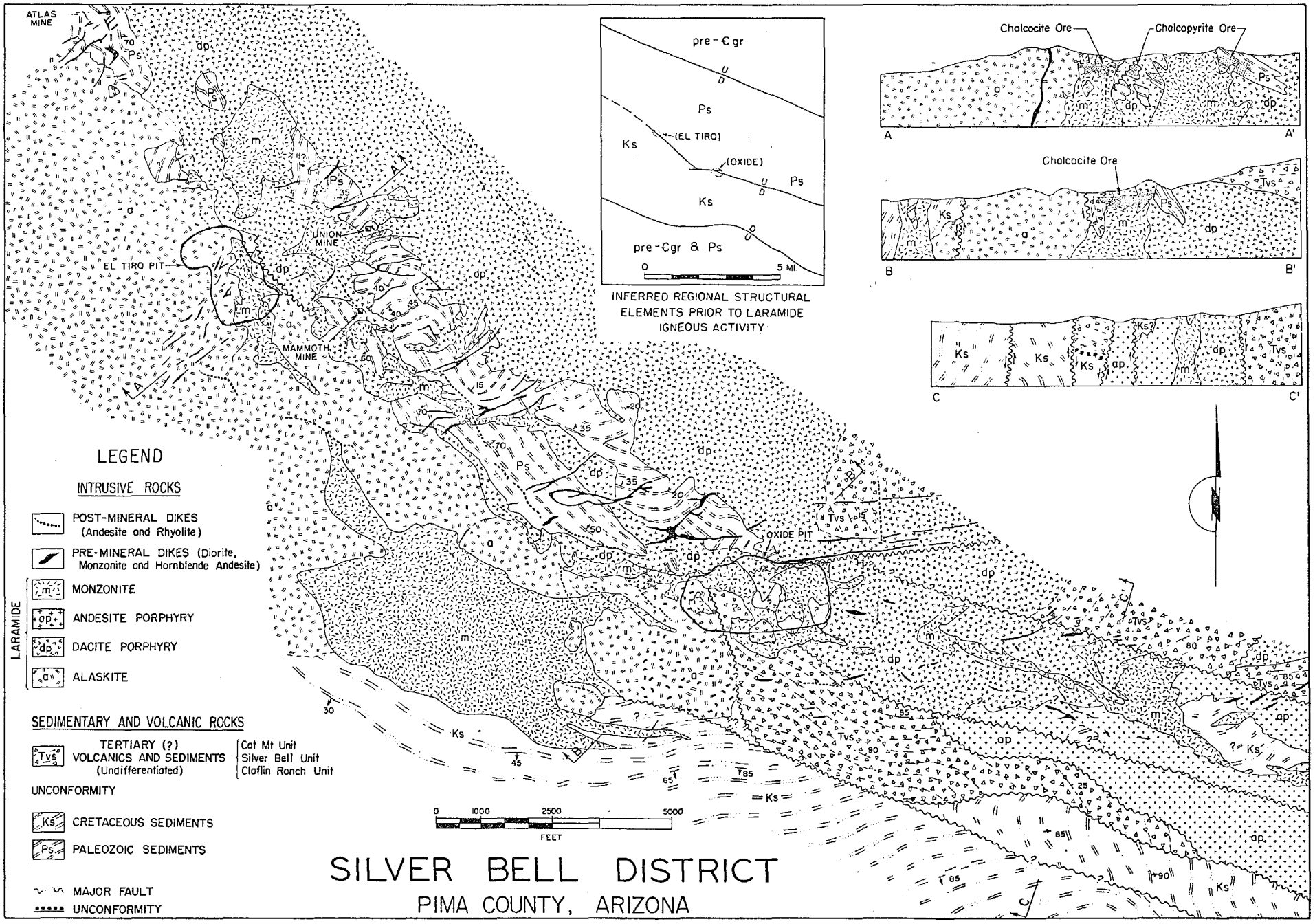

ATLAS MINE
EL TIRO PIT
UNION MINE
MAMMOTH MINE
OXIDE PIT
pre-€gr
Ps
Ks
(EL TIRO)
(OXIDE)
pre-€gr & Ps
0 5 MI
INFERRED REGIONAL STRUCTURAL ELEMENTS PRIOR TO LARAMIDE IGNEOUS ACTIVITY
Chalcocite Ore
Chalcopyrite Ore
A A'
B B'
C C'
LEGEND
INTRUSIVE ROCKS
POST-MINERAL DIKES (Andesite and Rhyolite)
PRE-MINERAL DIKES (Diorite, Monzonite and Hornblende Andesite)
LARAMIDE
MONZONITE
ANDESITE PORPHYRY
DACITE PORPHYRY
ALASKITE
SEDIMENTARY AND VOLCANIC ROCKS
TERTIARY (?) VOLCANICS AND SEDIMENTS (Undifferentiated)
Cat Mt Unit
Silver Bell Unit
Claflin Ranch Unit
UNCONFORMITY
CRETACEOUS SEDIMENTS
PALEOZOIC SEDIMENTS
MAJOR FAULT
UNCONFORMITY
0 1000 2500 5000
FEET
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA

FIGURE 2.

bench faces as a sharply defined highly irregular interface. Only rarely is there a transition zone of mixed sulfide and oxide copper minerals. Some of the irregularities of the base of oxidation are caused by displacement on post-chalcocite faults, but most seem to be due to variations in rock permeability. This is evidenced by the dense siliceous character of a few sulfide remnants occurring well up in the leached zone and by leached indentations of the sulfide zone along many of the fissures.

The present water table at Silver Bell is well below the chalcocite zone, a condition that exists in many of the porphyry copper districts (4). This indicates that the Silver Bell chalcocite zone now is in an environment of oxidation, and it should be undergoing leaching rather than enrichment. This current climatic cycle may have been relatively short and dry and may have caused only minor modifications of the chalcocite blanket.

The base of oxidation conforms in general shape to modern topography, although local relief is more than 200 feet. This rude conformance would seem to require a relatively wet climate with the water table being no more than a few tens of feet below the ground surface as the modern physiography developed.

In the early days at Morenci, Lindgren (7) observed that oxidation and leaching had, in some instances, penetrated along fissures down through the chalcocite into underlying primary sulfides; he also observed that erosion of Chase Creek Canyon had left the principal chalcocite zones stranded high above the canyon bottom, indicating that the chalcocite formed originally about an ancient water table several hundred feet above the present water table. Although erosion at Silver Bell has not penetrated as deeply as at Morenci, its chalcocite zone currently is in a similar unbalanced environment of oxidation with no appreciable enrichment now taking place. Reshaping of the upper surface of chalcocite zones in both districts to conform to the existing ground surface appears, then, to have occurred during formation of the modern topography but at some time prior to the current dry climatic cycle.

LEACHED OUTCROPS

In the formation of many disseminated chalcocite deposits the enrichment process is presumed to have taken place progressively—copper having been repeatedly dissolved, carried downward, and precipitated. It has been well established by Blanchard (1), Locke (8), and others that under these conditions "limonites" of certain colors and textures are left behind in the leached capping as evidence of the preexisting chalcocite. The Silver Bell district provides exceptionally good examples of this phenomenon, but limonites of chalcocite derivation are not confined to the outcrops over the ore bodies. They are widely dispersed through the zone of alteration. Proper interpretation of their significance in respect to ore possibilities has rested mainly on quantitative rather than qualitative appraisal. Mapping of the Silver Bell outcrops on this basis has provided a valuable guide in exploration drilling for the last 15 years. Results have demonstrated that the pattern of relatively strong chalcocite at depth is reflected in the outcrops by the distribution and abundance of diagnostic limonites.

It may be of interest at this point to mention the ancient excavations that are numerous in the outcrops of the mineralized zone at Silver Bell. There is evidence indicating that they are several centuries old. Since there are no precious metals or visible copper in these cuts, it is plausible to assume that the limonite and clay minerals were considered valuable, perhaps for pottery or warpaint. Thus, in the history of leached-outcrop investigations, it seems that some early Arizona Indian tribe deserves at least honorable mention.

Previous work and acknowledgments.—The first scientific study of the district was published in 1912 by Stewart (15). Considerable field and laboratory work has been done in more recent years by several groups and individuals, including the writers, all reporting privately to the American Smelting and Refining Co. Roland Blanchard conducted leached-outcrop studies in part of the area. Harrison Schmitt, H. M. Kingsbury, and L. P. Entwistle mapped structure and mineralization in the central part of the district. P. F. Kerr studied the alteration features and later published a comprehensive paper (6) on the district. Thomas Mitcham mapped structural features in the surrounding area. The writers have drawn considerably on these and other unpublished data, particularly in compilation of the geologic map. The high quality and usefulness of this material is gratefully acknowledged, but unfortunately it is not feasible to give special individual credits. Thanks are due the American Smelting and Refining Co. for permission to publish this paper.

LITERATURE CITED

1. Blanchard, Roland, 1939, Interpretation of leached outcrops: Jour. Chem., Met. and Min. Soc. of S. Africa, May.
2. Butler, B. S., and Wilson, E. D., 1938, Clifton-Morenci district: Arizona Bur. Mines Bull. 145, p. 74.
3. Damon, et al., 1963, Correlation and chronology of ore deposits and volcanic rocks: Univ. Arizona, Ann. Progress Report no. 5.
4. Emmons, W. H., 1917, The enrichment of ore deposits: U.S. Geol. Survey Bull. 625.
5. Holmes, Arthur, 1960, A revised geologic time-scale: Edinburgh Geol. Soc. Trans., v. 17, p. 183–216.

pyrite and chalcopyrite. Although occurring as discrete grains, they are more abundant—accompanied by quartz—in systems of veinlets or seams that are usually near vertical in attitude and persistently parallel. Varying in thickness from paper thin to several inches and in spacing from inches to several feet, these thin sulfide sheets occur as groups of various sizes in the narrow northwest-trending zone of hydrothermal alteration. (Due to the small scale, any single line in the pattern of "Mineralized Fissures" on figure 1 diagrammatically represents a large number of parallel veinlets, rather than an individual.) In detail the average individual fissure appears as a thin quartz-sulfide seam encased by a rather uniform band of sericite. The fissures are predominantly oriented in the northeast quadrant; a small proportion strike northwest and a few are random. From a broad viewpoint there are, among these systems or groups, no intersections of consequence. Within a group, changes in strike occur gradually and result in curving trends. As noted earlier, these groups of mineralized fissures are distributed along the major structural line, and it is assumed that they were formed in response to deep-seated uniform stress related to that line.

At least a few hundredths of 1 percent copper is present nearly everywhere in the zone of disseminated sulfides; better values occur where there are veinlets; and the best values occur where the veinlets are close spaced. The two comparatively large groups of these close-spaced structures coincide with the positions of the two ore bodies (fig. 1). However, the actual structural, mineralogical, and lithological distinctions among these and other smaller groups are minor, and the factors that controlled the position and size of these two groups are not clearly evident. A strong east-west fault that terminates in the Oxide area may have influenced the concentration of fracturing there, and at El Tiro the sharp bend in the alteration zone and the group of northeast-striking dikes likewise may indicate a cross-trending line of weakness that localized stresses. Nonetheless, the importance of these structural conditions is not clearly demonstrated, and no good evidence is found to explain the structural cause of the more intense fracturing which localized the two ore bodies in their present positions in preference to other locations along the major structural line.

Outside the zone of alteration the dacite porphyry is finely fractured and jointed in most of its large exposed area. In sharp contrast to the systems of parallel fissures in the alteration zone, these fractures in the dacite porphyry are almost completely of random orientation; parallelisms are rare and traceable for only a few inches or feet. They are pre-mineral in age where they are found in the alteration zone in the westerly and southwesterly parts of the dacite porphyry. It would seem that in physical aspect this formation was exceptionally well prepared to be mineralized—perhaps better than the rocks of the ore-zone proper. The fact that it was mineralized only locally may be accounted for, in part, by the absence of *systematic* fractures. That is, only the systems of parallel fractures were connected with the deep-seated source of mineralization, and the pervasive breaking of the dacite porphyry did not alone qualify it for mineralization.

Excepting the post-mineral andesite dikes, all igneous rocks in the narrow northwest-trending zone shown on figure 1 are hydrothermally altered. Variations in the intensity or in the completeness of the process have been subdivided by Kerr (6) into five stages. His analysis demonstrated, among other things, that the known ore bodies are in the more strongly altered areas. The area outlined by the writers on figure 1 includes all degrees of alteration, but no differentiation is made. It merely represents the areal extent of bleached-appearing igneous rocks showing evidence in the leached outcrops of pre-existing disseminated sulfides—principally pyrite. The transition to relatively fresh rock is quite sharp in many places, particularly along the contact with sedimentary rocks and on the faults in the southeast part. However, along most of the southwest margin the transition is gradational, and the limit is an arbitrary line.

Tactite—composed essentially of garnet, diopside, other lime-silicate minerals, and quartz—is confined to a narrow belt along the southwest margin of the limestone pendants, except near the Mammoth and Union mines where it has replaced the full width of the sedimentary block. There, parts of the tactite contain sufficient disseminated chalcopyrite to be classed as low-grade ore. As in the Mission deposit (13), this mineralized tactite is regarded by the writers as having been formed by the same processes that altered and mineralized the intrusive rocks. Thus, it is a product of hydrothermal metasomatism rather than contact metamorphism caused by the dacite porphyry and the monzonite as proposed by Stewart (15).

SUPERGENE ENRICHMENT

The two ore deposits consist of rudely tabular accumulations of chalcocite from 100 to 200 feet thick. Lying beneath about 100 feet of leached capping, they were formed by twofold to threefold enrichment of the copper contained in the primary mineralization. Typical ore is composed of altered rock and sulfides in a ratio of about 10:1 by weight.

Most of the capping over the ore bodies contains less than one-tenth of 1 percent copper as cuprite or other oxidation products mingled with the limonite. Occasionally, somewhat higher values occur where copper has been precipitated as silicates and carbonates by reactive gangue material present in less altered rock. In the ore bodies where alteration is strong and the gangue is nonreactive, the upper limit of the sulfide zone (or the base of oxidation) appears on open-pit

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15. Stewart, C. A., 1912, The geology and ore deposits of the Silver Bell mining district, Arizona: Am. Inst. Mining Metall. Petroleum Engineers Bull., v. 65, p. 455–506.

◇ ◇ ◇ THE MISSION COPPER DEPOSIT, ARIZONA

BY JOHN E. KINNISON

INTRODUCTION

The Mission mine, in southern Arizona near Tucson (fig. 1), is a recently developed open pit, which produces 15,000 tons per day of copper ore. The mine is 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.

Before development the ore body was covered everywhere by about 200 feet of alluvium, as were 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.

Previous publications directly pertaining to the geology of the Mission deposit appeared in 1959 (3) and 1963 (2). Cooper (1) has published a short paper on the district in which he brought forth several significant and previously unpublished stratigraphic and structural hypotheses. The mining history of the district, which is an old one with many small underground mines that are now largely inactive, was summarized by Thurmond and others in 1954 (7). Current activity was initiated with the geophysical discovery of the Pima mine by the United Geophysical Co. about 1951. The presence of a large zone of porphyry copper-type alteration and mineralization was indicated by pervasive alteration and sulfide dissemination, exposed in the hanging wall in the Pima mine exploration workings and by strong sericitic alteration and limonite-filled cavities derived from sulfides in a small outcrop southeast of the Pima shaft. Exploration by the American Smelting and Refining Co. in search of a covered disseminated copper deposit was begun in 1954.

GENERAL GEOLOGY

In brief summary, the geology of this region is diagrammed by the columnar-structure section (fig. 2). Paleozoic sediments totaling an estimated 5,000 feet were deposited on Precambrian granite. The formations are dominantly limestones or marls, with the exception of Cambrian and Permian quartzite layers. A thick sequence of clastic sediments—arkose and siltstones—of Cretaceous age disconformably overlies the Paleozoic rocks. Following or during the earliest part of the Laramide Revolution, 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 period of major deformation and erosion separates 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. Mineralization is believed to represent a single epoch following the

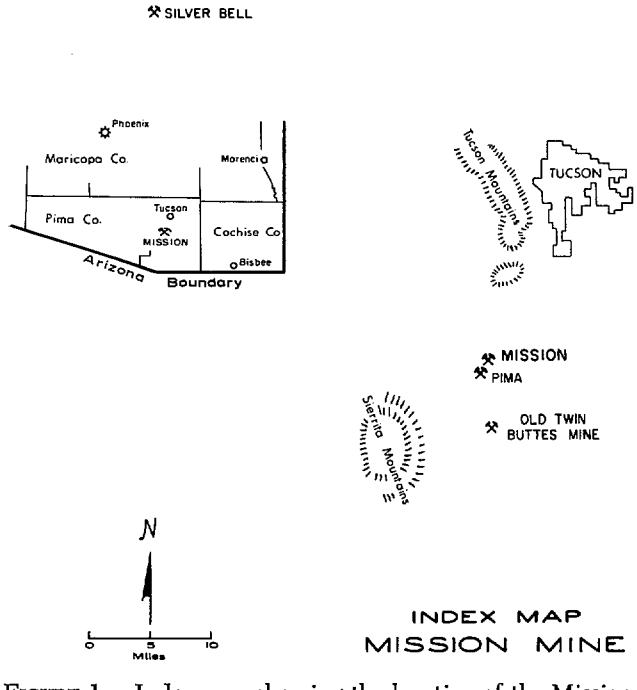

FIGURE 1.—Index map showing the location of the Mission mine.

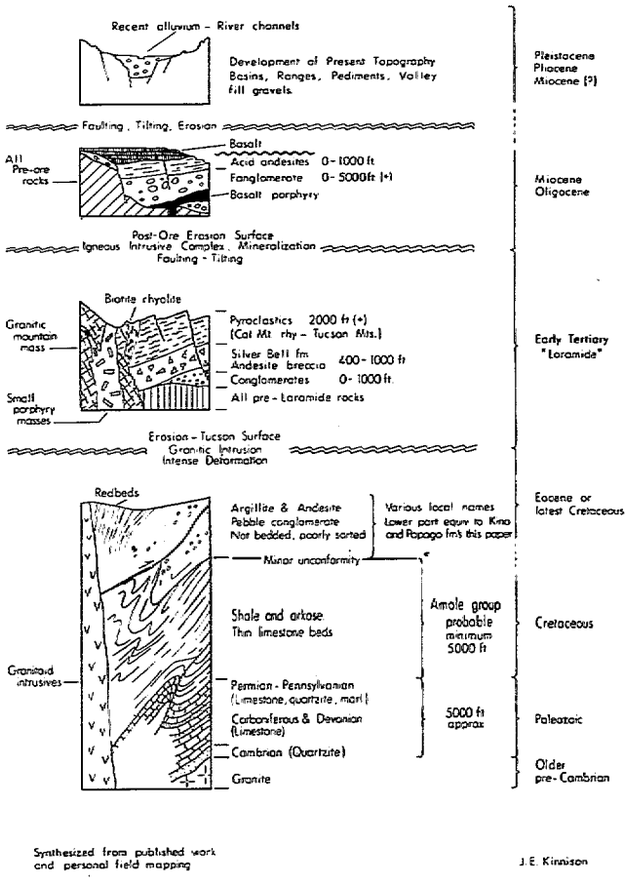

FIGURE 2.—Diagrammatic columnar section showing the generalized geologic history of the Sierrita and Tucson Mountains region.

porphyry intrusion. A thick sequence of middle to upper Tertiary sediments and volcanics was later deposited above a post-ore erosion surface.

Folding and thrust faulting are the dominant pre-ore structures. Major post-ore structural dislocations have produced the final chapter in an already complicated geologic history.

SUMMARY OF THE DEPOSIT

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, are within a large area of pervasive alteration and provided one of the principal exploration leads. The very simplified geologic sketch in figure 3 shows these features.

Hypogene sulfides are generally within 50 feet below the bedrock surface, and secondary enrichment by chalcocite is limited to a very thin veneer. The reasons for this lack of oxidation and enrichment may be manifold, but in part at least the process of pedimentation probably removed any original enriched blanket that might have existed below the older middle Tertiary erosion surface; in the final stage of pedimentation a combination of a high water level and a geologically short time duration has inhibited deep oxidation and consequent enrichment.

Alteration—the formation of new minerals or textures and the destruction of the original rock character—is pervasive in 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 3. The altered zone is roughly 3 by 2 miles in areal dimension, whereas ore or possible ore appears to be limited to an area not much larger than 1½ by 1 miles.

Copper and iron sulfides are disseminated in all rocks within the altered zone, and, conversely, there are no epigenetic sulfides disseminated outside of the altered zone. This relation is so singularly conspicuous and without exception that one is of necessity obliged to regard rock alteration and sulfide impregnation as a process that was integrated in time as well as space. The Mission ore body represents only that part 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 disseminated copper ore deposits in the Southwest.

Alteration of the feldspathic sediments and igneous rocks produced sericite, clay, and metasomatic quartz and orthoclase, whereas the alteration of limestone has formed an assemblage of lime-silicates, such as garnet and diopside. Both types of alteration occur in a mutual environment, and all are veined and impregnated with

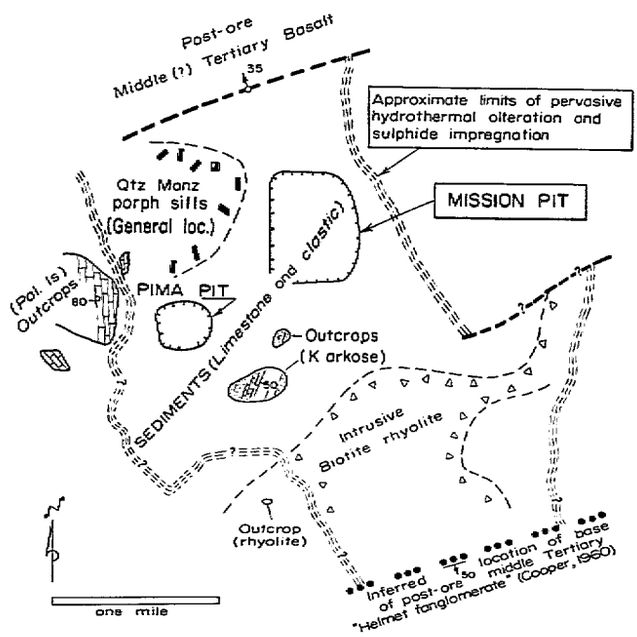

FIGURE 3.—Generalized map showing distribution of sediments, igneous rocks, and alteration beneath the alluvial plain as known through drill data.

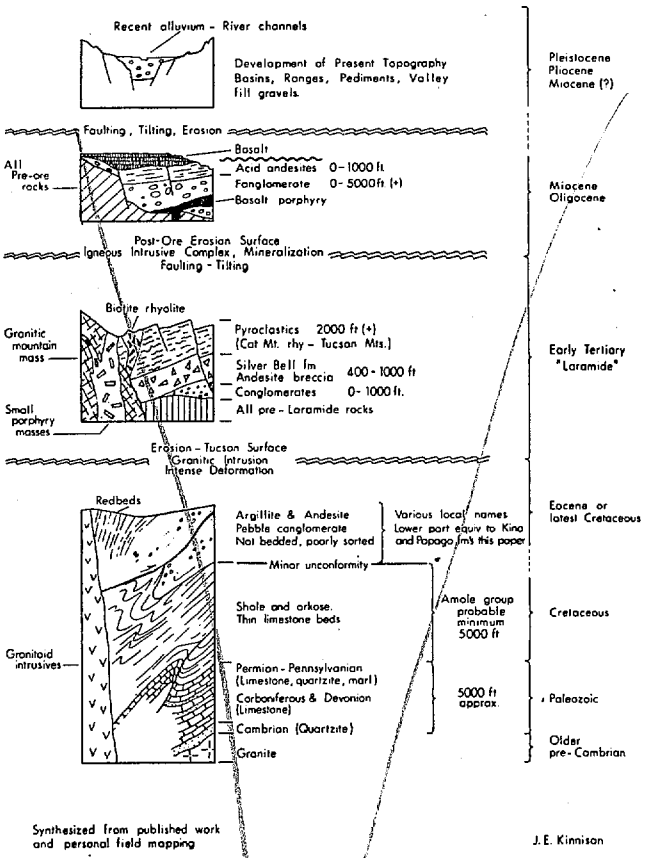

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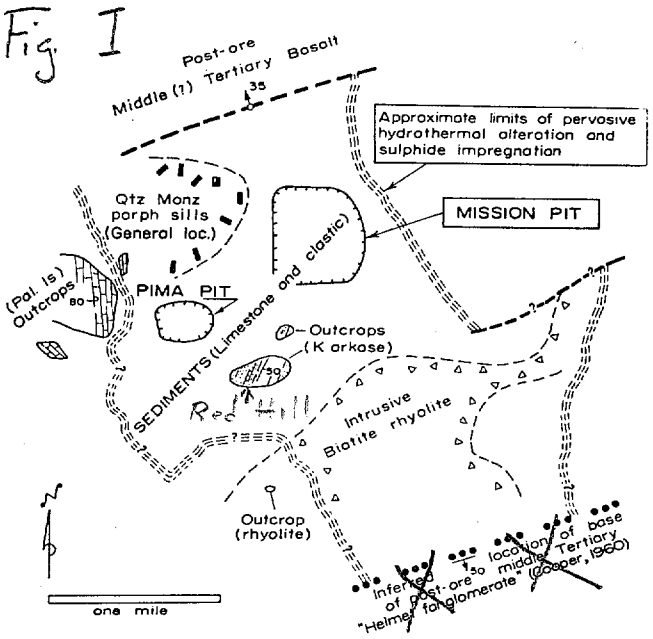
Fig. I



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J.E. Kinnison 1963

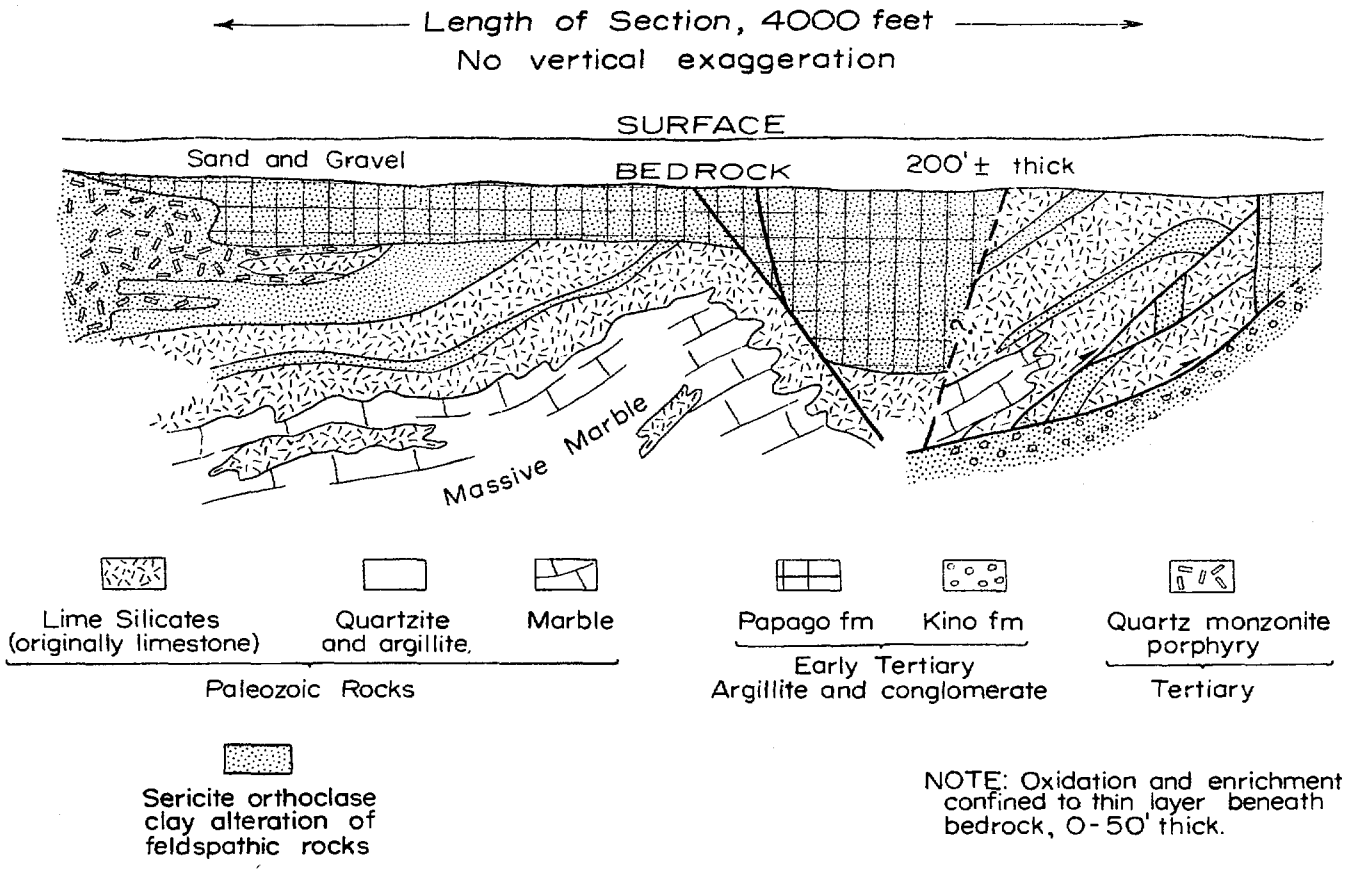


FIGURE 4.—Diagrammatic cross section through the Mission ore body (looking north).

sulfide minerals. The environment as a whole is so typical of porphyry copper deposits in 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."

ROCKS OF THE ALTERED ZONE

Not all the sedimentary formations known to occur in or near the Mission are found in the altered zone. Those that are recognized—and this is with some uncertainty due to alteration effects—are as follows:

Paleozoic: Silicated limestone, marble, and altered marl, siltstone, and quartzite are the dominant host rocks for copper sulfide 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 that consist of unsorted siltstone and volcanic pebble conglomerate are present in the Mission ore body. These rocks are hard and uniformly textured and are referred to as argillite or conglomerate for purposes of mine mapping. The oldest, the Papago Formation, consists dominantly of argillite, and 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 in the altered zone is a quartz monzonite porphyry of Stringham's (6) "aphanitic porphyry" class—a type almost universally present in porphyry copper districts. The porphyry is seen to form sill-like bodies that have intruded an apparently 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 channel. A large mass of intrusive biotite rhyolite occupies 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 here is grouped broadly in two categories. The first, which causes the most obvious changes in the rocks, 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 sulfides. A large area of marble in the central part of the ore zone displays only slight evidence of alteration, such as the coarse grain size of the calcite crystals, representing recrystallization, and traces of sulfide impregnation. The general distribution of alteration near the pit is diagrammatically shown in figure 4, 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 quartz monzonite porphyry, argillite, and quartzite.

The quartz monzonite porphyry contains euhedral to subhedral phenocrysts of plagioclase and resorbed quartz phenocrysts set in a recrystallized matrix of fine-grained quartz and feldspar. Ragged wisps of biotite usually are present. The rock is flooded by irregular blebs and replacement veinlets of pink orthoclase and quartz. The plagioclase phenocrysts are replaced by sericite in varying degrees and to a lesser extent by clay minerals. The metasomatically introduced quartz and orthoclase replaces both the matrix and plagioclase phenocrysts. For comparative purposes, alteration of the porphyry may be said to resemble more closely the alteration at Ajo or Bagdad than that at Morenci or Ray—to name a few typical and well-known districts. 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.

Argillite, both that of the Papago Formation and the thin beds in the Paleozoic rocks, is almost totally altered to a very fine grained aggregate of sericite and (or) a recrystallized mosaic of quartz and feldspar. Sulfide 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 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 virtually is absent, and pyrite is the principal sulfide.

Quartzite in the Paleozoic section generally was derived from quite pure quartz sand. Its alteration is evidenced by nearly complete recrystallization of the quartz grains and the formation of sericite from a minor silt fraction. Sulfides are sparsely disseminated and also occur as widely spaced veinlets. In certain areas, however, chalcopyrite in disseminated form grades as much as 0.6 percent 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 sulfide veinlets bordered by white halos composed of quartz and sericite. Pyrite and chalcopyrite are disseminated, partly as discrete grains and partly in the little veins.

The biotite rhyolite in the southern part of the altered zone is altered to clay, sericite, and minor carbonate. The original biotite is altered to sericite. Feldspar phenocrysts are less altered than the matrix, which was originally glassy, and also are 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 widespread.

Limy Rocks

The Paleozoic sediments, which are principally cherty limestone, pure limestone, and marl, have been converted in the Mission altered zone to various lime-silicate minerals. Two general groups are dominant: 1. tactite, which consists chiefly of garnet; and 2. hornfels, which consists of diopside and calcite. In the western part of the ore body a silicate zone separating two quartzite zones is composed almost entirely of the diopside hornfels type, suggesting that 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 sulfide 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 it is marked by the presence of wollastonite.

The tactite type consists megascopically of massive structureless yellow-brown garnet, yellow or brown euhedral friable masses, or red-brown garnet. Primary hematite is present in some areas. Spectrographic analysis and refractive index place all the types of garnet tested so far in the andradite group. A few garnets show small amounts of alumina in the spectrograph. Soft white material commonly admixed with the garnet was in the 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. Sulfides occur as

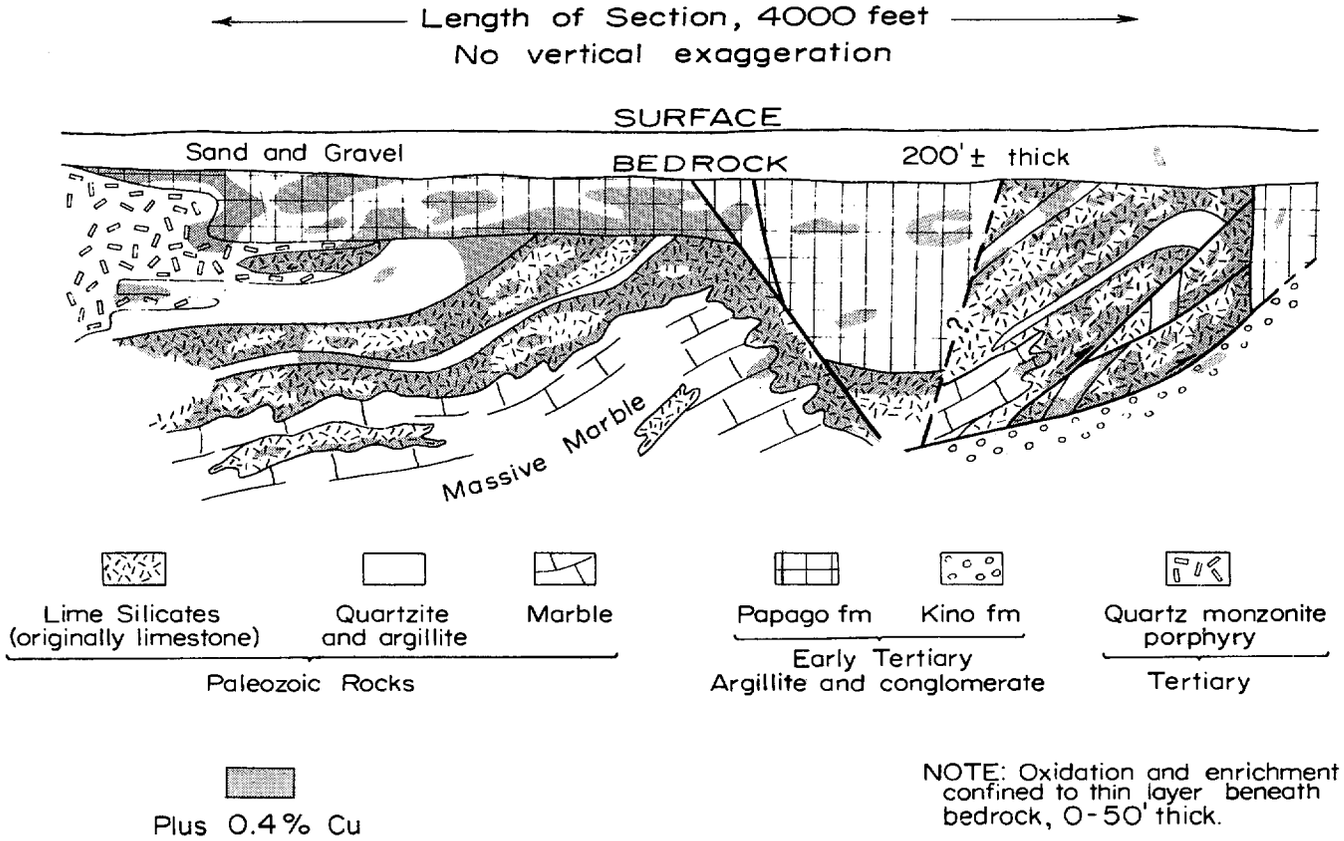


FIGURE 5.—Diagrammatic cross section through the Mission ore body (looking north).

small discrete grains, in thin irregular veinlets, in narrow replacement fissures, and as large pods of massive sulfides that locally assay 5 to 15 percent Cu.

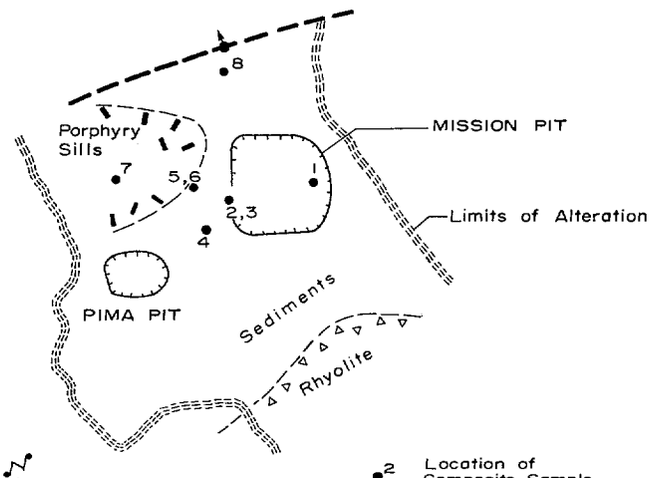
The hornfels type commonly is composed of a variable hard-to-soft, white fine-grained aggregate, which in thin section proves to be equigranular diopside with variable amounts of calcite (as much as 20 percent). A variation is a hard greenish variety, which in thin section is seen to be composed of stubby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

In the western part of the ore body a characteristic feature of the hornfels is the presence of small veinlets of blue-green actinolite, commonly $1/16$ to 1 inch wide, but not everywhere, having a medially disposed stringer of pyrite and chalcopyrite. The actinolite commonly is altered slightly to chlorite. Sulfides 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.

Sulfide Impregnation

Hypogene sulfide mineralization is, from an economic viewpoint, the most important change or altera-



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.

FIGURE 6.—Total sulfide content, Mission mine.

tion of the host rocks. Figure 5 shows the distribution of copper grading plus 0.4 percent 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 sulfide as do the shaded (plus 0.4 percent Cu) areas and only slightly less copper. The lower copper content, in some instances, represents a slight decrease in the total sulfide content, but more generally it reflects an increase in the pyrite-chalcopyrite ratio or a combination of both.

Total sulfide content obtained by calculations based on chemical analyses of composite samples of drill core is shown in figure 6. It will be noted that: 1. the total sulfide content is higher in the east part of the pit area; and 2. in any one sample location, the total sulfide 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 (fig. 4) because the difference in specific gravity between tactite and argillite would otherwise introduce an error when comparing the degree of sulfide replacement.

There is a paucity of published analytical information on the total sulfide content of porphyry copper ore bodies as a group. Spencer (5) gave the sulfide content of three samples from the Ely district—a "typical" porphyry copper—based on chemical analysis, which appears to represent sulfides by weight. Some assumptions and calculations of the author yield the rough figures of 2.8, 4.0, and 4.9 percent sulfides by volume for the three samples, which is comparable to the sulfide content at Mission (fig. 6).

ORE CONTROLS

All rocks in the Mission altered zone are recrystallized and (or) metasomatized to various silicate minerals, and all are impregnated with sulfides. 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 sulfides the method of implacement clearly did not depend on open channels of circulating hydrothermal solutions.

Referring again to figures 5 and 6, the unconformable contact between the Papago Formation and the underlying silicated sediments of the Paleozoic section has served as a localizing feature. Sulfides follow this contact in greater quantity and more uniformly grade in excess of 0.4 percent 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 sulfides.

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

That all these structural features are local sulfide concentrators is undisputed; however, the great bulk of copper and iron sufides occurs at significantly great distances from these structures. From this, the author draws the conclusion that the metasomatism that introduced great quantities of iron to form iron-lime-silicates and iron sulfides, along with sulfur, 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 that 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 because it was altered and impregnated with sulfides after solidification. The porphyry may have a genetic relation to mineralization to the extent that it may have been intruded from a deeper source of magma, which later furnished the elements that were introduced into the altered zone.

CONCLUSIONS

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. At Mission, however, 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 sulfides in such deposits are seen to replace the silicates, the sulfides 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 "Summary of the Deposits" in this paper, the intimate spatial relation of silicated limestone with sericitized feldspathic rocks

and their associations with sulfide mineralization admits of no other conclusion than that all rock alteration, including sulfide impregnation, was more or less contemporaneous. The temperatures existing in all rocks must have been similar. At Mission the sulfides, as might be expected, replace silicates—both the potassic and lime varieties. There is no evidence, such as pre-sulfide, post-silicate brecciation, to suggest that any appreciable time gap existed. As a comparison, the sulfides 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 (4). The inescapable conclusion at Mission is that either the lime-silicates formed at lower temperatures than would commonly be thought or the temperature range of sericite-pyrite-chalcopyrite must be considerably higher than generally admitted.

Similar conclusions were reached many years ago by Spencer (5) in his study at Ely, Nevada. There the porphyry copper deposit is more similar to Mission than most others in that extensive mineralization in sediments is present.

In the Ely district an altered zone about 7 miles long and 1 mile wide contains numerous separate porphyry masses that 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 alteration of the porphyry . . . comprise, in different stages, the progressive destruction of hornblende, 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 (8). Here a zoned sequence of lime-silicate minerals of classical "pyrometasomatic" or "contact" type occurs along the Linchburg fault, well away from a known igneous mass. Titley (8) 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.

To recapitulate my major conclusions:

1. The Mission mine is a "porphyry copper" deposit.
2. The monzonite porphyry within the altered area has no specific spatial relation to either ore or alteration but probably has an indirect genetic relation to the mineralization process.
3. Rock alteration and sulfide impregnation were more or less contemporaneous. The formation of lime-silicates was part of the hypogene-alteration process.
4. Diffusion was an important alteration process. Major channels for open circulation of hydrothermal fluids were widely spaced.

Acknowledgments.—The author is indebted to Kenyon Richard and J. H. Courtright for criticism of this paper and for their direction during the several years in which the Mission deposit was studied. Acknowledgment also is given to R. L. DuBois of the University of Arizona, consultant in petrography, for his help in this study. Permission to publish this paper was granted by the American Smelting and Refining Co.

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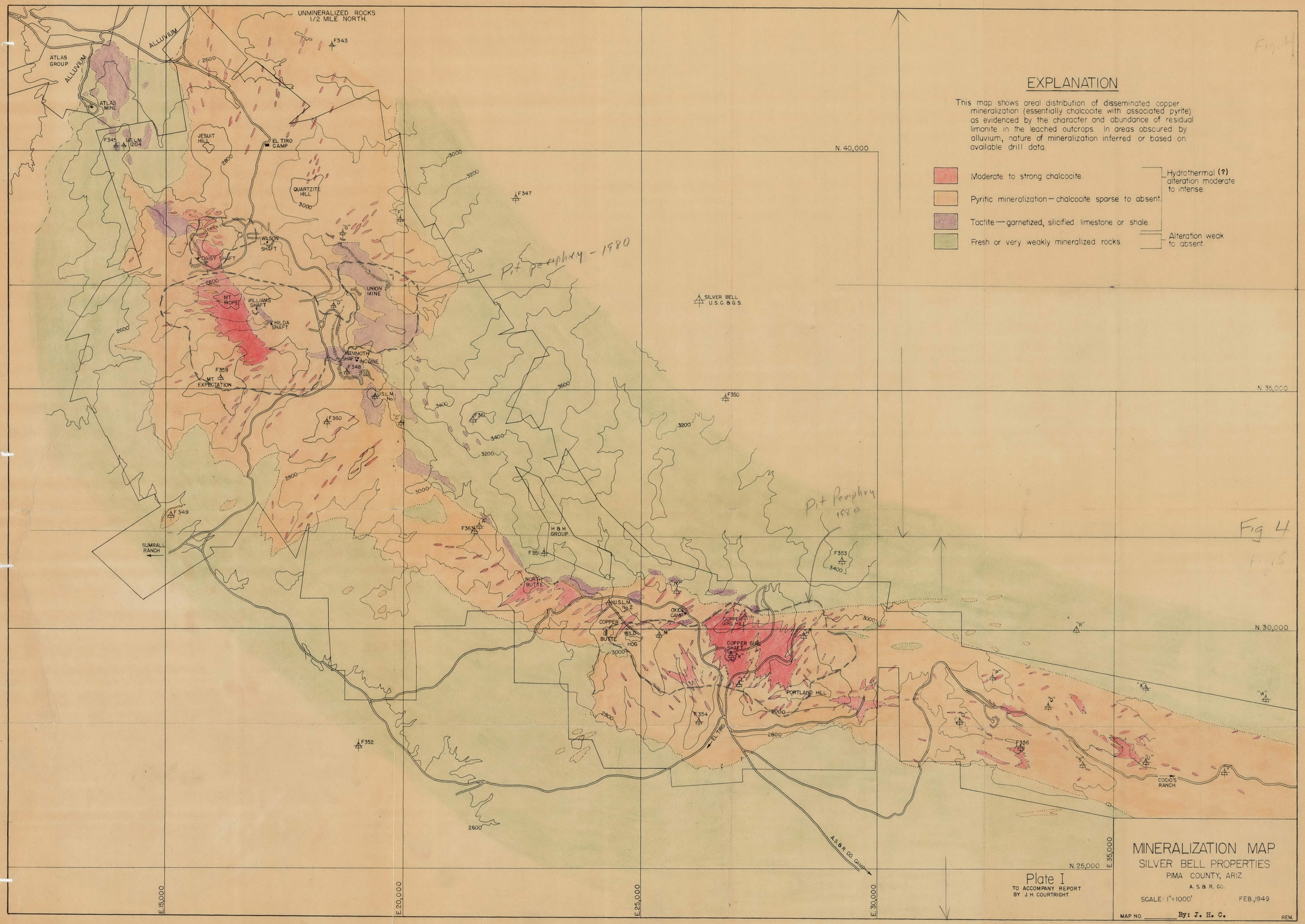


EXPLANATION

This map shows areal distribution of disseminated copper mineralization (essentially chalcocite with associated pyrite) as evidenced by the character and abundance of residual limonite in the leached outcrops. In areas obscured by alluvium, nature of mineralization inferred or based on available drill data.

- Moderate to strong chalcocite. — Hydrothermal (?) alteration moderate to intense.
- Pyritic mineralization — chalcocite sparse to absent. — Hydrothermal (?) alteration moderate to intense.
- Tactite — garnetized, silicified limestone or shale. — Hydrothermal (?) alteration moderate to intense.
- Fresh or very weakly mineralized rocks. — Alteration weak to absent.

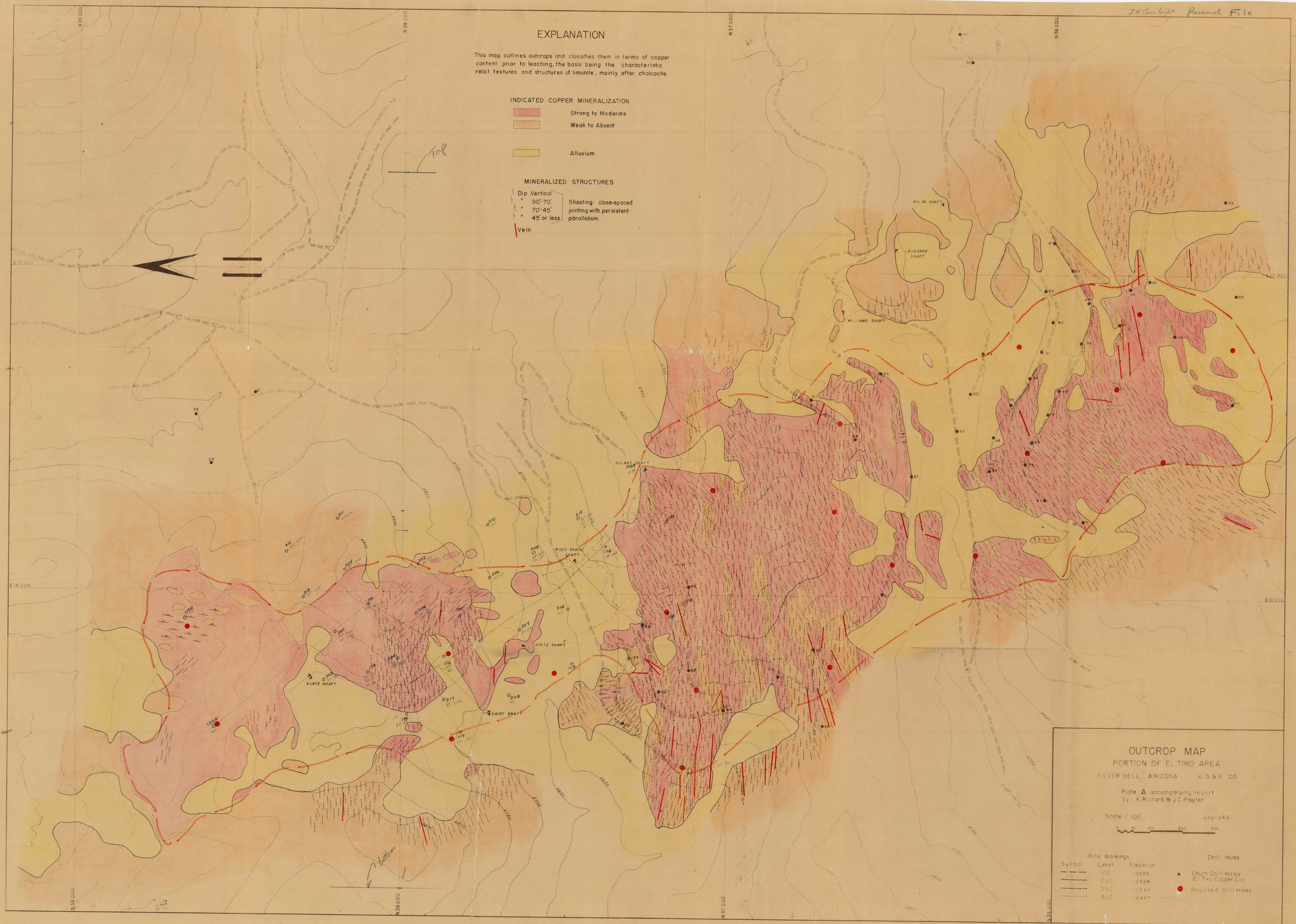
Plate I
TO ACCOMPANY REPORT BY J. H. COURTRIGHT

MINERALIZATION MAP
SILVER BELL PROPERTIES
PIMA COUNTY, ARIZ.
A. S. & R. CO.

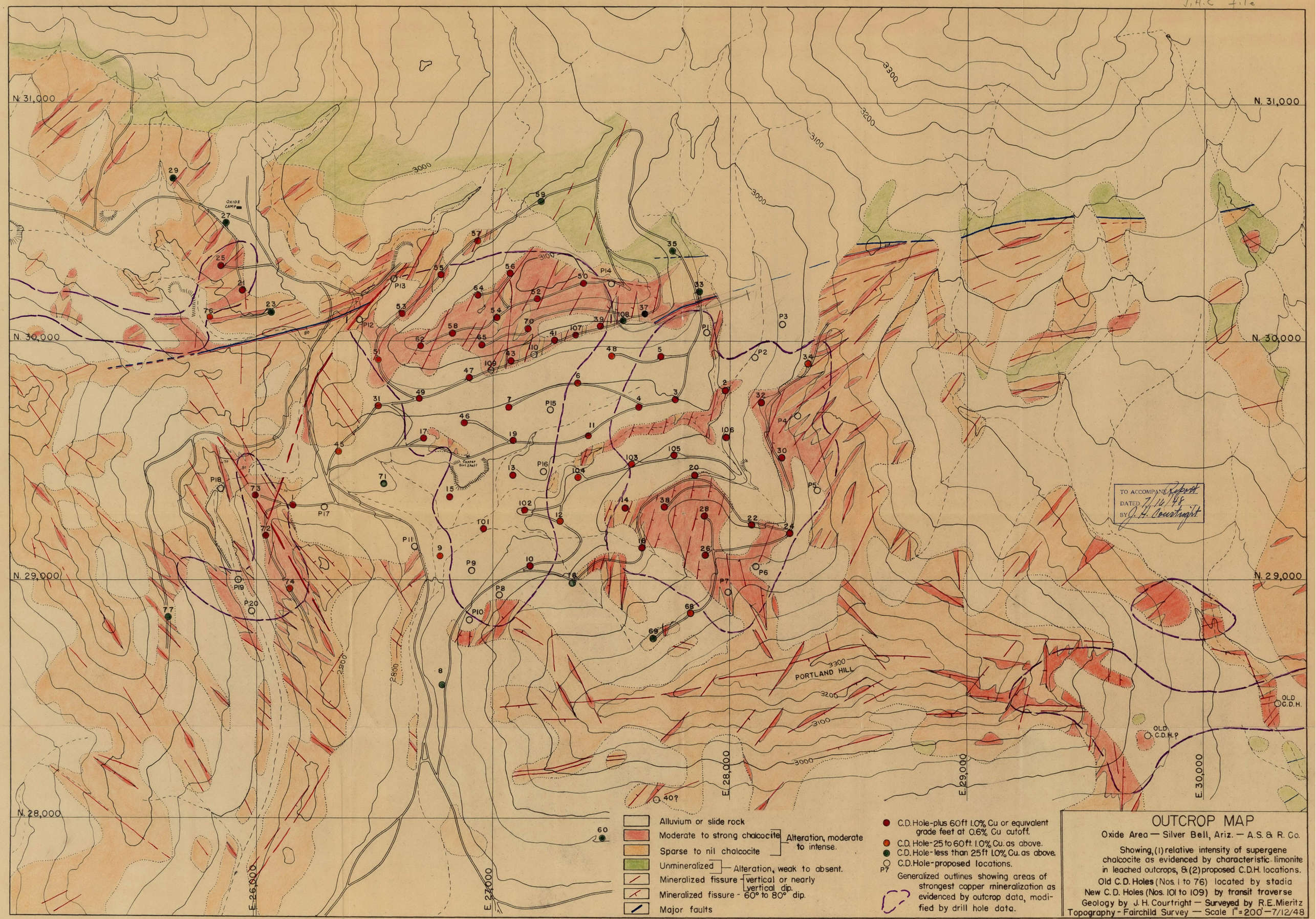
SCALE: 1" = 1000' FEB., 1949

MAP NO. _____ By: J. H. C. REM.

J.H. Courtright Personal File



J.H.C file


N. 31,000
N. 30,000
N. 29,000
N. 28,000
E. 26,000
E. 27,000
E. 28,000
E. 29,000
E. 30,000
OXIDE CAMP
Copper Girl Shaft
PORTLAND HILL
3300
3200
3100
3000
2900
2800
OLD C.D.H.
OLD C.D.H.P
TO ACCOMPANY Report
DATED 7/12/48
BY J. H. Courtright
Alluvium or slide rock
Moderate to strong chalcocite
Sparse to nil chalcocite
Alteration, moderate to intense.
Unmineralized
Alteration, weak to absent.
Mineralized fissure - vertical or nearly vertical dip.
Mineralized fissure - 60° to 80° dip.
Major faults
C.D. Hole-plus 60 ft 1.0% Cu or equivalent grade feet at 0.6% Cu cutoff.
C.D. Hole-25 to 60 ft. 1.0% Cu. as above.
C.D. Hole-less than 25 ft 1.0% Cu. as above.
C.D. Hole-proposed locations.
Generalized outlines showing areas of strongest copper mineralization as evidenced by outcrop data, modified by drill hole data.
OUTCROP MAP
Oxide Area — Silver Bell, Ariz. — A.S. & R. Co.
Showing, (1) relative intensity of supergene chalcocite as evidenced by characteristic limonite in leached outcrops, & (2) proposed C.D.H. locations.
Old C.D. Holes (Nos. 1 to 76) located by stadia
New C.D. Holes (Nos. 101 to 109) by transit traverse
Geology by J. H. Courtright — Surveyed by R.E. Mieritz
Topography - Fairchild Survey — Scale 1" = 200' — 7/12/48

AMERICAN MELTING AND REFINING COMPANY
Tucson Arizona

July 17, 1948

Mr. A.E. Ring, Manager,
Tucson, Arizona

ARIZONA, PIMA COUNTY
SILVER BELL, OXIDE
EXPLORATION

Dear Sir:

This report contains, (1) a brief discussion of recently acquired geological data and its significance in respect to exploration possibilities, (2) recommended churn drilling ~~and estimated costs~~, and (3) map of the Oxide area showing the distribution of copper mineralization and proposed drill holes.

SUMMARY AND CONCLUSIONS

The Oxide deposit consists of an irregular secondary chalcocite accumulation, derived from an even more irregular occurrence of primary chalcopyrite. However, results of the 8 recently drilled holes are within ranges similar to old drill results in respect to tenor and thickness of ore. To provide a means of appraising exploration possibilities, an outcrop map was prepared showing the distribution and relative intensity of chalcocite mineralization. It is concluded that the possibilities are limited to a few minor extensions beyond the margins reached by the old drilling. Small areas of relatively strong chalcocite mineralization occur well outside the limits of the Oxide deposit. With the exception of the area around CMM No. 73, it is advised that consideration of these be deferred for the present, at least.

A total of 20 holes is proposed as the minimum requirement (1) for definition of the limits of the deposit, and (2) to obtain the necessary information in the hole No. 73 area. Additional drilling well may be advisable to provide a basis for reasonably firm tonnage and grade estimates.

GEOLOGY

Structure: Briefly, the Oxide deposit occurs within a series of volcanic flows and intrusive rocks, the latter occupying a major east-west trending fault zone. The Cretaceous (?) flows and Paleozoic sediments (chiefly limestone and quartzite) have been intruded by alaskite, dacite porphyry and monzonite in the order named. Steep northeast to northwest crossbreaking shears are closely spaced throughout the east-west zone.

L. H. C.

JUL 20 1948

MINERALIZATION

Copper is widely dispersed throughout a belt of moderate to intense alteration which marks the east-west major structural break occupied by the intrusives. Deposition of primary chalcopyrite and pyrite, mainly in the crossbreaking shears and fissures, occurred after the intrusion of the monzonite. Frequently, both minerals occur as discrete grains; however, disseminated copper in significant concentrations occurs only in the scattered zones of relatively intense mineralization.

The processes of leaching and redeposition of copper as chalcocite enriched the deposit and accomplished a diffusion of copper, which to some extent modifies the original extremely uneven primary distribution.

As determined by examination of samples from recent drilling, ore grade (around 1% Cu.) material is composed essentially of pyrite, chalcocite and chalcopyrite, representing 6 to 7% of the rock. Over 90% of the sulphide copper is in the form of supergene chalcocite, as coatings and partial replacements of both chalcopyrite and pyrite. The former is commonly present as small cores in chalcocite grains. Oxide copper, forming around 20% of the total copper in the upper portions of the chalcocite zone, is present mainly as the silicate chrysocolla. Below the chalcocite zone, primary chalcopyrite values are extremely variable, but probably average over 0.3% cu.

An examination of ore exposed on the 130 level of the Copper Girl workings indicates that over 50% of the copper occurs in veins, slips and joints; the remainder as discrete, disseminated grains.

Thus far, no particular igneous rock appears to possess exceptional favorability as a host for disseminated copper mineralization. The three rocks, volcanic flows, dacite porphyry and monzonite, are irregularly distributed through the deposit, crossing rich and lean zones in what appears to be a haphazard fashion. However, the data at hand do not represent a sufficiently thorough coverage to be conclusive. The Paleozoic sedimentaries are considered unfavorable because intense mineralization as a rule extends but a few tens of feet into these rocks.

Summarizing, the deposit represents the product of progressive leaching and enrichment of a group of relatively close-spaced copper bearing shear zones. The irregularity of the chalcocite occurrence is due mainly to the spotty distribution of the primary copper, and to some extent to pre-existing climatic conditions, plus variations in rock permeability. Essentially, the deposit belongs in a category transitional between a typical disseminated "porphyry copper" and a copper bearing vein system.

LEACHED OUTCROPS

A study of the outcrops over the Oxide ore body and adjacent areas disclosed the fact that notable variations in both the color and intensity of residual limonite were present. The attached 200-scale map was prepared to depict the distribution and relative intensity of copper mineralization as evidenced by characteristic limonite visible in the bedrock exposures. This characteristic limonite, apparently derived from pyritic chalcocite, possesses a color varying from purple tinged dark red to chocolate brown. In contrast, the outcrops over essentially pyritic bodies exhibit yellow and brick red colors.

Blue-green stains and veinlets, representing chrysocolla for the most part, are prominent in some of the alaskite outcrops of the area. In these outcrops it is considered that the meager amount of copper originally present in the rock was dissolved by acid leaching and reprecipitated as silicate through the neutralizing effect of a less altered rock. Such areas, classed as weakly mineralized, are not considered to hold potentialities in respect to disseminated copper ore, regardless of their spectacular appearance.

Several limitations are inherent in the interpretation of leached outcrops: (1) The sparse occurrence of good bedrock exposures is perhaps the foremost. Roadcuts provide the best opportunity for appraisal of the nature and intensity of residual limonite; in the weathered croppings, the limonite has been largely brushed out by the elements, leaving quite often nothing more than an obscure "desert polish". (2) The transition from weak to strong mineralization is of a gradational nature; all shades and intensities are present; thus, divisions between classifications must be arbitrarily applied. (3) the surface expression of a mineralized body is not necessarily a vertical projection.

EXPLORATION POSSIBILITIES

On the attached map are shown the important structural features, the distribution of copper mineralization, the location of old and recent churn drill holes, proposed holes, and topography. Rock types were omitted for the sake of clarity. The dashed purple line was used to encompass areas of relatively intense chalcocite mineralization as evidenced by the characteristic limonite in rock exposures, modified in part by drill hole data. It is here emphasized that these outlines are not precise delimitations of commercial ore, but merely a means of segregating areas of stronger copper mineralization - the main objective being to narrow the target: if ore does not occur within any one of these particular areas, the chances outside are indeed slim.

The Oxide ore deposit consists of two strong zones separated by a narrow weak zone trending parallel to the mineralized fissures in the vicinity. Mineralization dies out rather abruptly on the north; on all other sides a tendency to feather out along fissure

trends is apparent. The possibilities appear to be limited to a few very small extensions around the margins of the deposit as defined by churn drilling.

Outside the apparent limits of the Oxide deposit, copper mineralization is generally weak, with the exception of a few rather small areas which are outlined on the map. The fact that "Old Timers" were aware to some extent of the significance of limonite after chalcocite is evidenced by the location of numerous trenches, shafts and drill holes over the whole area. The majority of the shafts, drifts and drill holes outside the Oxide deposit are spotted directly on notable concentrations of this characteristic limonite. The trenches were probably excavated as preliminary exploration in search of the characteristic limonite when alluvium obscured the bedrock.

PROPOSED DRILL HOLES

The locations of 16 proposed churn drill holes in the immediate Oxide area are spotted on the map. Of these, 14 are for the purpose of defining the margins of the deposit where possible extensions exist. P 15 and P 16 are to provide additional information on the extent of ore along the western margin of the less central zone where a sharp upward warp occurs in the chalcocite "blanket" (see section Oxide churn drill report for June '48.)

West of the Oxide deposit, holes No. 1, 72 and 73 are credited with ore in the logs. These holes, including No. 74, were drilled directly on a strongly mineralized fissure system; therefore, the possibility of a commercial extent of ore here is open to question. Proposed holes No. 17, 18, 19 and 20 are designed as the minimum number necessary to provide an answer to the question.

In addition to the areas discussed in the foregoing, two small irregular areas are indicated on the map. The ore to the west, which includes drill holes No. 21 and 23, may extend westerly beyond the border of the map, passing just north of Wild Hog and Copper Butte, and thence more northwesterly for some 2000 feet. Throughout this extent, a continuous band of stronger copper mineralization does not appear to exist - rather, there is a series of discontinuous lenses of minor size.

Near the east end of Portland Hill another small area of limonite after chalcocite is outlined. One, and possibly two, old churn drill holes were located here. This area may be contiguous with similar small and spotty showings which occur 1000 feet, more or less, to the east.

The potentialities are considered to be of such a limited extent in the above-described areas that no exploration is proposed for the present. In the event an operation is assured on the Oxide deposit, these scattered prospects may merit further consideration as a possible source of a few additional tons of ore.

FOOTAGE ESTIMATE

Total footage drilled to July 1st.....	2585 feet
Amount to complete 12 holes.....	1100 feet
TOTAL	3685 feet
20 proposed holes - averaging 320 ft.	6400 feet
TOTAL	10,085 feet

Yours very truly

J.H. COURTRIGHT.

JHC:m
Enclosure - Map
cc: WHLoerpabel
DJPope

H. Landwehr

AMERICAN SMELTING AND REFINING COMPANY
Tucson, Arizona

April 7, 1949

MINING DEPARTMENT
APR 13 1949

Mr. F. V. Richard, Manager
Southwestern Division, Mining Department
American Smelting and Refining Company
Tucson, Arizona

SILVER BELL, ARIZONA
Porphyry Copper Mineralization

Dear Sir:

This letter will serve as an explanation of the two accompanying maps of the entire property, showing (Plate I), the extent and nature of mineralization and (Plate II), the positions and relative copper values of all known drill holes.

General Features of Mineralization -

Copper, essentially as secondary chalcocite, is dispersed throughout a northwest trending belt of pyritic mineralization over five miles long and from one to five thousand feet in width. This copper, derived for the most part from the leaching of chalcopyrite bearing veinlets, occurs in significant concentrations approaching commercial size in but two areas, three miles apart. Both deposits are characterized by relatively strong fissuring or sheeting, striking across the major structural break which is marked by a belt of intrusive rocks trending northwest. The most prominent of these rocks are: alaskite, dacite, porphyry and monzonite.

In these deposits, the Oxide and the El Tiro, the ore containing around 1.0% Cu and 5.0% sulphide iron, occurs in flat lying rudely tabular bodies, one to two hundred feet thick, beneath an average of one hundred feet of leached capping. As evidenced by numerous drill holes which were extended one to two hundred feet below the chalcocite zone, the unenriched or primary mineralization contains from .2% to .4% copper in the form of chalcopyrite.

Outside the limits of the aforementioned deposits, copper is widely dispersed throughout the pyritic belt in relatively small, discontinuous zones.

Classification of Leached Outcrops -

All degrees or shades of intensity of mineralization are present in the area, however, for the sake of clarity, only four classifications were used in mapping (Plate I). These are discussed below in the order in which they occur on the map legend. In areas obscured by alluvium or mantle rock, the strength and nature of mineralization, shown on the map, was inferred from the character

W. R. L.
APR 13 1949

of the nearest outcrops, or determined by drill data.

1. Moderate to strong chalcocite -

In this classification are placed areas exhibiting relatively strong concentrations of maroon to black limonite, occuring essentially as narrow vein or seam fillings. These dark colored veinlets of residual limonite in the outcrops are assumed to have been formed by the oxidation and leaching of pyritic chalcocite veinlets, a process which took place beneath cap rock subsequently removed by erosion. This assumption is based on observations which support the conclusion that over known ore bearing areas the outcrops show a much closer spacing of seams bearing the dark colored limonite than the outcrops over areas known to be sub-marginal in copper values; over areas known to be practically free of chalcocite, the dark colored limonite is very sparse or absent entirely.

According to Mr. Louis Neber of the Phelps Dodge Corporation at Morenci, the dark maroon or purplish tone of the limonite derived from the leaching of chalcocite-pyrite is due to the presence of minor amounts of cupric oxide.

2. Pyritic Mineralization, chalcocite sparse to absent -

The interpretation in this case is based on the yellow to brown or red staining in the outcrops. Cavities and open seams, indicative of pre-existing sulphides, are present, but for the most part these are devoid of the dark colored pulverent limonite, characteristic of pre-mineral rock surfaces over supergene copper deposits. The generally accepted theory is that copper free pyrite leaves little or no residual limonite, but often stains the host rock various shades of brown or red.

Alteration, evidenced by the general bleached appearance of the outcrops, is present throughout the pyritic zone in various degrees of intensity. It is characterized essentially by the development of various clay minerals in the feldspars, and by the bleaching of the ferro magnesian minerals, represented mainly by biotite mica. The alteration appears to be more intense in areas of close-spaced fissuring accompanied by relatively strong mineralization, which includes the ore bearing areas. However, it has been noted in drill samples that the rock increases in hardness and possesses a comparatively fresh unaltered appearance in the primary zone, below the zone of secondary chalcocite. Thus it appears that descending acid solutions, derived from the

oxidation of pyrite mainly, may have been responsible to a large extent in producing the altered appearance of the outcrops. This observation does not imply that hydrothermal alteration (associated with primary mineralization) is entirely absent.

3. Tactite - Garnetized, Silicified Limestone and Shale -

This unit includes areas of so-called contact metamorphism, commonly termed "tactite". This type of mineralization is confined to a narrow belt in the limestones and limey shales along the major break trending northwest. The weathered surfaces of this material are characteristically black, a color produced by residual oxides of manganese and iron. A major portion of the copper produced in the past was derived from replacement type bodies along fissures in the garnetized limestone of the Mammoth and Union mines. Copper mineralization of the disseminated type is generally very weak or absent in these rocks in the Silver Bell district.

4. Fresh or Very Weakly Mineralized Rocks -

This classification includes all rocks that exhibit in general a relatively fresh, unaltered appearance. Due to the fact that transition from the fresh to strongly mineralized type is often gradational, the boundary between the two represents an arbitrary division.

Past Exploration -

Perhaps, the first to pursue the limonite, residual after chalcocite, in the outcrops of the Silver Bell district were the Indians which at one time inhabited the region. Evidence of their work is found in a large number of open cuts which, without exception, are located in outcrops containing prominent seams of the maroon or black limonite. Since the base and precious metal content of these deposits is very low, a plausible explanation ~~is~~ might be that the Indians used this particular limonite as a pigment--war paint, perhaps, or pottery coloring. The ancient character of the excavations is evidenced by the advanced weathering of the dumps and by the vegetation growing in the cuts; saguaros over 25 feet high were noted in some cases, indicating an age of at least 200 years. Kenyon Richard was the first person to call attention to the antiquity of these workings.

During the period of early activity in the low grade copper field (around 1910), an extensive search was carried on in the Silver Bell area for this type of ore. The disposition of the old churn drill holes, shafts and trenches indicate that the old timers recognized, to some extent at least, the significance of

dark colored residual limonite. The trenches were apparently excavated for the purpose of exposing bedrock in areas covered by a thin mantle of slide rock or alluvium so that a close appraisal of the nature and frequency of the limonite could be made. Where the evidence was considered favorable, a drill hole, a shaft or a drift was driven to the sulphide zone. It is notable that in many areas in which the old trenches expose comparatively little residual limonite, no other prospecting was done. An example of this is found in the area immediately east of the Oxide deposit where numerous trenches were dug, but no drilling was done, even though some of the eastern most holes in the Oxide contained ore. Recently, three holes drilled in this area proved it to be submarginal.

In conclusion, it is considered evident that, (1), secondary enrichment is entirely responsible for the commercial grade of the known copper occurrences of the disseminated type, and (2), commercial possibilities are confined to the two recognized deposits, the Oxide and El Tiro.

These conclusions do not preclude the possibility of higher grade primary copper mineralization occurring at depth, however, drill results obtained thus far in the two areas of strongest primary copper mineralization (the Oxide and El Tiro) provide no particular encouragement for deeper exploration.

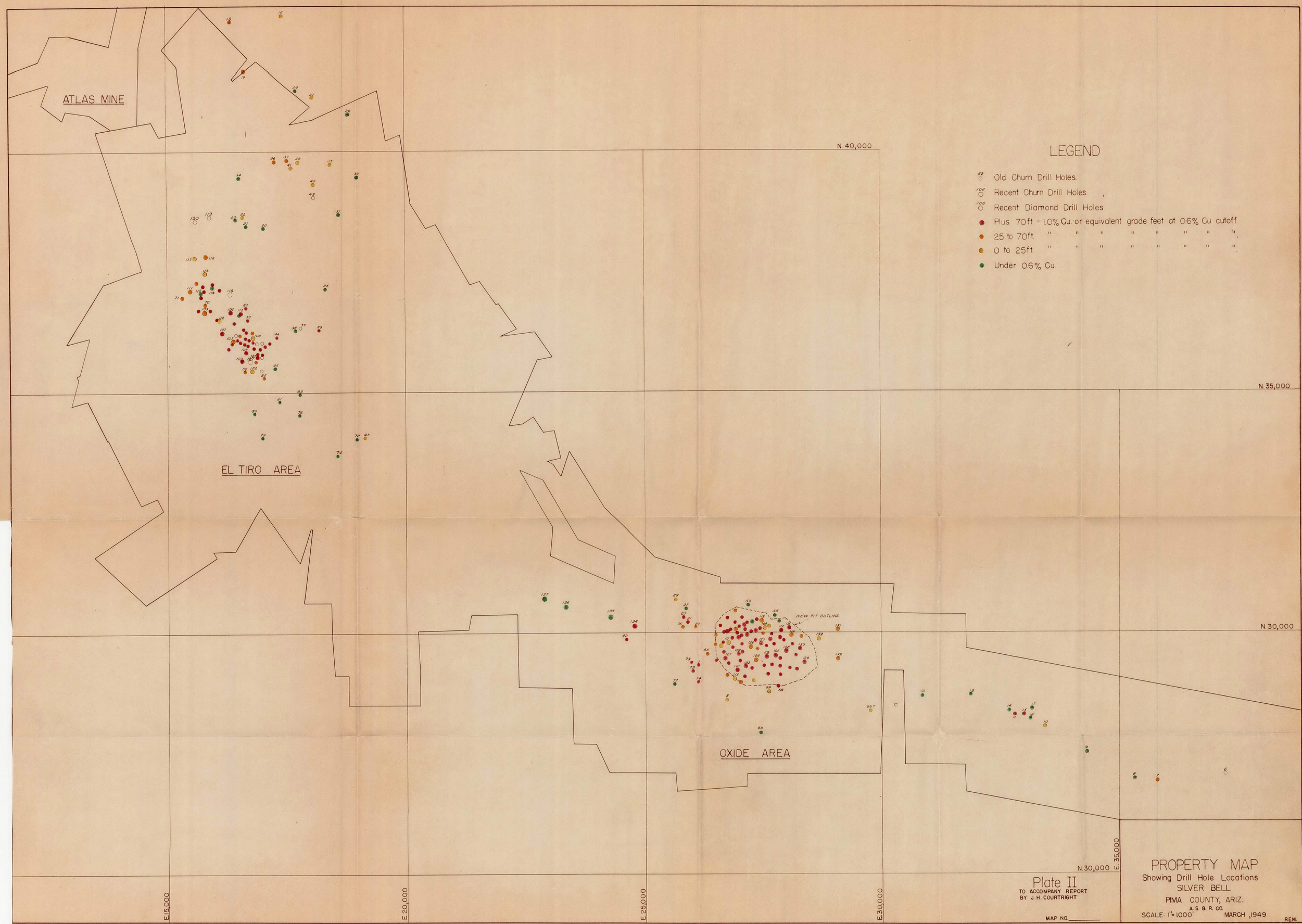
Kenyon Richard, in his report of July 26, 1948, on El Tiro, recommended that the possibility of primary disseminated copper ore occurring at depth along the structure marked by the zone of brecciation passing through the Williams, Hilda and Daisy shaft areas, should be tested by extending an occasional drill hole several hundred feet below the chalcocite zone. I am in accord with this recommendation, which has already been carried out to some extent in recent diamond drilling. During the current churn drill program, it is planned that two holes, located in areas which showed the best primary copper values in the diamond drilling, will be extended two or three hundred feet below the chalcocite zone.

Yours very truly,

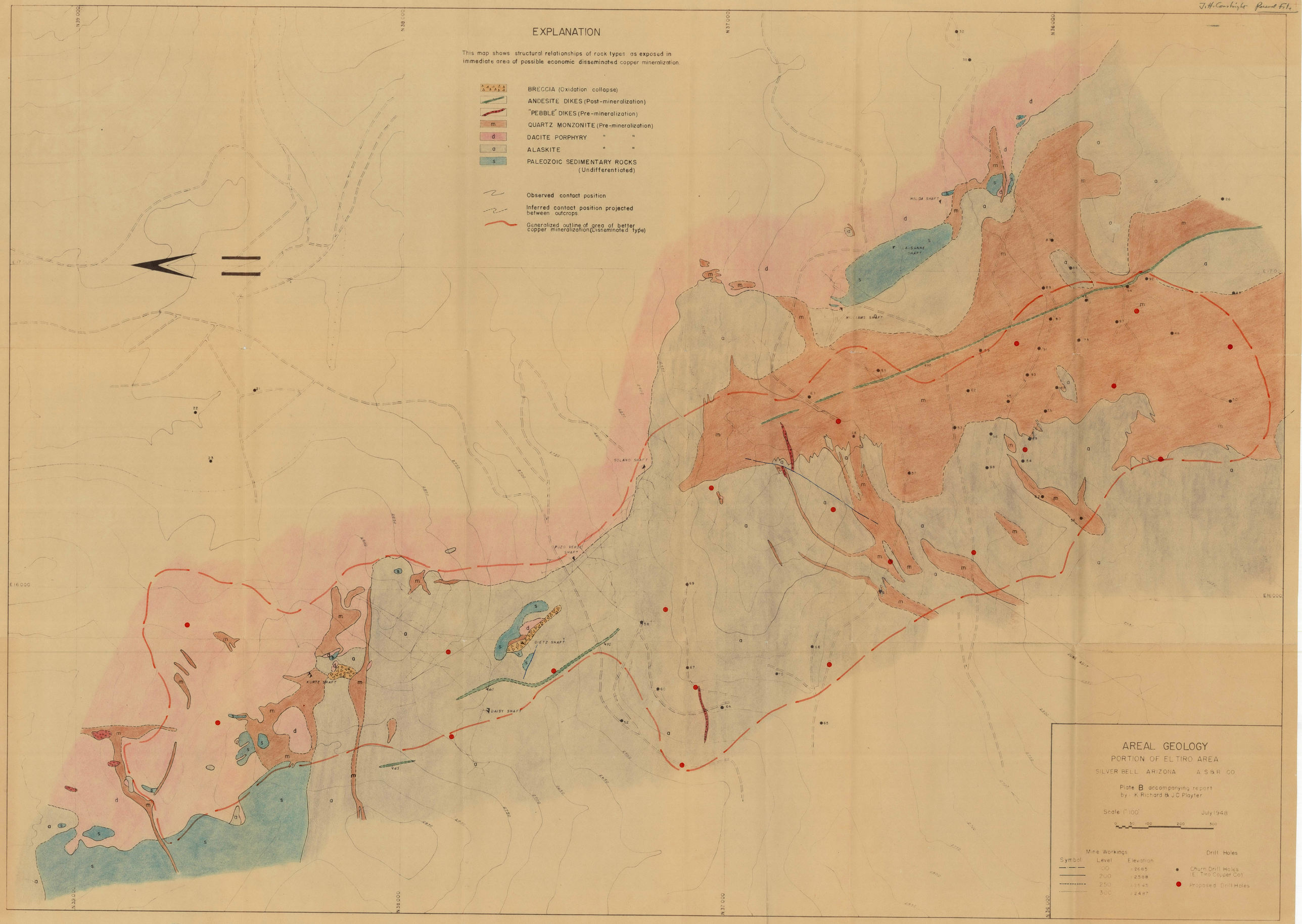
J. H. Courtright

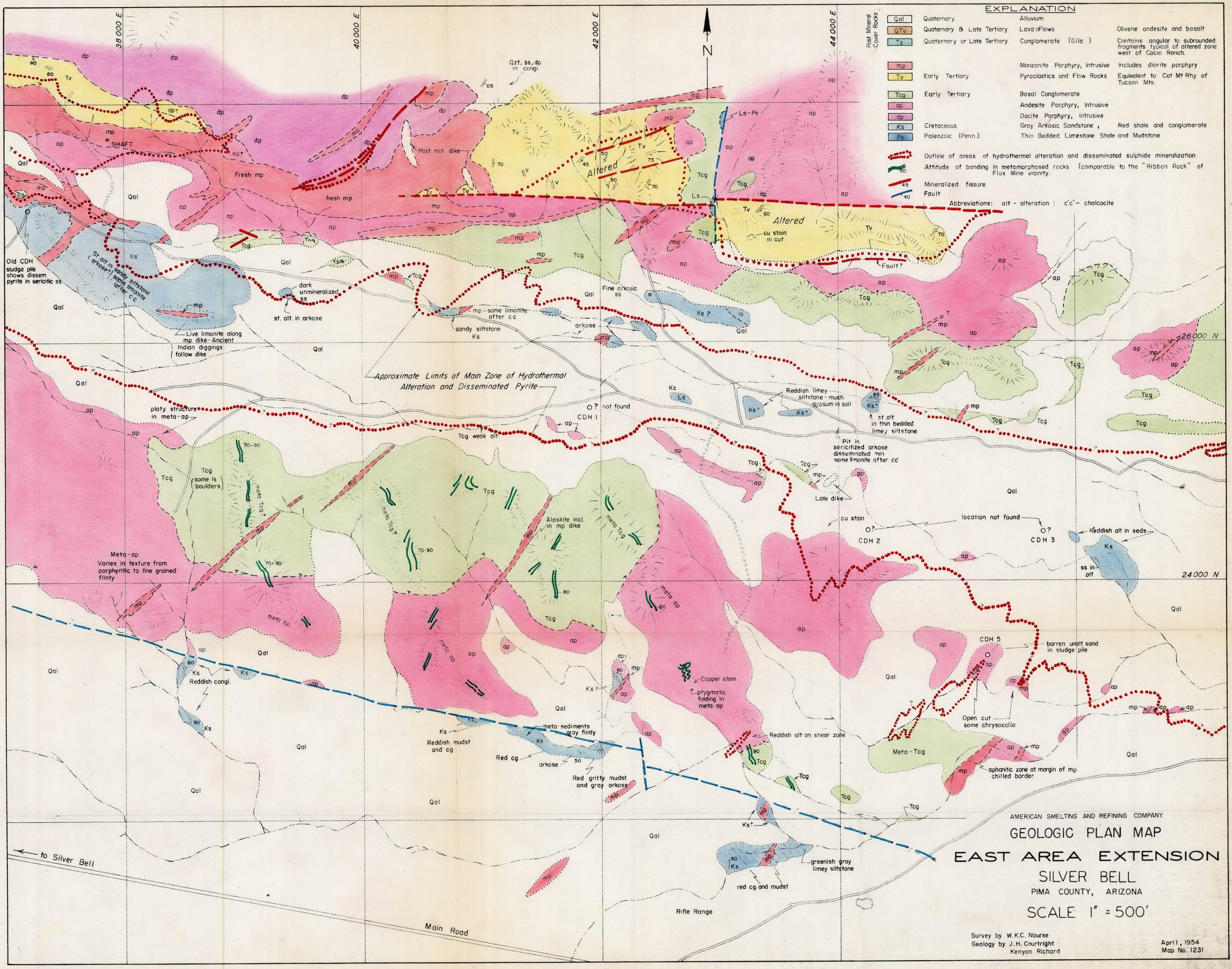
J. H. Courtright

JHC:cms
Enclosures - 2
cc-W. H. Loerpabel, w/enc.
D. J. Pope, w/enc.
W. H. Landwehr, w/enc.
Silver Bell - 2


ATLAS MINE
EL TIRO AREA
OXIDE AREA
NEW PIT OUTLINE
N. 40,000
N. 35,000
N. 30,000
N. 30,000
E. 35,000
E. 15,000
E. 20,000
E. 25,000
E. 30,000
LEGEND
Old Churn Drill Holes.
Recent Churn Drill Holes.
Recent Diamond Drill Holes.
Plus 70 ft. - 1.0% Cu. or equivalent grade feet at 0.6% Cu cutoff.
25 to 70 ft. " " " " " " " ".
0 to 25 ft. " " " " " " " ".
Under 0.6% Cu.
Plate II
TO ACCOMPANY REPORT
BY J. H. COURTRIGHT
MAP NO.
PROPERTY MAP
Showing Drill Hole Locations
SILVER BELL
PIMA COUNTY, ARIZ.
A. S. & R. CO.
SCALE: 1" = 1000'
MARCH, 1949
REM.

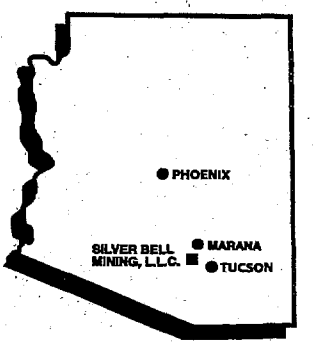
J. H. Courbright Record File




EXPLANATION
Post Mineral Cover Rocks
Qal Quaternary Alluvium
QTv Quaternary & Late Tertiary Lava Flows Olivene andesite and basalt
Ts Quaternary or Late Tertiary Conglomerate (Gila) Contains angular to subrounded fragments typical of altered zone west of Cocio Ranch.
mp Monzonite Porphyry, Intrusive Includes diorite porphyry
Tv Early Tertiary Pyroclastics and Flow Rocks Equivalent to Cat Mt Rhy of Tucson Mts.
Tcg Early Tertiary Basal Conglomerate
ap Andesite Porphyry, Intrusive
dp Dacite Porphyry, Intrusive
Ks Cretaceous Gray Arkosic Sandstone, Red shale and conglomerate
Ps Paleozoic (Penn.) Thin Bedded Limestone Shale and Mudstone
Outline of areas of hydrothermal alteration and disseminated sulphide mineralization
Attitude of banding in metamorphosed rocks (comparable to the "Ribbon Rock" of Flux Mine vicinity.
Mineralized fissure
Fault
Abbreviations: alt - alteration : c'c' - chalcocite
38 000 E
40 000 E
42 000 E
44 000 E
N
26 000 N
24 000 N
Qzt, ss, dp in congl
Post min dike
Fresh mp
fresh mp
SHAFT
Altered
Altered
cu stain in cut
Fault?
Ls-Ps
Old CDH sludge pile shows dissem pyrite in sericitic ss
St alt in sandy siltstone (arkose?) some limonite after c c
dark unmineralized ss
st. alt. in arkose
Live limonite along mp dike - Ancient Indian diggings follow dike
mp - some limonite after c c
sandy siltstone Ks
arkose
Fine arkosic ss
Approximate Limits of Main Zone of Hydrothermal Alteration and Disseminated Pyrite
not found CDH 1
Tcg weak alt
platy structure in meta-ap
Reddish limey siltstone - much gypsum in soil
st alt in thin bedded limey siltstone
Pit in sericitized arkose disseminated min some limonite after cc
Late dike
cu stain
location not found
CDH 2
CDH 3
Reddish alt in seds
ss in pit
Tcg (some ls boulders)
Alaskite incl. in mp dike
Meta-ap Varies in texture from porphyritic to fine grained flinty
Reddish congl.
Copper stain
ptygmatic folding in meta-ap
CDH 5
barren unalt sand in sludge pile
Open cut some chrysocolla
Reddish alt on shear zone
Meta-Tcg
aphanitic zone at margin of mp chilled border
Reddish mudst and cg
meta-sediments gray flinty
Red cg
arkose
Red gritty mudst and gray arkose
greenish gray limey siltstone
red cg and mudst
Rifle Range
to Silver Bell
Main Road
AMERICAN SMELTING AND REFINING COMPANY
GEOLOGIC PLAN MAP
EAST AREA EXTENSION
SILVER BELL
PIMA COUNTY, ARIZONA
SCALE 1" = 500'
Survey by W.K.C. Nourse
Geology by J.H. Courtright
Kenyon Richard
April, 1954
Map No. 1231

The Arizona Daily Star
Tucson, Sunday, July 20, 1997

Moneyplus



Silver Bell Mining, L.L.C.

SILVER BELL MINE

THIS COPPER CATHODE COMMEMORATES THE SILVER BELL MINE SOLVENT EXTRACTION/ ELECTROWINNING PLANT DEDICATION HELD ON WEDNESDAY, JULY 16, 1997

This cathode is symbolic of the first copper produced at the Silver Bell Mine solvent extraction/electrowinning plant in July of 1997. The actual cathodes produced at Silver Bell will contain up to 100 pounds of 99.999% pure copper - a metal critical to our civilization and to our economy. The newly completed plant at Silver Bell will produce 18,000 tons of 99.999% pure copper each year.

Silver Bell Mining, L.L.C. is a joint venture of ASARCO Incorporated and Mitsui & Co., Ltd.

5/31/83

HISTORY OF EXPLORATION AT SILVER BELL, ARIZONA

by Fred Fraghead

Silver Bell is located about 35 miles northwest of Tucson, Arizona. It is a classic porphyry copper deposit containing enriched dissaminated chalcocite ore in altered porphyritic rocks with chalcopyrite ore in porphyry and adjacent skarn zones. The discovery of Silver Bell was an evolutionary process which occurred over a 75 year period.

Recorded mining activity began about 1865 on Boot Hill just east of El Tiro pit where outcropping altered limestones were found to contain 15-17 oz. Ag mixed with copper oxides. By 1874 the Young America Copper Company was mining shallow occurrences of 30% Cu along the north side of the present Oxide Pit. The ore was shipped by wagon to Yuma, Arizona and then by boat to San Francisco for smelting. By 1881 the area supported several mining companies and two small smelters and the district was being favorably compared to Bisbee in local newspapers.

Most of the ore mined in the period 1865-1903 came from pods of massive sulfide or their oxidized products which were distributed in an unpredictable fashion through a large skarn zone in Paleozoic limestone east of El Tiro pit. Ore grades varied from 5-10% Cu.

In 1903 most of the properties were incorporated into or purchased by the Imperial Copper Company and the district had a population in excess of 1000. With the formation of Imperial, mining at Silver Bell became more organized, production increased, and by 1910 over 21 miles of workings existed in the district. During the period 1900-1909 the El Tiro Copper Company had mined oxidized

products of supergene enriched ore in a zone of brecciation along the alaskite-dacite contact west of the skarn ores. The significance of ~~small zones~~ exposures of disseminated chalcocite in alaskite in the El Tiro mine workings was apparently recognized by the Imperial Copper Co. which in 1909 acquired control of 240 acres owned by the El Tiro Copper Co. and in 1910 completed 44 churn drill holes in alaskite and quartz monzonite porphyry just southwest of the El Tiro mine. This drilling covered an area about 1000 ft. by 2500 ft. and discovered enriched disseminated chalcocite under leached capping at depths of about 100 ft. The geologic reports which were presumably written to recommend this drilling cannot be found. At the same time a similar drilling program was started by Oxide Copper Company in the area adjacent to the Young America mine workings. This program completed 72 churn drill holes and also encountered disseminated chalcocite. Finally, in 1909, the Seeley Mudd interests in Los Angeles drilled 10 churn drill holes in an altered area east of the present Oxide Pit with mostly negative results.

From 1907-1910 Imperial increased production sixfold which caused ore grades to decline to 2.4% Cu. During the same period copper prices fell from $.20 to $.13 and, despite the opening of a smelter in August 1909, the Imperial Copper Company closed operations in August 1910 and was declared bankrupt in July 1911. However, the importance of the previous churn drill results had not been overlooked and Meade Goodeloe, the general manager, wrote in an operating report of November 8, 1910:

> "A further element of great promise had appeared in the finding ..... of workable values in the granitic porphyry. The mining of porphyry deposits of this character ..... with no waste vein matter to be mined and discarded, can be accomplished at much less cost per ton than the mining of our contact orebodies, and ..... places the undertaking on a manufacturing basis."

By 1914 copper prices had increased to $.17/lb. and several companies investigated the district, including the American Smelting and Refining Company (ASARCO). On April 12, 1915, H. A. Guess, a mining engineer (who would later become Vice President of the Mining Department and a Director of Asarco), submitted a detailed report of his investigations at Silver Bell which stated:

> "I would not recommend spending money that would be necessary for a thorough sampling and examination of the Imperial mines, were it not for the possibilities of the disseminated area."

Guess sent an additional letter two days later which stated:

> "We cannot let this thing go by without looking fully into it and I therefore recommend, first, we acquire control of the Imperial Company's property, or the disseminated portion of it, and similarly of the El Tiro property on the same basis."

In September 1915 Asarco obtained an option on the Imperial and, probably, the El Tiro properties. Five holes were drilled under the supervision of Julius Kruttschnitt (who would later become Chairman of the Board of Mt. Isa Mining Co.) to check previous work by Imperial. The results were disappointing, but on December 16, 1916 Asarco purchased the Imperial properties which were operated until 1921. During 1916 Guess, Kruttschnitt, and J. Gordon Hardy examined the holdings of the Oxide Copper Co. which were eventually rejected as too small and of marginal grade. The recommendations were influenced by metallurgical tests which indicated 78% recovery of copper into a 14% Cu concentrate and perhaps by the purchase price of $1 million.

Geological activity was generally low from 1920-1940. In 1923 Roland Blanchard made a study of Silver Bell outcrops in which he indicated that variations in the color of limonite on the weathered surface did not bear an obvious relationship to ore-bearing rock. In his book (1968) Blanchard amended his earlier observations and noted that maroon-colored limonite was a reliable guide to chalcocite in the quartz monzonite porphyry (he called it alaskite porphyry), but not in adjoining alaskite. Later studies by Kenyon Richard and Harold Courtright were to find that the color of powdered limonite was a fairly reliable guide to chalcocite enrichment regardless of (produced by scratch) rock type or strength of alteration.

In 1929 the Oxide property was submitted to Asarco a second time. Blanchard, Kruttschnitt, and H. P. Hill restudied the area in 1930 and, after a $25,000 program of mapping, underground sampling, and drifting, estimated a reserve of 10,047,000 tons averaging 1.46% Cu in a blanket 85 ft. thick. However, due to (1) the inferred spotty distribution of mineralization interpreted from surface outcrops, (2) the fact that much of the area was estimated to contain roughly 1% Cu which was then submarginal, (3) indications that the churn drill samples were at least 0.3% Cu too high (presumably due to contamination from uncased holes), and (4) unfavorable projections of future copper prices, the property was again rejected.

Following closure of the mine in 1921, the area became a ghost town and in 1938 Asarco stopped making property tax payments on the Imperial properties. In 1939 the Pima County Treasurer advertised the Imperial claims for sale, but (because certain legal procedures had not been followed) no sale had occurred by

April 17, 1940 when H. A. Kursell wrote a brief, but thorough summary of the disseminated mineralization in the Silver Bell district. He noted that:

> "... a strong shear zone, or zone of brecciation ... through the El Tiro mine .... heads for the Mammoth Mine ... and beyond that towards the Oxide Copper orebody. This fracture zone was quite evidently a channel from which copper mineralization spread, and the fact that apparently no comprehensive mapping was ever done of this copper belt three miles in length, suggests to me that this problem has never been approached in a sufficiently broad way."

Kursell suggested that the disappointing results obtained in the 1915 check drilling at El Tiro were partly due to poor placement of holes and that a potential existed for 4.5 million tons averaging 1.2% Cu in a blanket 95 ft. thick. He noted that since Kruttschnitt's report in 1930 technological advances in bulk mining, mill construction, and flotation methods permitted new costs to be used and estimated that copper could be produced for about $.09/lb. He concluded by recommending purchase of the Oxide Copper and El Tiro properties.

Two weeks after Kursell wrote his report the Oxide Copper Company property was again offered to Asarco, this time for $40,000. On May 6, 1940, H. A. Guess, now Vice President of Mining, wrote W. H. Loerpabel, Manager of the Southwestern Mining Department, that purchase of the Oxide Copper property had been approved, that an immediate attempt be made to acquire the El Tiro Copper Company properties, that all delinquent taxes on the Imperial properties be paid, and that all open ground be staked. On May 8 an expenditure of $75,000 was approved to consolidate properties at Silver Bell. Loerpabel sent a coded telegram on May 17 indicating competition from Inspiration and from Calumet

and Hecla for the El Tiro properties, but on May 21 wrote that verbal agreement had been reached to purchase the properties for $10,000. The sale of Oxide Copper properties was approved by Oxide's Directors on June 3, 1940 and the payment of $40,000 made on June 5. Purchase of the El Tiro properties was consummated June 14 by payment of $10,000. By July 24, land acquisition strategies appeared firmly established, options on small claim blocks were being acquired, and a recommendation was made to begin compilation of a surface geological map of the district.

In 1941 Harrison Schmitt supervised a ~~detailed mapping~~ program by Lawson Entwistle and H. M. Kingsbury which established a topographic base between the El Tiro and Oxide areas and mapped all rock types. Their report did not consider the extent of surface alteration and Kingsbury concluded that in the El Tiro area there were no reliable indications in outcrop which could predict the continuity of secondary enrichment.

It had been recognized in 1914 that the Oxide area was clearly the larger of the two disseminated deposits and Kruttschnitt's suggestions made in 1930 regarding inaccurate drill results were of considerable concern. Further work was deferred until after World War II and in 1948 a churn drill program was begun in the Oxide area to check the previous results and to locate extensions of known mineralization. It was also recognized that reliable guides to chalcocite enrichment which could be interpreted from outcrop studies and then used to guide drilling more efficiently had yet to be established. In 1947 Prof. Paul F. Kerr of Columbia University was retained to study the distribution of alteration, which he had previously found to be a useful ore guide at Santa Rita. In

November 1947, Harold Courtright was sent to Tucson by W. R. Landwehr, Chief Geologist for the Western Mining Department, to set up and supervise the churn drill program and to make a study independent from Kerr's of the geology of the area as it related to the interpretation of the drill results.

Kerr [redacted] concluded ~~were~~ that surface alteration could be used as an ore guide regardless of whether ~~additional~~ surface indications of mineralization were present. Later drilling suggested that surface alteration was not the principal guide to supergene ore and, in addition, that some of the alteration was itself of supergene origin. In July 17, 1948, Courtright reported that:

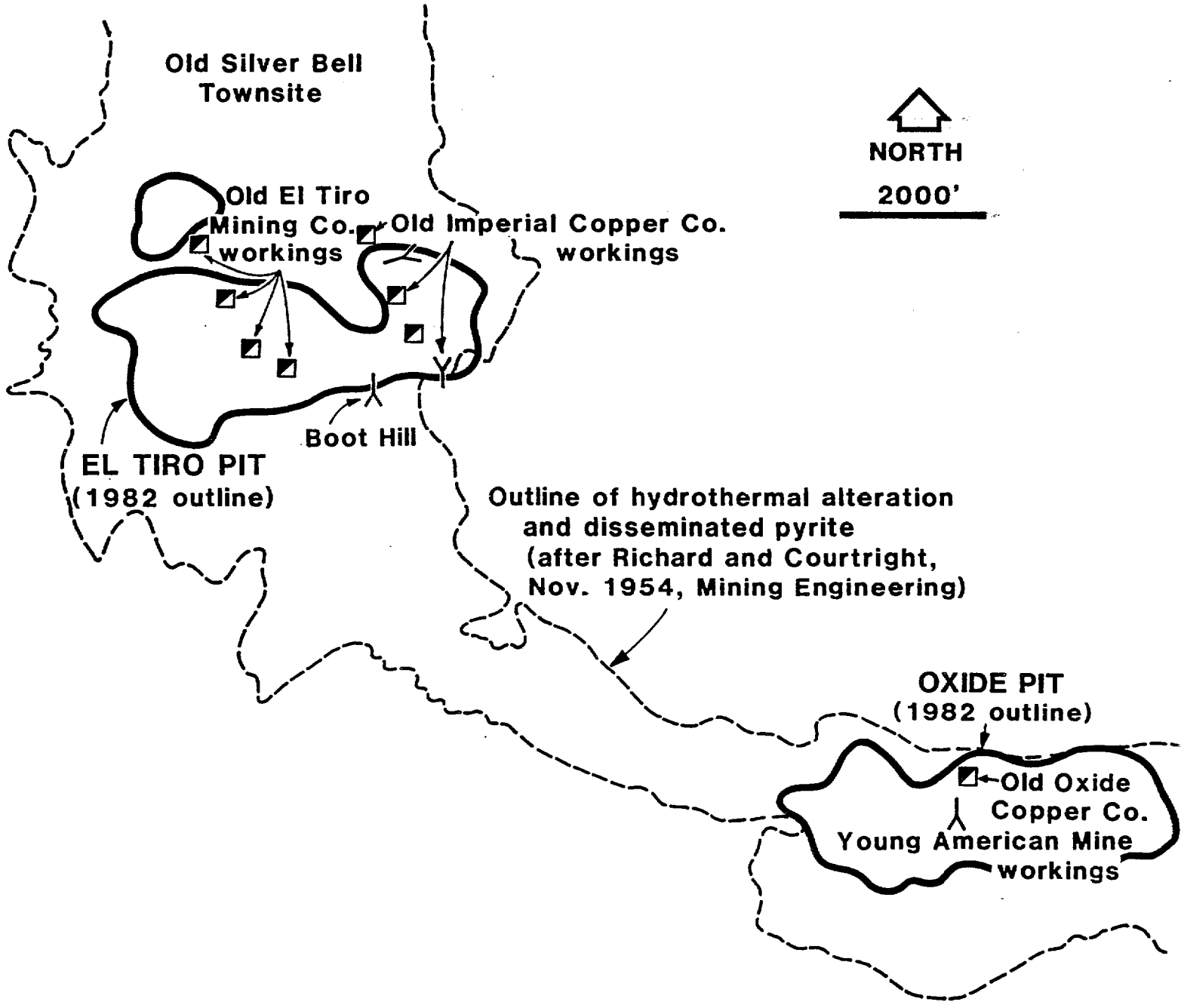
> "A study of the outcrops over the Oxide orebody and adjacent areas disclosed the fact that notable variations of both the color and intensity of residual limonite were present. The attached 200-scale map was prepared to depict the distribution and relative intensity of copper mineralization as evidenced by characteristic limonite visible in the bedrock exposures. The characteristic limonite, apparently derived from pyritic chalcocite, possesses a color varying from purple tinged dark red to chocolate brown. In contrast, the outcrops over essentially pyritic bodies exhibit yellow and brick red colors."
>
> "Blue-green stains and veinlets, representing chrysocolla for the most part, are prominent in some of the alaskite outcrops in the area. .... Such areas, classed as weakly mineralized, are not considered to hold potentialities in respect to disseminated copper ore, regardless of their spectacular appearance."

Utilizing the above guides an eventual mining reserve of _____ million tons averaging _____% Cu was defined in the Oxide area. Also in July ~~[illegible]~~ 1948, Kenyon Richard and J. C. Playter reported on ~~[illegible]~~ the area of previously indicated disseminated mineralization in the El Tiro area. Interpreting zones of strong sheeting in alaskite and a characteristic "live" limonite as ore guides they recommended 20 holes which eventually led to the definition of a mining reserve of _____

million tons averaging _____ % Cu. The essential aspects of the geological work by Richard and Courtright were published in the November 1954 issue of Mining Engineering. In 1951 the Defense Material Procurement Agency guaranteed to purchase 177 million pounds of copper from the first 197 million pounds produced at $.245/lb. Milling of open pit ore at 7000 tpd began in March 1954.

In 1959 Stephen Von Fay began a field study under the direction of Richard and Courtright of the exploration possibilities for small high grade copper deposits in the skarns east of El Tiro pit. He also reviewed old file data previously acquired from the Imperial Copper Company and found numerous comments regarding "low grade ..... cupriferous pyrite", "imperceptible grading of ore in stopes into non-ore grade material", and core intercepts containing 0.4-1.0% Cu being described as "barren rock." Von Fay's work led to recognition of the potential for disseminated mineralization in the altered sediments, and subsequent drilling in this area defined a zone containing roughly 10 million tons averaging 0.8% Cu as chalcopyrite overlain by an additional 10 million tons of oxidized material averaging 1% Cu as chrysocolla and malachite. Open pit Production to date at Silver Bell has been 89 million tons averaging .78 % Cu.

The importance of Silver Bell to Asarco transends its mere profitability. It was the Company's first open pit and large-scale mining operation and was a major step toward greater integration of mining operations into what had previously been largely a smelting and refining business. In addition, the success of Silver Bell and the emerging importance of Arizona as a major porphyry copper province led to the organization of a porphyry copper program by Kenyon Richard and Harold Courtright which resulted in discoveries at Mission, Sacaton and elsewhere.



LOCATION OF MINING AREAS
SILVER BELL DISTRICT
PIMA COUNTY, ARIZONA