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WILLARD D. PYE
Consulting Geologist
3418 NORTH FORGEUS AVENUE
TUCSON, ARIZONA 85716

TELEPHONE 327-2956

Kluger

November 4, 1969

[redacted]

The Sunrise property consists of 152 mining claims lying about 35 miles northwest of Tucson, Arizona, and a few miles west of the town of Silver Bell.

On the basis of several hours spent on the property and general knowledge of the ASARCO strip mining operations at Silver Bell and the geology of the area, the following observations can be made:

1. The claims lie just west but in contact with the western boundary of the ASARCO Silver Bell mining operation;

2. The claims lie just south but in contact with the southern boundary of the B.S. & K. mine now owned by Duval but currently inactive;

3. The claims lie just east but in contact with the eastern boundary of the newly discovered El Paso Natural Gas Company Lake Shore copper ore deposit;

4. On the northeast end of the Sunrise claims copper mineralization is found in the form of extensive copper oxides in granitic rock;

5. A fault cuts the above mineralized rock off and to the west of the fault only fault breccia and/or alluvium has been found but some of this alluvium adjacent to the fault has been mineralized by secondary(?) migration of the copper;

6. Holes drilled west of the fault to depths of 160 feet have not reached bed rock;

7. No bed rock exposures were observed west of the fault except in the hill at the extreme southwest corner of the claims, the entire area being flat lying and covered with alluvium of unknown thickness.

On the basis of the above information it is recommended that the claims be acquired since

(1) Copper bearing rock is exposed in the northeast corner of the claims, and

2. The claims occupy the open ground between the ASARCO Silver Bell open pit mine and the large ore body discovered under the El Paso Natural Gas Company Lake Shore prospect, the limits of which ore body have not yet been determined; the claims also lie south of the B. S. & K. mine.

Although from the few hours spent on the property no evidence of mineralization was observed underlying the alluvium which covers most of the claims, yet based upon observations elsewhere in the copper mining areas adjacent to Tucson, it is a good possibility that the mineralization will be continuous across the ground between the ASARCO Silver Bell mine and the El Paso Lake Shore mine. Although at the moment this continuity cannot be proved, the probability is such that the risk should be taken.

The ore deposit, if present under the claims, will be found at a depth of several hundred feet since it is known that adjacent to the fault drilling has not penetrated the base of the alluvial fill at a depth of 160 feet and the Lake Shore deep ore body is found at over 700 feet depth.

To explore the property the property should be

1. Mapped geologically using aerial photographs;

2. I.P. or other geophysical work should be used to determine the locality of any ore bodies; and

3. Deep drilling should be initiated to test geophysical anomalies or geological work.

It is believed that the property could have a very high ore potential and on this basis it is recommended for acquisition. Its main importance is its strategic location.

Yours sincerely,

Willard D. Pye

Willard D. Pye

REGISTERED GEOLOGIST
CERTIFICATE NO.
4033
WILLARD D.
PYE
Willard D. Pye
Signed 11/4/60
Arizona U. S. A.

736-7301

ALLAN P. FAWLEY, PH.D., P.ENG.
CONSULTING MINING AND GEOLOGICAL ENGINEER

1947 WEST KING EDWARD AVENUE
VANCOUVER 9, BRITISH COLUMBIA

THE SUNRISE PROPERTY, ARIZONA
of
MANTLE MINERALS LTD. (N.P.L.)

Property Examination September 20, 1967. Report Written October 1967.

INTRODUCTION

The Sunrise property of Mantle Minerals Ltd. which adjoins the Silver Bell Mine is in southern Arizona, an area noted for large-scale open-pit copper-molybdenum mines, and where several new mines and promising prospects have recently been discovered. Also the area is one where low-grade oxidized copper deposits may be profitably treated by leaching.

Information for this report is based on a personal examination of the property on September 20, 1967 in company with R.G. Hawley (geologist) and L. Cox (prospector) and on various reports, including: "Structure and Mineralization at Silver Bell, Arizona" by K.E. Richard and J.H. Courtright (Mining Engineering, November 1954); "Porphyry Copper Deposits" by S.E. Jerome (Western Miner, February 1963); "Southwest Copper" by J.V. Beall (Mining Engineering, October 1965); and in particular on a private report and maps of the Sunrise property by R.G. Hawley (April 1967).

LOCATION AND ACCESS

The Sunrise property is about 35 miles W.N.W. of Tucson, Arizona and adjoins the Silver Bell Mine of American Smelting and Refining Co. and the old B.S. & K. mine, which is now owned by Duval Corporation (see location map, in pocket). The property is accessible by 38 miles of paved highway from Tucson to the Silver Bell townsite and thence by 4 miles of gravel road to the Sunrise shaft. Most of the claims area can be reached by secondary trails or without trails by using a 4-wheel drive vehicle.

PROPERTY

The Sunrise property of Mantle Minerals Ltd. is in the Silver Bell Mining district of Arizona and consists of 152 mining claims named and numbered as follows:

Sunrise 1 - 94
Sunrise Extension 1 - 58

CLIMATE AND TOPOGRAPHY

The Sunrise property is in a semi-arid climate and the vegetation consists mainly of large to small cacti and low thorn bush. The claims are at an average elevation of about 2,500 feet above sea level and extend from the fairly rugged western foothills of the Silver Bell mountains to almost flat-lying overburden--covered plains.

HISTORY

"Extensive mining development has been carried out in the Silver Bell area since the opening of the first major mine in 1865. Intermittent selective mining had produced about 100 million pounds of copper by 1930. In 1954 American Smelting and Refining began production at the rate of 18,000 tons of copper annually. A molybdenum recovery plant was added in 1957 and a leaching plant in 1960." (Hawley, 1967) The present mining rate at the Silver Bell mine is about 10,000 tons per day of milling ore plus about 20,000 tons per day of waste, to produce (1965) 23,600 tons of copper per year in combined concentrates and cement copper (from leaching).

"The Sunrise Group has reportedly been held for 10 years, during which time very little exploratory work was carried out. A small pit about 10' by 10' by 12' deep has been sunk near the north boundary, on a 25° incline sunk about 4,000 feet to the south." (Hawley, 1967) Recently, geochemical soil sampling, geological mapping and percussion drilling (using a wagon drill) have been carried out, and the property has been carefully re-staked and claim location holes have been drilled.

GEOLOGY AND MINERALIZATION

The geology of most of the property is not known due to a cover of sandy overburden, however a reconnaissance geochemical survey has shown that copper anomalies exist throughout much of the claims area. The geology and mineralogy of the northern part of the claims area is concisely given by R.G. Hawley (1967) as follows:

"The host rocks for the porphyry copper deposits on the adjoining property of American Smelting and Refining are alaskite, dacite porphyry, and monzonite. Controlling structures are a northeast fracture and dike system at the El Tiro pit and an east-west fault at the Oxide pit. The Duval ore body is a contact deposit occurring in limestone along the northern extension of the Sunrise fault.

"On the Sunrise Group, monzonites with minor diabase and andesite dikes have been cut by a major fault striking N 20 E and dipping 50° W which has been traced for 5,000 feet south from the north boundary of the claims before being covered by overburden.

"A mineralized breccia has been exposed in several shallow open cuts along the hanging wall of the fault. The full width of this breccia is not known although it has been exposed for an average width of 200 feet from the fault along a strike length of 1,000 feet, before passing under overburden.

"Southeast of the shaft in the footwall monzonite mineralized northeast fractures similar to and on strike with the El Tiro structure were observed.

"The copper oxide tennorite (or melanochalcite) forms the main copper mineral throughout the breccia zone, where it occurs as a black stain on fracture planes and cementing the breccia fragments. At depth increasing amounts of malachite, azurite and chrysocolla appear. These, together with minor tennorite also occur in northeast trending gouge and shear zones in the footwall monzonites.

"Molybdenum oxide was observed at several points in the altered monzonite along the fault.

"Assays for samples taken from exposures along the fault varied from 0.01 to 3.57% copper. In the best exposed area near the shaft 3 chip samples across 140 feet averaged 1.35% copper. Values increase considerably with depth as indicated from sampling in the inclined shaft where a sample from the bottom assayed 3.57% copper."

ORE POSSIBILITIES

Geochemical sampling has shown that copper mineralization is widespread in the claims area (see enclosed "Geochemical Survey" map) and sampling of the Sunrise shaft and of bulldozer cuts along the known part of the Sunrise fault have yielded encouraging copper values (see enclosed "Geology and Topography" map). The percussion dry-drilling completed so far has been unsatisfactory due to rods sticking (caused by caving) and to the water table being reached at about 100 feet so that depths of the nine holes drilled were seldom more than 100 feet. Values obtained were considerably less than those obtained by channel sampling the nearby shaft and open cuts, possibly because recovery of the secondary copper oxides was poor, however values were generally best at the greatest depth penetrated, for example: hole No. 2 averaged 0.10% copper from 0 - 80 ft., and 0.43% from 80 - 115 ft. (and the deepest assay was 0.51% copper); and hole No. 8 averaged 0.25% copper from 0 - 90 ft. and 0.5% from 90 - 110 ft. (At the adjoining Silver Bell mine a leached surface capping generally containing less than 0.1% copper covers the ore bodies to a depth of about 100 feet, re Richard and Courtright (1954). A secondary enriched copper zone may exist in places, especially along the Sunrise fault, below the oxidized zone.

Summarizing, at present there is not sufficient information to calculate ore reserve grades or tonnage, but there is a reasonable possibility of finding sufficient ore (oxide and/or sulphide) for large scale operations.

LEACHING OF SUNRISE ORE

"The ore in the breccia zone will break fine enough to give large surface area for solution contact and the mineral tennorite is one of the most soluble of the copper minerals. For these reasons this ore is very amenable to leaching treatment and one of the fastest leaching ores in Arizona." (Hawley, 1967) An explanation of leaching is given in the appendix to this report.

CONCLUSIONS AND RECOMMENDATIONS

Sufficient work has been done on the Sunrise property, which is in an area of numerous large mines and which itself adjoins one large producer, to indicate the possibility of locating enough oxide ore for a leaching method of production on an economic scale, and enough ore may exist (including oxides and sulphides) for large-scale mining. Therefore a methodical and detailed exploration program should be undertaken to determine the amount and grade of ore, and leaching tests should be carried out to determine the percentage of copper that can be recovered, the amount of acid required per ton, etc.

A pronounced part of the economic geology of the property is the Sunrise fault that extends roughly north-south for more than 1 mile, and

possibly for 3 miles, within the claims area. Copper mineralization is associated with the fault, and the entire length of the fault should be prospected by trenching and/or drilling. A preliminary geochemical survey has found a number of pronounced copper anomalies and detailed exploration work should be done on these anomalies. The property appears to be ideal for leaching as oxidized copper occurs in a brecciated rock, though some calcium carbonate may be present, especially in near surface rocks.

A suggest exploration program is as follows, but it should be realized that this program is an outline only and that changes in the program may be necessary as work progresses:

1. Establish a trailer camp on the property (to avoid the expense and delays of basing personnel in Tucson, which is the only alternative).

2. Drill a well to a depth of about 400 feet and equip it with a diesel-powered pump to supply water for the trailer camp, for drilling, and for leaching tests. Also the well hole should provide valuable geological and assay information.

3. Complete a detailed geochemical survey over the anomalous zones discovered during the reconnaissance geochemical survey, and have the samples tested for copper in parts per million.

4. To test the reliability of percussion drilling with regard to assay results; drill 6 percussion holes within a small section, each to a depth of 20 feet, and carefully sample the holes, then trench and bulk sample the same section to obtain the true assay value.

5. Test anomalous geochemical zones and the zone along the Sunrise fault by trenching and/or percussion drilling. Bulk sample the trenches.

6. Have an induced polarization geophysical survey carried out over the area of the Sunrise shaft and part of the Sunrise fault to test the effectiveness of the method, and if successful, use further induced polarization surveys along the Sunrise fault and over geochemical anomalies.

7. Have leaching tests carried out both in the laboratory and in the field.

8. If trenching and percussion drilling and/or induced polarization surveying have given encouraging results, then diamond drill possible ore zones to obtain their depth and grade at depth.

When the above work has been completed, assuming encouraging results have been obtained, a feasibility study should be undertaken to determine the most satisfactory extraction method and treatment scale, or to decide whether further drilling is necessary.

ESTIMATED EXPLORATION EXPENSES

The estimated cost of the exploration program outlined above is as follows:

To buy and establish a small trailer camp on the property	$6,000.00

Drilling and equipping a water well	7,500.00
Carrying out a detailed geochemical survey including cost of assays	5,500.00
Trenching and percussion drilling including bulk sampling and assaying	25,000.00
Induced polarization geophysical surveys	3,000.00
Diamond drilling, 2,500 ft. at $10.00 per ft.	25,000.00
Supervision, travel, office overhead and contingencies	15,000.00
Total	$87,000.00

Further funds will be necessary, of course, if a large-scale diamond-drilling program becomes warranted, or if the property is put into production.

Respectfully submitted,

Allan P. Fawley, B.A.Sc.,
M.Sc., Ph.D., P.Eng.
Consulting Mining and Geological Engineer

Vancouver, B.C.
October 17th, 1967.

CERTIFICATE

I, ALLAN PRIEST FAWLEY, of the City of Vancouver, in the Province of British Columbia, HEREBY CERTIFY:

1. THAT I am a Consulting Mining Engineer and Geologist, and my address is 1947 West King Edward Avenue, Vancouver 9, B.C.

2. THAT I am a graduate of the University of British Columbia with the degree of B.A.Sc. (1937) in Mining Engineering, of Queen's University with the degree of M.Sc. (1946) in Geology, and of the University of California with the degree of Ph.D. (1948) in Geology.

3. THAT I am a registered Professional Engineer in the province of British Columbia and in the Yukon Territory, and also a member of the Society of Economic Geologists, of the Canadian Institute of Mining and Metallurgy, and of the Geochemical Society.

4. THAT I have practised my profession as a geologist for more than twenty years.

5. THAT I have no direct interest or indirect interest, nor do I expect to have any interest in the Sunrise property or in Mantle Minerals Ltd.

6. THAT I have no direct or indirect interest in any company acquiring control or intending to acquire control of the Sunrise property or in Mantle Minerals Ltd.

7. THAT this report on the Sunrise property of Mantle Minerals Ltd. is based on my personal examination of the property on September 20, 1967.

8. THAT I have examined the staking of the Sunrise property of Mantle Minerals Ltd. and found it to be in accordance with the staking requirements of the State of Arizona.

DATED this 17th day of October 1967.

Allan P. Fawley, Ph.D., P.Eng.
Consulting Mining and Geological Engineer

APPENDIX

DUMP LEACHING—AN EXPANDING SOURCE OF COPPER

On this page and the succeeding two pages of photographs attention is focused on the leaching of low-grade copper ore on mine dumps. This practice is expanding rapidly and may ultimately lead to large scale "chemical mining."

Leaching is still in the "art" stage because there is little precise knowledge of the chemistry. Although the practice is not new, it is only recently that intensive experimentation has begun with a view to lifting the process out of the category of a minor sideline and elevating it to an integral part of copper producing operations. For example, at Chino leaching has been dovetailed into overall mining plans by expanding the leaching operation, putting higher grade material on the leaching dumps, and raising the cut-off grade of ore that is sent to the concentrator.

It is quite possible that as experimental work progresses, dumps will be shattered by explosive charges for controlled percolation of solutions that may be injected under pressure and fortified with catalysts and solvents to achieve greater production in a shorter period of time. It is probable that the future will see more leaching in place than at present.

Current leaching practice is an approximation of natural processes, in which old dumps or low grade ore, considered waste, is irrigated with water, in some cases souped up with acid. The water percolates through the dump dissolving copper as it descends until the solution is trapped at the bottom where it drains to catchment reservoirs and is then delivered to tanks where it replaces iron placed there to precipitate the copper. Operating data given in table below show variations in different orebodies.

For all practical purposes, leaching is performed by sulfuric acid and ferric sulfate by oxidizing copper minerals to soluble copper sulfate. Where there is sufficient pyrite in the waste dump, leaching may be performed with natural water, the acid being formed by reaction with pyrite. The general equations given below approximate the reactions which are thought to take place for the minerals that are amenable to the process. Chalcopyrite, an important ore mineral, is not significantly leached by the solutions. Certain bacteria, utilizing iron and copper in their metabolism, are oxidizing agents which catalyze the leaching process. Other catalysts and solvents are coming on the market which may economically increase the efficiency of leaching. Precipitation of copper from the pregnant solution may see a change in method due to the high cost of iron scrap.

Azurite

$$Cu_3(OH)_2 \cdot (CO_3)_2 + 3H_2SO_4 = 3CuSO_4 + 2CO_2 + 4H_2O$$

Chalcocite

$$Cu_2S + 2Fe_2(SO_4)_3 = 2CuSO_4 + 4FeSO_4 + S$$

Covellite

$$CuS + Fe_2(SO_4)_3 = CuSO_4 + 2FeSO_4 + S$$

Cuprite

$$Cu_2O + H_2SO_4 + Fe_2(SO_4)_3 = 2CuSO_4 + H_2O + 2FeSO_4$$

Chrysocolla

$$CuSiO_3 \cdot 2H_2O + H_2SO_4 = CuSO_4 + SiO_2 + 3H_2O$$

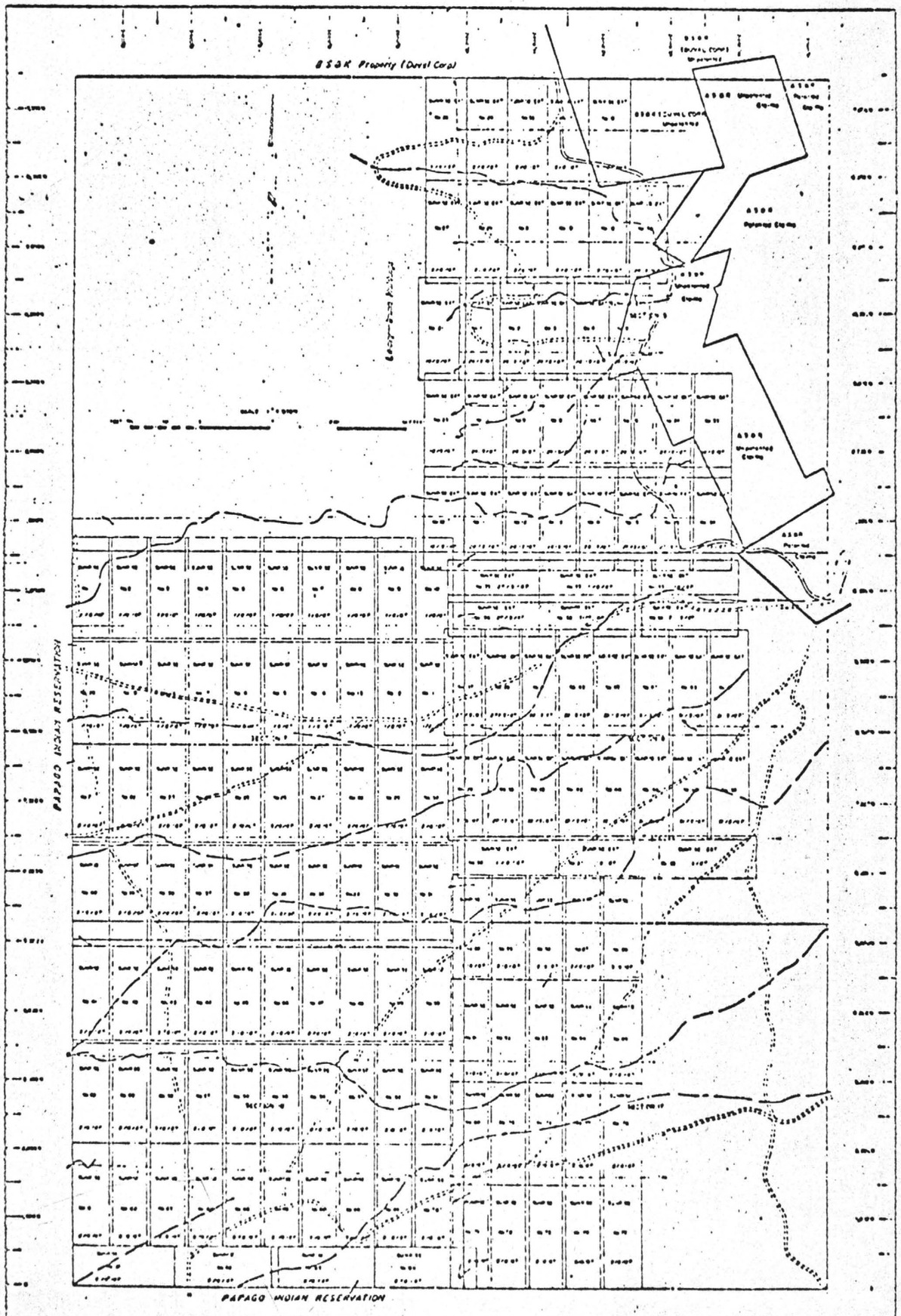
Malachite

$$Cu_2(OH)_2 \cdot CO_3 + 2H_2SO_4 = 2CuSO_4 + CO_2 + 3H_2O$$

Pyrite

$$2FeS_2 + 2H_2O + 7O_2 = 2FeSO_4 + 2H_2SO_4$$

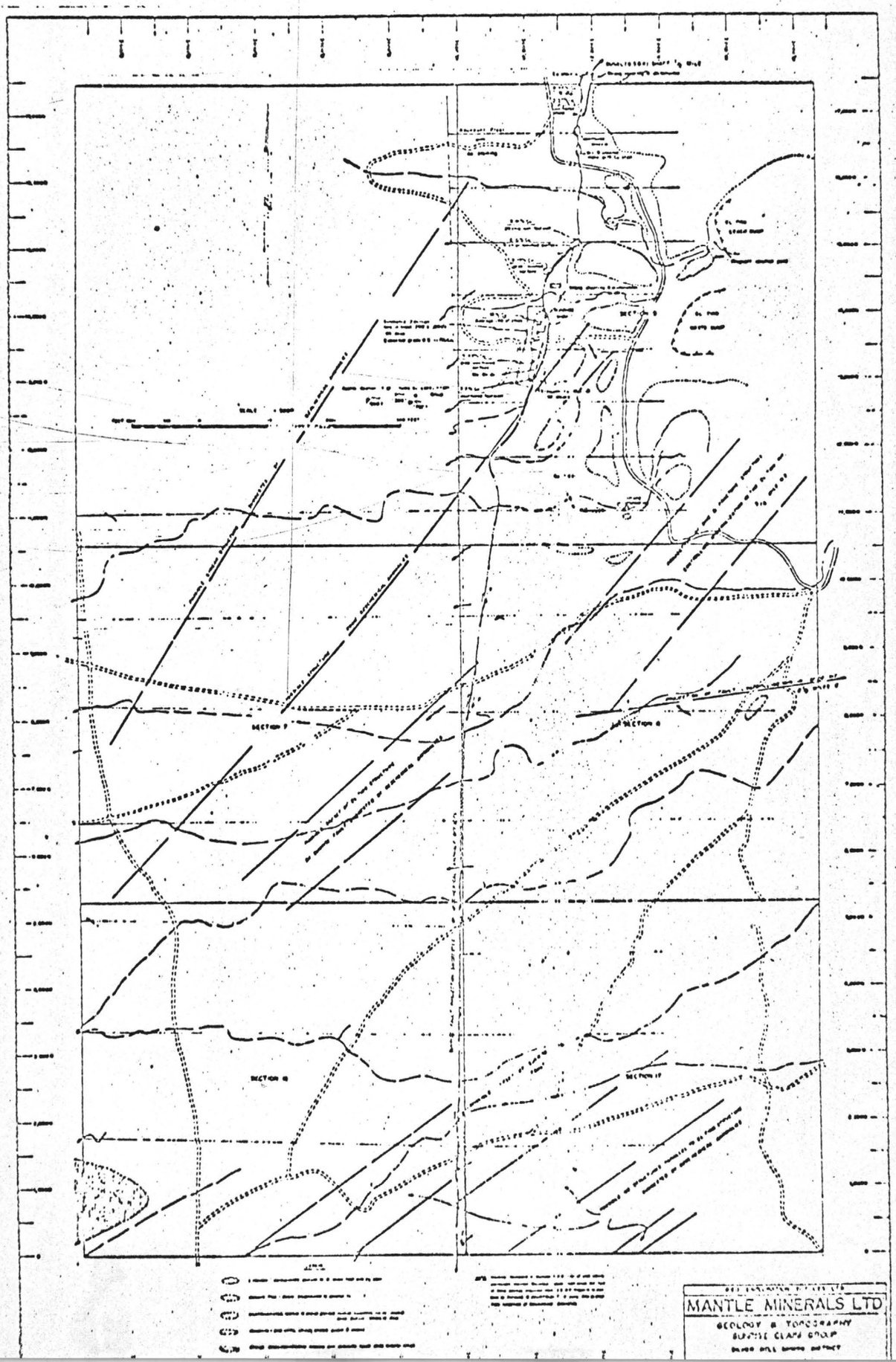
DUMP LEACHING DATA	[illegible]	COPPER QUEEN	[illegible]	CHINO	[illegible]	BAGDAD	[illegible]
[illegible]	1200	2100	5000	11,000	n.a.	3300	1000
[illegible]	0.2-0.4	0.3	n.a.	0.05	n.a.	0.25-0.75	0.15-0.4
[illegible]	2.75	3.5	2.1-3.5	3.5	2.64	2.00	4.5
[illegible]	20.0	10	1.2-2.4	3.6	4.96	3.60-4.20	1.44
[illegible]	2.2	nil	0.06	<.1	0.50	.10-.20	trace
[illegible]	0.15	nil	trace	.1	0.24	0.02	trace
[illegible]	2.0	2.0	2.0-2.5	2.5	1.65	2.3-2.5	2.5
[illegible]	6.0	3.5	0-0.96	1.0	3.24	.01-.05	trace
[illegible]	12.0	3.0	0.24-1.60	1.0	2.73	1.60-2.00	0.24
[illegible]	1.50	1.4	0.24-3.60	1.8	1.877	1.10-1.30	1.2
[illegible]	none	none	n.a.	3.3*	9.82	14-16	none
[illegible]	1.30-2.50	1.1-2.4	0.60	1.2-2.4	n.a.	1.3-1.10	n.a.
[illegible]	5.0	1	n.a.	5-6	4.65	7	25-30
[illegible]	4	2.5	n.a.	1.5	2.52	1.4	1.33
[illegible]	6	12	n.a.	4	n.a.	2½	none

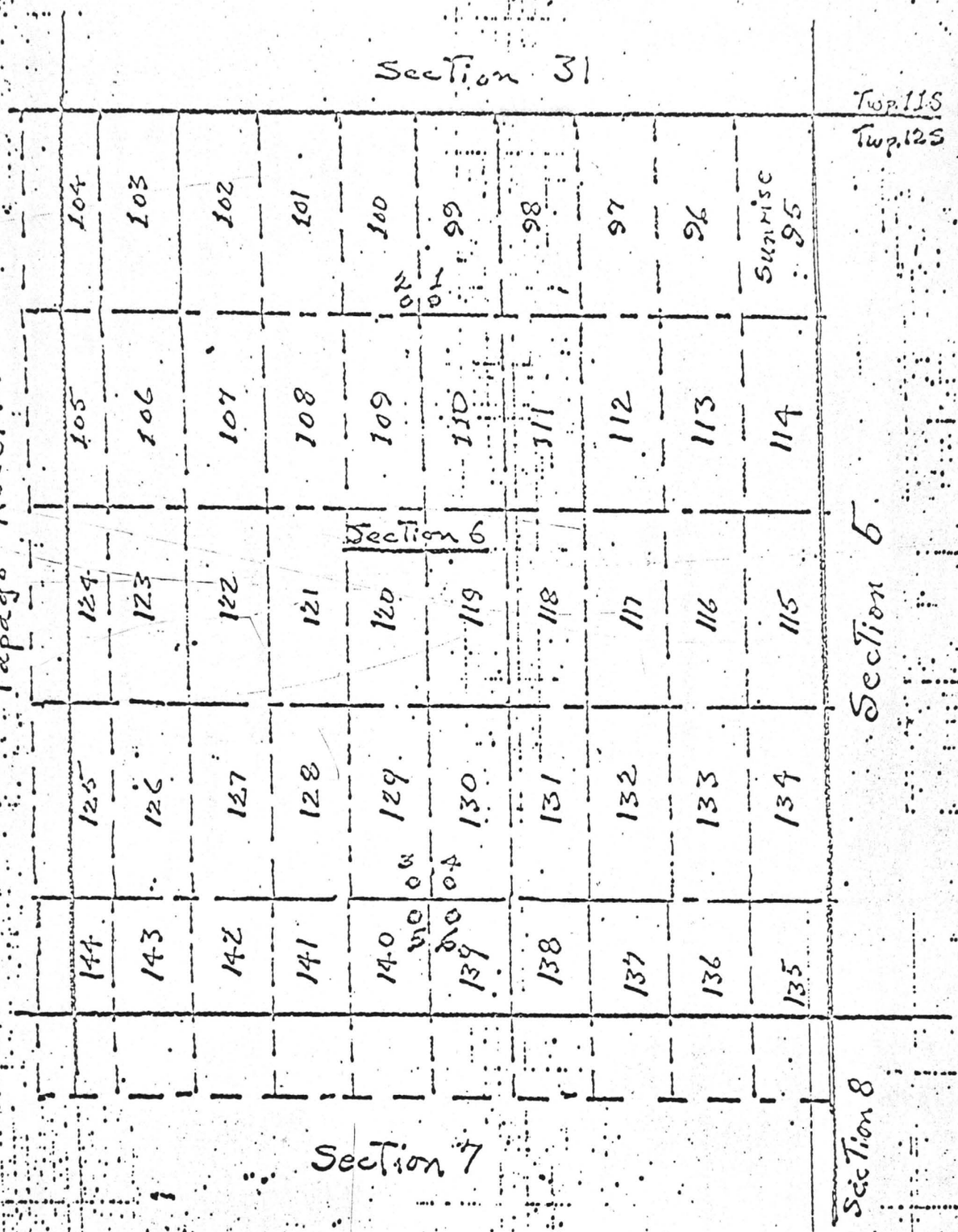


To accompany report by FAWLEY GEOLOGICAL ENGINEERING LTD.

MANTLE MINERALS LTD

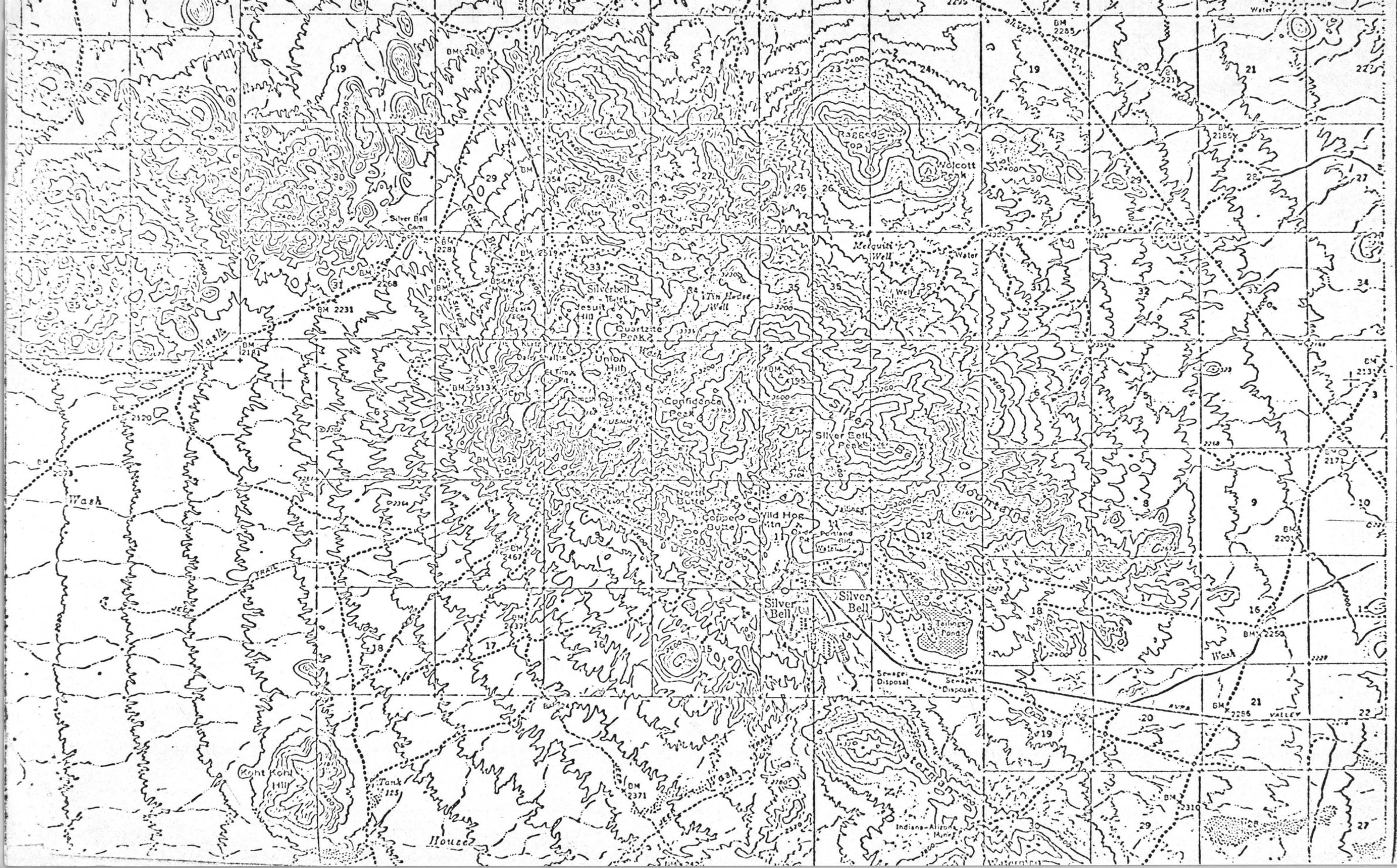
CLAIMS LOCATION MAP


MANTLE MINERALS LTD
GEOLOGY & TOPOGRAPHY
SURVISE CLAIM GROUP



Plan showing
Location of 6 Drill Holes
in relation To Claims Sunrise
#95 - 144 Incl. To which
They are applied as Location work.
Scale 1" = 1,000 Ft.

BOOK 3207 PAGE 227


Silver Bell Cem
Silverbell
Jesuit Hill
Quartzite Peak
Tin Horse Well
Union Hill
Confidence Peak
North Butte
Copper Butte
Wild Hog Mtn
Silver Bell Peak
Silver Bell
Silver Bell
Tailings Pond
Sewage Disposal
Sewage Disposal
Ragged Top
Wolcott Peak
Mesquite Well
Well
Water
Wash
Wash
Wash
Wash
Wash
Kohl Kohl Hill
Tank
Houses
Indiana-Arizona Mine
Waterman
BM 2231
BM 2281
BM 2519
BM 2513
BM 2518
BM 2467
BM 2437
BM 2371
BM 2354
BM 2195
BM 2120
BM 2181
BM 2285
BM 2185
BM 2171
BM 2201
BM 2250
BM 2286
BM 2310
BM 2268
BM 2221

THE SUNRISE PROPERTY, ARIZONA

of

MANTLE MINERALS LTD. (N.P.L.)

Allan P. Fawley January, 1969

ALLAN P. FAWLEY, PH.D., P.ENG.
CONSULTING MINING AND GEOLOGICAL ENGINEER

1947 WEST KING EDWARD AVENUE
VANCOUVER 9, BRITISH COLUMBIA

THE SUNRISE PROPERTY, ARIZONA

of

MANTLE MINERALS LTD. (N.P.L.)

by

Allan P. Fawley

Property Examinations September 1967 and November 1968

Report Written January 1969

THE SUNRISE PROPERTY, ARIZONA

of

MANTLE MINERALS LTD. (N.P.L.)

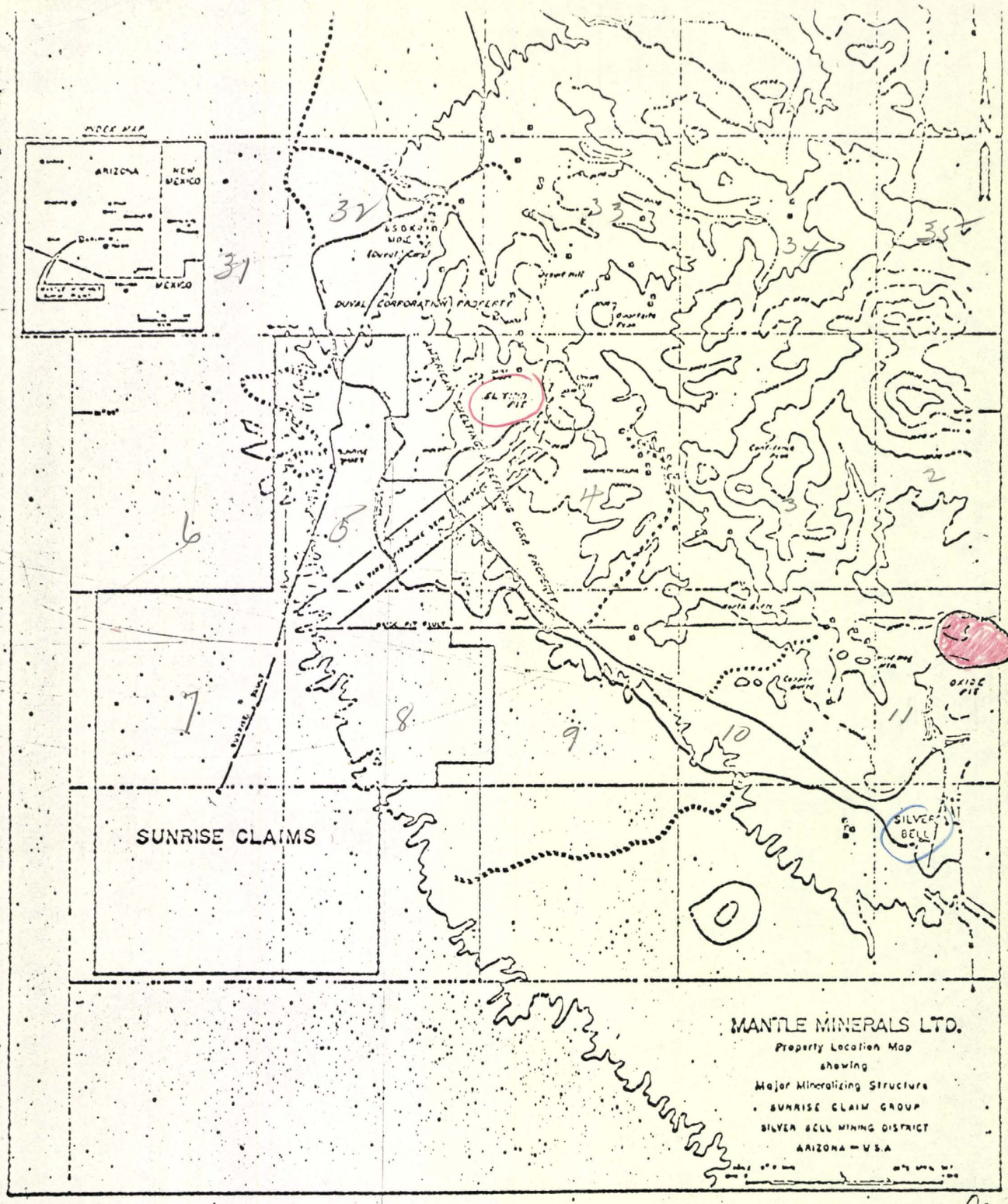
INTRODUCTION

The recent discovery of a very large copper deposit at the Lake Shore property of El Paso Natural Gas Co. has greatly increased exploration activity throughout the Casa Grande - Silver Bell area. The Lake Shore deposit contains 150 million tons with a grade of more than 1 percent copper; the deposit lies at a depth of more than 700 ft. and is capped by sub-marginal copper oxides which are too low grade to be economic at present. The Sunrise Property of Mantle Minerals Ltd. lies between the Lake Shore property and the large producing Silver Bell Mine, of American Smelting and Refining Co., and hence is well located.

Exploration drilling on the Sunrise Property that has been undertaken to date has been restricted to relatively shallow drill holes but, in view of the El Paso discovery, consideration may now be given to some deep drilling.

Information for this report is based on various published reports, on a geological map prepared by the Arizona Bureau of Mines (1960), on reports and information supplied by R. G. Hawley (resident geologist at the property), and on examinations in September 1967 and November 1968 of the Sunrise Property and of oxide copper mines where copper is recovered by the leaching method.

ALLAN F. FAWLEY, Ph.D., P.ENG.
CONSULTING MINING AND GEOLOGICAL ENGINEER



Map No. 1 To accompany report by Fawley Geological Engineering Ltd.

LOCATION AND ACCESS

The Sunrise Property is about 35 miles W.N.W. of Tucson, Arizona and adjoins the Silver Bell Mine of the American Smelting and Refining Co. and the old B.S. & K. mine, which is now owned by Duval Corporation (see Map No. 1). The property is accessible by 38 miles of paved highway from Tucson to the Silver Bell townsite and thence by 4 miles of gravel road to the Sunrise shaft. Most of the claims area can be reached by secondary trails or without trails by using a 4-wheel drive vehicle.

PROPERTY

The Sunrise property of Mantle Minerals Ltd. is in the Silver Bell mining district of Arizona and consists of 152 mining claims (Map No. 2) named and numbered as follows:

Sunrise 1 - 94

Sunrise Extension 1 - 58.

CLIMATE AND TOPOGRAPHY

The Sunrise property is in a semi-arid climate and the vegetation consists mainly of large to small cacti and low thorn bush. The claims are at an average elevation of about 2,500 feet above sea level and extend from the fairly rugged western foothills of the Silver Bell mountains to almost flat-lying overburden-covered plains.

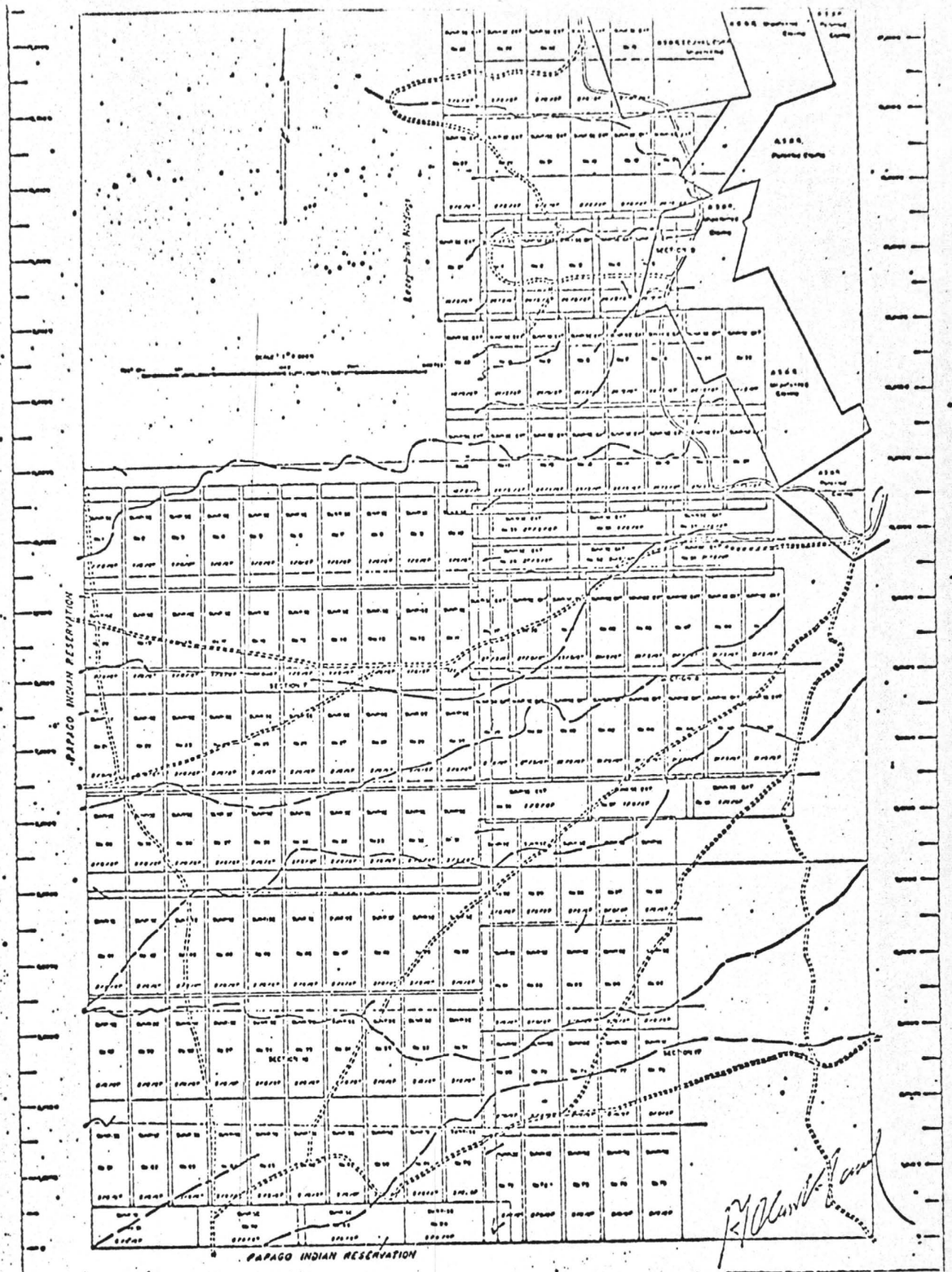
HISTORY

"Extensive mining development has been carried out in the Silver Bell area since the opening of the first major mine in 1865. Intermittent selective mining had produced about 100 million pounds of copper by 1930. In 1954 American Smelting and Refining began production at the rate of 18,000 tons of copper annually. A molybdenum recovery plant was added in 1957 and a leaching plant in 1960," (Hawley, 1967). The present mining rate at the Silver Bell Mine is about 11,500 tons per day of sulphide milling ore plus about 5,000 tons per day of oxidized ore, mixed with some sulphides, for the leaching dumps.

The Sunrise Property has been held for about a dozen years. Very little exploration work was carried out during the early years. During 1967-68, geochemical soil sampling, geological mapping induced polarization geophysical surveying, trenching, and rotary and percussion drilling have been carried out, and the property has been carefully re-staked and claim location holes have been drilled.

GEOLOGY AND MINERALIZATION

The geology of most of the property is not known due to a cover of sandy overburden, however a reconnaissance geochemical survey has shown that copper anomalies exist throughout much of the claims area. The geology and mineralogy of the northern part of the claims area is concisely given by R.G. Hawley (1967) as follows:



Map No..2

To accompany report by Fawley Geological Engineering Ltd.

"The host rocks for the prophyry copper deposits on the adjoining property of American Smelting and Refining are alaskite, dacite porphyry, and monzonite. Controlling structures are a northeast fracture and dike system at the El Tiro pit and an east-west fault at the Oxide pit. The Duval ore body is a contact deposit occurring in limestone along the northern extension of the Sunrise fault.

"On the Sunrise Group, monzonites with minor diabase and andesite dikes have been cut by a major fault striking N 20 E and dipping 50° W which has been traced for 5,000 feet south from the north boundary of the claims before being covered by overburden.

"A mineralized breccia has been exposed in several shallow open cuts along the hanging wall of the fault. The full width of this breccia is not known although it has been exposed for an average width of 200 feet from the fault along a strike length of 1,000 feet, before passing under overburden.

"Southeast of the shaft in the footwall monzonite mineralized northeast fractures similar to and on strike with the El Tiro structure were observed.

"The copper oxide tennorite (or melanochalcite) forms the main copper mineral throughout the breccia zone, where it occurs as a black stain on fracture planes and cementing the breccia fragments. At depth increasing amounts of malachite, azurite and chrysocolla appear. These, together with minor tennorite also occur in northeast trending gouge and shear zones in the footwall monzonites.

"Molybdenum oxide was observed at several points in the altered monzonite along the fault."

ALLAN P. FAWLEY, Ph.D., P.ENG.
CONSULTING MINING AND GEOLOGICAL ENGINEER

EXPLORATION WORK AND RESULTS FOR 1967-1968

The first work carried out by Mantle Minerals Ltd. was a geological and geochemical survey, and careful surveying and re-staking and claim location hole drilling for the entire property.

The geochemical survey located quite a number of large copper anomalies (see Map No. 3) and helped outline part of the geological structure.

Percussion drilling, using an air-trac drill, was then undertaken. This type of drilling proved only partially successful as holes could seldom be drilled to a depth of more than 100 ft. due to a combination of caving and the water level being reached at about that depth; however this percussion drilling did obtain some sections of more than 0.5 percent copper and in general proved that the ore went to considerable depth as the best sections were, in general, at or near the bottom of the holes.

The next stage was trenching and stripping, using a bulldozer. Several new copper-bearing zones were found by this method, other zones were extended, and channel samples at depths of 6 to 20 ft. were obtained (three of these samples, assaying from 0.37 to 1.22 percent copper over lengths of 20 ft. each, are shown on enclosed Map No. 4).

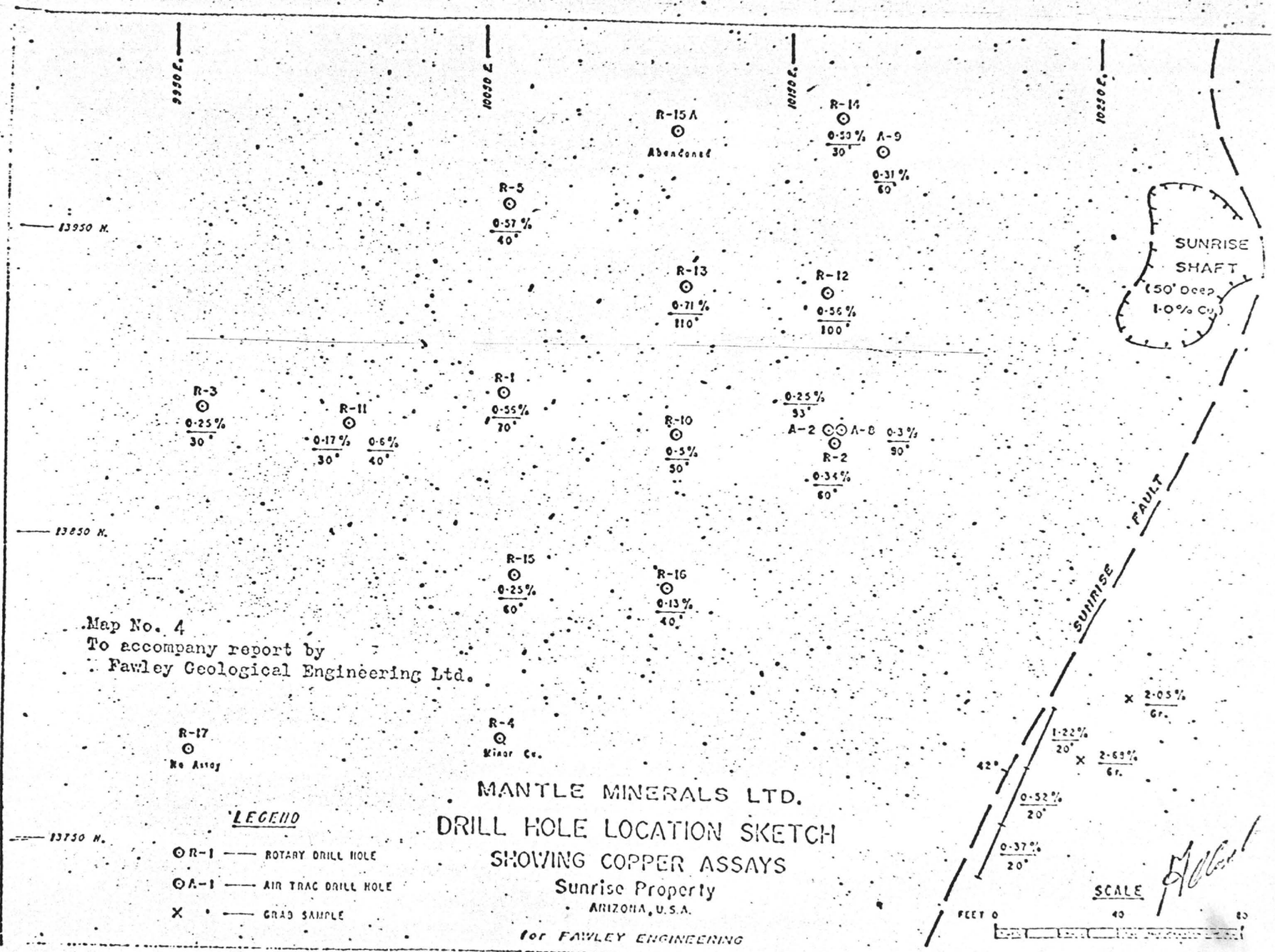
In the summer of 1968 an I.P. (induced polarization) geophysical survey was carried out over the entire property by Seigel Associates Ltd. The results were disappointing but not entirely unexpected as oxidized ore does not give a response for I.P. surveys and sulphide ore, if present below the oxide capping, may be at too great a depth

for detection. Possibly some of the minor anomalous zones shown by the I.P. survey indicate sulphide zones at depth.

A rotary drilling program was undertaken during November and December 1968 to test an ore zone previously partially outlined by trenching and percussion drilling. Twenty holes were drilled (including one drilled as a water well test hole) for a total of 4,281 ft. The rotary drilling method is quite satisfactory for this property although there was some trouble obtaining representative samples where large volumes of water were encountered. Some of the rotary drilling results were good such as at drill hole location R 13 where a 110 ft. section (from 50 to 160 ft.) averaged 0.71 percent copper. The rotary drilling also showed that individual ore zones are more localized than originally supposed, and in places there appears to be a rather rapid cut-off. The ore controls are not yet known, but are probably at least partially due to faulting.

CONCLUSIONS AND RECOMMENDATIONS

Only a small part of the large Sunrise Property of Mantle Minerals Ltd. has yet been tested by drilling and only the section in the shaft area and to the west of the Sunrise Fault has been explored by a grid drilling program (see Map No. 4) hence overall ore reserves are not yet known. Prior to the last drilling program, Mr. R.G. Hawley estimated the reserves for half a dozen separate zones, on the basis of trenching and minor percussion drilling, to be about 1.1 million tons with an average grade of 0.32 percent copper (this grade can be



Map No. 4
To accompany report by
Fawley Geological Engineering Ltd.

economic if amenable to leaching). The rotary drilling program just completed has not increased the above tonnage but for the zone drilled the grade has been increased to about 0.5 per cent copper. Grid drilling of the other known ore zones might greatly increase the above tonnage estimate, and other ore zones probably occur.

Leaching tests, both bottle tests and column tests, on material obtained from the drill holes are imperative as the rate of copper extraction by leaching and the amount of acid needed to leach a ton of ore must be known before the economics of the project can be calculated.

A satisfactory valley for the operation of a copper leaching dump lies within 1/4 mile of the main known ore zone, which is in the shaft area.

Water is generally scarce in this district but several of the drill holes, including hole R 20 which was drilled to test for water, encountered considerable volumes of water. (Tests for capacity were not made, but the flow of water caused by compressed air during drilling of hole R 20 was estimated at about 30 gallons per minute.)

A reconnaissance drilling program, using the inexpensive percussion method, should be carried out over the entire property, and a grid drilling program should be undertaken over the known mineralized zones and over any new zones discovered during the exploratory drilling to determine the grade and tonnage.

A reconnaissance drilling program at 200 ft. intervals along the picketed lines on the property which are themselves 500 to 1,000 ft.

apart, would require 468 drill holes, however the required number can probably be reduced to about 150 holes by the use of geological and geochemical data. These holes should be drilled by the percussion method to a depth of about 100 ft. for 15,000 ft. of drilling and should be assayed at 10 ft. intervals. Where copper oxides are noticeable the regular copper assays should be obtained, otherwise assays should be obtained in parts per million of copper, to guide in further exploration.

Grid drilling of both the known ore zones and zones discovered during the reconnaissance drilling should be started using the percussion method, but where depths greater than about 100 ft. are required the rotary method should be used. The amount of drilling that will be required for this program will depend upon the results obtained, a rough estimate is that about 10,000 ft. of percussion drilling and 20,000 ft. of rotary drilling will be needed.

When the above programs have been completed, consideration should be given towards testing some of the minor I.P. anomalies by deep drilling.

ESTIMATED EXPLORATION EXPENSES

Drilling costs by both the percussion and rotary methods at the Sunrise Property are very low by comparison with diamond drilling costs in British Columbia and the direct drilling costs will range from about $1.00 to $4.00 per foot, depending on depth and conditions.

However there are additional costs of site and trail preparation with a bulldozer, sample collection and assays, engineering and administration expenses, etc. Roughly the costs, including the above items, for the reconnaissance exploration drilling (about 15,000 ft.) plus the grid percussion drilling (about 10,000 ft.) will be about $30,000.00, and the rotary grid drilling program (20,000 ft.) will be about $60,000.00. Hence the drilling and associated drilling costs will be approximately $90,000.00

Leaching tests cost $30.00 for a bottle test and about $200.00 for a column test. The number of tests that will be necessary will not be known until the drilling is completed, but tests of all ore zones should be made. The estimated cost for this work is . . . . . $ 3,000.00

When the drilling and leaching tests have been completed a feasibility study should be made, for which the ore grade, tonnage, rate of leaching, acid cost, transportation costs, etc. will be required, to determine the economics of the project. The cost of this straightforward feasibility study will probably be in the $2,000.00 to $5,000.00 range, say . . . . . $ 3,000.00

A contingency fund should be available in case deeper drilling is required, for possible deep trenching to obtain coarse material for leaching tests, to equip a water well, etc. The sum suggested for this purpose is $15,000.00

Hence $111,000.00 should be available for the suggested exploration program.

Respectfully submitted,

Allan P. Fawley, B.A.Sc., M.Sc., Ph.D., P.Eng.

Consulting Mining Engineer and Geologist

Vancouver, B.C.

January 15, 1969

CERTIFICATE

I, ALLAN PRIEST FAWLEY, of the City of Vancouver, in the Province of British Columbia, HEREBY CERTIFY:

1. THAT I am a Consulting Mining Engineer and Geologist, and my address is 1947 West King Edward Avenue, Vancouver 9, B.C.

2. THAT I am a graduate of the University of British Columbia with the degree of B.A.Sc. (1937) in Mining Engineering, of Queen's University with the degree of M.Sc. (1946) in Geology, and of the University of California with the degree of Ph.D. (1948) in Geology.

3. THAT I am a registered Professional Engineer in the Province of British Columbia and in the Yukon Territory, and a member of the Society of Economic Geologists, of the Society of the Sigma Xi, of the Canadian Institute of Mining and Metallurgy, and of the Geochemical Society.

4. THAT I have practised my profession as a geologist for more than twenty years.

5. THAT I have no direct interest or indirect interest, nor do I expect to have any interest in the Sunrise property or in Mantle Minerals Ltd.

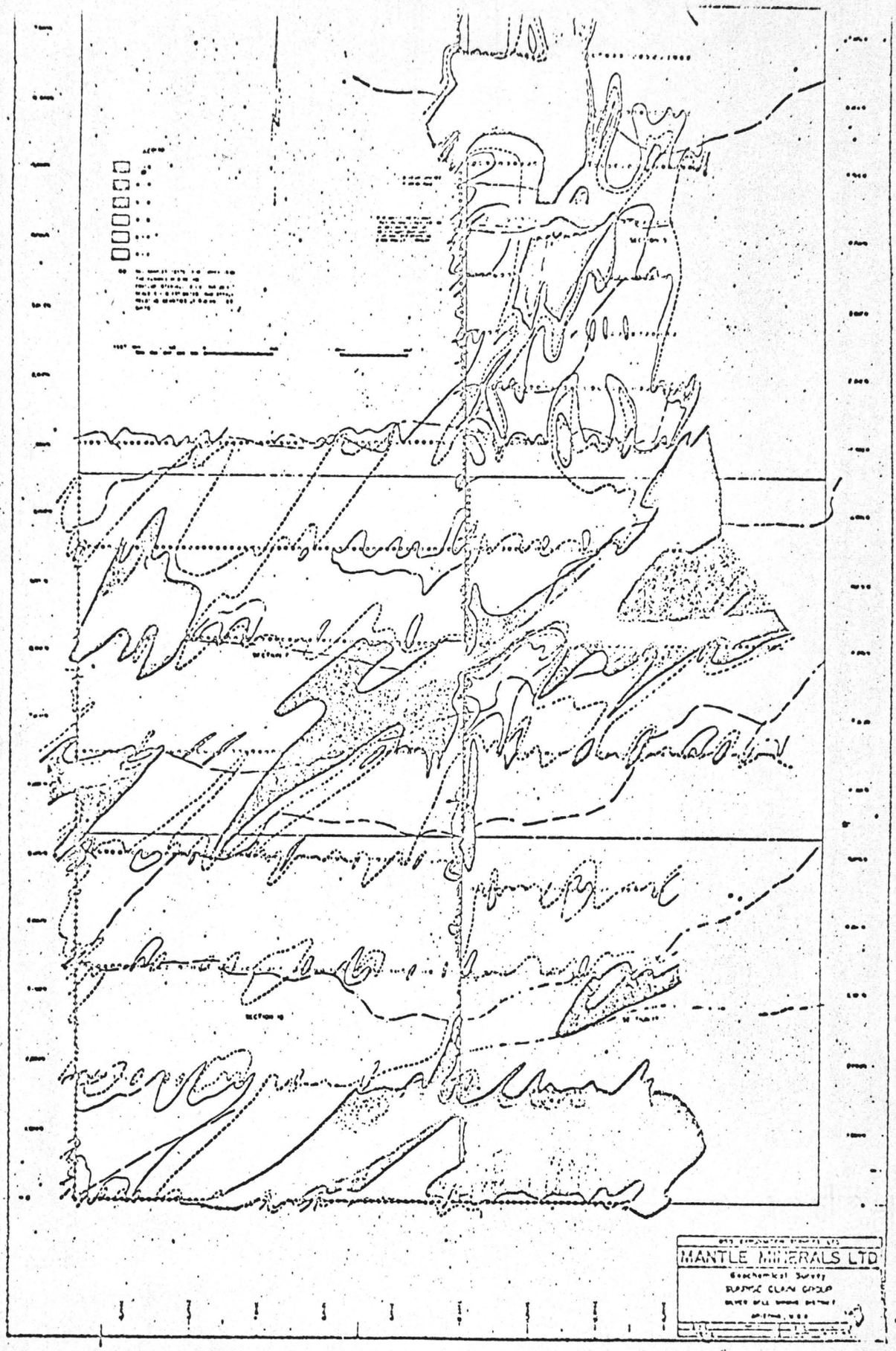
6. THAT I have no direct or indirect interest in any company acquiring control or intending to acquire control of the Sunrise property or in Mantle Minerals Ltd.

7. THAT this report on the Sunrise Property of Mantle Minerals Ltd. is based on my personal examination of the property on September 20, 1967 and during November 6 - 9, 1968.

8. THAT I have examined the staking of the Sunrise property of Mantle Minerals Ltd. and found it to be in accordance with the staking requirements of the State of Arizona.

DATED this 15th day of January 1969

Allan P. Fawley, Ph.D., P.Eng.
Consulting Mining and Geological
Engineer


MANTLE MINERALS LTD

SILVER BELL

STRUCTURE AND MINERALIZATION, SILVER BELL, ARIZONA

By

Kenyon Richard and J. H. Courtright, Geologists

AMERICAN SMELTING AND REFINING COMPANY

A paper to be presented at the annual meeting of
THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
New York, February 17, 1954

ABSTRACT

Replacement-type ore bodies in tactite have accounted for the Silver Bell District's production of copper in the past. In the near future, substantial production will come from porphyry-type copper ores occurring in two deposits spaced two miles apart within a northwesterly trending zone of hydrothermal alteration several miles in length. This zone lies along a major regional fault which is believed to have formed initially in Paleozoic and Cretaceous sedimentary rocks, and subsequently to have been the locus of repeated Laramide igneous activity. Alaskite followed by dacite porphyry were intruded first. Then, after an erosional interval marked by basal conglomerate, a thick series of dacite flows and pyroclastics was deposited. Intrusions of small stocks of monzonite and related dikes were preceded and partly controlled by: (a) regenerative movement along the major structure and (b) development of cross-breaking fractures. Renewed development of cross-breaking joint systems along the main zone provided the principal control of ensuing hypogene mineralization. Post-mineral andesite dikes were emplaced parallel to the major structures. Lastly, enrichment by supergene chalcocite formed the two ore bodies.

Features considered significant: (a) The belt of alteration and copper mineralization coincides with the inferred position of the original major fault. (b) The systems of close-spaced parallel joints were most favorable to deposition of the primary chalcopyrite. (c) The intensity and extent of supergene enrichment are reflected by the quantity of limonite-after-chalcocite in outcrops. (d) The erosional interval between alaskite and monzonite may be a useful means in age-distinction of Cretaceous and Tertiary igneous rocks.

INTRODUCTION

Purpose:

At Silver Bell the mineralized zone and a number of structural features trend west-northwest. Yet, mineralization is controlled in detail by northeast, cross-trending fractures. The purpose of this paper is to present interpretations of these and other relationships.

Previous Work and Acknowledgments:

The first scientific study of the district was published in 1912 by C. A. Stewart (5). 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 Company. Roland Blanchard conducted leached outcrop studies in a portion of the area. Harrison Schmitt with H. M. Kingsbury and L. P. Entwistle mapped structure and mineralization in the central part of the district. Paul F. Kerr studied the alteration features, and later published a comprehensive paper (3) on the district. Thomas Mitcham mapped structural features in the surrounding area. The writers have drawn considerably on unpublished data, particularly in compilation of the geologic map. The high quality and usefulness of the work of these men is gratefully acknowledged, but unfortunately it is not feasible to give specific individual credits.

Thanks are due the American Smelting and Refining Company for permission to give this paper.

Location:

Silver Bell is situated 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 Plate 1. The climate is semi-arid. Altitudes range within 2000 and 4000 feet.

History:

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 three years and resulted in the partial delineation of two copper sulphide 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 Company 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 7500 tons per day. Production will start during the second quarter of this year at a rate of about 18,000 tons of copper annually.

GENERAL GEOLOGY

Formations ranging in age from Pre-Cambrian to Recent are exposed in the Silver

Bell vicinity. The more erosion-resistant of these, Paleozoic limestone and Tertiary volcanics, predominate in the scattered peaks and ridges comprising the Silver Bell mountains. The porphyry copper deposits are located along the southwest flank of these mountains in hydrothermally altered igneous rocks. These are principally intrusives which cut 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 (Plate I). There now is no single structure which 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 hereinafter be referred to as the "major structure". It was obliterated by the Laramide intrusive bodies, but it affected 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), and by others.

As shown on the inset map on Plate II, a fault of parallel trend and considerable displacement lies to the north. This fault is now marked by a line of small Laramide 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. They are high-angle, and the southerly one may be reverse. Stratigraphic separations on these faults are of the order of several thousand feet.

The local Paleozoic section is about 4000 feet thick. It is composed predominantly of limestone with a basal quartzite member. The Cretaceous section appears to exceed 5,000 feet. Conglomerates, red shales, and arkosic sandstones (the youngest) characterize the three principal members.

Intrusion of alaskite marked the beginning of Laramide igneous activity. It was emplaced as an elongate stock with one side closely conforming to the major structure line throughout a distance of nearly four miles. The alaskite was at one time regarded as a thrust block of pre-Cambrian rock (2); however, its intrusive relationship and consequent post-Paleozoic age has been established by inclusions of limestone found in outcrops north of El Tiro. It is believed also to be post-Cretaceous although conclusive evidence of this has not been found at Silver Bell.

The next event was the intrusion of a large stock of dacite porphyry into Paleozoic sediments and alaskite. The stock was some three miles in width and at least six miles in length in a northwesterly direction. It was sharply confined along its southwest side by the major structure line. A number of large pendants of moderately folded Paleozoic sediments occur within and along its southwest edge. Thus, the inferred, original major fault between Paleozoic and Cretaceous sediments became a contact between alaskite and Paleozoic sediments and then, a contact between dacite porphyry and alaskite.

Andesite porphyry may have been intruded later than the dacite porphyry, but relationships are not clear; it may be simply a facies of the latter.

The intrusive activity was at this stage interrupted by an interval of erosion. The erosion surface probably was rugged as there were local accumulations of coarse, angular conglomerate. Subsequently, a series of volcanic flows and pyroclastics several thousand feet in thickness was deposited. A similar unconformity has been recognized elsewhere in the Southwest, particularly in the Patagonia Mountains

near the Flux mine, some 75 miles southeasterly. Here, as at Silver Bell, volcanics were deposited on an erosion surface cut in Cretaceous and older sediments which had been intruded by alaskite.

Though no evidence is offered which closely defines the age of this unconformity, and proper analysis of the problem is beyond the scope of this paper, it is interesting to speculate that it may mark the close of the Cretaceous Period and provide a distinction between Tertiary and Cretaceous igneous rocks within the Laramide Revolution.

Subsequent parallel faulting along the major structure line sliced the volcanics and Cretaceous sediments into horst and graben structures. These faults are remarkably persistent southeasterly, extending several miles beyond the map. It is not clear if they originally extended through the northwest part of the district; they may have terminated against the earlier east-west fault shown on the inset map on Plate II. The formation of these faults indicates at that time a still-existent, deep-seated zone of weakness along the major structure line.

Monzonite stocks and contemporaneous dikes were then emplaced along and near this line, obliterating portions of the faults described in the foregoing paragraph. The stocks are elongate parallel to the major structure line. The dikes are distributed along this line but trend across it, for the most part, with an average east-northeast strike. Systems of close-spaced, parallel fractures then developed. Like the dikes, these fractures are distributed along the major structure and strike across it. Alteration and sulphide mineralization then took place. The deposition of sulphides, particularly chalcopyrite, was controlled in detail by the cross-trending fractures. Although these were distributed along the major structure line as a narrow band, it is notable that throughout much of its length there are now no fault structures to account for this trend.

Post-sulphide dikes of andesite represent the last intrusive activity in the immediate district. Curiously, most of these dikes parallel the strike of the major structure, although it would seem that the cross-breaking fractures represented available lines of weakness. This serves to emphasize the major structure line as being a profound, deep-seated zone of weakness persisting through a long period of time.

Uplift and erosion of the region during late Tertiary or Quaternary time exposed the lean primary mineralization to processes of weathering and enrichment, resulting in the accumulation of the two chalcocite ore bodies.

Small plugs and flows of basaltic lava occur in the flats surrounding the Silver Bell range. These are later in age than the Gila conglomerate and mark one of the more recent events in the geologic history of the region.

STRUCTURAL CONTROL OF HYPOGENE MINERALIZATION

As in the majority of porphyry copper deposits, the principal primary sulphide minerals at Silver Bell are pyrite and chalcopyrite. Although occurring as disseminated grains, they are more abundant as narrow veins or seams which 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 sulphide sheets occur as groups of various sizes throughout the narrow, northwest-trending zone of hydrothermal alteration. (Due to the small scale, a

single line in the pattern of "Mineralized Fissures" on Plate I usually represents a large number of parallel structures, rather than an individual.) In detail the average individual fissure appears as a thin quartz-sulphide 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 groups, changes in strike occur gradually and result in curving trends. As noted earlier, these groups of mineralized fissures are distributed along the major structure line, and it is assumed they were formed in response to deep-seated, uniform stress related to this line.

At least a few hundredths of one per cent copper is present nearly everywhere in the altered zone; better values occur where there are mineralized fissures; and the best values, where the fissures are close-spaced. The two comparatively large groups of these close-spaced structures coincide with the positions of the two ore bodies (Plate I). 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. The strong east-west fault which 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 structure line.

Outside of the zone of alteration the dacite porphyry is finely fractured and jointed throughout most of its large exposed area. In sharp contrast to the systems of parallel fissures in the alteration zone, these breaks in the dacite porphyry are almost completely disoriented; parallelisms are rare and traceable for only a few inches or feet. They appear to be pre-mineral where they are found in the alteration zone in the westerly and southwesterly portions 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 to a minor degree may be accounted for 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 within the narrow northwest-trending zone shown on Plate I are hydrothermally altered. Variations in the intensity or in the completeness of the process, have been subdivided by Kerr (2) into five stages. His analysis demonstrated, among other things, that the known ore bodies occur within the more strongly altered areas.

The area outlined on Plate I 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 sulphides---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 portion. However, along most of the southwest margin the transition is gradational, and the limit is an arbitrary line.

Tactite, composed essentially of garnet, quartz and lime-silicate minerals,

is confined to a narrow belt along the southwest margin of the limestone pendants, except in the vicinity of the Mammoth and Union mines where it has replaced the full width of the sedimentary block. It has been suggested by Stewart (1) that the dacite porphyry and monzonite are responsible for this "contact metamorphism". The areal distribution of this tactite is such that, if it were to be considered strictly as a contact phenomenon, the alaskite would be as related to it as the other intrusives. Without going into the problem in detail, it is worth noting that the tactite occurs along the major structure line in such a manner as to indicate a close genetic connection with it. Supporting evidence in the form of well-defined structural controls of individual pods of tactite is not recognized. An occasional mineralized fissure cuts the tactite in the Mammoth and Union deposits, although the primary chalcopyrite ore bodies have little obvious structural control. Elsewhere, fissures in igneous rocks terminate abruptly at tactite margins.

SUPERGENE ENRICHMENT

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

Most of the capping over the ore bodies contains less than one-tenth of one per cent 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. Within the ore bodies, where alteration is strong and the gangue is non-reactive, the upper limit of the sulphide zone (or, the base of oxidation) appears on open-cut faces as a sharply defined, highly irregular line. Only rarely is there a transition zone of mixed sulphide and oxidized minerals. In general shape the base of oxidation conforms to modern topography, even though local relief exceeds 200 feet. The water table for the most part now is well below the chalcocite zone.

Some of the irregularities of the base of oxidation are caused by displacement on post-chalcocite faults, but most are due to variations in rock permeability. This is evidenced by the dense siliceous character of a few sulphide remnants occurring well up in the leached zone, and by leached indentations of the sulphide zone along some of the fissures.

It is significant that the base of oxidation shows general conformance to the topography, but that in detail it is a highly irregular, sharply defined "front". Its present shape may have been produced by modification of a pre-existing base---one which was established during relatively moist climatic periods of the past. Under such conditions the water table would have oscillated at uniformly shallow depths and thus would have served to limit the depth of oxidation, thereby determining the shape of its base to some extent. Otherwise, under conditions involving depression of the water table---principally those of dryer climates---it appears that the oxidation process proceeded in the vadose zone independent of the water table, and that it advanced downward on a sharply defined front whenever oxygen-charged meteoric water reached it.

Opinions vary as to the role of the water table in the deposition of chalcocite and as to the reason for the chalcocite's distribution through a considerable vertical range. At Silver Bell pyrite and, preferentially, chalcopyrite are only partially replaced by chalcocite immediately below the line at the base of

oxidation as well as on down through the zone of enrichment. This condition appears to be an argument favoring the theory that chalcocite is deposited at or below the water table. That is, the dissolved copper on its downward course by-passed available chalcopyrite and pyrite until it reached the water table where it formed chalcocite. The partial replacement of primary sulphides by chalcocite and its vertical distribution, as now existing, may then be explained as originating through the numerous cyclic fluctuations of the water table position.

LEACHED OUTCROPS

In the formation of most disseminated chalcocite deposits the enrichment process takes place progressively---copper is repeatedly dissolved, carried downward and precipitated. It has been well established by Blanchard (1), Locke (4) and others that under these conditions "limonites" of certain colors and textures are left behind in the leached capping as evidence of the pre-existing 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 rests mainly on quantitative rather than qualitative appraisal. Mapping of the Silver Bell outcrops on this basis provided a valuable guide in exploration drilling. Results have demonstrated conclusively that the pattern of relatively strong copper mineralization 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 which are numerous in the outcrops of the mineralized zone at Silver Bell. There is evidence indicating they are several centuries old. These shallow open cuts invariably follow close-spaced, parallel fissures containing the dark maroon limonite-after-chalcocite. Since there are no precious metals or visible copper in these fissures, it is plausible to assume that this limonite with its particular hue was considered valuable in the past as a pigment, perhaps for pottery or war paint. Thus, in the history of leached outcrop investigations, it seems that some early Arizona Indian tribe deserves at least honorable mention.

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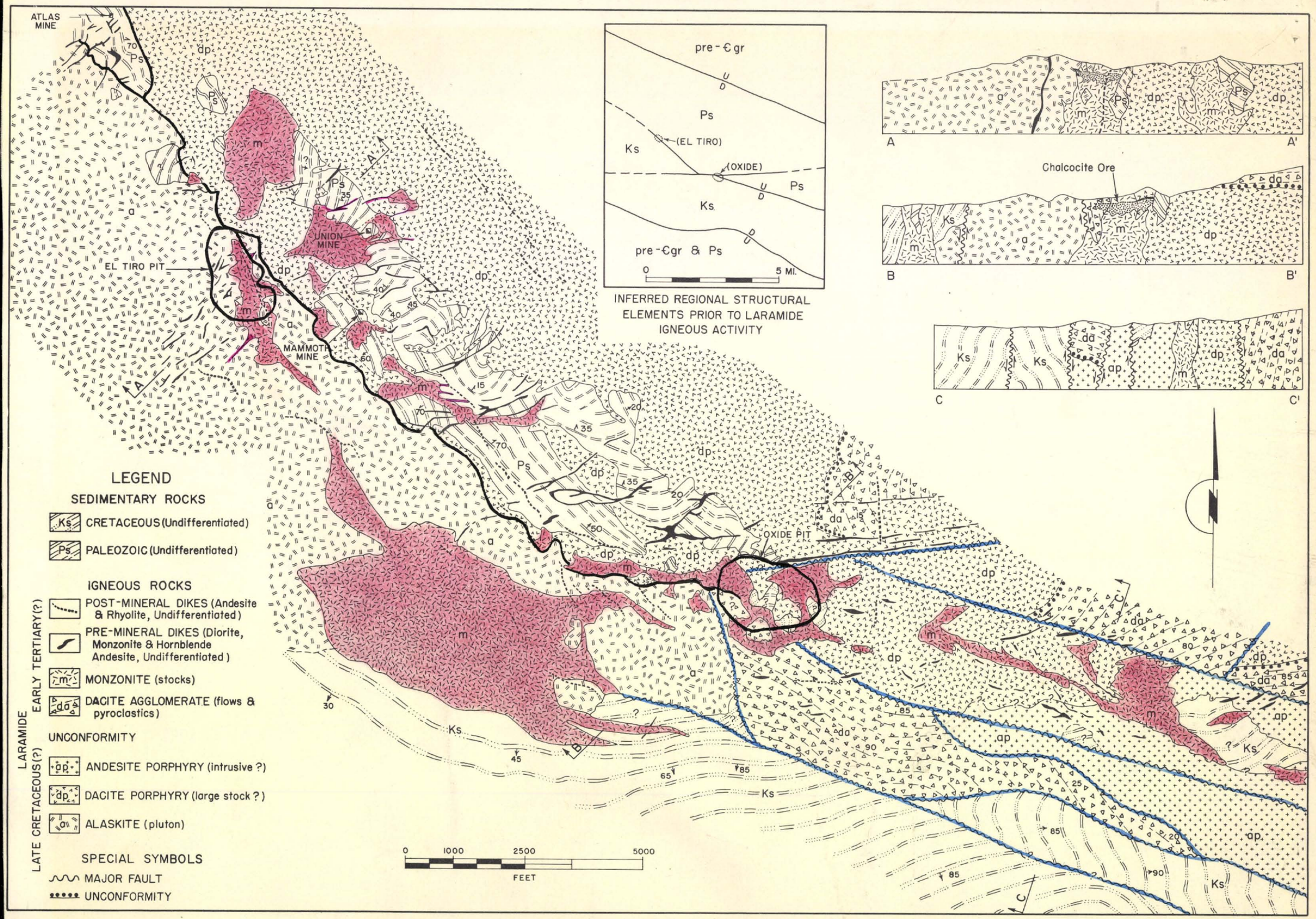
E. N. Cummelaber

Structure and Mineralization at Silver Bell, Ariz.

by Kenyon E. Richard and James H. Courtright

Fig. 1—Patterns of mineralized fissures, zone of hydrothermal alteration, and areas of pyrometasomatism in sedimentary rocks.

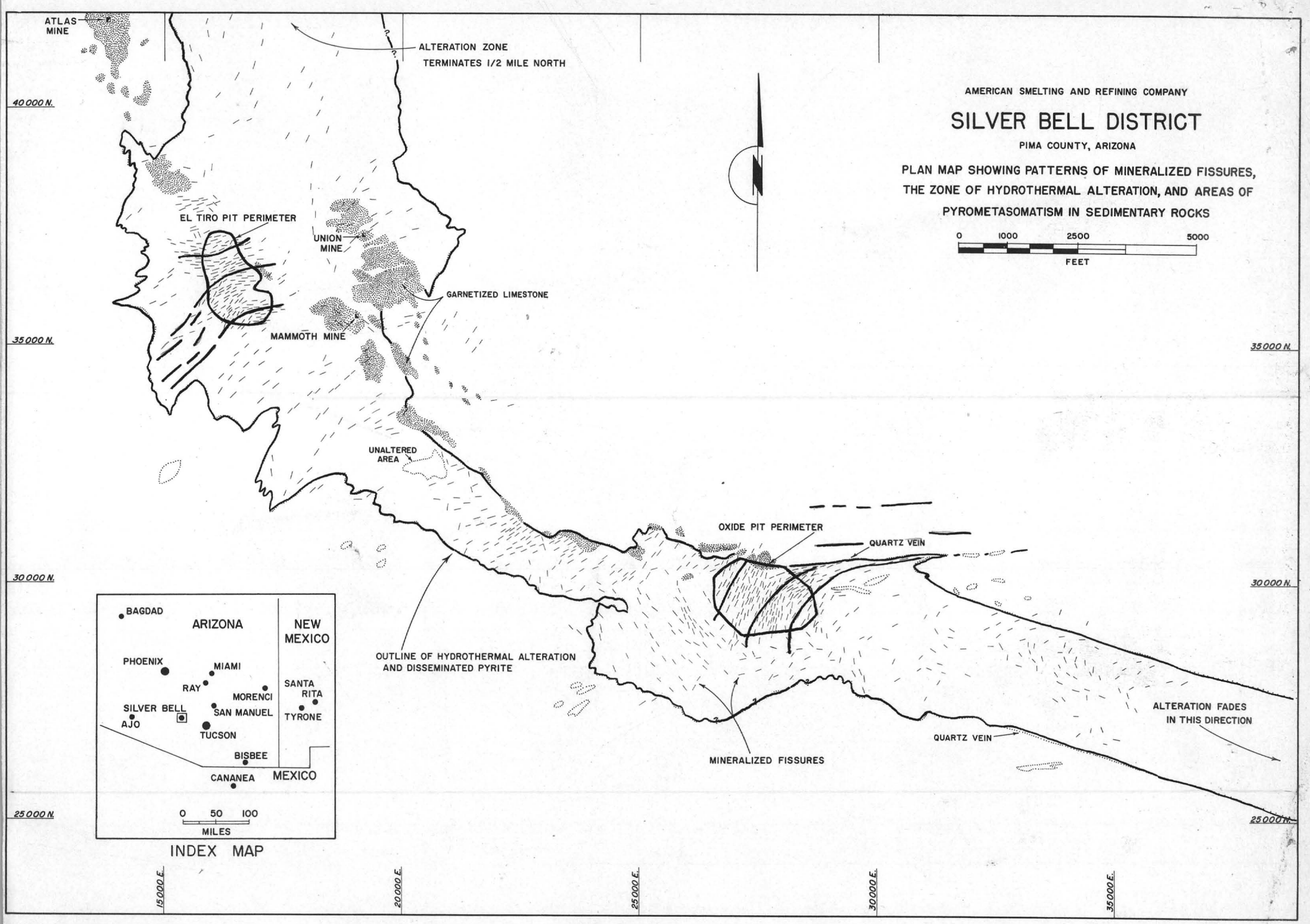
Fig. 2—Geologic map, Silver Bell district, Pima County, Ariz.



E. N. PENNEBAKER

GEOLOGIC MAP, SILVER BELL DISTRICT, ARIZONA

PLATE II



E. N. PENNEBAKER

PLATE I

PIMA CO.

STRUCTURE AND MINERALIZATION, SILVER BELL, ARIZONA

By

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AMERICAN SMELTING AND REFINING COMPANY

A paper to be presented at the annual meeting of
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ABSTRACT

Replacement-type ore bodies in tactite have accounted for the Silver Bell District's production of copper in the past. In the near future, substantial production will come from porphyry-type copper ores occurring in two deposits spaced two miles apart within a northwesterly trending zone of hydrothermal alteration several miles in length. This zone lies along a major regional fault which is believed to have formed initially in Paleozoic and Cretaceous sedimentary rocks, and subsequently to have been the locus of repeated Laramide igneous activity. Alaskite followed by dacite porphyry were intruded first. Then, after an erosional interval marked by basal conglomerate, a thick series of dacite flows and pyroclastics was deposited. Intrusions of small stocks of monzonite and related dikes were preceded and partly controlled by: (a) regenerative movement along the major structure and (b) development of cross-breaking fractures. Renewed development of cross-breaking joint systems along the main zone provided the principal control of ensuing hypogene mineralization. Post-mineral andesite dikes were emplaced parallel to the major structures. Lastly, enrichment by supergene chalcocite formed the two ore bodies.

Features considered significant: (a) The belt of alteration and copper mineralization coincides with the inferred position of the original major fault. (b) The systems of close-spaced parallel joints were most favorable to deposition of the primary chalcopyrite. (c) The intensity and extent of supergene enrichment are reflected by the quantity of limonite-after-chalcocite in outcrops. (d) The erosional interval between alaskite and monzonite may be a useful means in age-distinction of Cretaceous and Tertiary igneous rocks.

E. N. Cameron

INTRODUCTION

Purpose:

At Silver Bell the mineralized zone and a number of structural features trend west-northwest. Yet, mineralization is controlled in detail by northeast, cross-trending fractures. The purpose of this paper is to present interpretations of these and other relationships.

Previous Work and Acknowledgments:

The first scientific study of the district was published in 1912 by C. A. Stewart (5). 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 Company. Roland Blanchard conducted leached outcrop studies in a portion of the area. Harrison Schmitt with H. M. Kingsbury and L. P. Entwistle mapped structure and mineralization in the central part of the district. Paul F. Kerr studied the alteration features, and later published a comprehensive paper (3) on the district. Thomas Mitcham mapped structural features in the surrounding area. The writers have drawn considerably on unpublished data, particularly in compilation of the geologic map. The high quality and usefulness of the work of these men is gratefully acknowledged, but unfortunately it is not feasible to give specific individual credits.

Thanks are due the American Smelting and Refining Company for permission to give this paper.

Location:

Silver Bell is situated 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 Plate 1. The climate is semi-arid. Altitudes range within 2000 and 4000 feet.

History:

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 three years and resulted in the partial delineation of two copper sulphide 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 Company 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 7500 tons per day. Production will start during the second quarter of this year at a rate of about 18,000 tons of copper annually.

GENERAL GEOLOGY

Formations ranging in age from Pre-Cambrian to Recent are exposed in the Silver

Bell vicinity. The more erosion-resistant of these, Paleozoic limestone and Tertiary volcanics, predominate in the scattered peaks and ridges comprising the Silver Bell mountains. The porphyry copper deposits are located along the southwest flank of these mountains in hydrothermally altered igneous rocks. These are principally intrusives which cut 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 (Plate I). There now is no single structure which 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 hereinafter be referred to as the "major structure". It was obliterated by the Laramide intrusive bodies, but it affected 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), and by others.

As shown on the inset map on Plate II, a fault of parallel trend and considerable displacement lies to the north. This fault is now marked by a line of small Laramide 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. They are high-angle, and the southerly one may be reverse. Stratigraphic separations on these faults are of the order of several thousand feet.

The local Paleozoic section is about 4000 feet thick. It is composed predominantly of limestone with a basal quartzite member. The Cretaceous section appears to exceed 5,000 feet. Conglomerates, red shales, and arkosic sandstones (the youngest) characterize the three principal members.

Intrusion of alaskite marked the beginning of Laramide igneous activity. It was emplaced as an elongate stock with one side closely conforming to the major structure line throughout a distance of nearly four miles. The alaskite was at one time regarded as a thrust block of pre-Cambrian rock (2); however, its intrusive relationship and consequent post-Paleozoic age has been established by inclusions of limestone found in outcrops north of El Tiro. It is believed also to be post-Cretaceous although conclusive evidence of this has not been found at Silver Bell.

The next event was the intrusion of a large stock of dacite porphyry into Paleozoic sediments and alaskite. The stock was some three miles in width and at least six miles in length in a northwesterly direction. It was sharply confined along its southwest side by the major structure line. A number of large pendants of moderately folded Paleozoic sediments occur within and along its southwest edge. Thus, the inferred, original major fault between Paleozoic and Cretaceous sediments became a contact between alaskite and Paleozoic sediments and then, a contact between dacite porphyry and alaskite.

Andesite porphyry may have been intruded later than the dacite porphyry, but relationships are not clear; it may be simply a facies of the latter.

The intrusive activity was at this stage interrupted by an interval of erosion. The erosion surface probably was rugged as there were local accumulations of coarse, angular conglomerate. Subsequently, a series of volcanic flows and pyroclastics several thousand feet in thickness was deposited. A similar unconformity has been recognized elsewhere in the Southwest, particularly in the Patagonia Mountains

near the Flux mine, some 75 miles southeasterly. Here, as at Silver Bell, volcanics were deposited on an erosion surface cut in Cretaceous and older sediments which had been intruded by alaskite.

Though no evidence is offered which closely defines the age of this unconformity, and proper analysis of the problem is beyond the scope of this paper, it is interesting to speculate that it may mark the close of the Cretaceous Period and provide a distinction between Tertiary and Cretaceous igneous rocks within the Laramide Revolution.

Subsequent parallel faulting along the major structure line sliced the volcanics and Cretaceous sediments into horst and graben structures. These faults are remarkably persistent southeasterly, extending several miles beyond the map. It is not clear if they originally extended through the northwest part of the district; they may have terminated against the earlier east-west fault shown on the inset map on Plate II. The formation of these faults indicates at that time a still-existent, deep-seated zone of weakness along the major structure line.

Monzonite stocks and contemporaneous dikes were then emplaced along and near this line, obliterating portions of the faults described in the foregoing paragraph. The stocks are elongate parallel to the major structure line. The dikes are distributed along this line but trend across it, for the most part, with an average east-northeast strike. Systems of close-spaced, parallel fractures then developed. Like the dikes, these fractures are distributed along the major structure and strike across it. Alteration and sulphide mineralization then took place. The deposition of sulphides, particularly chalcopyrite, was controlled in detail by the cross-trending fractures. Although these were distributed along the major structure line as a narrow band, it is notable that throughout much of its length there are now no fault structures to account for this trend.

Post-sulphide dikes of andesite represent the last intrusive activity in the immediate district. Curiously, most of these dikes parallel the strike of the major structure, although it would seem that the cross-breaking fractures represented available lines of weakness. This serves to emphasize the major structure line as being a profound, deep-seated zone of weakness persisting through a long period of time.

Uplift and erosion of the region during late Tertiary or Quaternary time exposed the lean primary mineralization to processes of weathering and enrichment, resulting in the accumulation of the two chalcocite ore bodies.

Small plugs and flows of basaltic lava occur in the flats surrounding the Silver Bell range. These are later in age than the Gila conglomerate and mark one of the more recent events in the geologic history of the region.

STRUCTURAL CONTROL OF HYPOGENE MINERALIZATION

As in the majority of porphyry copper deposits, the principal primary sulphide minerals at Silver Bell are pyrite and chalcopyrite. Although occurring as disseminated grains, they are more abundant as narrow veins or seams which 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 sulphide sheets occur as groups of various sizes throughout the narrow, northwest-trending zone of hydrothermal alteration. (Due to the small scale, a

single line in the pattern of "Mineralized Fissures" on Plate I usually represents a large number of parallel structures, rather than an individual.) In detail the average individual fissure appears as a thin quartz-sulphide 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 groups, changes in strike occur gradually and result in curving trends. As noted earlier, these groups of mineralized fissures are distributed along the major structure line, and it is assumed they were formed in response to deep-seated, uniform stress related to this line.

At least a few hundredths of one per cent copper is present nearly everywhere in the altered zone; better values occur where there are mineralized fissures; and the best values, where the fissures are close-spaced. The two comparatively large groups of these close-spaced structures coincide with the positions of the two ore bodies (Plate I). 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. The strong east-west fault which 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 structure line.

Outside of the zone of alteration the dacite porphyry is finely fractured and jointed throughout most of its large exposed area. In sharp contrast to the systems of parallel fissures in the alteration zone, these breaks in the dacite porphyry are almost completely disoriented; parallelisms are rare and traceable for only a few inches or feet. They appear to be pre-mineral where they are found in the alteration zone in the westerly and southwesterly portions 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 to a minor degree may be accounted for 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 within the narrow northwest-trending zone shown on Plate I are hydrothermally altered. Variations in the intensity or in the completeness of the process, have been subdivided by Kerr (2) into five stages. His analysis demonstrated, among other things, that the known ore bodies occur within the more strongly altered areas.

The area outlined on Plate I 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 sulphides---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 portion. However, along most of the southwest margin the transition is gradational, and the limit is an arbitrary line.

Tactite, composed essentially of garnet, quartz and lime-silicate minerals,

is confined to a narrow belt along the southwest margin of the limestone pendants, except in the vicinity of the Mammoth and Union mines where it has replaced the full width of the sedimentary block. It has been suggested by Stewart (1) that the dacite porphyry and monzonite are responsible for this "contact metamorphism". The areal distribution of this tactite is such that, if it were to be considered strictly as a contact phenomenon, the alaskite would be as related to it as the other intrusives. Without going into the problem in detail, it is worth noting that the tactite occurs along the major structure line in such a manner as to indicate a close genetic connection with it. Supporting evidence in the form of well-defined structural controls of individual pods of tactite is not recognized. An occasional mineralized fissure cuts the tactite in the Mammoth and Union deposits, although the primary chalcopyrite ore bodies have little obvious structural control. Elsewhere, fissures in igneous rocks terminate abruptly at tactite margins.

SUPERGENE ENRICHMENT

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

Most of the capping over the ore bodies contains less than one-tenth of one per cent 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. Within the ore bodies, where alteration is strong and the gangue is non-reactive, the upper limit of the sulphide zone (or, the base of oxidation) appears on open-cut faces as a sharply defined, highly irregular line. Only rarely is there a transition zone of mixed sulphide and oxidized minerals. In general shape the base of oxidation conforms to modern topography, even though local relief exceeds 200 feet. The water table for the most part now is well below the chalcocite zone.

Some of the irregularities of the base of oxidation are caused by displacement on post-chalcocite faults, but most are due to variations in rock permeability. This is evidenced by the dense siliceous character of a few sulphide remnants occurring well up in the leached zone, and by leached indentations of the sulphide zone along some of the fissures.

It is significant that the base of oxidation shows general conformance to the topography, but that in detail it is a highly irregular, sharply defined "front". Its present shape may have been produced by modification of a pre-existing base---one which was established during relatively moist climatic periods of the past. Under such conditions the water table would have oscillated at uniformly shallow depths and thus would have served to limit the depth of oxidation, thereby determining the shape of its base to some extent. Otherwise, under conditions involving depression of the water table---principally those of dryer climates---it appears that the oxidation process proceeded in the vadose zone independent of the water table, and that it advanced downward on a sharply defined front whenever oxygen-charged meteoric water reached it.

Opinions vary as to the role of the water table in the deposition of chalcocite and as to the reason for the chalcocite's distribution through a considerable vertical range. At Silver Bell pyrite and, preferentially, chalcopyrite are only partially replaced by chalcocite immediately below the line at the base of

oxidation as well as on down through the zone of enrichment. This condition appears to be an argument favoring the theory that chalcocite is deposited at or below the water table. That is, the dissolved copper on its downward course by-passed available chalcopyrite and pyrite until it reached the water table where it formed chalcocite. The partial replacement of primary sulphides by chalcocite and its vertical distribution, as now existing, may then be explained as originating through the numerous cyclic fluctuations of the water table position.

LEACHED OUTCROPS

In the formation of most disseminated chalcocite deposits the enrichment process takes place progressively---copper is repeatedly dissolved, carried downward and precipitated. It has been well established by Blanchard (1), Locke (4) and others that under these conditions "limonites" of certain colors and textures are left behind in the leached capping as evidence of the pre-existing 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 rests mainly on quantitative rather than qualitative appraisal. Mapping of the Silver Bell outcrops on this basis provided a valuable guide in exploration drilling. Results have demonstrated conclusively that the pattern of relatively strong copper mineralization 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 which are numerous in the outcrops of the mineralized zone at Silver Bell. There is evidence indicating they are several centuries old. These shallow open cuts invariably follow close-spaced, parallel fissures containing the dark maroon limonite-after-chalcocite. Since there are no precious metals or visible copper in these fissures, it is plausible to assume that this limonite with its particular hue was considered valuable in the past as a pigment, perhaps for pottery or war paint. Thus, in the history of leached outcrop investigations, it seems that some early Arizona Indian tribe deserves at least honorable mention.

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