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J. D. SELL

McPHAR

A GEOPHYSICAL CASE HISTORY OF THE LAKESHORE OREBODY

by

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ABSTRACT

The Lakeshore Orebody occurs in Pinal County, Arizona about 30 miles south of Casa Grande. In February 1969, when the latest figures were published, the ore reserves were reported at 241 million tons of disseminated sulphide ore (0.7% Cu) and 24 million tons of concentrated metallic ore (1.69% Cu).

The first hole intersected primary ore (magnetite, pyrite, chalcopyrite) in the metasediments (tactite) at a depth of 1147 feet in early 1967. The successful conclusion of this exploration program by El Paso Natural Gas Company is an excellent example of an integrated exploration approach. The application of regional geological planning, geophysical methods and detailed geological reasoning resulted in the discovery of a major copper orebody.

Due to the depth of the ore zone, and the less than massive character of the ore, the only geophysical technique that was useful in the direct detection of the ore mineralization was the induced polarization method. Variable frequency induced polarization measurements, made using the dipole-dipole electrode configuration and electrode intervals from 300' to 1,000', successfully indicated the presence of the metallic mineralization at depth, and gave some indication of its extent.

Comparisons of the induced polarization data and the appropriate geological sections give information concerning the usefulness of the method.

Introduction

On February 7, 1969 an announcement was made by El Paso Natural Gas Co. that the latest calculations for the Lakeshore Orebody gave 241 million tons of disseminated sulphide ore averaging 0.70% copper and 24 million tons of concentrated (tactite) metallic ore containing 1.69% copper. This was the latest announcement that has been made. The orebody is currently being developed jointly by El Paso Natural Gas Co. and Hecla Mining Co.

The discovery of this major copper deposit by the Mineral Division of El Paso Natural Gas Co. was the result of a well planned, integrated exploration program. The application of regional geological studies, modern geophysical techniques and detailed geological reasoning all contributed to the success of the program.

The Lakeshore Orebody lies under the southwest pediment of the Slate Mountains in Section 25, T10S, R4E, Pinal County, Arizona. (Fig. 1). This location is in the Papago Indian Reservation, about 30 miles south of Casa Grande, Arizona and 70 miles northwest of Tucson. The surface elevation in this area is about 1,800 feet.

Interest in the area dates back to the early 1880's. The mineralized outcrop consisted primarily of copper silicates and iron oxides. Between 1917 and 1919, a shaft was sunk to a depth of 225 feet. An excellent history of the Lakeshore Property is given in the paper by Harper and Reynolds (1969).

El Paso Natural Gas Co. first examined the area in 1962, but the mineral rights to the Lakeshore Property were not acquired until mid-1966. Investigations were begun into processes to recover the copper in the copper silicates exposed in the old Lakeshore Pit. At the same time, regional exploration was initiated. After preliminary geologic studies, a reconnaissance induced polarization survey was completed by McPhar

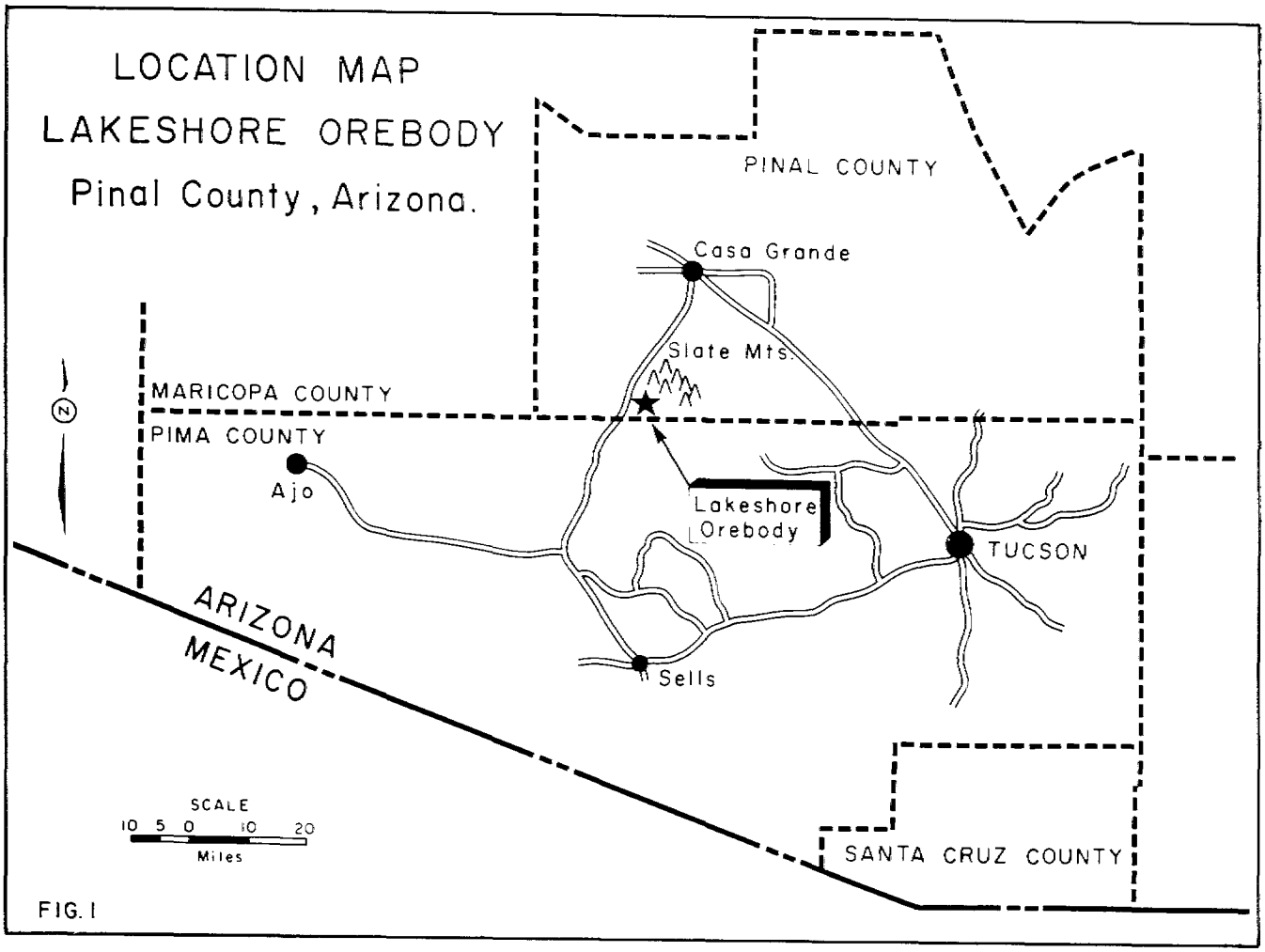

LOCATION MAP
LAKESHORE OREBODY
Pinal County, Arizona.
PINAL COUNTY
Casa Grande
Slate Mts.
MARICOPA COUNTY
PIMA COUNTY
Ajo
Lakeshore Orebody
TUCSON
ARIZONA
MEXICO
Sells
SCALE
10 5 0 10 20
Miles
SANTA CRUZ COUNTY
N

FIG. 1

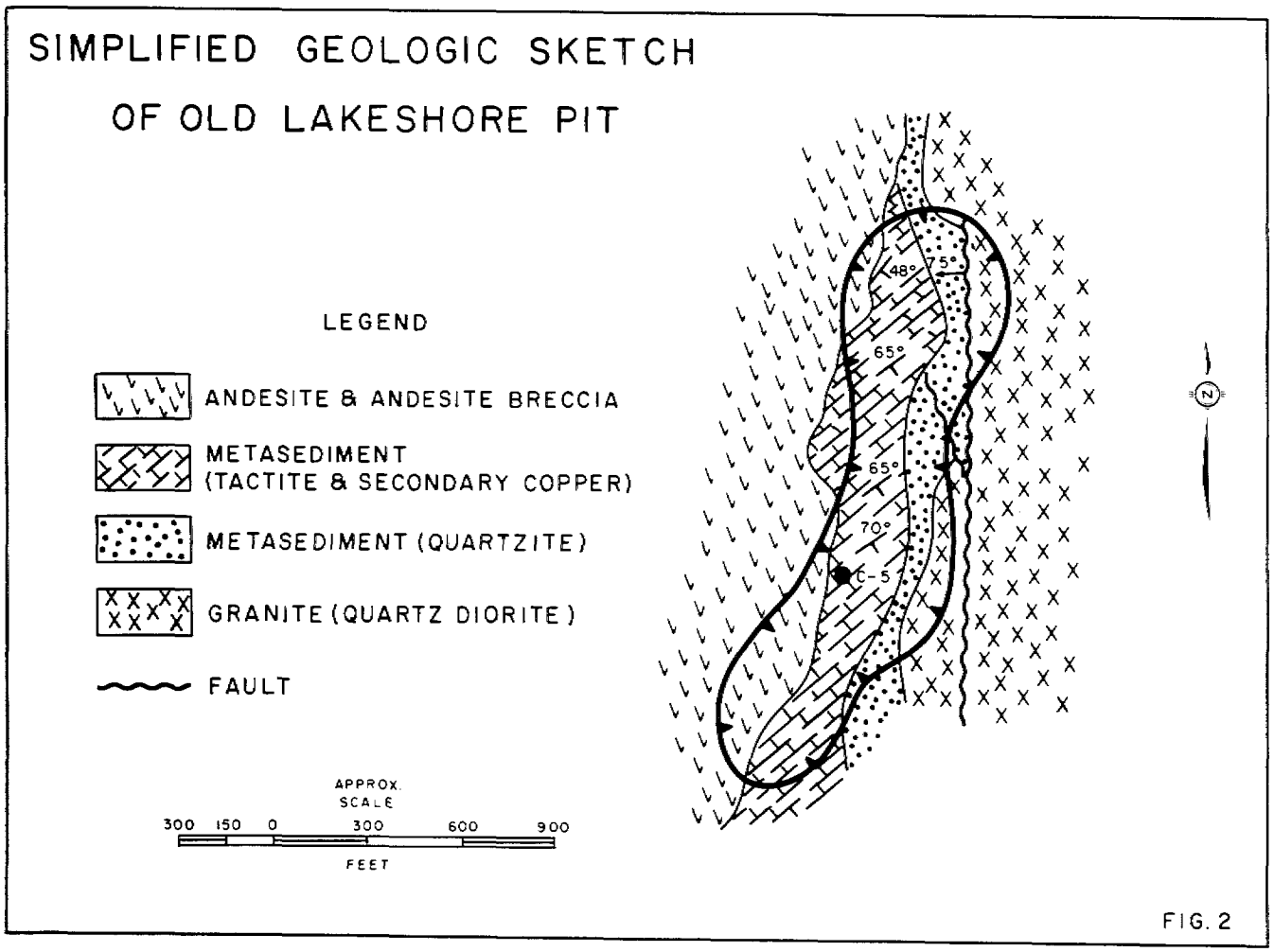

SIMPLIFIED GEOLOGIC SKETCH
OF OLD LAKESHORE PIT
LEGEND
ANDESITE & ANDESITE BRECCIA
METASEDIMENT
(TACTITE & SECONDARY COPPER)
METASEDIMENT (QUARTZITE)
GRANITE (QUARTZ DIORITE)
FAULT
APPROX.
SCALE
300 150 0 300 600 900
FEET
48°
75°
65°
65°
70°
C-5
N

FIG. 2

Geophysics Inc. in August - September 1966. The IP survey was planned to locate any zones of metallic mineralization that might be associated with the surface zone.

Geology

The general geology of the area is described briefly by Harper and Reynolds (1969). A complete geologic description is given by Barron (1969). The mass of the Slate Mountains (about 2.0 miles northeast of the Lakeshore Property) is primarily Precambrian Pinal Schist. Near the centre of the mountains, an elongated body of Laramide age quartz-diorite (granite) has intruded the schist. Around the southwest edge of the Slate Mountains, and outcropping through the valley fill, are outlying hills of Devonian and Carboniferous limestone, Cretaceous volcanic and sedimentary rocks and Tertiary andesite and andesite breccia.

At the Lakeshore Property, the geology has been exposed in the old Lakeshore Pit. (Fig. 2). In the centre of the pit, mineralized, banded tactite (metasediment) overlaid by a fine-grained quartzite, striking N50E and dipping 60°SE, is exposed. These metasediments are terminated on the east side of the pit by a very strong fault that strikes northwest and dips 65°SW.

Along the west wall of the pit, altered and fractured andesite occurs on the footwall of an andesite and metasediment contact. This contact, striking N40°E and dipping 50°SE, forms the footwall of the oxide orebody in the wedge-shaped block of metasediment (tactite).

The drilling recently completed at the Lakeshore Property has obviously added a great deal to information about the subsurface geology. The simplified geological section shown in Figure 3 shows the main features, as presently known. The correlations from the drill hole sections have resulted in a completely unexpected picture !

Hole C-5 is one of several churn drill holes completed in 1948 by the U.S. Bureau of Mines. The hole penetrated the oxide mineralization in the pit and then entered fractured andesite. At a depth of 455 feet, the hole penetrated 90 feet of secondary copper mineralization. A proper interpretation of these results in 1966-67, gave added importance to IP anomalies, at depth, to the west.

The picture in Fig. 3 is much simplified. For instance, the tactite is not completely mineralized and the concentrated mineralization (magnetite, pyrite, chalcopyrite) extends into the surrounding rock units at some points. The overturned position of the oxidized tactite at the surface is shown as a result of simple folding; in fact, complex faulting may be a part of the structure !

The biotite porphyry (quartz monzonite) intrusive which contains much of the disseminated mineralization intrudes the Cretaceous andesitic breccia and the late Precambrian metasediments. It was not known to reach the surface in the vicinity of the Lakeshore Property, at the time of this exploration program.

The andesites, porphyry, metasediments and the upper portions of the underlying intrusive have been extensively shattered and are moderately to strongly altered. The principal host rocks are the andesite, porphyry and the tactite. Chalcopyrite and pyrite are the principal sulphide minerals. They are disseminated throughout the shattered porphyry and andesite; they are present in greater concentration with the near-massive magnetite in the metasomatic replacement in the tactite.

The copper mineralization is younger than the intrusive porphyry, but may be associated with it. The granite (quartz-diorite) stock has been dated as Laramide in age; the porphyry, and the copper mineralization, are probably related to later phases of the same magmatic period. The complete picture is that of a typical southwestern U.S., "porphyry copper" deposit that reaches the present surface at only one, very small, outcrop area.

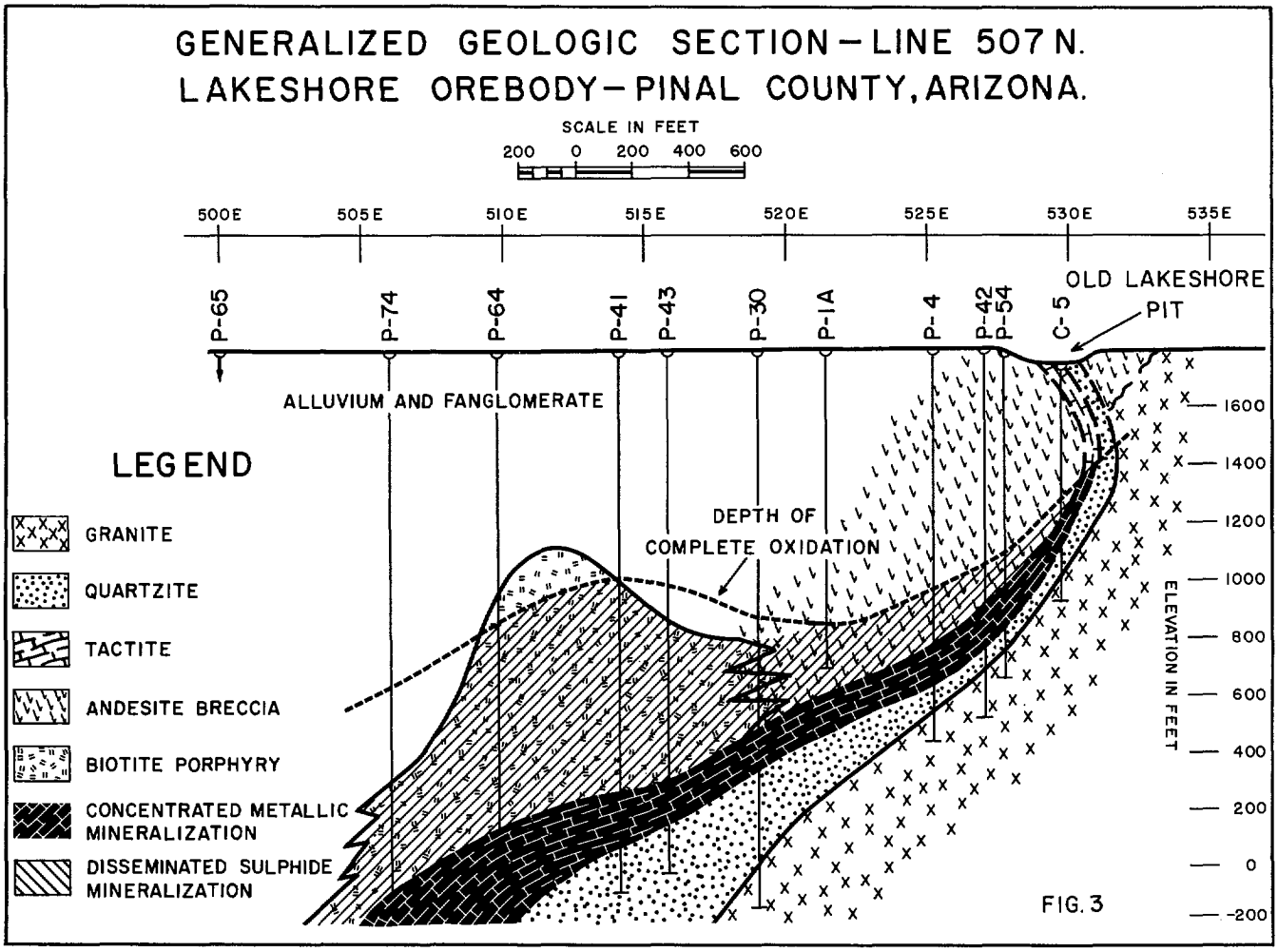

GENERALIZED GEOLOGIC SECTION – LINE 507 N.
LAKESHORE OREBODY – PINAL COUNTY, ARIZONA.
SCALE IN FEET
200 0 200 400 600
500E
505E
510E
515E
520E
525E
530E
535E
P-65
P-74
P-64
P-41
P-43
P-30
P-1A
P-4
P-42
P-54
C-5
OLD LAKESHORE PIT
ALLUVIUM AND FANGLOMERATE
DEPTH OF COMPLETE OXIDATION
ELEVATION IN FEET
1600
1400
1200
1000
800
600
400
200
0
-200
LEGEND
GRANITE
QUARTZITE
TACTITE
ANDESITE BRECCIA
BIOTITE PORPHYRY
CONCENTRATED METALLIC MINERALIZATION
DISSEMINATED SULPHIDE MINERALIZATION

FIG. 3

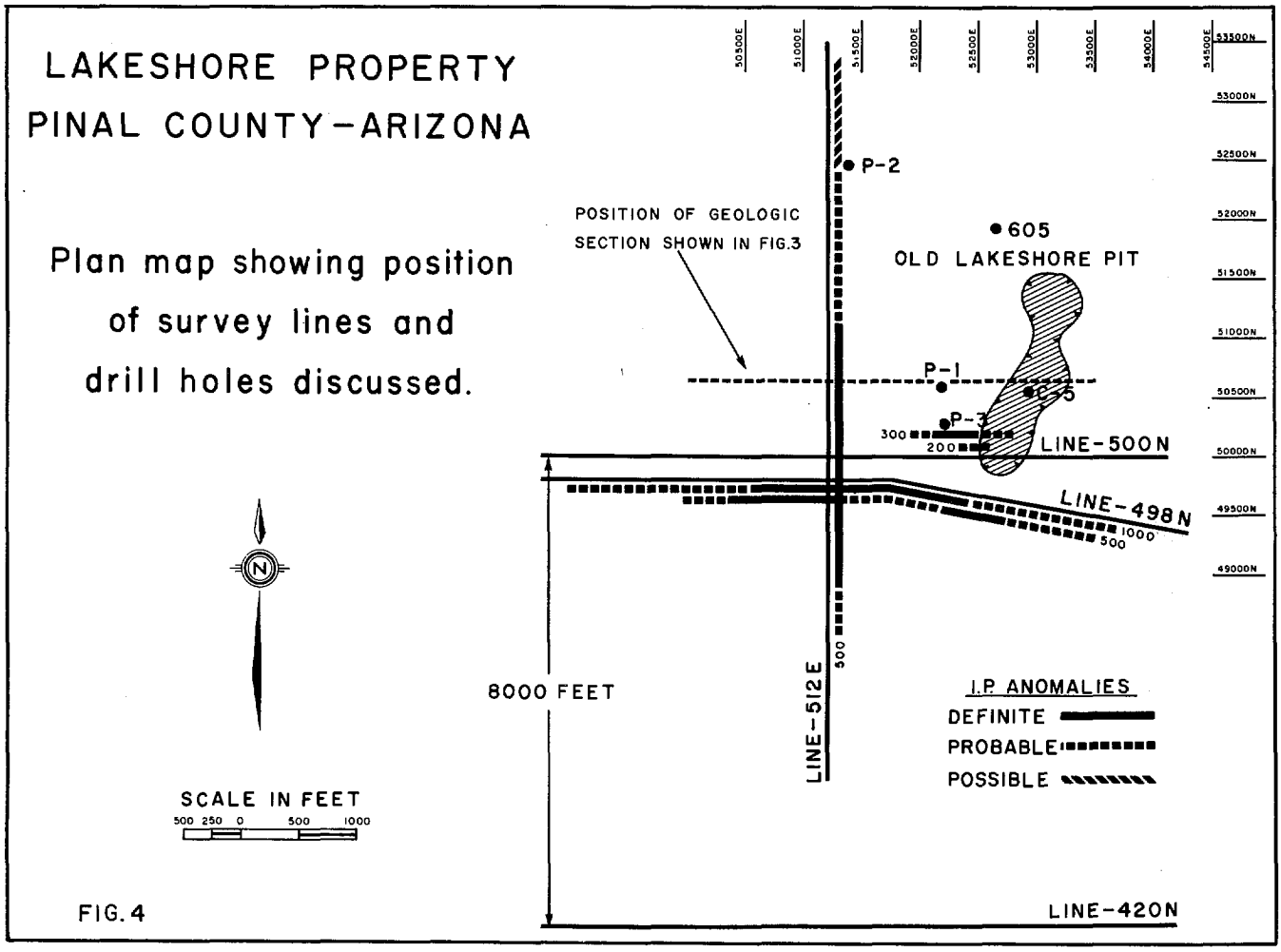

LAKESHORE PROPERTY
PINAL COUNTY – ARIZONA
Plan map showing position of survey lines and drill holes discussed.
POSITION OF GEOLOGIC SECTION SHOWN IN FIG.3
P-2
605
OLD LAKESHORE PIT
P-1
C-5
P-3
300
200
LINE-500N
LINE-498N
1000
500
LINE-512E
500
8000 FEET
LINE-420N
I.P. ANOMALIES
DEFINITE
PROBABLE
POSSIBLE
N
SCALE IN FEET
500 250 0 500 1000

FIG. 4

Drilling Sequence For First Holes

The reconnaissance IP survey completed in August - September 1966 was made on north-south lines, at approximately one-quarter mile intervals. The dipole-dipole electrode configuration was used, with X = 500'. A few east-west lines were surveyed over the old Lakeshore Pit mineralization using X = 200' and X = 300'. The reconnaissance results indicated a moderate magnitude anomaly, at depth, to the west of the known mineralization in the old Lakeshore Pit. The depth to the top of the source was interpreted to be 1.0 - 2.0 electrode intervals (i.e. 500' to 1,000').

In Figure 4 we have shown the drill holes and surveyed lines that will be discussed. The first drilling done after the IP survey, was a deepening of Hole #605. This old rotary hole lay at the edge of the anomalous zone. It had been stopped at 288 feet in a porphyry, weakly mineralized with secondary copper minerals. Core drilling was completed to 790 feet, before the hole was lost due to poor drilling conditions. Fractured and altered porphyry and andesite breccia were encountered, with secondary copper minerals. No sulphide mineralization was encountered.

At this point, Hole P-1 and Hole P-2 were begun at widely separated points within the IP anomaly. Hole P-2 was drilled through 800 feet of cemented fanglomerate and abandoned due to poor conditions. No oxide or sulphide mineralization was encountered. Hole P-1 was continued to a depth of 750 feet in fractured and altered andesite and andesite breccia; a few, sill-like, masses of biotite porphyry were encountered. At 750 feet the hole was still in weak copper oxide mineralization. At this point in time, drilling was discontinued while all of the geological and geophysical data was re-evaluated.

Laboratory measurements were made on core samples of all of the rock types encountered. The samples were of relatively low resistivity (25 - 250) due to porosity from fracturing, alteration, etc.; a few of the frequency effects measured were 1.0% to 1.25% (using 0.31 - 5.0 cps),

but most were less than 1.0%. These true IP effects were not large enough in magnitude to be the source of the apparent effects previously measured. The anomaly was then confirmed using 500' electrode intervals on a few east-west lines.

At the same time a complete review of all of the geological information available was being completed by the Mineral Division of El Paso Natural Gas Co. This work was done by Claude E. Barron, Senior Mining Geologist, under the supervision of John R. Reynolds, Chief Geologist of the Minerals Division.

The major result of this review was the decision that the last structural event effecting the Lakeshore geology has been a 45° rotation about a horizontal axis trending N50°E. The interpretation was made that before this event the mineralized metasediments outcropping in the old Lakeshore Pit had been dipping steeply to the northwest, and overlain by the andesite and andesite breccia. This interpretation was confirmed by the two intersections of secondary copper mineralization in the old churn drill hole, Hole C-5; it also suggested that the mineralized tactite should be, at depth, in the area of the deep IP anomaly.

With the review completed, the possible importance of the IP anomalies was confirmed. It was decided to continue Hole P-1, in an attempt to intersect metallic mineralization that could be the source of the IP effects. At 850 feet, the hole encountered weak copper sulphide mineralization in the andesite breccia. Hole P-1 was lost at about 1,100 feet, due to poor drilling conditions.

Meanwhile, Hole P-3 had been started about 300' south of Hole P-1. The fractured and altered andesite and andesite breccia were difficult to drill; however, careful drilling gave consistently high core recovery. Some secondary copper mineralization was encountered, but little or no sulphides ! The hole passed from altered volcanics to altered sediments (limestone and dolomite) at 1,080 feet. At 1,147 feet the hole penetrated 90 feet of mineralized, banded tactite with massive magnetite, pyrite, and chalcopyrite. The interval

assayed 1.75% copper.

This intersection (in mid-1967) marked the discovery of sulphide mineralization in the metasediments (tactite). The drilling program was accelerated, and in early 1968 an announcement was made that a major copper deposit had been discovered.

Geophysical Results

The only geophysical technique used in the direct detection of the metallic mineralization at Lakeshore was the induced polarization method. Ground and airborne magnetic data does exist for the area, but this data has not been released for publication here. The surface magnetic results show a weak anomaly associated with the mineralized tactite in the old Lakeshore Pit; these effects are interpreted to be due to small quantities of remnant magnetite in the weathered zone. There are variable, and sometimes large, concentrations of magnetite in the andesites. The surface expressions from these features effectively mask any interpretable anomaly from the approximately flat-lying magnetite zone in the tactite at depth.

Before Hecla Mining Co. joined El Paso Natural Gas Co. in the development of the Lakeshore Orebody, several other major mining companies reviewed the drilling and geophysical data. As part of their review, several of these companies carried out induced polarization surveys over the mineralized zone. These IP measurements were made in both the frequency domain and the time domain, with many different electrode configurations. If these measurements were made with the proper electrode interval, and electrode configuration, they usually confirmed the IP anomaly at depth. None of this data has been released for inclusion in this paper.

The variable frequency induced polarization surveys completed by McPhar Geophysics Inc., for El Paso Natural Gas Co., were done using the dipole-dipole electrode configuration. We will present enough of the

data here to confirm the usefulness of the method in detecting and delimiting the Lakeshore Orebody.

a) Line 420N (Background)

The results shown on Figure 5 are from a portion of Line 420N, which passes approximately two miles south of the centre of the ore zone. These results were chosen to show typical background levels on the pediment, southwest of the Slate Mountains. The resistivity level is moderate and the apparent frequency effects are variable, but low in magnitude.

b) Line 512E (Discovery Line)

The results shown on Figure 6 are part of the original 1966 reconnaissance survey done on north-south lines, about one-quarter mile apart. The survey was done using 500' electrode intervals and 0.05 - 1.25 cps.

There is almost no resistivity expression of the anomaly. The apparent frequency effect and apparent Metal Factor results both show a definite anomaly centred at 503N. There is some depth indicated to the source, but the depth to the top was not interpreted to be much more than one electrode interval (i.e. 500' - 600').

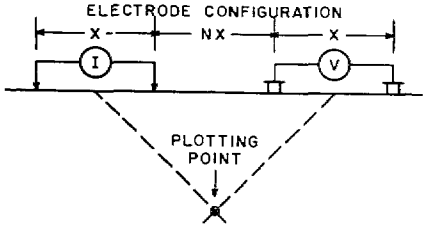
The geological section shown at the bottom of Figure 6 is drawn to the same vertical and horizontal scale as the IP data plots. The locations of the holes that have been drilled since 1966 are also shown. The rock-type symbols used are those identified in Figure 2 and Figure 3. The geologic section shows that the IP anomaly correlates with the shallowest portion of the mineralized porphyry. At about 503N on Line 512E, the disseminated mineralization is about 600' to 700' nearer the surface than it is for several thousand feet in all directions.

Under Line 512E, the more concentrated metallic mineralization in the tactite is at a depth of 1,800 feet. This mineralization would not be expected to influence the measurements using 500' electrode intervals.

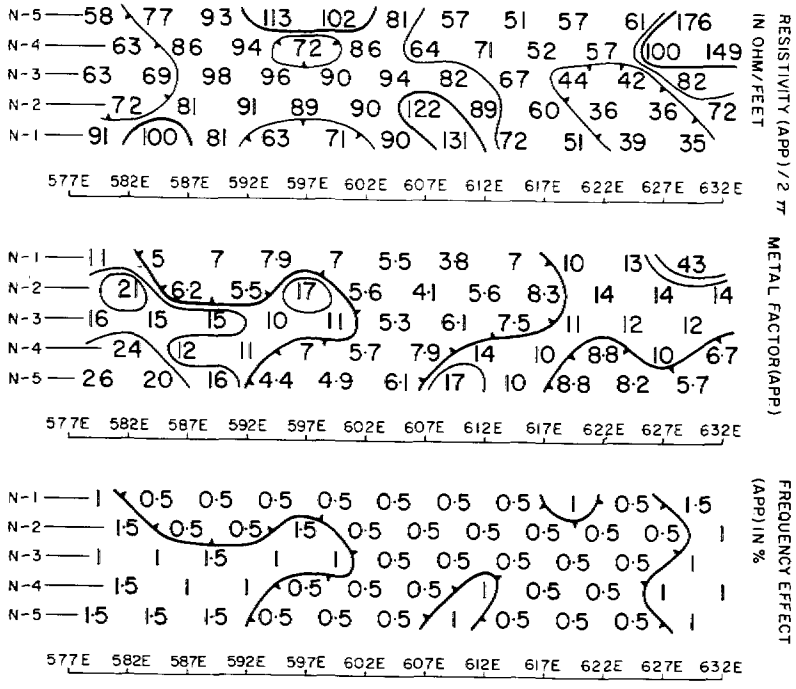
INDUCED POLARIZATION AND RESISTIVITY RESULTS FROM LAKESHORE GRID PINAL COUNTY-ARIZONA

LINE-420N (1968)

FREQUENCIES-0·125/1·25 HZ.



X= 500 FEET



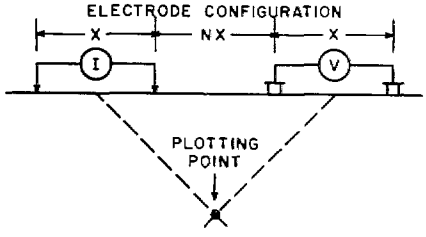
NO GEOLOGICAL DATA AVAILABLE

FIG. 5

INDUCED POLARIZATION AND DRILLING RESULTS FROM LAKESHORE OREBODY PINAL COUNTY-ARIZONA

LINE-512E (1966)

FREQUENCIES-0·05/1·25 HZ.



X= 500 FEET

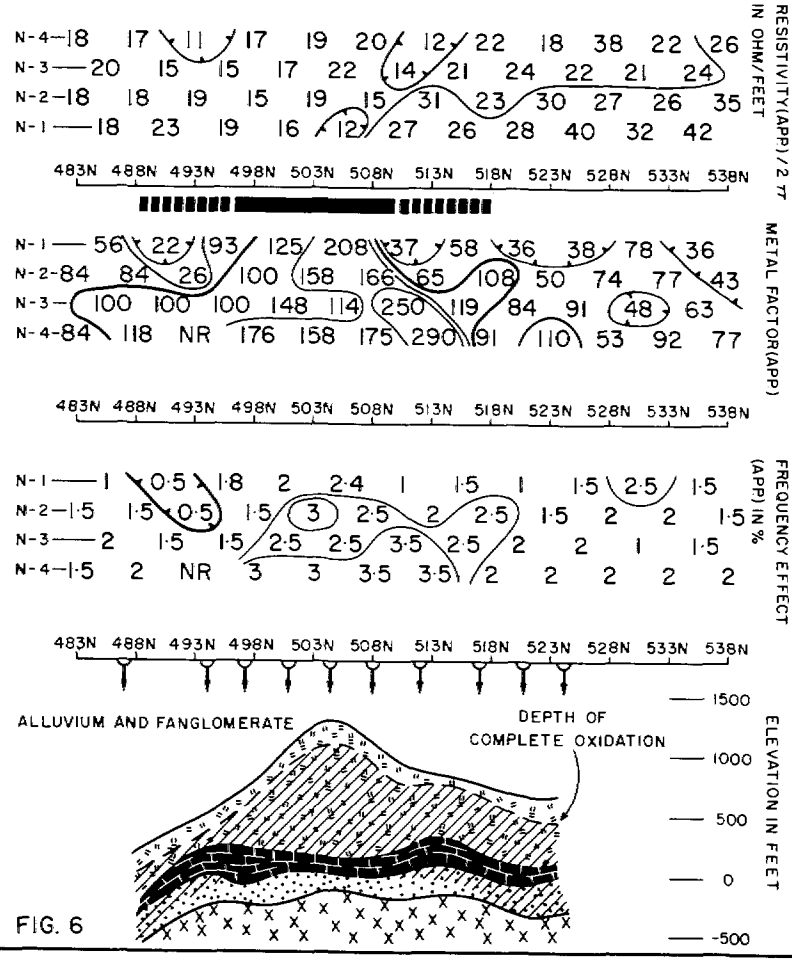


FIG. 6

This is the most definite anomaly located on the reconnaissance survey, probably because of the decrease in the depth to the top, at this point.

c) Line 500N (X = 200' and X = 300')

At the end of the reconnaissance survey in 1966, a few east-west lines were surveyed in the vicinity of the old Lakeshore Pit. For this work X = 200', n = 1,2,3,4,5 were used. The data shown on Figure 7 is from Line 500N. This line passes over the south end of the old Lakeshore Pit.

No anomalous frequency effects were measured. The apparent Metal Factor results show a weak anomaly, at considerable depth, centred at 524E. As shown by the geological section, constructed using later drill holes, this deep anomaly correlates with the up-dip edge of the metallic mineralization, beneath the depth of oxidation.

Definite information about the depth of oxidation is sparse. However, the available data suggests that no fresh sulphide mineralization could be present above a depth of 400' to 500'. There would certainly be some interval of partial oxidation, in which some metallic minerals might be present. The metallic mineralization present is at the extreme limit of the depth at which X = 200' measurements would be expected to detect it.

Because of the great depth of the anomaly detected using X = 200', the measurements on Line 500N were repeated using X = 300'. (Figure 8). The 50% increase in electrode interval gave rise to a much more definite anomaly.

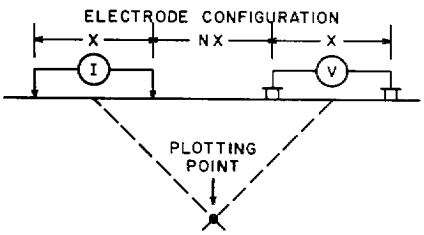
The resistivity pattern centred between 531E and 534E is a typical pattern indicating a near-vertical contact between high resistivity rocks to the east and lower resistivity rocks to the west. There is a slight resistivity low associated with the anomaly.

There is a slight increase in the apparent frequency effects for n = 4,5 but the increase is less than the increased frequency effects to the east in the high resistivity rocks. The Metal Factor parameter shows a

INDUCED POLARIZATION AND DRILLING RESULTS FROM LAKESHORE OREBODY PINAL COUNTY-ARIZONA

LINE-500N (1966)

FREQUENCIES-0·05/1·25 HZ.



X= 200 FEET

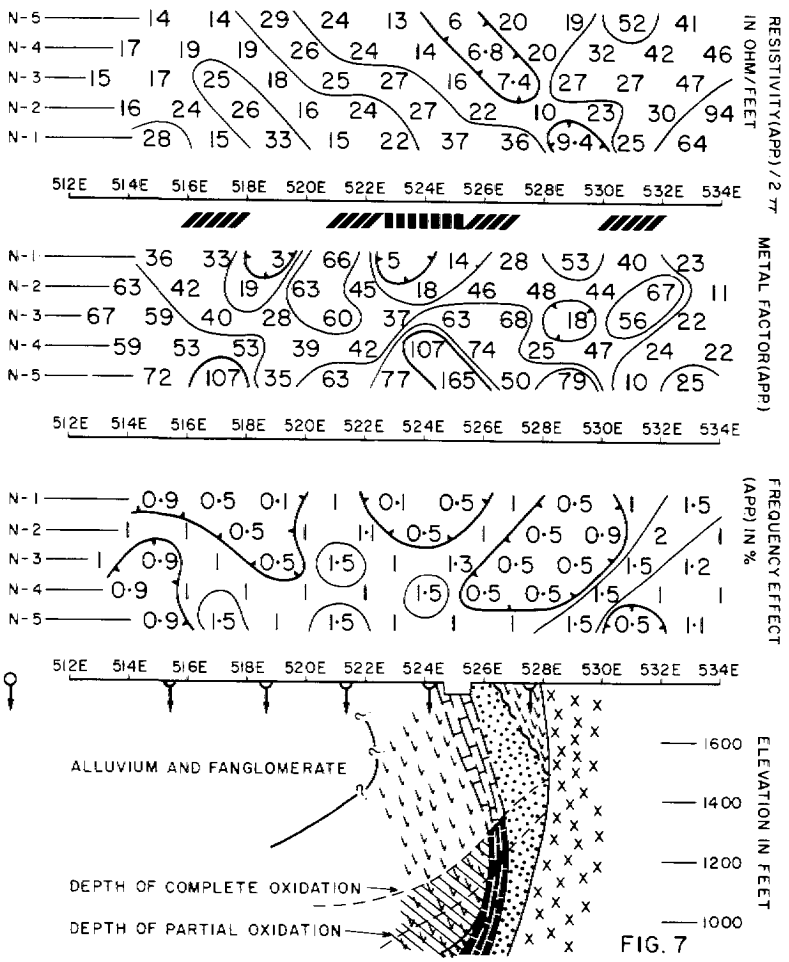
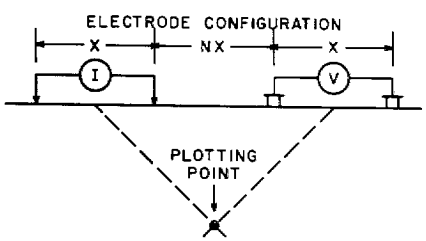


FIG. 7

INDUCED POLARIZATION AND DRILLING RESULTS FROM LAKESHORE OREBODY PINAL COUNTY-ARIZONA

LINE-500N (1966)

FREQUENCIES-0·05/1·25 HZ.



X= 300 FEET

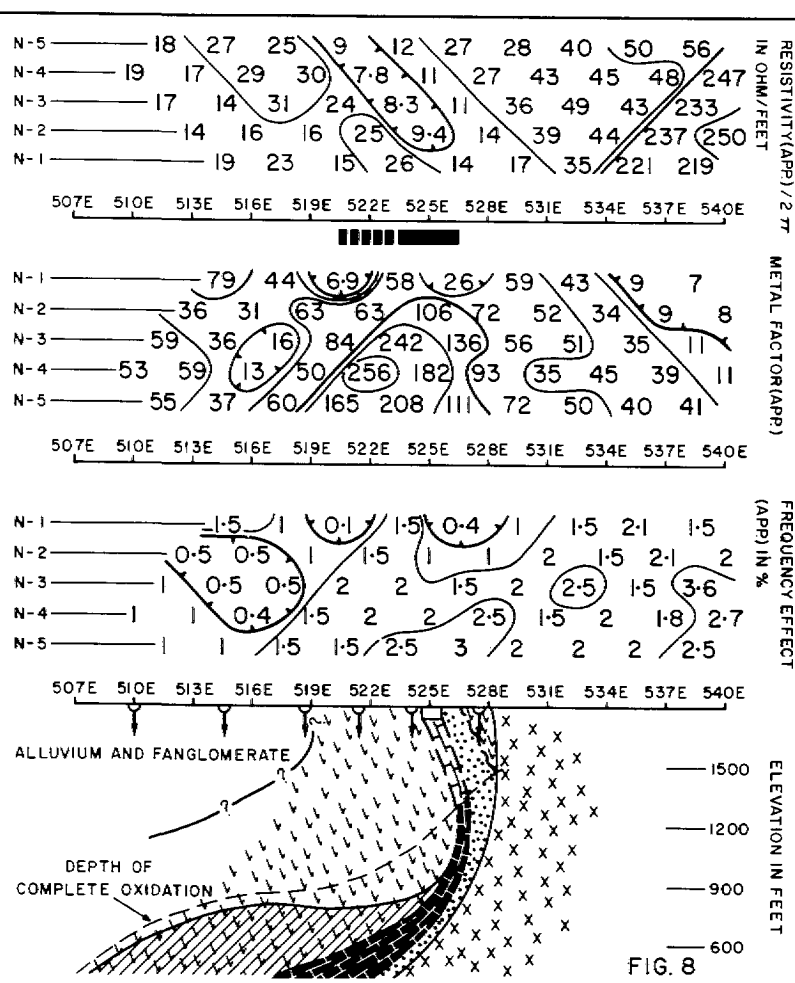


FIG. 8

definite anomaly, at depth, centred at 525E. The anomalous pattern suggests a near-vertical, tabular source that has a width less than the electrode interval (300').

The results on Line 500N show clearly that if the Lakeshore Orebody is to be detected using 200' or 300' electrode intervals, it is necessary to use the dipole-dipole configuration and make accurate measurements for n = 4 and n = 5.

d) Line 498N (X = 500' and X = 1000')

As mentioned above, the deep IP anomaly at Lakeshore was confirmed using east-west lines and larger electrode intervals after the first drilling had not intersected significant sulphide mineralization to depths of 700 to 800 feet. Measurements using X = 500' and X = 1000' were made on Line 498N. This line is close enough to Line 500N, that the data can be considered to be from the same survey line.

The measurements with 500' electrode intervals can be seen on Figure 9. The most distinctive resistivity feature is the high resistivity level east of 530E to 535E. There is only a very slight resistivity low associated with the orebody.

The IP anomaly is quite definite when 500' electrode intervals are used. The apparent frequency effect values and the apparent Metal Factor values are both definitely anomalous. The largest effects are measured for n = 4 and n = 5.

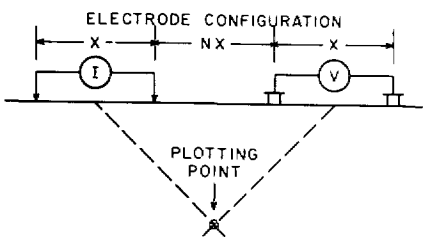
The anomalous pattern suggests an asymmetric source and the pattern is complex. The source of the IP effects could be approximated by a tabular source dipping to the west. The theoretical scale modelling results shown in Figure 10 show a typical pattern for a source dipping at 30°. The pattern is not unlike that measured over the Lakeshore Orebody using 500' electrode intervals.

The results of measurements with X = 1000' on Line 498N are

INDUCED POLARIZATION AND DRILLING RESULTS FROM LAKESHORE OREBODY PINAL COUNTY–ARIZONA

LINE-498N (1967)

FREQUENCIES - 0·125/1·25 HZ.



X = 500 FEET

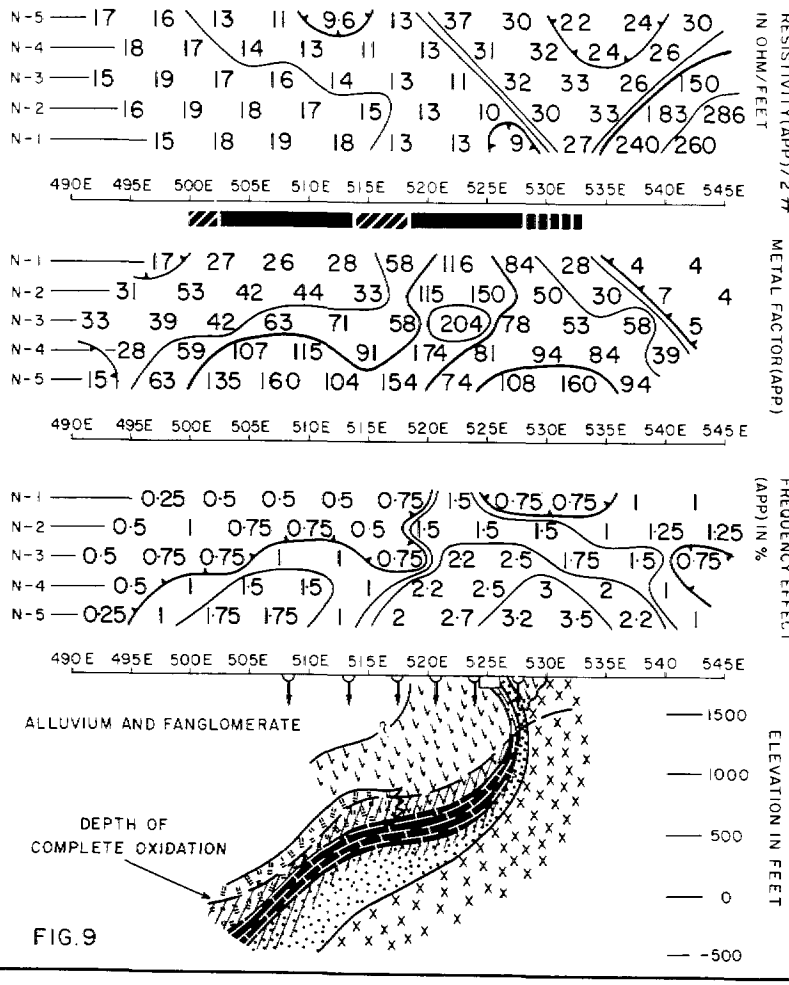
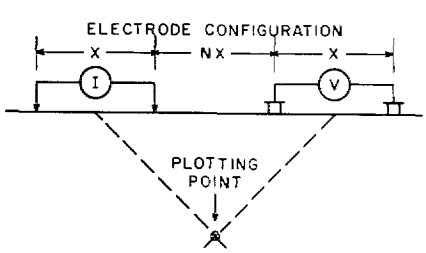


FIG. 9

THEORETICAL INDUCED POLARIZATION AND RESISTIVITY STUDIES

SCALE MODEL CASES DIPPING TABULAR SOURCE



X = 1·0 UNITS

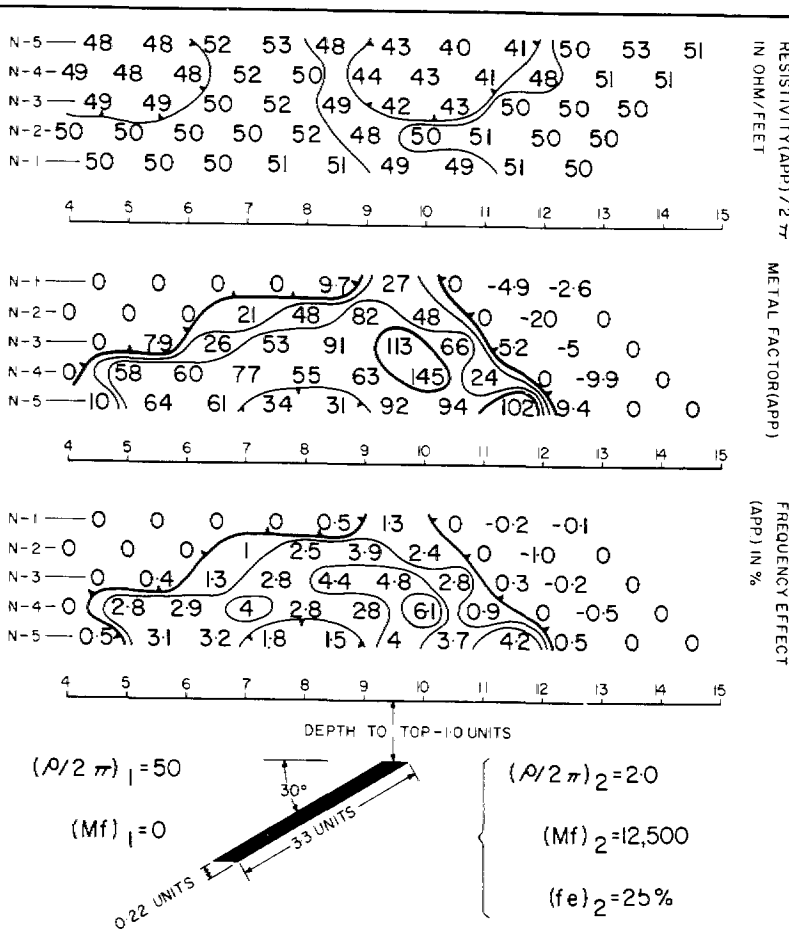


FIG. 10

shown on Figure 11. The IP anomaly centred at 520E correlates with the centre of the Lakeshore Orebody. The apparent frequency effect values and the apparent Metal Factor values are definitely anomalous. With 1000' electrode intervals, it is probable that the IP anomaly is due to the entire volume of metallic mineralization rather than just the near-vertical, up-dip end of the tactite zone that gave rise to anomalies when shorter electrode intervals were used.

Conclusions

The variable frequency IP results described above were chosen to demonstrate the role played by geophysics in the discovery and evaluation of the major copper deposit at the Lakeshore Property. The IP measurements at Lakeshore were made at irregular intervals over a period of three years. Some of the results contributed to the eventual discovery of the ore; in other cases the results were misleading. Now that more complete geological data is available, it is, of course, possible to explain all of the effects measured.

On Figure 12, we have shown all of the anomalies interpreted during the various IP surveys at Lakeshore. Also shown are all of the drill holes completed prior to November 1969. The line surrounding all of the IP anomalies is the surface outline of a sample open pit prepared as the result of one, of several, computer analyses of the drill hole data. The correlation is quite specific.

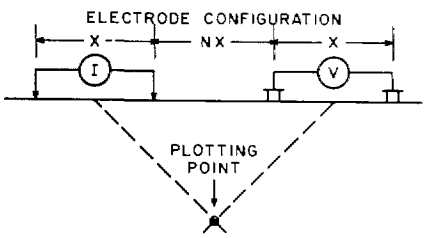
Acknowledgements

The authors feel that there is a lesson for all exploration people in the history of the discovery of the Lakeshore Orebody. The successful conclusion of the Exploration Program by the Mineral Division of El Paso

INDUCED POLARIZATION AND DRILLING RESULTS FROM LAKESHORE OREBODY PINAL COUNTY-ARIZONA

LINE-498N (1967)

FREQUENCIES-0·125/1·25 HZ.



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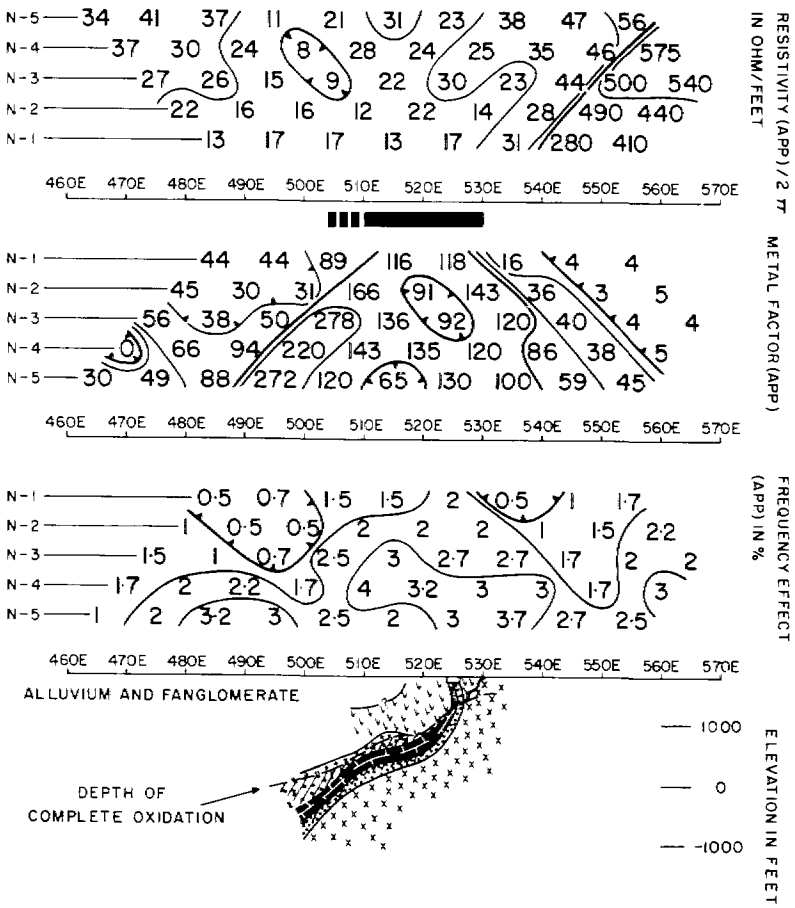

FIG.-11

LAKESHORE PROPERTY PINAL COUNTY-ARIZONA

Plan showing all I.P. anomalies and present existing drill holes.

Outline of open pit planned by computer

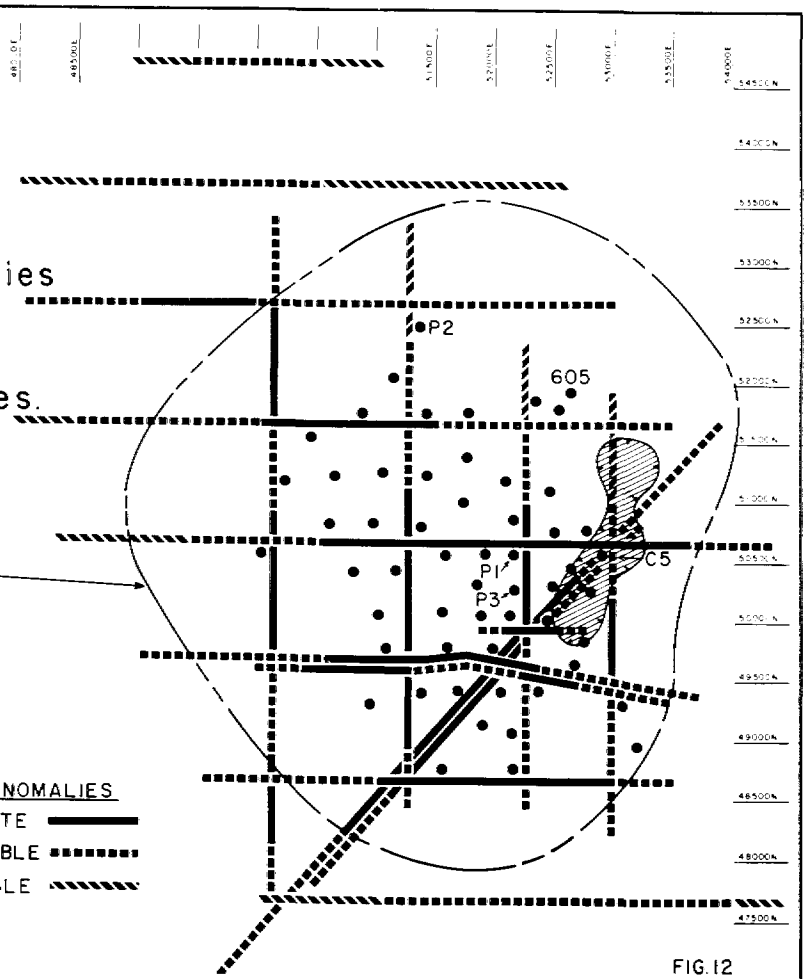

FIG.12

Natural Gas Co. was accomplished by the application of integrated exploration techniques. All of the available geological and geophysical data was considered; not just once, but repeatedly. The success of the program was due in large part to the patient re-evaluation of geophysical and geological data by the Geologic Staff of El Paso Natural Gas Co.

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