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THE USE OF GEOPHYSICS TO LOCATE SULPHIDE MINERALIZATION AT DEPTH

BY

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Prepared for Presentation at the International Geological Congress
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This paper by Dr. P.G. Hallof was prepared originally for presentation at the International Geological Congress in Prague, Czechoslovakia in August 1968. The paper was not presented, as this conference was never concluded. It was presented at a meeting of KEGS in Toronto in 1969, and in February and March 1970 was used as the basis for informal geophysical discussions during the course of a Scientific Equipment Mission to Eastern Europe for the Canadian Government. Interest generated during these Presentations indicated that printing of the paper and general mail-out would be appreciated by many who receive this.

THE USE OF GEOPHYSICS TO LOCATE SULPHIDE MINERALIZATION AT DEPTH

ABSTRACT

In the last twenty years, there has been a great expansion in the use of geophysical methods in exploration for base metal sulphide deposits. New instruments, techniques and methods have been developed. One natural result of this increased experience is that sulphide mineralization can now be detected at greater depths than previously. However, it is still true that most of the mineralization located is largely pyrite that is of little economic interest.

The zones of mineralization located may be beneath 150 to 1,500 feet of ice, glacial till, alluvium, younger limestones or volcanic rocks, etc. The costs of drilling to test the geophysical anomalies increases with the depth to the top of the source. A fruitful line of endeavor for exploration geochemists would be the extension of existing techniques or the development of new techniques to give possible information concerning the nature of the mineralization at depth.

INTRODUCTION

The period since the end of World War II has seen a tremendous expansion in the use of geophysical techniques in the search for base metal sulphide deposits. Geophysicists' experience in these methods now reaches into all parts of the world.

The increased use of geophysics has resulted in the refinement of techniques and equipment for existing methods (Magnetics, Gravity, Electromagnetic) and the development of new methods (Afmag, Induced Polarization). These improvements in exploration ability have made it possible to locate, and outline, zones of mineralization that were not previously considered to be geophysical targets. Zones of disseminated sulphide mineralization and zones at considerable depth can now be located with a reasonable degree of certainty.

The systematic use of geophysical techniques in extensive areas has resulted in the discovery of large quantities of sulphide mineralization; most of this mineralization is of little, or no, economic value. The geophysicist has confirmed the fundamental fact long known by earth chemists; i. e. that iron is much more common than copper, lead, zinc, etc. In short, there is a great deal of pyrite in the world!

Since drilling costs to evaluate geophysical anomalies are the largest single item in an exploration budget, it would obviously be desirable to develope methods to yield advance information concerning the type of minerals present. This is particularly true for sources at depth. The problem appears to fall within the field of exploration geochemistry.

The geochemist can appreciably increase the success ratio of an exploration program by using regional and reconnaissance techniques to assist the geologist in the selection of areas of primary interest. The geochemical techniques useful in the evaluation of outcropping, or very shallow, zones of mineralization have been widely employed. The geophysicist could now use the assistance of the geochemist in the evaluation of sulphide zones located at depth.

As is well understood, the problems presented are extremely difficult. The sampling procedures must necessarily involve some type of mechanical drill and the overlying material can be widely variable in its characteristics. In some areas the overlying material will be loose and porous, such as a deeply weathered layer, alluvium or glacial till. In other areas solid rocks, of some type, may lie above the zone of mineralization.

This paper will present geophysical data and drilling results which demonstrate the depth of detection that is possible with modern geophysical techniques. The nature of the rocks covering the zones of mineralization included in the data is variable; this has been done intentionally, in order to demonstrate the magnitude of the problem.

GEOPHYSICAL METHODS

There have been recent instrumentation advances with gravimeters and magnetometers, and data reduction has been greatly facilitated by the use of computers. However, the limitations of the methods are much the same as they have been in the past. Therefore, the data that will be presented here will demonstrate the usefulness of the electrical methods.

a) The Electromagnetic Method

The various electromagnetic methods have been in use for some time, and they have recently been covered in detail in several excellent books (Ward, Grant and West). In all systems the distortions in the total field (primary plus secondary) are detected as variations in magnitude and/or phase or as changes in field direction.

Recent advances in electronics have permitted great improvements for the weight/power ratio for the transmitter and for the sensitivity of the receiver. Modern systems are more sensitive and can be used with greater coil separations than before. This has resulted in a greater usable depth of detection.

b) The Afmag Method

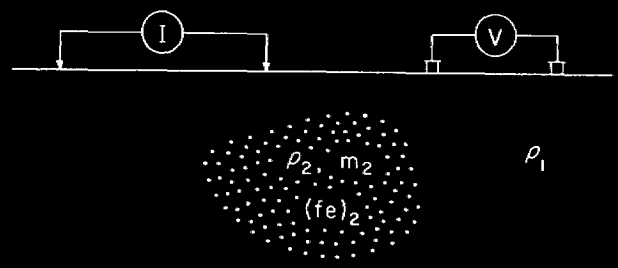
This is a relatively new electromagnetic method that detects distortions in the earth's natural fields; measurements are made in the low audio range. An excellent list of references is given by Ward. There are several ways to plot the results, but the simplest is to profile the apparent dip-angle of the field in a direction at right angles to the conductor.

c) The Induced Polarization Method

The electrochemical phenomena giving rise to the induced polarization effects used in exploration have been previously described (Hallof 1957; Madden & Marshall 1959). There are two well-known and widely applied measurement techniques used in exploration. (Seigel 1962; Wait 1959; Hallof 1960, 1961). It has been shown that the chargeability parameter (M_a) used in the "pulse-transient" type survey is mathematically equivalent to the frequency effect parameter (Fe_a) usually recorded in the "variable frequency" type survey (Hallof 1964; Seigel 1959).

Our field experience has confirmed that the chargeability and the frequency effect are exactly equivalent. Any differences that exist between the two measurement techniques have to do with the necessary instrumentation and the electrode configurations that are possible. In either measurement technique, it is possible to use one or more derived parameters. One such parameter is the Metal factor, or Metallic conduction factor, (MF); the definition of this parameter is shown in Figure 1. It is very useful in the interpretation of induced polarization results. (Hallof 1964; 1967). The

apparent resistivity, apparent frequency effect and the apparent Metal factor are the three parameters that we use in our exploration work.



$$ma \simeq m_2 \rho_2 \times \frac{1}{\rho_a} \frac{\partial \rho_a}{\partial \rho_2} \qquad (fe)a = (fe)_2 \rho_2 \times \frac{1}{\rho_a} \frac{\partial \rho_a}{\partial \rho_2}$$

$$mf \equiv \frac{(fe) \times 100}{\rho_{dc}/2\pi} \times 1000 = \frac{\left[\rho_{dc}/\rho_{ac} - 1\right] \times 100}{\rho_{dc}/2\pi} \times 1000$$

$$= \left[\frac{1}{\rho_{ac}} - \frac{1}{\rho_{dc}}\right] \times 2\pi \times 10^5 = \left[\sigma_{ac} - \sigma_{dc}\right] \times 2\pi \times 10^5$$

FIG. 1

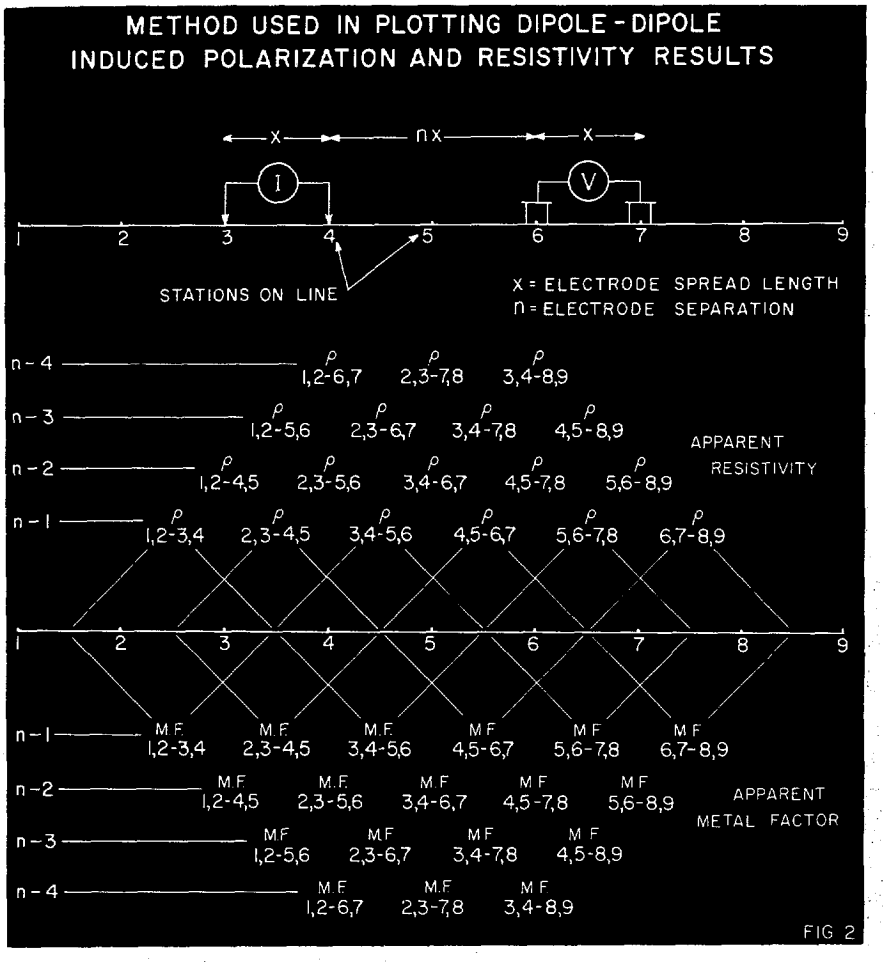
There are numerous techniques that can be used to plot induced polarization and resistivity results. Many geophysicists plot profiles along the measurement line; others construct two-dimensional, contoured plan maps using data measured along survey lines. The field measurements can be made using any four electrode configurations, and in our field work we use the dipole-dipole electrode configuration shown in Figure 2.

The results are plotted in the two-dimensional, "pseudo-section" manner shown in Figure 2. In this field procedure, measurements on the surface are made in a way that allows the effects of lateral changes in the properties of the ground to be separated from the effects of vertical changes in the properties. Current is applied to the ground at two points a distance (X) feet apart. The potentials are measured at two other points (X) feet apart, in line with the current electrodes. The distance between the nearest current and potential electrodes is an integral number (n) times the basic distance (X).

The measurements are made along a surveyed line, with a constant distance (nX) between the nearest current and potential electrodes. In most surveys, several traverses are made with various values of (n); i. e. (n) = 1, 2, 3, 4, etc. The type of survey required (detailed or reconnaissance) decides the number of values of (n) used.

In plotting the results, the values of the apparent resistivity and the apparent Metal Factor measured for each set of electrode positions are plotted at the intersection of grid lines, one from the centre point of the current electrodes and the other from the centre point of the potential electrodes. The resistivity values are plotted above the line and the Metal factor values below. The lateral displacement of a given value is determined by the location along the survey line of the centre point between the current and potential electrodes. The distance of the value from the line is determined by the distance (nX) between the current and potential electrodes when the measurement was made.

The separation between sender and receiver electrodes is only one factor which determines the depth to which the ground is being sampled in any particular measurement. These plots then, when contoured, are not section maps of the electrical properties of the ground under the survey line. They are merely convenient plots of all of the data.



GEOPHYSICAL RESULTS FROM SOURCES AT DEPTH

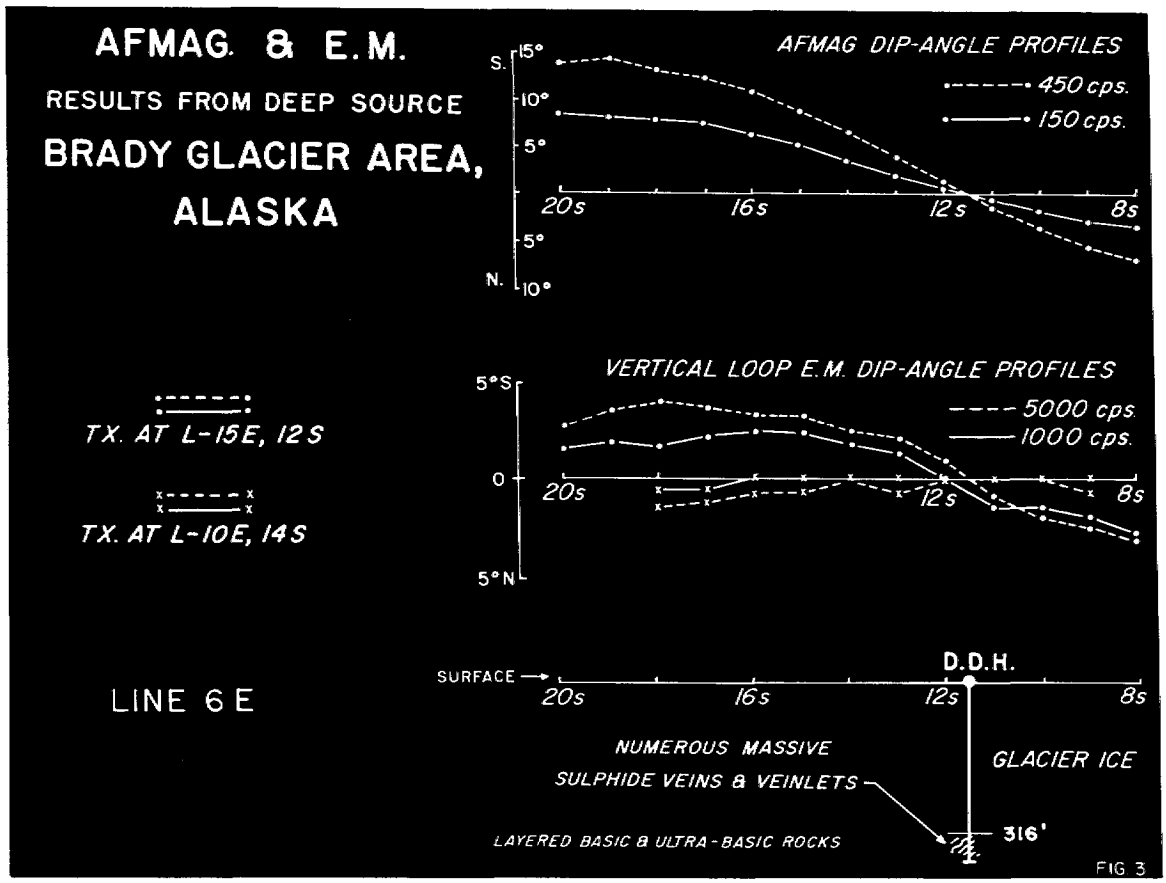
The depths to the tops of the sulphide mineralization located by the geophysical results described below varies from 150 feet to more than 1,000 feet. The covering material is ice, loose rock, or hard rock and the conductivity of the surface layer varies from very low to more than twice as conductive as sea water. In each case the drill holes shown were recommended and located on the basis of the data shown, and the mineralization was located as a result of the geophysical survey.

a) EM and Afmag Results from Alaska

The Electromagnetic and Afmag results shown on Figure 3 are from surveys carried out on the Brady Glacier in Alaska. The Vertical Loop EM data shows an anomaly only when the transmitting coil is located 900 feet from the receiver traverse. The anomaly is low in magnitude, but definite. The profiles indicate a zone of moderate conductivity at considerable depth.

The Afmag measurements were made at much lower frequencies than the EM measurements, but the anomaly is larger in magnitude. This is the expected result for the field source at infinity and a long conductor at depth. The source is indicated to be of moderate conductivity.

Because of movement of the glacier, it was possible to drill only a few feet into the rock beneath the ice. Further, vertical holes had to be used and this reduced the chances of intersecting the source, which could be relatively narrow. However, as shown on Figure 3 the hole intersected several zones of massive sulphide mineralization in the basement rocks beneath more than 300 feet of ice. This mineralization was considered to be the source of the anomalies.

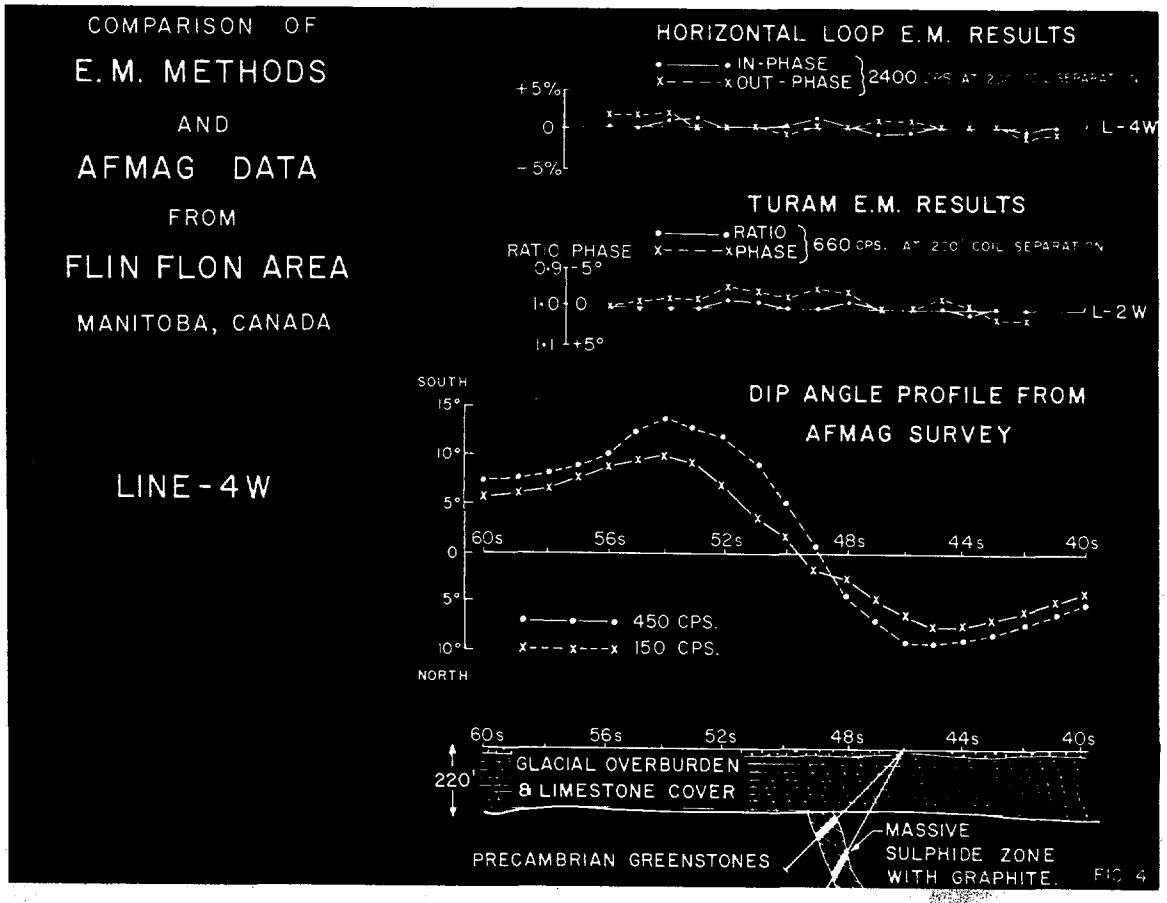


b) EM and Afmag Results from Manitoba

The zone of mineralization shown in Figure 4 had a shorter strike length than that shown in Figure 3. In this case the EM data is from vertical field systems with a coil separation of 200 feet. The Horizontal Loop EM results and the Turam EM results show small variations, but no anomaly can be interpreted.

The Afmag dip-angle profile shows a definite "cross-over" at 50S to 49S. A good conductivity source is indicated to be at a moderate depth. The approximately symmetric curve suggests a near vertical source.

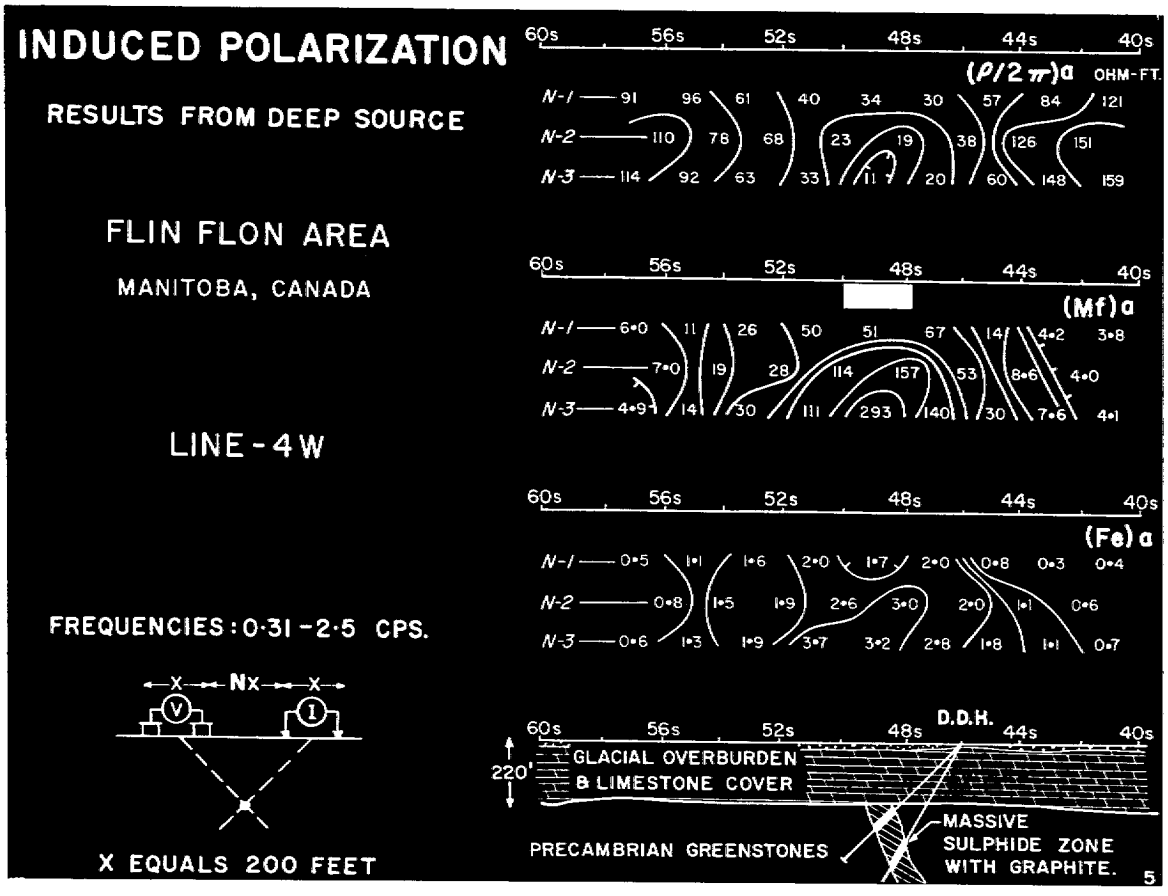
The later drilling confirms the presence of a zone of massive sulphide mineralization, with graphite. The top of the conductor is at a depth of 220 feet, beneath glacial overburden and younger limestones.



c) IP Results from Manitoba

The IP results shown in Figure 5 located the zone of mineralization that was later checked with Afmag and EM, as shown on Figure 4. The measurements were made with a 200' electrode interval (X = 200') and n = 1, 2, 3. The magnitude of the apparent IP effects measured increase for the larger values of (n) indicating that the source is at depth.

The depth to the top of the source was estimated to be about one electrode interval (i. e. about 200') and the first hole was located to pass beneath 49S at a depth of 250 feet.



d) IP Results from Arizona

The equation governing current flow in the earth is Poisson's equation, so that the IP measurement is largely independent of scale. A source of considerable volume can be located at great depth, by using a large electrode interval. The data shown in Figure 6 was measured using X = 1000' and n = 1, 2, 3, 4.

The results show a high resistivity rock to the east of about 20E; this correlates with the probable contact of a large intrusive mass that outcrops a few thousand feet to the east. The moderately low resistivity rocks to the west of the contact correlate with older volcanic flows and flow breccias.

The IP results suggest a source at some depth. The alluvium covering the surface was expected to be only a few hundred feet thick, which placed the expected source within the basement rocks. Extensive drilling has confirmed the presence of a flat-lying zone of concentrated mineralization of considerable lateral extent.

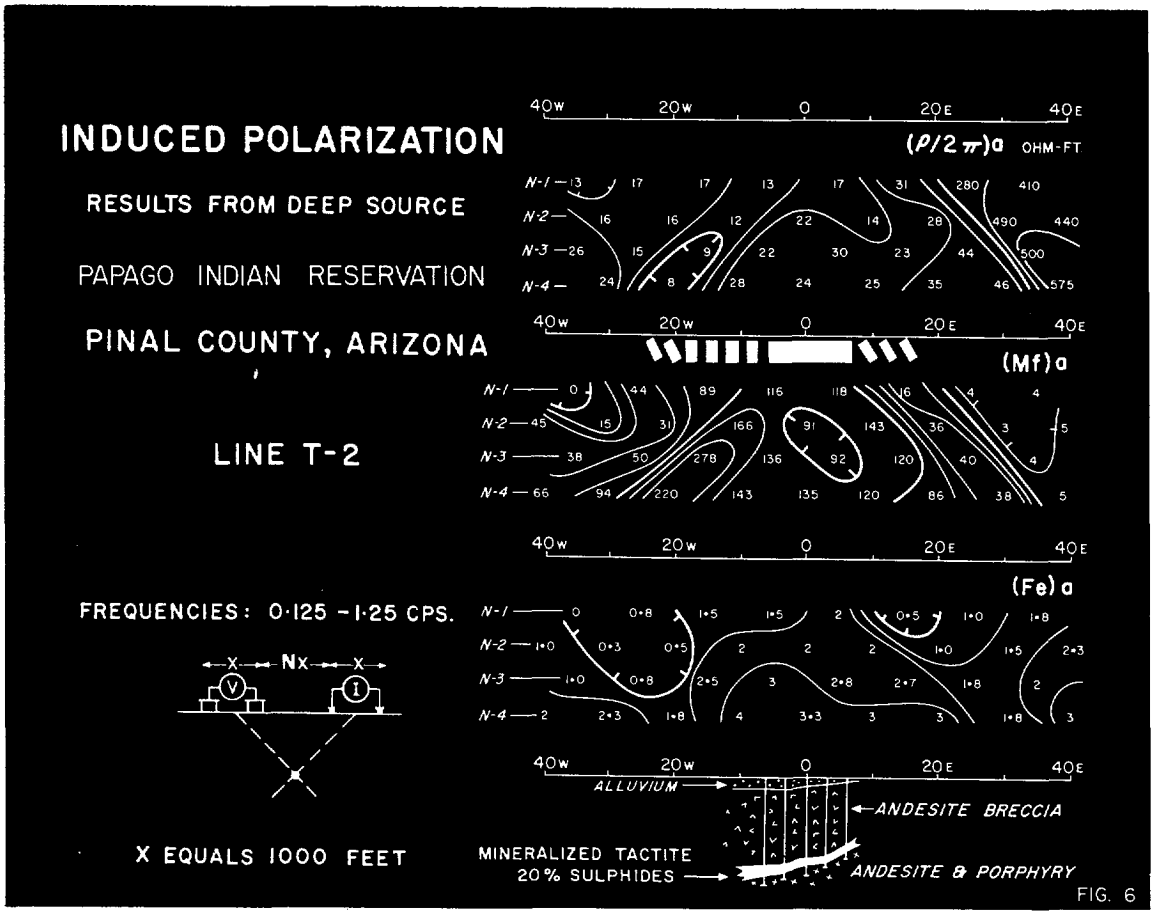


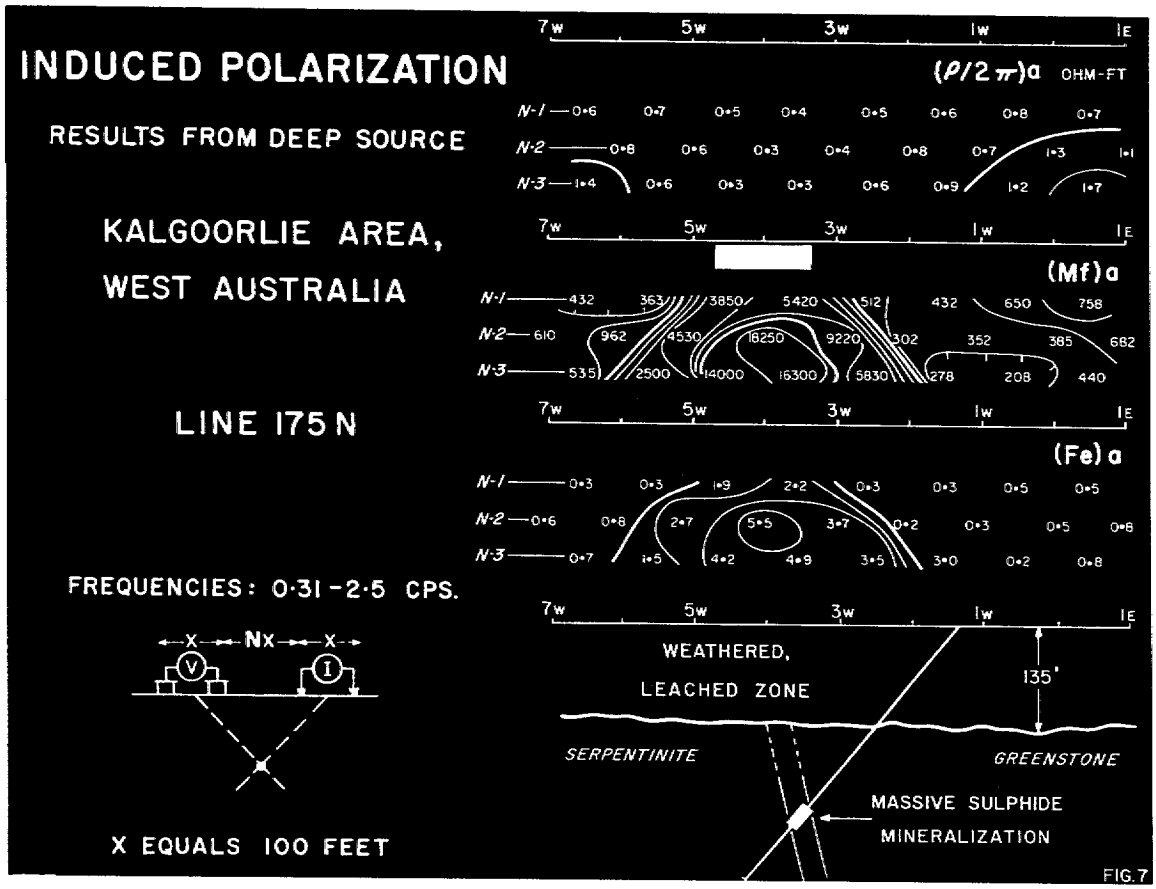
FIG. 6

e) IP Results from West Australia

In most of the semi-arid and tropical areas of the world, the deep weathering conditions assure that the top of any sulphide zone will be at some depth. The weathering and leaching of the near-surface rocks creates definite problems for the geochemist, and the geophysicist.

The IP data shown in Figure 7 is from an intensely weathered area near Kalgoorlie, West Australia. The rocks are completely decomposed and leached to depths of 100' to 200' and even more. The resulting porous surface layer, saturated with saline solutions, has a very high conductivity.

The IP anomaly is large in magnitude, and definite, suggesting a relatively narrow source at depth. The measurements with X = 100' suggest a depth to the top of about one electrode interval, and the first hole was spotted to pass beneath 4W to 3W at a depth of 200 feet. The hole intersected a narrow zone of massive sulphide mineralization that correlates with the IP anomaly.

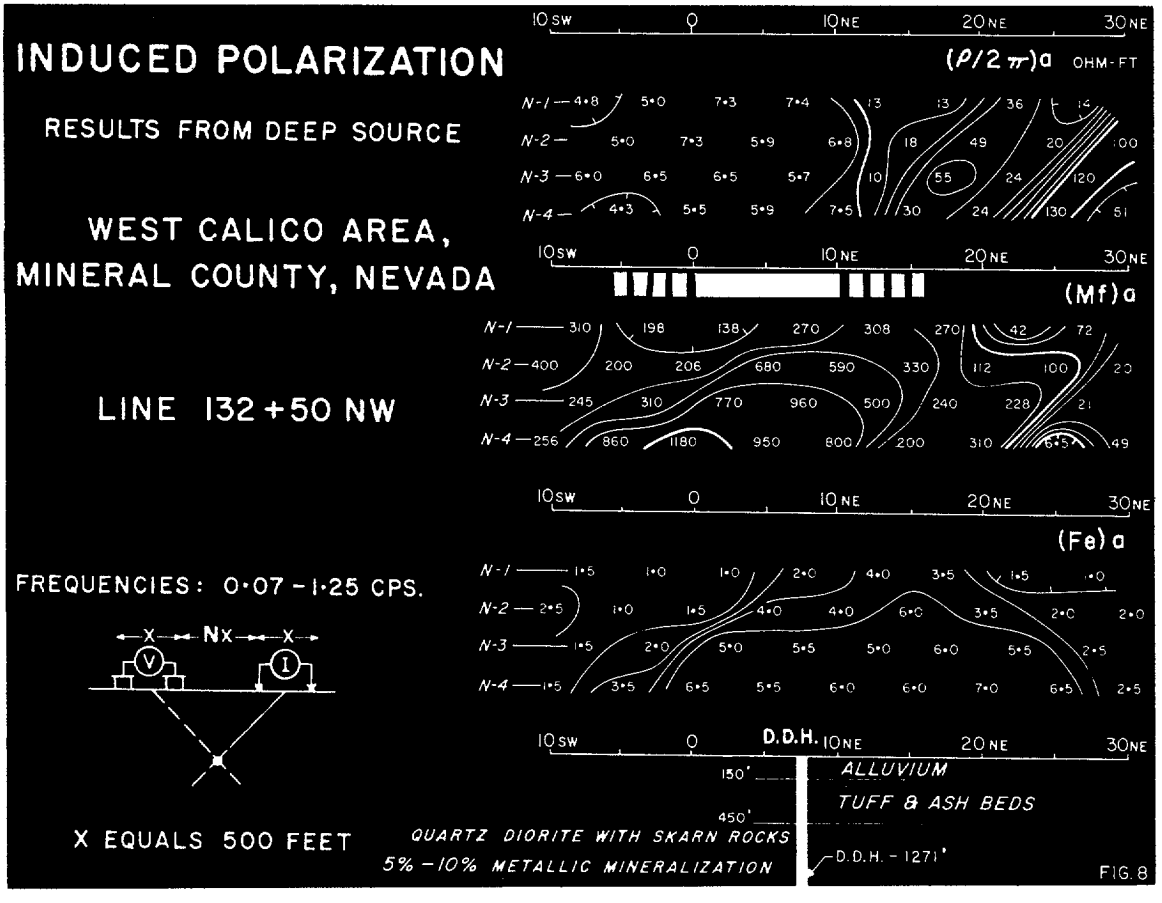


f) IP Results from Nevada

A large portion of the exploration effort in North and South America is involved in the search for large zones of disseminated mineralization of the "porphyry copper" type. The mineralization (3% to 10%) gives anomalous IP effects, and the large lateral extent of the zones results in a depth of detection of 750 to 1,500 feet, if large electrode intervals are used.

The results shown in Figure 8 are from the Basin and Range Province of Nevada. The resistivity data suggests the presence of the valley fault at 10 NE to 15 NE; to the southwest, the resistivities do not increase with depth. There is no evidence of the higher resistivity basement rock at depths, to the southwest of the fault.

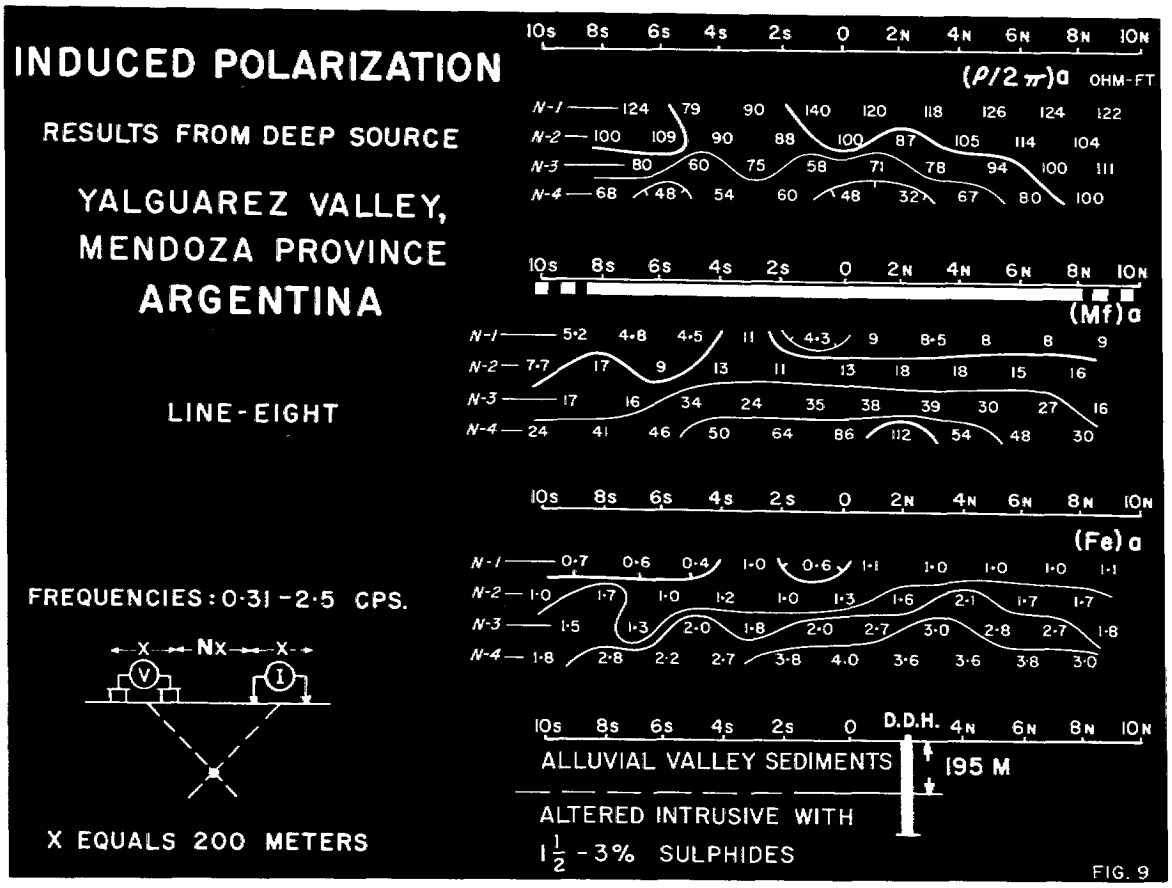
However, the basement is present at depths of approximately 500 feet. The IP results show a definite anomaly, at depth, centred at 0+00 to 10 NE. The drill hole shown intersected altered quartz diorite containing disseminated sulphide mineralization at 510 feet. These rocks have a low resistivity that is approximately equal to the resistivity of the overlying alluvium and ash beds; the apparent resistivity measurement did not detect a contrast.



g) IP Results from Argentina

The zone of disseminated mineralization located by the IP data shown in Figure 9 is located in northwestern Argentina. The depth to the top of the mineralization is about 200 meters. In this area, the alluvium in the valley has a relatively high resistivity. There is a small decrease in the resistivities, at depth, due to the slightly lower resistivity value in the altered intrusive.

The induced polarization results show the typical pattern for a layered medium; the source of the IP effects is indicated at about one electrode interval (200 meters). The zone has an indicated width of more than one kilometer. The drill hole shown penetrated 195 meters of alluvium and intersected weakly disseminated sulphide mineralization in the altered intrusive.



CONCLUSIONS

Experience in recent years has shown that modern geophysical equipment and techniques can be used to locate zones of sulphide mineralization at considerable depth. Depths of detection of 750 feet to 1,000 feet are not unusual for large sources.

In most situations, the mineralization located is largely pyrite, and therefore of no economic value. For sources at depth, the cost of drill holes to test the geophysical anomalies is an increasingly large portion of the exploration budget. It is obviously desirable for the geochemist to develope procedures that would permit a preliminary evaluation of the IP anomalies when the drilling program is being planned.

REFERENCES

Grant and West (1965), Interpretation Theory in Applied Geophysics, Chapter 15.

McGraw Hill Book Company

Hallof, P. G. (1957) - "On the Interpretation of Resistivity and Induced Polarization Results" - Doctoral Thesis, M. I. T. Department of Geology and Geophysics.

Hallof, P. G. (1960) - "The Uses of Induced Polarization in Mining Exploration"- Transactions of the AIME (Mining), Vol. 217, pp. 319-327.

Hallof, P. G. (1964) - "A Comparison of the Various Parameters Employed in the Variable Frequency Induced Polarization Method" - Geophysics Vol. XXIX, No. 3, pp. 425-434.

Hallof, P. G. (1965) - "The Proper Choice of Frequencies for Induced Polarization Measurements" - Presented at the Society of Exploration Geophysicists Annual Meeting, Dallas, Texas, November 1965.

Hallof, P. G. (1967) - "An Appraisal of the Variable Frequency IP Method after Twelve Years of Application" - Presented at the University of California, Berkeley; Symposium on Induced Polarization, February, 1967.

Marshall, D. J. and Madden, T. R. (1959) - "Induced Polarization, A Study of its Causes" - Geophysics Vol. XXXIV, pp. 790-816.

Seigel, H. O. (1959) - "Mathematical Formulation and Type Curves For Induced Polarization" - Geophysics Vol. XXIV, pp. 547-563.

Seigel, H. O. (1962) - "Induced Polarization and its Role in Mineral Exploration"- Transaction at CIMM (1962), Vol. LXV, pp. 151-158.

Sutherland, D. B. (1967) - "Afmag for Electromagnetic Mapping" - Transactions of the Canadian Centennial Conference on Mining and Groundwater Geophysics.

Wait, J. R. (Editor) (1959) - "Overvoltage Research and Geophysical Applications" - Pergamon Press, London, 1959.

Ward, S. H. (1967) - Society of Exploration Geophysicists Mining Geophysics Vol. II, Chapter II.

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