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GEOPHYSICAL SURVEY ON
PROPERTY NEAR KAMLOOPS
FOR AFTON MINES LTD

CANADIAN AERO-MINERAL SURVEYS

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REPORT ON
INDUCED POLARIZATION SURVEY
OF THE PROPERTY NEAR
IRON MASK LAKE, KAMLOOPS, B.C.

FOR

AFTON MINES LTD.

BY

CANADIAN AERO MINERAL SURVEYS LTD.

Project No. 7002.

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OTTAWA, Ontario.
September 22, 1966

W. Schuur,
Geophysicist.

TABLE OF CONTENTS

		Page
	SUMMARY	(i)
I.	INTRODUCTION	1
II.	SURVEY PERSONNEL AND EQUIPMENT	3
III.	GEOLOGY	4
IV.	DISCUSSION OF RESULTS	4
V.	CONCLUSIONS AND RECOMMENDATIONS	7

APPENDIX I - Time Distribution

APPENDIX II - "A Decade of Development in Overvoltage Surveying".

by: Robert W. Baldwin.

Accompanying this Report:-

- Profile Presentation of apparent chargeability and apparent resistivity (2 sheets)
  #1, #2
- Chargeability contour plan (a = 200 feet)
  #3
  Scale 1" = 200 feet.

SUMMARY

During the period August 4, 1966 till August 17, 1966, Canadian Aero Mineral Surveys Limited conducted an induced polarization survey for Afton Mines Limited on their property near Iron Mask Lake, Kamloops, B.C.

The survey outlined four anomalous zones, of which two are recommended for immediate follow up. Four drill hole locations are given to check the source of these anomalies. The third anomalous zone must probably be explained as caused by magnetite and so must the moderate anomaly on line 156 East.

REPORT ON
INDUCED POLARIZATION SURVEY
OF THE PROPERTY NEAR
IRON MASK LAKE, KAMLOOPS, B.C.
FOR
AFTON MINES LTD.

I. INTRODUCTION

During the period August 5, 1966 to August 17, 1966, an induced polarization survey was carried out by Canadian Aero Mineral Surveys Limited in the area near Iron Mask Lake, Kamloops, B.C. on behalf of Afton Mines Limited.

A total of approximately 94,000 feet was covered during the survey, including some 10,000 feet detailing over anomalous areas.

High sensitivity D.C. pulse-type equipment was used for the survey. A current on-time of 1.5 seconds and a measuring time of 0.5 seconds were employed. Attached to this report is a copy of a paper by Robert W. Baldwin entitled "A Decade of Development in Overvoltage Surveying". This paper gives a good description of the basic theory of induced polarization, the phenomena involved, measuring techniques and the interpretation methods.

At each observation point both primary voltages (steady state voltages) and secondary voltages (polarization voltages) are measured. The primary voltages are converted by formula to apparent resistivities expressed in units of ohm meters. The transient voltages are measured by integration, in units of millivolt seconds and divided by the corresponding primary voltages to obtain the apparent chargeabilities. The chargeability expressed in units of millivolt seconds per volt, or milliseconds, is the IP characteristic of that particular region.

Secondary voltages arise from the discharge of overvoltages which occur on interfaces where there is a transition from electronic to ionic conduction. This is the reason why the IP method of geophysical prospecting is particularly well suited for the detection of disseminated metallic sulphides. Certain other rock building minerals like graphite, serpentines and magnetite can give rise to overvoltage effects as well. At present, there is no way in which these latter effects can be distinguished from the effects caused by metallic sulphides using the IP data alone.

Throughout the survey a standard equispaced three-electrode array was used. With this electrode configuration one current electrode is placed at "infinity" (a distance more than 5 times the largest survey electrode spacing from any survey point) while the second current electrode and the two potential electrodes are equally spaced in line along the survey traverses.

An electrode spacing of 200 feet was employed and readings were taken at 200 foot intervals along the lines. In areas of interest this interval was decreased to 100 feet and in certain anomalous areas readings were taken using an electrode spacing of 100 feet and 50 feet as well, to provide additional information with regard to the change of electrical properties with depth.

The results are presented as combined apparent resistivity and apparent chargeability profiles at a scale of 1" = 200 feet. Apparent resistivities are plotted at a logarithmic scale of 2" = 1 cycle (100 - 1000 ohm meters) and apparent chargeabilities are plotted at a scale of 1" = 5 m. seconds. For the sake of clarity of presentation of the profiles, the lines are not spaced to scale.

The IP data obtained with the 200 foot spacing is also presented on a contour map, at a scale of 1" = 200 feet. The contour interval used is 2.0 milliseconds.

II. SURVEY PERSONNEL AND EQUIPMENT

The personnel associated with the IP survey are as follows:

J. Irvine - Geophysicist (Field)
Merritt, B.C.

W. Schuur, - Geophysicist
Ottawa, Ont.

H. Stolz, - Helper
Ottawa, Ont.

W. Tschaikowsky - Helper
Ottawa, Ont.

N. Neale, - Helper
Lower Nicola, B.C.

G. Horne - Helper
Merritt, B.C.

R. Paradela - Draughtsman
Ottawa, Ont.

The equipment used for the survey was a Seigel Mark V-A time domain unit, built by Sharpe Instruments of Canada Limited.

III. GEOLOGY

The geology of the area is described in Geological Survey Memoir [illegible] Canadian Department of Mines and Resources.

The area surveyed is [illegible] the Iron Mask batholith, varying in composition from [illegible] ultrabasic types. Evaporites occur in a large [illegible] as part of the Kamloops group. In the southwestern part of the property the presence of the Nicola group is indicated by the Geologic Map No. [illegible]

In various places in the Iron Mask Batholith are found indications of copper mineralization and in the cases of the Pothook Claim and the Iron Cup Claim, copper mining has been reported. The copper occurrences appear to be related to intrusives of picrite - olivine basalt - which is largely altered into talc. The assumed dip of the picrite is approximately 45° to the south. A deposit of approximately $6x10^6$T of magnetite is said to occur in the area. The magnetite is present as a series of veins of varying thickness, in the Iron Mask Batholith.

IV. DISCUSSION OF RESULTS

The area surveyed can be roughly divided in two parts; a southwestern zone, characterised by overall extremely low resistivities of average 25 ohm meters, and with minimum values as low as 6 ohm meters and a northeastern half with resistivities in the order of 100 ohm meters. The southwestern half corresponds probably with the Kamloops Series which in this case appear to consist at least partly of evaporites. No significant anomalies were detected in this part of the survey area. The northeastern half probably corresponds with the Nicola Series and the Iron Mask Batholith. No distinction between these two formations could be made on the base of the IP data.

The main anomalous feature in this northeastern half is a long, more or less continuous zone of high chargeability readings, which extends from 117 North on line 84 East to 103 North on line 140 East and is still open to the East. The amplitude of the anomalies, however, is considerably less in the eastern part of the zone than in the remaining part. The zone itself appears to be built up by various smaller anomalous areas, situated in echelon along a strike of approximately N 110° E. In a number of cases the presence of two separate bands of anomalous readings is indicated. The northern most band normally corresponds with copper stains on the surface and in one instance previous drilling proved the presence of considerable copper mineralization: the area around 108 North on line 116 East and line 120 East. The southern most bands do not appear to have any surface indications of copper mineralization.

Iron stains at 105 North on line 120 East might indicate that pyrite is the main source of the anomaly.

IP data indicates a definite dip to the South of the source material of both the northern and the southern anomalous bands. A series of drill holes is suggested to investigate the structures to be collared respectively at 117 North on line 100 East, at 119 North on line 92 East and at 101 North on line 116 East. Drilling in these cases should proceed over 250 feet North along the line at an angle of -45°. Since the area around the shaft, corresponding with the northern anomalous band at line 116 East and 120 East has been extensively drilled, no further follow-up is recommended here.

Corresponding to rather intensive copper staining at the east side of the lake on line 88 East is another strong multiple anomalous zone, with maximum readings on line 92 East of over 20 m. seconds on the 100 foot spacing. A rather shallow dip is indicated by the IP data. The best location to collar a drill hole to check the nature of this anomalous zone is at 129+50 N on line 92 East, to be drilled North along the line over 250' at an angle of -45°. This anomalous zone, II, appears to fall in line with a third zone of anomalous readings located around 126 N on line 110 E and possibly extending to 117 N on line 140 E. The anomaly on lines 112 East and 116 East presumably relates to a confirmed occurrence of magnetite. This is stressed moreover by the fact that the moderate anomaly, IV, at 116 North on line 156 East coincides with magnetite showings. In case the drill results on anomalous zone II prove the presence of substantial copper mineralization it is recommended to check anomalous zone III as well, to determine whether magnetite is the sole cause of the high chargeability readings or whether some sulphide mineralization is present as well. The best location for an eventual drill hole appears to be at 125 North on line 116 East, to be drilled over 200' North along the line at an angle of -45°. The moderate chargeability values observed on line 156 East around 116 North together with the presence of several small veins of magnetite appear to discard the possibility of sulphide mineralization as the source material of the anomalies.

V. CONCLUSIONS & RECOMMENDATIONS:

The survey outlined four anomalous zones, two of which are almost certainly caused by magnetite. The main anomaly, I, extending for approximately 5000 feet across the property, corresponds in various locations with copper stains on surface and in one location around 108 North on line 120 East - an appreciable amount of copper sulphides was detected by previous drilling. The other zone is located around a lake in the northwestern part of the property. Here, also, copper stains are present on the surface. The average percentage of sulphides indicated by the IP data is from 2½ - 6% by volume. Initial drilling is recommended on three difference locatior on Zone I and on one location on Zone II:

ZONE I

(1) At 117 North on line 100 East, to be drilled over 250 feet North along the line at an angle of -45°.

(2) At 119 North on line 92 East, to be drilled over 250 feet North along the line at an angle of -45°.

(3) At 101 North on line 116 East, to be drilled over 250 feet North along the line at an angle of -45°.

ZONE II

(4) At 129+50 North on line 92 East, to be drilled North along the line at an angle of -45° over 250 feet.

Since the contour map suggests a relationship between Zone II and Zone III, the presence of sulphides can not be excluded for Zone III and in case of favourable results over anomaly II, a hole should be warranted to check the source of Zone III, which should be collared

(5) At 125 North on line 116 East, to be drilled North along the line at an angle of -45° over 250 feet.

Respectfully submitted,

OTTAWA, Ontario,
September 22, 1966.

W. Schuur,
Geophysicist.

APPENDIX I

The following Canadian Aero Mineral Surveys Limited personnel were necessary to the completion of the IP survey carried out from August 4 to August 17, 1966:

		No. of Man Days
W. Schuur, Geophysicist	(Field)	8
Ottawa, Ontario.	(Office)	3
J. Irvine, Geophysicist	(Field)	3
Merritt, B.C.		
R. Paradela, Draughtsman		3
Ottawa, Ont.		
H. Stolz, Helper		8
Ottawa, Ont.		
W. Tschaikowsky, Helper		8
Ottawa, Ont.		
N. Neale, Helper		3
Lower Nicola, B.C.		
G. Horne, Helper		3
Merritt, B.C.		
	Total	39

OTTAWA, Ontario.
September 22, 1966

W. Schuur,
Geophysicist.

CANADIAN AERO *Mineral Surveys* LIMITED

Mineral Surveys
LTD

A DECADE OF DEVELOPMENT IN OVERVOLTAGE SURVEYING

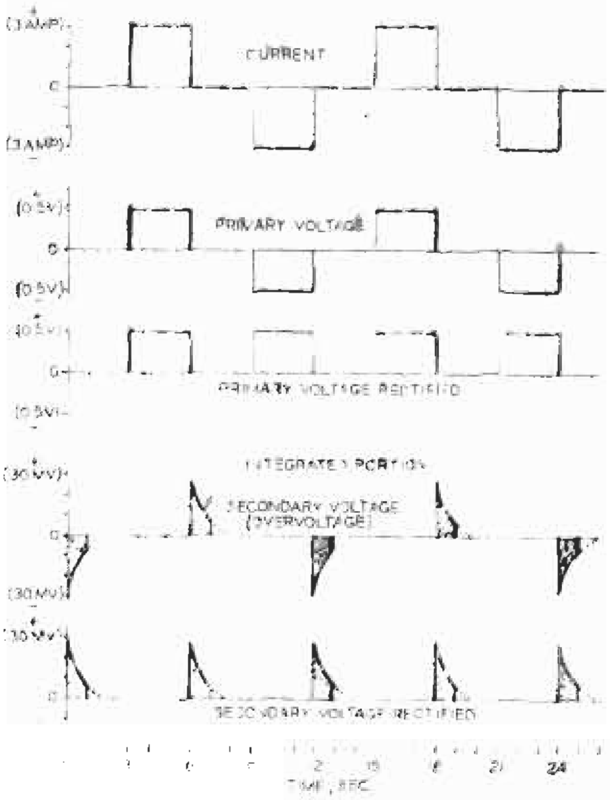
by ROBERT W. BALDWIN

As used in geophysical exploration, the term *overvoltage* applies to secondary voltages set up by a current into the earth which decay when the current is interrupted. These secondary effects may be measured by pick-up electrodes. The term *induced polarization* has often been employed to describe this same phenomenon. In its own operations Newmont Exploration Ltd. commonly uses the word *pulse*.

The basis of this method in prospecting is that metallic particles, sulfides in particular, give a high response, whereas barren rock, with certain exceptions, gives a low response. Overvoltage has been tried in searching for many types of mineral occurrence but has been most successful in outlining the widespread disseminated mineralization associated with porphyry coppers.

History:[1] Newmont Mining Corp. has been interested in overvoltage since 1946, when Radio Frequency Laboratories of Boonton, N. J. drew the company's attention to phenomena observed in the laboratory. At the instigation of A. A. Brant further model studies were undertaken, and the first tests were performed in 1947. Tests at San Manuel, Ariz., in 1948 were very encouraging, clearly demonstrating that the method could be used to distinguish scattered sulfides at depth. H. O. Seigel followed up the San Manuel work with a study to determine the phenomena involved.[2]

Fig. 1—Current and voltage sequences, typical measurement. Overvoltage response to be plotted equals integrated secondary voltage divided by primary voltage



R. W. BALDWIN, Member AIME, is with the Geophysical Department, Newmont Exploration Ltd., Danbury, Conn. TP [illegible]L. Manuscript, June 25, 1958. New York Meeting, February 1958.
AIME Trans., Vol 214, 1959.

Further field experiments took place at Jerome, Ariz., in 1949-1950. Since 1950 this method has been a standard prospecting tool of Newmont Exploration Ltd. Overvoltage surveys have been carried out in the U. S., Canada, Latin America, and Africa. Field equipment has been constantly improved.

Concurrent with field exploration, theoretical and experimental investigations were pursued at Jerome. H. O. Seigel, J. R. Wait, V. Mayper, E. H. Bratrober, and L. S. Collett were notable contributors. Work at the Jerome laboratories included:

1) Study of the phenomena involved, with extensive investigation into the causes of background nonsulfide effects.

2) Study of the possibilities of taking induced polarization measurements with low-frequency alternating current instead of pulsed direct current.

3) Mathematical development of type curves showing the anomalies to be expected from mineralized bodies of various shapes and sizes under varying depths and conditions of cover.

4) Laboratory testing of rock samples, study of the form of overvoltage decay and the a-c response for various types and sizes of mineral particles, and model orebody studies.

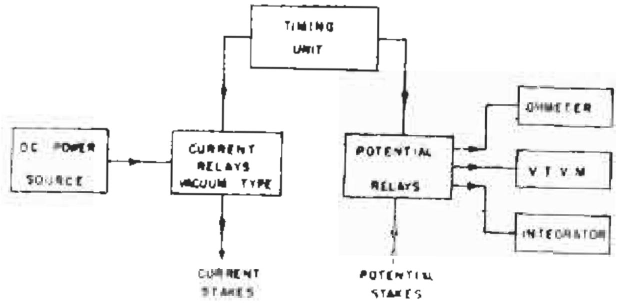


Fig 2—Block diagram of typical field equipment.

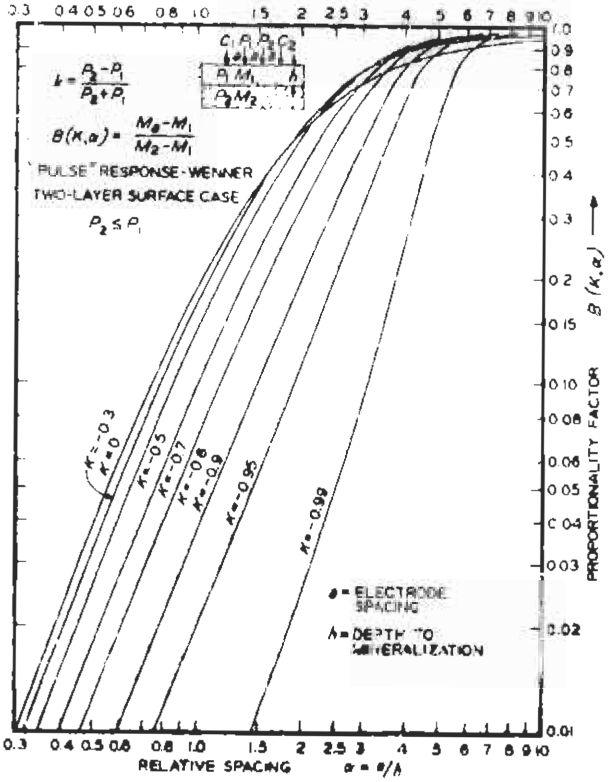


Fig. 3—Typical theoretical overvoltage response curves.

Operational Methods: The overvoltage method requires direct connection to the ground, by means of two current electrodes and two potential electrodes. Field methods are thus similar to those of resistivity surveys. Various electrode arrays have been used: electrode spacings are chosen according to the type of target and expected depth. Spacings as wide as 1500 ft have been regularly employed. In laboratory work also, four direct connections must be made to the specimen or model.

Fig. 1 illustrates, in idealized form, the sequences encountered in a typical d-c overvoltage measurement.[*] While the current is on there is a primary voltage across the potential electrodes which may be measured with a vacuum tube voltmeter—a simple resistivity measurement. On cessation of current (allowing 10 to 15 milliseconds for inductive and capacitive coupling effects to disappear) the decaying secondary voltage or overvoltage appears at the potential electrodes. This decay curve may be presented on an oscilloscope and photographed—the procedure in many laboratory experiments. Field practice is to integrate the decay voltage over an interval following current cessation. Common operating times are 3 sec of current pulse and 1 sec of integrating time. To obtain a reading the integrated secondary voltage is divided by the primary voltage. The units are then millivolt-seconds per volt.

In practice, of course, not just one pulse of current is applied but a succession of pulses as shown, every second pulse being of reversed polarity. Rectifying relays are provided so that the primary and secondary voltages always read positively.

Field Equipment: Fig. 2 is a block diagram of typical field equipment. The heart of the equipment is the timing unit, which controls both current switching and the connections of potential electrodes to the vacuum tube voltmeter for primary voltage and to the integrator for secondary voltage measurement. Two types of timing units have been employed: the first electronic, using multivibrators, and the second mechanical, using a constant-speed motor and cam-operated switches. The integrating device is a General Electric fluxmeter, model 32C248. The d-c power supply has usually consisted of a gasoline-motor a-c generator followed by a high-voltage d-c rectifier unit. The smaller units (order of 1000 to 1500 w) are relatively mobile and have been transported by burros; the larger units (up to 25,000 w) are mounted in heavy-duty trucks.

Most field equipment was designed and constructed in the Jerome laboratories by A.W. Love, K. E. Ruddock, and W. E. Bell

Type Curves: H. O. Seigel has developed mathematical expressions for the overvoltage response to be expected from mineralized bodies of various geometric forms. The analysis is equally applicable if the source of overvoltage effects is not mineralization. Seigel uses an electrodynamic model of overvoltage which considers the effect of resistivity contrasts within the region of measurement on both primary and secondary fields. His basic postulate is that the action of the primary field sets up a volume distribution of current dipoles—all antiparallel to the primary field—whose moment equals the product

[*] The voltage and current values quoted are samples to indicate an order of magnitude.

of the primary current density and a mineralization* factor which is a property of the medium. He then develops a procedure for calculating overvoltage responses from associated resistivity curves by weighting the overvoltage contribution of any medium according to the logarithmic derivative of apparent resistivity with respect to the resistivity of that medium.

Mathematically,

$$M_a = \sum_i M_i \frac{\partial \log \rho_a}{\partial \log \rho_i}$$

where M_i and ρ_i are the *mineralization* factor and apparent resistivity of the ith medium, M_a and ρ_a are the overvoltage response and apparent resistivity at the point of measurement and $\sum_i$ represents a summing of the terms for all media.

Where there are only two media concerned the above formula reduces to

$$\frac{M_a - M_1}{M_2 - M_1} = \frac{\delta \log \rho_a}{\delta \log \rho_2}$$

where the subscripts 1 and 2 refer to media 1 and 2.

An important approximation of overvoltage surveys is the two-layer case. This assumes a horizontal layer of barren material overlying an infinite layer of mineralized material. The overvoltage responses have been derived directly from the well known resistivity two-layer formula. Fig. 3 gives the type curves when the lower layer has the lower resistivity. The abcissa is relative electrode spacing (i.e., in terms of thickness of top layer) and the ordinate, in effect, indicates what proportion of the lower layer mineralization factor should appear in the observed reading. The different curves are for different resistivity contrast conditions. Note that the plotting is logarithmic. Examples of the use of these curves are given in the field results to follow.

Phenomenological Theory:[8] To account for overvoltage effects, J. R. Wait has proposed the following theoretical model:

Each conducting particle is considered to be coated with a thin dielectric film that poses a block action to current flow into the particle. Thus the action at the interface of each particle is somewhat comparable to that of a lossy condensor, and any ground exhibiting an overvoltage response may be considered to contain in effect a large number of tiny condensers. It should be noted, however, that the dielectric constant of these condensers may vary with frequency.

Wait applied his model theory to predict the form of the decay curve and its variation with particle size. His predictions have been borne out by laboratory experiments. Some typical results are shown in Fig. 4. The tests were performed on a compact mixture of 98 pct andesite and 2 pct pyrite particles, plus a weak electrolyte. Different samples contained different sizes of pyrite particles, ranging from 0.25 to 12-mm diam. Duration of current pulse was 1 sec. Primary voltage was the same in all cases. Note that the time scale is logarithmic. It will be observed that decay is more rapid with the smaller sulfide particles. It can also be noted that at any time following the cessation of current there is an optimum particle size for which the decay voltage is maximum.

A-C Overvoltage Methods:[9] As is perhaps suggested by the condenser analogy mentioned above,

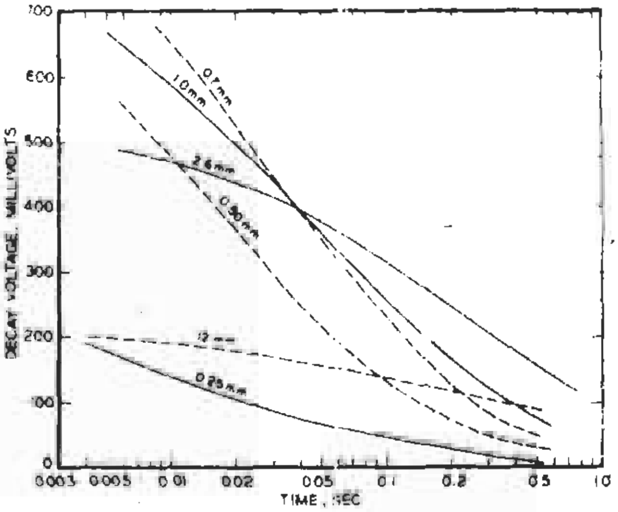


Fig. 4—Observed decay voltage e(t) as a function of time. For V = 15 volts, $v = 0.02$ and $\sigma = 5x10^{-3}$ mhos/m. This graph and Fig. 5 are examples of extensive overvoltage experiments at Newmont's laboratories in Jerome, Ariz. Fig. 4 illustrates work in transient domain, Fig. 5 work in frequency domian.

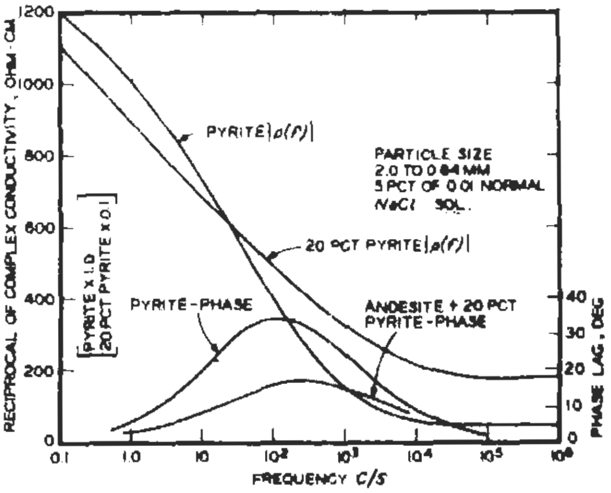


Fig. 5—Variation of complex conductivity with frequency. From experiments at Newmont laboratories.

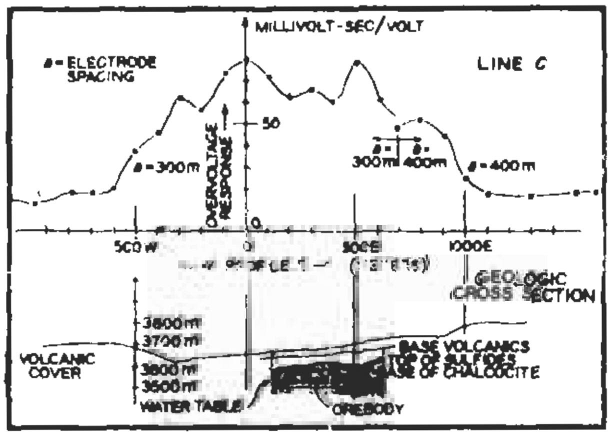


Fig. 6—Overvoltage profile, north end, Quellaveco.

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* The term *mineralization* is understood to include other sources of overvoltage effects.

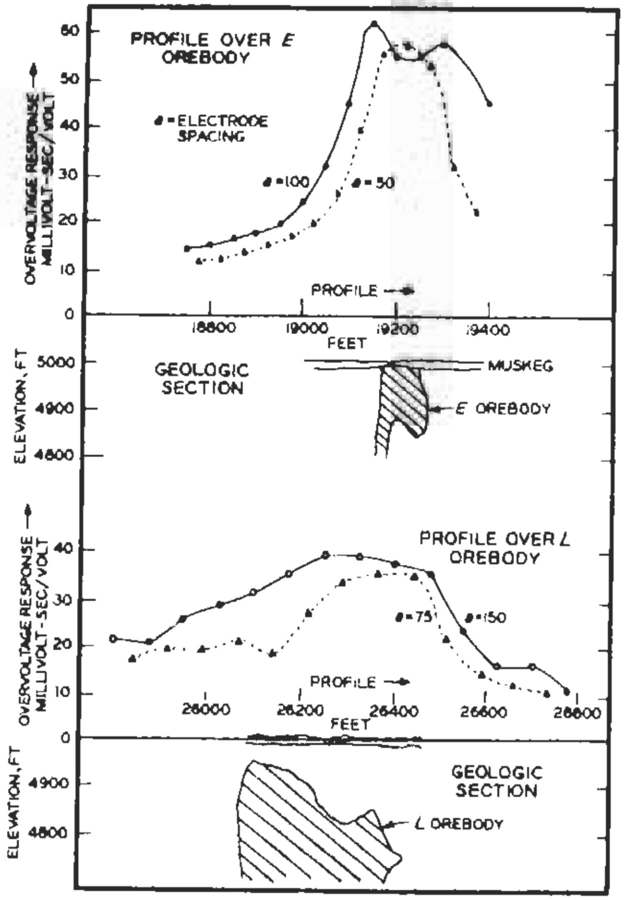

Fig. 7—Overvoltage profiles at Lynn Lake, Manitoba.

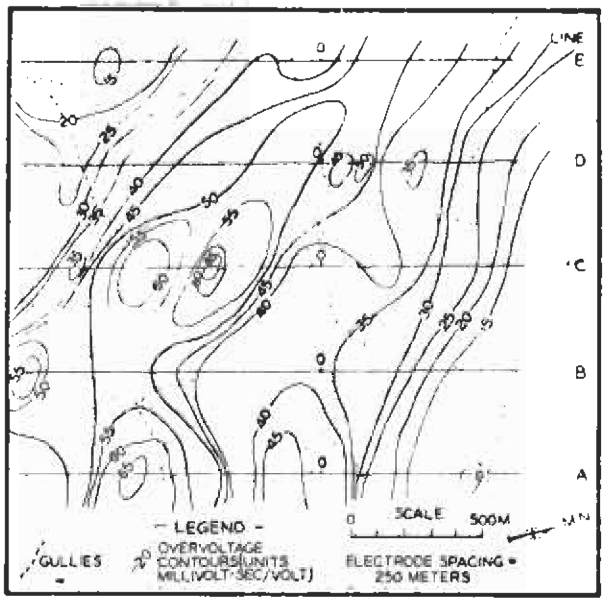

Fig. 8—Copper prospect, Peru. Overvoltage contours here directly outline distribution of sulfides.

the overvoltage phenomena may be measured in the frequency domain instead of in the transient domain, that is, by applying alternating current instead of pulsed direct current. The earth in general has a complex impedance in which the d-c resistivity is a pure resistive component and the overvoltage contributes a somewhat complicated combination of capacitance and resistance. The complex impedance and the phase angle vary with frequency. This variation is especially pronounced in the case of sulfides.

Results of some complex impedance measurements in the laboratory are shown in Fig. 5. Complex impedance and phase angle for pyrite and for pyrite in andesite particles are plotted against log frequency. The maximum slope of the impedance curve occurs at that frequency at which phase angle is a maximum. In comparison, impedance vs frequency curves for barren rock material (over the frequency range up to the order of several hundred cycles) are almost flat and the phase angle remains low.

It should be noted that a-c overvoltage measurements should be made in the low frequency range where electromagnetic propagation effects are negligible. Caution should also be taken to avoid excessive line coupling between the current and potential circuits. Probably several tens of cycles is about the upper frequency limit for operations in the field.

Wait has demonstrated the relation between the response in the frequency domain and that in the transient domain. From experimentally observed frequency response data he derived the overvoltage decay curve to be expected following a pulse of direct current. The agreement with the experimentally observed decay curve was excellent.

Field Results:[7] To date pulsed d-c methods have been used in field exploration. The technique of measurement is described above under Operational Methods and Field Equipment.

To repeat, the basis of the overvoltage method as a prospecting device is that metallic particles, especially sulfides, give a high response, whereas barren rock, with certain exceptions, gives a low response.

In the earlier days it was not realized that barren rock could display a considerable range of response, and minor anomalies of less than 50 pct of background were deemed evidence of sulfides. At Jerome, Ariz., anomalies of this order were found to be caused by certain portions of the Pre-Cambrian basement beneath the Palaeozoic cover. At the present time overvoltage readings of two to three times background are usually necessary to excite interest. Even then it must be recognized that some anomalies may have causes other than sulfides.

In overvoltage surveys results fall into four classes:

1) No significant anomalies.
2) Anomalies due to economic sulfides.
3) Anomalies due to noneconomic sulfides.
4) Anomalies due to nonsulfides.

Groups 2 and 3 above may both be considered geophysical successes if not exploration successes. The ratio of noneconomic to economic mineralization disclosed is certainly no worse than for other geophysical methods. The chief villain has been disseminated pyrite. Many porphyry copper deposits have a surrounding halo of disseminated pyrite, and the zone of maximum sulfides is not necessarily the zone of maximum copper.

While there have been a few striking examples of nonsulfide anomalies, most major anomalies have been explained by sulfides. For example, in almost four years of work in Peru, only one recommended

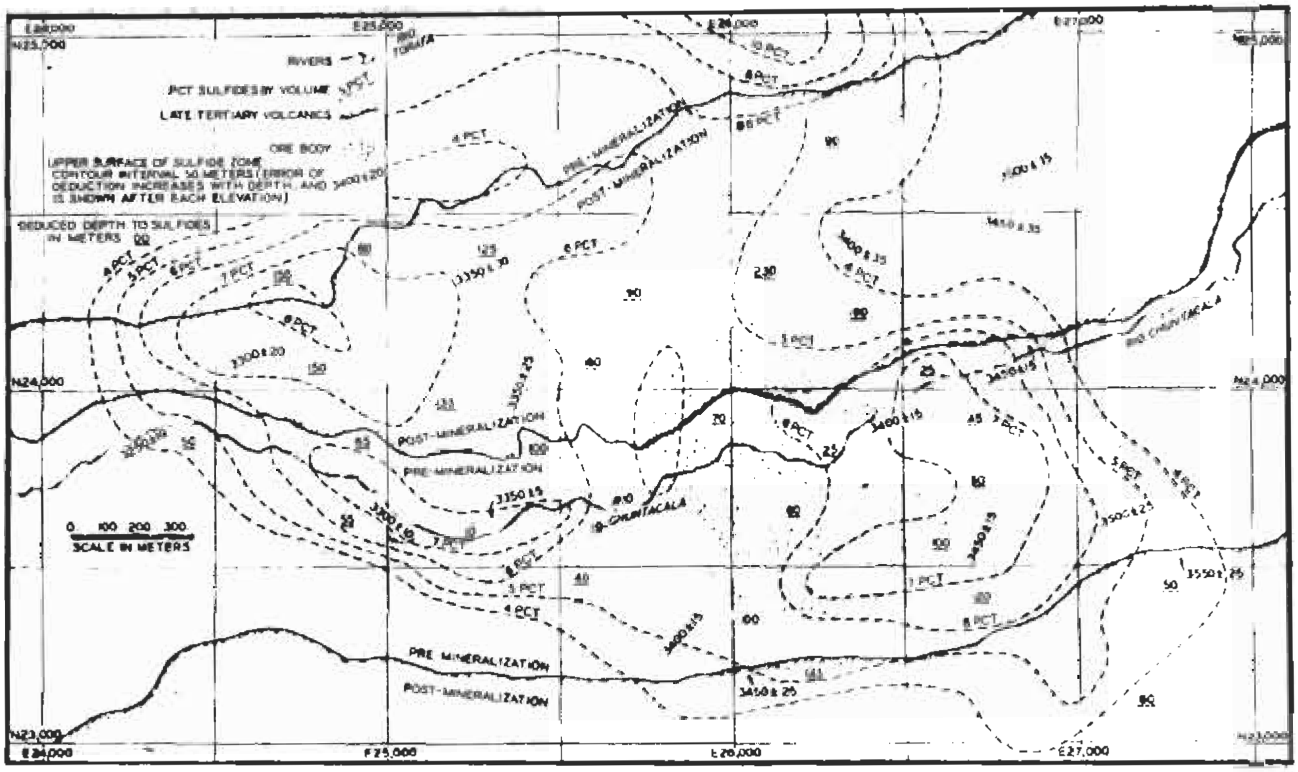

Fig. 11—The sulfide distribution at Cuajone, Peru, as deduced from the overvoltage data. Note the great variation in depth to the top of the sulfides. The mineralization that is outside the orebody consists mostly of pyrite.

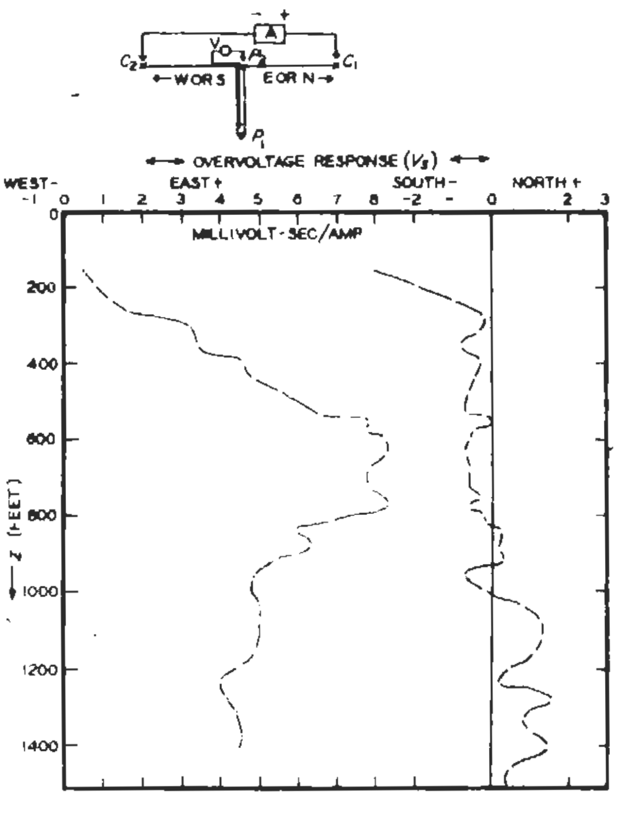

Fig. 12—Nababeep West, South Africa, borehole WP 12. The direction of mineralization from a drillhole is indicated here by the overvoltage azimuth survey.

An expander across the south end of the orebody at Cuajone, Peru (Fig. 10) gives depth to sulfides as 100 meters. Depth actually is about 90 meters.

With the aid of readings on more than one electrode spacing over a large area, it is possible to obtain mineralization factors and depths at a great number of points and then to contour this deduced data. At Cuajone two electrode spacings, one twice the other, were used on every line throughout the anomalous area, and additional control was provided by short spacing readings on several lines and by a few formal expanders. Fig. 11 shows a portion of the deduced mineralization and top of sulfide contour map; Fig. 11a, an aerial photograph of the region, illustrates to some extent the type of topography. For mineralization, it was assumed that a mineralization factor of 10 represented 1 pct sulfides by volume.* Depth to sulfides varies from less than 10 meters in the Chuntacala Valley to more than 160 meters where the late Tertiary volcanics cap the pampa or mesa to the north. The Cuajone orebody has now been extensively drilled and a rough outline is shown on the map. The deduced mineralization extends more than a kilometer to the west and more than half a kilometer to the east of the orebody, also (not shown here) far to the northwest. The deduced mineralization is at some points actually higher on the rim than directly over the orebody. The mineralization rim is disseminated pyrite. The drilling has in general verified the deduced mineralization pattern, but only relatively. A recent study of the assays from 35 drillholes has revealed that predicted sulfide content was on the average 1.95 times actual

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* This factor was based on tests made in Arizona.

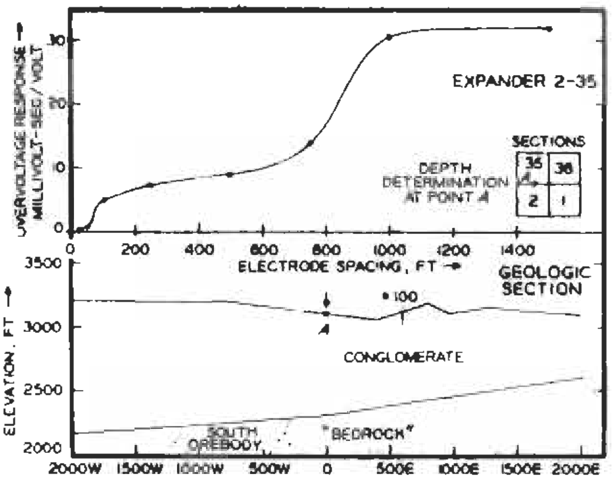

Fig. 9—Detection of deep mineralization is possible at San Manuel by use of large electrode spacings.

drillhole completely failed to find a reasonable quantity of sulfides.

Over a disseminated sulfide deposit the anomalous overvoltage response (i.e., in addition to the rock background) will depend on:

1) The percentage by volume of sulfides.

2) The geometry of the deposit with respect to surface and the electrode array in use. Geometry thus includes size and depth below surface.

3) The resistivity contrast conditions between the sulfide zone and the cover and surroundings.

In any one area the overvoltage response of a mineralized zone has been found to vary more or less directly with the percent of volume of sulfides for moderate percentages of sulfides. It is not safe, however, to project from one area and type of mineral occurrence to another.

A fair number of the examples to follow were obtained over known or later proven orebodies. In attacking any new area, it has been the general policy to test over known mineralization first, where possible, and work out from there, so that the type of anomaly to be sought is known.

Fig. 6 shows an overvoltage profile over the north end of the orebody at Quellaveco, Peru. The ore zone is covered by about 40 meters of postmineral volcanics, and depth to sulfides is from 60 to 100 meters. The orebody is well detected; however, it is to be noted that the anomaly is some 800 meters wider than the orebody, presumably because of a surrounding zone of disseminated pyrite.

Fig. 7 shows the response over an entirely different type of orebody, the *E* and *EL* orebodies at Lynn Lake, Manitoba. The scale of operations is reduced here: to discriminate those relatively narrow bodies, an electrode spacing of about 100 ft was used as opposed to 300 meters at Quellaveco, and readings were taken every 50 ft instead of every 100 meters. The smaller *E* body gives a better response than the *EL*. Some reasons for this are: 1) the *EL* body has massive sulfides, whereas the *E* is more disseminated,* and 2) the overburden is deeper over the *EL*. While both these bodies are adequately detected from their immediate surroundings, varying rock backgrounds reduce the certainty of the method in this area. For instance, not far to the west of the *EL* a quartzite formation gave response in the 50's, higher than that obtained over the *EL* itself Disseminated pyrite possibly contributed to the high quartzite response.

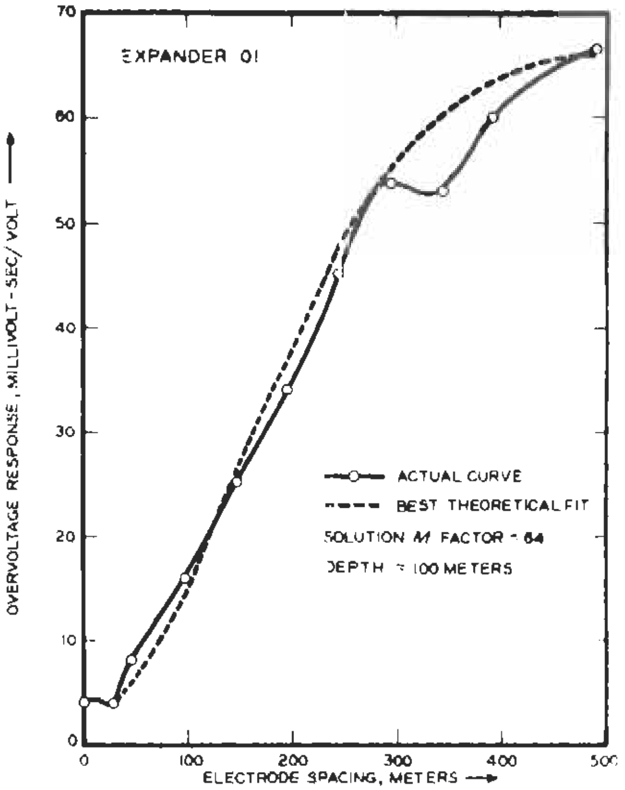

Fig. 10—Mineralization and depth, Cuajone.

A contour map of anomalous overvoltage response provides a good picture of the distribution of sulfide mineralization; in regions where the depth to top of sulfides is less than about a third the electrode spacing and resistivity contrasts are not extreme. An example is given in Fig. 8, which is from a prospect in Peru; the contours here include a background response of about 5. Drilling in the highs provided approximate confirmation of the distribution in a limited portion.

A reading on one electrode spacing only gives no indication of depth of cover. This information can be obtained from expanders. An expander is a series of readings at different electrode spacings taken at one station. The results are then compared with type curves. In a great many cases the simple two-layer approximation is adequate. The derivation of two-layer type curves has been discussed under Type Curves. The investigator solves for depth and for anomalous response or mineralization factor of the underlying zone. The examples below are plotted linearly for greater clarity, but the method of solution requires the field results to be plotted on two-cycle logarithmic paper of the same size as the type curve paper. An expander is entirely analogous to the vertical profile of resistivity surveys.

Fig. 9 shows an expander taken at San Manuel, Ariz., plus a geological section in the region. The surrounding pyrite mineralization presumably renders the two-layer case applicable. This example is particularly interesting in illustrating how such deep mineralization as San Manuel's is detectable.

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*The overvoltage method works best with disseminated sulfides.

Fig. 11a—Air photo of Cuajone site shows steep hillsides, especially bordering the Rio Torata.

sulfide content. If this correction had been known in advance, the probable error of mineralization prediction at any point would have been about 30 pct of the predicted sulfide content, or less than 1 pct sulfides by volume. The probable error of depth prediction at Cuajone was 10 meters.

The overvoltage method has been tried in drillholes. This application, though it has given useful indications, has not had the widespread success that was first expected. One major problem has been correcting for the masking effect of low resistivity fluid in the drillhole, especially when working in very high resistivity Pre-Cambrian formations.

One important sideline to drillhole work is azimuth determinations. Once a significant anomaly is obtained in a drillhole using normal electrode arrays, direction is determined by placing the two current electrodes on surface an equal distance on each side of the collar, lowering one potential electrode down the hole, and measuring the overvoltage response with respect to a reference electrode. A positive response indicates that the source of the anomaly lies in the direction of the negative current electrode and vice versa. Two azimuth runs (north-south and east-west) are necessary to fully establish direction. Results in Nababeep West, South Africa, drillhole No. 12 (Fig. 12), suggest that in the upper part of the hole mineralization lies chiefly west, whereas in the lower part it lies chiefly to the south. These deductions were confirmed in the course of drilling the orebody.

There remain to be mentioned those unfortunate cases where overvoltage anomalies are not caused by sulfides.

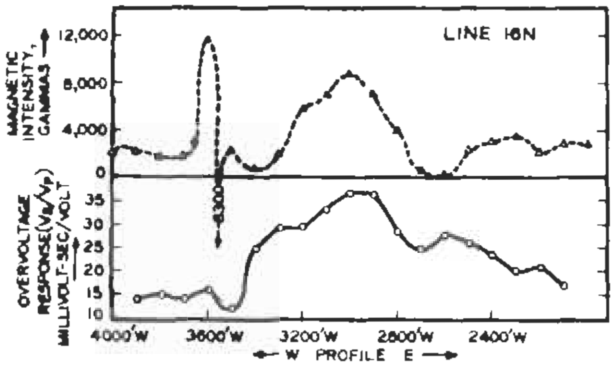

Fig. 13—Magnetic and overvoltage profiles at Engels, Calif. Overvoltage anomaly is attributed to magnetite.

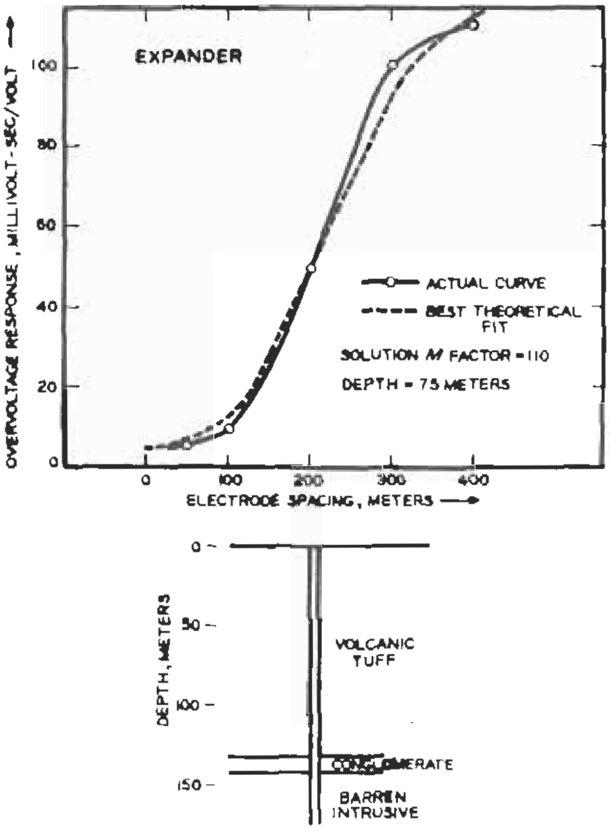

Fig. 14—Unexplained anomaly, Wildcat prospect, Peru.

Magnetite, being a metallic substance, gives an overvoltage response. An example of an anomaly presumably caused by disseminated magnetite comes from Engels, Calif. (Fig. 13). There is good correlation between the overvoltage and magnetic profiles. Of course the presence of an associated magnetic anomaly is not necessarily unfavorable. The two Lynn Lake examples both had excellent magnetic anomalies also.

Response from graphite has been observed in the laboratory, and in Southern Rhodesia a field anomaly was attributed to this mineral. However, graphite has not proved generally troublesome, for the simple reason that most surveys have not been in graphitic areas.

A wildcat anomaly obtained in Peru is still not satisfactorily explained. This occurred in a trough of post-mineral volcanic tuff. The expander taken at the center of the anomaly is shown in Fig. 14. Mineralization was predicted at less than 100 meters, the best solution being about 75 meters. In fact, drilling disclosed no lithological change for nearly twice this depth and the basement was only negligibly mineralized.

Victor Mayper[8] has shown that clay minerals with high ion exchange capacity can give a considerable overvoltage response. Notable extraneous anomalies were obtained in low resistivity phyllites in South West Africa and in certain schists in British Columbia.

The process of taking an overvoltage reading provides a resistivity reading automatically. The resistivity data are of direct use to the overvoltage survey in providing information necessary in depth calculations. A resistivity survey also has many well known applications—such as determining depth of overburden—and in itself is often a guide to mineralization. Porphyry coppers, for example, offer a fairly limited range of resistivity values. Most of the examples given in this article have accompanying resistivity anomalies. It is standard practice always to consider overvoltage results in conjunction with resistivity data.

Despite some unforeseen complications, e.g., the high response from certain nonsulfide material, the overvoltage method has proved its usefulness in detecting and outlining disseminated sulfide mineralization, even at depths as great as 200 meters.

The following firms have kindly granted permission to publish various items of information: Newmont Mining Corp., American Smelting & Refining Co., Cerro de Pasco Corp., San Manuel Copper Corp., Sherritt Gordon Mines Ltd., and O'okiep Copper Co. Ltd.

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* These items are private company papers, but it is hoped that they will soon be presented in a monograph to be published by the Pergamon Press.

Discussion of this article sent (2 copies) to AIME before April 30, 1959, will be published in MINING ENGINEERING.

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Mines and Petroleum Resources
ASSESSMENT REPORT
NO. 879 MAP # 1

LEGEND

ELECTRODE CONFIGURATION.............3 ARRAY
ELECTRODE SPACING...................SEE INDEX

CHARGEABILITY	RESISTIVITY	
o———o	o- - - - -o	a= 50'
x———x	x- - - - -x	a= 100'
⊙———⊙	⊙- - - - -⊙	a= 200'

SCALE

APPARENT CHARGEABILITY.....1"= 5·0 MILLISECONDS
APPARENT RESISTIVITY.........2"/CYCLE LOG. ρ a

SCALE.... 1 INCH = 200'
(NOTE: LINES NOT SPACED TO SCALE)

(APPROX.)

INDUCED POLARIZATION SURVEY

PROFILE PRESENTATION

IRON MASK LAKE AREA, B.C.

FOR

AFTON MINES LDT.

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ASSESSMENT REPORT
NO. 879 MAP # 2

LEGEND

ELECTRODE CONFIGURATION................3 ARRAY
ELECTRODE SPACING....................SEE INDEX

CHARGEABILITY	RESISTIVITY
x———x	x- - - - - - -x a= 100'
•———•	•- - - - - - -• a=200'

SCALE

APPARENT CHARGEABILITY.....1"= 6·0 MILLISECONDS
APPARENT RESISTIVITY.........2"/CYCLE LOG. ρa
SCALE.....1 INCH = 200'
(NOTE: LINES NOT SPACED TO SCALE)

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Department of
Mines and Petroleum Resources
ASSESSMENT REPORT
NO. 879 MAP # 3

LEGEND

ELECTRODE CONFIGURATION.............3 ARRAY
ELECTRODE SPACING.........................200'
CONTOUR INTERVAL..............2·0 MILLISECONDS
INDEX CONTOUR.......................
INTERMEDIATE CONTOUR...............
FAULT INDICATION.....................〰〰

SCALE
1 INCH = 200 FEET

(APPROX)

INDUCED POLARIZATION SURVEY
CHARGEABILITY CONTOUR PLAN
IRON MASK LAKE AREA, B.C.

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