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REPORT ON

GEOPHYSICAL SURVEYS
BARKERVILLE AREA, BRITISH COLUMBIA

ON BEHALF OF

Ron, Park, Roundtop

COAST INTERIOR VENTURES LTD. (N.P.L.)

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93A/14W

by:

James M. Haynes, B.Sc., D.I.C.

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Location: Barkerville, B.C.
Cariboo Mining District
121° 52° NE

Dates: June 6 to June 23, 1973.

SUMMARY

Three separate geochemical anomalies (lead) were investigated by four ground geophysical systems, namely; induced polarization, vertical field magnetics, VLF and vertical loop electromagnetics. Induced Polarization was considered as the primary exploration tool. Anomalies of prime interest were chosen on their chargeability response and/or correlation with one or more of the other systems.

Numberous anomalous chargeability zones were revealed in each area, one in particular (area A) may reflect up to 6% by volume of disseminated sulphides.

Six diamond drill holes, totalling 1900 feet in length are tentatively recommended to examine the anomalies considered to be of prime interest.

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INTRODUCTION

During the period June 6th. to June 23rd., 1973, geophysical surveys were carried out near Barkerville, British Columbia by Scintrex Surveys Limited on behalf of Coast Interior Ventures Ltd. (N.P.L.). These surveys included Induced Polarization, vertical field magnetics, VLF electromagnetics, and vertical loop electromagnetics. The survey crew was under the direction of Mr. Tony Guernier.

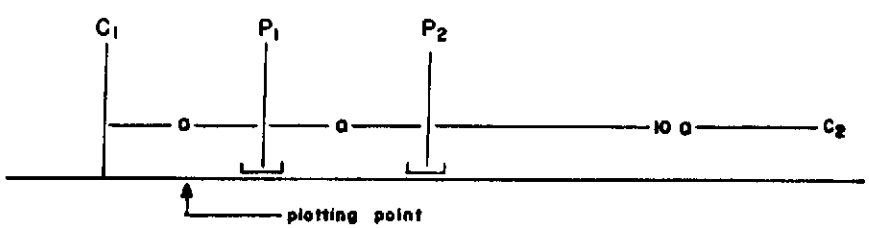
The survey property is located in the Cariboo Mining District near Barkerville as shown in Figure 1. Access to the property is by dirt road out of Barkerville. The purpose of the survey was to examine three geochemical anomalies for sulphide mineralization particularly lead sulphides.

METHOD & INSTRUMENTATION

Induced Polarization

A Scintrex Mark VII 2.5 Kw time-domain induced polarization unit was used on the present survey. This unit has a current "on" time of 2.0 seconds and a current "off" (potential measuring time) of 2.0 seconds. The polarization/transient voltages are integrated between the .45 to 1.1 second part of the "off" cycle and normalized to the "on" cycle voltage at the receiver. The resulting chargeability, in milliseconds, is a measure of the induced polarization effect. The resistivity, in ohmmeters, of the rocks in the measurement zone is computed from the formula R=CVp/I where Vp="on" cycle voltage at the receiver, I=current output from the transmitter; C=a constant depending on the array geometry.

For the present survey the Three Electrode array was employed. The array is shown schematically below in Figure 2.



Potential or "a" spacings of 100 and 200 feet were utilized throughout. Readings were taken at intervals of 100 feet.

Magnetics

Measurement of the vertical component of the earth's magnetic field was made with a Scintrex MF-2 fluxgate magnetometer, giving a reading accuracy better than 5 gammas. Appropriate corrections for diurnal variations were made by checking back at regular intervals to established base stations. Measurements were taken every 100 feet except in areas with very high magnetic relief where the observation interval was shortened to 50 ft.

VLF-EM Scopas

The Scintrex SE-80 VLF receiver employs as a source the field of VLF transmitters in the 15-25 K Hz band. For this particular survey, station NLK, Jim Creek, Washington, U.S.A. was used. A more complete description is included in Appendix S.

SE-300 Vertical Loop EM

The Scintrex SE-300 EM unit was used for the vertical loop EM section of the present survey. It consists of two identical "transceiver" units which can operate at 400 cps or 1600 cps. A more complete description of the instrument and its application is contained in Appendix V.

Survey Grids

The survey covered three grids with a total of eight lines. The lines traverse three separate areas labelled A, B and C of anomalous geochemical results, particularly high in lead values.

Area A - lines 12N, 20N and 28N
Area B - lines 36S and 40S
Area C - lines 24S, 28S and 32S.

A total of approximately 4.19 line miles was to be surveyed with each of the geophysical systems mentioned in the section entitled, Method and Instrumentation.

PRESENTATION OF RESULTS

The survey results are presented in profile form on three plates. The plates and scales are listed in Table 1 below:-

TABLE 1

Plate	Geophysical System (s)	Horizontal Scale *	Vertical Scales
Plate 1	Vertical Field Magnetics and Vertical Loop E.M.	1'' = 200'*	Magnetics 1''=200 gammas base at 500 gammas Vertical Loop 1'' = 20^{o}
Plate 2	Induced Polarization	1'' = 200'*	Resistivity - 1.33''=1 log cycle base at 1000 ohmmeters Chargeability 1''=20 milli-seconds
Plate 3	VLF-E.M. (Scopas)	1'' = 200'*	Horizontal Amplitude 1''=50 base = 0 Vertical Component 1''=50% base = 0 Azimuth 1''=20^{o} base = 0 Tilt Angle 1''=20^{o} base =0

*Interline spacing not to scale

DISCUSSION OF RESULTS

The discussion of results is based entirely on the geophysical data. No geological information was available to the authors.

Each area is described separately. The induced polarization results are of prime interest and the magnetic and E.M. results are used as an aid in defining and classifying induced polarization anomalies.

Area A

The induced polarization and resistivities results are presented on Plate 2. Background resistivities average below 1000 ohmmeters, reaching as low as 1.4 ohmmeters at station 33+50E on line 28N. Background chargeabilities average between 5 to 10 milliseconds, with peak amplitudes as high as 60 milliseconds on line 28N , station 29+50E.

Three anomalous zones are noted on line 28N. The peak amplitudes are listed below:-*

14.75 milliseconds, station; 12+50E (a=100')
16.0 milliseconds , station; 19+50E (a=100')
60.0 milliseconds , station; 29+50E (a=100')

One anomalous zone is noted on line 20N at station 10+50E and reaches a peak of 22 Milliseconds for the a=100' spacing.

The above 60 millisecond response could be caused by up to 6% by volume of disseminated metallically conducting mineralization very near surface at station 29+50E on line 28N, and 2% by volume possibly within 50' of the surface for the three lower amplitude anomalies. The high amplitudes between 25E and 32E on line 28N are typical of the kind of response expected from pyritic and/or carbonaceous mineralization. A weak vertical loop distortion is shown on the profiles, lies just to the east of the chargeability peak and is associated with the lowest resistivity values. The strongest chargeabilities (60 milliseconds) however, are bordering the lowest resistivities and not coincident. Caution is advised in assessing the anomalous chargeabilities for its potential for economic sulphides.

The VLF and vertical loop results over the three lines are inconclusive. Weak electromagnetic conductor axis are marked on the profiles (plates 1 and 3). However, no correlation with the induced polarization seems apparent.

The magnetic profiles over the three lines show very little significant relief with background values averaging about 500 gammas. There is no evident correlation between the magnetic and the induced polarization results.

Area B

Background resistivities and chargeabilities average between 1500 to 1800 ohmmeters and 3-7 milliseconds respectively. Four anomalous chargeability zones are observed, with selected peak amplitudes at the following locations:-*

1. 20.0 milliseconds at L-36S; 16+50E (a=100')
2. 29.2 milliseconds at L-36S; 20+50E (a=100')
   21.8 milliseconds at L-36S; 23+60E (a=100')
3. 20.0 milliseconds at L-40S; 12+00E (a=100')
   27.0 milliseconds at L-40S; 13+50E (a=100')
4. 21.8 milliseconds at L-40S; 22+50E (a=100')

* The above zones are shown on plate 2 by a shaded bar.

The above induced polarization responses could be caused by up to 2-3% by volume of disseminated metallically conducting mineralization coming to within 50' of the ground surface in the vicinity of the chargeability peaks.

The high amplitudes and width of the anomalies on L-36S and 40S between station 19+00E and 26+00E is typical of the kind of response expected from disseminated mineralization (eg. sulphides, mainly pyrite, galena and carbonateous material).

The VLF and vertical loop E.M. results have not revealed any highly conductive zones. Two moderately low conducting axis have been revealed by the vertical loop results centered on line 36S station 13+50E and line 40S station 15+00E. A doubtful VLF conductor has been revealed on line 40S station 10+00E. However, the close association of these conductive zones with the induced polarization anomalies may put some significance to this weak-questionable conductor. The association on line 40S with the IP peaks located between the E.M. conductors at 10+00E to 15+00E. makes this zone therefore of interest.

Background values average 500 gammas for the magnetic results over area B. One anomalous peak 400 gammas above background, was indicated by the results on line 40S station 7+00E. This zone does not coincide with the induced polarization anomalies.

Area C

Background resistivities from the baseline to about station 14+00E on all three lines average about 1000 ohmmeters. Resistivities to the east however, are extremely erratic and average well below 1000 ohmmeters.

The chargeabilities indicating a background around 5 milliseconds show broad anomalous zones with high amplitude peaks superimposed. Five anomalous zones have been indicated on plate 2 by shaded bands.

The peak amplitudes average 30-40 milliseconds. This type of broad anomalous response is typical of the kind expected from pyritic and/or carbonaceous mineralization. However, the geochemical values particularly in Pb increase the possibility of a combination of galena and pyrite.

The VLF and vertical loop E.M. results have both indicated zones of strong E.M. distortion. The conductor axes are presented on the VLF and vertical loop results plates 3 and 1 respectively. The zone of E.M. distortion seems to correlate more closely with the steep gradients of the resistivity results, rather than correlating with the chargeability peaks.

The E.M. Distortions and the resistivities in this zone may be reflecting primarily geological contacts. This hypothesis is supported at present by the fact that no anomalous chargeability peaks are present on line 32S, where as the electromagnetic (VLF) distortions are still coincident with the steep resistivity gradients.

The magnetic profiles on the three lines in area C have revealed small magnetic anomalies on lines 24S and 28S stations 28+50E.

It is now suggested that at least four geological units are reflected by the geophysical results over the three lines. The geophysical parameters and locations of these zones are listed in Table 2.

It is suggested that zone 2 may be similar to zone 1 in geology but contains a greater percentage of chargeable mineralization. As interpreted from the geophysical results zone 2 and 3 show totally different characteristics as illustrated by the resistivity profiles. Zone 4 shows higher magnetic values, and for this reason is interpreted as being a separate geological unit.

It is suggested that zones 2,3 and 4 be investigated in order to distinguish the sources of the induced polarization and electromagnetic anomalies.

CONCLUSIONS AND RECOMMENDATIONS

The interpretation of and recommendations for the ground geophysical surveys over three separate grids in the Barkerville area, B.C. have been based on geophysical results alone. No geological information was available at the time of writing this report.

Area A

The induced polarization results, electromagnetic (VLF and vertical loop) and magnetic results were completed over three lines. Four anomalous induced polarization zones were noted, with two being of particular interest. These are listed below:-

1. line 28N, Station 29+50E
2. line 20N, Station 10+50E

The IP responses could be caused by up to 6% by volume of disseminated metallically conducting mineralization coming very near surface on line 28N and within 50' of surface on line 20N.

The electromagnetic results do not reveal any strong conductive zones suggesting a disseminated rather than a massive nature. Three weak

TABLE 2

Zone	Approx. Location	IP	ρ_a	Anomalous E.M.	Anomalous Magnetics	Remarks
1	0+00 - 4+00E	5-10 msec	>1000 ohmmeters	none	none	IP steady and smooth
2	4+00E - 14+00E	30-40 msec	500-800 ohmmeters	none	none	IP reflects 2-3% by volume chargeable material
3	14+00E - 28+00E	25-40 msec	erratic as low as 3 ohmmeters	stong E.M. distortion	none	E.M. conductor axes coincident with resistivity gradients
4	28+00E - end of lines	20-30 msec.	10 ohmmeters	strong E.M. distortion	>100 gammas above back-ground	

vertical loop distortions and one VLF distortion have been interpreted. There is no close association between the induced polarization results and the electromagnetic and magnetic results.

It is recommended to test the two zones of interest with the following diamond drilling:

DDH#1 Collar on line 28N station 28+70E , drill grid east at 50^{o} for a distance of 400 feet.

DDH#2 Collar on line 20N station 12+00E , drill grid west at 50^{o} for a distance of 400 feet.

Area B

The induced polarization results over two lines have revealed four anomalous zones. The amplitude, width and shape of the responses and the lack of any definite electromagnetic disturbances over these lines suggests that the source is primarily of a disseminated nature (2-3% by volume) consisting of sulphides (most likely pyrite and galena) and possibly some carbonaceous material.

One anomaly was revealed by the magnetic profiles ,however it is not coincident with the induced polarization results.

It is recommended to test this area with the following initial drilling program:

DDH#3 Collar on line 40S station 12+50E, drill grid east at 50^{o} for a distance of 300 feet.

Area C

The induced polarization results over three lines have revealed 5 broad anomalous zones (shaded plate 2). The resistivity profiles from the base line to about station 14+00E average around 1000 ohmmeters on all three lines. To the east the resistivity profiles become very erratic, showing sharp gradients (with lows of 3.0 ohmmeters) and may possibly reflect geological contact (s).

Coincident with the very low resistivities is, as is to be expected, a zone of strong electromagnetic distortion as shown by both the VLF and vertical loop results. The conductor axes are coincident with sharp resistivity gradients, and are believed not to be directly coincident with the sources of the induced polarization response.

DOMINION OF CANADA:
PROVINCE OF BRITISH COLUMBIA.
TO WIT:

In the Matter of a geophysical survey on behalf of Coast Interior Ventures Ltd, (N.P.L.)

I, Leslie A. Merrifield for Scintrex Surveys Limited

of #750 - 890 West Pender Street, Vancouver

in the Province of British Columbia, do solemnly declare that an induced polarization survey has been executed on some BON, PARK, BASEMETAL, ROUNDTOP AND RT claims, Barkerville area, British Columbia between June 6th to June 23rd, 1973.

(1)	Wages:			
	T. Guernier	18 days @ $35.00/day	$630.00	
	F. Bourqui	18 days @ $27.50/day	$495.00	
	M. Vallee	18 days @ $27.50/day	$495.00	
	W. Clark	18 days @ $27.50/day	$495.00	
				$2115.00
(2)	Transportation & shipping to the job			$842.67
(3)	Transportation on the job			$252.00
(4)	Food and Living Expenses			$15.23
(5)	Use of geophysical equipment	18 days @ $30.00/day		$540.00
(6)	Paid to Scintrex Surveys Limited to cover geophysicist's supervision, calculating, plotting and fairdrawing data and preparation of final reports			$1945.00
				$5709.90

And I make this solemn declaration conscientiously believing it to be true, and knowing that it is of the same force and effect as if made under oath and by virtue of the "Canada Evidence Act."

Declared before me at the City of Vancouver, in the Province of British Columbia, this 17th day of September, 1973, A.D.

Leslie A. Merrifield

A Commissioner for taking Affidavits for British Columbia or A Notary Public in and for the Province of British Columbia.

SUB-MINING RECORDER

Two small magnetic anomalies are coincident with chargeability peaks at the ends of lines 24 and 28S. This suggests a third change in geology type within the area.

It is recommended to investigate the causitive source of the induced polarization anomalies as an initial follow up program.

The following diamond drill program is suggested:

DDH#4 Collar on line 24S station 24+50E, drill grid east at 50° for a distance of 300 feet.

DDH#5 Collar on line 24S station 28+50E, drill grid east at 50° for a distance of 300 feet.

DDH#6 Collar on line 28S station 13+50E, drill grid east at 50° for a distance of 200 feet.

Additional drilling and/or geophysical coverage would be dependent upon the results of the above programme.

Respectfully submitted,

SCINTREX SURVEYS LIMITED

James M. Haynes

James M. Haynes, B.Sc.,D.I.C.
Geophysicist

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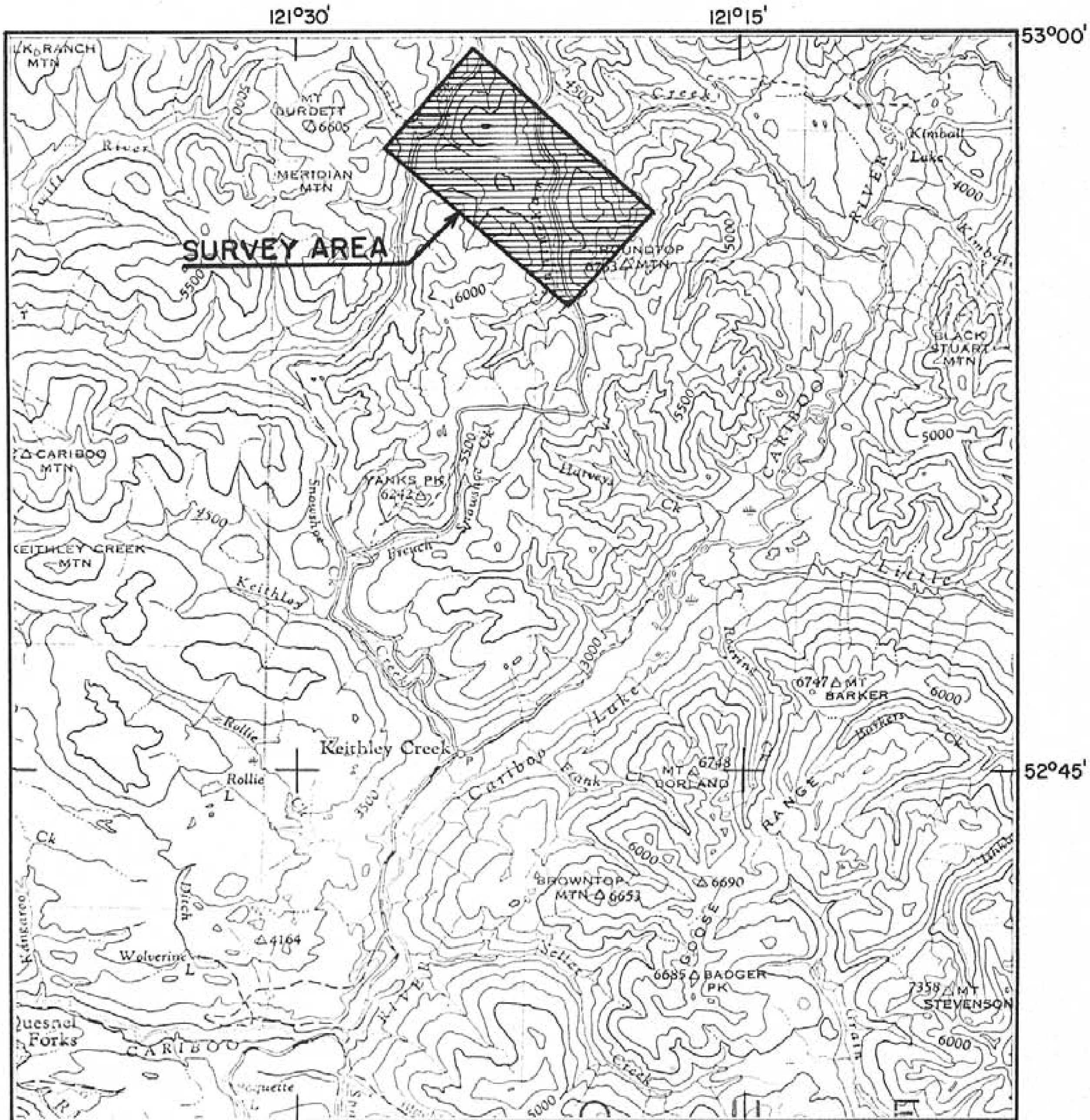
Geophysicist



LOCATION MAP

COAST INTERIOR VENTURES LTD (N.P.L.)

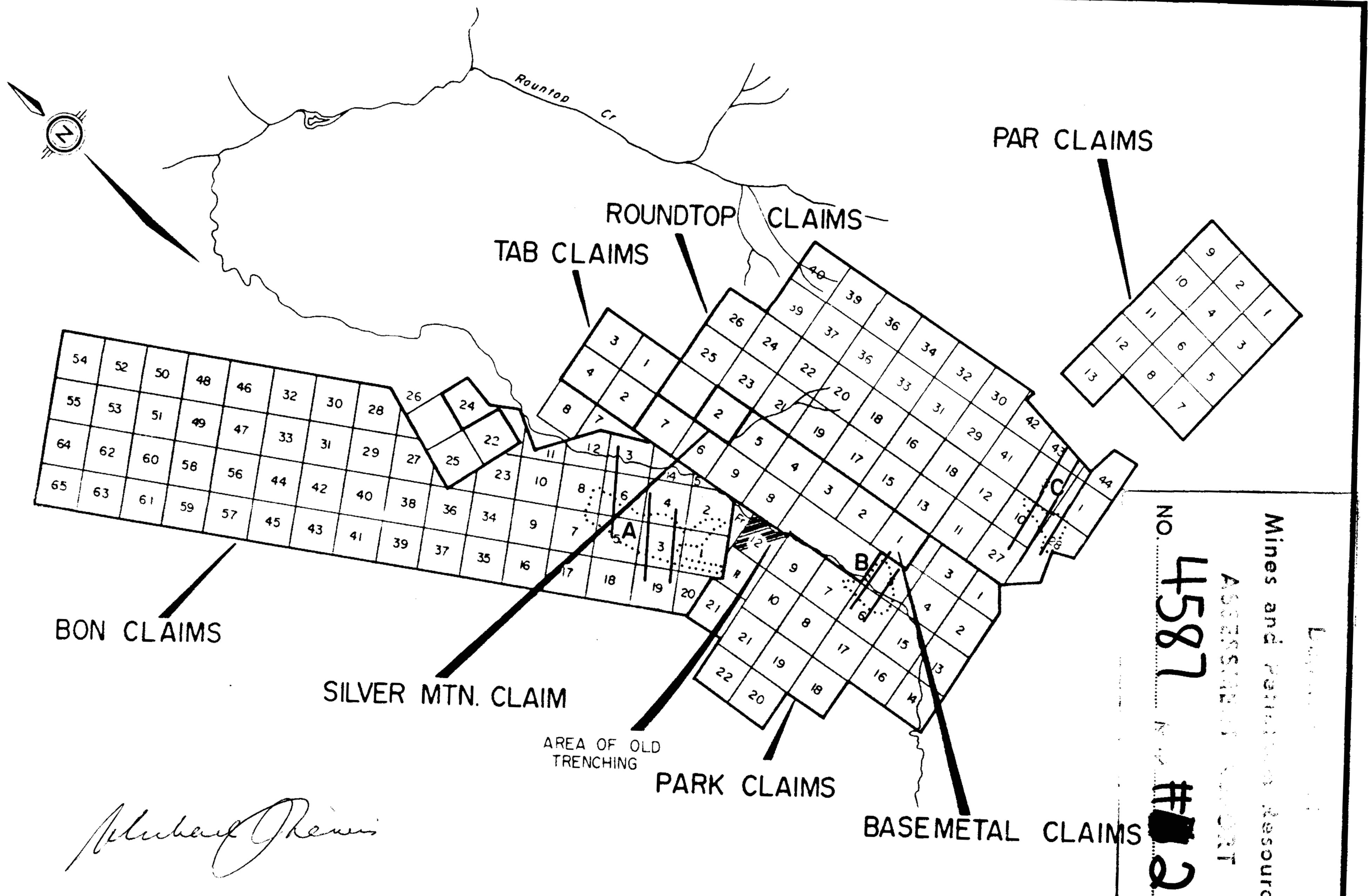
BARKERVILLE AREA, B.C.

GROUND GEOPHYSICAL SURVEY

Scale : 1:250,000

Figure 1

73-908



GEOCHEMICAL ANOMALY

GRID LOCATION

Figure 3

73-908

B. Measurements

It is possible to measure a large number of characteristics of the VLF fields with the SCOPAS SE-80 receiver, including vertical and horizontal amplitudes, tilt angle, azimuth and relative phase angles. In practice, it is usual to measure only one characteristics, diagnostic of the presence of sub-surface conductors and restrict other measurements to anomalous areas. It is the tilt angle measurement (#3 below) which is commonly used for such reconnaissance coverage (in general, marked by "cross-overs" directly over conductor axis). The following additional data are usually of value, azimuth (#1), horizontal amplitude (#4) -- both of which peak directly over the conductor axis, phase angle of the vertical component (#5) and the vertical component (#2).

1. Azimuth: This is the orientation of the VLF horizontal field.

Adjust the moveable compass dial (E) until 90° lies opposite the small white mark on the case. Rotate the coil in the horizontal plane until the minimum signal is obtained.

It is easier to get an accurate orientation from the minimum rather than the maximum VLF signal. The azimuth of the VLF field is 90° from the minimum signal. Since the compass dial has been set to read 90° from the coil axis the apparent compass azimuth may now be read directly (0-180° only). Near a strong conductor axis the VLF field tends to point at right angles to the strike of the body. The azimuth disturbance will be a maximum immediately over the conductor axis.

2. Vertical Component: For fast reconnaissance it is sufficient to only measure the vertical component. Turn the SCOPAS in the horizontal plane until a maximum is obtained. Set the amplifier gain control (F) until the meter reads 100, or if the signal is not strong enough, to whatever value it reaches at maximum gain. Rotate the SCOPAS upward through 90°. The face of the unit is then toward your body. Note the amplitude of the vertical component on the meter. This will read directly in percent of the normal horizontal field (if the meter setting was 100%) or else can be considered as a relative value only. If the field is undisturbed this amplitude will be nearly zero. Conductors are indicated by the presence of a vertical field, usually of amplitude equal to at least 5% of the maximum horizontal field and forming a double peaked curve with the central dip located directly over the conductor axis. If the conductor is close to surface the peak separation may be so close together that the dip may be missed (e.g. Figure 3).

3. Tilt Angle: The most commonly employed reconnaissance technique consists in measuring tilt angles. This is done by tilting the coil from the vertical position (in the vertical plane of the maximum direction) to the position of minimum signal, and measuring the tilt (from the vertical) on the clinometer (H). The SCOPAS axis at the minimum points downwards towards the conductor axis.

Conductors are indicated by a "cross-over" on the dip angle curve and are located directly below the inflection point, usually, but not always, a zero tilt point.

4. Horizontal Amplitude: Over conductor axes, the maximum horizontal amplitude will increase, often over the original deflection obtained under A (4). Note this reading and divide by the original deflection. If the deflection exceeds full scale then note the setting of the gain control pot (F) and decrease this setting until the meter reads 100 once again. Note the new setting. The observed amplitude is then obtained from the ratio of $\frac{\text{old setting}}{\text{new setting}}$ x value obtained under A (4)

The amplitude will be maximum immediately over the conductor axis.

5. Phase Angle of Vertical Component: When the horizontal field amplitude has been adjusted to 100, the value Z of the vertical component is then expressed in percent of the horizontal. From this value and the tilt angle D the phase angle Θ may be calculated.

The phase angle is significant in giving information on the conductivity of a conducting body. For very low conductivity the phase angle is 90° (mainly out-of-phase) and for a very high conductivity the phase angle is 0° (mainly in-phase). Thus, a knowledge of the phase angle gives some indication of the conductivity of the disturbing body. This is helpful, for example, in differentiating overburden from bedrock (sulphide and graphite conductors). The former are generally more poorly conductive than the latter and thus give rise to a larger phase angle. The phase shifts in overburden are, due to the relatively high operating frequency (15-25 kHz), stronger than those obtained employing conventional low frequency moving source EM systems (e.g. vertical loop and horizontal loop). A 50 ft. layer of relatively non-conductive ($\sigma = 10^{-3}$ mhos/m) overburden gives a 10^{o} phase shift employing a 20 kHz transmitting signal. The depth penetrations are strongly reduced as well (see N.R. Paterson, V. Ronka, "Five Years of Surveying with the VLF-EM Method", 1969 SEG Annual Meeting).

The phase angle O can be calculated from:

$$\text{Cos } \Theta = \tfrac{1}{2} \left(\frac{1}{Z} - Z \right) \tan 2D$$

The accompanying chart (Figure 2) shows a plot of Θ (between 0 and 90°) versus Z and D from which Θ can be obtained.

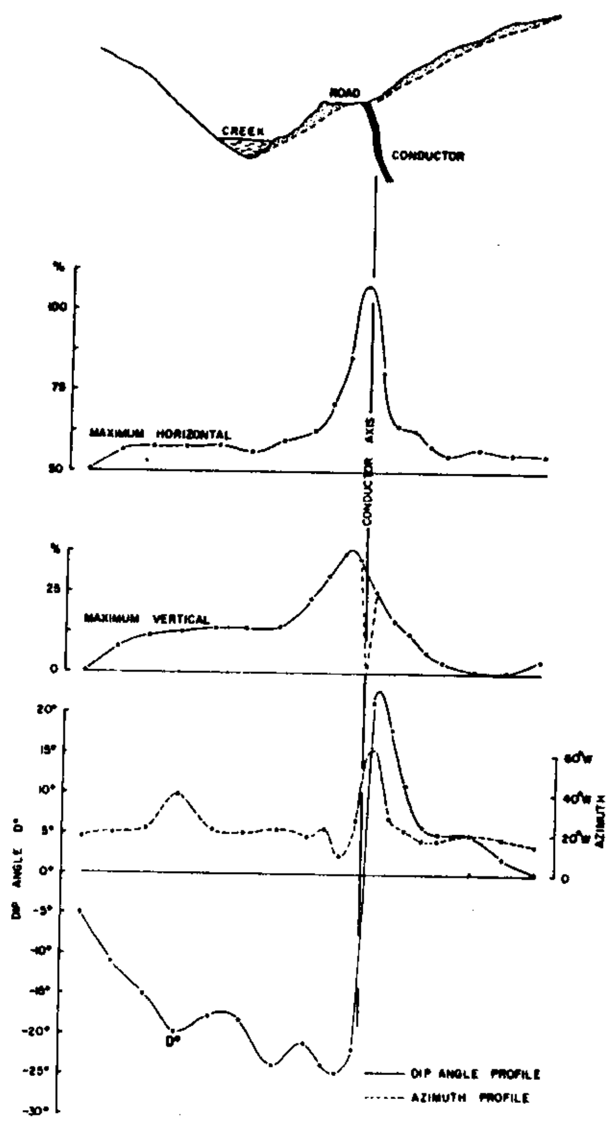
A series of typical results across a known conductor are shown in Figure 3.

5. Strong Field Regions

In some areas a strong field from one transmitter precludes the use of other stations. The strong field may be oriented normally at a small angle to the strike direction of the conductors in the area. The procedure of B(4) above should be employed but, instead of seeking the horizontal maximum the Scopas unit is oriented by the compass in the horizontal direction at right angles to the probable local strike. Over conductor axes this amplitude will increase to a maximum.

Strong conductors will tend to rotate the VLF field to be perpendicular to their strike, thus making this measurement a particularly sensitive one.

SCOPAS SE-80 RECEIVER



APPENDIX V

SE-300 PORTABLE ELECTROMAGNETIC UNIT

INTRODUCTION

The use of electromagnetic induction methods for the detection of subsurface conductors, including base metal sulphide ore bodies, is well established and accepted. The fundamental principal on which all these methods are based is as follows: When a conductor is placed in an audio frequency alternating magnetic field eddy currents are caused to flow within it. These eddy currents set up a secondary field which distorts the original field. All electromagnetic methods detect the presence of a subsurface conductor by measuring the distortion of the transmitted field.

Chief among subsurface geologic conductors are metallic sulphide bodies and graphite zones. The former include the majority of copper, lead, zinc and nickel ore bodies. Other conductors, generally of lesser strength, include electrolyte filled shears and faults, massive magnetite, serpentine and certain types of overburden.

The SE-300 consists of two identical "transceiver" units each embodying a coil which can be used for receiving or transmitting; a battery pack for both functions; 400 c.p.s. and 1600 c.p.s. oscillators for transmitting at these frequencies; high gain amplifier for receiving, which also provide considerable noise suppression, and a set of earphones by which one may judge how the received signal is varying.

All the field techniques which will be discussed below employ the SE-300 as a "null" measuring device. That is, one coil is used as transmitter and is held stationary with a selected orientation, while the other coil, used as a receiver on the same frequency, is rotated about a selected axis until a minimum of signal is heard. This may be done on either or both of the 400 and 1600 c.p.s. frequencies The tilt of the receiver coil out of the plane normally occupied at the null is recorded in terms of amplitude and direction, and is used to interpret the presence, location and other characteristics of subsurface conductors. Essentially, then, the unit measures the tilt or distortion in the direction of the electromagnetic field transmitted.

Field procedures employing three types of null configurations will be described below. These are designated A, B, and C, and are shown on the accompanying sketches. In configuration A the coil being used as transmitter is held with its plane vertical and pointing toward the receiver coil. The receiver coil is held with its plane horizontal and then tilted about the axis joining the two coils until the "null" or minimum signal tilt is observed. This is the configuration which is most recommended for reconnaissance and detail surveys, particularly in the Precambrian Shield, or elsewhere where the geologic conductors are expected to dip at angles of greater than about 30°. This configuration gives a minimum of response from truly flat lying conductors, such as overburden. It is also not effected by elevation differences between the coils, providing that the transmitter coil is properly aligned.

Configuration B has the plane of the transmitter coil vertical but perpendicular to the line joining the two coils. The plane of the receiver coil is rotated out of the horizontal about a horizontal axis perpendicular to the line joining the two coils. This configuration couples better with truly flat lying conductors than configuration A. It also provides a greater effective range since it gives rise to twice the primary field at the same coil separation that A provides. However, it is susceptible to overburden effects and to differences in elevation between the two coils.

In configuration C the plane of the transmitter coil is held horizontal. The plane of the receiveer coil is first held vertical and rotated about a vertical axis to obtain a null. The orientation of the coil axis at this null is recorded. The coil is then turned 90° and rotated out of the vertical about this axis to get a new null. This configuration thus gives rise to two angles, a "strike angle" and a "dip angle". Its advantages lie in the fact that it can be used by a single operator for reconnaissance of an area, without cut lines, providing the transmitter is placed horizontal on the ground, with the press button taped down so that it is continuously transmitting. It is, however susceptible to overburden effects and to effects due to elevation differences between the coils.

With any of these configurations under certain conditions a true sharp null cannot be heard. These conditions include: very low signal, i.e. when operating with a large coil separation; high background noise due to power lines, thunderstorms, etc; or large out-of-phase components due to the effects of relatively poor conductors. Under these conditions, as the receiver coil is tilted, the true signal either drops below a steady noise background, remains steady or effectively disappears. The earphone sound remains the same for some further degrees of tilting, and then the signal eventually reappears for still further tilting. Instead of mentally estimating the null tilt it usually better policy to record each of the tilt angles where the signal is just audibly stronger than the uniform low sound at the null. The difference between these angles, termed the "null width" provides useful information about the reliability of the reading and, in the case of the out-of-phase background, it gives an estimate of the phase angle of the secondary fields.

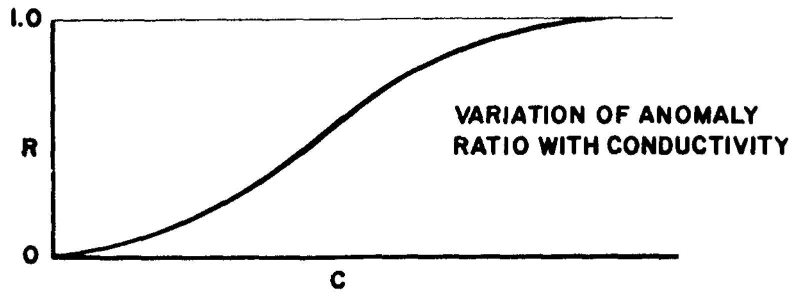
For all these configurations one simple convention of tilt direction applies. If one thinks of the plane of the receiving coil as that of a geologic bed, then the tilt at the null will be in the direction of dip of the corresponding bed. Generally on a survey with lines in one direction only, the tilts are indicated as North or South, and East or West, depending on the line direction.

The relationship between the anomalous tilt angles at 400 c.p.s. and 1600 c.p.s. on a particular conductor is useful in deciding whether a conductor is of high or low conductivity. For a body of a specific size and shape the ratio (R) of

$$\frac{\text{400 c.p.s. anomaly}}{\text{1600 c.p.s. anomaly}}$$

will vary with the conductivity (C) of the body in accordance with a curve of the following form.

FIG.1



For low conductivity the 1600 c.p.s. will give a much larger response than will the 400 c.p.s. For high conductivity the ratio will become very nearly unity.

A similar curve relates the ratio of response for bodies of different sizes but of the same shape and conductivity, so that the large bodies give rise to ratios nearer unity than do small bodies. The spacial distribution of the conductor will, however, help to separate the size effect from the conductivity effect.

Generally speaking, the average base metal sulphide body is of sufficient size and conductivity to give ratios near unity. Exceptions are not difficult to find, however. Strong graphitic zones may likewise give rise to high ratios. Overburden effects, serpentines, shear zones, weaker sulphide and and graphite distributions may all give rise to smaller ratios. There is no way that these various possible conductive sources may be resolved from electrical measurements only.

It is often asked "what is the depth penetration of a particular electromagnetic method?" By "depth penetration" one usually implies the maximum depth of burial at which a measurable indication may be obtained from a subsurface conductor.

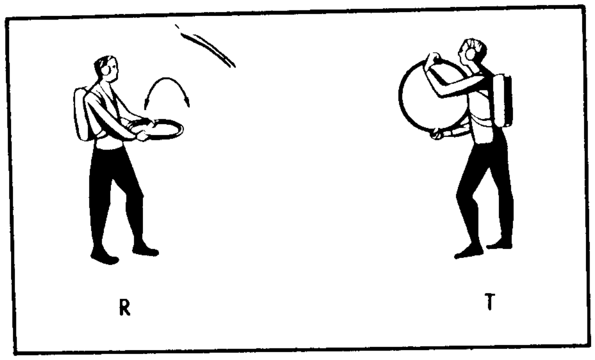
The response from a given body depends on the size, shape, attitude, conductivity and depth of burial of the body, plus the type of coil configuration, technique employed and frequencies used. Other things being equal, the larger the body the greater the depth at which it can be detected, providing that the coil separation can be simultaneously increased in proportion. Under few circumstances can a body be detected at a depth greater than its mean dimensions. Also, to obtain optimum response from a particular body the coil spacing should not be much larger than the strike length of the body. Under optimum conditions a highly conducting, long, steeply dipping tabular body will not be clearly detectible (i.e. will give rise to less than about 3° of tilt) at a depth greater than about 60% of the coil spacing. Thus the coil spacing to be employed should be at least twice the expected maximum depth of overburden and preferably even larger still. The upper limitation is imposed by the maximum coil spacing at which an adequate signal is detected, and also by the strike length of the target to be detected.

For base metal bodies in the Precambrian Shield, an average strike length of about 1000' of heavy sulphide mineralization may be expected, under 100' or less of overburden. A coil spacing of between 400' and 600' is satisfactory for reconnaissance surveys under these conditions, with the latter to be used in areas of heavier than average overburden. In areas of particularly favourable geology, for example near a known base metal deposit, the search for more deeply buried conductors, i.e. for "blind" ore bodies may be warranted. In such areas spacings of as much as 1000' may be employed.

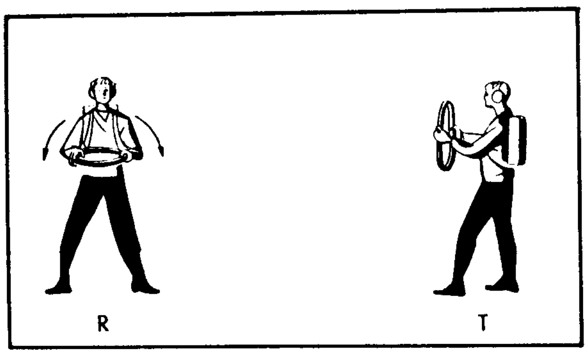
For first quality surveys an accuracy of 1° of tilt is desirable. In the absence of external noise and conductive (out-of-phase) effects this implies that a maximum of about 10° in null width is permissible. Actual field tests on the SE-300 indicates a conservative range of 600' when using the 400 c.p.c. frequency, and 1200' when using the 1600 c.p.s. frequency, within the 10° null width limitation.

Since both operators have the ability to transmit and receive, the SE-300 has a built in communication system. With the axis of each coil pointing towards the other, audible 1600 c.p.s. signals will be detectable at least over 2000' coil separation. With the transmitter modulation switched off, the 1600 c.p.s. channel provides a ready carrier for the Morse code, if desired, or a more limited code adequate to handle routine messages (see page 13 for details.) Providing that both operators are required to transmit O.K. signals before moving on to the next station the necessity of repeating a station will be largely removed.

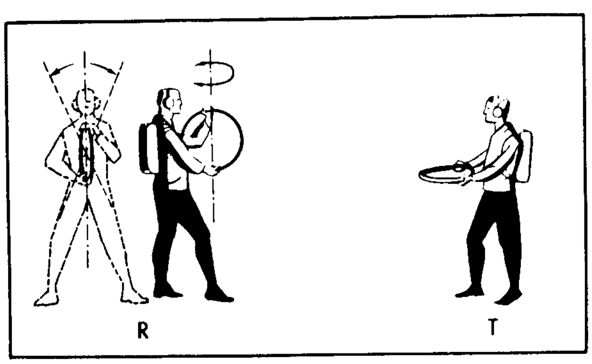
CONFIGURATION A



CONFIGURATION B



CONFIGURATION C



RECONNAISSANCE TECHNIQUES

The purpose of reconnaissance coverage of an area is to detect the presence of all conductors of sufficient size and proximity to the ground surface, with a minimum of time and expense. In all such techniques both operators move progressively from station to station and each coil acts in turn as transmitter and receiver. Both high and low frequency tilt angles may be recorded or, with little loss of information and some gain in time, only the higher frequency need be used througnout until the detail phase of the survey (see below), at which time both frequencies should be employed. As a glance at Fig. 6 b will show, high frequency tilt angles are always at least as large as the low frequency angles, so that no conductor will be missed thereby. Tilt angles are plotted against the appropriate receiver location and there is always some indication of where the corresponding transmitter coil is located.

Traverse lines may be properly cut and picketed, as on a property to be systematically covered, or may be blazed only, using pace and compass control. Stations should be preferably at 100' intervals and not more than 200' intervals since reconnaissance type anomalies tend to be rather sharply peaked.

I. Broadside Method (otherwise called the Parallel Line Method)

In this method the traverse lines are inclined at approximately 90° to the expected strike, although the direction is not critical. The two coils move progressively up two parallel lines separated by at least 400', with both coils being at the same "latitude" relative to the grid. At the proper station interval each coil stops. (Fig 2a)

Configuration A is used. One coil acts as transmitter on the 1600 c.p.s. frequency and the second coil acts as receiver on the same frequency. After a certain time (say 1/2 to one minute) the frequency is changed to 400 c.p.s., if desired, and a new tilt angle is recorded. The roles of transmitter and receiver coils are then reversed so that the first operator records tilt angles. An interchange of O.K. signals completes the station and both coils are moved to the next station. In this fashion both lines are covered adequately by reconnaissance and no detectible conductors will be missed.

Figure 2b shows the type of tilt angle curves which might be encountered near a conductor in a typical survey. The results from a single frequency survey are shown. Additional profiles could be plotted from the second frequency tilt angles, if measured.

BROADSIDE TECHNIQUE TYPICAL SURVEY RESULTS

SINGLE FREQUENCY

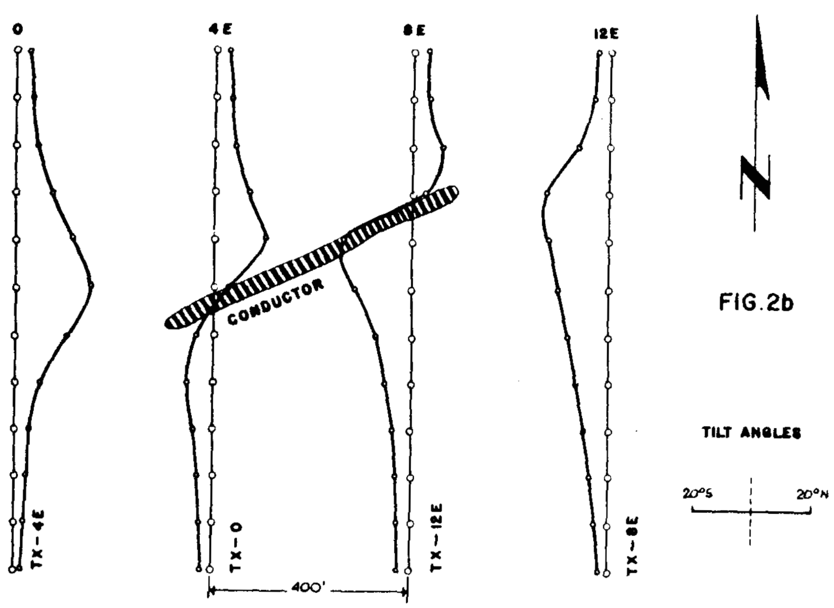
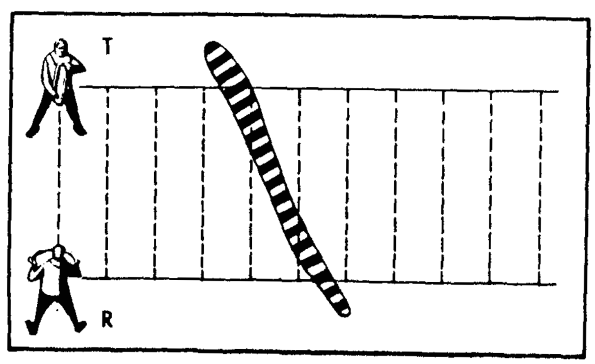


FIG.2b

BROADSIDE METHOD FIG.2a



Note how the transmitter line is indicated for each receiver line.

Some interpretive points to note are as follows: Conductors may be indicated by a crossover (i.e. the coil tilts away from the conductor on both sides, forming an "anticlinal" pattern if one used the dipping bed anology) when crossed by a receiver coil (line 4E and 8E). True crossovers occur most often when the conductor strikes truly at right angles to the line direction. When the conductor strikes at a shallower angle to the picket lines it is usually reflected by unidirectional tilt angles which peak when the transmitter coil is closest to the conductor (lines O and 12E). For this reason one must keep track of the locations of both coils, although the tilt angle is plotted against the receiver coil location. In the case or undirectional tilts, the tilt direction is away from the conductor, which gives an indication of strike direction of the conductor.

2. <u>In-Line Methods</u>

In special circumstances it may be desirable to only traverse a single line. Usually this line is predetermined, i.e. an existing road or trail. Configurations A or B may be employed, with both coils moving in unison along the line with a coil separation of 400' - 600'. (Fig. 3a) Two profiles are obtained for each frequency employed.

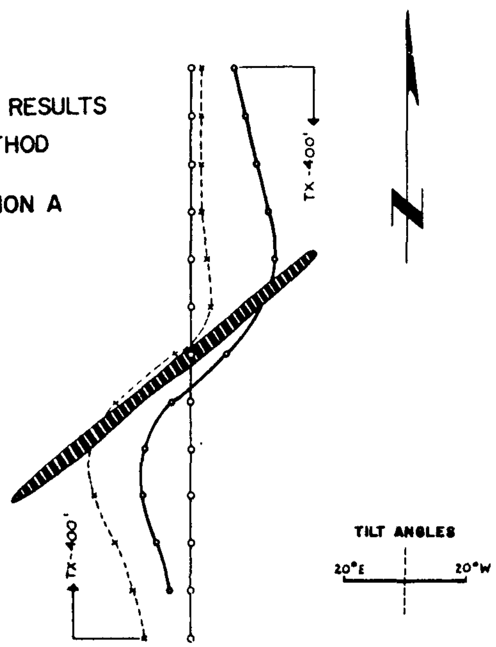
Configuration A is generally recommended over Configuration B for steeply dipping conductors and for reasons mentioned above. It suffers by comparison with the latter, however, in that the single line traverse should not be at right angles to the probable conductor strike and preferably should be about 30° - 45° to the probable strike direction.

Figure 3b shows an example of single frequency profile results crossing a conductor, using a 400' coil spacing.

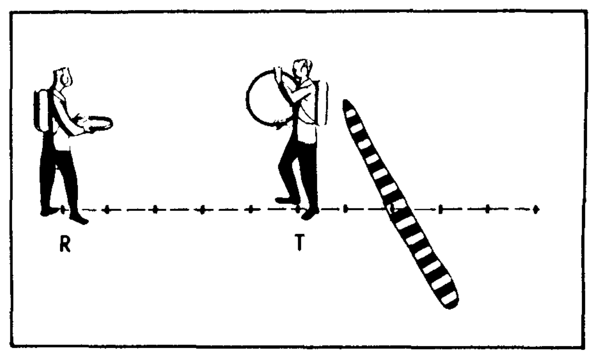
TYPICAL SURVEY RESULTS
IN LINE METHOD

CONFIGURATION A

FIG. 3b



IN LINE METHOD FIG. 3a



As with the broadside Method, conductors may be indicated by crossovers or largely unidirectional tilt angles. The latter are more likely than the former because of the small angle between the traverse line and the conductor strike.

Because each line is essentially covered twice, it can be seen that the In-Line Method is twice as time consuming and costly as the Broadside Method. Moreover, because of the preference for small angles between the regional strike and the line direction, the areal coverage is not as effective.

Configuration B may be employed as an In-Line Method where one or more of the following conditions exist: flat lying conductors are expected; the overburden is not expected to be conductive, and topographic variations are not severe. The traverse line is preferably nearly at right angles to the expected conductor strike. The coil separation will be 400' - 600'. Figure 4 shows a typical pair of single frequency tilt angle curves over a flatly dipping conductor.

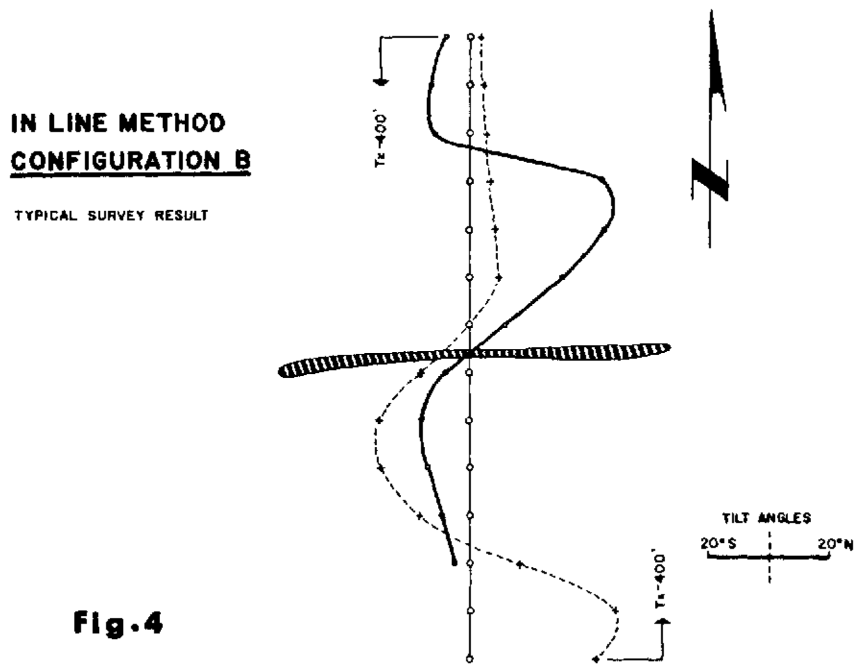


Fig.4

Note how the location of the transmitter is indicated relative to the receiver coil position for each profile. It is seen that very asymmetrical, double crossover curves are generally obtained, one crossover being a normal "anticlinal" sequence and the other a reversed crossover or "syncline" These curves are accordingly somewhat more difficult to interpret than methods 1 or 2 above.

Elevational effects must be watched closely with this configuaration, since an effective tilt angle will be observed which is about 1.5 times the vertical angle between the coils. Elevational tilts will be of equal amplitude and opposite direction when the coils are reversed, so that some corroboration of their presence is possible, particularly in the absence of the subsurface conduction.

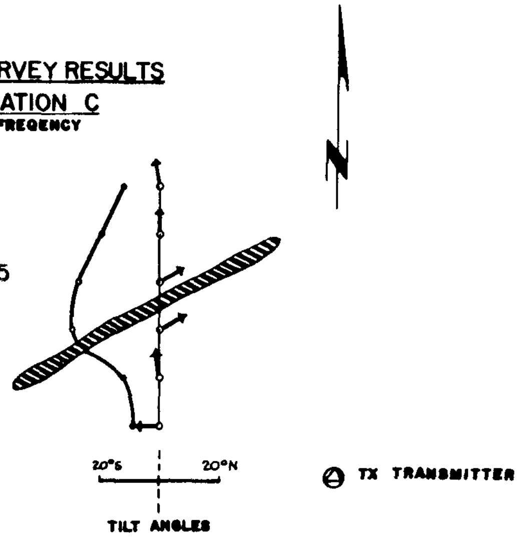
3. One Man Search Pattern

The above reconnaissance methods all assume that two operators are available, one to carry each transceiver. When both coils move systematically through the search area the optimum and most effective reconnaissance coverage is achieved. On rare occassions there may be only a single operator available. A technique suitable for such occassions would be as follows: Configuration C is employed. The transmitter is laid horizontal on the ground with the "on" switch taped down so that it is continuously transmitting, on the high frequency. The second coil is used as high frequency receiver only and is moved to any point within range of the transmitter coil. As indicated in the Introduction, both strike angles and dip angles may be recorded.

Figure 5 shows the results of a typical traverse across a conductor in the vicinity of the configuration C transmitter. The arrows indicate the direction of the strike angle. Note that the angles are measured relative to the vertical plane as reference. The conductor axis is marked by a maximum of tilt angle, not by a crossover.

TYPICAL SURVEY RESULTS
CONFIGURATION C
SINGLE FREQENCY

FIG. 5



This configuration is particularly sensitive to elevational differences between the two coils. The apparent tilt angle due to elevational effects is three times the vertical angle between the coils, for small angles.

DETAIL TECHNIQUE

As indicated above, the results of the reconnaissance survey may be interpreted to give some idea of the presence and location of all the detectible conductors in the survey area. The function of the detail survey is to confirm the conductor presence and pin-point its location with sufficient accuracy to permit drilling, trenching or other investigation. A recommended field technique employs a transmitter coil which is held at one point on the trace of each conductor (for a long conductor) or on strike of each conductor (for a short conductor). The coil configruation A is once again used. (Fig. 6a) The second coil, used as a receiver only, is moved from station to station on all lines within range of the transmitter, in the vicinity of the probable conductor position. At most 500' either side of the conductor axis need be covered. For all but very flatly dipping conductors a crossover will result, marking the conductor location very accurately. On very flatly dipping conductors the crossover location will be shifted somewhat towards the hanging wall side.

Both frequencies should be employed, so that some information can be obtained regarding the conductivity of the conductor.

Figure 6b shows typical two frequency detail survey results over a rather strong conductor due to a massive sulphide body. The strength of the conductor is evident from the fact that the 400 c.p.s. and 1600 c.p.s. tilt angle curves are almost equal in amplitude. Note how the transmitter location is indicated for each traverse and how the different frequency profiles are distinguished.

TYPICAL DETAIL SURVEY RESULTS
MASSIVE SULPHIDE BODY

CONFIGURATION A

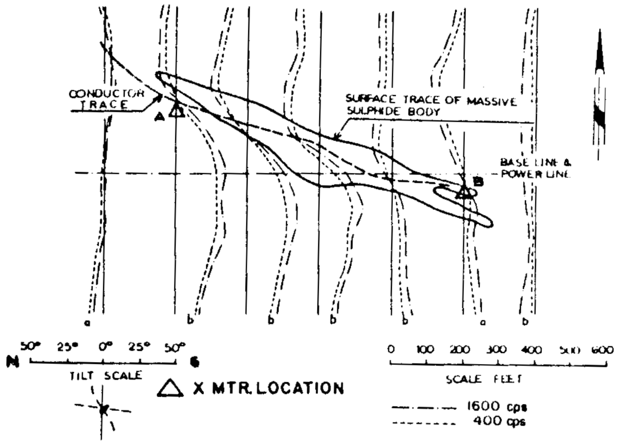


FIG. 6b

DETAIL METHOD

FIG.6a

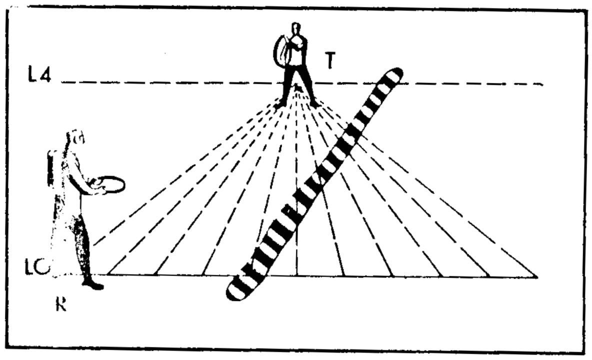


Figure 7 shows detail type (fixed transmitter) tilt angle curves based on model studies for several conducting bodies of different depths and dip. These curves assist in the interpretation of dip angle profiles resulting from the detail surveys. Points to note include the following:

(a) The double crossover curve exhibited by the flat lying body, with the crossovers close to the body edges.

(b) The slight shift of the crossover towards the hanging wall side of a flatly dipping conductor.

(c) The asymmetry of the tilt angle curve caused by a flatly dipping conductor, with the larger tilt angles on the footwall side of the crossover.

EM TILTS — TYPE CURVES (MODEL STUDIES)

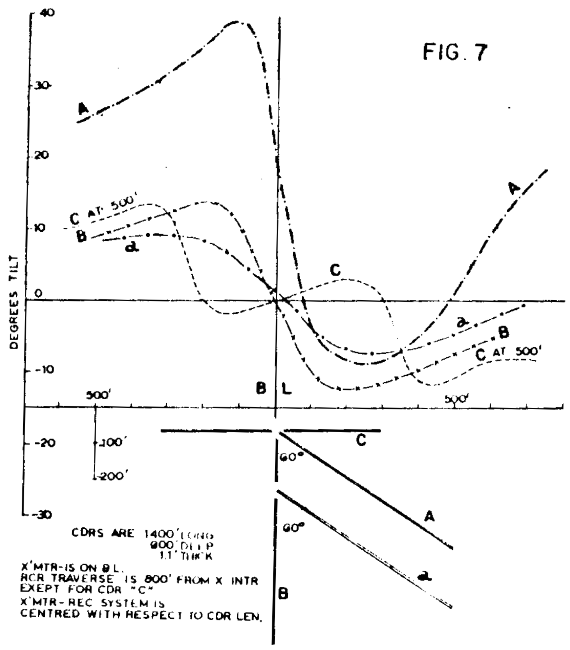
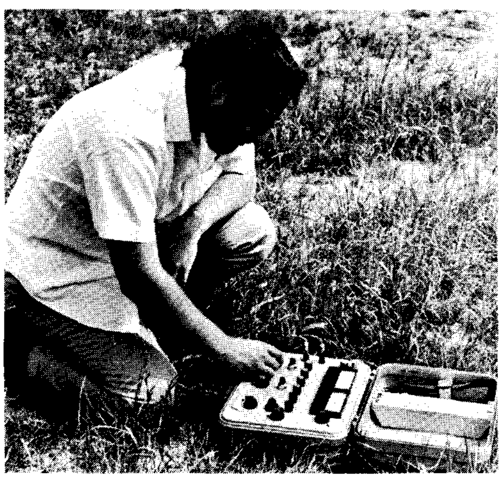
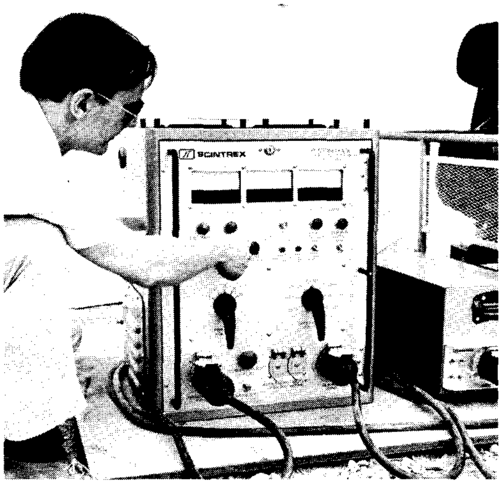


FIG. 7

SCINTREX

INDUCED POLARIZATION





Scintrex Induced Polarization systems, employing the Time Domain method, are very sensitive and accurate tools for Induced Polarization prospecting. The Transmitter and Receiver are light-weight, small-sized units of advanced, solid-state design, predominantly featuring Integrated Circuits. The latest (Mk VII) I.P. system offers a choice of three transmitters of different capacity (IPC-7) series which can be combined with the same Newmont type receiver (IPR-7).

The IPR-7 receiver is self-triggering, which removes the need for a direct cable connection between transmitter and receiver. As a result, mobility and operational flexibility are increased. Further advantages of the IPR-7 are, automatic self-potential compensation, automatic summation of any desired number of polarization signals, built-in A.C. noise filter and the ability to obtain transient curve shape information.

The IPC-7 transmitters all provide alternating, interrupted square wave current pulses of 2, 4 or 8 seconds duration and equal on and off times.

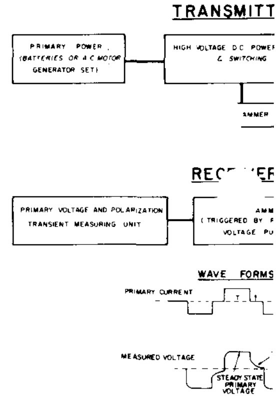
All Mk VII systems are of extremely rugged construction and have an excellent record of performance under the widest variety of climatic and topographic conditions and temperatures ranging from —20°F to 130°F (—30°C to 55°C).

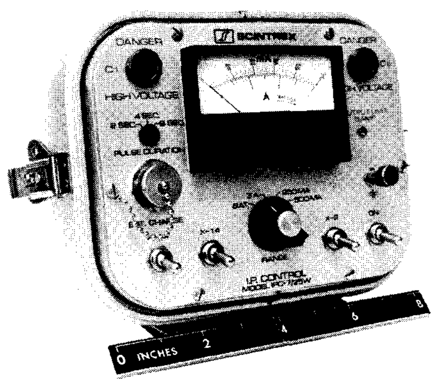
Due to the inherent noise suppression capability of this system, I.P. surveys can be conducted closer to sources of spurious electrical noise, such as power lines or mines. The receiver cannot be falsely triggered by a short duration electrical pulse. The direct reading of chargeability values enables even a relatively inexperienced operator to immediately recognize an anomaly.

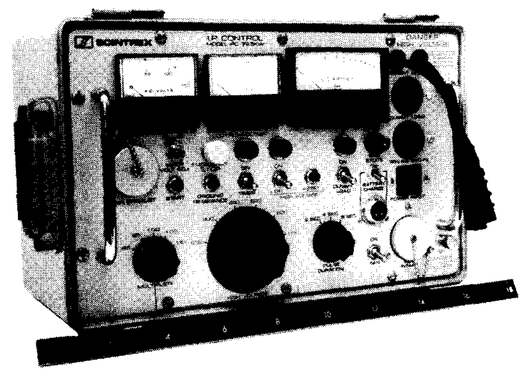
ILLUSTRATIONS:

Top: IP 25W System — lightweight and portable.
Center: In-situ use of IPR-7 receiver.
Bottom: IPC-7/15 kW Transmitter.

3 CONTROL UNITS TO CHOOSE FROM IN THE IPC-7 SERIES....







25 W TRANSMITTER

The 25 watt transmitter is a featherweight, battery powered transmitter. Because of its solid state design, the unit requires little maintenance. It employs sealed, rechargeable, lead-acid batteries. Recharging can take place overnight (required time is 10 hours) from a D.C. source such as two car batteries (12V) or from the 110V A.C. mains. This transmitter is especially useful for light reconnaissance prospecting, (e. g. to map the extension of surface showings), drill hole measurements, model studies and physical property testing.

SPECIFICATIONS:

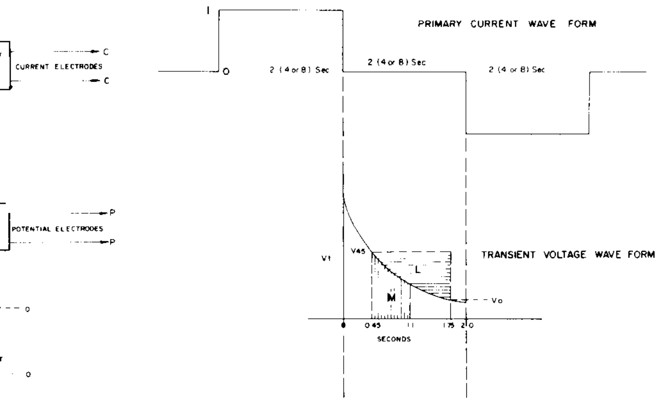
Output voltage	in 5 steps between 40 and 200 V
Max. output current	0.5 amps
Dimensions	7"x 7"x 9" (18 cm x 18 cm x 23 cm)
Weight	*11 lbs. (5 kg) including batteries*
Batteries	2 sealed lead-acid
Battery life	approx. 2 days continuous approx. 200 recharges
Charging source	20 - 30 V (D.C.) charger or 115/230 V (A.C.) 50/400 Hz charger

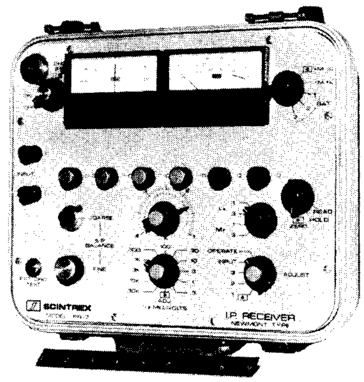
2.5 kW TRANSMITTER

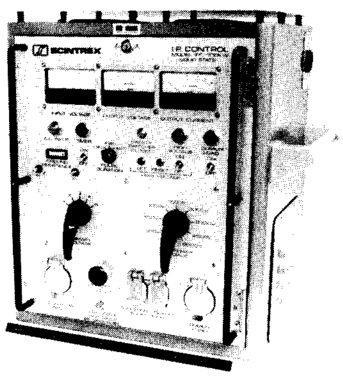
The major system functions of the control unit are performed by removable circuit boards, which simplifies servicing. All circuits, including the high voltage switching, are solid state. The dummy load is mounted in the control unit cover. The source of electric power is a 2.5 kW motor generator set, providing regulated single phase 400 Hz current. The drive motor is a four cycle light-weight 7 h.p. engine. This power system and control unit are adequate for almost all exploration problems and drill hole measurements.

SPECIFICATIONS:

Control Unit:	
Max. output voltage	1500 V (D.C.)
Max. output current	10 amps
Dimensions	*11"x 18"x 12" (28 cm x 46 cm x 31 c*
Weight	65 lbs. (30 kg)
Motor Generator Set:	
Max. output power	2.5 kW (single phase)
Output voltage	110 V (A.C.), 400 Hz
Weight	130 lbs. (59 kg)







15 kW TRANSMITTER

The construction of this control unit is of modular design with solid state electronics and high voltage switching. Because of its larger size and weight, the dummy load is packaged separately. The 15 kW motor generator set provides single phase, regulated 400 Hz current. It is driven by an air-cooled Volkswagen industrial engine. This power system and control unit are adequate for all mineral exploration problems, including exploration for porphyry copper bodies to depths in excess of 2000′ (600 m).

SPECIFICATIONS:

Control Unit:	
Max. output voltage	5,000 V (D.C.)
Max. output current	20 amps
Dimensions	18½"x 27"x 27" (47 cm x 69 cm x 69 cm)
Weight	170 lbs. (77 kg)
Motor Generator Set:	
Max. output power	15 kW (single phase)
Output voltage	208 V (A.C.), 400 Hz
Weight	500 lbs. (227 kg)
Dummy Load:	
Dimensions	10"x 10"x 20" (25 cm x 25 cm x 51 cm)
Weight	75 lbs. (34 kg)
Max. power dissipation	15 kW

IPR-7 NEWMONT TYPE RECEIVER

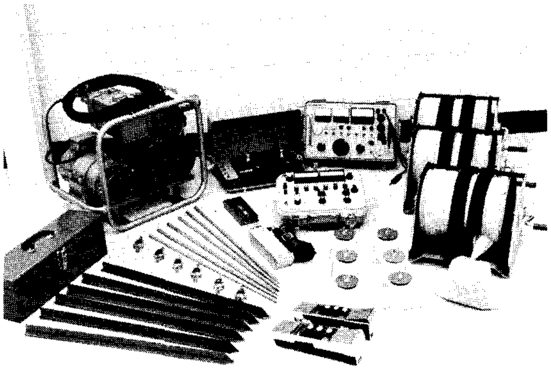
This I.P. receiver measures the chargeability (M) by integrating the area under the decay curve for 0.65 sec. with a delay of 0.45 sec. after the transmitter cut-off. This delay under most conditions largely eliminates the influence of electromagnetic transient effects. Besides the chargeability, which is read directly on a meter scale, it is possible to measure the "complement" (L) of the decay curve and thus obtain a sensitive curve shape factor. In this fashion, it is possible to learn more about the nature of the sources of anomalous chargeability and the influence of electromagnetic transients. Since the signal to noise ratio increases approximately as the square root of the number of readings taken, effective filtering is achieved by the automatic summing of as large a number of readings as necessary. Both M and L are read directly without the necessity of computation, giving an immediate indication of anomalous conditions.

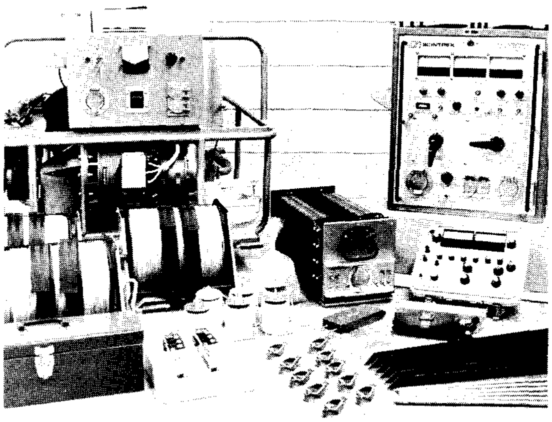
Although the integration measurement provides a high degree of A.C. noise suppression, a special 60 Hz filter (50 Hz opt.) has been incorporated to further reduce possible power line interference. A simulating network is provided for calibration and general function testing of the receiver in situ.

SPECIFICATIONS:

Primary voltage range	0.0003 V - 30 V
Accuracy	±3%
Input impedance	300 kilohms
Chargeability:	
reading range	0 - 100 and 0 - 300 msec.
accuracy	±5%
Curve factor:	
reading range	0 - 100 and 0 - 300 msec.
accuracy	±5%
SP and Telluric noise compensation	
Manual	± 1.5 V
Automatic	depending on primary voltage range: up to ±10 V total on 30 V range
Power Supply	rechargeable nickel cadmium batteries: rated life 45 hours per charge
Temperature range	—20°F to 130°F (—30°C to 55°C)
Dimensions	14"x 11"x 6½" (36 cm x 28 cm x 16 cm)
Weight	13½ lbs., including batteries (6 kg)

ACCESSORIES AND OPTIONS AVAILABLE





25 W Transmitter

S (2) Double reel DR 3020 2000′ I.P. wire
S (4) Porous pots with electrodes
S (4) Tee Stakes
S (4) Stainless steel stakes
S (2) Supercon plug
S (6) Alligator clips
S (1) Copper sulphate polybag (2 lbs.)

2.5 kW Transmitter

O (1) Spare parts kit, Major
O (1) Back pack
O (3) Walkie talkies
O (18) Stainless steel stakes (for winter operation)
S (6) Reel SR 4020
S 3500′ I.P. wire each reel
S (6) Stainless steel stakes
S (6) Porous pots with electrodes
S (10) Alligator clips
S (2) Joy plugs
S (1) Copper sulphate polybag (2 lbs.)

15 kW Transmitter

O (1) Spare parts kit, Major
O (3) Walkie talkies
O (18) Stainless steel stakes (for winter operation)
S (6) Reel SR 4020
S 3500′ I.P. wire each reel
S (6) Stainless steel stakes
S (6) Porous pots with electrodes
S (6) Tee Stakes
S (2) Supercon connector
S (10) Alligator clips
S (1) Copper sulphate polybag (2 lbs.)
S (1) Tool box with tools

IPR-7 Receiver

S (1) Battery charger
S (1) Cable for recharging receiver from other than line current
S (1) Simulating Network
S (1) Spare parts kit, Minor
O (1) Spare parts kit, Major

(S: Standard, O: Optional)

BRANCH OFFICES AND SUBSIDIARIES

SCINTREX LIMITED, (HEAD OFFICE)
222 Snidercroft Road
Concord, Ontario, Canada

SCINTREX INC.
Amherst Industrial Park
Creekside Drive
Tonawanda (Buffalo) New York 14150

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SEIGEL ASSOCIATES LIMITED
222 Snidercroft Road
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SCINTREX MINERAL SURVEYS, INC.
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Cerro de San Francisco 221
Mexico 21, D.F.

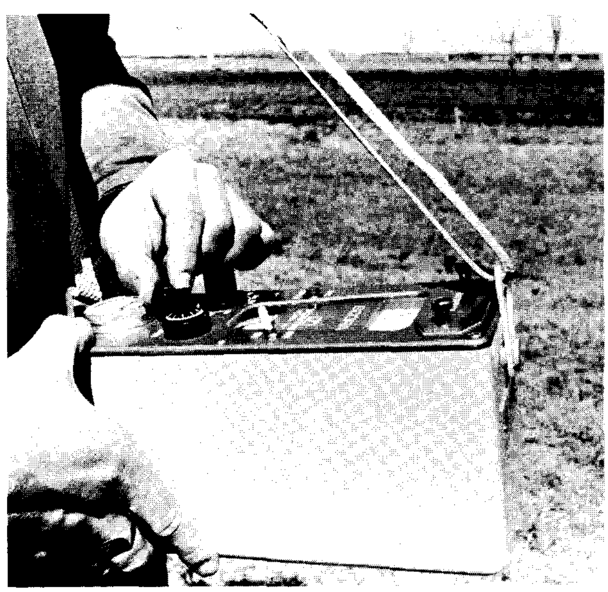
SCINTREX LIMITED
222 Snidercroft Road · Concord, Ontario, Canada

SCINTREX

VLF ELECTROMAGNETIC UNIT MODEL SE-80

The SCOPAS* VLF System employs V.L.F. Radio Stations in the 15 to 25 kHz Range as primary field sources. The undisturbed field from these remote sources is essentially horizontal and of relatively constant strength. When conductors are present, the geometry and amplitude of the field are locally distorted and polarization of the field may occur.

With the versatile SCOPAS* unit, all amplitudes and geometric parameters as well as the characteristics of the polarization ellipse can be measured. For fast reconnaissance surveys dip-angle and field directions can be rapidly determined. For detailed surveys, amplitude relations and the elliptical polarization in the horizontal and vertical planes can be determined as well. Thus, the operator can select the parameters most useful for his search problem.



*Can. Pat. 678765

Primary Field: From any selected VLF transmitting station in frequency range between 15.4 kHz to 25 kHz.

Station Selection: By means of an eight step switch and variable control covering full range.

Measured Values:

a) The azimuth of horizontal field.

b) The dip of the axis of the coil at the minimum field, measured from the vertical.

c) The amplitude of the horizontal field strength in any direction.

d) The amplitude of the vertical field strength.

The phase angle between the maximum horizontal and vertical field can be calculated from measured values.

Normal Reading Accuracy:

Amplitude $\pm 2\%$.
Azimuth $\pm 2°$.
Dip $\pm 1°$. — Dependent on signal strength.

Batteries: Two 9 volt dry cells.

Dimensions:

9.66"x 3.68"x 5.80"
24.5 cm x 9.4 cm x 14.7 cm

Weight: 3 lbs. (1.35 kg)

Accessories: Carrying strap.

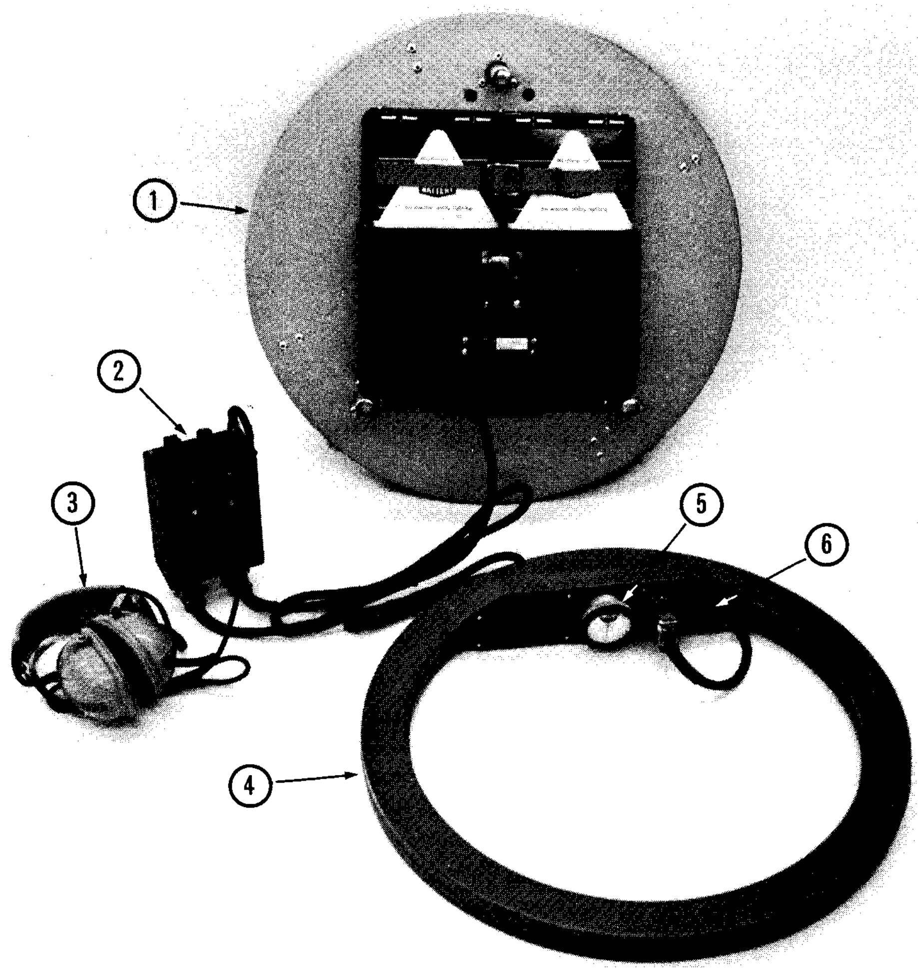
SCINTREX LIMITED
222 Snidercroft Road · Concord, Ontario, Canada

SCINTREX

DUAL FREQUENCY ELECTROMAGNETIC TRANSCEIVER

The SE-300 Electromagnetic Unit consists of two identical transceiver units to provide maximum operational efficiency. Used in a broadside configuration ground may be surveyed at twice the normal rate of coverage. Dual frequency excitation provides diagnostic information to distinguish between subsurface conductors and aids in resolving overburden from bedrock conduction effects. A unique receiver circuitry extends the useful separation of the transceivers to 1200 ft., providing greatly increased effective depth penetration.

FREQUENCY RANGE:	400 cps. and 1600 cps. (other frequencies optional).
FREQUENCY TRACKING:	Better than ± 2% over extended periods at normal ambient temperatures.
FREQUENCY TRACKING:	Receiver versus transmitter: Better than 1% over temperatures from —40°F to 104°F.
TRANSMITTER OUTPUT:	Approx. 150 NI at 1600 cpa. and approx. 180 NI at 400 cps. Higher outputs optional.
SEPARATION:	Up to 1200 feet using 1600 cps. deflection is ± 5°. 600 feet using 400 cps. deflection is ± 5°.
RECEIVER SENSITIVITY:	50 Millimicrovolts.
BATTERY:	2 x No. 731 Eveready lantern batteries or NEDA 918.
BATTERY LIFE:	Approximately 10 days.
WEIGHT:	Coil — 8½ lbs., 3.85 Kg. Receiver — 2 lbs., .90 Kg. Transmitter — 20½ lbs., 9.3 Kg.



1. Transceiver Power Supply
2. Amplifier
3. HC-6C Headphones
4. Transceiver Coil
5. Clinometer
6. Transmitter Switch

SCINTREX LIMITED
222 Snidercroft Road · Concord, Ontario, Canada

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SCINTREX

MF-2

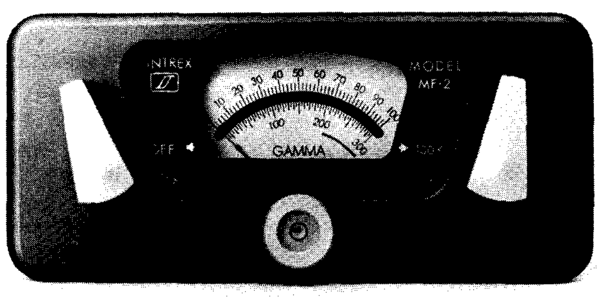
The MF-2 is a completely new concept in vertical force fluxgate magnetometers. These instruments, which are designed for fast and accurate mineral ground surveys, are orientation independent, self levelling and require no tripod.
The MF-2 combines the electronics and sensor in one compact 3¾ lb. package. An external dry cell battery pack is provided as standard power source for the instrument. As an option, rechargeable batteries may be provided and housed directly in the instrument.
With the latest I.C. and F.E.T. circuitry and high precision components, a temperature stability better than 1 gamma per °C is standard (with .25 gamma on special order) over a range of —40° to +40°C.
The instrument has a built-in hemisphere polarity switch providing two overlapping ranges. For the Northern hemisphere the full range is +80,000 to —20,000 gammas, and reversible for the Southern hemisphere.
A calibrated feedback system can be provided which makes it possible to determine the total vertical component strength.
Measuring resolution, on the 100 gamma scale (optional) is 0.5 gamma, and on the 1000 gamma scale is 5 gammas.
The Scintrex MF series of magnetometers have been in use for many years in varied applications, e.g. ground reconnaissance, base station recording and monitoring, study of magnetic properties of rocks, observatory monitoring and recording of both vertical and horizontal components. A high impedance recorder outlet is standard.

OPTIONAL

a) MF-2G
The MF-2G Fluxgate Magnetometer has the same electronics and specifications as the MF-2, but the sensor is detached and enclosed in a small cylindrical tube which permits it to be oriented and tilted in any desired direction. A 25 foot cable connects the sensor to the instrument housing. This version is particularly suitable for the study of the magnetic properties of rocks, and the measurement of magnetic field components of any orientation, etc.

b) MF-2GS
The MF-2GS Magnetometer has the same electronics and specifications as the MF-2 but has two sensors, the enclosed self-levelling sensor of the MF-2 as well as the detached geoprobe of the MF-2G, either one of which can be employed at any one time. Thus, this instrument can be employed as the standard MF-2 and for the determination of the magnetic properties of rocks, etc.

c) MF-2-100
100 gammas and 300 gammas full scale ranges are added to the standard MF-2 and its options.



SPECIFICATIONS OF FLUXGATE MAGNETOMETER MODEL MF-2

	RANGES	SENSITIVITY
Standard: (MF-2)	Plus or minus	
	1,000 gammas f.sc.	20 gammas/div.
	3,000 gammas f.sc.	50 gammas/div.
	10,000 gammas f.sc.	200 gammas/div.
	30,000 gammas f.sc.	500 gammas/div.
	100,000 gammas f.sc.	2000 gammas/div.
Optional: (MF-2-100)	100 gammas f.sc.	2 gammas/div.
	300 gammas f.sc.	5 gammas/div.

Meter: Taut-band suspension
100 gamma scale 2.1" long — 50 div.
300 gamma scale 1.9" long — 60 div.

Resolution: All scale ranges ±0.5% of full scale.

Operating Temperature: —40°C to +40°C
—40°F to +100°F

Temperature Coefficient: Less than 1 gamma per °C (½ gamma/°F)

Noise Level: Less than 1 gamma P-P

Bucking Adjustments: (Latitude) —20,000 to +80,000 gammas
9 steps of 10,000 gammas plus fine control of 0 - 10,000 gammas by ten turn potentiometer. Reversible for southern hemisphere.

Recording Output: Standard — for high impedance recorder (> 1 megohm)
Optional — for low impedance recorder

Electrical Response: D.C. to 3 cps (3db down) on most sensitive range with meter in circuit. D.C. to 20 cps with meter network shorted for recording purposes.

Connector: Cannon KO2-16-10SN for plug Cannon KO3-16-10-PN and cover KO6-16-⅜

Batteries: Standard — battery pack (16 dry cell batteries)
Optional — internal 3 x 6V - 1 amp/hr. Sealed lead acid rechargeable, Centralab GC 6101. Recharge time 8 hrs.

Consumption: 60 milliamperes — GC6101 batteries are rated for 16 hours continuous use.

Dimensions: 6¼"x 2¾"x 10" Instrument
161 mm x 71 mm x 254 mm

Weights: Standard 3 lb. 12 oz. — 1.7 kg
Optional 5 lb. 8 oz. — 2.5 kg (with rechargeable batteries)

Battery Charger: 6"x 2½"x 2½"
155 mm x 64 mm x 64 mm
110V-220V 50/60 Hz supply or 28-42V D.C. supply. Automatic charge rate and cutoff preset for Centralab GC6101 batteries.

SCINTREX LIMITED
222 Snidercroft Road • Concord, Ontario, Canada

Induced polarisation method

By Dr. HAROLD O. SEIGEL
President, Scintrex Limited

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for SCINTREX

The induced polarization method is based on the electrochemical phenomenon of Overvoltage, that is, on the establishment and detection of double layers of electrical charge at the interface between ionic and electronic conducting material when an electrical current is caused to pass across the interface.

In practice, two different field techniques (Time Domain and Frequency Domain) have been employed to execute surveys with this method. These techniques can yield essentially equivalent information but do not always do so. Instrumentation and field procedures using both techniques have evolved considerably over the past two decades. Much theoretical information for quantitative interpretation has been accumulated.

All naturally occurring sulphides of metallic lustre, some oxides and graphite, give marked induced polarization responses when present in sufficient volume, even when such materials occur in low concentrations and in the form of discrete, non-interconnected particles.

Induced Polarization is the only method presently available which has general application to the direct detection of disseminated sulphide deposits such as "porphyry type" or bedded copper deposits, and bedded lead-zinc deposits in carbonate rocks.

A number of case histories are documented where standard geo-electrical and other geophysical methods failed to yield an indication of sulphide mineralization detectable by the induced polarization method.

Each rock and soil type exhibits appreciable induced polarization response, usually confined to a relatively low amplitude range, which is characteristic of the specific rock or soil. Certain clays and platey minerals including serpentine, sericite and chlorite, sometimes give rise to abnormally high responses. These effects are attributed largely to so-called "membrane" polarizations.

Despite a moderate amount of laboratory and field investigation, it is not feasible in general to differentiate between induced polarization responses due to Overvoltage and non-metallic sources, nor to differentiate between possible sources within each group.

Because of other variables, it is likewise difficult to uniquely equate a specific induced polarization response to a specific percentage of metallic content, although mean relationships have been established.

Through the measurement of secondary parameters, such as the transient decay curve form characteristics, one may obtain useful information relating to the average particle size of metallic responsive bodies or to the influence of electromagnetic transients on the I.P. measurements. The latter effect becomes prominent when surveys are made in areas with highly conducting surface materials, e.g. semi-arid regions.

Induced polarisation method

By Dr. HAROLD O. SEIGEL
President, Scintrex Limited

THE induced polarization (or I.P. as it is commonly known) method is, in application, the newest of our mining geophysical tools, having come into active use only in late 1948. Its roots extend somewhat farther back, however. Schlumberger (1920) reports having noted a relatively lengthy decay of the residual voltages in the vicinity of a sulphide body after the interruption of a primary D.C. current. Unfortunately, measurements in non-mineralized areas gave rise to rather similar residual polarization potentials, so he apparently abandoned his efforts.

In the late 1930's in the U.S.S.R. (Dakhnov, 1941) I.P. measurements were being made in petroleum well logging in an attempt to obtain information relating to the fluid permeability of the formations traversed by the well. Dakhnov mentions the possible application of the method to the exploration for sulphide mineralization, although it would appear that no such use was being made use thereof at that time. Unfortunately the volume of Dakhnov did not come to the attention of abstracters in North America until the spring of 1950.

Active development of the I.P. method as applied to mineral exploration in North America commenced with the writer's theoretical study in 1947 of the phenomenon of Overvoltage and his report (Seigel, 1948) on its possible application to geophysical prospecting. Laboratory and subsequent field investigation, sponsored by Newmont Mining Corporation in 1948 eventually led to the development of a working field technique and the recognition of polarization effects in all rocks (Seigel 1949).

Contemporaneously and independently D.A. Bleil (Bleil 1953) indicated the possibility of utilizing I.P. in prospecting for magnetite and sulphide mineralization but apparently did not recognize the presence of non-metallic polarization effects in rocks.

Until 1950 all I.P. measurements were of the "time-domain" type (see below). In 1950, as the result of some laboratory measurements, L.S. Collett and the writer suggested the method of measuring I.P. effects using sinusoidal current forms of different frequencies. J.R. Wait expanded greatly on the possibilities of this approach and successful field tests were carried out in that year. The work of the Newmont group is summarized in a monograph (Wait 1959).

Since 1950 several groups have been active in the development of the I.P. method by means of theoretical laboratory model and field studies. Prominent among these groups has been that at the Massachusetts Institute of Technology (Hall of 1957) (Madden 1957) (Marshall 1959).

Within the literal meaning of the term, polarization is a separation of charge to form an effective dipolar distribution within a medium. Induced polarization is, therefore, a separation of charge which is due to an applied electric field. It may also include phenomena which cause voltage distributions similar to those due to true polarization effects.

For practical purposes, only polarization effects with time constants of build up and decay longer than a few milliseconds are of importance. This usually excludes such phenomena as dielectric polarization and others which are encompassed by the normal electromagnetic equations.

In order to measure I.P. effects in a volume of rock one passes current through the volume by means of two contact points or electrodes and measures existing voltages across two other contact points.

Theoretically, any time varying current form can be used, but in practice only two such forms are employed. In the first technique a steady current is passed for a period of from one second to several tens of seconds and then abruptly interrupted.

The polarization voltages built up during the passage of the current will decay slowly after the interception of the current and will be visible for at least several seconds after the interception. This is termed the "Time Domain" method.

The "Frequency Domain" method entails the passage of sine wave current forms of two or more low, but well separated, frequencies, e.g. 0.1 and 2.5 c.p.s., or 0.5 c.p.s. and 10 c.p.s.

Since polarization effects take an appreciable time to build up, it can be seen that they will be larger at the lower frequency than at the higher, so that apparent resistivities or transfer impedances between the current and measuring circuits will be larger at the lower frequency. The change of measured resistivities with frequency is, therefore, an indication of polarization effects.

Further discussion of the precise quantities measured in the Time and Frequency Domain methods will be resumed after a presentation of some of the polarization phenomena involved.

When a metal electrode is immersed in a solution of ions of a certain concentration and valence, a potential difference is established between the metal and the solution sides of the interface. This difference in potential is an explicit function of the ion concentration and valence, etc.

When an external voltage is applied across the interface a current is caused to flow and the potential drop across the interface changes from its initial value. If the electrode is a cathode it becomes more negative with respect to the solution, whereas if it is an anode, it becomes more positive with respect to the solution.

The change in interface voltage is called the "Overvoltage" or "Polarization Potential" of the electrode. If the electrode is a cathode, we speak of "Hydrogen Overvoltage" and, if an anode, of "Oxygen Overvoltage".

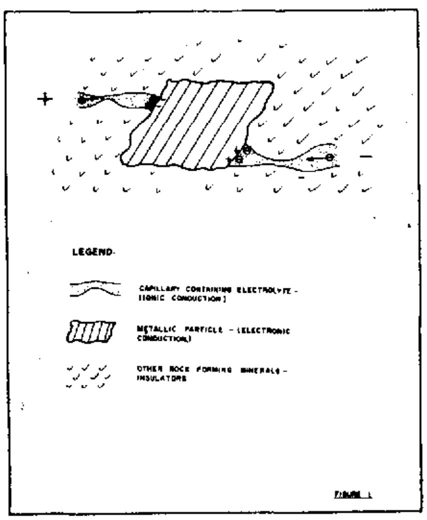
These Overvoltages are due to an accumulation of ions on the electrolyte side of the interface, waiting to be discharged. The charge of these ions will be balanced by an equal opposite charge due to electrons or protons on the electrode side of the interface.

For small current densities the Overvoltage is proportional to the current density, i.e. is a linear phenomenon. The variation of Overvoltage with several other factors is presented in the writer's Doctoral Thesis (Seigel, 1949). The time constant of build up and decay is of the order of several tenths of seconds.

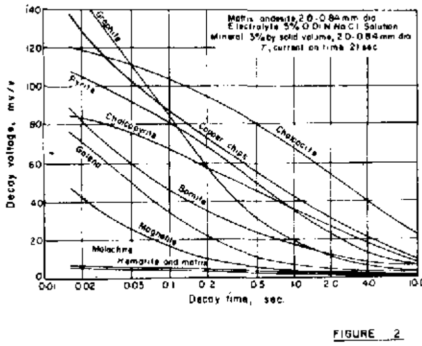
Overvoltage is, therefore, established whenever current is caused to flow across an interface between ionic and electronic conduction. In normal rocks the current which flows under the action of an impressed E.M.F. does so by virtue of ionic conduction in the electrolyte in the capillaries of the rock.

There are, however, certain rock forming minerals which have a measure of electronic conduction, and these include almost all the metallic sulphides (except sphalerite), graphite, some coals, some oxides such as magnetite, and pyrolusite, native metals and some arsenides and other minerals with a metallic lustre.

When these are present in a rock subjected to an impressed E.M.F., current will be caused to flow across capillary — mineral interfaces and



Induced Polarization Response of a Metallic Conducting Particle in a Rock.



Decay Curves for Metallic and Non-metallic Minerals (after Wait, 1959).

hydrogen and oxygen Overvoltages will be established. Figure 1 is a simplified representation of what happens to an electronic conducting particle in a rock under the influence of current flow.

Despite attempts by various workers to investigate the source of non-metallic I.P. in rocks, an adequate explanation of all observed effects is still lacking. A number of possible contibutory agents have been established. Vacquier (Vacquier et al, 1957) has carefully examined strong polarization effects due to certain types of clay minerals.

These effects he believed to be related to electrodialysis of the clay particles. This is only one type of phenomenon which can cause "ion-sorting" or "membrane effects".

For example, a cation selective membrane zone may exist in which the mobility of the cation is increased relative to that of the anion, causing ionic concentration gradients and, therefore, polarization effects (see also Marshall, 1959). Much work remains to be done to determine the various agencies, other than clay particles, which can cause such membrane effects.

Time Domain Method: Figure 2 shows the typical transient I.P. voltage decay forms for various rock forming materials in a laboratory testing apparatus. See also Scott (1969). A primary current time of the order of 21 seconds was employed on these tests.

It will be noted that the voltages are plotted against the logarithm of the decay time and are approximate linear functions of the log t for reasonable lengths of time (t). The amplitude of the transient voltages has been normalized with respect to the steady state voltage existing immediatly before the interception of the primary current.

In order to indicate the magnitude of the I.P. effects one may measure one or more characteristics of the transient decay curve and relate it back to the amplitude of the measured primary steady state voltage prior to the interception of the primary current.

It may be shown that the ratio is Vs/Vp, i.e. peak polarization voltage to the primary voltage just before interception is a physical property of the medium, which has been called the "Chargeability" of the medium.

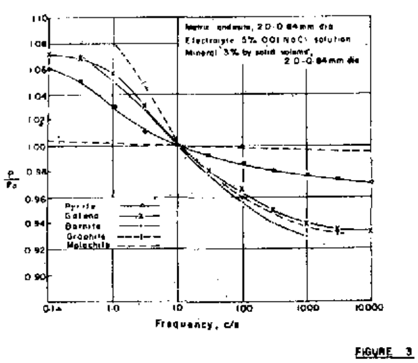
Since it has been demonstrated that most I.P. decay voltages are similar in form but differ in amplitude (for the same charging time) one can take the average of several transient voltages at different times, or indeed use the time integral of the transient voltages as a diagnostic criterion. The advantage of averaging or integrating lies in the suppression of earth noises and of electromagnetic coupling effects.

The chargeability is often designated by the letter "M". If the time integral is used the units of M will be in millivolt seconds/volt or milliseconds. If one or more transient voltage values are measured and normalized, M will be dimensionless.

For homogeneous, isotropic material, the value of M is independent of the shape or size of the volume tested and of the location of the electrodes on it. It is a true physical property. For a given medium it is dependent on the current charging time and on the precise parameter of the decay curve measured. There are also subsidary variations with temperatures and electrolyte content, etc.

Frequency Variation Method: Figure 3 shows typical curves of the variation of normalized resistivities with frequency for various sulphide, graphite and non-metallic rock minerals in artificial mixtures. Both the fact of the variation of apparent resistivity with frequency and the presence of phase angle lags may be used to indicate the presence of I.P. effects, although generally only the first is so employed.

Since the I.P. phenomena may be shown to be linear, within the usual range of voltages and currents, there is



Resistivity-frequency Characteristics of Metallic and Non-metallic Minerals (after Wait, 1959).

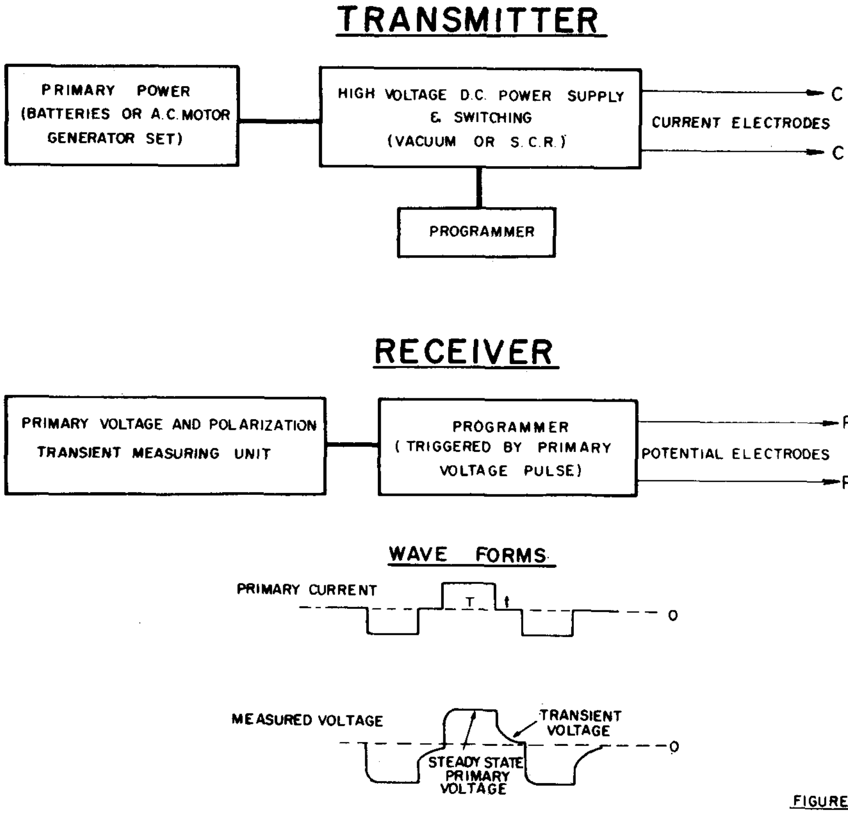


FIGURE 4

Time Domain Apparatus, Block Diagram and Wave Forms.

Figure 4 shows a block diagram of apparatus commonly used in field operations with the time-domain method and the primary current and resultant voltage wave forms. The transient voltage amplitudes are considerably exaggerated to be visible.

Power sources up to 30 K.V.A., 5000 volts and 20 amperes have been employed where extreme penetration is desired in low resistivity areas. The current-on time T ranges from one second to as much as 30 seconds, and the current-off time t may be as much as 10 seconds. It is not strictly necessary to employ a cyclic current wave form, but considerable advantages in signal-to-noise ratio are achieved thereby.

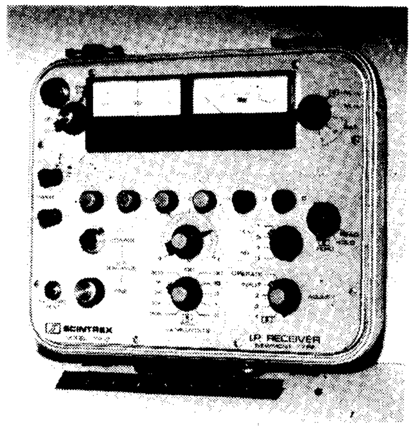
Most of the receivers now employed are remote triggering, i.e. they are internally programmed, triggered by the primary voltage pulse and do not require a cable interconnection to the cycle timer on the power control unit. Figure 5a shows a typical time-domain remote-triggered receiver (Scintrex MK VII, Newmont-Type). This particular receiver has several interesting features.

For one, there is a memory circuit which provides an automatic self potential adjustment at the tail end of each cycle. For another, it has the ability to integrate the area either below the transient curve (standard M measurement) or above the transient curve (denoted as the L measurement) over a specific time interval. The ratio of these quantities gives a direct relationship between the transient curve form and the variation of apparent resistivity with frequency. To arrive at a dimensionless parameter equivalent to the chargeability, one would have to normalize the apparent resistivity, by dividing by the resistivity at one particular frequency. The factor used is called the "Percent Frequency Effect" or P.F.E. and is defined as $(R_1 - R_2/R_1) \times 100$ where R_1 and R_2 are the apparent resistivities at the lower and higher frequencies used (Marshall, 1959).

A second parameter is sometimes employed which is really a mixture of physical properties. It is called the Metal Factor (M.F.) and is proportional to P.F.E./R_2 or to M/R. As such, it serves to emphasize I.P. effects which occur in obviously conductive environments, i.e. concentrated sulphide deposits or sulphides and graphite in shear zones.

Since it is not a dimensionless factor nor a true single physical property, it is subject to variation related to the changes of shape and resistivity of the medium under investigation, rather than simply to variations in polarization characteristics.

In my opinion, the metal factor has some merit in emphasizing I.P. anomalies due to concentrated metallic bodies, but should not be used as a primary indicator of abnormal I.P. conditions.



Typical Modern Time Domain I.P. Receiver (Scintrex Mk. VII)

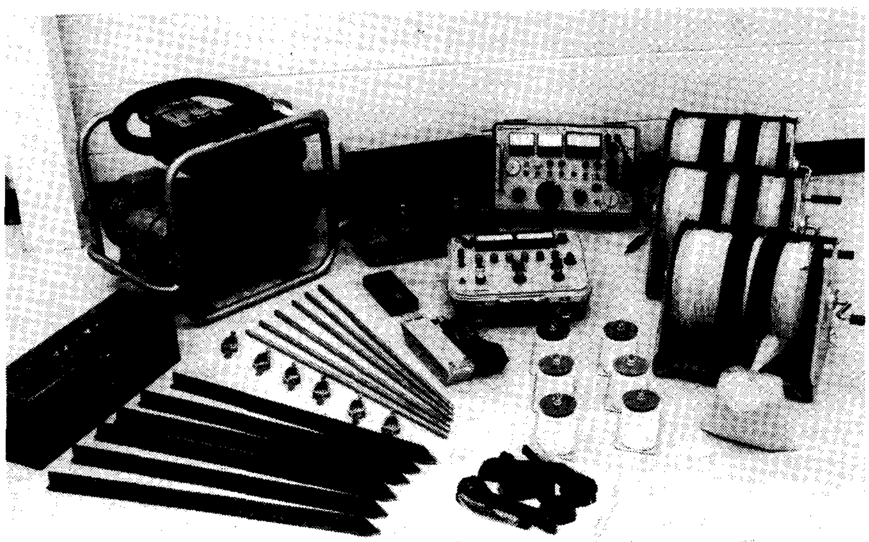


FIGURE 5b

Typical Modern Time Domain I.P. Unit (Scintrex Mk VII)

Array	Domain Employed	Advantages	Disadvantages
Wenner	Time	For local vertical profiling.	Poor depth penetration. Requires four linemen.
Three Electrode (or Pole-Dipole)	Time and Frequency	Three linemen. Universal coupling. Good depth penetration.	Susceptible to surface masking effects.
Dipole-Dipole	Frequency	Good resolution. Universal coupling.	Complex curve forms. Low order signals. Susceptible to surface masking effects.
Gradient	Time	Minimum masking. Two linemen only. Excellent depth penetration. Excellent resolution. Can use multiple receivers for speed.	Couples best with steeply dipping bodies. Low order signals.

measure of the decay curve form, which may be of diagnostic value (see below). In areas of low electric earth noise useful measurements may be made with primary voltages as low as 300 microvolts. Figure 5b shows a complete typical modern time domain induced polarization unit (Scintrex MkVII) of which the Newmont-type receiver above is a part.

Figure 6 shows a block diagram of a typical frequency domain field apparatus and voltage wave form. Since the primary current and earth voltages are usually measured by separate devices and their ratio employed to obtain the apparent earth resistivity and its variation with frequency, it is common practice to adjust the current to a standard value and maintain it there to the required accuracy.

The primary wave form is usually a commutated D.C. Commonly, up to 6 frequencies are available in the range of 0.05 to 10 c.p.s. Figure 7 shows a typical modern frequency domain measuring unit. This unit has a high degree of power line frequency (50 c.p.s. to 60 c.p.s.) rejection.

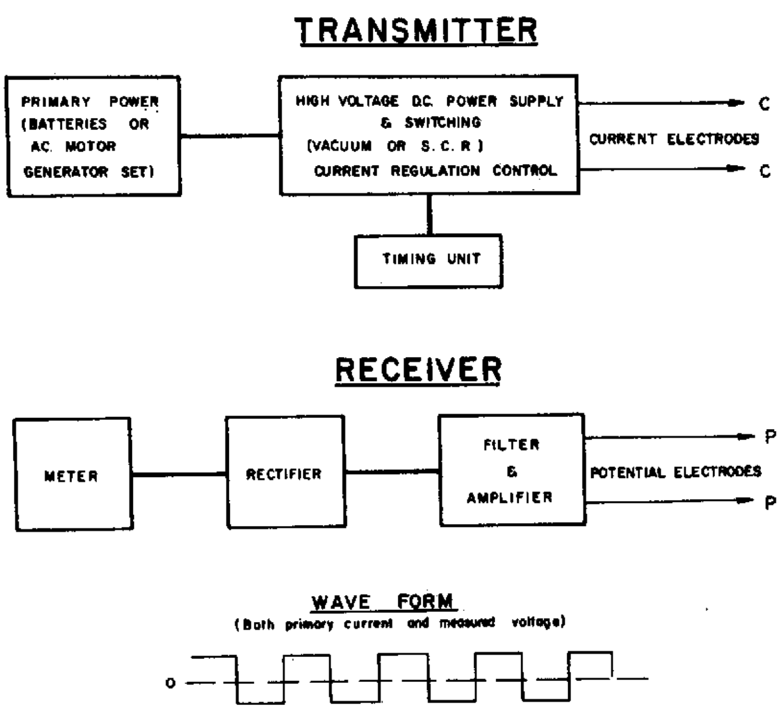
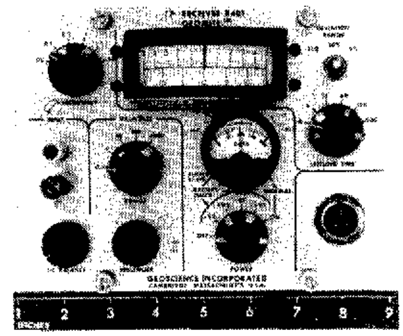


FIGURE 6

Frequency Domain Apparatus, Block Diagram and Wave Forms.



Typical Modern Frequency Domain Receiver (Geoscience).

It measures both the primary voltage and the change of primary voltage with change in operating frequency, the latter to an accuracy of about ∓0.3% when the former exceeds 100 microvolts. It has the added feature of a phase lock voltmeter which assists in making measurements under low signal-to-noise conditions.

Common field electrode arrays are shown in Figure 8. The electrodes marked C are current electrodes and those marked P are potential or measuring electrodes. Each of the electrode arrays has its own advantages and disadvantages in respect of depth of penetration, labour requirements for moving, susceptibility to earth noise, electromagnetic earth transients and interline coupling. The following table summarizes the features of these arrays.

For each array (except the gradient array) the basic electrode spacing "a" is selected to give adequate penetration down to the desired depth of exploration. For the pole-dipole and double dipole it is customary to obtain several profiles for different values of "a" or for integral values of n from 1 to as much as 4.

For the symmetric arrays (Wenner and Dipole-Dipole) the measured values are plotted against the midpoint of the array. When using the Three Electrode Array (time-domain) the station position is taken to be the midpoint of the moving current and the nearest potential electrode. When using the Pole-Dipole (frequency domain) the station position is taken as the midpoint between the moving current electrode and the *midpoint* of the two potential electrodes.

With the Gradient array it is the midpoint of the two potential electrodes. For the Three Electrode array and Pole-Dipole these station locations are not unique and represent conventions only.

I.P. data may be plotted in profile form or contoured, although it should be noted that somewhat different results will be obtained with different line orientations so that contouring is

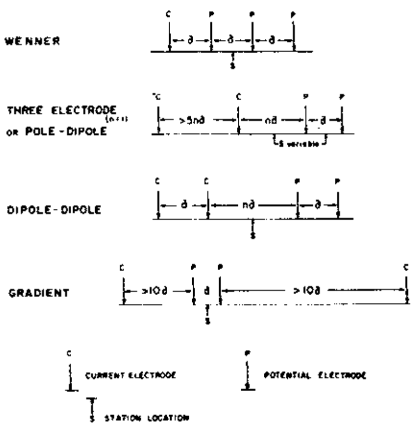


FIGURE 8

Common Field Electrode Arrays.

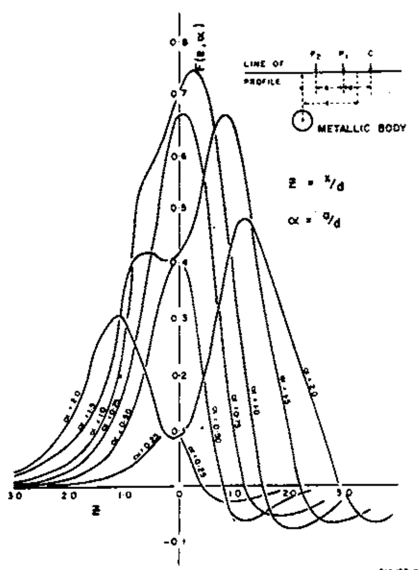


FIGURE 9

Theoretical Response of a Sphere, Three Electrode Array.

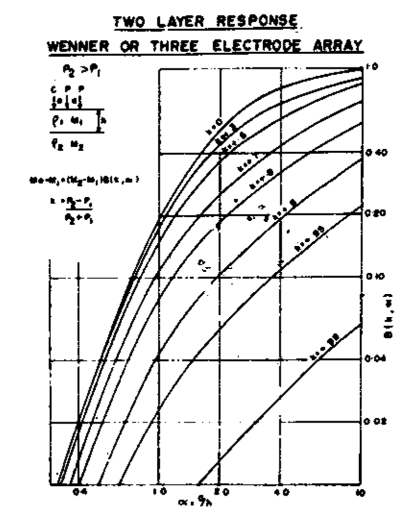


FIGURE 10

Theoretical Response of Two Layer Earth, Wenner or Three Electrode Array.

not strictly justified. Profile interpretation is superior, particularly for shallow, confined bodies, because multiple peaked curves may arise from such bodies using certain electrode arrays, and the plotted peaks may give an erroneous impression of the location of the polarizable body.

To obtain the variation of physical properties with depth, expanding arrays may be used with any of the electrode systems, keeping the spread centre fixed and simply changing the relative spacing "a". This is of particular value where it is known or expected that vertical variations of physical properties will be much greater than lateral variations.

As the spacing is increased the influence of the deeper regions becomes more significant, and the resultant resistivity and I.P. curves may often be interpreted to give the depth to discontinuities in physical properties and the physical properties themselves.

Common practice in presenting frequency domain results is to plot the measured data below the line at a depth equal to the distance of the station position (as defined above) from the midpoint of the pontential dipole. When this is done for a variety of values of "n" a pseudo two-dimensional section results which show, albeit in a markedly distorted fashion, the variation of physical properties with depth.

A mathematical representation of I.P. effects has been developed by the writer (Seigel, 1959), which relates the observed I.P. response of a heterogeneous medium to the distribution of resistivities and I.P. characteristics. To a first approximation it is equally applicable to any I.P. parameter measured in the time and frequency domains.

From this theory, one may predict the anomalous response to be expected from a specific body with a given chargeability and resistivity contrast. For example, Figure 9 shows the form factor F plotted for the Three Electrode Array for a sphere for various values of √, where √ is the ratio of the electrode spacing to the depth to the centre of the sphere. The sphere response is proportional to F times the chargeability contrast, times its volume and times a resistivity-ratio factor. A number of such theoretical curves, for the pole-dipole and gradient arrays, using spheres and ellipsoids as models, may be seen in the paper by Dieter (1969) et al.

Curves of this sort permit one to interpret anomalies due to localized bodies. It will be seen that for each array there is an optimum spacing for a body at a particular depth, and, therefore, there is some meaning to the term "depth of penetration", except for the gradient array.

When the dimensions of the polarizable medium are large in comparison with its depth below surface, as is often the case, particularly in investigation of porphyry copper type deposits, a two layer approximation is adequate. Theoretical curves based on this approximation (Figure 10) may be used to interpret the results of expanding Wenner or Three Electrode array depth determinations.

For more complex geometries mathematical solutions in closed form are often lacking. For such cases one may resort to model studies (e.g. Figure 11 for buried dike.) or to computer calculated solutions.

The most productive use of the I.P. method to date has been in the exploration for deposits of metallically conducting minerals, where the amounts and degree of interconnection of these minerals are too low to give rise to an electromagnetically detectable body.

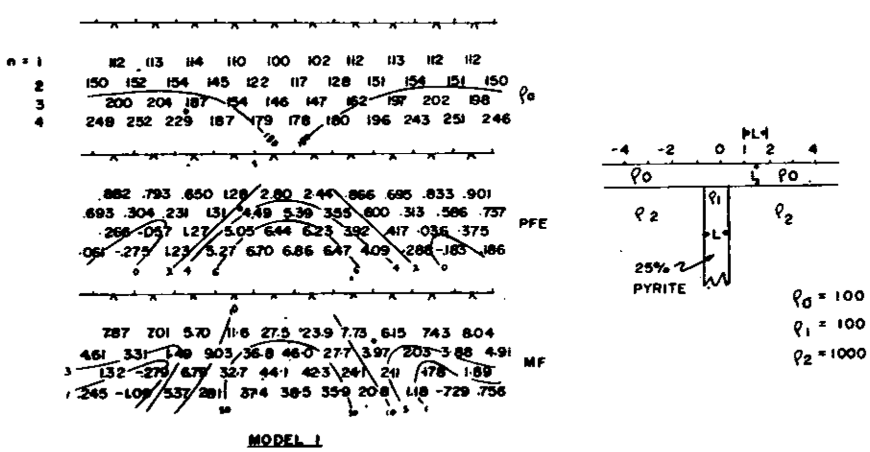


FIGURE 11

Model Response of a Dike, Dipole-Dipole Array (courtesy K. Vozoff).

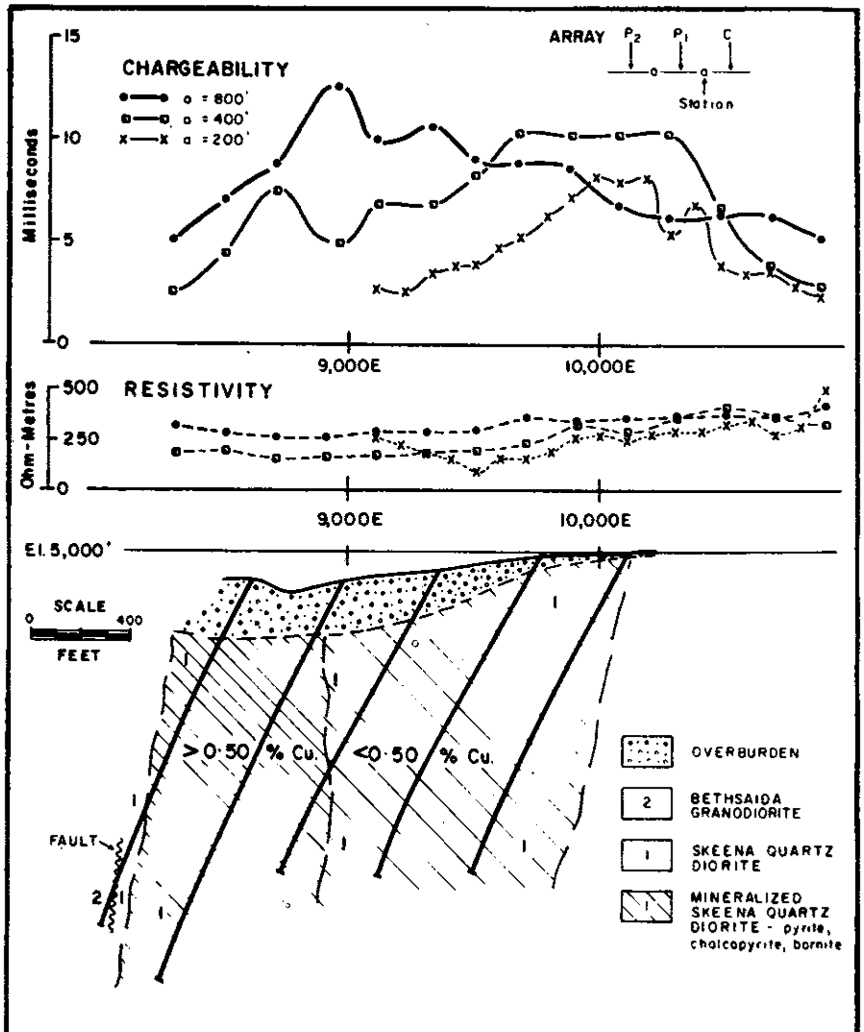


FIGURE 12

Geophysical and Drilling Results, Lornex Porphyry Copper Ore Body, British Columbia, Canada (courtesy Lornex Mining Corp. Ltd.)

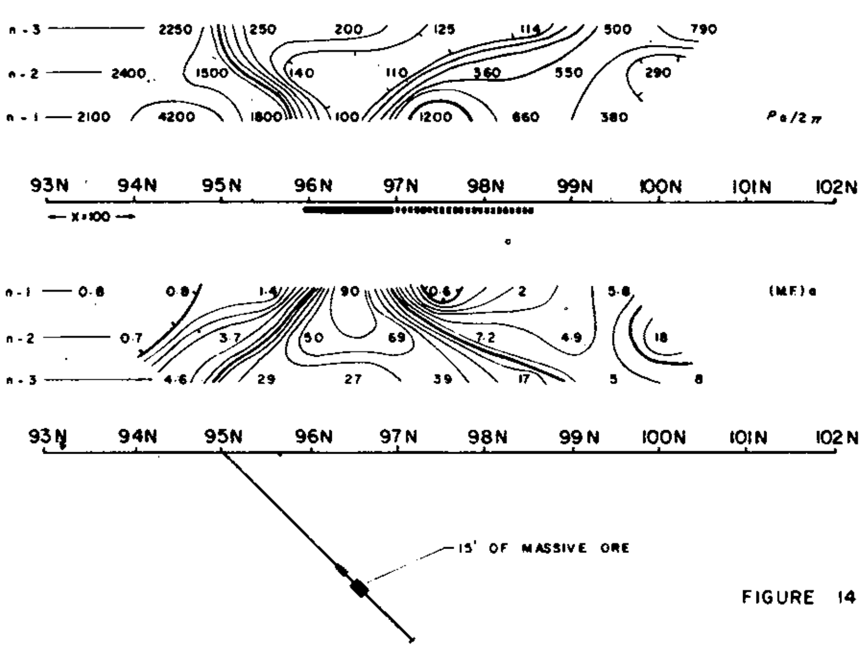


FIGURE 14

Geophysical and Drilling Results Lead-Zinc-Copper Ore Body, Heath Steele Mine, New Brunswick, Canada (courtesy P. Hallof).

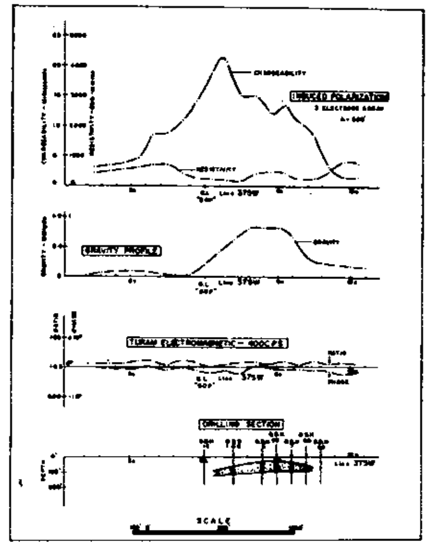


FIGURE 13

Geophysical and Drilling Results, Pyramid No. 1 Lead-Zinc Ore Body Pine Point Area, Northwest Territories, Canada (courtesy Pyramid Mines, Ltd.).

Where electromagnetic detection is feasible it is usually far more rapid and economical to apply electromagnetic induction methods to the problem. The I.P. method is the only geophysical tool available which is capable of direct detecting 1 percent or less by volume of metallic conducting sulphides.

It is best used, therefore, where there is a high ratio of economic minerals to total sulphide mineralization. Included in the proper I.P. range are such types of deposits as disseminated copper ores, in porphyry or bedded forms; lead-zinc deposits, particularly of the bedded type in carbonate rocks; gold and other deposits which have an association with disseminated metallic conductors. For many of these mineral occurrences the I.P. method is unique in providing detection.

Figure 12 shows time-domain discovery traverses over a typical newly discovered porphyry copper deposit in British Columbia. The lateral limits of the mineralization can be readily determined from the geophysical data, as well as the depth to the upper surface of the mineralization.

Figure 13 shows a discovery traverse over a major bedded body of sphalerite-galena-marcasite mineralization in carbonate rocks in the Pine Point area, Northwest Territories, Canada. For comparison purposes both gravity and Turam electromagnetic profiles on the same section are shown.

It is interesting to note that, despite an appreciable resistivity depression over the mineralization there is no significant Turam response at 400 c.p.s. The conductivity of the ore is, in fact, no higher than that of the surficial deposits in the general area, so that electromagnetic and resistivity methods yield, in themselves, no useful information.

The gravity method, although yielding a positive response in this instance, does not provide a good reconnaissance tool in this area because of karst topography and other sources of changes in specific gravity.

One occasionally encounters a deposit of the "massive sulphide" type which is normally thought of as an electromagnetic type of target because of its high conducting sulphide content, but which, obviously because of the lack of large scale continuity of the conducting sulphides, does not respond to the electromagnetic techniques. Figure 14 shows an intersection of ore grade material of this type, in New Brunswick, Canada, where electromagnetic methods had yielded negative results.

In many types of ore deposits the bulk of the I.P. response is due to the accessory non-economic sulphides, usually pyrite and pyrrhotite, and the ore minerals themselves are in the minority. A true test of the sensitivity of the I.P. method is an example of a low grade disseminated deposit with no such accessory minerals. Figure 15 illustrates such a case, with an I.P. discovery section over the Gortdrum copper-silver-mercury deposit in Ireland. The ore minerals consist of chalcocite, bornite and chalcopyrite in a dolomitic limestone, and there is less than 2% average by volume of metallic conducting minerals.

Whereas the bulk of I.P. measurements in mineral exploration has, naturally, been made on surface, the technology of drill hole exploration has been well developed, particularly by the Newmont group (see Wagg, 1963). The time-domain method is suitable for drill hole applications since it permits a relatively close coupling of the current and potential lines in a small diameter bore hole.

The three electrode array has been extensively employed for logging purposes, with a variety of electrode spacings to give varying ranges of detection away from the hole. In this fashion the variation of electrical properties with distance from the hole may be determined. A second, "directional log" then gives information on the direction of any anomalous material indicated by the detection log.

Whereas the I.P. method is usually employed as a primary exploration tool it may play an auxiliary role as well, e.g. to distinguish between metallic and ionic conducting sources of other types of electrical anomalies, e.g. electromagnetic.

Figure 16 shows a typical conducting zone revealed by a ground

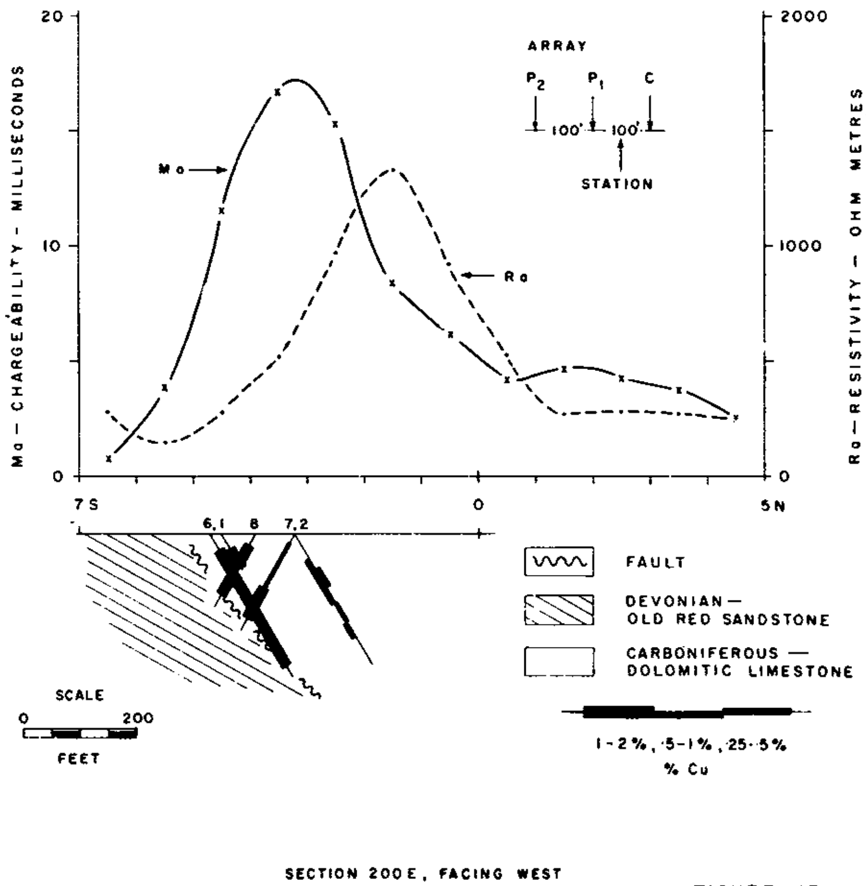


FIGURE 15

Geophysical and Drilling Results, Copper-Silver Ore Body, Gortdrum Mines, Ireland (courtesy Gortdrum Mines, Ltd.).

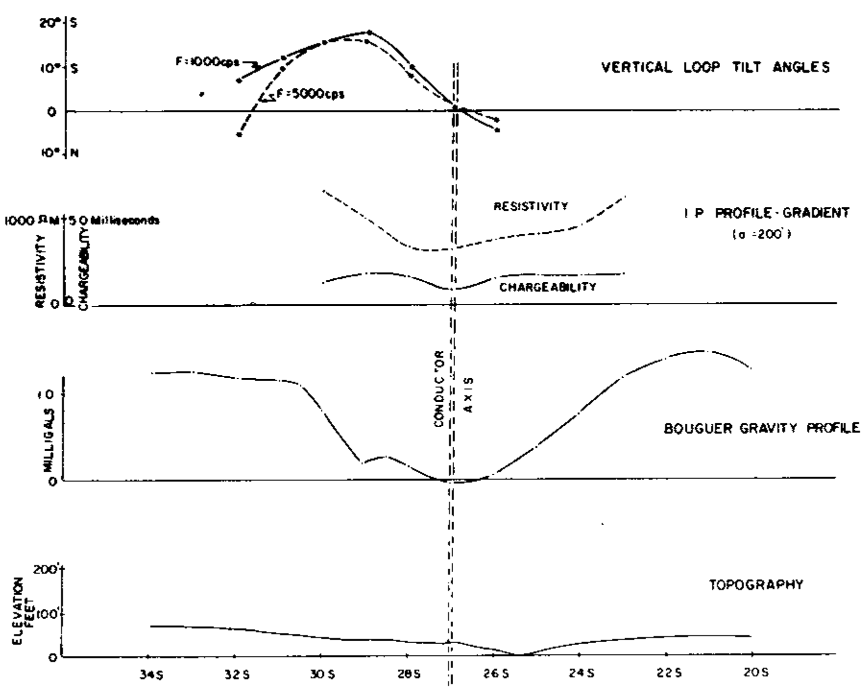


FIGURE 16

Geophysical Recognition of Overburden Trough, Northwest Quebec, Canada.

electromagnetic survey which was later proven, by drilling, to be due to overburden conduction in a bedrock trough. The I.P. response is in the low-normal range. The gravity profile, also shown, corroborates the presence of the bedrock depression.

Attempts have been made by a number of workers to employ the I.P. method in the field of groundwater exploration (e.g. Vacquier, 1957, Bodmer, 1968) but with no consistent success as yet. There are variations of chargeability from one type of non-consolidated sediment to another, but these fall, in general, within a relatively small range compared to the usual sulphide responses.

More investigation remains to be done in this area before a definitive conclusion can be reached. It is clear that more accurate measurements will have to be made in groundwater I.P. than in base metal I.P. investigations.

The I.P. method has a number of recognized limitations, some of a fundamental nature and others of a temporary nature reflecting the current state of the art. On a unit coverage basis the method is relatively expensive to apply, costing between $200 and $500 per line mile surveyed, in most instances. This cost has, however, been progressively reduced by advances in instrumentation resulting in decreased weight, increased sensitivity and rejection of earth noise effects. Some degree of improvement is yet to be expected in this area.

The same geometric limitations apply as with the resistivity method employing the comparable array. As a rule, a body of up to 10 per cent disseminated metallic conductors cannot be detected at a distance from its nearest point much exceeding its mean diameter. This detectability may be somewhat improved by the use of secondary criteria, but such improvement is likely to be only marginal.

Since Overvoltage is essentially a surface phenomenon the I.P. response from a given volume percentage of metallic conductors generally increases as the individual particle size is decreased. From the usual simple I.P. measurements, therefore, one cannot reliably predict the percentage by volume of such conductors in a deposit as there may be a variation of particle size throughout the deposit.

Still less can one differentiate between metallic conductors (e.g. chalcopyrite, galena, pentlandite) of economic interest and those of non-economic interest (e.g. pyrite, pyrrhotite and graphite). In addition we cannot even reliably differentiate between metallic sources of I.P. responses. The latter may include certain types of clay and, in consolidated rocks, such platey alteration minerals as serpentine, talc and sericite.

Empirically it has been found that, on the average, 1% by volume of metallic sulphides will increase the chargeability by about 2 – 3 times, depending on the host rock type.

Figure 17 shows a section across each of two anomalous I.P. areas in the Pine Point area, Northwest Territories, Canada. Section A is a discovery traverse across an ore body containing one half million tons of 11.4 per cent combined Pb and Zn and coming within 40 ft. of the ground surface. Section B is a traverse across what proved, by drilling, to be a karst sink hole, filled in with a variety of unconsolidated material including boulders and clay.

Based upon the chargeability amplitudes and the relative resistivity depressions the second case would appear to be far more promising than the first. In such cases the gravimeter has sometime proven to be of value in resolving the two types of occurrence but there is the very real possibility of the coincidence of a sink hole and a lead-zinc deposit, which would give rise to an uncertain resulting gravity response.

Any normal transient (time-domain) polarization decay and equivalently any curve of variation of apparent resistivity with frequency may be simulated by means of a mixture of metallic conductors of a suitable particle size distribution.

It is, however, possible in an area of common geology, that the various possible sources of I.P. responses may have significantly different characteristic curves in each of these two domains. A more thorough analysis of these curves at significant points is, therefore, of value.

Modern receivers in both domains (Figures 5 and 7) have the ability to give curve form information as well as a single quantity related to an I.P. amplitude.

Komarov (1967) documents such an example over a copper nickel deposit in the U.S.S.R. where, effectively the sulphide responses have a longer time constant than the normal non-metallic polarization.

An important source influencing I.P. measurements is the electromagnetic response of the earth. For a given electrode array the electromagnetic effect is dependent upon the frequency times the conductivity and the square of the spacing. In the frequency domain this source becomes troublesome (communication from P.G. Hallof) when:

1. The electrode spacing is 500 ft. or over and n = 3 or greater.
2. The highest frequency employed is 2.5 c.p.s. or greater.

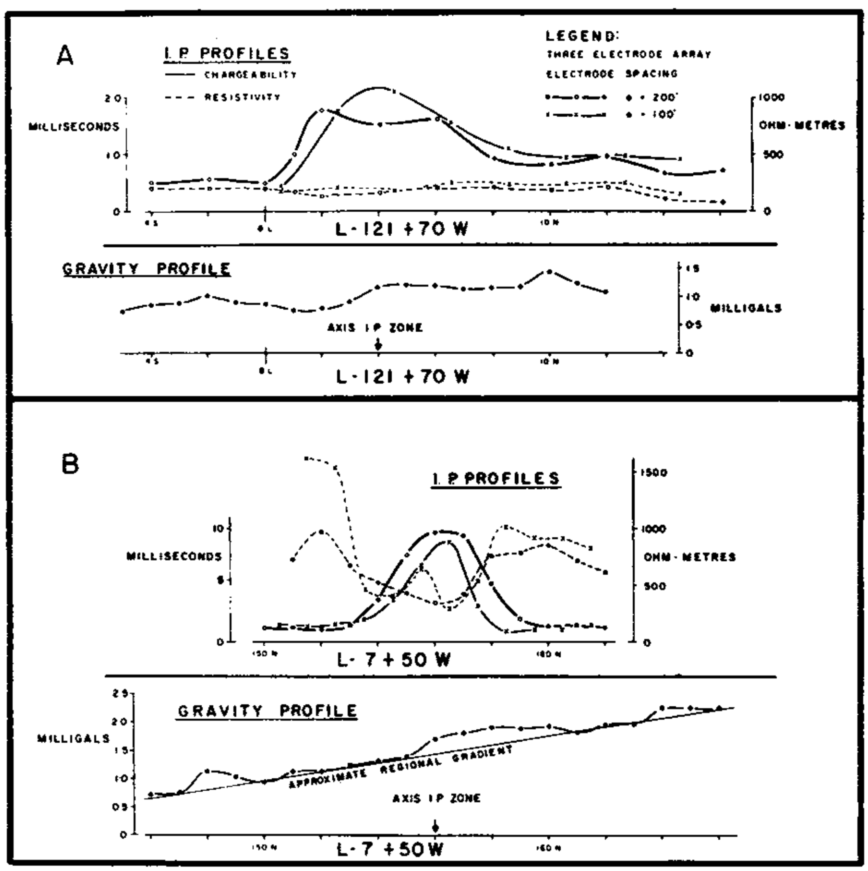


FIGURE 17

Possible Ambiguity of Induced Polarization Results, Pine Point Area, Northwest Territories, Canada.

3. The average earth resistivity is lower than about 25 ohm metres.

Electomagnetic effects are present in the time-domain measurements as well, of course, but are usually of lesser amplitude for the same array and earth conductivity, because the effective frequencies employed in the time domain are considerably lower (commonly 0.03 to 0.125 c.p.s.).

In the extreme, the electromagnetic response of a conducting earth may seriously interfere with useful I.P. measurements in either domain.

In the time domain I.P. measurements commonly only a single amplitude (at a specific time after current interruption) or an average amplitude over an interval of time after the current interruption is used to characterize the transient decay curve and act as a measure of the induced polarization characteristics of the medium in question.

It has been known since 1950 that useful secondary information is available in the shape of the transient decay curve associated with time domain induced polarization measurements. Equivalent remarks may be made in respect of frequency domain measurements where, instead of measuring the average slope of resistivity frequency over one decade of frequency, more information is obtained about the shape of this curve.

The type of information inherent in the curve shape relates primarily to two factors – (a) average metallic particle size associated with the source of an anomalous I.P. response, and (b) the presence of electromagnetic transients arising from highly conducting geologic units. For convenience we will restrict the following remarks to time domain measurements, although equivalent statements may be made in the frequency domain.

It has been established through laboratory measurements that (a) metallic conductors of large average particle size give rise to time domain decay curves of relatively long time constant, and (b) metallic conductors of small average particle size give rise to decay curves of relatively short time constant. For these reasons, if a shape factor as well as an amplitude factor of the decay curve can be established we may obtain information which is helpful in some of the following circumstances:

(1) very large or very small metallic particles – the response from these may distort the shape as well as the amplitude of the transient curve. Thus rather small amplitude anomalous metallic responses may be recognized in the presence of equal I.P. relief due only to non-metallic variations.

(2) two different types of anomalous response materials, in the same survey area, but differing in average particle size and/or decay curve form – e.g. serpentine, graphitic particles of small average size and coarse grained metallic sulphides.

One additional and rather common circumstance is the presence of (ionically) highly conductive overburden or consolidated rock units (e.g. saline overburden or shales). These units can give rise to electromagnetic transients of sufficiently long time constant to affect the usual I.P. amplitude measurement.

The shape of the E.M. transient is, in practice, markedly different from that of the usual I.P. transient, having a much shorter time constant than the latter. In addition, the polarity of the E.M. transient is often reversed to that of the I.P. transient. Curve shape measurements can provide a clear indication of the presence of significant E.M. interference and even a semi-quantitative estimate of the latter, enough to allow a correction factor to be applied.

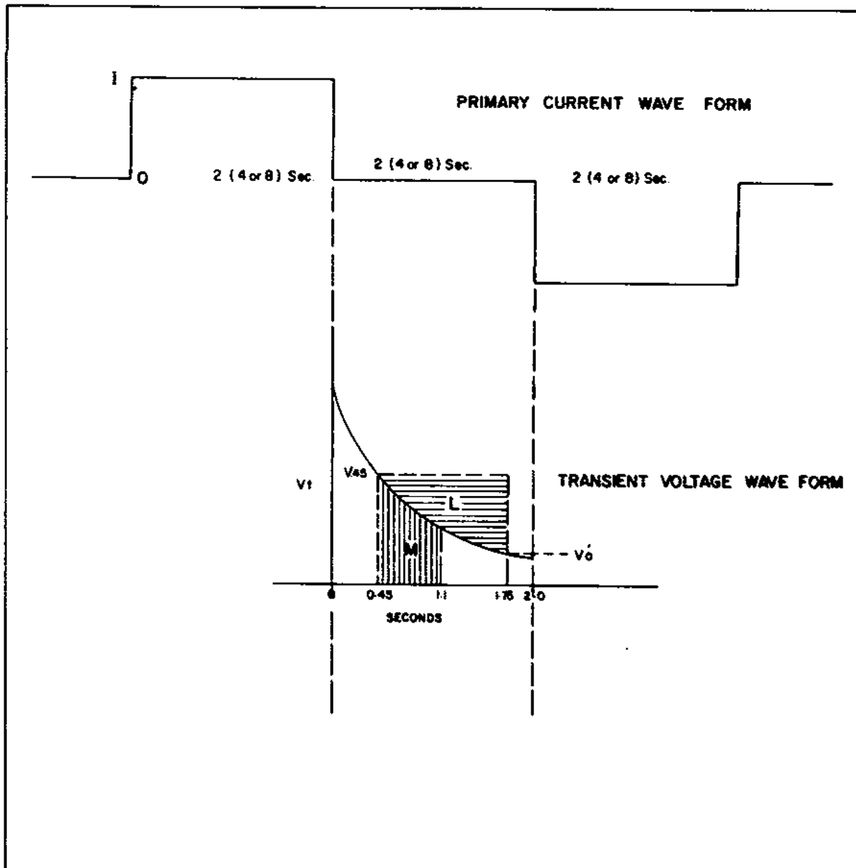
Equipment of the type illustrated in Figures 4 and 5 (e.g. Scintrex MK VII System) permit appropriate transient curve shape information to be obtained. Common to all the transmitters in this system is the ability to pass a repetitive, interrupted square wave pattern current into the ground, as shown on Figure 4. The current-on time may be 2, 4, or 8 seconds and the current-off time may be likewise selected. Measurements of I.P. transient curve characteristics are made during the current-off time.

Figure 18 shows the quantities measured by the Newmont-type receiver. In these receivers one sets the gain of certain amplifiers common to both the primary voltage Vp and transient voltage Vt measurements so that these voltages are essentially normalized.

The usual amplitude measurement performed by these receivers consists of an integration of the area under the transient curve over a specified interval after the interruption of the primary current and is designated by the letter M – the "chargeability" namely, 0.45 seconds to 1.1 seconds.

The 0.45 second delay time allows most E.M. transients, switching transients and interline coupling effects to disappear prior to the making of the measurement. Different measuring intervals may be employed under specific conditions.

In addition to M, the Newmont-type MK VII receiver is equipped to measure a quantity "L" which is defined as the time integral of the area *over* the transient curve, for a specified time interval, taking as reference voltage the



Operation of Scintrex Mk VII (Newmont-type) I.P. System.

transient voltage value at the beginning of the time interval. In practice, the interval selected is 0.45 seconds to 1.75 seconds, as shown on Figure 18, although different intervals may be employed under certain conditions.

The ratio of L/M is taken as a sensitive indication of transient curve shape. It has been well established, by many tens of thousands of I.P. measurements with these systems in many parts of the world, that the L/M measurements in non-metallically-mineralized areas, for a given current wave form, are constant within better than 20%.

Significant departures from these ratios usually imply an abnormal condition – either an anomalous metallic polarization response, electromagnetic or interline coupling.

Figure 19 shows a range of transient curves and their possible cause. For each case the "normal" transient curve is also shown. These cases illustrate the sensitivity of the L/M ratio to the transient time constant. A significant increase in L/M implies an abnormally short time constant, (Case A) reflecting either positive E.M. effects or small particle size. This should, in either case, normally be accompanied by an increase in apparent chargeability M.

A modest increase in L/M ratio, reflecting an increase in time constant (Case B) may reflect either the presence of large particle size metallic conductors, in which event an increase in M may or may not be appreciably reduced.

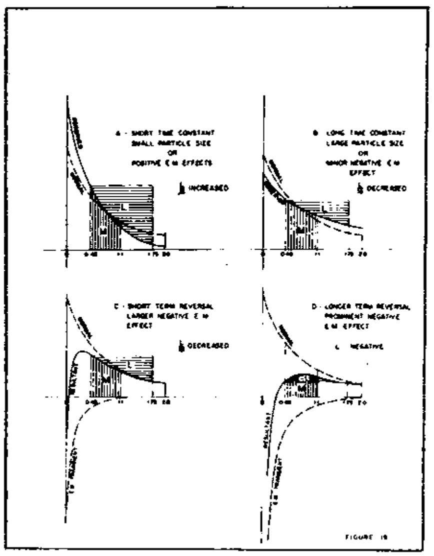
Cases C and D show the effect of reversed polarity E.M. transients of increasing amplitude. In Case C there is a short term Vt reversal and, although M is only slightly reduced, L/M is considerably reduced. In Case D, which is considerably more extreme, Vt is still rising at 0.45 seconds, so that L and thus L/M are, in fact, negative. M is considerably reduced from its normal value in this case, but a warning to this effect is clearly indicated by the L measurement.

A quantitative estimate of the E.M. transient response and, therefore, correction for it, may be obtained by one of a number of means. One may, for example, vary the current-on time, e.g. from 2 seconds to 8 seconds. The E.M. transient, being of relatively short time constant, will not change. The I.P. response will change by an amount which is fairly predictable, assuming a normal decay form. We thus obtain two equations in two unknowns from which the true I.P. response may be derived.

Curve shape measurements may be made in other ways as well, for example, by actually recording the complete transient decay curve. Whereas theoretically useful, such measurements have proven unwieldy from a weight and time standpoint. To obtain clean decay curves requires a high signal/noise ratio and thus high powers.

In the frequency domain the equivalent curve form information would be obtained through the use of three or more properly selected operating frequencies.

There is a continuing rivalry between protagonists of time-domain and frequency domain measurements. All that is clear is that neither method is superior in all respects to the other. The same phenomenon is being measured in different ways often with different arrays and the results are presented different formats (pseudo-sections in the frequency domain versus profiles in or contour plans in the time domain).



Significance of Curve Shape (L/M) Information.

The "Metal Factor", which is a mixture of physical properties, is commonly presented with frequency domain measurements only. These differences are largely superficial and are based on separate historical developments and subjective preferences.

There is a direct mathematical transformation between I.P. measurements in the two domains. Theoretically, at least, the same information can be obtained in either domain. Practically, however, there are certain differences.

The time domain measurements are absolute, i.e. are measured in the absence of the steady state voltage and are disturbed only by earth noises as a background. The amplitude of these measurements is usually less than 1% of the steady state voltage, but even so they can usually be made to an accuracy of better than 10 per cent even in unmineralized rocks.

The limit of useful sensitivity is related only to the regional uniformity of the background I.P. response. In the frequency domain the I.P. response is measured as a difference in transfer impedances. This difference can be measured with an accuracy of only 0.3% with extremely stable equipment. Since the non-metallic background P.F.E. over the interval of 0.1 to 2.5 c.p.s. is usually less than 1%, the probable error of these measurements may be 30% or more.

For this reason it is seen that it is feasible to obtain greater sensitivity of measurement in the time domain. This increased sensitivity is of value in areas of low "geologic" and electrical noise. By "geologic noise" is meant the range of variation of I.P. parameters within the normal rock types of the area. The application of I.P. to groundwater prospecting may have to develop through the time domain avenue because of the sensitivity requirements.

The frequency domain equipment requires somewhat less primary power than the time domain equipment because the former measurements in an A.C. one with the ability to use tuned filters and amplifiers as well as devices as phase-lock detectors. This advantage is not so marked as it once was, as current time-domain equipment, with its self adjusting earth voltage balance and ability to sum any desired number of integrations, provides a high degree of noise rejection.

Under truly random noise conditions the summation of n integrations provides the usual $1/\sqrt{n}$ reduction in statistical noise and is a powerful non-subjective means of noise suppression. The suppression of A.C. power line noise is much better with the time domain (integrating type) measurements than with frequency domain measurements.

Reference has already been made above to the relative effects of the electromagnetic response of the earth in both methods. Similar remarks apply to capacitative and inductive coupling effects between current and potential cables, although such effects can be largely avoided in any event by careful positioning of the cables, except possibly in drill hole surveying. So far, only in the time domain may useful drill hole measurements be made with both current and potential electrodes lying side by side in a small diameter bore hole.

An individual geologist or geophysicist may have had his first acquaintance with or instruction in the I.P. method using either the time domain or frequency domain. He becomes familiar with the arrays used and with the method of presentation of data employed. Thereafter, he tends to resist switching to the other domain in the belief that not only will he have to deal with different geophysical equipment and electrode arrays but also with different quantities, presented in quite a different fashion. This is erroneous.

So far as arrays are concerned the time domain uses them all – dipole-dipole, pole-dipole (three electrode) Wenner and gradient (Schlumberger). The frequency domain commonly uses only the first two and is restricted from using the latter two because of interline coupling effects.

Of the quantities measured in both domains the resistivity is, of course, the same, making due allowance for units. The time domain "Chargeability" is, normally very nearly proportional to the "Percent Frequency Effect" or "P.F.E.". The so-called "Metal Factor" is the ratio of P.F.E./Resistivity, and would, therefore, be equivalent to the ratio of Chargeability/Resistivity.

The time domain data presentation is commonly in the form of profiles and contour plans.

The frequency domain presentation is commonly in the form of "pseudo-sections" showing the different spacing results displaced progressively downwards with increased electrode spacing. Either type of data may be presented in either form of course, to suit the tastes and experience of the individual geologist or geophysicist.

The Gradient array is very useful in obtaining bedrock penetration where the bedrock is highly resistive compared to the overlying overburden. In such cases using the pole-dipole or dipole-dipole array very little current actually penetrates the bedrock and the I.P. characteristics observed are those of the overburden only. As was mentioned above, only time domain measurements may be carried out using this array.

There is a special practical advantage to the time domain measurements in areas where it is very difficult to make good ground contact. In such areas the problem of keeping the primary current rigidly constant, necessary for the frequency domain measurements, becomes severe.

In the time domain, if the primary current varies by as much as 10% during the measurement the absolute error in the chargeability may only be about 5%, which is not significant. This problem is often encountered in very arid areas, e.g. parts of Peru, Chile and other desert regions.

Despite these slight effective differences both methods of I.P. exploration have amply demonstrated their value through important mineral discoveries in many parts of the world. The role of I.P. in mineral exploration is well acknowledged and rapidly expanding.

The writer wishes to thank the various sources of case histories and illustrations cited in the text and in particular, Dr. Keeva Vozoff and Dr. Philip Hallof for valuable contributions.

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AREA "A"
L 28 N
L 20 N
L 12 N
BASE LINE
6 W
10 E
20 E
30 E
AREA "B"
L 36 S
L 40 S
BASE LINE
10 E
20 E
30 E
AREA "C"
L 24 S
L 28 S
L 32 S
BASE LINE
10 E
20 E
30 E
4587
M3
Department of Mines and Petroleum Resources
ASSESSMENT REPORT
NO. 4587 MAP #3
LEGEND
CONFIGURATION A BROADSIDE
CONFIGURATION A IN-LINE
CONDUCTOR AXIS
CONVENTION: EAST TILT ANGLES ON NORTH SIDE OF LINE - BROADSIDE
NORTH TILT ANGLES ON NORTH SIDE OF LINE - IN-LINE
600 γ
500 γ
400 γ
VERTICAL SCALE : 1" = 20°
NOTE: INTERLINE SPACING NOT TO SCALE
COAST INTERIOR VENTURES LTD. (N.P.L.) (1)
BARKERVILLE AREA, B.C.
GROUND GEOPHYSICAL SURVEY
SCINTREX MF-2 MAGNETOMETER
SCINTREX SE-300 VERTICAL LOOP E.M.
SCALE 1" = 200'
SURVEY BY
SCINTREX SURVEYS LTD.
JUNE 1973
PLATE 1
73-908-1


AREA "A"
L 28 N
L 20 N
L 12 N
N.R.
BASE LINE
6 W
10 E
20 E
30 E
AREA "B"
L 36 S
L 40 S
BASE LINE
10 E
20 E
30 E
AREA "C"
L 24 S
L 28 S
L 32 S
N.R.
BASE LINE
10 E
20 E
30 E
4587 M4
Department of Mines and Petroleum Resources ASSESSMENT REPORT
NO. 4587 MAP #4
LEGEND
3 ELECTRODE ARRAY
RESISTIVITY OHM-METERS
10,000
5000
1000
CHARGEABILITY MILLISECONDS
20
10
0
a=100 FEET
a=200 FEET
ANOMALOUS ZONE
NOTE: INTERLINE SPACING NOT TO SCALE
COAST INTERIOR VENTURES LTD. (N.P.L.) (2)
BARKERVILLE AREA, B.C.
INDUCED POLARIZATION SURVEY
SCINTREX MARK VII 2·5 kw UNIT
SCALE 1" = 200'
SURVEY BY SCINTREX SURVEYS LTD. JUNE 1973
PLATE 2
73-908-2

Department of Mines and Petroleum Resources
ASSESSMENT REPORT
NO. 4587 MAP #5

COAST INTERIOR VENTURES LTD. (N.P.L.) (3)

BARKERVILLE AREA, B.C.

GROUND GEOPHYSICAL SURVEY

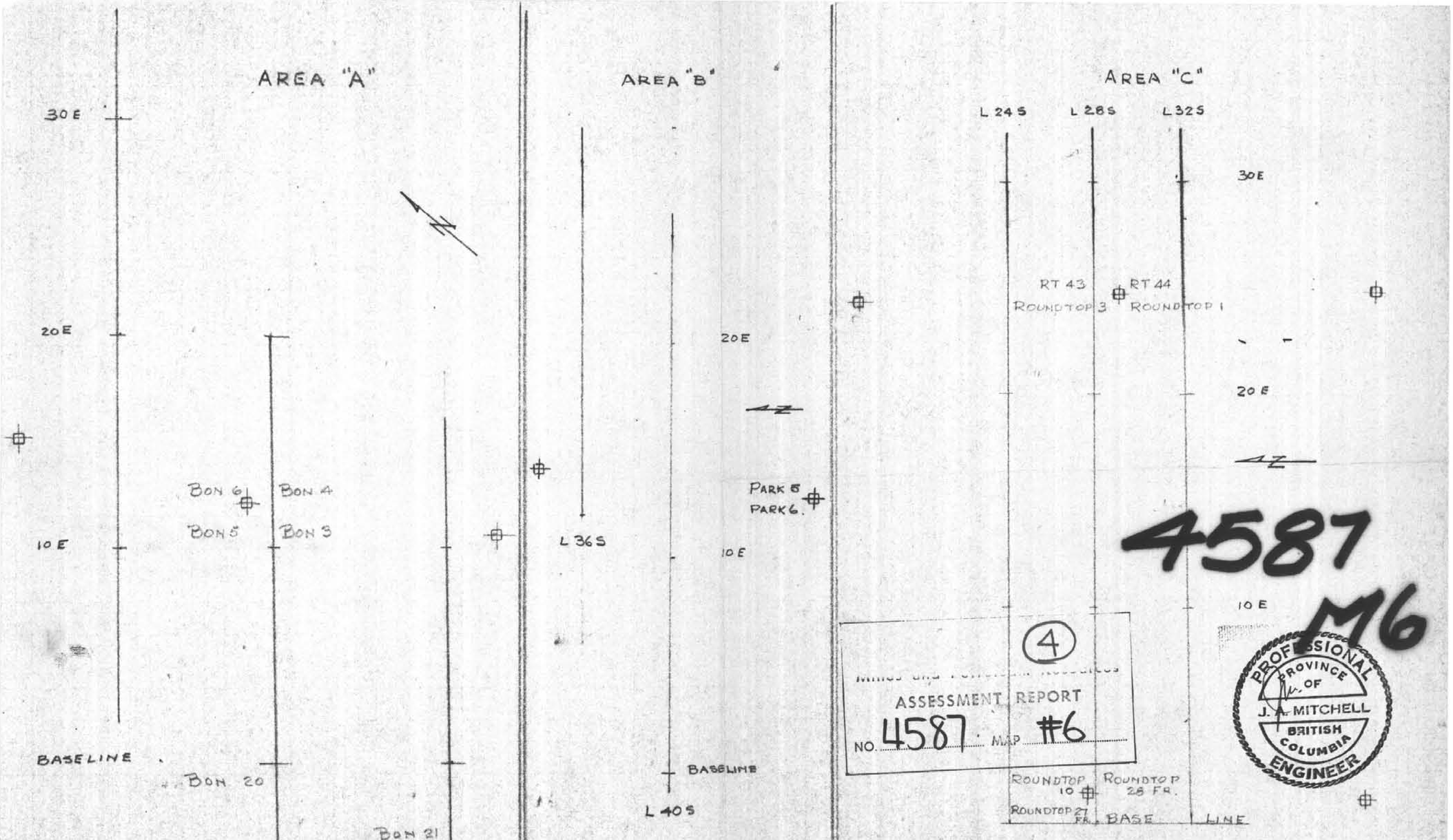
SCINTREX VLF-E.M.-SCOPOS

SCALE 1"=200'

SURVEY BY
SCINTREX SURVEYS LTD.
JUNE 1973

PLATE 3

73-908-3



NOTE: POSTS SHOWN RELATIVE TO NEAREST GEOPHYSICAL LINE. SCALE 1" = 400'.

CLAIM POST LOCATIONS RELATIVE TO GEOPHYSICAL LINES.
TO ACCOMPANY GEOPHYSICAL REPORT BY SCINTREX FOR COAST INTERIOR VENTURES.
JUNE 1973.