REPORT ON GROUND GEOPHYSICAL SURVEYS
CONDUCTED ON THE KOZOWY PROPERTY
DRYDEN AREA, NORTHWESTERN ONTARIO

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JVX Ref: 8760
July, 1987

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MINING LANDS SECTION
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A REPORT ON GROUND GEOPHYSICAL SURVEYS
CONDUCTED ON THE KOZOWY PROPERTY
DRYDEN AREA, NORTHWESTERN ONTARIO

On Behalf Of

FALCONBRIDGE LIMITED

1. INTRODUCTION

Between June 10th and July 3rd, 1986 Induced Polarization (IP)/Resistivity surveys were conducted on behalf of Falconbridge Limited on the Kozowy Property, Dryden, Ontario by JVX Ltd.

The IP survey employed the gradient array with a potential electrode spacing of 25 metres. A total of 38.5 line-km (1580 measurement points) of gradient coverage was achieved.

Additional ground surveys were conducted by JVX Limited over the same area. These included Magnetics, VLF and pole-dipole IP/Resistivity. The results of these surveys are described in earlier report (JVX Ref: 8616, dated August 1986).

This report describes the survey logistics, procedures, interpretation and includes the final data presentation products consisting of contour plan maps.

2. SURVEY LOCATION AND ACCESS

The Kozowy Property survey area is located near Flambeau Lake off provincial Hwy. 594, approximately 7km southwest of Dryden, Ontario in the Eagle Lake area of Northwestern Ontario.

Figure 1 show the location of the survey area with respect to nearby population centres at a scale of 1:250,000.

Access to the grid is via Ojibway Drive off the Dryden/Ft. Francis Highway (Hwy.# 502).

3. SURVEY GRID AND COVERAGE

A outline map of the survey grid may be found in Figure 2. The baseline of the grid is oriented east-west and the wing lines are nominally 50 metres apart.

The claim map of the survey area is shown in Figure 3.
LOCATION MAP

FALCONBRIDGE LTD.

DREYDEN AREA, ONTARIO

GROUND GEOPHYSICAL SURVEY

Scale: 1:250,000

Survey by JVX Ltd.

Figure 1
SURVEY AREA MAP
FALCONBRIDGE LTD.
DRYDEN AREA, ONTARIO
GROUND GEOPHYSICAL SURVEY
Scale: 1:50,000

Survey by JVX Ltd.

Figure 2
A detailed breakdown of the survey coverage follows in Table 1.

**TABLE 1**  
**PRODUCTION SUMMARY: IP/RESISTIVITY**

<table>
<thead>
<tr>
<th>LINE</th>
<th>COVERAGE FROM</th>
<th>TO</th>
<th>LINE LENGTH (Metres)</th>
<th>MEASUREMENT POINTS</th>
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<td>1050S</td>
<td>825N</td>
<td>1875</td>
<td>76</td>
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<td>1200S</td>
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</tr>
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<td>875N</td>
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<td>42</td>
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<td>L-650E</td>
<td>225N</td>
<td>825N</td>
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<td>43</td>
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<tr>
<td>L-700E</td>
<td>225N</td>
<td>825N</td>
<td>1050</td>
<td>43</td>
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<td>825N</td>
<td>1050</td>
<td>43</td>
</tr>
<tr>
<td>L-750E</td>
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<td>43</td>
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<td>825N</td>
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<td>225N</td>
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<td>43</td>
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<td>1050</td>
<td>43</td>
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<tr>
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<td>825N</td>
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<tr>
<td>L-1050E</td>
<td>675N</td>
<td>700N</td>
<td>25</td>
<td>2</td>
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**Total**                  
**38,525m**                  
**1580pts**
The following claims have been covered with the IP/Resistivity survey. The claims boundaries are shown in Figure 3.

| TABLE 2 |
| List of the claims covered with IP/Resistivity survey |

| Claim Number: |
| 862783 |
| 862784 |
| 862785 |
| 862786 |
| 862787 |
| 842078 |
| 842079 |
| 842081 |
| 842082 |
| 842085 |
| 842089 |
| 842090 |
| 590318 |
| 590552 |
| 862781 |
| 862782 |

4. PERSONNEL

Mr. Steve Bortnick - Geophysical Technician/Party Chief. Mr. Bortnick operated the IP receiver and compiled the data with the Corona PC-400 microcomputer and Scintrex Soft II program. Mr. Bortnick acted as party chief and was responsible for data quality and the day to day operation and direction of the survey.

Mr. Fred Moher - Geophysical Technician. Mr. Moher operated the IP receiver and assisted in data compilation.

Mr. Zdenek Duchoslav - Geophysicist. Mr. Duchoslav assisted in the in-field data compilation.

Mr. Steve Bortnick, Jr. - Field Assistant/Transmitter Operator.

Three men were hired locally to act as field assistants.

Mr. Neil Hughes - Geophysicist. Mr. Hughes compiled the geophysical results and prepared the report.

Mr. Blaine Webster - Consulting Geophysicist, JVX Ltd. Mr. Webster provided overall supervision of the survey and reporting from the Toronto office.

A list of those involved in field portion of the survey follows.
Based on average of 12 hours per work day a total of approximately 1188 work hours has been spent in the field.

A list of those involved in the office compilation for this survey follows.

**5. INSTRUMENTATION**

5.1 IP Receiver

The Scintrex IPR-11 Time Domain microprocessor-based Receiver was employed. This unit operates on a square wave primary voltage and samples the decay curve at ten time gates or slices. The instrument continuously averages primary voltage and chargeability until convergence takes place and the averaging process is stopped. Accepted data is stored internally on solid-state memory.

5.2 IP Transmitter

The survey employed the Scintrex TSQ-3/3kw Time Domain Transmitter powered by an 8hp motor generator. The TSQ-3 is designed for a selectable square wave output of 2, 4 or 8 seconds 'on' time. The in-field current output was accurately monitored with a digital multimeter placed in series to the current loop.
5.4 Data Processing

The IP survey data were archived, processed and plotted by a Corona PC-400 microcomputer using an Epson FX-80 dot matrix printer. The system was configured to run the Scintrex Soft software package, a suite of programs that was written specifically to interface with the IPR-11 IP receiver. At the conclusion of each day’s data collection, data resident in the receiver’s memory was transferred, via serial communication link, to the computer—thereby facilitating editing, processing and presentation operations. All data was archived on floppy disk. In the Toronto office the data was ink-plotted in plan contour format on a Nicolet Zeta drum plotter interfaced to an IBM PC/XT microcomputer.

6. EXPLORATION TARGET, SURVEY METHOD, AND FIELD PROCEDURES

6.1 Exploration Target

There are two geophysical targets described as follows:

a) Zones consisting of close-spaced, fracture filling quartz vein swarms in competent quartz-diorite sills; the main showing is of this type. The wall rock between the quartz veins is carbonatized and has generally 1-2% disseminated pyrite, but with sections to 15m with containing 3-4% pyrite. There are minor silicified zones. The quartz vein swarms have a preferred N40 W orientation and a steep dip. They appear to be following cross-structures that are themselves occupied by quartz-feldspar porphyry dykes.

b) Quartz vein swarms with up to 30% pyrite cutting carbonatized volcanics with 5-10% pyrite as veinlets and disseminations. It is thought to be controlled by the same NW-SE cross-structure system.

Overburden is reported to be less than 2m thick. There is 3-5% disseminated magnetite in the quartz-diorite and also in parts of the volcanics.

6.2 Survey Method (IP)

The phenomenon of the IP effect, which in the time domain can be likened to the voltage relaxation effect of a discharging capacitor, is caused by electrical polarization at the rock or soil interstitial fluid boundary with metallic or clay particles lying within pore spaces. The polarization occurs when a voltage is applied across these boundaries. It can be measured quantitatively by applying a time varying sinusoidal wave (as in the frequency domain measurement) or alternately by an interrupted square wave (as in the time domain measurement).
In the time domain the IP effect is manifested by an exponential type increase or decrease in voltage with time. The frequency domain measures either the difference in voltage as a function of frequency (maintaining constant current) or the real and quadrature components of the voltage compared to the transmitted current.

Both methods measure essentially the same phenomenon and theoretically the response of one can be translated to the other domain by Fourier analysis. The two methods are qualitatively comparable if only a change in relative response amplitude is required, i.e. an anomaly in the time domain will have a similar anomaly in the frequency domain provided the noise levels and resolution of the measuring devices are the same.

The direct current apparent resistivity is a measure of the bulk electrical resistivity of the subsurface. Electricity flows in the ground primarily through the groundwaters present in rocks either lying within fractures or pore spaces or both. Silicates which form the bulk of the rock forming minerals are very poor conductors of electricity. Minerals that are good conductors are the sulphide minerals, some oxides and graphite where the electrical flow is by electronic means rather than ionic.

The two methods of measuring the IP effect employ the same geometries of electrodes. The measurement is made by applying a current across the ground using two electrodes (current dipole). The potential field (voltage) and IP effect can then be mapped in an area around the current source using what is essentially a very sensitive voltmeter and a second electrode pair (potential dipole). The former parameter, when normalized for the amount of current flowing in the ground, reflects the bulk apparent electrical resistivity of the subsurface. The latter parameter, as previously mentioned, says something of the polarizability of the ground which is due to the content of metallic or clay minerals.

Gold mineralization, the target of this survey, does not occur in sufficient quantities to effect either the bulk polarizability or resistivity of the ground. The anomalous IP response will be engendered by the sulphides which are commonly associated with gold deposits.

The resistivity data is useful in mapping lithologic units and geologic structures such as faults and shear zones. For gold exploration it is particularly useful to delineate zones of silicification which is often associated with gold mineralization.

Historically the time domain IP response was simply a measure of the amplitude of the decay curve, usually integrated over a given period of time. Over the last decade, advances in technology have made it possible to measure the decay curve at a number of points, thus allowing the reconstruction of the shape of the curve. By measuring the complete decay curve in the time domain, the spectral characteristics of the IP response may be derived.
Recent studies have shown there is a relationship between the decay form and the texture or grain size of the polarizable minerals, i.e. the IP response is not only a function of the amount or type of the polarizable material. This could be important when it comes to ranking anomalies of equal amplitude or discriminating between economic and non-economic sources. The parameters that describe all the properties of the IP response are the spectral parameters m, c, and tau. These parameters are described further in a paper accompanying this report.

The spectral data has proved useful in differentiating between fine-grained and coarse-grained sulphides or graphite. Gold is often found associated with sulphides that are fine grained. Experience has shown the M-IP parameter (derived m) is helpful in ranking anomalies in areas of high resistivity, where the apparent chargeability is increased sympathetically. Also in areas of low conductivity, the parameter has proved advantageous in determining which anomalies have sulphide sources.

As the source discrimination capability of the IP measurement (either time or frequency domain) remains somewhat unclear, we might recommend that in areas with geologic control, the IP decay forms be studied for significant and systematic differences. If such differences appear (at a particular receive time), such may be applied elsewhere in the same geologic environment. Our experience has shown time constants (tau) are important interpretation aids in areas of moderate to high resistivities which occur with pyrite in zones of silicification.

6.3 Field Procedures (IP)

The IP/resistivity survey on the Falconbridge project employed the time domain method with a gradient array. The geometry of the gradient array is illustrated in the figure below.

Cross Section

Gradient Array
Figure 4
The electrodes marked Cl and C2 comprise the fixed current electrodes. Those marked by a P1 and P2 are the potential electrodes and are moved between the current electrodes on a grid within the following constraints:

\[
\begin{align*}
x/L & \text{ remains less than 0.3} \\
d/L & \text{ remains less than 0.3} \\
a/L & \text{ remains less than 0.05}
\end{align*}
\]

The line joining the two potential electrodes must remain parallel to the line joining the current electrodes. The gradient array survey employed a 25m potential electrode separation.

The waveform of the transmitted current is a two second on-off alternating square wave. The IPR-11 measures the voltage (primary voltage) across each potential dipole at an appropriate time after the current begins its on cycle, which approximates a D.C. measurement of voltage, in order to determine the apparent resistivity of the ground.

The equation for the apparent resistivity is given by

\[
\rho_a = L^2 k / 4a \times V/I
\]

where 

\[
k = 2 / \left( \left( (1-D) / (Z^2 + (1-D)^2 \gamma_{4a}) + (1+D) / (Z^2 + (1+D)^2 \gamma_{4a}) \right) \right)
\]

and 

\[
Z = 2x/L \quad \text{and} \quad D = 2d/L
\]

The value of resistivity is a true value of subsurface resistivity only if the earth is homogeneous and isotropic. In nature, this is very seldom the case, and apparent resistivity is a qualitative result used to locate relative changes in subsurface resistivity only.

The IPR-11 will also measure the secondary or transient relaxation voltage during the two second off cycle of the current, which is a measure of the polarizability of the ground.

Employing the two second cycle time, ten slices of the decay curve will be measured at semi-logarithmically spaced intervals starting at 45 milliseconds after current turn-off up to 1590 milliseconds after turn-off. The measured transient voltage when normalized for the width of the slice and the amplitude of the primary voltage yields a measure of the polarizability called chargeability in units of millivolts/volt.

Chargeability (M) as measured by the IPR-11, is averaged over several periods of the transmitted waveform and normalized for:

1. the length of the integration interval;
2. the steady state voltage and
3. the number of pulses.
Mathematically this is described as:

\[ M = \frac{1000}{V_p \cdot tr} \int_{t_1}^{t_2} Vs \, dt \]

where

- \( M \) = chargeability (mV/V)
- \( Vs \) = secondary voltage
- \( V_p \) = primary steady state voltage
- \( tr \) = integration interval \((t_2 - t_1)\)
- \( t_1 \) = time at beginning of integration
- \( t_2 \) = time at end of integration

By adjusting \( t_1 \) and \( t_2 \) the chargeability is sampled at different points of the decay. Figure 5 illustrates the decay waveform and the 10 slices of integration.

For a 2 second transmit and receive time the slices of integration are as follows:

<table>
<thead>
<tr>
<th>SLICE</th>
<th>DURATION (msec)</th>
<th>FROM (msec)</th>
<th>TO (msec)</th>
<th>MIDPOINT (msec)</th>
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</thead>
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<td>M0</td>
<td>30</td>
<td>30</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>M1</td>
<td>30</td>
<td>60</td>
<td>90</td>
<td>75</td>
</tr>
<tr>
<td>M2</td>
<td>30</td>
<td>90</td>
<td>120</td>
<td>105</td>
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<td>M3</td>
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<td>1770</td>
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</table>
7. DATA PROCESSING AND PRESENTATION

To allow for the computer processing of the IP data, the raw data stored internally in the IPR-11 was transferred at the end of a survey day to floppy diskette by the in-field microcomputer and the Soft communications software. The raw data was filed on diskette in ASCII character format using an IBM compatible (MSDOS) microcomputer. Once the data was stored on diskette, a number of processing techniques were employed.

An archive edited binary format data file was created in the field from the raw data file by the operator removing repeat or unacceptable readings and correcting any header errors such as station or line numbers. The concisely labelled and edited data was then dumped to a printer under the heading Data Summary.

Chargeability (M7) and apparent resistivity data was plotted and contoured by hand in the field in plan form.

In the JVX office M7 and resistivity data was gridded and after the completion of the survey contoured plan maps of a) the M7 slice of the n=1 dipole and b) the apparent resistivity of the n=1 dipole were computer generated and fine-drafted on mylar at the Toronto office at a scale of 1:2500 and with appropriate contour intervals. The maps for M7 chargeability and apparent resistivity show the grid lines with stations and lines labelled and have the geophysical values posted.

A listing of the final presentation product follows:

7.1 Plan Maps Plate Index (Table 3)

<table>
<thead>
<tr>
<th>Plate No.</th>
<th>Grid and Parameter</th>
<th>Scale</th>
</tr>
</thead>
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<td>1:</td>
<td>Apparent Resistivity Contour Plan Map (East Block)</td>
<td>1:2500</td>
</tr>
<tr>
<td>2:</td>
<td>Apparent Resistivity Contour Plan Map (West Block)</td>
<td>1:2500</td>
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<tr>
<td>3:</td>
<td>Chargeability (M7) Contour Plan Map (East Block)</td>
<td>1:2500</td>
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<tr>
<td>4:</td>
<td>Chargeability (M7) Contour Plan Map (West Block)</td>
<td>1:2500</td>
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<td>5:</td>
<td>Compilation / Anomaly Map (East Block)</td>
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<tr>
<td>6:</td>
<td>Compilation / Anomaly Map (West Block)</td>
<td>1:2500</td>
</tr>
</tbody>
</table>

Gradient array anomalous sections are identified with a representative axis and labelled with an identifying letter on the compilation map.

The large scale or regional anomalies due to major lithological units are not identified on the compilation map and are best represented by the broad changes in the contour plan maps.
8. DISCUSSION OF RESULTS

The following interpretation is based all geophysical surveys conducted on the Kozowy Property by JVX Ltd. including IP/Resistivity gradient and pole-dipole electrode arrays, Magnetic and VLF surveys.

One broad, WSW trending zone of anomalous chargeability, and two minor zones of anomalous chargeability are identified on the Kozowy Property. These zones are marked by weak to strong chargeabilities and moderate to very high resistivities.

The major chargeability zone transects the whole grid from L-1800E to L-600W, between Sta. 400S and 400N. Within this broad zone several chargeability trends are defined, corresponding to areas having local anomalous highs and also displaying line to line correspondence. The broad chargeability zone is also coincident with high to very high resistivities, generally greater than 30 000 ohm-m. A similar trend is apparent throughout the grid: areas having anomalous local chargeability highs will either have higher coincident resistivities, or more variable resistivity responses when compared to local background.

ZONE 1:

As mentioned before, Zone 1 is a broad anomalous IP expression which transects the entire grid. Within this broad zone 14 axes have been defined which connect areas of local anomalous highs which also have line to line correspondence.

Axis A1:

This anomaly axis defines a narrow chargeability zone lying to the east of the grid, extending from L-1800E to L-1550E, between Sta. 0 and 100N. The trend appears to be terminated to the west by a resistivity low (perhaps a shear zone). The axis is coincident with a magnetic high axis, corresponding to the eastern extension of the diabase dyke.

Chargeability values along the axis are moderate to high, 10 to 27mV/V, with background values less than 8mV/V. The section is associated with a weak resistivity low, values being between 10 000 and 30 000 ohm-m. To the north of the section and sub-parallel to it is a stronger, well defined resistivity low, possibly a shear zone. Pole-dipole coverage of this area mapped the same axis, with M7 peaks greater than 20mV/V. Computation of the spectral parameters yielded values of M-IP greater than 450mV/V, and tau values less than 0.1sec, suggesting the source of the chargeability response is large quantity of fine grained polarizable material (probably sulphides considering the low time constant).

The axis is cross-cut by a NE trending zone of magnetic dislocation/contact.
Recommendation: Even though the anomaly is associated with a magnetic high this is a high priority target because of the high M-IP's and low tau values. If drilling is contemplated the target zone should be near the zone of magnetic dislocation.

Axis B1:

This anomaly axis again defines a narrow anomalous zone, and lies to the north of, and parallel to, axis A1. Axis B1 extends from L-1800E to L-1550E, between Sta. 75N and 200N.

The section is marked by moderate to strong chargeability responses, 10 to 20mV/V, and background values of less than 8mV/V. The section is associated with resistivity values greater than 30 000 ohm-m, and the axis itself is coincident with a local resistivity high trend. Coincident pole-dipole chargeability M7 peaks are weak to moderate, and calculated M-IP values vary between 180 and 250mV/V. An exception on L-1550E has a peak M7 value of 24.4mV/V and a calculated M-IP value of 763mV/V. Calculated time constants for the section are short, less than 0.1sec.

The axis is intersected by two NE trending zones of magnetic dislocation at L-1700E, Sta.100N and near L-1550E, Sta. 175N. The section lies in an area of uniform magnetics on the northern flank of the diabase dyke.

Recommendation: This anomaly is associated with high resistivities and higher chargeabilities and is therefore recommended for follow-up work.

Axis C1:

Anomaly axis C1 extends from L-1800E to L-1500E, between Sta. 200N and 300N, and is sub-parallel to axes A1 and B1. The axis defines a broad, moderate strength chargeability high, with coincident chargeabilities of 14 to 18mV/V, and background values of 8 to 10mV/V. Corresponding pole-dipole chargeabilities are weak to moderate, with the exception of L-1750E which has a M7 peak value of 26.6mV/V and a calculated spectral M-IP of 751mV/V. These high values are, however, restricted to the first dipole. For the rest of the area the calculated spectral M-IP is moderate to high, 250 to 350mV/V. Calculated time constants are short, less than 0.1sec.

Resistivity values across the section are uniformly high to very high, greater than 30 000 ohm-m.

From L-1800E to L-1650E there are uniform, lower valued magnetics. From L-1650E to L-1550E the magnetic results are higher and more active (higher spatial frequency), possibly defining a different source lithology. NE trending zones of magnetic dislocation are interpreted to bound this area of complex magnetics. To the west of this section are again more uniform magnetics.
The area bounded by L-1800E to L-1550E, between Sta. 200N and 375N, is characterized by a uniform, moderate chargeability response, 14 to 16mV/V, and high to very high resistivities, 30,000 to 50,000 ohm-m. It is reported that in this area bedrock is covered by a thin layer of moss which may result in electrode contact problems, leading to higher measured resistivities and inflated chargeabilities. Because the calculated spectral M-IP for this area is uniformly moderate to high, it is felt that the cause of the IP response is a large amount of polarizable material.

Recommendation: Since this area has uniformly high resistivities and a uniform chargeability response, the area is recommended for further evaluation. Sta. 300N, L-1650E is recommended for immediate follow-up work as it is situated in a local magnetic low and near a possible zone of dislocation/contact.

Axis D1:

This anomaly axis extends from L-1800E to L-1450E, between Sta. 275N and 375N, and is the northern extent of the broad anomalous Zone 1. It is marked by a moderate to strong chargeability response, 12 to 25mV/V, with the peak values recorded on L-1650E and L-1450E. The axis is associated with a resistivity low bounded by two local resistivity highs, and possibly marks a shear zone. Resistivity values associated with the section are high to very high, greater than 30,000 ohm-m.

Like axis C1, axis D1 transects a zone of higher frequency, higher valued magnetics lying in a background of more uniform magnetics between L-1700E and L-1600E. To the north of the axis is an area of lower, uniform magnetics.

On L-1650E, at Sta. 350N, is an area of high chargeability located in an area of magnetic and possible structural complexity. To the north of this high is a sharp resistivity and chargeability contrast. Pole-dipole coverage along L-1650E located a peak chargeability to the north of that located by the gradient array, suggesting the polarizable body is dipping to the north. The associated calculated M-IP for this body is 700mV/V suggesting a large amount of polarizable material. Again calculated time constants for the area are short, less than 0.1sec.

Apart from the two obvious chargeability highs, a third area recommended for follow-up work is Sta. 300, L-1550E to L-1500E. This area correlates to a local magnetic low, and is also situated near a zone of magnetic and possibly structural, complexity.

Axis E1:

This E-W trending axis defines a broad anomalous high within Zone 1 extending from L-1500E to L-1225E, between Sta. 175N and 225N. The axis is resolvable to Axis B1 but has not been as the two sections these axes define have different chargeability and resistivity characteristics.
With the exception of the peak on L-1500E the section is marked by a moderate peak chargeability response, 10 to 14mV/V, and background response of 10mV/V. The chargeability axis is coincident with a local resistivity high axis, and resistivities in the area are high to very high, 30 000 to 100 000 ohm-m. Pole-dipole coverage for this sector of the grid extends from L-1750E to L-1400E. The calculated M-IP values for the axis E1 section from L-1500E to L-1400E are weak to moderate, 200 to 250mV/V.

The axis lies in a slight magnetic low, compared to background.

The peak gradient chargeability response on L-1500E, Sta. 175N, is 26.5mV/V and corresponds to a strong pole-dipole chargeability peak, at Sta. 150N. The calculated spectral M-IP for the high is 350mV/V, with the peak M7 value identified in the latter potential dipoles, indicating a source at depth. This chargeability high is located in an area of structural complexity. There is a sharp resistivity and chargeability contrast to the south, a resistivity low to the north, and a NE trending zone of magnetic dislocation/dislocation to the west.

The high chargeability peak maps onto the low magnetic side of a conspicuous high-low magnetic pair. The peak magnetic value is greater than 62 500nT while the low is less than 60 000nT. If these results are valid they indicate a strongly magnetic prism as the source. (The data appear to be valid since there are several measurement points ie. 20m Sta. interval.) This magnetic high-low is cross-cut by both a resistivity low (shear zone) and a VLF conductor.

Recommendation: Apart from the large chargeability peak on L-1500E, the other area of interest is Sta. 200N, L-1225E. This area correlates to a slight magnetic low.

Axis F1:

Axis F1 defines a WNW trending, broad anomalous section that is coincident with the diabase dyke and extends from L-1400E to L-1050E, between Sta. 125N and 175N. The axis is also coincident with a resistivity low (a possible shear zone) from L-1275E to L-1100E. Chargeability peak values for the section are moderate, 10 to 16mV/V, with a background of 10mV/V. The higher chargeabilities being recorded on L-1150E and L-1100E. Resistivity values associated with the section are very high, 50 000 to 100 000 ohm-m.

The anomaly axis is bounded to the east and west by a pair of NE trending zones of magnetic dislocation/contact, the westerly one is also coincident with a local resistivity high across the dyke. The axis is also cross-cut by a zone of magnetic dislocation/contact at L-1150E, Sta. 150N.
There are no coincident VLF conductors that show structural control, or areas of dislocation. A weak VLF conductor sub-parallel to the diabase dyke is thought to be topographically controlled (basement and/or surface variations).

Recommendation: The area recommended for follow-up is from L-950E to L-850E, between Sta. 100N and 150N. It is not directly related to axis F since it does not show as an anomalous local chargeability high. However, the area is associated with a subtle resistivity change and is also associated with a local magnetic low.

Axis Gl:

Axis Gl extends from L-850E to L-700E, between Sta. 100N and 150N and is characterized by moderate to strong peak chargeabilities, 12 to 20mV/V, and background values of 8 to 10 mV/V. Resistivities for the area are very high, greater than 50 000 ohm-m. Coincident pole-dipole calculated M-IP values are moderate to high, 200 to 350mV/V, with the peaks coincident with the gradient peaks. The calculated time constants, τ, for the area are short, less than 0.03sec. To the east of the axis, on L-850E, is an area that was stripped in 1984 and showed strong carbonate alteration and quartz veining.

The axis is coincident with an area of more uniform magnetics situated in a complex magnetic package. To the west of the axis a NE trending zone of magnetic dislocation/contact is coincident with a lithologic boundary. Also coincident with the boundary is a weak VLF conductor.

Recommendation: There are two areas of particular interest associated with axis Gl. Sta. 100N, L-800E is located in an area of high resistivities and uniform magnetics, and has a high chargeability response. Sta. 0, L-500E and L-550E, has a moderate chargeability response and is located in an area of high resistivities. It is also associated with a local magnetic low.

Axis H1:

Axis H1 defines a broad, weak to moderate strength anomalous chargeability section extending from L-700E to L-150W, between Sta. 100N and 100S, and is coincident with a local resistivity high trend. Chargeability peak values vary from 10 to 15mV/V, with the higher values being recorded on L-600E to L-500E. Resistivities associated with the section are high to very high, 30 000 to 100 000 ohm-m, with the higher values recorded east of L-200E. Pole-dipole coverage across this section is limited to lines L-650E, L-550E to L-450E and L-50W. Pole-dipole anomalies corresponding to axis H1 are weak, with calculated special M-IP's less than 200mV/V.
The magnetics from L-700E to L-550E are complex, of a higher frequency and generally higher valued. From L-550E to L-150W axis H1 lies on the higher magnetic side of a magnetic boundary. To the south of the axis are lower value, longer spatial frequency magnetics. To the north there are higher valued but still relatively uniform magnetics.

There is no coincident VLP conductors. A geologically, and magnetically, mapped fault trending NE-SW may intersect the axis on L-150E.

Recommendation: An area of interest is Sta. 0, L-500E which is associated with a local magnetic low. The axis defines a long chargeability section and further geological, and other geotechnical work is recommended to further define possible target zones.

Following is a brief description of several short strike length or single line chargeability anomalies (Axes I1 to J4) located within Zone 1:

Axis I1:

This is a single line anomaly on L-1050E, Sta. 25S, with a peak chargeability of 15mV/V and background of 5 to 8mV/V. Coincident resistivities are lower than the rest of the zone, less than 10 000 ohm-m. The anomaly maps to the contact of the intermediate metavolcanics and the intermediate to felsic intrusives, and is also associated with a NW trending quartz feldspar porphyry (QPP) structure. Located in a local magnetic low near this short axis at Sta. 75S, L-900E is an area of interest. This area has a moderate chargeability response, 10mV/V, and a high resistivity.

Axis I2:

Axis I2 defines a chargeability section of short strike length extending from L-1050 to L-950E, between Sta. 50S and 150S. The peak chargeabilities are weak to moderate, 8 to 12mV/V, with the peak occurring on L-1000E. Pole-dipole coverage of L-1000E yields calculated spectral M-IP for the peak of 199mV/V. The section is located in the intermediate to felsic intrusives and associated with the above mentioned QPP structure.

Both axis I1 and I2 comprise the Main Kozowy Showing.

Axis I3:

Axis I3 extends from L-1050E to L-950E, between Sta. 25N and 50N, and is marked by weak peak chargeability values, 8 to 11mV/V, and background values of 6 to 8mV/V. Associated resistivities for the section are high to very high, 30 000 to 50 000 ohm-m. Pole-dipole coverage of L-1000E gives a weak chargeability response with a calculated M-IP value for the peak of 143mV/V.

The axis is located in an area of high, uniform magnetics and also lies to west of a NE trending zone of magnetic dislocation/contact.
Axis J1:

This section extends from L-600E to L-500E, between Sta. 125N and 150N. Peak chargeabilities are weak to moderate, 7 to 12 mV/V, with the peak recorded on L-550E. Coincident resistivities are high, 10,000 to 30,000 ohm-m. The axis is cross-cut by a NE trending resistivity low (a possible shear zone) on L-550E, Sta. 150N. Pole-dipole coverage of L-550E gives weak M7 peak response at Sta. 150N with a calculated spectral M-IP of 110 mV/V. The anomaly is located in an area of structural complexity. Magnetic results are high and variable. Two areas of weak chargeability, less than 10 mV/V, are identified with local magnetic lows and should be further investigated. These areas are Sta. 125N, L-600E and Sta. 175N, L-600E.

Axis J2:

This axis extends from L-600E to L-500E, between Sta. 50N and 75N. The peak chargeabilities are 10 to 21 mV/V, with the high recorded on L-500E. Background chargeabilities are 5 to 8 mV/V. The section is associated with an area of high to very high resistivities, 10,000 to 50,000 ohm-m. Calculation of the spectral M-IP for the peak, from the pole-dipole data returned a value of 203 mV/V. The anomaly is again located in an area of structural complexity, and this is reflected in the complex magnetics in the area.

Axis J3:

This section extends from L-600E to L-450E, between Sta. 0 and 75S. Chargeabilities are moderate, 10 to 16 mV/V, with the peak recorded on L-550E. The axis is located near a local resistivity high, with coincident resistivities greater than 50,000 ohm-m. The axis is also coincident with a zone of magnetic dislocation/contact and parallel to a lithologic boundary. The section lies in an area of uniformly lower magnetics.

Axis J4:

This section extends from L-500E to L-400E, between Sta. 125S and 150S, and is marked by a weak to moderate chargeability response, 8 to 14 mV/V. Coincident pole-dipole coverage gave spectral M-IP values of 100 to 200 mV/V for the section. Resistivities for the section are variable, 10,000 to 50,000 ohm-m. The chargeability high is located near a NW trending QPP structure. Magnetic results for the section are variable and generally higher valued.

Axis K1:

This axis defines a broad, weak anomaly that extends from 300W to 450W, between Sta. 325S and 375S. Chargeabilities for the axis are 8 to 12 mV/V with background values of 8 to 9 mV/V. Pole-dipole coverage was achieved for L-350W, and the associated spectral M-IP for the peak chargeability is 256 mV/V. Calculated time constants for the line are short, less than 0.1 sec.
The section lies in an area of very high resistivities, 50 000 to 75 000 ohm-m. To the south of the axis is a sharp resistivity contact, perhaps marking a lithologic boundary. The section is located in an area of lower, uniform magnetics.

Axis L1:

An isolated, very weak chargeability anomaly extending from L-500E to L-400E, between Sta. 350S and 250S. Chargeability values for this section vary from 5 to 8mV/V, 1 to 3 mV/V greater than local background. The anomaly is located in an area of lower resistivities, less than 10 000 ohm-m, and uniform, lower value magnetics.

Axis M1:

Axis M1 defines a disjointed, weak to moderate strength chargeability anomaly extending from L-350E to L-100W, between Sta. 100S and 150S. The anomaly has a peak chargeability of 12.7 mV/V on L-100E, and background values of 8 to 10mV/V. Pole-dipole coverage was achieved for L-50W. The calculated spectral M-IP for the peak at Sta. is 168mV/V. The anomaly axis is located in an area of high resistivities, 10 000 to 30 000 ohm-m.

Axis N1:

This axis extends from L-250E to L-150W, is centered about Sta. 125N, and is marked by a moderate chargeability response, 10 to 14mV/V. Coincident resistivities are uniform and high, 10 000 to 30 000 ohm-m.

To the north of Zone 1, between L-1150E and L-750E, is an area of slightly elevated chargeabilities, 8 to 10 mV/V. It is impossible to define a target zone in such a uniform chargeability field, based on chargeabilities alone. However, parts of this area map to magnetic lows, some close to the diabase dyke, for example L-950E, Sta. 300N. To further narrow the target zone only those areas having resistivities greater than 10 000 ohm-m and/or located in areas of structural complexity should be chosen for more immediate follow-up work.

ZONE 2:

This zone lies to the north of Zone 1 and is identified with a local resistivity high, greater than 10 000 ohm-m. The zone has two short anomaly axes, labelled A2 and B2.

Axis A2:

This axis defines a weak to moderate strength, narrow chargeability anomaly extending from L-1000E to L-850E, centered on Sta. 725N. Chargeability values are 6 to 14mV/V, with the peak value recorded on L-900E. The anomaly lies to the west of a broad magnetic high in an area of uniform magnetics.
Recommendation: This area should be further investigated as it has moderate chargeabilities and locally high resistivities.

Axis B2:

This axis defines a very weak chargeability anomaly that has been noted because the peak values are generally 2mV/V or more greater than the local background. Also, the peaks are in an area of higher resistivity. This section maps to a local weak magnetic low in an area of higher magnetics.

ZONE 3:

Zone 3 is located to the south of the grid and is associated with an area of predominantly mafic intrusives. There are, however, lithologic contacts and structural complexity to the north of the zone. Five anomalous areas are identified with Zone 3. These include two isolated, single line, moderate strength anomalies, two weak anomaly axes, and several chargeability anomalies associated with a north trending QFP structure.

Anomaly A3 and B3:

Anomaly A3 is a moderate strength chargeability response, 16.4mV/V, on L-450E, Sta. 550S, which lies in an area of low background chargeabilities, less than 4mV/V. The coincident resistivities are lower than the rest of the grid, less than 10 000 ohm-m. The anomaly is located between a pair of magnetically high 'ridges' and may lie in a zone of structural dislocation.

Anomaly B3 is a moderate strength anomaly, 12.3mV/V, also located in an area of lower chargeabilities, less than 6mV/V. The anomaly is on the low resistivity side of a resistivity contact, and is also located on the flank of a magnetic ridge.

Both anomaly A3 and B3 are located in a swamp, which would account for the lower resistivities.

Axes C3 and D3 both define weak chargeability anomalies located in an area of high resistivities, 10 000 to 50 000 ohm-m. Anomaly C3 is also located in a magnetic low, possibly a zone of alteration.

Several isolated, weak to moderate strength chargeability responses on L-550E and L-500E, between Sta. 400S and 700S, are associated with a north trending QFP structure. Coincident resistivities are high, 10 000 to 50 000 ohm-m.
9. SUMMARY AND RECOMMENDATIONS:

From June 10th to July 3rd, 1986 JVX Ltd. carried out induced polarization/resistivity surveys on the Kozowy Property on behalf of Falconbridge Limited. A total of 50.9 line-km of gradient coverage was achieved.

The IP survey identified one major zone, and two minor zones of anomalous IP response. Each zone is subdivided to reflect local anomalous high trends. Within Zone 1, fourteen anomaly axes are recognized, within Zone 2, two anomaly axes are recognized, and within Zone 3, three areas of anomalous IP response and two anomaly axes are recognized.

Because IP noise levels are considered good, +/- .5mV/V, several weak anomaly axes have been chosen. These anomalies should, however, be further appraised using other geotechnical information before a drill program is considered for them.

Those areas recommended for follow-up work, and as possible drill targets, are done so based on the following criteria:

- the area has a local anomalous chargeability response.
- the area is located in, or near a zone of high to very high resistivities (high resistivities indicate possible silicification of the host rock resulting from hydrothermal fluid activity).
- the area is located near a resistivity contrast (possible shear zone) or contact (possible lithologic boundary).
- the area is coincident with, or near a local magnetic low, (indicating the alteration of the original magnetic minerals by possible mineralizing hydrothermal solutions)

Based on the above mentioned criteria the following area are recommended for follow-up work using other geotechnical methods, and also as possible drill targets:

Zone 1:

Axis A1 - high priority
Axis B1 - moderate to high priority
Axis C1 - Sta. 300N, L-1650E moderate to high priority
Axis D1 - Sta. 325N to 375N, L-1650E high priority
   - Sta. 475N, L-1450E moderate priority
   - Sta. 300N, L-1550E to L-1500E moderate priority
Axis E1 - Sta. 175N, L-1500E high priority
- Sta. 200N, L-1225E moderate priority
Axis F1 - Sta. 150N, L- 950E and Sta. 125N, L-900E
  low to moderate priority
Axis H1 - Sta. 0, L-500E low to moderate priority
Axis I1 - Sta. 75S, L-900E
Axis J1 - Sta. 125N to 175N, L-600E low priority

Zone 2: - Axis A2 moderate priority

Zone 3: - Anomaly A3 and the anomalies near the QFP structure
  moderate priority

If there are any questions with regard to the survey please do not hesitate to contact the author at JVX Ltd., Thornhill, Ontario.

Respectfully submitted,

JVX Ltd.

Neil Hughes, B.Sc.
Consulting Geophysicist

Blaine Webster, B.Sc.
Consulting Geophysicist
Appendix 1

Specification Sheets
The microprocessor based IPR-11 is the heart of a highly efficient system for measuring, recording and processing spectral IP data. More features than any remotely similar instrument will help you enhance signal/noise, reduce errors and improve data interpretation. On top of all this, tests have shown that survey time may be cut in half, compared with the instrument you may now be using.

Function

The IPR-11 Broadband Time Domain IP Receiver is principally used in electrical (EIP) and magnetic (MIP) induced polarization surveys for disseminated base metal occurrences such as porphyry copper in acidic intrusives and lead-zinc deposits in carbonate rocks. In addition, this receiver is used in geoelectrical surveying for deep groundwater or geothermal resources. For these latter targets, the induced polarization measurements may be as useful as the high accuracy resistivity results since it often happens that geological materials have IP contrasts when resistivity contrasts are absent. A third application of the IPR-11 is in induced polarization research projects such as the study of physical properties of rocks.

Due to its integrated, microprocessor-based design, the IPR-11 provides a large amount of induced polarization transient curve shape information from a remarkably compact, reliable and flexible format. Data from up to six potential dipoles can be measured simultaneously and recorded in solid state memory. Then, the IPR-11 outputs data as: 1) visual digital display, 2) digital printer profile or pseudo-section plots, 3) digital printer listing, 4) a cassette tape record or 5) to a modem unit for transmission to head office by telephone line and by providing data which are essentially computer compatible.

Cables are used, members of a crew can prepare new dipoles at the end of a spread while measurements are underway. When the observation is complete, the operator walks only one dipole length and connects to a new spread leaving the cable from the first dipole for retrieval by an assistant.

Simultaneous multipole potential measurements offer an obvious advantage when used in drillhole logging with the Scintrex DHIP-2 Drillhole IP/Resistivity Logging Option.

The built-in, solid state memory also saves time. Imagine the time that would be taken to write down line number, station number, transmitter and receiver timings and other header information as well as data consisting of SP, Vp and ten IP parameters for each dipole. With the IPR-11, a record is filed at the touch of a button once the operator sees that the measurement has converged sufficiently.

The IPR-11 will calculate resistivity for you. Further time will then be saved when the IPR-11 begins plotting your data in profile or pseudo-section format in your base camp on a digital printer. The same printer can also be used to make one or more copies of a listing of the day’s results. If desired, an output to a cassette tape recorder can be made. Or, the IPR-11 data memory can be output directly into a modem, saving time by transmitting data to head office by telephone line and by providing data which are essentially computer compatible.

If the above features won't save as much time as you would like, consider how the operator will appreciate the speed in taking a reading with the IPR-11 due to: 1) simple keyboard control, 2) resistance check of six dipoles simultaneously, 3) fully automatic SP buckout, 4) fully automatic Vp self ranging, 5) fully automatic gain setting, 6) built-in calibration test circuits, and 7) self checking programs. The amount of operator manipulation required to take a great deal of spectral IP data is minimal.

Compared with frequency domain measurements, where sequential transmissions at different frequencies must be made, the time domain measurement records broadband information each few seconds. When successive readings are stacked and averaged, and when the pragmatic window widths designed into the IPR-11 measurement are used, full spectral IP data are taken in a minimum of time.

Improved interpretation of data. The quasi-logarithmically spaced transient windows are placed to recover the broadband information that is needed to calculate the standard spectral IP parameters with confidence. Scintrex offers its SPECTRUM software package which can take the IPR-11 outputs and generate the following standard spectral IP parameters: M, chargeability: T, time constant and C, exponent.
Interpretability of spectral IP data are improved since time domain measurements are less affected by electromagnetic coupling effects than either amplitude or phase angle frequency domain measurements, due to the relatively high frequencies used in the latter techniques. In the field, coupling free data are nearly always available from the IPR-11, by simply using chargeability data from the later transient windows. Then, in the base camp or office, the Scintrex SPECTRUM computer program may be used to resolve the EM component for removal from the IP signal. The electromagnetic induction parameters may also be interpreted in order to take advantage of the information contained in the EM component.

A further advantage of the IPR-11 in interpreting spectral IP responses is the amount of data obtainable due to the ability to change transmitted frequencies (pulse times) and measurement programs by keypad entry.

Enhance signal/noise. In the presence of random (non-coherent) earth noises, the signal/noise ratio of the IPR-11 measurements will be enhanced by $\sqrt{N}$ where $N$ is the number of individual readings which have been averaged to arrive at the measurement. The IPR-11 automatically stacks the information contained in each pulse and calculates a running average for $V_p$ and each transient window. This enhancement is equivalent to a signal increase of $\sqrt{N}$, or a power increase of $N$. Since $N$ can readily be 30 or more (a 4 minute observation using a 2 second on/off waveform), the signal/noise improvement realized by the IPR-11 cannot be practically achieved by an increase in transmitter power. Alternatively, one may employ much lower power transmitters than one could use with a non-signal enhancement receiver.

The automatic SP program backs out and corrects completely for linear SP drift: there is no residual offset left in the signal as in some previous time domain receivers. Data are also kept noise free by: 1) automatic rejection of spheric spikes, 2) 50 or 60 Hz powerline notch filters, 3) low pass filters and 4) radio frequency (RF) filters. In addition, the operator has a good appreciation of noise levels since he can monitor input signals on six analog meters, one for each dipole. Also, with the Optional Statistical Analysis Program, he can monitor relative standard error continuously on the digital display and then file these calculations in the data memory when the observation is complete.

Noise free observations can usually be made using the self-triggering feature of the IPR-11. The internal program locks into the waveform of the signal received at the first dipole (nearest a current electrode) and prevents mistriggering at any point other than within the final 2.5 percent of the current on time. In particularly noisy areas, however, synchronization of the IPR-11 and transmitter can be accomplished either by a wire link or using a high stability, Optional Crystal Clock which fits onto the lid of the instrument.

Reduce Errors. The solid state, fail-safe memory ensures that no data transcription errors are made in the field. In base camp, data can be output on a digital printer or a read-after-write cassette tape deck and played back onto a digital printer for full verification. The fact that the IPR-11 calculates resistivity from recorded $V_p$ and $I$ values also reduces error.

The self check program verifies program integrity and correct operation of the display, automatically, without the intervention of the operator. If the operator makes any one of ten different manipulation errors, an error message is immediately displayed.

The Multidipole Potential Cables supplied by Scintrex are designed so there is no possibility of connecting dipole to the wrong input terminals. This avoids errors in relating data to the individual dipoles. The internal calibrator assures the operator that the instrument is properly calibrated and the simple keypad operation eliminates a multitude of front panel switches, simplifying operation and reducing errors.

Features

Six Dipoles Simultaneously. The analog input section of the IPR-11 contains six identical differential inputs to accept signals from up to six individual potential dipoles. The amplified analog signals are converted to digital form, multiplexed and recorded with header information identifying each group of dipoles. Custom-made multdipole cables are available for use with any electrode array.

Memory. Compared with tape recording, the IPR-11 solid state memory is free from problems due to dirt, low temperatures, moving parts, humidity and mechanical shock. A battery installed on the memory board ensures memory retention if main batteries are low or if the main batteries are changed. The following data are automatically recorded in the memory for each potential dipole: 1) receiver timing used, 2) transmitter timing used, 3) number of cycles measured, 4) self potential (SP), 5) primary voltage ($V_p$) and 6) ten transient IP windows (Ms). In addition, the operator can enter up to seventeen, four digit numerical headers which will be filed with each set of up to six dipole readings. Headers can include, for example, line number, station number, operator code, current amplitude, date, etc.

In the standard data memory, up to 200 potential dipole measurements can be recorded. Optional Data Memory Expansion Blocks can be installed in the IPR-11 to increase memory capacity in blocks of about 200 dipoles each to a total of approximately 800 dipoles. Memory capacities will be reduced somewhat if the Optional Statistical Analysis Program is used.
Memory Recall. Any reading in memory can be recalled, by simple keypad entry, for inspection on the visual display. For example, the operator can call up sequential visual display of all the data filed for the previous observation or for the whole data memory.

Carefully Chosen Transient Windows. The IPR-11 records all the information that is really needed to make full interpretations of spectral IP data, to remove EM coupling effects and to calculate EM induction parameters. Ten logarithmically spaced transient windows are measured simultaneously for each potential dipole over selectable total receive times of 0.2, 1.0, 2.0 or 4.0 seconds.

After a delay from the current off time of t, the width of each of the first four windows is 1t and of the last three windows is 12t. The t values are 3, 15, 30 or 60 milliseconds. Thus, for a given dipole, up to forty different windows can be measured by using all four receive times. The only restriction is, of course, that the current off time must exceed the total measuring time. Since t is as low as 3 milliseconds and since the first four windows are narrow, a high density of curve shape information is available at short times (high frequencies) where it is needed for confident calculation of the EM coupling parameters.

Calculates Resistivity. The operator enters the current amplitude and resistivity geometry (K) factors in header with each observation. If the K factors remain the same, only a code has to be entered with each observation. Then, using the recorded Vp values, the IPR-11 calculates the apparent resistivity value which can be output to the printer or cassette tape recorder.

Normalizes for time and Vp. The IPR-11 divides the measured area in each transient window by the width of the window and by the primary voltage so that values are read out in units of millivolts/volt (mils).

Signal Enhancement. Vp and M values are continuously stacked and averaged and the display is updated for each two cycles when the operator sees that the displayed values have adequately converged, he can terminate the reading and file all values in memory.

Vp Integration. The primary voltage can be sampled over 50 percent or more of the current on (T) time, depending on the transmit and receive programmes selected. The integrated result is normalized for time. Long Vp integration helps overcome random noise.

Digital Display. Two, four digit LCD displays are used to display measured or manually entered data, data codes and alarm codes.

Automatic Profile Plotting. When connected to a digital printer such as the Scintrex DP-4 having an industry standard RS-232C, 7 bit ASCII serial data port, data can be plotted in a base camp. The IPR-11 is programmed to plot any selected transient window and resistivity in pseudo-section or profile form. Line orientation is maintained consistent, that is station numbers on profiles are sorted in ascending number. In the profile plot, the scale for resistivity is logarithmic with 10 to 100,000 ohmmeters in four decades with another four decades of overrange both above and below. The chargeability scale is keypad selectable. In the pseudo-section plot, any one chargeability window can be presented in conventional, pseudo-section form.

Printed Data Listing. The same digital printer can be used to print out listings of all headers and data recorded during the day’s operation. Several copies can be made for mailing to head office or for filing in case copies are lost. Baud rate is keypad selectable at 110, 300 or 1200 baud, depending on the printer used.

Cassette Tape Output. A cassette recorder having an industry standard RS-232C, 7 bit ASCII serial interface may be used for storing data directly from the IPR-11. If all six dipoles are used, then 16, 80 character blocks of data per observation are transferred at a rate of 1200 baud. The storage capacity of one side of cassette tape is approximately 1400 blocks or about 80 six dipole observations. The MFE Model 2500 is recommended since it has a read-after-write feature for data verification.

The recording format is compatible with the Texas Instruments ‘Silent 700’ terminals and records are made on standard digital grade cassettes. Once a cassette tape record is made, the tape can be played back onto the DP-4 Digital Printer for an additional verification that the data on tape are correct.

Pseudo-section printout on DP-4 Digital Printer. Chargeability data are shown for the sixth transient window (M6) for the dipole-dipole array and six 'n' spacings. Line number and station number are also recorded. The contours have been hand drawn. Resistivity results can be plotted in a similar manner.
Modem. Data in the IPR-11 memory can be output directly into a modem near the field operation and transmitted by telephone through a modem terminal in or near head office, where data can be output directly onto a digital printer or tape recorder. In this way a geophysicist in head office can receive regular transmissions of data to improve supervision and interpretation of the data from field projects and no output device other than the modem is required in the field.

External Circuit Check. Six analog meters on the IPR-11 are used to check the contact resistance of individual potential dipoles. Poor contact at any one electrode is immediately apparent. The continuity test uses an AC signal to avoid electrode polarization.

Self Check Program. Each time the instrument is turned on a check sum verification of the program memory is automatically done. This verifies program integrity and if any discrepancy is discovered, an error signal appears on the digital display. Part of the self check program checks the LCD display by displaying eight ones followed sequentially by eight twos, eight fours and eight eights.

Malfunction Error Checks. Alarm codes appear on the digital display if any of the following ten errors occur: tape dump errors, illegal keypad entry, out of calibration or failed memory test, insufficient headers, header buffer full, previous station's data not filed, data memory full, incorrect signal amplitude or excessive noise, transmit pulse time incorrect and receiver measurement timing incorrect.

Internal Calibration. By adjustment of the function switch, an internal signal generator is connected across the inputs to test the calibration of all six signal inputs for SP, Vp and all M windows simultaneously. Then the software checks all parameters. If there is an error in one or more parameters, an alarm code appears on the display. The operator can then push a key to scan all parameters of all input channels to determine where the error is.

- Data listing output on DP-4 Digital Printer. Header information is shown in the first two lines. In this case, data are for Line 1, Station 3. Transmitted current is 80 mA. Next are the resistivity K factors for the six dipoles. 8292 indicates that receive and transmit times are each 2 seconds. The last header item records that fact that 14 cycles were stacked. Following the header are the geophysical data for six dipoles which were measured simultaneously. For each dipole, the values for the 10 transient windows are shown on one line. The next line shows Vp and Sp in mV and resistivity. 5.71 E+3 indicates that the calculated resistivity is 5.71 x 10^3 ohm-metres.
Automatic SP Correction. The initial self-potential buckout is entirely automatic - no adjustment need be made by the operator. Then, throughout the measurement, the IPR-11 slope correction software makes continual corrections, assuming linear SP drift during a transmitted cycle. There is no residual SP offset included in the chargeability measurement as in some previous time domain receivers.

Automatic Vp Self ranging. There is no manual adjustment for Vp since the IPR-11 automatically adjusts the gain of its input amplifiers for any Vp signal in the range 100 microvolts to 6 volts.

Spheric Noise Rejection. A threshold, adjustable by keypad entry over a linear range of 0 to 99, is used to reject spheric pulses. If a spheric noise pulse above the set threshold occurs, then the IPR-11 rejects and does not average the current two cycles of information. An alarm code appears on the digital display. If the operator continues to see this alarm code, he can decide to set the threshold higher.

Powerline and Low Pass Filter. An internal switch is used to set the IPR-11 for either 50 or 60 Hz powerline areas. The notch filter is automatically switched out when the 0.2 second receive time is used since the filters would exclude EM signals.

RF Filter. An additional filter in the input circuits ensures that radio frequency interference is eliminated from the IPR-11 measurement.

Input Protection. If signals in excess of 6 V and up to 50 V are applied to any input circuit, zener diode protection ensures that no damage will occur to the input circuits.

Synchronization. In normal operation, the IPR-11 synchronizes itself on the received waveform, limiting triggering to within 2.5% of the current on time. However, for operation in locations where signal/noise ratios are poor, synchronization can be done either by running a cable from the transmitter or by using the Optional Crystal Clock which can be installed in the lid of the IPR-11.

Optional Statistical Analysis. As an option, the IPR-11 can be provided with software to do statistical analysis of some parameters. The relative standard error is calculated, displayed on the LCD display and may be recorded in data memory. The total dipole capacity of data memory will be reduced, depending on the extent of statistical data recorded. If the Optional Statistical Analysis Program is chosen, some thought should be given to purchasing one or more blocks of Data Memory Expansion.

Software for EM Coupling Removal. In transient measurements, the EM coupling component occurs closest to the current off time (i.e. it is primarily in the early windows). Thus, it is usually possible to obtain coupling-free IP data simply by using the later windows of IPR-11 measurement program. If, however, full spectral information is desired, the data from the early windows must be corrected for the EM component. This can be done with confidence using a desk top of mainframe computer and the Scintrex SPECTRUM program.

Software for Spectral IP Parameters. Using the chargeability data from the ten quasilogarithmically spaced IPR-11 windows, a desk top or mainframe computer and the Scintrex SPECTRUM program, spectral IP parameters can be calculated. The basis for this calculation as well as for the EM coupling removal calculation is discussed in a technical paper by H.O. Seigel, R. Ehrat and I. Brcic, given at the 1980 Society of Exploration Geophysicists Convention, entitled “Microprocessor Based Advances in Time Domain IP Data Collection and In-Field Processing”.

Operation
In relation to the efficiency with which it can produce, memorize, calculate and plot data, the IPR-11 is quite simple to operate, using the following switches and keypad manipulations.

Power On-Off. Turned on to operate the instrument.
Reset. Resets the program to begin again in very poor signal/noise conditions.
Function Switch. Connects either the potential dipoles or the internal test generator to the input amplifiers or connects the external circuit resistance check circuitry to the potential dipoles.

Keypad. The ten digit and six function keys are used to: 1) operate the instrument, 2) enter information, 3) retrieve any stored data item for visual display, and 4) output data on to a digital printer, cassette tape deck or modem. Examples of some of these manipulations, most of which are accomplished by three key strokes, follow. E is the general entry key.

A concise card showing the keypad entry codes is attached inside the lid of the IPR-11.
Example 1. Keying 99E commands the battery test. The result is shown on the digital display.
Example 2. Keying 90E tells the IPR-11 to use the 0.2 second receive time. 91, 92 and 94 correspond to the three other times.
Example 3. Keying 12M results in the display of the chargeability of the first dipole, window number 2, during the measurement. Similarly, 6SP or 4 Vp would result in the display of the SP value in the sixth dipole or Vp in the fourth dipole respectively.
Example 4. Keying NNNNH, where N is a variable digit, records an item of header information. Seventeen such items can be entered with each file of up to six dipoles of data.
Example 5. 73E, 74E or 75E are used to output the data from the memory to the digital printer or modem at 110, 300 or 1200 baud respectively.

---

**Diagram:**

Nominal total receive time: 0.2, 1, 2, 4 sec.

---

**Diagram:**

IPR-11 transient windows

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IPR-11 Options

The following options are available for purchase with the IPR-11.

Multidipole Potential Cables. These cables are custom manufactured for each client, depending on electrode array and spacings which are to be used. They are manufactured in sections, with each section a dipole in length and terminated with connectors. For each observation, the operator need only walk one dipole length and connect a new section, in order to read a new six dipole spread. There is no need to move the whole spread. The connectors which join the cables are designed so that there is no possibility of connecting the wrong dipole to the wrong input amplifier. The outside jacket of these cables is flexible at low temperatures. About 5 percent extra length is added to each section to ensure that the cable reaches each station.

Data Memory Expansion Blocks. The standard data memory of the IPR-11 allows for data for up to 200 dipole measurements to be recorded, assuming a common header for six dipoles. Up to three additional memory blocks can be installed in the instrument, each of about 200 dipole capacity.

Statistical Analysis Program. Scintrex can provide, in EPROM, a statistical program to give real time calculations of relative standard error of the 10 IP windows in a selected dipole. If this option is chosen, one or more Data Memory Expansion Blocks may be warranted.

Crystal Clock. Scintrex can provide a high stability clock to synchronize the IPR-11 with a similar clock in the transmitter. This option is, however, only required for work in extremely noisy and/or low signal environments.

Software. Scintrex offers its SPECTRUM programs for EM coupling removal, calculation of EM induction factors and calculation of the same spectral IP parameters as in common use in frequency domain IP measurements.

Digital Printers. The Scintrex DP-4 Digital Printer is a modified Centronics Microprinter with an RS-232C, 7 bit ASCII serial port. It is a self contained module, including 110/230 V power supply, control electronics and printing mechanism. It produces copy on aluminum coated paper by discharging low voltages through tungsten stylus. Characters are formed from the appropriate dots of a 5 x 7 dot matrix. All 96 standard ASCII characters are available, the paper width is 120 mm and 80 characters can be printed per line at a rate of up to 150 lines per minute.

Cassette Tape Recorder. The MFE Model 2500 with read-after-write verification is recommended. It has an RS-232C, 7 bit ASCII serial interface with a recording format compatible with the Texas Instruments 'Silent 700' terminals.

Modem. A number of modem units are available on the market which are compatible with the IPR-11. Scintrex would be pleased to recommend or supply such equipment if required.
**Technical Description of the IPR-11**

**Broadband Time Domain IP Receiver**

<table>
<thead>
<tr>
<th>Input Potential Dipoles</th>
<th>1 to 6 simultaneously</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Impedance</td>
<td>4 megohms</td>
</tr>
<tr>
<td>Input Voltage (Vp) Range</td>
<td>100 microvolts to 6 volts for measurement.</td>
</tr>
<tr>
<td>Automatic SP Bucking Range</td>
<td>±1.5 V</td>
</tr>
<tr>
<td>Chargeability (M) Range</td>
<td>0 to 300 mV/V (mils or 0/00)</td>
</tr>
</tbody>
</table>
| Absolute Accuracy of Vp, SP and M| Vp: ±3% of reading for Vp > 100 microvolts
                                        SP: ±3% of SP bucking range
                                        M: ±3% of reading or minimum ±0.5 mV/V |
| Resolution of Vp, SP and M       | Vp: 1 mV above 100 mV approaching 1 microvolt at 100 microvolt
                                        SP: 0.1 mV/V except for M0 to M3 in 0.2 second receive time where resolution is 0.4 mV/V. |

**IP Transient Program**

Ten transient windows per input dipole. After a delay from current off of 1, first four windows each have a width of 1, next three windows each have a width of 0.6 and last three windows each have a width of 0.2. The total measuring time is therefore 58t. It can be set at 3, 15, 30 or 60 milliseconds for nominal total receive times of 0.2, 1, 2 and 4 seconds.

| Vp Integration Time              | In 0.2 and 1 second receive time modes; 0.51 sec
                                        In 2 second mode; 1.02 sec
                                        In 4 second mode; 2.04 sec |

**Transmitter Timing**

Equal on and off times with polarity change each half cycle. On/off times of 1.2.4 or 8 seconds with ±2.5% accuracy are required.

**Header Capacity**

Up to 17 four digit headers can be stored with each observation.

**Data Memory Capacity**

Depends on how many dipoles are recorded with each header. If four header items are used with 6 dipoles of SP, Vp and 10 M windows each, then about 200 dipole measurements can be stored. Up to three Optional Data Memory Expansion Blocks are available, each with a capacity of about 200 dipoles.

**External Circuit Check**

Checks up to six dipoles simultaneously using a 31 Hz square wave and readout on front panel meters, in range of 0 to 200 k ohms.

**Filtering**

RF filter, spurious spike removal, switchable 50 or 60 Hz notch filters, low pass filters which are automatically removed from the circuit in the 0.2 sec receive time.

**Internal Calibrator**

1000 mV of SP, 200 mV of Vp and 24.3 mV/V of M provided in 2 sec pulses.

**Digital Display**

Two, 4 digit LCD displays. One presents data, either measured or manually entered by the operator. The second display: 1) indicates codes identifying the data shown on the first display, and 2) shows alarm codes indicating errors.

**Analog Meters**

Six meters for: 1) checking external circuit resistance, and 2) monitoring input signals.

**Digital Data Output**

RS-232C compatible. 7 bit ASCII, no parity. Serial data output for communication with a digital printer, tape recorder or modem.
## Technical Description

### of the IPR-11

**Broadband Time Domain**

**IP Receiver**

<table>
<thead>
<tr>
<th>Standard Rechargeable Power Supply</th>
<th>Eight Eveready CH4 rechargeable NiCad D cells provide approximately 15 hours of continuous operation at 25°C. Supplied with a battery charger, suitable for 110/230 V, 50 to 400 Hz, 10 W.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disposable Battery Power Supply</td>
<td>At 25°C, about 40 hours of continuous operation are obtained from 8 Eveready E95 or equivalent alkaline D cells. At 25°C, about 16 hours of continuous operation are obtained from 8 Eveready 1150 or equivalent carbon-zinc D cells.</td>
</tr>
<tr>
<td>Dimensions</td>
<td>345 mm x 250 mm x 300 mm, including lid.</td>
</tr>
<tr>
<td>Weight</td>
<td>10.5 kg, including batteries.</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-20 to +55°C, limited by display.</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>-40 to -60°C.</td>
</tr>
<tr>
<td>Standard Items</td>
<td>Console with lid and set of rechargeable batteries, 2 copies of manual, battery charger.</td>
</tr>
<tr>
<td>Optional Items</td>
<td>Multipole Potential Cables, Data Memory Expansion Blocks, Statistical Analysis Program, Crystal Clock, SPECTRUM Program, Digital Printer, Cassette Tape Recorder, Modem.</td>
</tr>
<tr>
<td>Shipping Weight</td>
<td>25 kg includes reusable wooden shipping case.</td>
</tr>
</tbody>
</table>

---

**SCINTREX**

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Telex: 06-964570

Geophysical and Geochemical Instrumentation and Services
Function

The TSQ-3 is a multi-frequency, square wave transmitter suitable for induced polarization and resistivity measurements in either the time or frequency domain. The unit is powered by a separate motor-generator.

The favourable power/weight ratio and compact design of this system make it portable and highly versatile for use with a wide variety of electrode arrays. The medium range power rating is sufficient for use under most geophysical conditions.

The TSQ-3 has been designed primarily for use with the Scintrex Time Domain and Frequency Domain Receivers, for combined induced polarization and resistivity measurements, although it is compatible with most standard time domain and frequency domain receivers. It is also compatible with the Scintrex Commutated DC Resistivity Receivers for resistivity surveying. The TSQ-3 may also be used as a very low frequency electromagnetic transmitter.

Basically the transmitter functions as follows. The motor turns the generator (alternator) which produces 800 Hz, three phase, 230V AC. This energy is transformed upwards according to a front panel voltage setting by a large transformer housed in the TSQ-3. The resulting AC is then rectified in a rectifier bridge. Commutator switches then control the DC voltage output according to the waveform and frequency selected. Excellent output current stability is ensured by a unique, highly efficient technique based on control of the phase angle of the three phase input power.

Features

Current outputs up to 10 amperes, voltage outputs up to 1500 volts, maximum power 3000 VA.

Solid state design for both power switching and electronic timing control circuits.

Circuit boards are removable for easy servicing.

Switch selectable wave forms: square wave continuous for frequency domain and square wave interrupted with automatic polarity change for time domain.

Switch selectable frequencies and pulse times.

Overload, underload and thermal protection for maximum safety.

Digital readout of output current.

Programmer is crystal controlled for very high stability.

Low loss, solid state output current regulation over broad range of load and input voltage variations.

Rectifier circuit is protected against transients.

Excellent power/weight ratio and efficiency.

Designed for field portability; motor-generator is installed on a convenient frame and is easily man-portable. The transmitter is housed in an aluminum case.

The motor-generator consists of a reliable Briggs and Stratton four stroke engine coupled to a brushless permanent magnet alternator.

New motor-generator design eliminates need for time domain dummy load.

Waveforms output by the TSQ-3
Technical Description of TSQ-3/3000W Time and Frequency Domain IP and Resistivity Transmitter

<table>
<thead>
<tr>
<th>Output Power</th>
<th>3000 VA maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltages</td>
<td>300, 400, 500, 600, 750, 900, 1050, 1250, 1500 volts, switch selectable</td>
</tr>
<tr>
<td>Output Current</td>
<td>10 amperes maximum</td>
</tr>
<tr>
<td>Output Current Stability</td>
<td>Automatically controlled to within ±0.1% for up to 20% external load variation or up to ±10% input voltage variation</td>
</tr>
<tr>
<td>Digital Display</td>
<td>Light emitting diodes permit display up to 1999 with variable decimal point; switch selectable to read input voltage, output current, external circuit resistance. Dual current range, switch selectable</td>
</tr>
<tr>
<td>Absolute Accuracy</td>
<td>±3% of full range</td>
</tr>
<tr>
<td>Current Reading Resolution</td>
<td>10 mA on coarse range (0-10A) 1 mA on fine range (0-2A)</td>
</tr>
<tr>
<td>Frequency Domain Waveform</td>
<td>Square wave, continuous with approximately 6% off time at polarity change</td>
</tr>
<tr>
<td>Frequency Domain Frequencies</td>
<td>Standard: 0.1, 0.3, 1.0 and 3.0 Hz, switch selectable  Optional: any number of frequencies in range 0 to 5 Hz.</td>
</tr>
<tr>
<td>Time Domain Polarity Change</td>
<td>each 2t; automatic</td>
</tr>
<tr>
<td>Time Domain Pulse Durations</td>
<td>Standard: t = 1, 2, 4 or 8 seconds  Optional: any other timings</td>
</tr>
<tr>
<td>Time and Frequency Stability</td>
<td>Crystal controlled to better than ±0.01%</td>
</tr>
<tr>
<td>Efficiency</td>
<td>.78</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>-30°C to +50°C</td>
</tr>
<tr>
<td>Overload Protection</td>
<td>Automatic shut-off at 3300 VA</td>
</tr>
<tr>
<td>Underload Protection</td>
<td>Automatic shut-off at current below 75mA</td>
</tr>
<tr>
<td>Thermal Protection</td>
<td>Automatic shut-off at internal temperature of +85°C</td>
</tr>
<tr>
<td>Dimensions</td>
<td>350 mm x 530 mm x 320 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>25.0 kg</td>
</tr>
</tbody>
</table>

Power Source

Type | Motor flexibly coupled to alternator and installed on a frame with carrying handles. |
Motor | Briggs and Stratton, four stroke, 8 H.P. |
Alternator | Permanent magnet type, 800 Hz, three phase 230 V AC |
Output Power | 3500 VA maximum |
Dimensions | 520 mm x 715 mm x 560 mm |
Weight | 72.5 kg |

Total System

Shipping Weight | 150 kg includes transmitter console, motor generator, connecting cables and re-usable wooden crates |

TSO-3 transmitter with portable motor generator unit

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Geophysical and Geochemical Instrumentation and Services
Appendix 2

Plates 1 to 6

Plate 1: Apparent Resistivity (n=2) Contour Plan Map (East Block), scale 1:2500
Plate 2: Apparent Resistivity (n=2) Contour Plan Map (West Block), scale 1:2500
Plate 3: Chargeability (M7, n=2) Contour Plan Map (East Block), scale 1:2500
Plate 4: Chargeability (M7, n=2) Contour Plan Map (West Block), scale 1:2500
Plate 5: Compilation / Anomaly Map (East Block), scale 1:2500
Plate 6: Compilation / Anomaly Map (West Block), scale 1:2500
Appendix 3

Literature


Spectral induced polarization parameters as determined through time-domain measurements

Ian M. Johnson

ABSTRACT

A method for the extraction of Cole-Cole spectral parameters from time-domain induced polarization data is demonstrated. The instrumentation required to effect the measurement and analysis is described. The Cole-Cole impedance model is shown to work equally well in the time domain as in the frequency domain. Field trials show the time-domain method to generate spectral parameters consistent with those generated by frequency-domain surveys. This is shown to be possible without significant alteration to field procedures. Cole-Cole time constants of up to 100 s are shown to be resolvable given a transmitted current of a 2 s pulse-time. The process proves to have added usefulness as the Cole-Cole forward solution proves an excellent basis for quantifying noise in the measured decay.

INTRODUCTION

The induced polarization (IP) phenomenon was first observed as a relaxation or decay voltage as a response to the shut-off of an impressed dc current. This decay was seen to be quasi-exponential with measurable effects several seconds after shut-off. Differences in the shape of decay curves seen for different polarizable targets have been recognized from the start (Wait, 1959). A systematic method of analyzing time-domain responses in order to generate an unbiased measure of source character has, until recently, been lacking. Developments in the frequency domain have been more pronounced.

In an attempt to improve our understanding of time-domain IP phenomenon, the Cole-Cole impedance model, developed and tested in the frequency domain, is used to generate the equivalent time-domain responses. Time-domain field data are then analyzed for Cole-Cole parameters and the results used to interpret differences in the character of the source.

The theoretical basis for the work will be presented. The instrumentation required to effect the measurement and analysis will be described. Field examples will be discussed.

SPECTRAL IP

The term "spectral IP" has been used to designate a variety of methods which look beyond the familiar resistivity and chargeability (or "percent frequency effect") as measured in electrical surveys. A number of geophysical instrument manufacturers/contractors have developed instrumentation and methodologies which, in essence, collect and analyze data from electrical surveys at a number of frequencies or delay times. The data analysis produces a set of quantities which characterize the information gained. These quantities or parameters are promoted by the sponsor for application in a variety of search problems for mineral and hydrocarbon resources.

In recognition of the pioneering work of Pelton (Pelton et al., 1978), the Cole-Cole impedance model has been adopted. The model has been extensively field tested and found to be reliable (Pelton et al., 1978). Pelton suggested that the complex impedance (transfer function) of a simple polarizable source may be best expressed as

\[
Z(\omega) = R_0 \left\{ 1 - m \left[ 1 - \frac{1}{1 + (i\omega \tau)^c} \right] \right\},
\]

where

- \(Z(\omega)\) = complex impedance (in \(\Omega \cdot \text{m}\))
- \(R_0\) = the dc resistivity (in \(\Omega \cdot \text{m}\))
- \(m\) = the chargeability (in volts/volt)
- \(\tau\) = the time constant (in seconds)
- \(\omega\) = the angular frequency (in seconds\(^{-1}\))
- \(c\) = the exponent (or frequency dependence, dimensionless)

and

\[i = \sqrt{-1}.\]

The dc resistivity \(R_0\) is related to the apparent resistivity...
calculated in conventional electrical methods. The chargeability (m) is the relative residual voltage which would be seen immediately after shut-off of an infinitely long transmitted pulse (Siegel, 1959). It is related to the traditional chargeability as measured some time after the shut-off of a series of pulses of finite duration. The time constant (τ) and exponent (c) are those newly measurable physical properties which describe the shape of the decay curve in time domain or the phase spectrum in frequency domain. For conventional IP targets, the time constant has been shown to range from approximately 0.01 s to greater than 100 s and is thought of as a measure of grain size. The exponent has been shown to have a range of interest from 0.1 to 0.5 or greater and is diagnostic of the uniformity of the grain size of the target (Pelton et al., 1978).

Selection of the Cole-Cole model is the primary step in simulating the response of a single polarizable target. A number of other effects are present to a greater or lesser extent depending upon the geoelectric environment. Multiple targets of differing characteristics will cause overlapping effects. Measurements may contain an appreciable component due solely to inductive coupling effects. In very conductive terrain, this contribution may be large enough to dominate the IP effects (Hallof and Pelton, 1980). The inductive effect itself may be a valued measurement in its own right (Wynn and Zonge, 1977).

SPECTRAL IP IN THE TIME DOMAIN

The earlier work is well summarized in Wait (1959). By that time enough data had been gathered to point to differences in measured decay curves and a number of decay curve modeling schemes had been tried. Developments in instrumentation were less pronounced. In 1967 the Newmont Standard IP decay was introduced (Dolan and McLaughlin, 1967). Induced polarization receivers were subsequently introduced which used the Newmont Standard as a basis for IP measurements. The so-called I/M parameter was used for a number of years as a sensitive measure of agreement with the Newmont Standard and of source character (Swift, 1973).

IP receivers evolved in the mid 1970s through single dipole instruments which could be programmed to measure a number of points on the decay. Decay curve analysis was possible (Vogelsang, 1981), if tedious and inexact. Extremely long pulse times were suggested as a means of effecting some type of time-domain spectral discrimination given the equipment then available (Halverson et al., 1978). The late 1970s saw the introduction of time-domain IP receivers which could measure and record digitally a number of points on the decay. The performance of both transmitters and receivers was improving in parallel.

The first studies of the shape of the time-domain decay given a Cole-Cole impedance model were made by Jain (1981) and Tombs (1981). Both authors show a number of numerically generated decay curves as the steady-state response to a conventional (+, 0, −, 0) pulse train. Measured decays were compared to master curves with uncertain results.

Both contributions stopped short of routine application. Having generated a set of standard decays, the differences in curve shape could be quantified. A measure of the accuracy in the field measurement required to effect a reasonable resolution in spectral character could be gained. Routine application would better define the limitations of the method under average field conditions.

Although the master-curve approach is considered the most practical one for routine spectral IP work, other approaches are possible. The time-domain decay may be modeled as a series of decaying exponentials from which the frequency-domain phase spectrum is easily calculated (Gupta Sarma et al., 1981). Both input current and output voltage may be expressed as transform pairs of time-domain signals. The transfer function may be extracted directly.

NUMERICAL MODELING

From Tombs (1981), the (+, 0, −, 0) transmitted current of amplitude I₀ and of pulse time T's used in conventional time domain IP may be expressed in Fourier series form as

\[
I(t) = I_0 \sum_{n=1}^{\infty} \frac{2}{\pi n} \left( \cos \frac{n\pi}{4} - \cos \frac{3n\pi}{4} \right) \sin \frac{n\pi}{4} T.
\]

A homogeneous earth whose electrical properties may be modeled by a single Cole-Cole impedance of Z(ω) is assumed. Ignoring the effect of array geometry, the steady-state voltage as measured at the receiving dipole pair is

\[
V(t) = I_0 \sum_{n=1}^{\infty} \frac{2}{\pi n} \left( \cos \frac{n\pi}{4} - \cos \frac{3n\pi}{4} \right) Z \left( \frac{n\pi}{2T} \right) e^{-n\pi T}.
\]

For conventional time-domain IP receivers, it is common to sample the decay through a sequence of N slices or windows. The value recorded for each slice is

\[
S_i = \frac{10^3}{V_p(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} V(t) \, dt \quad \text{(mV/V)},
\]

where \( t_i, t_{i+1} \) are the limits on the integration and \( V_p \) is the time average of measured voltage during the current on-time. In addition, it is common to average \( S_i \) over a number of cycles and to filter out those signals at frequencies well below the transmitted fundamental f₀ (= 1/4T).

For ease of presentation, we define a function \( G(t_i, t_{i+1}, \tau, c, T) \) which describes the \( \tau, c \) and \( T \) dependence of \( S_i \) and is derived by inserting the expression for the Cole-Cole impedance from equation (1) and \( V(t) \) from equation (3) into the right-hand side of equation (4) as follows:

\[
G(t_i, t_{i+1}, \tau, c, T) = \frac{1}{(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} \left( \frac{1}{1 + \left( \frac{n\pi}{2T} \right)^c} \right) e^{-n\pi T} \, dt.
\]

Combining equations (3) and (4) and using the notation of equation (5), the theoretical decay during the off-time is given by

\[
S_i = \frac{10^3 I_0 R_o m}{V_p} G(t_i, t_{i+1}, \tau, c, T).
\]

The measured theoretical primary voltage may be expressed
Spectral IP Parameters

\[ \frac{mG(t_i, t_{i+1}, \tau, c, T)}{1 - m + mG(t_i, t_{i+1}, \tau, c, T)} = \frac{m_0 G(t_i, t_{i+1}, \tau, c, T)}{G(t_i, t_{i+1}, \tau, c, T)} \]  

Hence,

\[ m = \frac{m_0 \times 10^3}{G(t_i, t_{i+1}, \tau, c, T) + m_0 [1 - G(t_i, t_{i+1}, \tau, c, T)]} \text{ mV/V.} \]  

(12)

Confidence in the spectral parameters so determined is related to the agreement between measured data and the selected master curve. This agreement is quantified by the root-mean-square (rms) deviation defined as

\[ D = \left\{ \frac{1}{N} \sum_{i=1}^{N} \left( 1 - \frac{M_i}{m_0 S_i} \right)^2 \right\}^{1/2} \text{ percent.} \]  

(13)

The process outlined above will yield spectral parameters which are only apparent. Polarizable targets of interest are most often of finite size and embedded in a medium which may itself possess characteristic impedances. The theoretical problem of greater generality is a complex one with no reasonably general forward solution yet available.

Pelton et al. (1978) presented the case of a simple polarizable target buried in a nonpolarizing host. They showed that as the relative size of the target, as defined by the dilution factor decreases, the exponent is effectively unchanged. The time constant is similarly unaffected as long as the true chargeability is not large. The apparent resistivity and apparent chargeability are, however, not as stable under large changes in the dilution factor.

This implies that the shape of the time-domain decay and therefore the apparent time constant \( \tau \) and exponent \( c \) are relatively stable under large changes in the dilution factor. The apparent chargeability is not.

By inspection,

\[ G(t_i, t_{i+1}, \tau, c, T) = G(n t_i, n t_{i+1}, n \tau, c, nT). \]  

(14)

If for example, the receiver timing, pulse time, and Cole-Cole time constant are all doubled, the master-curve values are unaffected. This is a useful result for predicting the pulse length required to resolve spectral parameters given that one already has a complete understanding of the resolution capabilities of the method for one pulse time (e.g., \( T = 2 \text{ s} \)). As an example, let us assume that time-domain IP surveys using a pulse time of 2 s are known to result in spectral discrimination (i.e., decay curve shape differences) for time constants up to 100 s. If it is suspected that it may be important to resolve time constants of 1 000 s, for example, all other things being equal, a pulse time of 20 s would be required.

All of the above applies for a homogeneous earth whose behavior is described by a single Cole-Cole impedance. Measured decays may be the result of the superposition of effects due to more than one source type. Resolution of more than one impedance type should be possible if all types are sufficiently different in time constant (Major and Silic, 1981). If this condition is met, the net impedance may be expressed as the sum of impedances of each type. This implies that measured voltages may be modeled as the sum of voltages due to both IP and inductive coupling effects and the mathematical summary...
Johnson

shown above will apply equally well to both. At a minimum, any analysis should be capable of measuring and resolving IP effects (relatively low c, large τ) and inductive coupling (IC) effects (relatively high c, small τ).

Further developments are based on the timing characteristics of the IP receiver involved. The Scintrex IPR-11 receiver is assumed through the remainder of the paper and all results are specific to this receiver.

IPR-11 MODEL CURVES

The Scintrex IPR-11 time-domain IP receiver is a microprocessor-controlled unit which measures ten semi-logarithmically spaced points on the decay for up to six dipoles simultaneously. Receiver slice-timing can be reset to fill in other parts of the decay curve in 10 point sets. The measured decay is recorded to a resolution of 0.1 mV/V.

The master curves are numerically generated per equation (8). In the calculation of \( G(t_1, t_2, \tau, c, T) \) the integration is done before the summation. The coding used is taken in part from that published by Tombs (1980).

The master curves are generated assuming \( m = 1 \) V/V and \( T = 2 \) s. The exponent \( c \) is allowed the values 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 1.0. The time constant \( \tau \) is allowed the values 0.01, 0.03, 0.1, 0.3, 1.0, 10.0, 30.0, and 100.0 s. The exponent values reflect the expected range for polarizable targets (0.1 to 0.3) and inductive coupling effects (\( c = 1.0 \)) (Pelton et al., 1978). The time-constant values are limited at the low end by the minimum sampling interval (3 ms) and at the high end by what curve shape differences can reasonably be resolved given a pulse time of 2 s. The time constant values chosen are thought to give reasonably uniform rms deviations between different master curves.

Master curve data for longer pulse times is immediately available given the identity of equation (14).

The weighting factors used in equations (9) and (10) have the values 0.773, 0.800, 0.823, 0.843, 0.879, 0.978, 1.048, 1.143, 1.306, and 1.389.

Figure 1 shows simulated IP decays for variable time constant and fixed exponent. A simulated decay as sampled by the IPR-11 is shown, assuming that both 0.2 and 2 s IPR-11 receive modes have been used.

Figure 2 shows simulated IP decays for variable \( c \) and fixed \( \tau \). Also shown is the Newmont Standard curve (Dolan and McLaughlin, 1967) for a pulse time of 2 s. It has been found to fit best to the master curve given by a time constant of 1 s and \( c \) value of 0.1. The rms deviation of the fit is 0.3 percent. A time constant of 1 s is consistent with the fact that the Newmont Standard was influenced by the average of a large number of measured decays. With regard to the \( c \) values, Pelton (1978) noted an average value for \( c \) of 0.25 as seen in most field surveys. The \( c \) value of 0.1 for the Newmont Standard decay is, however, understandable. Averaging time-domain decay curves of fixed \( c \) and variable \( \tau \) will generally result in a curve with an exponent value less than that of the individual decays.

Numerical experiments have been conducted to examine the stability of the curve-matching process. In essence, the measured decay is set to one of the master curves. The rms deviation between this decay and each of the master curves is then calculated. The master curves are arranged in order of increasing

![Figure 2. Theoretical time-domain decay curves for fixed \( \tau \) and variable \( c \). The Newmont Standard decay for a 2 s pulse time is shown with fitted time constant and exponent.](image)

![Figure 3. Curve shape differences (or rms deviation) between selected master curves. Arranged in order of increasing deviation from the \( c = 0.2, \tau = 1 \) and the \( c = 0.5, \tau = 1 \) curves.](image)
Spectral IP Parameters

**Fig. 4.** Measured data (10 point), best-fit master decay curve, and calculated spectral parameters. Array is pole-dipole with $a = 10$ m, $n = 6$ with $V_p = 1.2$ mV. Rms deviation = 0.65 percent. $V_t$ designates the voltage measured during the transmitter off-time.

**Fig. 5.** Measured data (20 point composite), best-fit master curves, and calculated spectral parameters. Both IP and inductive coupling (IC) effects are modeled. Array is dipole-dipole with $a = 100$ m, $n = 6$ with $V_p = 2.6$ mV.

(1) As $c$ is reduced from 0.5 to 0.2, the differences in the shape of the curve between master curves of different $\tau$ are reduced and the confidence in the time-constant determination is lessened. This is no more than the familiar result obtained in the frequency domain. That is, as $c$ approaches 0.1, the phase spectrum flattens, the peak in the phase spectrum becomes less distinct, and the time constant becomes more poorly determined.

(2) Figure 3 gives an indication of the order of rms deviation required to achieve reasonably reliable spectral parameters. An rms deviation between the measured and master curve data on the order of 1 percent is indicated.

An important consideration in any time-domain spectral IP approach is the maximum resolvable time constant given a fixed transmitted pulse time. Resolution will be in part a function of the differences in master curves as quantified by the rms deviation. The differences measured between the $\tau = 30$ s and the $\tau = 100$ s master curves are 3.06 percent for $c = 0.5$ and 0.12 percent for $c = 0.1$. A number of unknown factors will be introduced when the method is taken into the field. The performance of various IP transmitters under the normal variety of load conditions is not precisely known. Measured decays will display a reliability which is a complex function of the design of the receiver, field procedures, natural noise, etc. Most conventional IP targets are not well modeled as a homogeneous earth. The role of spectral IP parameters in minerals exploration is still in debate.

Given all of these factors, the method described herein has been designed with reasonable compromise such that basic spectral parameters can be determined using traditional field procedures. Through such a scheme, spectral data over a wide variety of targets may be collected to improve understanding of the method reliability and function and to modify strategy to best fit the exploration problem at hand.

**FIELD WORK**

The results shown below have been taken from a variety of field IP surveys. Most of these surveys have been undertaken without modification or special consideration for the determination of spectral parameters. The IPR-11 receiver was used exclusively. All of the data were gathered with a pulse time of 2 s. A variety of crystal-controlled transmitters were used. Analysis was, in all cases, effected by a specially prepared application software set which is resident on a microcomputer of common manufacture.

**Decay curve analysis**

Measured decays are shown in Figures 4 and 5.

The time-domain decay shown in Figure 4 is taken from a survey over a near-surface Canadian volcanogenic sulfide zone. Array geometry was pole-dipole with a spacing of 10 m and $n = 1$ to 6. The decay shown is from the $n = 6$ dipole. The measured primary voltages were 3685 mV ($n = 1$) and 1.2 mV ($n = 6$). Apparent resistivity for the sixth dipole was 290 $\Omega\cdot$m. Eight transmit cycles were stacked or averaged to make the reading.
The fit is quite good with a deviation of 0.65 percent. The observed chargeability ($m_0$) is 283.1 mV/V. The Cole-Cole spectral parameters are given as 582 mV/V (m), 30 s (τ), and 0.3 (c).

Given the array style, a spacing, and a relatively resistive host, no significant IC component was expected (Dey and Morrison, 1973). Figure 5 shows a measured decay from dipole-dipole survey in an area of Australia with a considerable thickness of conductive cover. More than 100 m of 50 Ω·m ground are involved. The a spacing (100 m) and the n value (6) were additional reasons to measure the early-time portion of the decay. The decay shown is measured by sampling both early- and late-time 10 point decays to give a composite 20 point decay.

For the early-time measurement, 8 cycles were averaged with a V$_p$ of 2.6 mV. For the late-time measurement, 10 cycles were averaged with a V$_p$ of 2.6 mV. Acceptable data quality is possible for such low primary voltages in part because the IPR-11 receiver timing is triggered off the signal from the first potential dipole pair. Primary voltages in the n = 1 dipole in both cases were greater than 400 mV.

For the IC component a c value of 1 was assumed. The fitted parameters for both IP and IC effects are shown on Figure 5. The theoretical decays for IP, IC, and the summed responses are superimposed.

The IP fit is based on the 10 points of the late-time measurement. The IC component decayed rapidly and had no measurable influence after 40 ms following shut-off. The theoretical IC curve is a good approximation to the early-time decay after

**APPARENT RESISTIVITY /100 (ohm-m)**

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**CHARGEABILITY (690-1050 ms) - mV/V**

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**TIME CONSTANT - T - (seconds)**

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**EXponent - C**

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**FIG. 6.** Segment of results from an IPR-11 survey using the pole-dipole array with a = 10 m and n = 1 to 6. Shown are apparent resistivity/100 (Ω·m) eighth-slice chargeability (mV/V), Cole-Cole time constant (seconds) and exponent (c). Near-current electrode is to the left of the potential electrode string.
Figure 5 shows the effective decomposition of a decay curve into IP and 1C components where respective time constants are less than one order of magnitude apart. The difference in c values is influential in giving recognizably different forms.

In the example cited, the IC component has died out before seriously affecting the 10 point IP measurement from which the spectral IP parameters are determined. In extreme cases, inductive effects may persist and the early sample points of the 10 point IP decay will be corrupted. Spectral parameters determined without removal of such inductive effects may be unreliable. In such cases, the early-time measurement is important to the proper definition of IC effects, separation of IP and IC decays, and determination of spectral parameters.

**Pseudosection plots**

The results of a portion of a time-domain induced polarization survey are shown in Figure 6. Shown are the apparent resistivity (divided by 100) in Ω·m, the 8th slice chargeability (690 to 1 050 ms) in mV/V, the time constant in seconds, and the exponent c. Array geometry was pole-dipole, with a = 10 m. The current trailed the potential electrode string, the whole advancing to the right. The standard 10 point decay of the 2 s receive mode was used throughout.

The area is one of very resistive Precambrian basic volcanics with little or no overburden. The line segment shown passes into a broad zone of near-surface metallic sulfides of which pyrite is the most common.

Two distinct zones are seen in the pseudosections. The left-hand portion or host rock is an area of high resistivities and low chargeabilities. The right-hand portion is an area of extremely low resistivities and high chargeabilities. The ground is indeed so conductive under the “anomaly” as to reduce primary voltages below that point at which a reliable IP measurement can be made.

The time constant shows a strong correlation with the two zones. The time constant is uniformly low in areas of the host rock and uniformly high over the anomaly. The spatial stability of the calculated time constant is promising given the low inherent chargeabilities of the host and the sometimes low primary voltages over the anomaly.

The c values averaged 0.26 for the host and 0.27 for the anomaly. These exponent values compare well with the 0.25 value suggested by Pelton et al. (1978) as the most expected value.

The distribution of rms deviations as a function of primary voltages is shown in Figure 7. In this example, the spectral fits are equally good down to primary voltages of 1 mV below which the rms deviations have become large, and the spectral IP results are judged unreliable.

The same line segment was surveyed with both dipole-dipole and gradient arrays. Average values of the c value for the three arrays used, for host and anomalous regions, are shown in Table 1. The time-constant agreement column shows the percentage of calculated time constants which are within a factor of three of those calculated using the pole-dipole array. The gradient array time constants are compared with the nearest plotted vertical average of time constants as determined using the pole-dipole array.

The calculated time constants are reasonably stable and independent of array geometry. The gradient array gives consistently lower c values. This is a reasonable result given that the primary field in the gradient array will, in general, energize a wider variety of polarizable targets. The measured decay may be the result of the superposition of responses of possibly different time constants from more than one source.

**Comparison with frequency-domain spectral results**

In 1981, Selco Mining Corporation contracted Scintrex Ltd. and Phoenix Geophysics Ltd. to conduct spectral IP surveys on five selected lines over the Detour deposit. Cole-Cole parameters were determined independently by Scintrex working in the time domain and by Phoenix working in the frequency domain. Array setups were in each case dipole-dipole with a = 100 m, n = 1 to 6. Surveys were completed within one month of each other over the same grid.
Fig. 8. Cole-Cole parameters as determined through time-domain (by Scintrex) and frequency-domain (by Phoenix) measurements over line 8 W of the Detour deposit. Spectral parameters are omitted in the time-domain data where the rms deviation exceeds 7.5 percent.
Fig. 9. Time-domain spectral IP results over a known gold producer. Deposit is centered some 50 m below station 450 S. An iron formation is located near the baseline.
The Detour zinc-copper-silver deposit is situated in the Abitibi volcanic belt in northwestern Quebec. Three mineralized zones have been identified. Most prominent metallic sulfides are sphalerite, pyrite, and to some extent chalcopyrite. The results of this type would be more informative if they were of comparison.

The Cole-Cole parameters $c$ and $\tau$ as determined by both methods for a portion of line 8 W are shown in pseudosection form in Figure 8. The line was traversed from north to south with the current dipole trailing. Economic mineralization is known at depths of 10 to 150 m and from stations 1 S to 3 N. Both methods produced a coincident apparent chargeability high/apparent resistivity low with anomalous values from 5 S to 7 N. From the time-domain data, average apparent chargeabilities (610 to 1 050 ms) were up to 3 mV/V away from the anomaly and, over 100 mV/V near station 1 N. Apparent resistivities were on the order of 1 000 to 3 000 $\Omega\cdot$m (host) and less than 100 $\Omega\cdot$m over limited segments of the anomaly.

Both pseudosection pairs in Figure 8 show relatively higher time constants and exponent values over the center of the deposit. A detailed comparison reveals a number of differences, some of which may be caused by the following. The time-domain data by current standards are noisy. Spectral parameters were not plotted when the rms deviation exceeded 7.5 percent. Even with this rather high cut-off a number of plot points in the time-domain pseudosection remain blank. Fixing the exponent in the frequency-domain analysis may affect the comparison.

This comparison suggests that both methods will produce spectral parameters which are at least roughly equivalent. Results of this type would be more informative if they were of better quality and more extensive. The work cited is, however, the only controlled in-field comparison of the two methods available at this time.

An exploration application

In 1983, the Ontario Geological Survey sponsored a series of geophysical surveys by Scintrex Limited over known gold deposits in the Beardmore-Geraldton greenstone belt. The results of this work are described in the open file report by Marcotte and Webster (1983). Part of this work involved an IP-11 survey on five lines over the Jellicoe deposit. Earlier gold production came from a sheared silicified and brecciated zone of quartz stringers and veinlets hosted by arkose. Mineralization consists of gold and disseminated sulfides (pyrite, arsenopyrite, and sphalerite) up to 10 percent locally. The deposit is centered some 50 m subsurface. Overburden is moderately conductive and of 10 to 20 m thickness. The host rocks are Precambrian metasediments including arkose and greywacke. The deposit is some 200 m south of an extensive and prominent iron oxide formation.

The IP survey was carried out using a pole-dipole array with an $a$ spacing of 25 m and $n = 1$ to 5. The results over one survey line are shown in pseudosection form in Figure 9. The apparent resistivity, eighth-slice chargeability, Cole-Cole time-constant, chargeability, and $c$ values are shown in contoured pseudosection form.

The deposit is centered at station 450 S and is seen as a broad chargeability high. The apparent resistivity section shows no marked coincident low. At the extreme north end of the line a resistivity low and strong chargeability high are indicated. This is most probably an area of barren sulfides, probably pyrite associated with the iron formation.

The spectral IP results are interesting from a number of points of view. The time constant of the deposit is higher than the host and yet noticeably lower than that indicated by the barren sulfides near the baseline. The true chargeability pseudosection has amplified the anomaly over the deposit. The $c$ values show an average value consistent with expectations. The low $c$ values of 0.1 over the deposit suggest more than one Cole-Cole dispersion may be present.

CONCLUSIONS

A method for extracting Cole-Cole spectral parameters from routine time-domain IP measurements was developed, exercised, and applied. Resolution over a broad range of time constants was shown to be possible given time-domain decays from transmitted waveforms with a pulse time of 2 s. The apparent $c$ values are governed in part by the type of array geometry used. Limited field tests demonstrated a coarse agreement with results seen in the frequency domain.

Independent of the direct use of the spectral parameters, the analysis procedure using the Cole-Cole model was found to give a number of useful side effects. The agreement between measured and theoretical decay curves is an excellent way to quantify the noise quality of the measured decay. Method performance using a 2 s pulse time suggests a maximum resolvable time constant of approximately 100 s. This may be used to predict pulse times required to resolve targets of longer time constants.

Further developments could make good use of a forward solution which can more accurately predict the spectral response of more complex geologic models. More field work involving both the time- and the frequency-domain spectral IP methods is required. More spectral IP data from surface and downhole surveys would extend our understanding of the method and would contribute to its evolution.

The method appears a promising one for systematic application to a variety of exploration problems. Field experience with the method should suggest the best uses of the information gained. Spectral IP results may be most useful when judged on a prospect-by-prospect basis. In-field spectral calibration through downhole and small-scale array studies and close liaison between geologists and geophysicists will be important.

ACKNOWLEDGMENTS

The cooperation of Selco, Campbell Resources, Geopeko, and the Ontario Geological Survey is greatly appreciated.

REFERENCES


Spectral IP Parameters


Expanded Abstract

SPECTRAL IP: EXPERIENCE OVER A NUMBER OF CANADIAN GOLD DEPOSITS

By

Blaine Webster
JVX Limited
Toronto, Ontario

and

Ian Johnson
Scintrex Limited
Toronto, Ontario

February, 1985

Submitted to the Society of Exploration Geophysicists for consideration for inclusion into the technical program of the 55th Annual International Meeting of the SEG, Oct. 6-10, 1985, Washington, D.C.
SUMMARY

Time domain induced polarization survey results over a variety of Canadian volcanogenic gold deposits are presented. The results are accompanied by the interpreted spectral parameters and the usefulness of such parameters is discussed. A variety of geological interpretation problems are shown to be simplified by spectral IP survey results. The time constant may be used to map areas of fine grained disseminated metallic sulphides which experience has shown to be favourable targets for gold. The true chargeability may be used as a more accurate representation of the volume percent metallic sulphides. Spectral IP parameters may be used to prioritize areas which may appear uninteresting in conventional IP surveys.
Discussions about spectral IP have appeared regularly in the literature for more than ten years. Despite a high academic profile, the method has failed to make a significant impact on routine IP surveys. The result to date has been a well-developed theory with too few examples of application to exploration problems. Geophysicists remain unsure about cost benefits and cautious about recommending spectral analysis in their IP surveys.

This paper is intended to present data from a variety of surveys over a number of gold prospects. All are taken from essentially routine time domain surveys in which the spectral requirement was not considered important in advance and did not result in significant additional survey costs. It is intended that these examples will better illustrate the strengths and limitations of the method. The cost benefits are examined.

When conducting spectral IP surveys in the time domain, field procedures are effectively unaltered from conventional methods. That extra time required to produce the better quality data at each station is compensated for by the efficiencies of the new microprocessor controlled receivers. The spectral analysis which is done in the field on a microcomputer is of value in the first instance as a quality control device. Measured decays are compared to a suite of master curves. The comparison yields an rms deviation which is used by the operator to check data quality. Independent of the use of spectral parameters, spectral analysis is an essential tool in high quality production IP surveys. The spectral parameters so derived are, in essence, "free".
Spectral IP should therefore be viewed more as the next step in the natural evolution towards better IP/resistivity surveys and not as some exotic or hybrid technique suitable for special applications only. The latter is a more common attitude when using frequency domain techniques where production rates suffer from the requirement of sequential measurements at a number of frequencies.

Figure 1 shows the contoured chargeability data over the Jellicoe deposit in the Beardmore-Geraldton area of Ontario. The gold is found in a sheared silicified and brecciated zone of quartz stringers hosted by arkose. Disseminated metallic sulphides (mainly pyrite), with concentrations greater than 10 percent locally, are found in association with the gold. The deposit is centered some 60 m below surface and under some 10 to 20 m of moderately conducting transported overburden. Hole to hole correlation of the mineralization is often complicated by faulting and folding. An oxide iron formation lies 200 m north of the deposit.

The IP survey was done with a pole-dipole array employing an a spacing of 25 m and n values of 1 to 5. The Scintrex IPR-11 receiver was used with a two second pulse time.

The topmost contour map shows the seventh slice chargeability (690 to 1050 ms after shutoff) from the n=2 dipole. This type of presentation is common for conventional IP surveys. The deposit is roughly outlined by the 4 mV/V contour line in the center of the survey area. The largest IP response is moderate (less than 8 mV/V) above relatively low (less than 2 mV/V) background values. The pseudosections show this to be true for dipoles 2 to 5. There is no coincident resistivity response. The iron formation to the north is seen as a more...
prominent chargeability high. A pipeline running NE-SW gives an equally large response in the northwest corner of the area.

The lower contour map shows the Cole-Cole chargeability as derived from the spectral analysis of measured decays. The IP anomaly over the deposit is enhanced relative to background levels. The response is now more suited to that expected from some 15% sulphides by volume at these depths. The conventional IP response is quite modest and might be overlooked in a more complex electrical environment. The Cole-Cole chargeability is thus more sensitive to small variations in volume percent sulphides. The spectral IP presentation appears to define the complex structure of the deposit more so than conventional IP.

Figure 2 is taken from an IP survey in an area of Manitoba with a geological model similar to that described above - that is, gold in a relatively resistive environment in association with disseminated metallic sulphides adjacent to an iron formation. This type of model is thought to give an IP response characterized by:

- high apparent resistivities due to silicification
- higher chargeabilities due to the metallic sulphides
- short Cole-Cole time constants resulting from the fine-grained nature of the sulphides

Experience has shown this to be a promising IP signature for some types of volcanogenic gold deposits.
The IP survey was conducted using a pole-dipole array with an a spacing of 100 feet and $n$ values of 1 to 6. The IPR-11 receiver was used with a two second pulse time.

The pseudosection in Figure 2 shows a broad chargeability high in an area of moderate to high apparent resistivities. The chargeability anomaly is quite wide and a drill location would be difficult to assign if no other information were available. The Cole-Cole time constants as determined from spectral analysis of the measured decays does show a segmentation of the IP anomaly into areas of different time constants. The areas of low time constant values are the preferred areas for follow-up.

Limited trenching has revealed a two foot thick zone of massive arsenopyrite and pyrite with pods of sphalerite and galena at station 29+50S. Prospecting away from the showing indicates disseminated sulphides. HLEM surveys over the same ground gave no response. Drilling is currently in progress.

The spectral IP results illustrate the possibility of mapping based solely on the IP characteristics (as opposed to volume percent) of metallic sulphides. Conventional IP data are handicapped by the inability to map these characteristics and by the mixing of different types of geological information, i.e. grain size and percent sulphides.

These and other examples which illustrate the use of time domain spectral IP data are presented. The spectral parameters so determined are shown to be
important in assessing data quality and useful in interpreting IP survey results. With modern receivers and analysis techniques, the method is very cost-effective given the small additional cost associated with spectral IP in the time domain.

ACKNOWLEDGEMENTS

The cooperation of Dome Mines and Manitoba Mineral Resources Limited is gratefully acknowledged.

FIGURE CAPTIONS

Figure 1: Contoured chargeabilities in mV/V. Pole-dipole array with a=25 m, n=1 to 5. Seventh slice IPR-11 (690 to 1050 ms after shutoff) data for the n=2 dipole shown in upper half. Cole-Cole chargeabilities in mV/V for the same area and dipole number shown below.

Figure 2: Pseudosections showing apparent resistivity, sixth slice IPR-11 (510 to 690 ms after shutoff) and Cole-Cole time constant. Pole-dipole array with a=100 feet and n values from 1 to 6.
CONVENTIONAL CHARGEABILITY

SPECTRAL CHARGEABILITY
Induced Polarization

Claim Holder
Kidd Creek Mines Ltd.
Address
40th Floor, Commerce Court West, Toronto, Ontario M5L 1B4

Survey Company
JVX Ltd.

Name and Address of Author (of Geotechnical report)
Blaine Webster, Unit 2, 33 Glen Cameron Rd., Thornhill, Ontario L3T 1N9

Credits Requested per Each Claim in Columns at right

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Geological
Geochemical

Man Days
Complete reverse side and enter total(s) here

Airborne Credits

Expenditures (excludes power stripping)

Type of Work Performed

Performed on Claims

Calculation of Expenditure Days Credits

Total Days Credits

Instructions
Total Days Credits may be apportioned at the claim holder’s choice. Enter number of days credits per claim selected in columns at right.

Expenditure Days Credits

Note: Special provisions to Airborne Surveys.

For Office Use Only

Certification Verifying Report of Work

I hereby certify that I have a personal and intimate knowledge of the facts set forth in the Report of Work annexed hereto, having performed the work or witnessed same during and/or after its completion and the annexed report is true.

Date Recorded
July 21/87

Certified: July 20/87

Muir, Surveyor
**Induced Polarization**

**Claim Holder(s)**
Kidd Creek Mines Ltd.

**Address**
Box 40, Commerce Court West, Toronto, Ontario M5L 1B4

**Survey Company**
JVX Ltd.

**Date of Survey (from & to)**
10 June 86 to 24 June 86

**Total Miles of line Cut**
27.25km

**Type of Survey(s)**

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**Airborne Credits**

- Electromagnetic
- Magnetometer
- Radiometric

**Expenditures (excludes power stripping)**

The Mining Act

**Number of mining claims traversed**

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**Total number of mining claims covered by this report of work.**

862781

**Certification Verifying Report of Work**

I hereby certify that I have a personal and intimate knowledge of the facts set forth in the Report of Work annexed hereto, having performed the work or witnessed same during and/or after its completion and the annexed report is true.

Date: July 20/87

Branch Director
**GEOCHEMICAL SURVEY - PROCEDURE RECORD**

- **Numbers of claims from which samples taken:**
- **Total Number of Samples:**
- **Type of Sample:** (Nature of Material)
- **Average Sample Weight:**
- **Method of Collection:**
- **Soil Horizon Sampled:**
- **Horizon Development:**
- **Sample Depth:**
- **Terrain:**
- **Drainage Development:**
- **Estimated Range of Overburden Thickness:**

**ANALYTICAL METHODS**

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**Field Analysis:** (tests)

**Extraction Method:**

**Analytical Method:**

**Reagents Used:**

**Field Laboratory Analysis**

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**Commercial Laboratory:** (tests)

**Name of Laboratory:**

**Extraction Method:**

**Analytical Method:**

**Reagents Used:**

**General:**

**SPECIAL PROVISIONS**

**CREDITS REQUESTED**

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<td>ENTER 20 days for each additional survey using same grid.</td>
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**AIRBORNE CREDITS**

- **Magnetometer**
- **Electromagnetic**
- **Radiometric**

**DATE:** Aug. 18/87 **SIGNATURE:**

**RES. GEO. Qualifications:** 2.238

**OFFICE USE ONLY**

**PREVIOUS SURVEYS**

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**MINING CLAIMS TRAVERSED**

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**TOTAL CLAIMS:** 16
## Ground Surveys

- Number of Stations: 158
- Station interval: 25m
- Profile scale: NA
- Contour interval: Chargeability: 2mV/V
- Resistivity: 1 ohm
- Number of Readings: 316
- Line spacing: 50m

### Magnetic

- Instrument:
- Accuracy - Scale constant:
- Diurnal correction method:
- Base Station check-in interval (hours):
- Base Station location and value:

### Electromagnetic

- Instrument:
- Method: [ ] Fixed transmitter [ ] Shoot back [ ] In line [ ] Parallel line
- Frequency (specify VLF station)
- Parameters measured:

### Gravity

- Instrument:
- Scale constant:
- Corrections made:
- Base station value and location:
- Elevation accuracy:

### Self Potential

- Instrument:
- Accuracy - Scale constant:
- Diurnal correction method:
- Base Station check-in interval (hours):
- Base Station location and value:
- Range:

### Radiometric

- Instrument:
- Values measured:
- Energy windows (levels):
- Height of instrument:
- Background Count:
- Size of detector:
- Overburden:

### Others (Seismic, Drill Well Logging Etc.)

- Type of survey:
- Instrument:
- Accuracy:
- Parameters measured:
- Additional information (for understanding results):

### Airborne Surveys

- Type of survey(s):
- Instrument(s):
- Accuracy:
- Aircraft used:
- Sensor altitude:
- Navigation and flight path recovery method:
- Aircraft altitude:
- Line Spacing:
- Miles flown over total area:
- Over claims only:
August 18, 1987

Mr. Fred Mathews
Ministry of Natural Resources
Land Management Branch
Room 6542, Whitney Block
Queen's Park
Toronto, Ontario
M7A 1W3

Dear Mr. Mathews:

Re: Geophysical Work filed July 20, 1987 - File Nos. Kenora 139-87 & 140-87

Please find attached the following information regarding geophysical work performed on claims held by Kidd Creek Mines Ltd. in Aubrey Township, Kenora Mining Division:

1. photocopy of reports of work
2. duplicates of geophysical report (IP) by Neil Hughes and Blaine Webster, JVX Ltd.
3. duplicates of geophysical technical data statement

I trust you will find everything in order.

Yours truly,

FALCONBRIDGE LIMITED

R.B. Band
Senior Exploration Geologist
RBB/1b
Enclosures
cc: R.H. Tays
December 2, 1986

Dear Sir:

RE: Notice of Intent dated November 13, 1987
Geophysical (Induced Polarization) Survey on Mining Claims K 590318 in the Areas of Aubrey and Contact Bay

The assessment work credits, as listed with the above-mentioned Notice of Intent, have been approved as of the above date.

Please inform the recorded holder of these mining claims and so indicate on your records.

Yours sincerely,

W.R. Cowan, Manager
Mining Lands Section
Mines and Minerals Division

Whitney Block, Room 6610
Queen's Park
Toronto, Ontario
M7A 1W3

Telephone: (416) 965-4888

AB:pl
Enclosure: Technical Assessment Work Credits

cc: Mr. G.H. Ferguson
Resident Geologist
Mining & Lands Commissioner
Kenora, Ontario

Kidd Creek Mines Ltd.
40th floor
Commerce Court W.
Toronto, Ontario
M5L 1B4
**Recorded Holder**

Kidd Creek Mines Limited

**Area**

Aubrey and Contact Bay

<table>
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Man days

Airborne

Special provision

Ground

- Credits have been reduced because of partial coverage of claims.
- Credits have been reduced because of corrections to work dates and figures of applicant.

**Special credits under section 77 (16) for the following mining claims**

10 Days Induced Polarization

K 842085
842089-90 inclusive

**No credits have been allowed for the following mining claims**

- not sufficiently covered by the survey
- insufficient technical data filed

K 842079
Work Credits

Ontario Geoscience Assessment

Work 140-87: Kidd Creek Mines Limited

Type of survey and number of days

Geophysical

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Special credits under section 77 (16) for the following mining claims

No credits have been allowed for the following mining claims

JP not sufficiently covered by the survey

Sufficient technical data filed

Maximum credits are limited as follows:

Geophysical: 80
Geochemical: 40
Geological: 40
Section 77(19): 60

Audrey and Contact Bay

Recorded Holder

2.10295
Recorded Holder
Kidd Creek Mines Limited
Area
Aubrey & Contact Bay

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<td>Magnetometer</td>
<td>K 590552</td>
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<tr>
<td>Radiometric</td>
<td></td>
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<tr>
<td>Induced polarization</td>
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<tr>
<td>Other I.P.</td>
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Section 77 (19) See "Mining Claims Assessed" column

Geological

Geochemical

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<tr>
<th>Men days</th>
<th>Airborne</th>
<th>Special provision</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td>☑</td>
<td>☑</td>
</tr>
</tbody>
</table>

☐ Credits have been reduced because of partial coverage of claims.
☐ Credits have been reduced because of corrections to work dates and figures of applicant.

Special credits under section 77 (16) for the following mining claims

10 Days Induced Polarization      5 Days Induced Polarization
K 862782                         K 862781

No credits have been allowed for the following mining claims

☐ not sufficiently covered by the survey     ☐ insufficient technical data filed

The Mining Recorder may reduce the above credits if necessary in order that the total number of approved assessment days recorded on each claim does not