ARIS SUMMARY SHEET

District Geologist, Smithers   Off Confidential: 94.12.24

ASSESSMENT REPORT 23254   MINING DIVISION: Skeena

PROPERTY: Stewart
LOCATION: LAT 56 37 00   LONG 129 34 00
UTM 09 6274646 465221
NTS 104A12E
CLAIM(S): Fox 1-24
OPERATOR(S): American Barrick Res.
AUTHOR(S): Molloy, D.E.;Webster, Blaine
REPORT YEAR: 1993, 222 Pages
COMMODITIES
SEARCHED FOR: Gold
KEYWORDS: Dome,Window,Paleozoic,Stikine Assemblage,Volcanics,Hazelton Group Volcanics,Intrusives,Alteration,Pyrite,Sphalerite,Chalcopyrite Malachite,Azurite,Gold,Upper Jurassic,Bowser Lake Group
WORK
DONE: Geochemical,Geophysical
IPOL 3.5 km
Map(s) - 10; Scale(s) - 1:2500,1:2000
MAGG 4.4 km
Map(s) - 2; Scale(s) - 1:2500
ROCK 301 sample(s) ;ME
Map(s) - 9; Scale(s) - 1:1 000 000,1:50 000,1:10 000,1:2500
SILT 237 sample(s) ;ME
Map(s) - 5; Scale(s) - 1:50 000,1:10 000,1:2500
SOIL 256 sample(s) ;ME
Map(s) - 4; Scale(s) - 1:2500
MINFILE: 104A 165,104A 166

REPORT ON GEOPHYSICAL SURVEYS ON THE STEWART PROJECT DELTAIC TARGET AREA NORTHWESTERN BRITISH COLUMBIA

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JVX Ref: 9346
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JVX

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Appendix 3: Literature

Spectral IP parameters as determined through Time Domain Measurements by I.M. Johnson, Scintrex Limited, Toronto, Ontario, Canada, 1984.

Spectral IP: Experience over a number of Canadian Gold Deposits by B. Webster, JVX Ltd., and I.M. Johnson, Scintrex Limited, Toronto, Ontario, Canada, 1985.

Time domain Spectral Induced Polarization, some recent examples for gold, by Ian M. Johnson and Blaine Webster, JVX Limited, Thornhill, Ontario, Canada, 1987. Prepared for delegates to Exploration 87, 1987, Toronto, Canada

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On Behalf Of

GEOFINE EXPLORATION CONSULTANTS LTD.

1. INTRODUCTION

Between September 25th and October 6th, 1993 Time Domain Spectral Induced Polarization, Resistivity and Total Field Magnetics surveys were conducted by JVX Ltd. on behalf of Geofine Exploration Consultants Ltd. on the Stewart Deltaic Glacier property in the Stewart area of Northwestern B.C..

The objective of the survey was to follow-up colour soil anomalies and to outline areas of anomalous IP response and hence areas of disseminated sulphide sources. In conjunction with the survey soil geochemical samples were taken by Geofine. The final product of this survey are recommendations of IP targets which are thought favourable sites for gold.

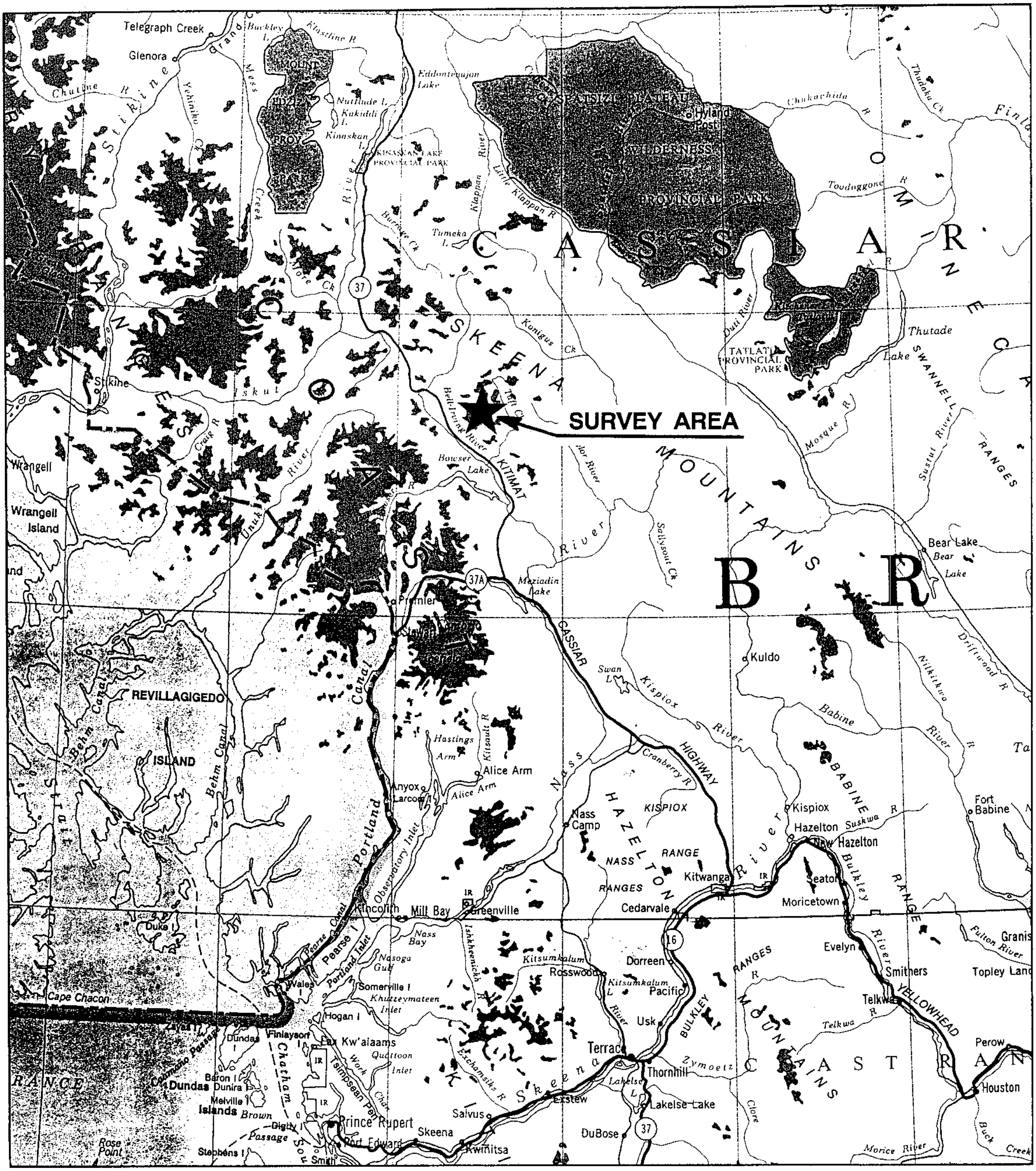
The IP survey employed the pole-dipole array with six potential dipoles (n=1 to 6) and a dipole spacing of 25 metres. The line spacing was nominally 100 metres. A total of 3.53 line-km of IP coverage over 4 lines was achieved. A total of 4.41 line-kilometres were read with magnetometer.

This report describes the survey logistics, field procedures, and data processing/presentation. An interpretation of the results which are presented as a compilation/anomaly map, magnetics contour map, offset profiles and offset pseudosections.

2. SURVEY LOCATION

The survey grid is located in the Skeena Mining Division about 80 km northeast of the town of Stewart, B.C. (Figure 1). The Stewart property is located about 2 km east of the Cassiar Highway, about one hour's drive north of the Meziaden Junction . The property is centred on NTS Map Sheet 104A/12, at latitude 56°40'N longitude 129°35' W.

The main access to the Stewart property is via helicopter from the Cassiar Highway; or, from the helicopter base at Bob Quinn, located on the Cassiar Highway, about 60km north of the property; or, via helicopter from the Bulkely Valley Maintenance Camp located at the Highways' Maintenance Yard at Meziadin Lake. Figures 1 and 2 show the survey area with respect to local topographic features at a scale of 1:2,000,000 and 1:66,600 respectively.



LOCATION MAP

GEOFINE EXPLORATION CONSULTANTS

STEWART PROJECT

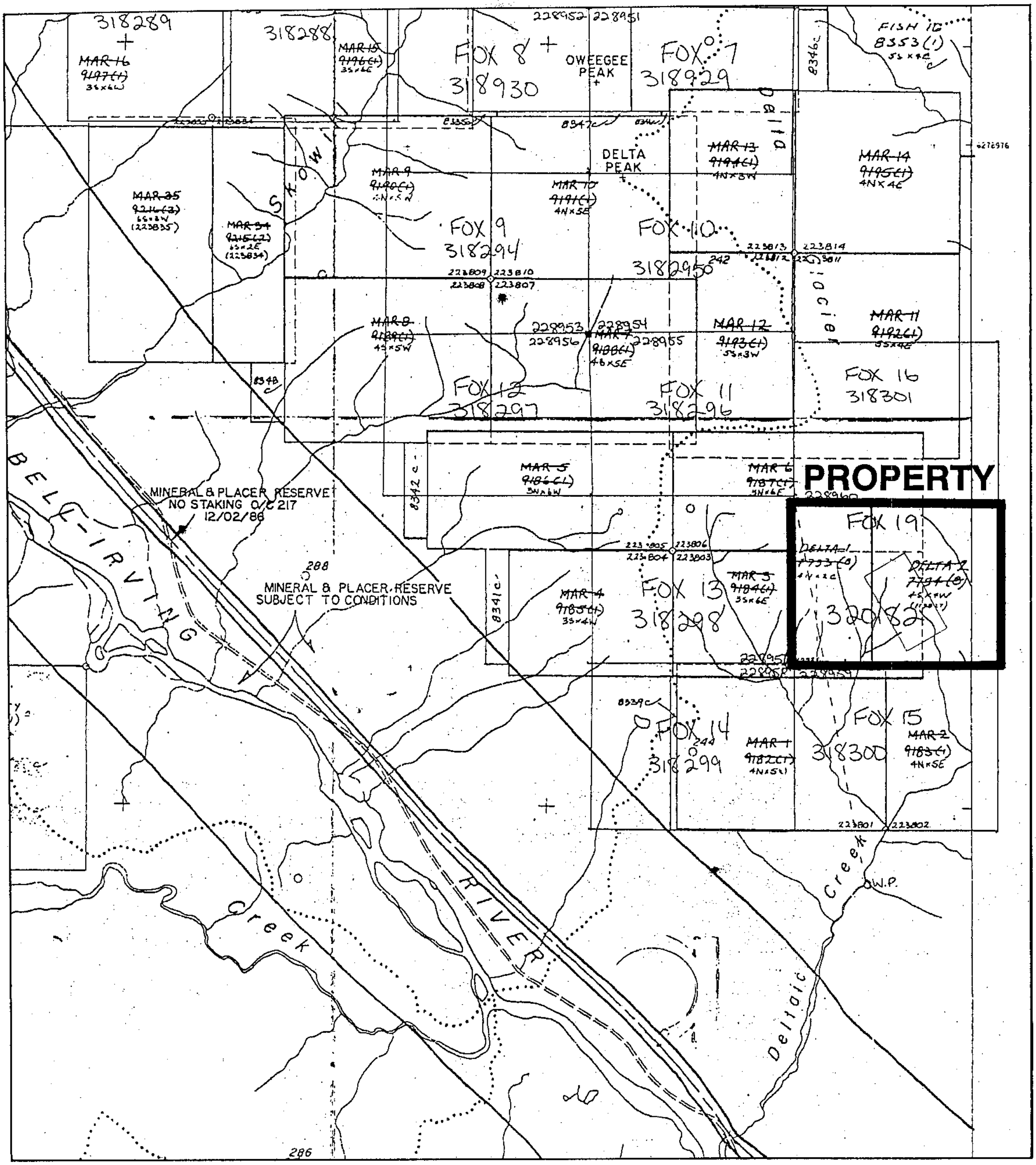
DELTA GLACIER, B.C.

GROUND GEOPHYSICAL SURVEY

Scale : 1 : 2,000,000

Survey by: **JVX Ltd.**

Figure 1



PROPERTY MAP

GEOFINE EXPLORATION CONSULTANTS

STEWART PROJECT

DELTA GLACIER, B.C.

GROUND GEOPHYSICAL SURVEY

Scale : 1 : 66,600

Survey by: **JVX Ltd.**

Figure 2

3. SURVEY GRID AND COVERAGE

A total of 3.57 line-km of IP coverage was achieved over the grid. A detailed production summary of the work executed by JVX is given in Table 1 below.

TABLE 1

PRODUCTION SUMMARY - INDUCED POLARIZATION

LINE	COVERAGE FROM	TO	LINE LENGTH (metres)	MEASUREMENT POINTS
L-50E	3800N	4875N	1075	264
L-52E	4000N	4650N	650	162
L-53E	3850N	4750N	900	150
L-54E	4050N	4950NW	900	222
Total			3.525 km	798

The Magnetics survey totalled 4.41 line-kilometres.

4.0 GEOLOGY (From D. Molloy)

4.1 Regional Geology:

The Stewart property is situated on the eastern margin of a broad, north-northwest trending volcanogenic - plutonic belt consisting of the Upper Triassic Stuhini Group and the Upper Triassic Lower Middle Jurassic Hazelton Group. This belt has been termed the " Stewart Complex "and forms part of the Stikinia Terrane. The Stikinia Terrane together with the Cache Creek and Quesnel Terranes constitute the Intermontane Superterrane which was accreted to North America in Middle Jurraissic time. To the west the Stewart Complex is bordered by the Coast Plutonic Complex. Sedimentary rocks of the Middle to Upper Jurrassic Bowser Lake Group overlay the Stewart Complex in the east.

4.2 Property Geology:

The property is postulated to cover a tectonic window in which Jurraissic Hazelton Group and Paleozoic Stikine Assemblage rocks have been exposed by the uplift of broad anticlinal features known as the Oweege and Ritchie Domes and by the erosion of Upper Jurassic sediments of the Bowser Basin.

The property is known to consist of Carboniferous and Permian volcanic rocks. The southern and northwestern areas of the Stewart property are dominated by rocks of the Lower Jurassic Hazelton Group: intermediate to mafic plagioclase-pyroxene lapilli tuff-breccia, lapilli, ash and dust tuffs; intermediate and felsic flows and derived debris flows; tuffaceous arkose and siltstone; and conglomerate and sandstone.

Based on Geofine's observations there is some altered porphyritic intrusion of unknown age. Verbal communication with D. Molloy indicates the volcanics are pyroclastics consisting of tuffs, agglomerates and breccias.

5. PERSONNEL

Mr. Denis Palos - Geophysicist/Party Chief. Mr. Palos operated the IP receiver and IGS Magnetometer system and compiled the data with the Corona microcomputer and Scintrex Soft II programme.

Mr. Jan Kozel - Geophysicist. Mr. Kozel operated the IP transmitter and IGS Magnetometer system. Mr. Kozel assisted Mr. Palos with the in-field data processing and plotted all of the maps in Toronto.

Geofine provided three field assistants.

Mr. Blaine Webster - President, JVX Ltd. Mr. Webster provided overall supervision of the survey, interpreted the data and prepared the report.

6. INSTRUMENTATION

6.1 IP Receiver

The Scintrex IPR-12 time domain microprocessor-based receiver was employed. This unit operates on a square wave primary voltage and samples the decay curve at ten gates or slices. The instrument continuously averages primary voltage and chargeability until convergence takes place. At this point, the averaging process is stopped. Data is stored internally in solid-state memory.

6.2 IP Transmitter

The survey employed the Scintrex IPC-7/2.5 kW time domain transmitter powered by a motor generator. This instrument is capable of putting out a square wave of 2, 4 or 8 seconds 'on-off' time. The current output was accurately monitored with a digital multimeter placed in series with the current loop.

6.3 Magnetometer

A Scintrex IGS-2/MP-4 proton precession magnetometer system was employed to take readings of the total magnetic field over the grid. Readings were taken along line at 12.5 metre station intervals. The geophysical measurements, time and position information are recorded in the instrument's solid state memory. A second magnetometer was used to monitor the diurnal change. At the end of each day the magnetometers were linked and the correction for the diurnal shift made automatically.

6.4 Data Processing

The survey data were archived, processed and plotted with a Compaq microcomputer using an Epson FX-85 dot matrix printer. The system was configured to run the Scintrex Soft II software systems, a suite of programs that was written specifically to interface with the IPR-12 receiver. At the conclusion of each day's data collection, data resident in the magnetometer or IP 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 were ink-plotted in pseudosection format on a Nicolet Zeta drum plotter interfaced to an IBM PC/AT microcomputer.

The instrumentation is described in detail in the specification sheets appended to this report.

7. SURVEY METHOD

7.1 Exploration Target

Gold mineralisation, the target of this survey, does not occur in sufficient quantities to affect either the bulk polarizability or resistivity of the ground. Induced Polarization anomalies will results from disseminated metallic sulphides if they are of sufficient concentration and volume. Gold may in turn be found in association with the sulphides. The resistivity data is useful in mapping lithologic units and zones of alteration, shearing or silicification, all of which may help define the geological/geophysical character of the area.

7.2 Quantities Measured (IP/resistivity)

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 by an interrupted square wave (as in the time domain measurement). In the time domain the IP effect is manifested by an exponential type decrease in voltage with time.

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 current flow is electronic rather than electrotlytic.

Measurements are made by applying a current across the ground using two electrodes (current dipole). The current is in the form of an interrupted square wave with on-off periods of 2 seconds. The primary voltage and IP effect is mapped in an area around the current source using what is essentially a sensitive voltmeter connected to a second electrode pair (potential dipole). The primary voltage determines the apparent resistivity after corrections for transmitter current and array geometry. (See Figure 3).

For any array, 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-12 also measures the secondary or transient relaxation voltage during the two second off cycle. Fourteen slices of the decay curve are measured at semi-logarithmically spaced intervals between 60 and 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.

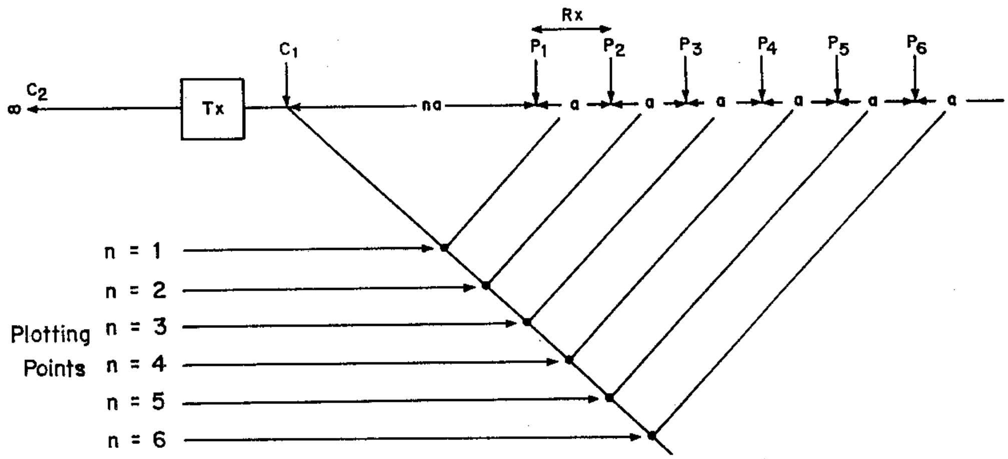
For a 2 second transmit and receive time the slices are located as follows:

SLICE	WIDTH msec	FROM msec	TO msec	MIDPOINT msec
4	20	50	70	60
5	40	70	110	90
6	40	110	150	130
7	80	230	450	190
8	80	150	270	310
9	140	310	450	380
10	140	450	590	520
11	230	590	820	705
12	230	820	1050	935
13	360	1050	1410	1230
14	360	1410	1770	1590

Traditionally, the M7 slice (from 690 to 1050 ms after shut-off) is chosen to represent chargeability in pseudosection form.

7.3 Field Procedures (IP/resistivity)

The surface IP/resistivity survey employed the time domain method with a pole-dipole array. The geometry of the pole-dipole array is illustrated in Figure 3.



ARRAY GEOMETRY

Apparent Resistivity:

$$\rho_a = 2\pi \ na(n+1) \ Vp/I$$

where

ρ_a = apparent resitivity (ohm.m)
n = dipole number (dimensionless)
a = dipole spacing (m)
Vp = primary voltage (mV)
I = primary current (mA)

Pole-Dipole Array
Array Geometry and Formula for Apparent Resistivity

Figure 3

The electrodes marked C1 and C2 are the current electrodes. Those marked as P1, P2, etc., are the potential electrodes. The receiver measures the voltage across adjacent pairs of potential electrodes; e.g. P1-P2, P2-P3, ... P6-P7. These potential pairs are labelled by an integer 'n' which indicates the multiple of the dipole width that the given dipole lies away from the near current electrode.

The further the potential dipole lies from the current dipole the greater is the depth of investigation. Resolution of the survey is increased by decreasing the 'a' separation. The current survey employed a dipole spacing of 25 metres.

7.4 Field Procedures (Mag)

The magnetic survey employed a proton procession magnetometer to measure the Total Field component of the earth's magnetic field along lines at 12.5 metre station interval.

8. DATA PROCESSING AND PRESENTATION

8.1 Summary

To allow for the computer processing of the survey data, the raw data stored internally in the IPR-12 were transferred at the end of a survey day to floppy diskettes. The raw data were filed on diskette in ASCII character format using an IBM compatible (MS-DOS) microcomputer.

An archived edited data file, in binary format, 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 spectral parameters (c, tau and MIP) are derived from the IPR-12 data with the Soft II software. The edited data were then dumped to a printer as formatted data listings, contoured pseudosections and profiles.

The apparent resistivity and average chargeability data and spectral M-IP and tau were machine contoured in pseudosection form and then photoreduced to a scale of 1:2000. Pseudosection pairs (resistivity and chargeability or M-IP and tau) were then joined according to the survey grid to form 'offset' pseudosections.

IP anomalies were picked from the pseudosections and entered on an anomaly/compilation map as anomaly bars parallel to the grid lines. IP characteristics of chargeability amplitude, time constant and MIP amplitude are indicated by the bar style or by numerical values.

The results of the survey are presented on the following plates:

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Plate 1: Stacked M8/Res.Pseudosections with anomalies & targets;
50E - L-54E
Plate 2: Stacked M11/Res.Pseudosections; L-50E - L-54E
Plate 3: Stacked M-IP/TAU Pseudosections; L-50E - L-54E
Plate 4: Chargeability (M11) Contours (n=2)
Plate 5: Resistivity Contours (n=2)
Plate 6: IP-COLE-COLE 'M'CONTOURS (n=2)
Plate 7: Total Magnetic Field Contours
Plate 8: Total Magnetic Field Profiles
Plate 9: Compilation/Anomaly Map

Plates 4 to 9 are at scale of 1:2500, pseudosections plates are at scale of 1:2000.

Elements of the data processing are discussed in greater detail below.

8.2 Spectral Analysis

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 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 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.

IP decay forms are quantified using the Cole-Cole model developed by Pelton et al (1978). Pelton was one of the first to use the term Spectral IP. The Cole-Cole model is determined by the resistivity and three spectral parameters , m, tau and c. These parameters are interpreted as follows:

m(or MIP)- Chargeability Amplitude (mV/V). This is related to the volume percent metallic sulphides (although there is no simple quantitative relationship between the two).

tau - Time Constant (sec). A short time constant (e.g. 0.01 to 0. s)suggests a fine grained source. A long time constant (e.g. 10 to 100 s) suggests a coarse grained (or interconnected or massive) source.

c - Exponent (dimensionless). A high c value (e.g. 0.5) implies one uniform polarizable source. A low c value (e.g. 0.1) implies a mixture of sources.

Conventional chargeability is a mixture of these spectral parameters and a change in any one parameter will produce a change in the apparent chargeability. In the absence of spectral analysis, such changes are always ascribed to a change in the volume percent metallic sulphides, even though the cause may be a shift from fine to coarse grained material.

In practice, the spectral parameters are used to characterise and priorize IP anomalies which have been picked from the pseudosections of conventional single slice (or average) chargeability. In this regard, the chargeability amplitude (MIP) and the time constant are the most useful. IP anomlies which are similar in all other respects may be separated based on their spectral characteristics.

Spectral parameters are extracted from all measured decay curves by finding a best fit between the measured decay and a suite of master curves. The process yields a fit parameter which is the root mean square difference (expressed as per cent) between the ten values of the measured and best fit master decays. The fit parameter is low (i.e. less than 1%) for high quality data of moderate to high amplitude. The fit parameter is high (i.e. greater than 10%) for poor quality or low amplitude data.

Normally fit values in excess of 5% are considered too high and spectral values are not posted on the pseudosections.

8.3 Anomaly Selection and Classification

IP anomalies are picked off the pseudosections of chargeability. The selection is based in part on some idea of what a true bedrock IP or resistivity anomaly should look like in contoured pseudosection form. Such ideas are normally taken from model results.

Standard IP/resistivity anomaly shapes are shown in contoured pseudo- section form in Figure 4. These are theoretical results for a pole- dipole survey over a near surface tabular body. The body has a width which is two times the dipole spacing.

Of note in these results is the change in IP anomaly shape as the target changes from being more conductive than the host to being more resistive. In the later case, the IP response is very much to one side of the target (the current side) and of reduced amplitude and breadth. Based on this type of behavior, all IP anomalies of the form seen in Figure 4, regardless of amplitude, are selected, assigned characteristics such as location, peak amplitude, MIP value and time constant and entered on the pseudosections and compilation map

Areas of high resistivity have been noted with an H(n) where the 'n' represents the dipole in which the peak value occurs; accompanying arrows symbolize the high resistive blocks. Areas of low resistivity are rated as very weak, weak, medium or strong and are shown as anomaly bars.

Chargeability anomalies are represented on the pseudosections and compilation plan map by anomaly bars that take the following form:

——— very strong chargeability high; > 30 mV/V and well defined

——— strong chargeability high; 20 - 30 mV/V and well defined

— — moderate chargeability high; 10 - 20 mV/V

- - - - - weak chargeability high; 5 10 mV/V

. . . . . . very weak chargeability high; < 5 mV/V and poorly defined

A similar scheme describes the resistivity anomalies.

If a given IP anomaly has a resolvable peak then the dipole in which the peak value occurs is indicated by the notation "n=1" or "n=4", etc., beside the anomaly bar. The dipole in which the peak IP response occurs suggests in a very qualitative sense the depth to the top of the source. The location of the notation with respect to the anomaly bar represents the interpreted centre of the source body.

The numerical value of the chargeability amplitude (MIP) of the peak response and the time constant range value between 0.0 and 2000 sec. Time constants of 0 to 1 sec. are short; 1 - 10 sec. are medium and 30 to 1,000 are long.

8.4 Compilation Map

The IP anomalies are fine drawn onto a grid map using anomaly bar symbols which parallel the grid lines. IP anomalies are shown to the right of the grid lines.

IP anomalies showing line to line correlation have been grouped into anomalous zones and labelled with a letter. Resistivity highs (or lows) which show good line to line correlation may be grouped into anomalous zones. Definable resistivity peak highs (or lows) which show good line to line correlation may be joined as axes.

9. DISCUSSION OF RESULTS

The Induced Polarization survey yielded a number of chargeability anomalies that were grouped into five major trends (A, B, C, D, and E) according to their primary strike. The magnetic survey showed a magnetic relief of only 100 nanoteslas across the grid with average responses being 25 nT. Some high frequency (shallow) resonses occur on the grid. Line 55E has the most of the shallow magnetic sources. The magnetometer operator determined that these sources were real, it was not apparent that these are boulders.

Trend A

Trend A is located in the northern part of the survey area consists of three IP zones labeled A-1 through A-3.

Zone A

Zone A is a strong to very strong chargeability response with a weak resistivity low occuring on lines 5400E to 5000E near 4700N. The zone has generally short time constants which is indicative of fine grained sulphide mineralization. Zone A appears to be associated with a weak resistivity high of approximately 1,000 ohm-meters. The narrow resistivity high located at 5200E / 4700 N has a shape that may be associated with a zone of silicification or a quartz feldspar porphyry intrusive.

Zone A1

Zone A1 is a moderate to strong chargeability response located on the south flank of zone A. The zone is generally a moderate response but its MIP spectral response is quite high with a short time constant indicating a relative high percent by volume of fine grained sulphide. On line 5200N the anomaly is associated with a weak resistivity high which may be significant. Also the relationship of zone A1 to A may be important economically because in gold environments often the mineralization adjacent to the main zone of sulphide mineralization is economically significant.

Zone A2

Zone A2 is a weak chargeability response that occurs on the south flank of a magnetic low which is also associated with a weak resistivity high. The magnetic low should be examined to see if it is associated with the weak resistivity high located between 4875N and 4925N on line 5400N.

Zones A3 and A3'

Zone A3 and A3' are weak chargeability responses located at the ends of lines 5000E and 5400E respectively.

Recommendation:

The geochemical data should be correlated with the various geophysical responses associated with Zone A. From a geophysical perspective zones A and A1 are the best drill targets because of the association of relatively higher resistivities on line 5200N.
Zones A and A1 could also be tested on line 5400N. Note that the northern part of line 5400N was moved to the east as shown to avoid an area of talus which gave poor contact for the receiver.

It is apparent that the lines could be extended to the north to further define the anomalies and locate new targtes.

Trend B:

Zone B is a weak chargeability response located to the south of zone A1 on lines 5300 E and 5400 E. On line 5400 E there is a weak resistivity low.

Recommendation: Zone B should be evaluated with geochemistry. The testing of Zone B should be dependent on the results of Zone A1 on line 5200E.

Trend C

Trend C consists of a weak to moderate chargeability response crossing lines 5200E to 5400E near 4325N. On line 5400E zone C is on the north flank of anomaly D. Zone C on 5400E has a nicely shaped spectral IP response. On line 5300E anomaly C looks like it is narrow or has limited depth extent.

Recommendation: Zone C should be checked geochemically. The resistivity data does not indicate silicification to be present.

Trend D

Trend D consists of two weak to moderate chargeability responses labelled D extending from line 5300E to line 5000E and D1. Anomaly D on lines 5200E and 5000E are moderate chargeability responses with an associated weak resistivity low on line 5200E. On line 5200E the anomaly is in a slightly higher resistivity environment which may suggest silicification. The other lines have some higher resistivities associated in the n=1 & 2 dipoles suggesting poor contact or higher shallow resistivities. The generally short time constants suggest a fine grained sulphide source.

Recommendations Trend D:

Check with geochemical survey. The anomaly should be trenched and sampled especially on lines 5000E and 5200E. Anomaly D1 should be examined on line 5400E because the response although unusually shaped may be associated with a resistive chargeable source. The resistive source is indicated by the negative center of the chargeability anomaly. A possible fault may separate anomalies D and D1.

Trend E

Trend E consists of a weak response on line 5400E to a very strong response on line 5000E. Anomaly E has a weak resistivity high associated with it and generally short time constants associated with moderate MIP (350 mV/V.) The anomaly on line 5000E warrants drilling.

Recommendations Trend E

Drill anomaly E on line 5000E. A high priority target for drilling

10. CONCLUSIONS AND RECOMMENDATIONS:

The induced polarization survey though small in size provided a tremendous amount of information about the property. Five chargeability trends were delineated on the property. The associated resistivities were between 300 and 3000 ohm meters which is quite low. The higher resistivities must be calibrated to zones of observed silicification to determine what is significant for identifying resistivity anomalies associated with silicification. It appears that resistivities of 1,500 ohm - m or greater may have associated silicification.

The magnetic survey showed the lithologies to have very little magnetic expression. Some weak responses near IP anomalies may be significant.

The low resistivities may reflect the high porosity of the volcanic pyroclastics and the relative unwelded nature of the material.

Trends A and E have very strong chargeability responses with weaker zones of interest designated A1, A2 etc. Two high priority targets are zone A and A1 on line 5200 East; the spectral IP response makes zone A1 particularly interesting. The zero time response of A1 is higher than zone A on lines 5200E, 5300E and 5400E which, with the short time constant, means abundant fine grained sulphide. IP zones A and A1 should be drilled on line 5200E. The lines could be extended to the north to locate additional targets and further define Trend A.

Zone C should be checked geochemically especially on line 5200E where there is a high resistivity associated with it and high zero time spectral values.

Zone D1 has two moderate priority targets for follow-up on lines 5200E and 5400E. Line 5400E has a higher M11 slice which makes the anomaly stronger and better shaped in later time. The negative IP in the center of the anomaly on line 5400E may mean there is a resistive chargeable body present.

Zone E has a high priority response on line 5000E where the strong IP response is in a slightly higher resistivity environment. The spectral indicates a fine grained sulphide. This target should be drilled.

I feel the high priority responses should be drilled and the survey extended to the north.

Some of the priority ratings may change when additional information is supplied.

If there are any questions with regard to the survey or the reporting, please call the undersigned at JVX Limited.

Respectfully submitted,

JVX LIMITED

Blaine Webster, B.Sc.
President

Jan Kozel, B.A.Sc, M.Sc.
Geophysicist

Appendix 1

Instrument Specification Sheets

SCINTREX IGS Integrated Portable Geophysical System

Scintrex has used low power consumption microprocessors and high density memory chips to create the IGS Integrated Portable Geophysical System; instrumentation which will change the way you do ground geophysics.

Here are the main benefits which you will derive from the IGS family of instrumentation:

1. Depending on your choice of optional sensors you can make one, two or all of: magnetic, VLF and electromagnetic measurements. Thus, you may optimize the IGS system for different geophysical conditions and production requirements.

2. You will save time and money in the acquisition, processing and presentation of ground geophysical survey data.

3. You will achieve an improvement in the quality of data through enhanced reading resolution, an increase in the number of different parameters measured and/or a higher density of observations. Further, errors which occur in manual transcription and calculation will be eliminated.

4. Your operator will appreciate the simplicity of operation achieved through automation.

5. Since add-on sensors are relatively less expensive, your investment in a range of IGS instrumentation may be much less than it would be with a number of different instruments, each dedicated to a different measurement.

The Scintrex IGS-2/MP-4/VLF-4/EM-4 permits one operator to efficiently measure magnetic, VLF and EM fields and to record data in computer compatible solid-state memory.

SCINTREX

IPR-12 Time Domain Induced Polarization/Resistivity Receiver

The IPR-12 Receiver measures spectral IP signals from eight dipoles simultaneously then records measured and calculated parameters in memory.

Brief Description

The IPR-12 Time Domain IP/Resistivity Receiver is principally used in exploration for precious and base metal mineral deposits. In addition, it is used in geoelectrical surveying for groundwater or geothermal resources, often to great depths. 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 differences are absent.

Due to its integrated, microcontroller based design and its large, 16 line display screen, the IPR-12 is a remarkably powerful, yet easy to use instrument. A wide variety of alphanumeric and graphical information can be viewed by the operator during and after reading taking. Signals from up to eight potential dipoles can be measured simultaneously and recorded in solid-state memory along with automatically calculated parameters. Later, data can be output to a printer or a microcomputer (direct or via modem) for processing into profiles and maps.

The IPR-12 is compatible with Scintrex IPC and TSQ Transmitters, or others which output square waves with equal on and off periods and polarity changes each half cycle. The duration of such periods is normally variable in the range of 1 to 32 seconds. The IPR-12 measures the primary voltage (Vp), self potential (SP) and time domain induced polarization (Mi) characteristics of the received waveform. Resistivity, statistical and Cole-Cole parameters are calculated and recorded in memory with the measured data and time.

Scintrex has been active in induced polarization research, development, manufacture, consulting and surveying for over thirty years. We offer a full range of instrumentation, accessories and training.

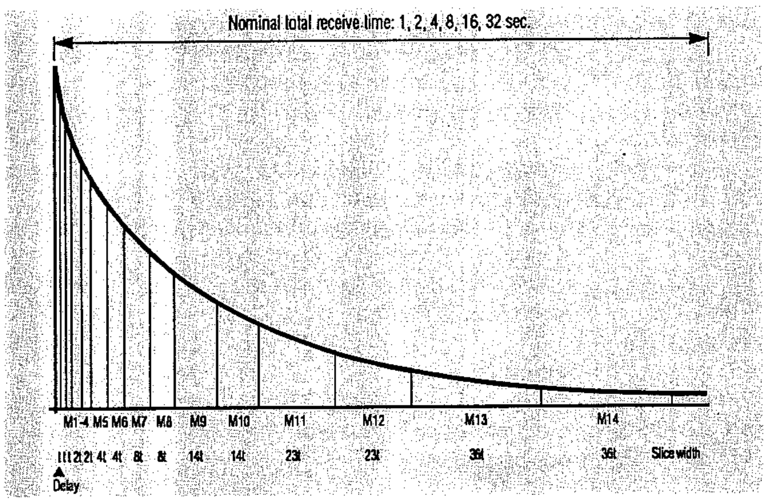
Features

Eight dipoles simultaneously. The analog input section of the IPR-12 contains eight identical differential inputs to accept signals from up to eight individual potential dipoles. The amplified analog signals are converted to digital form by a high resolution A/D converter and recorded with other pertinent information identifying each group of dipoles.

Large display. The 16 line by 42 character Liquid Crystal Display (LCD) is used to great advantage to enhance the operator's understanding of the status of the instrument and the accuracy of the measured data. Any one of twelve different display screens may be selected, by one or two keystrokes, at any time during or after the measurement. A full description of most of these display screens is given later in this brochure. If required, the display is heated for low temperature operation.

Keyboard. Seventeen large keys control the instrument and permit input of alphanumeric information.

Spectral quality IP. Depending on receive time, ten to fourteen windows are measured simultaneously for each dipole Selectable total receive times are 1, 2, 4, 8, 16 and 32 seconds. After the current is shut off, there is a delay of t milliseconds. Then, the width of each window in the seven following pairs of windows is, respectively: t, 2t, 4t, 8t, 14t, 23t and 36t. This format provides a high density of information at early times where the decay of the curve is steepest.



IPR-12 Transient Windows

Variable chargeability summing. By keyboard selection, you can choose an additional, summed transient window. This value, Mx, is recorded in memory along with the value for each of the measured transient windows. Summing can be done for the purpose of obtaining a parameter close to that measured with earlier receivers. The width of the Mx window ranges upwards from 10 milliseconds in 10 millisecond steps.

Statistical Parameters. The IPR-12 calculates statistical error parameters for Mx. The RMS error of the deviation between the measured data and best fit of the Cole-Cole calculation is also derived. These parameters, which are excellent indicators of data quality, are displayed and are recorded in memory.

Selectable reading termination. By keyboard selection the receiver can be set up to terminate readings by any one of: manual key press, when a preset number of cycles have been measured or when a preset statistical error for the summed chargeability (Mx) has been reached.

Solid state memory. All instrument parameters as well as; entered, measured and calculated quantities are stored in the large capacity, fail-safe memory. See the separate listing for the full list of data items which are recorded.

Memory recall. Any observation recorded in memory can be recalled, by simple keypad entry, for inspection on the display.

Printed data listings. A simple digital printer can be connected to the IPR-12 to print out listings of data recorded in memory.

Microcomputer compatibility. The IPR-12 comprises an RS-232C, 7 or 8 bit ASCII high baud rate interface, compatible with most personal or lap-top computers. This permits data to be dumped from the receiver's memory for archiving or processing.

Calculates Cole-Cole parameters. The IPR-12 calculates the Cole-Cole parameters; true chargeability (M), and time constant (Tau) for a fixed C of 0.25. These parameters, which are recorded in memory, may be used to assist interpretation by distinguishing between different chargeable sources, based mainly on textural differences. For example, a coarse grained graphite may be distinguished from a fine grained sulphide source.

Signal enhancement. Primary voltage, self potential and individual transient windows are continuously averaged and the display is updated every cycle so the operator is fully aware of signal improvement.

Noise rejection. Individual samples contaminated by noise can be automatically rejected.

Normalizes for time and Vp. The value recorded for each window is in millivolt/volt, that is to say that normalization is automatically done for the width of each window and for the primary voltage. The Vp is also normalized for time of integration.

Automatic resistivity calculations. The IPR-12 calculates the geometrical (K) factors for the standard arrays shown in the Info display based on electrode positions given in the Locations display. This feature is particularly helpful for arrays like the Gradient or Schlumberger in which the K-Factors change for every station. Then, using measured primary voltages with

Benefits

Speed Up Surveys

The IPR-12 will save you time and money in carrying out field surveys. Its capacity to measure up to eight dipoles simultaneously is far more efficient than older receivers measuring a single dipole. This advantage is particularly valuable in drill-hole logging where electrode movement time is minimal.

The built-in, solid-state memory records all information associated with a reading, dispensing with the need for any hand written notes. Microcomputer compatibility means rapid electronic transfer of data from the receiver to a computer for rapid data processing.

Taking a reading is simple and fast. Only a few keystrokes are typically needed since the IPR-12 features automatic circuit resistance checks, SP buckout and gain setting.

Compared with frequency domain measurements, where sequential transmissions at different frequencies must be made, the IPR-12 time domain measurement records broadband information each few seconds.

High Quality Data

Perhaps the most important feature of the IPR-12 in permitting high quality data to be acquired, is the large display screen which allows the operator easy real time access to graphic and alphanumeric displays of instrument status and measured data. This instrument works with the operator to ensure that useful, accurate data result from field work.

The number and relative widths of the IP decay curve windows have been carefully chosen to yield the transient information required for proper interpretation of spectral IP data. Timings are selectable to permit a very wide range of responses to be measured.

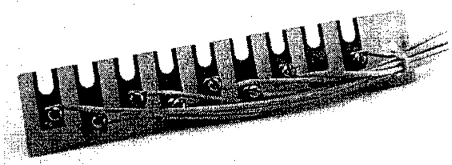
The IPR-12 stacks the information for each cycle and calculates a running average for Vp, SP and each transient window. This enhancement is equivalent to a noise decrease of $\sqrt{N}$ or a transmitter power increase of N where N is the number of values averaged. Since values are measured each few seconds, it does not take long for this signal enhancement technique to have great effect.

The automatic SP program bucks out and corrects completely for linear SP drift. Data are also kept noise free by: radio-frequency (RF) filters, low pass filters and statistical spheric noise spike rejection. To prevent mistriggering, the IPR-12 does not accept trigger-like signals at inappropriate times.

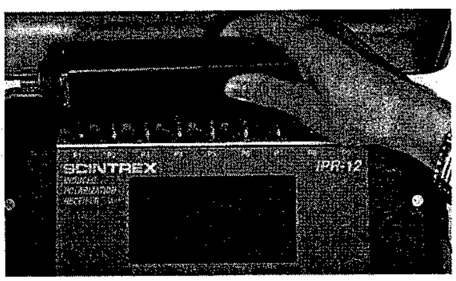
The internal, computer-compatible memory ensures that there are no data transcription errors from the taking of readings, through calculations to the plotting of maps.

Parameters Recorded by the IPR-12

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 reached each station.



The Field Wire Terminator may be used to custom make cables for up to eight dipoles, using ordinary field wire. Connection in either forward or reverse position is easily made to the Receiver.



The Multidipole Cable Adaptor is used to connect Multidipole Potential Cables to the IPR-12.

Header Information:

- time (year, month, day, hour, minute, second)
- job number
- operator name
- instrument serial number
- alphanumeric notebook messages
- station number
- coordinates of all electrodes
- transmitted current
- electrode array
- receiver timing
- units (feet or metres)

Measured Data:

- electrode resistances
- SP
- Vp
- M1 to M14
- duration of measurement

Calculated Data:

- Mx
- Error of Mx
- Cole-Cole M
- Cole-Cole Tau
- Windows (Wi) omitted in Cole-Cole calculation to remove EM coupling
- RMS error of deviation of Cole-Cole fit
- resistivity K factors
- apparent resistivity

High production rates are obtained using Multidipole Potential Cables.

Features

operator entered current values, the receiver calculates and records apparent resistivity values.

Automatic Vp self ranging. There is no manual adjustment for different primary voltages since the IPR-12 automatically adjusts the gain of its signal conditioning amplifiers for any Vp signal in the range of 50 microvolts to 14 volts full scale.

Automatic SP correction. Self potential buckout is entirely automatic, both initially and throughout the measurement.

Synchronization. In normal operation, the IPR-12 synchronizes itself on the received waveform, and triggering is disabled until to within about 60 milliseconds before a signal transition. This reduces to a negligible level the possibility of false triggering.

External circuit check. A built-in AC ohmmeter avoids electrode polarization, while checking the ground resistance of electrodes and the continuity of field cables. The circuit resistance values are displayed and are automatically recorded in memory.

Self-check program. Each time the instrument is turned on, a verification of the program memory is automatically done. Each time data are erased from memory, the memory is checked. If any discrepancy is discovered, an error message appears on the display.

Out of limit checks. Messages appear on the display if any of the following errors occur: out of calibration or failed memory test, incorrect signal amplitude or excessive noise, signal input with respect to the reference electrode in excess of the permitted range, synchronization failure, previous station's data not filed and data memory full.

Analog meter. While signals on up to eight dipoles are presented simultaneously on the digital display, one analog meter, easily switchable from dipole to dipole, has been provided for monitoring particularly noisy conditions.

Internal test generator. An internal signal generator is used to test the instrument periodically, to ensure that it is functioning properly.

Noise filters. Radio frequency and 10 Hz, 6 pole low pass filters enhance signal quality. The low cut off frequency and steep roll-off of the latter filters provide better powerline noise rejection than notch filters.

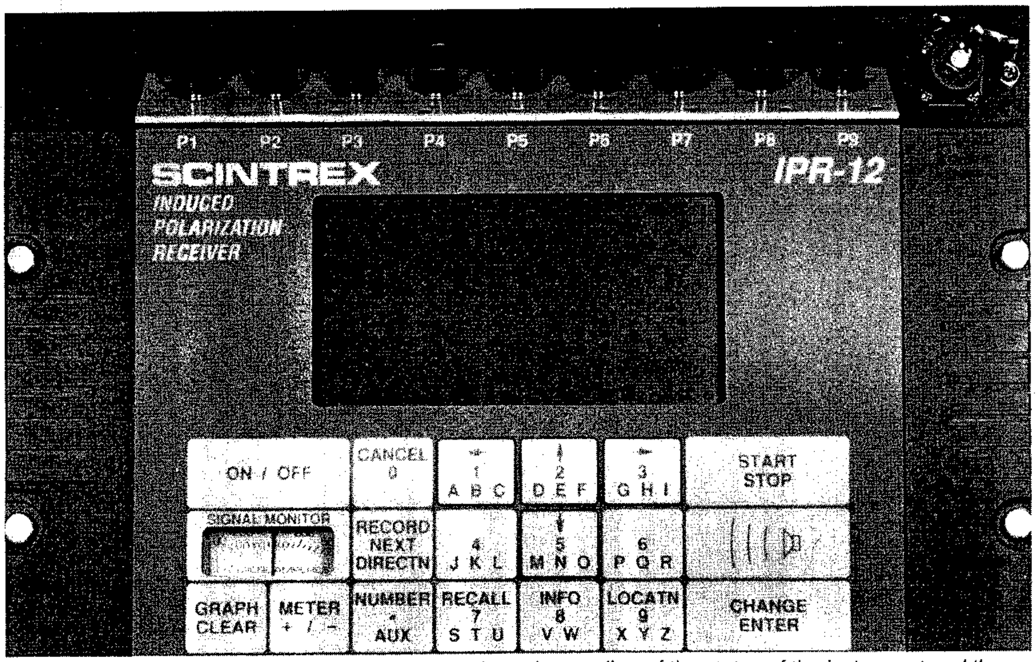
Overload detection. All analog signal levels are monitored to prevent measurements on individual dipoles for which limits are exceeded and appropriate messages are displayed. The affected samples are not added to the previous average.

Input protection. If signals in excess of 14 V and up to 60 V are accidentally applied at the input, zener diode protection ensures that no damage will occur. For higher voltages fuse protection is used.

Binding posts. To avoid inter-electrode leakage which may occur in humid conditions with small, multipin connectors, the IPR-12 has been designed with widely spaced binding posts mounted on a Teflon strip.

Cables. Either standard IP/resistivity field wire or custom made Multidipole Potential Cables may be used, depending on survey requirements. The former may be used with the IPR-12 Field Wire Terminator while the latter require the Optional Multidipole Cable Adaptor.

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



The IPR-12's large display enhances the operator's understanding of the status of the instrument and the accuracy of the measured data.

```
     DIP 1       DIP 2       DIP 3       DIP 4
M 1  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 2  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 3  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 4  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 5  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 6  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 7  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 8  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M 9  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M10  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M11  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M12  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M13  mmm.mm      mmm.mm      mmm.mm      mmm.mm
M14  mmm.mm      mmm.mm      mmm.mm      mmm.mm
                                     BAT1: bbb
```

In case it is desired to scrutinize the actual numerical values for any or all chargeability windows of any or all dipoles, the above screen may be called up when the reading is finished.

```
DIP  RHO     DUR   MO      TAU     RMS%   W

1  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww
2  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww

3  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww
4  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww

5  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww
6  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww

7  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww
8  mmm.mm   ddd   nnn.nn  ttt.tt  r.rrr  ww

                                BAT1: bbb
```

Additionally, calculated values may be observed after termination of the reading.

```
DUMP PARAMETERS:
DATA BITS:      b          BAUD RATE: r
CR DELAY:     ddd               300 (1)
                                600 (2)
                               1200 (3)
START DUMP?     s              2400 (4)
                               4800 (5)
                               9600 (6)
                              19200 (7)
                              38400 (8)
CLEAR MEMORY?   c            115200 (9)


Change?        Messages       BAT1: bbb
```

When it is desired to output data to a printer or computer, the Output screen is called up so that data bits, carriage return delay and baud rate may be selected, a dump started and lastly, the memory cleared.

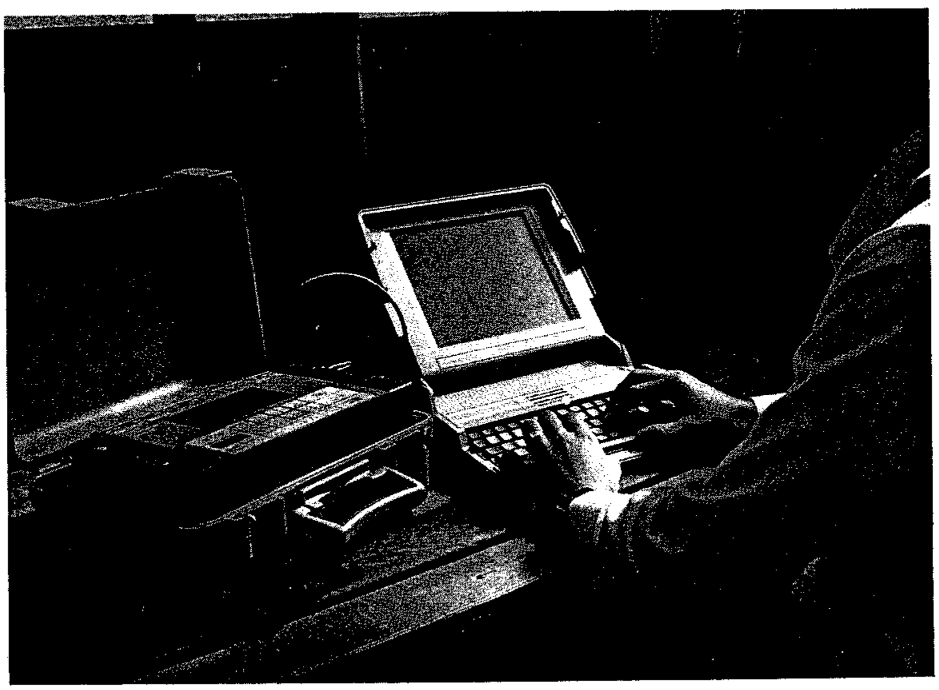
It is important to note that most of the above screens can be called up directly. There is generally no need to move sequentially from one screen to the next.

Software

Scintrex supplies a range of software, mainly for use with IBM PC compatible microcomputers, which is useful for processing induced polarization and resistivity data. These programs are used for archiving, calculating and presenting the data in contour, profile or pseudo-section format.

Programs are available for Cole-Cole parameter determinations in case it is desired to do more refined investigations of these parameters than is done by the IPR-12, which fixes the C parameter at 0.25.

Finite element modeling programs for IP and resistivity assist interpretation by doing forward calculations of geological models for variable topography and electrode array.



Displays

The simplest way to understand the operation of the IPR-12 is through consideration of the main display screens which are used for setting instrument parameters, entering information, monitoring the progress of a reading and checking data prior to and after recording. A given screen is usually called up with a single keystroke.

First, there is an Auxilliary Functions screen from which other functions may be selected.

```
     ****  S C I N T R E X  ****
              IPR-12
    INDUCED POLARIZATION RECEIVER
            Version 1.0


    (0)        INITIALIZATION
    (1)        OUTPUT
    (Start)    MEASURE
    (Info)     Information
    (< >)      LCD INTENSITY

Select ?                       BAT1: bbb
```

```
    HH:MM:SS     hh : mm : ss
    YY/MM/DD     yy / mm / dd

JOB #:      jjjjjj      COLE-COLE:     ccc
OPERATOR: oooooo        OMIT # SLICES:   m
SERIAL #:nnnnnnn        UNITS:      uuuuuu
TEST:          eee
HEATER:        hhh
DURATION:      ggg
TRIGGER CH.:     1
AUTO.REJ.:     rrr
Mx xxxxx - xxxxx        TIMING:          t


Change?          Messages        BAT1: bbb
```

Then the initialization screen permits the entry of time, job number, operator name and instrument serial number as well as the setting of instrument parameters such as: 1) self test enabled, 2) display heater on, 3) number of cycles (duration) to be measured, 4) selection of dipole to trigger readings, 5) automatic rejection of statistically bad values enabled, 6) timing (window) for Mx, 7) Cole-Cole calculation enabled, 8) windows to be omitted, 9) feet or meters and 10) receiver timing.

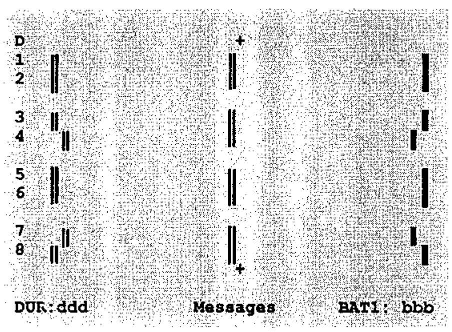
```
ARRAY SELECTED: a
1-Dip.Dip.     2-Pol.Dip.     3-Schlumb.
4-Wenner       5-Gradient     6- Pol.Pol.
7-Other

K-FACTORS:
K1:xxxx.xxx    K2:xxxx.xxx    K3:xxxx.xxx
K4:xxxx.xxx    K5:xxxx.xxx    K6:xxxx.xxx
K7:xxxx.xxx    K8:xxxx.xxx

NOTES:
tttttttttttttttttttttttttttttttttttttttt
tttttttttttttttttttttttttttttttttttttttt
tttttttttttttttttttttttttt
MEM.FREE (%):fff                BAT2: bbb
Change?         Messages        BAT1: bbb
```

Next, the Info display permits selection of the electrode array, shows the calculated K-Factors and, permits entry of special K-Factors and note taking.

In routine surveying, the above three screens are not required for each reading.

```
CURRENT:     rrrrr        MOVE:      i
STAT.#:   sss.ssd A: a    ST.SEP.:+nnn.nn

C-LINE #:111.11d          C1: ccc.ccd   A: a
                          C2: ccc.ccd   A: a

P-LINE #:111.11d          P1: ppp.ppd   A: a
                          P2: ppp.ppd   A: a
                          P3: ppp.ppd   A: a
---------------------|    P4: ppp.ppd   A: a
RECALL:              |    P5: ppp.ppd   A: a
STAT.#:   sss.ssd    |    P6: ppp.ppd   A: a
P-LINE #:111.11d     |    P7: ppp.ppd   A: a
---------------------|    P8: ppp.ppd   A: a
                          P9: ppp.ppd   A: a
Change?         Messages     BAT1:      bbb
```

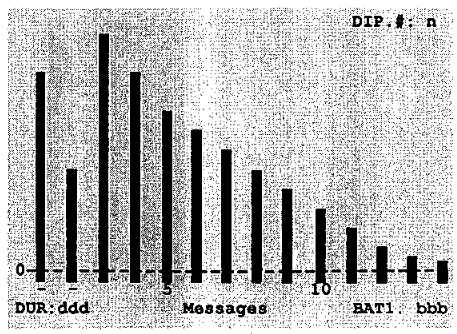
The Locations display, which automatically appears when power is turned on, permits entry of the station number, station separation, transmitted current and the coordinates of electrodes. All electrode locations can be incremented or decremented by the station separation with a single keystroke, avoiding the need to re-enter individual electrode positions. This screen is also used when it is desired to disable inactive dipoles and to recall data.



During the initial part of a reading, the operator will likely select the Analog display which will confirm to him that he has proper signal on all dipoles. The bars represent the needles of edgewise analog meters and monitor Vp (outside positions) and Mx (centre position).

```
DIP  RES     SP      Vp        Mx      ERR

 1   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee
 2   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee

 3   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee
 4   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee

 5   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee
 6   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee

 7   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee
 8   rrr.r  ssss  vvvv.vv   mmm.mm   e.ee
DUR:ddd        Messages        BAT1: bbb
```

Once a number of cycles have been received, it will likely be best to monitor the reading on the Numeric display. Here all the continuously averaged values are shown. Of particular interest to the operator will be the Error column, which shows him how the quality of his most indicative chargeability value, Mx,improves with time.



A more graphic display, and one which may be of most interest when spectral IP data are desired, or when there is question of electromagnetic coupling, is the Decay display. Here vertical bars represent the chargeability windows on a given dipole. Negative values are indicated by a negative sign at the foot of the bar.

Technical Description of the IPR-12 Time Domain Induced Polarization/Resistivity Receiver

SCINTREX

222 Snidercroft Road
Concord,Ontario,Canada
L4K 1B5

Telephone: (416) 669-2280
Telefax: (416) 669-6403
Telex: 06-964570

Inputs
1 to 8 dipoles are measured simultaneously

Input Impedance
16 megohms

SP Bucking
±10 volt range. Automatic linear correction operating on a cycle by cycle basis

Input Voltage (Vp) Range
50 microvolt to 14 volt

Chargeability (M) Range
0 to 300 millivolt/volt

Tau Range
1 millisecond to 1000 seconds

Reading Resolution of Vp, SP and M
Vp, 10 microvolt; SP, 1 millivolt; M, 0.01 millivolt/volt

Absolute Accuracy of Vp, SP and M
Better than 1%

Common Mode Rejection
At input more than 100 db

Vp Integration Time
10% to 80% of the current on time.

IP Transient Program
Total measuring time keyboard selectable at 1, 2, 4, 8, 16 or 32 seconds. Normally 14 windows except that the first four are not measured on the 1 second timing, the first three are not measured on the 2 second timing and the first is not measured on the 4 second timing. See diagram. An additional transient slice of minimum 10 ms width, and 10 ms steps, with delay of at least 40 ms is keyboard selectable.

Transmitter Timing
Equal on and off times with polarity change each half cycle. On/off times of 1, 2, 4, 8, 16 or 32 seconds. Timing accuracy of ±100 ppm or better is required.

External Circuit Test
All dipoles are measured individually in sequence, using a 10 Hz square wave. The range is 0 to 2 Mohm with 0.1 kohm resolution. Circuit resistances are displayed and recorded.

Synchronization
Self synchronizes on the signal received at a keyboard selectable dipole. Limited to avoid mistriggering.

Filtering
RF filter, 10 Hz 6 pole low pass filter, statistical noise spike removal.

Internal Test Generator
1200 mV of SP; 807 mV of Vp and 30.28 mV/V of M.

Analog Meter
For monitoring input signals; switchable to any dipole via keyboard.

Keyboard
17 key keypad with direct one key access to the most frequently used functions.

Display
16 lines by 42 characters, 128 x 256 dots, Liquid Crystal Display. Displays instrument status and data during and after reading. Alphanumeric and graphic displays.

Display Heater
Used in below -10°C operation. Thermostatically controlled. Requires the Ancilliary Rechargeable Batteries.

Memory Capacity
Stores approximately 400 dipoles of information when 8 dipoles are measured simultaneously.

Real Time Clock
Data is recorded with year, month, day, hour, minute and second.

Digital Data Output
Formatted serial data output for printer and computer etc. Data output in 7 or 8 bit ASCII, one start, one stop bit, no parity format. Baud rate is keyboard selectable for standard rates between 300 baud and 115.2 kBaud. Selectable carriage return delay to accommodate slow peripherals. Handshaking is done by X-on/X-off.

Standard Rechargeable Batteries
Eight rechargeable Ni-Cad D cells. Supplied with a charger, suitable for 110/230V, 50 to 60 Hz, IOW. More than 20 hours service at +25°C, more than 8 hours at -30°C.

Ancilliary Rechargeable Batteries
An additional eight rechargeable Ni-Cad D cells may be installed in the console along with the Standard Rechargeable Batteries. Used to power the Display Heater or as back up power. Supplied with a second charger. More than 6 hours service at -30°C.

Use of Non-Rechargeable Batteries
Can be powered by D size Alcaline batteries, but rechargeable batteries are recommended for longer life and lower cost over time.

Field Wire Terminator
Used to custom make cables for up to eight dipoles, using ordinary field wire.

Optional Multiconductor Cable Adaptor
When installed on the binding posts, permits connection of Multidipole Potential Cables.

Optional Multiconductor Cables
Specially manufactured in dipole lengths, terminated with plugs and takeouts for electrodes. Connects up to 6 dipoles.

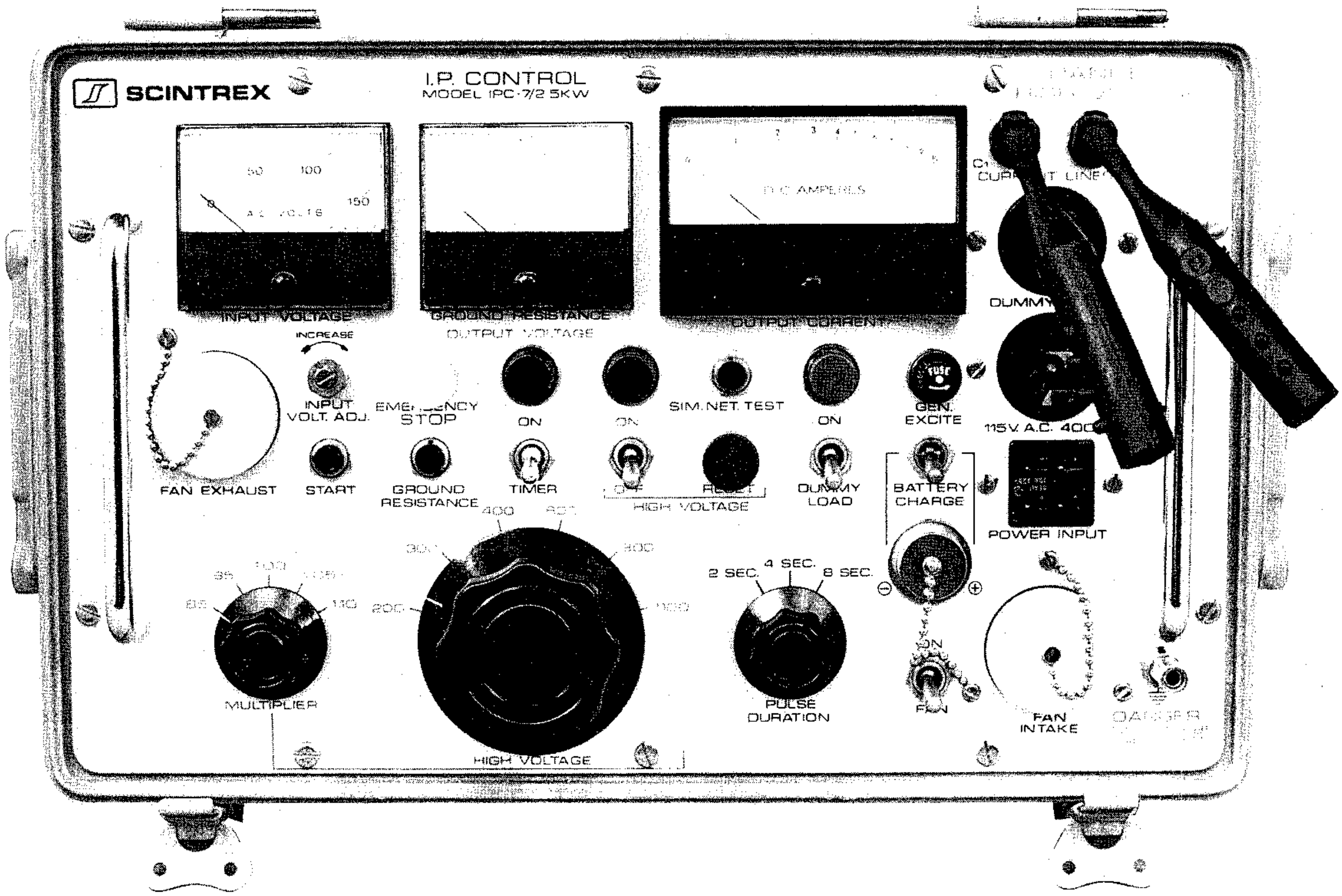
Operating Temperature Range
-30°C to +50°C

Storage Temperature Range
-30°C to +50°C

Dimensions
Console; 355 x 270 x 165 mm
Charger; 120 x 95 x 55 mm

Weights
Console; 5.8 kg.
Standard or Ancilliary Rechargeable Batteries; 1.3 kg.
Charger; 1.1 kg.

SCINTREX IPC-7/2.5kW Induced Polarization and Commutated DC Resistivity Transmitter System



Function

The IPC-7/2.5 kW is a medium power transmitter system designed for time domain induced polarization or commutated DC resistivity work. It is the standard power transmitting system used on most surveys under a wide variety of geophysical, topographical and climatic conditions.

The system consists of three modules: A Transmitter Console containing a transformer and electronics, a Motor Generator and a Dummy Load mounted in the Transmitter Console cover. The purpose of the Dummy Load is to accept the Motor Generator output during those parts of the cycle when current is not transmitted into the ground, in order to improve power output and prolong engine life.

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.

Features

Maximum motor generator output, 2.5 kW; maximum power output, 1.85 kW; maximum current output, 10 amperes; maximum voltage output, 1210 volts DC.

Removable circuit boards for ease in servicing.

Automatic on-off and polarity cycling with selectable cycling rates so that the optimum pulse time (frequency) can be selected for each survey.

The overload protection circuit protects the instrument from damage in case of an overload or short in the current dipole circuit.

The open loop circuit protects workers by automatically cutting off the high voltage in case of a break in the current dipole circuit.

Both the primary and secondary of the transformer are switch selectable for power matching to the ground load. This ensures maximum power efficiency.

The built-in ohmmeter is used for checking the external circuit resistance to ensure that the current dipole circuit is grounded properly before the high voltage is turned on. This is a safety feature and also allows the operator to select the proper output voltage required to give an adequate current for a proper signal at the receiver.

The programmer is crystal controlled for the very high stability required for broadband (spectral) induced polarization measurements using the Scintrex IPR-11 Broadband Time Domain Receiver.

Appendix 2

Plates 1 to 9

Plate 1: Stacked M8/Res.Pseudosections with anomalies & targets; L-50E - L-54E
Plate 2: Stacked M11/Res.Pseudosections; L-50E - L-54E
Plate 3: Stacked M-IP/TAU Pseudosections; L-50E - L-54E
Plate 4: Chargeability (M11) Contours (n=2)
Plate 5: Resistivity Contours (n=2)
Plate 6: IP-COLE-COLE 'M'CONTOURS (n=2)
Plate 7: Total Magnetic Field Contours
Plate 8: Total Magnetic Field Profiles
Plate 9: Compilation/Anomaly Map

Appendix 3

Literature

Spectral IP parameters as determined through Time Domain Measurements by I.M. Johnson, Scintrex Limited, Toronto, Ontario, Canada, 1984.

Spectral IP: Experience over a number of Canadian Gold Deposits by B. Webster, JVX Ltd., and I.M. Johnson, Scintrex Limited, Toronto, Ontario, Canada, 1985.

Time domain Spectral Induced Polarization, some recent examples for gold, by Ian M. Johnson and Blaine Webster, JVX Limited, Thornhill, Ontario, Canada, 1987. Prepared for delegates to Exploration 87, 1987, Toronto, Canada.

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

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

where

$Z(\omega)$ = complex impedance (in $\Omega \cdot$m),

R_0 = the dc resistivity (in $\Omega \cdot$m),

m = the chargeability (in volts/volt),

τ = the time constant (in seconds),

ω = 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 L/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 I_0 and of pulse time T s used in conventional time domain IP may be expressed in Fourier series form as

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

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

$$V(t) = I_0 \,\mathrm{Im} \sum_{n=1}^{\infty} \frac{2}{n\pi}\left(\cos\frac{n\pi}{4} - \cos\frac{3n\pi}{4}\right) Z\left(\frac{n\pi}{2T}\right) e^{in\pi t/2T}. \qquad (3)$$

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

$$S_i = \frac{10^3}{V_p(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} V(t)\, dt \qquad (\mathrm{mV/V}), \qquad (4)$$

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 $f_0 (= 1/4T)$.

For ease of presentation, we define a function $G(t_i, t_{i+1}, \tau, c, T)$. This function describes the t, τ, 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:

$$G(t_i, t_{i+1}, \tau, c, T) = \frac{1}{(t_{i+1} - t_i)} \int_{t_i}^{t_{i+1}} \mathrm{Im} \sum_{n=1}^{\infty} \frac{2}{n\pi} \times \left(\cos\frac{n\pi}{4} - \cos\frac{3n\pi}{4}\right) \times \left[\frac{1}{1 + \left(\frac{in\pi\tau}{2T}\right)^c}\right] e^{in\pi t/2T}\, dt. \qquad (5)$$

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

$$S_i = \frac{10^3\, I_0 R_0 m}{V_p} G(t_i, t_{i+1}, \tau, c, T). \qquad (6)$$

The measured theoretical primary voltage may be expressed

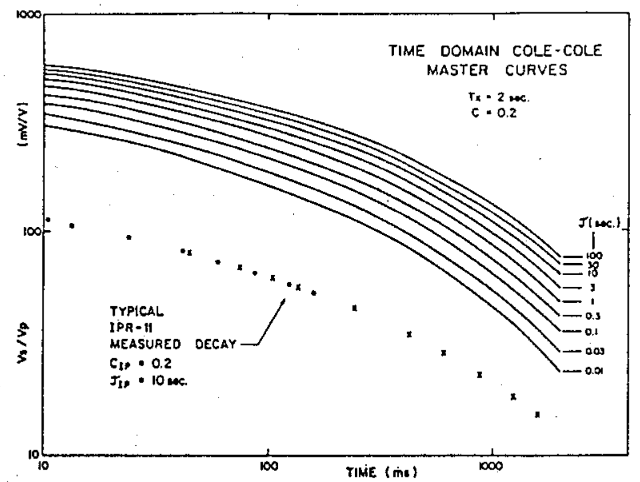


FIG. 1. Theoretical time-domain decay curves for fixed c and variable τ. A typical IPR-11 measured decay is shown as a series of dots (0.2 s receiver mode) and x's (2 s receiver mode).

as

$$V_p = I_0 R_0 - I_0 R_0 m + I_0 R_0 m G(t_a, t_b, \tau, c, T), \qquad (7)$$

where t_a, t_b are the limits of integration during the current on-time.

Combining equations (6) and (7), the theoretical decay is given by

$$S_i = \frac{10^3\, mG(t_i, t_{i+1}, \tau, c, T)}{1 - m + mG(t_a, t_b, \tau, c, T)} \quad (\text{mV/V}),\ i = 1, N. \qquad (8)$$

Preferred Cole-Cole spectral parameters may be determined by a "best-fit" match of measured data to a suite of master curves. The process used may be summarized as follows.

The master-curve set is numerically generated through equation (8) by allowing c and τ to vary in discrete steps over ranges of interest. The chargeability is set to 1 V/V and the pulse time to 2 s. Both S_i and $G(t_a, t_b, \tau, c, T)$ are retained in the master-curve set.

If the measured decay is given by M_i mV/V ($i = 1, N$), an observed chargeability m_0 V/V is defined as the weighted average amplitude shift in log amplitude space between measured and master curves, i.e.,

$$\log m_0 = \frac{1}{N} \sum_{i=1}^{N} (\log M_i - \log S_i) w_i. \qquad (9)$$

Observed chargeability values are determined for all master curves. The weighting factors w_i bias the averaging to late delay times where integration intervals are longest.

The "best-fit" master curve is selected by minimizing

$$\text{SD} = \sum_{i=1}^{N} [\log M_i - \log (m_0 S_i)]^2 w_i, \qquad (10)$$

where the m_0 used is that value appropriate to the master curve under consideration.

The true chargeability m may be found by setting

$$\frac{mG(t_i, t_{i+1}, \tau, c, T)}{1 - m + mG(t_a, t_b, \tau, c, T)} = \frac{m_0\, G(t_i, t_{i+1}, \tau, c, T)}{G(t_a, t_b, \tau, c, T)}. \qquad (11)$$

Hence,

$$m = \frac{m_0 \times 10^3}{G(t_a, t_b, \tau, c, T) + m_0 [1 - G(t_a, t_b, \tau, c, T)]} \quad \text{mV/V}. \qquad (12)$$

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

$$D = \left\{ \frac{1}{N} \sum_{i=1}^{N} \left(1 - \frac{M_i}{m_0 S_i}\right)^2 \times 10^4 \right\}^{1/2} \text{percent.} \qquad (13)$$

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 τ and exponent c are relatively stable under large changes in the dilution factor. The apparent chargeability is not.

By inspection,

$$G(t_i, t_{i+1}, \tau, c, T) = G(nt_i, nt_{i+1}, n\tau, c, nT). \qquad (14)$$

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., $T = 2$ 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 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 $G(t_i, t_{i+1}, \tau, c, T)$ 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 τ is allowed the values 0.01, 0.03, 0.1, 0.3, 1.0, 3.0, 10.0, 30.0, and 100.0 s. The exponent values reflect the expected range for polarizable targets (0.1 to 0.8) 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, 0.897, 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 τ. 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 τ 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 increas-

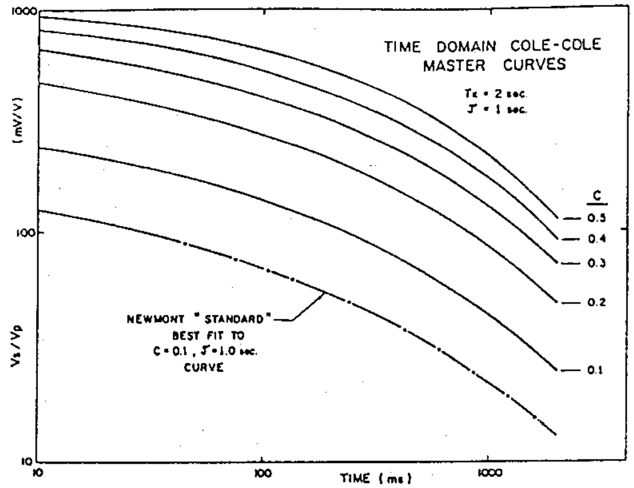


FIG. 2. Theoretical time-domain decay curves for fixed τ and variable c. The Newmont Standard decay for a 2 s pulse time is shown with fitted time constant and exponent.

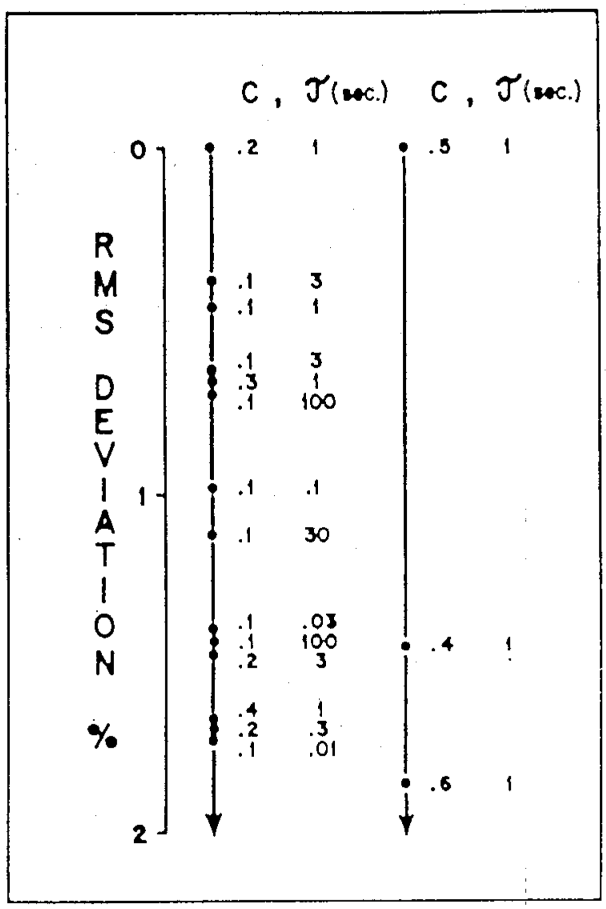


FIG. 3. Curve shape differences (or rms deviation) between selected master curves. Arranged in order of increasing deviation from the $c = 0.2, \tau = 1$ and the $c = 0.5, \tau = 1$ curves.

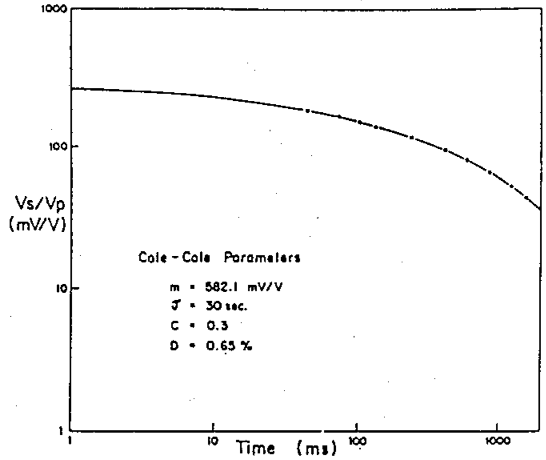


FIG. 4. Measured data (10 point), best-fit master decay curve, and calculated spectral parameters. Array is pole-dipole with $a = 10$ m, $n = 6$ with $V_p = 1.2$ mV. Rms deviation = 0.65 percent. V_s designates the voltage measured during the transmitter off-time.

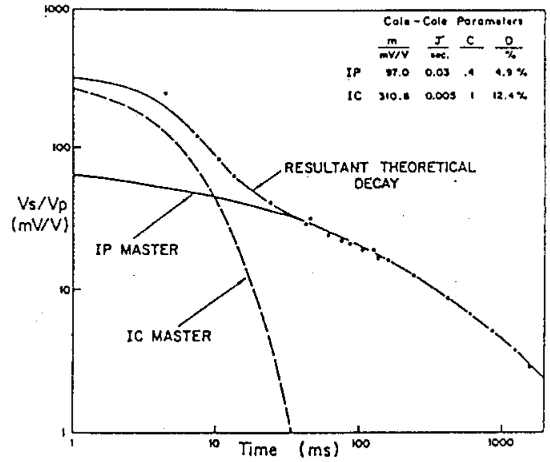


FIG. 5. Measured data (20 point composite), best-fit master curves, and calculated spectral parameters. Both IP and inductive coupling (IC) effects are modeled. Array is dipole-dipole with $a = 100$ m, $n = 6$ with $V_p = 2.6$ mV.

ing rms deviation. The results for part of this work are shown in Figure 3. The left-hand column shows the ranking in order of increasing curve shape difference away from a measured decay as given by the $c = .2$, $\tau = 1$ s master curve. The right-hand column shows the ranking away from a measured decay as given by the $c = .5$, $\tau = 1$ s master curve. These results serve to illustrate the following.

(1) As c is reduced from 0.5 to 0.2, the differences in the shape of the curve between master curves of different τ 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 3 685 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 $\Omega\cdot$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 large 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

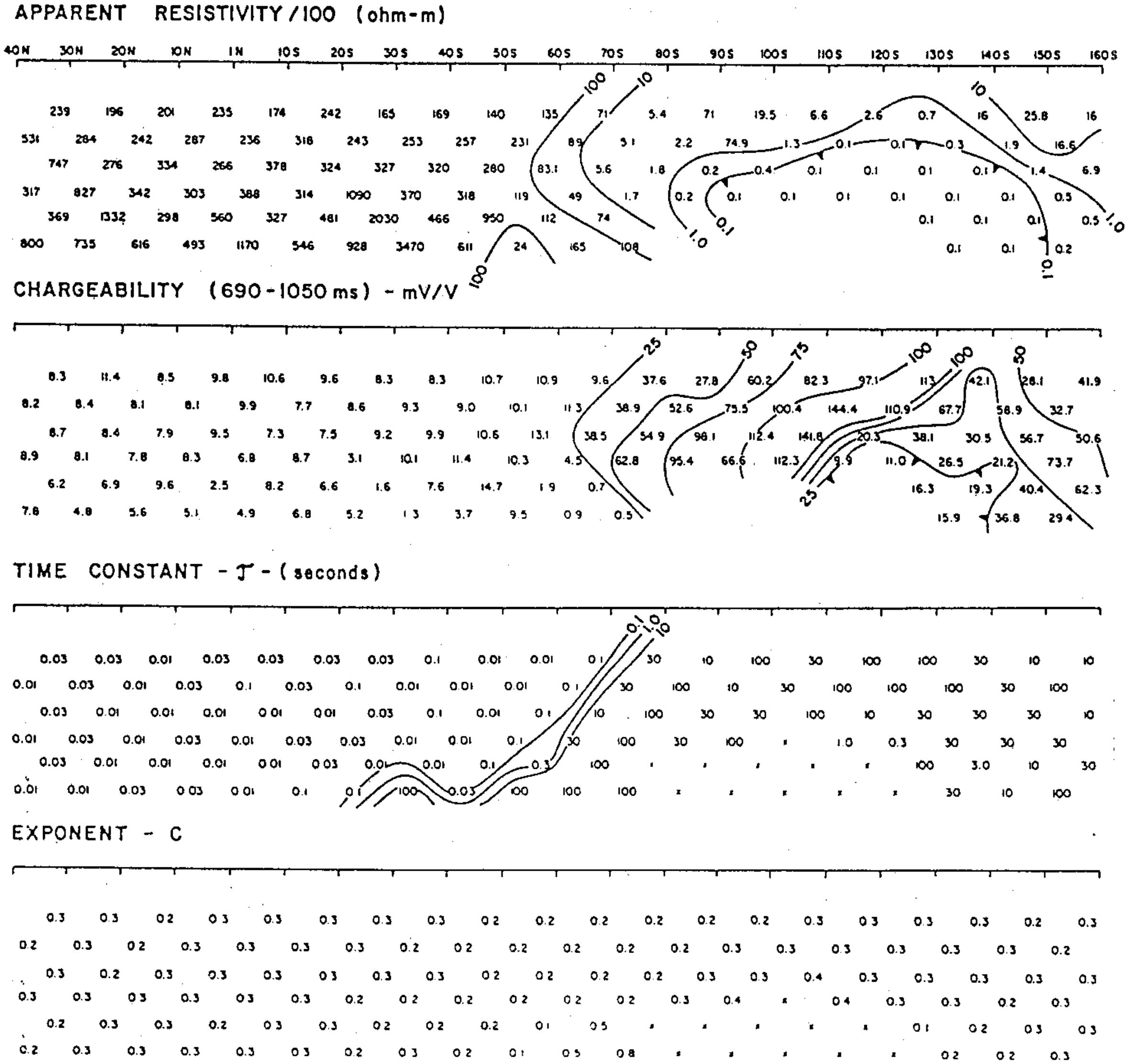


FIG. 6. Segment of results from an IPR-11 survey using the pole-dipole array with $a = 10$ m and $n = 1$ to 6. Shown are apparent resistivity/100 ($\Omega\cdot$m) eighth-slice chargeability (mV/V), Cole-Cole time constant (seconds) and exponent (c). Near-current electrode is to the left of the potential electrode string.

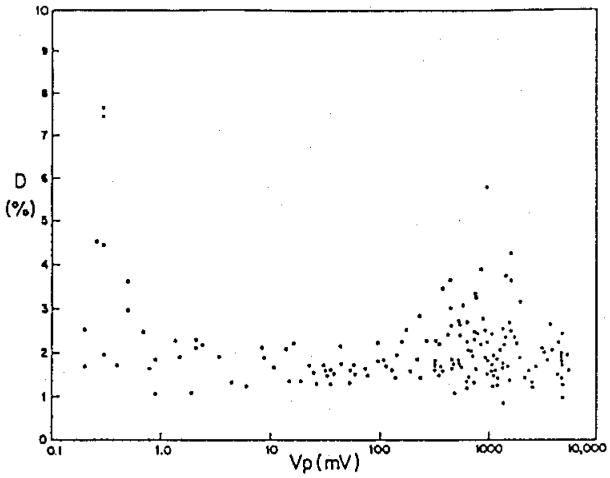


FIG. 7. Rms deviation as a function of primary voltage (V_p) for spectral fits from data shown in part in Figure 6.

Table 1. Spectral parameters, average values. Spectral parameter summary for different array geometries. The data set for the survey line is a portion of that shown in Figure 6.

Array	c Host	c Anomaly	c Total	τ Agreement (%)	D (%)
Pole-dipole	0.26	0.27	0.27	100	2.17
Dipole-dipole	0.27	0.29	0.28	88	2.59
Gradient	0.10	0.17	0.13	75	2.40

subtraction of the IP effect. The first measuring point at 4.5 ms after shut-off shows an anomalously high value. This value causes the large rms deviation seen for the IC component.

It was remarked earlier that impedances could be summed without excessive error if time constants were sufficiently different. Figure 5 shows the effective decomposition of a decay curve into IP and IC 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 $\Omega \cdot$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.

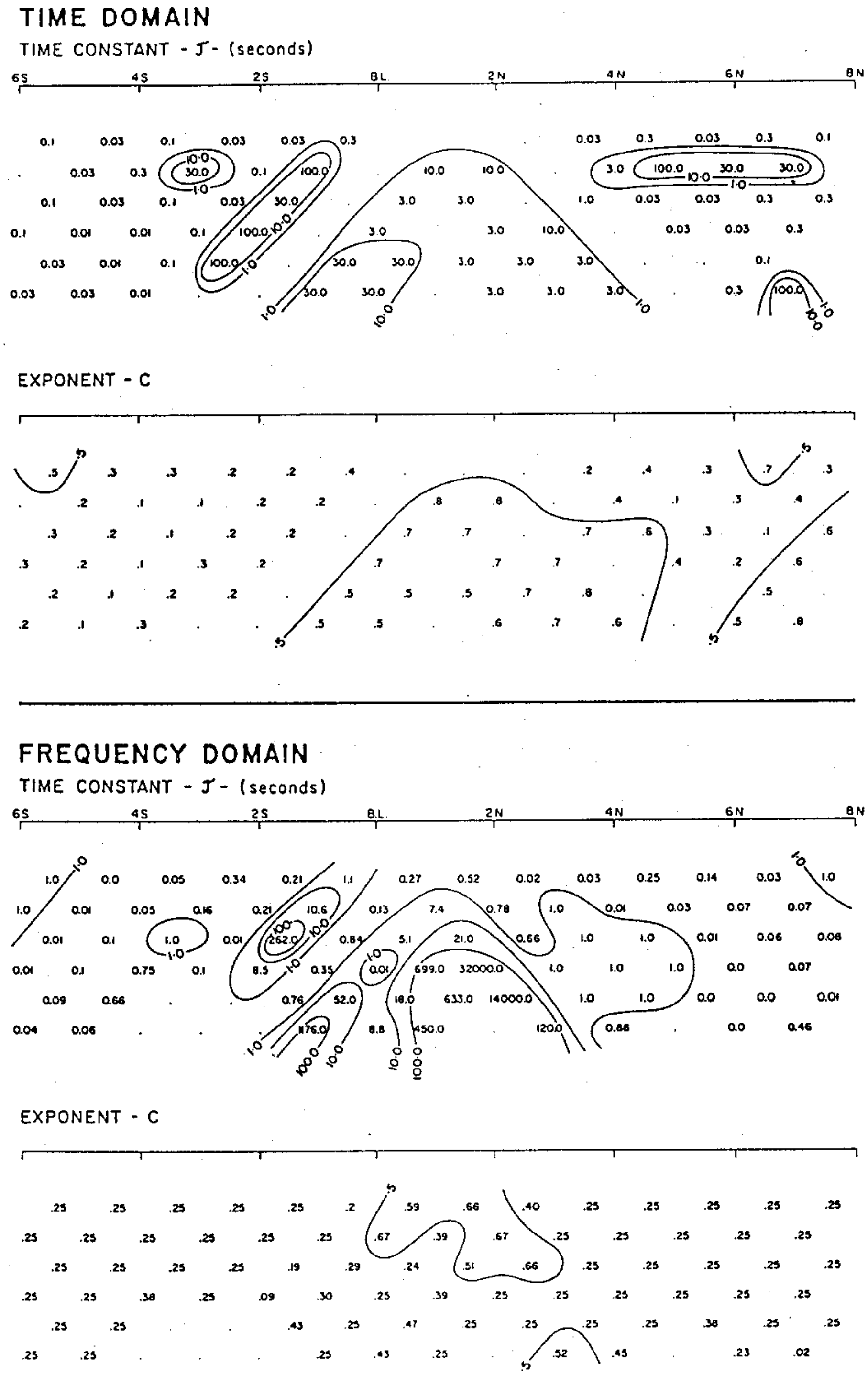


FIG. 8. Cole-Cole parameters as determined through time-domain (by Scintrex) and frequency-domain (by Phoenix) measurements over line 8 W of the Detour deposit. Spectral parameters are omitted in the time-domain data where the rms deviation exceeds 7.5 percent.

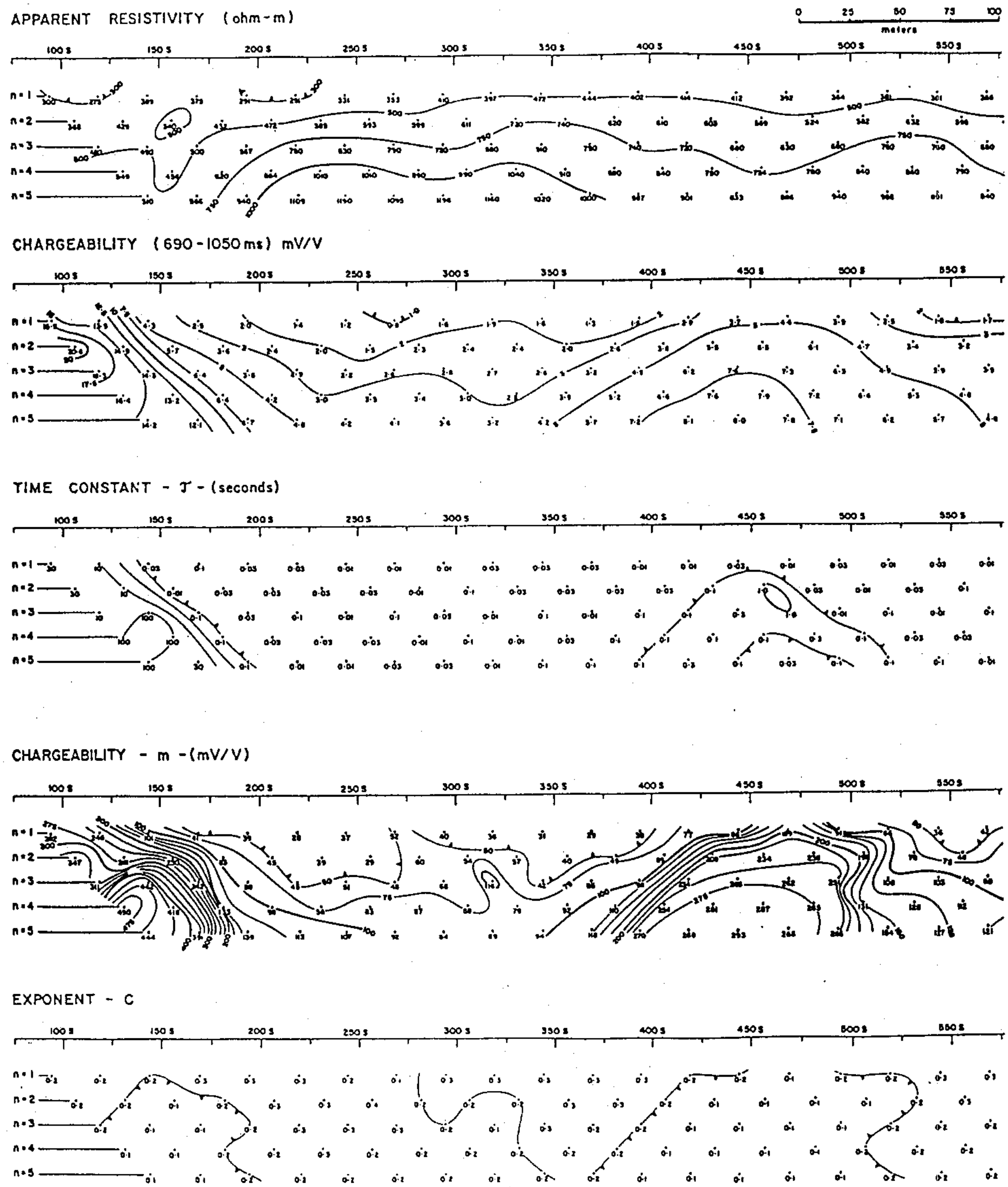


FIG. 9. Time-domain spectral IP results over a known gold producer. Deposit is centered some 50 m below station 450 S. An iron formation is located near the baseline.

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 distribution patterns of zinc, copper, and silver are irregular at times and inconsistent.

The Cole-Cole parameters c and τ 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 IPR-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 value 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 adequately 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.

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Expanded Abstract

SPECTRAL IP: EXPERIENCE OVER A NUMBER OF CANADIAN GOLD DEPOSITS

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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.

SPECTRAL IP: EXPERIENCE OVER A NUMBER OF CANADIAN GOLD DEPOSITS

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.

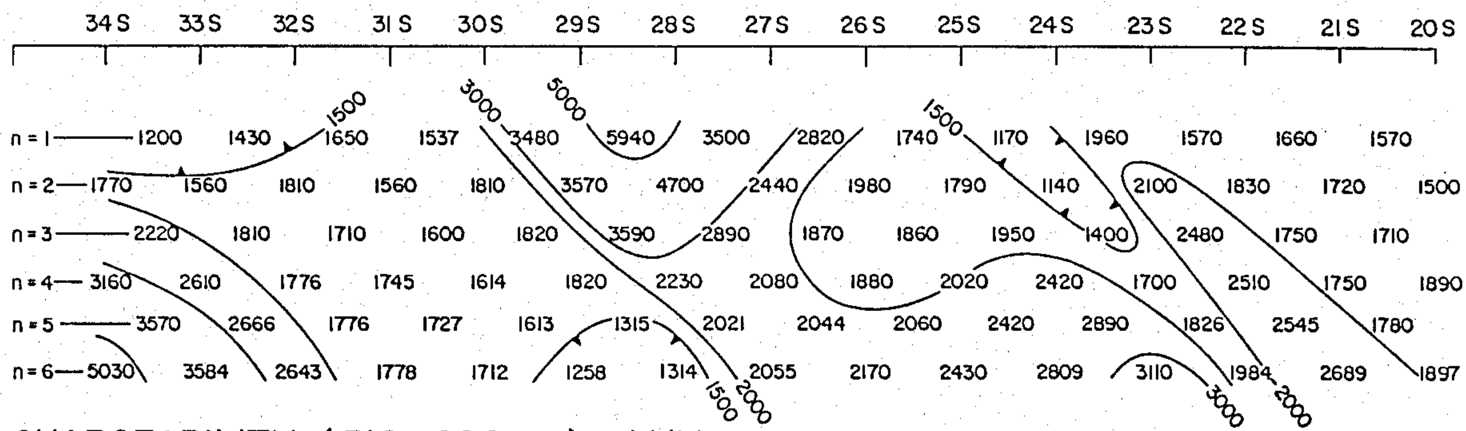
FIGURE CAPTIONS

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.

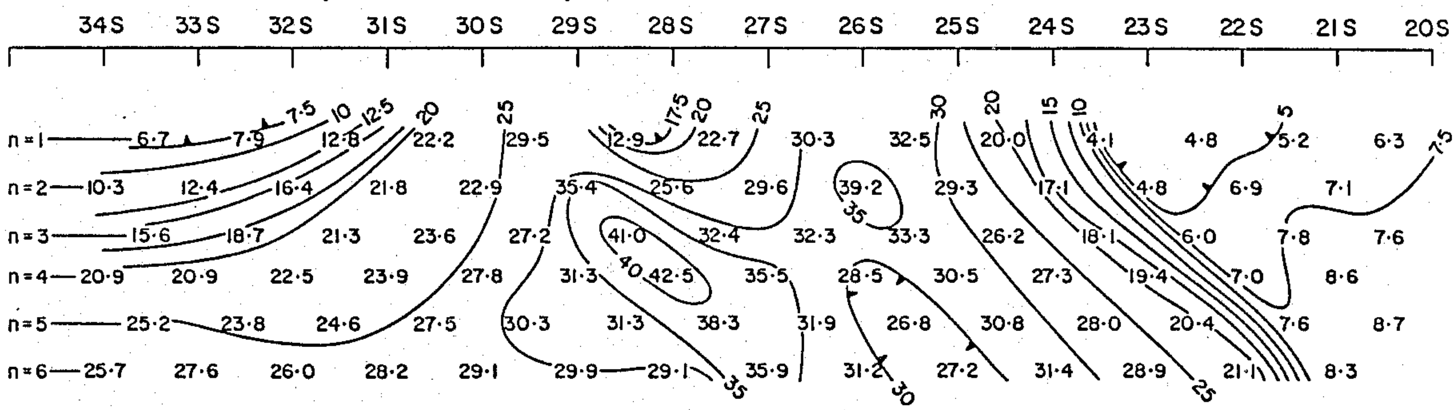
Figure 2: Pseudosections showing apparent resistivity, sixth slice IPR-11 (510 to 690 ms after shutoff) and Cole-Cole time constant. Pole-dipole array with a=100 feet and n values from 1 to 6.

100 feet

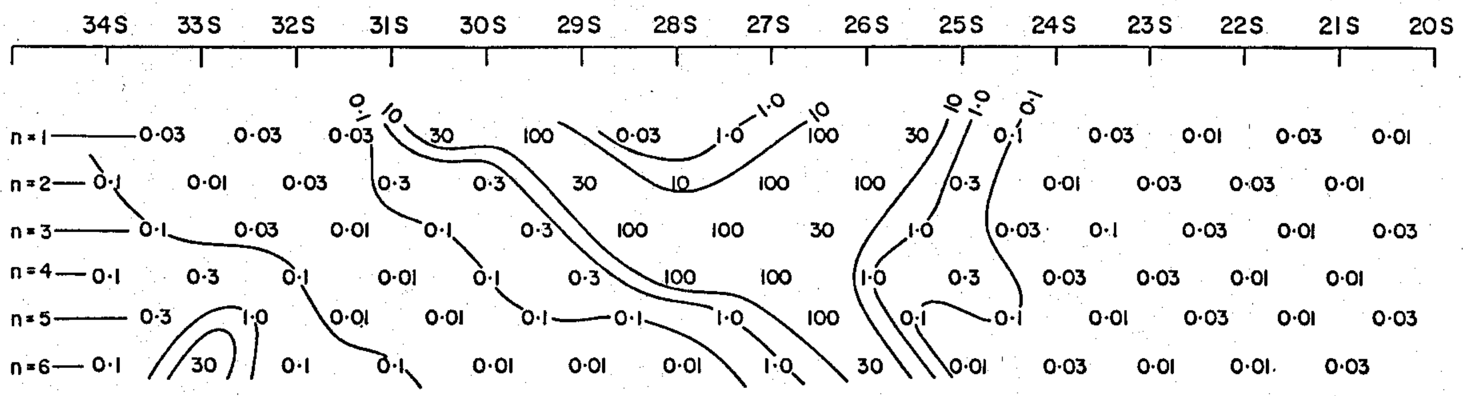
APPARENT RESISTIVITY (ohm-m)



CHARGEABILITY (510-690 ms) mV/V



TIME CONSTANT - τ - (seconds)



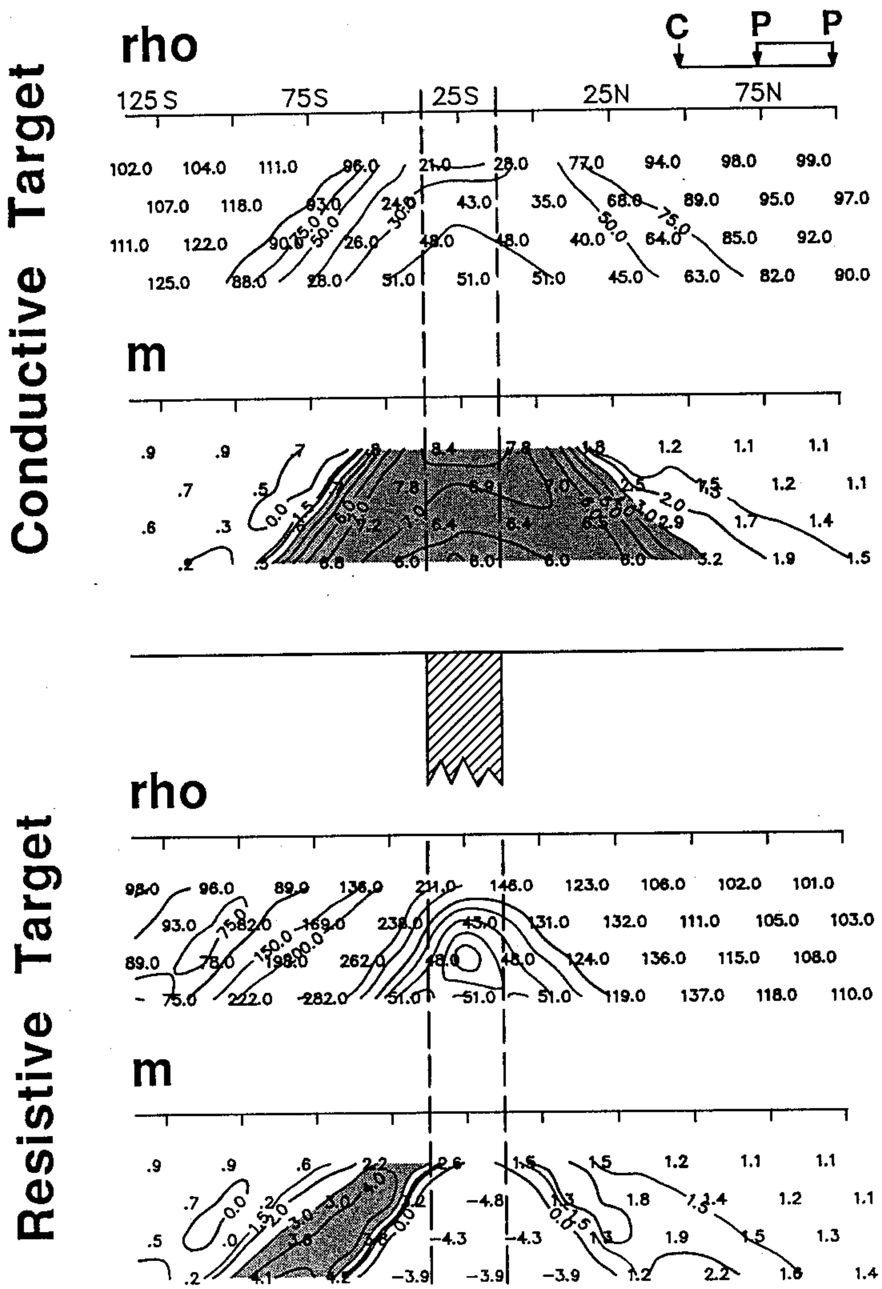
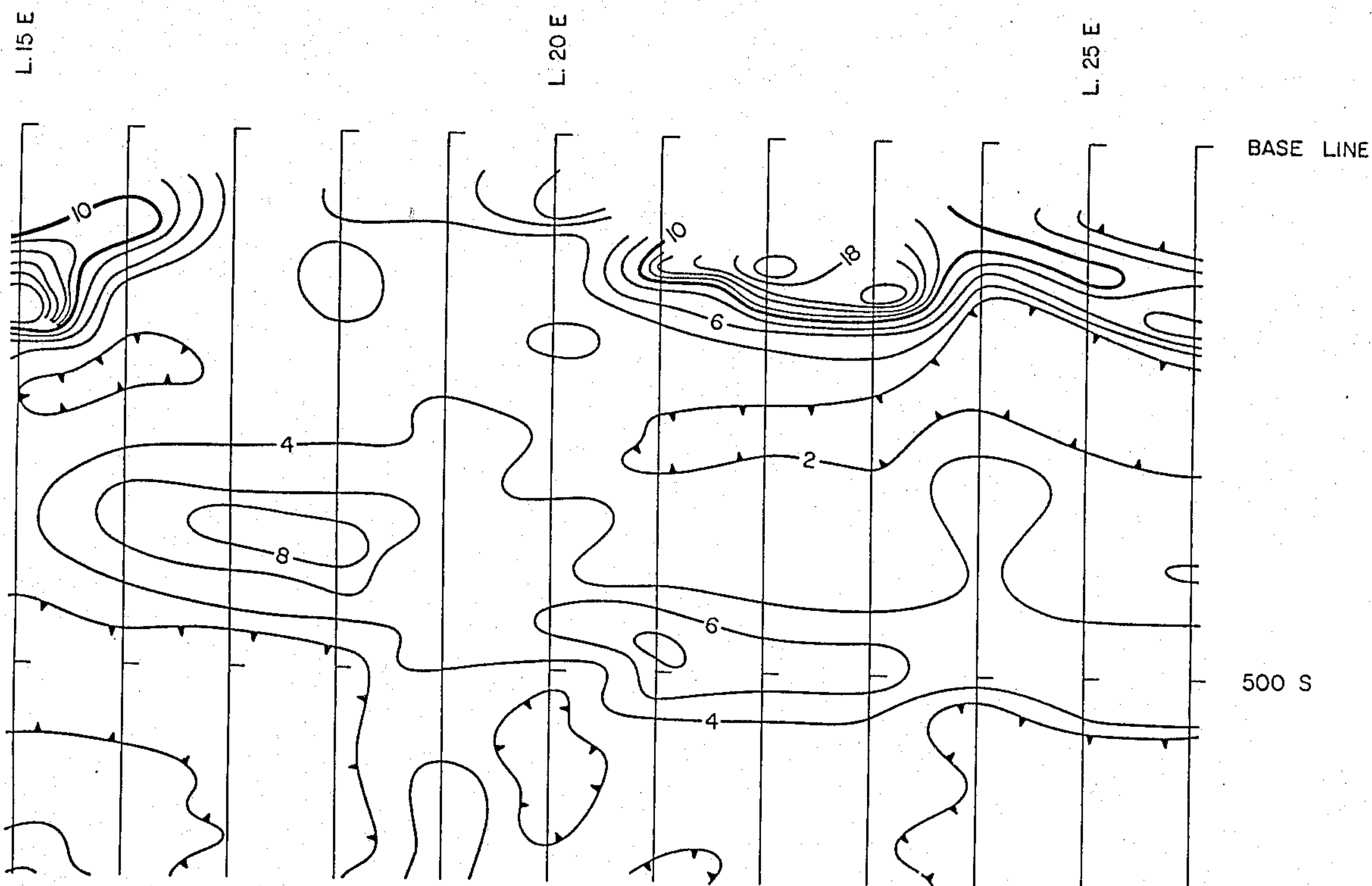
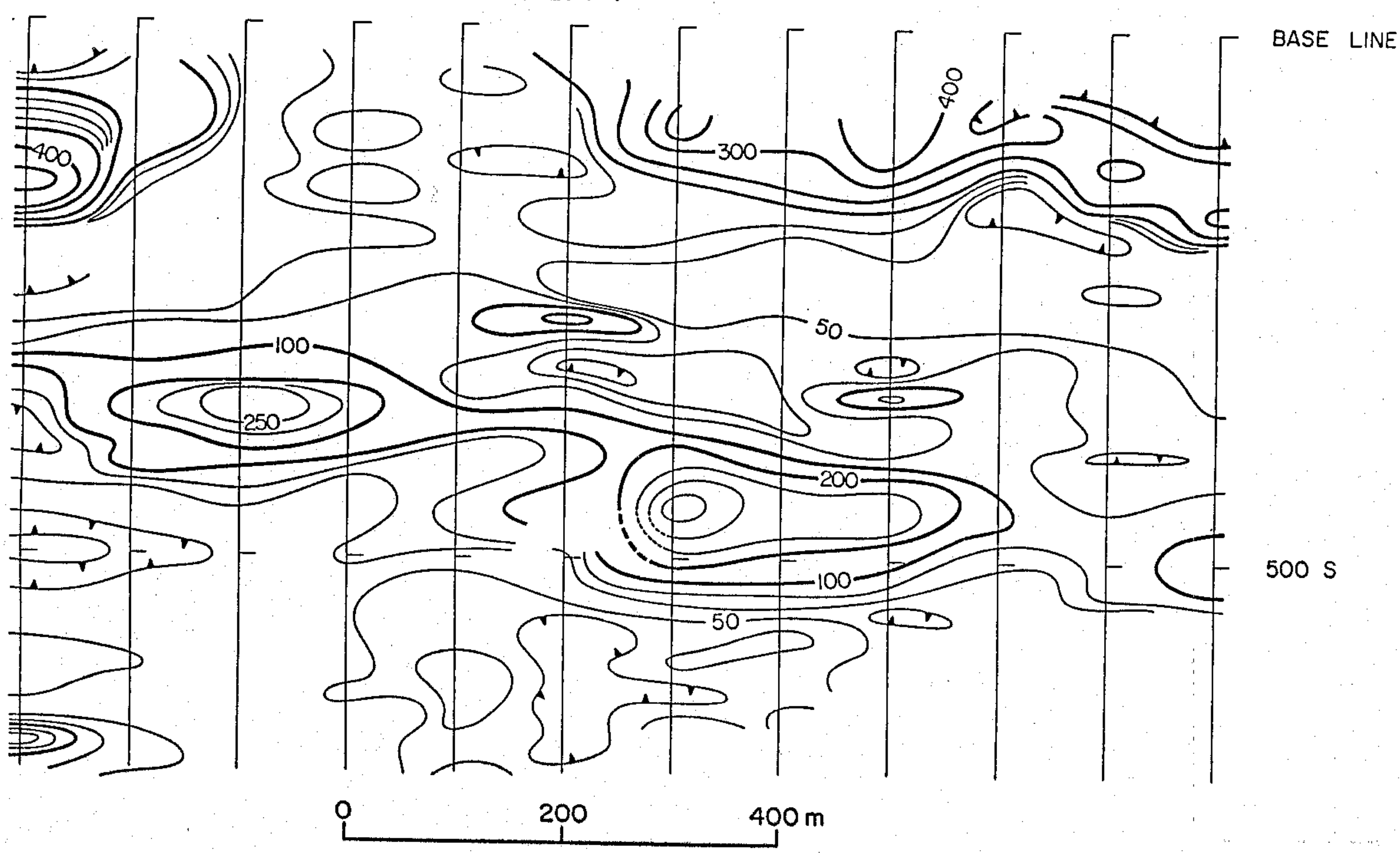


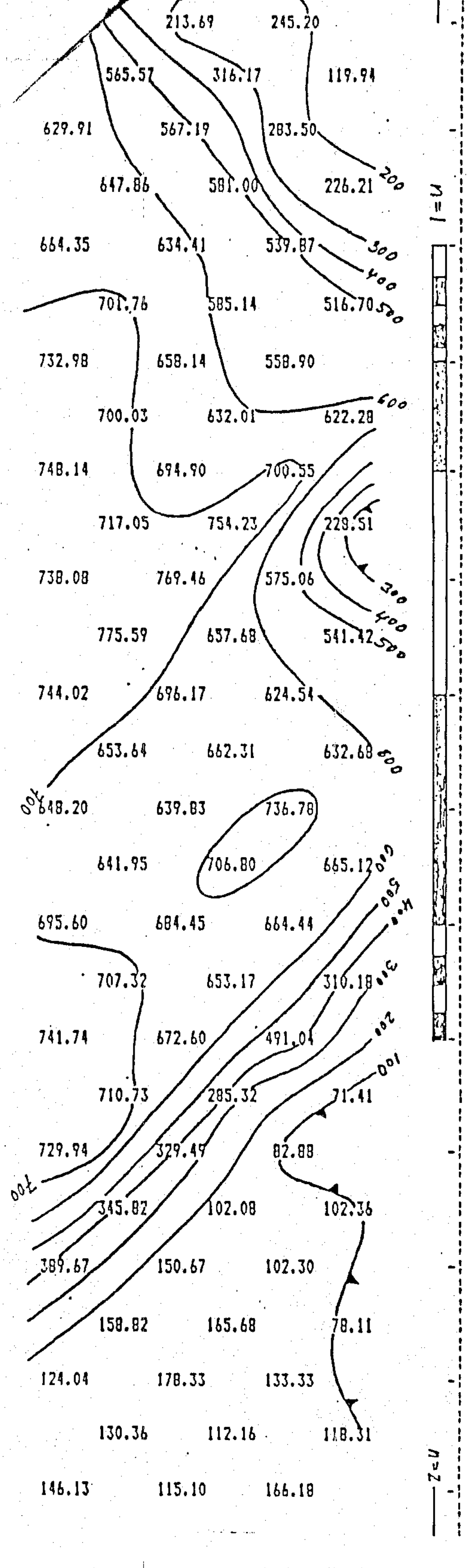
Figure 4. Theoretical resistivity / IP pseudosections for a vertical tabular body at surface. Results are for a pole-dipole array traversing from left to right. The host medium has a resistivity (rho) of 100 and a chargeabiltiy (m) of 1. The tabular body has resistivities of 10 and 1000 respectively and a chargeability of 10 (all units are relative). Areas with chargeabilities greater than 3 have been shaded.

CONVENTIONAL CHARGEABILITY



SPECTRAL CHARGEABILITY





213.69 245.20
565.57 316.17 119.94
629.91 567.19 283.50
647.86 581.00 226.21
200
664.35 634.41 539.87
300
400
701.76 585.14 516.70
500
732.98 658.14 558.90
700.03 632.01 622.28
600
748.14 694.90 700.55
717.05 754.23 229.51
738.08 769.46 575.06
300
400
775.59 657.68 541.42
500
744.02 696.17 624.54
653.64 662.31 632.68
600
700
648.20 639.83 736.78
641.95 706.80 665.12
600
500
695.60 684.45 664.44
707.32 653.17 310.18
300
741.74 672.60 491.04
200
710.73 285.32 71.41
100
729.94 329.49 82.88
700
345.82 102.08 102.36
389.67 150.67 102.30
158.82 165.68 78.11
124.04 178.33 133.33
130.36 112.16 118.31
146.13 115.10 166.18
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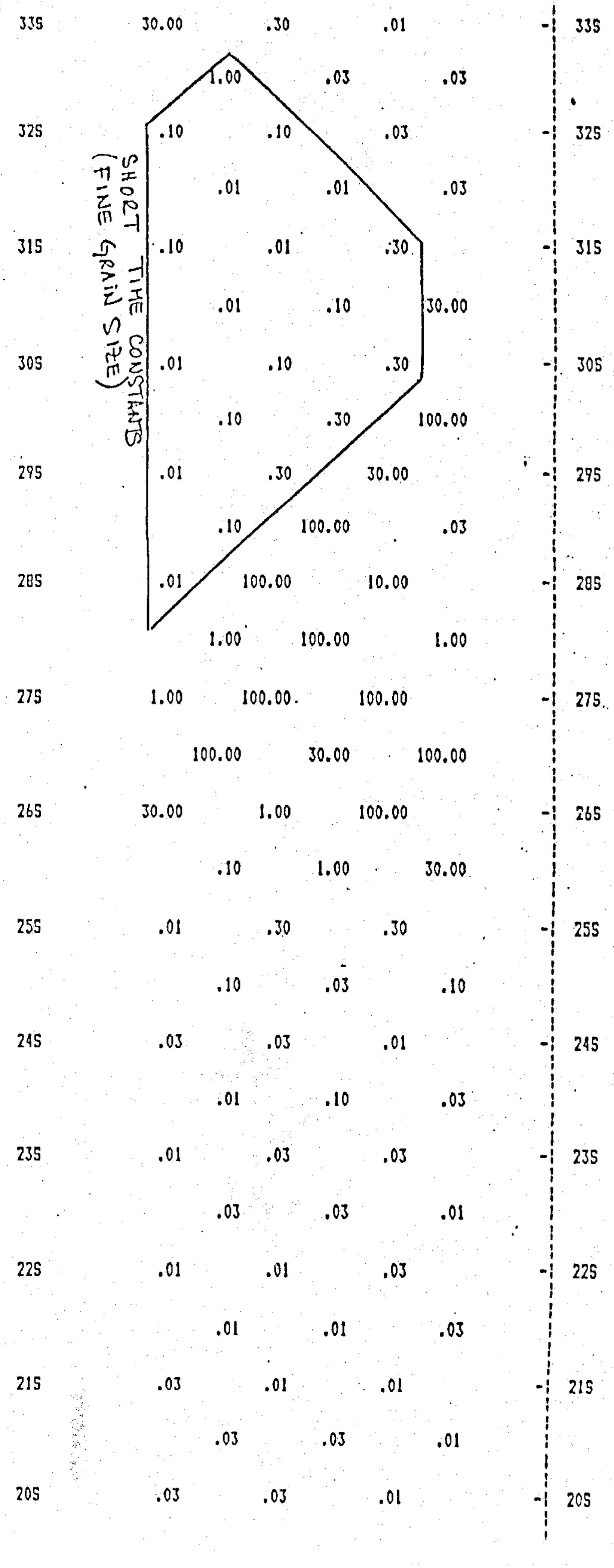

SHORT TIME CONSTANTS
(FINE GRAIN SIZE)
33S 30.00 .30 .01 33S
1.00 .03 .03
32S .10 .10 .03 32S
.01 .01 .03
31S .10 .01 .30 31S
.01 .10 30.00
30S .01 .10 .30 30S
.10 .30 100.00
29S .01 .30 30.00 29S
.10 100.00 .03
28S .01 100.00 10.00 28S
1.00 100.00 1.00
27S 1.00 100.00 100.00 27S
100.00 30.00 100.00
26S 30.00 1.00 100.00 26S
.10 1.00 30.00
25S .01 .30 .30 25S
.10 .03 .10
24S .03 .03 .01 24S
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.03 .03 .01
22S .01 .01 .03 22S
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21S .03 .01 .01 21S
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20S .03 .03 .01 20S

TIME DOMAIN SPECTRAL INDUCED POLARIZATION
SOME RECENT EXAMPLES FOR GOLD

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TIME DOMAIN SPECTRAL INDUCED POLARIZATION
SOME RECENT EXAMPLES FOR GOLD

Spectral induced polarization was developed for the frequency domain in the 1970s. An early development was the establishment of the Cole-Cole model as that which best fit field results. The advantage to spectral IP was the ability to extract more usefull physical properties from survey data by way of the Cole-Cole model parameters. Among those are the time constant which is related to grain size and the chargeability amplitude which is related to the volume percent metallic sulphides. Application was not routine however because of the need to make sequential measurements of phase at a number of frequencies. This was and is too time consuming for most surveys.

The time domain equivalent was established in the early 1980s. In this case, the spectral parameters are extracted from the measured decays. This was an improvement on the frequency domain based method as all of the information needed for spectral IP is in a single measurement: survey production rates are unaffected.

The result has been the routine use by some of time domain spectral IP and the collection of a wide range of field experience. Methods of intepretation based on this experience have been developed. The spectral information has been found to be of particular use in gold exploration where the interest is often in fine grained disseminated sulphides. Coarse grained or massive sulphides may not be of interest. The spectral parameters may be the only indicators as to which is which.

The adoption of spectral analysis techniques for properly sampled time domain decays is a natural evolution of the IP method. IP receivers and transmitters, survey methods and analysis schemes are expected to evolve with time in response to the greater accuracy demands of spectral IP.

Spectral IP results from five areas in Ontario and Quebec are presented. All of the data has been collected in exploration projects for gold. The Scintrex IPR-11 receiver and IPC-7 or TSQ-3 transmitter has been used throughout. The data have been collected by JVX survey crews using the pole-dipole array and a 2 second pulse time.

1. CHIBOUGAMAU AREA, QUEBEC

Figure 1 shows the results from part of a survey conducted in the Chibougamau area of Quebec. The data was collected with an a spacing of 25 meters and six potential dipoles. The survey area is covered with up to 10 meters of sand and clay overburden.

The contoured pseudosections show the apparent resistivity divided by 100. The chargeability is that of the eighth slice (IPR-11 designation - M7) which is taken over the period from 690 to 1050 milliseconds after shut-off. The unit of measurement is millivolts per volt (mV/V). The spectral parameters tau (time constant) and M are derived by comparing the measured decay curve with a library of known curves. The best fit between the measured curve and the chosen master curve is often better than 2 % rms deviation. The time constant is shown in seconds. The Cole-Cole amplitude factor M is shown in mV/V.

The IP survey mapped two anomalous zones. The northern zone, Zone A, at station 825N is characterised by M7 chargeability values of 30 to 33 mV/V. There is a slight decrease in the coincident apparent resistivity. The southern zone, Zone B-1, at station 500N to 575N exhibits slightly higher M7 chargeabilities at from 33 to 39 mV/V and a resistivity response lower than background.

The most notable feature of these results is the clear difference in the derived time constant associated with the two zones. The spectral computation returned a high tau (time constant) for Zone A and a low tau for Zone B-1. The time constant is considered to be a semi-quantitative measure of grain size of the polarizable source. A high tau indicates a coarse grained source and a low tau indicates a fine grained source.

Diamond drilling has confirmed this interpretation. Drill testing of Zone B-1 encountered a wide zone of fine grained disseminated sulphides with a ten foot section running 0.5 oz Au/ton. Zone A was tested 200 meters along strike from the profile and barren course grained sulphides were intersected.

It should be noted that without the spectral information, the zone A anomaly might have been selected as the more promising drill target. This would have been based on the higher apparent resistivities as a possible indicator of silicification.

This case history demonstrates the capability of the time domain spectal IP method to discriminate between anomalies that exhibit similar values of chargeability amd resistivity. In this project, the spectral parameters proved to be a valuable diagnostic in separating IP anomalies with associated gold from those without.

2. RATIOS vs. SPECTRAL IP

The ratio of selected slices has been suggested as an alternative to the time constant derived from spectral analysis. The idea is that polarizable sources which are fine grained will show a faster decay than that from course grained or massive sources. The ratio of chargeabilities from early and late times would therefore be greatest for fine grained and least for course grained sources.

This is correct in a rough sense only. The routine use of ratios as a substitute for the Cole-Cole model time constant is an error. Some reasons are:

1. All of the work which has been done on spectral IP (time of frequency domain) supports the Cole-Cole model. This is a three parameter model for chargeability with one parameter for amplitude and two parameters to describe decay curve shape. These two parameters are the time constant (tau) and the exponent (c). They are linked in a complicated way and there is no simple method in the time domain to separate their effects.

   Characterizing the decay with a ratio assumes a two parameter model; amplitude and decay ratio. The ratio (or decay rate) is a mixture of time constant and exponent. Variations in the ratio can be due to variations in either time constant (ie. grain size) or exponent (ie uniformity of grain size).

   The assumption that the decay can be characterised by a ratio is equivalent to setting the exponent to a value of 1.0 (ie. modelling the decay as a negative exponential). All of the spectral IP work done to date suggests this is not the case. Exponent values between 0.1 and 0.5 are expected.

2. Spectral analysis uses a least squares fit over the whole measured decay. Ratios use two slices one of which is normally taken in the early part of the decay. Such slices arise from a short window width for which noise is greatest. Using one of the first four slices from the IPR-11 for example means the ratio is limited by data collected over 30 milliseconds. The spectral parameters are determined from data taken over almost 2 seconds.

3. For low exponent values (eg. c=0.1), the differences in ratios is least pronounced. This is the expected value of c however (the Newmont standard decay fits best to a c value of 0.1). The following table lists the theoretical ratios of the IPR-11 M3 (fourth slice centered at 135ms after shut off) to M7 (eighth slice centered at 870ms after shut off). A Cole-Cole exponent of 0.1 and time constants of 0.01 to 100 seconds are used.

Cole-Cole Time Constant (Sec)	M3/M7
0.01	2.61
0.03	2.59
0.10	2.58
0.30	2.57
1.00	2.56
3.00	2.54
10.00	2.53
30.00	2.51
100.00	2.50

The difference in the ratio between time constants for 0.01 and 100 seconds is only 4.2%. Assuming that M3=10.0mV/V and M7=3.9mV/V and that M7 is error free, the full range of ratios is found within the range for M3 of 10.0 +/- 0.4mV/V.

Spectral analysis using the whole decay is not so dependent upon the quality of chargeability values for a single slice.

A field example of ratios vs. Spectral IP is shown in figure 2. The data is taken from figure 1. Reading from top to bottom, pseudosections show the Cole-Cole time constant, the exponent and the M3/M7 ratio. It is clear from this example that variations in the ratio may be explained by either a change in time constant (ie grain size) or a charge in exponent (uniformity of grain size). The ratio alone cannot be relied upon to discriminate between coarse and fine grained metallic sulphides.

3. POWER LINE RESPONSE

Figure 3 shows the measured apparent resistivity, eighth slice chargeability and time constant. These results are from a survey in Joutel area. A pole-dipole array with an "a" spacing of 25m was used.

A power line is located at station 975N. The pseudosection of chargeability shows a distinct anomaly which could pass for that due to bedrock sources.

The time constant is uniformly long under the power line. This pattern was repeated at all points where the survey passed under the power line. This result might be expected given the nature of the cause of the response. This same signature can be seen for fences.

The spectral parameters have been determined in an area of only modest chargeabilities. Away from the power line, background chargeabilities are low. The rms deviation between the measured and theoretical decays is greater than 5% due mostly to the resolution limit of the IPR-11 (0.1 mV/V). Five percent is the limit beyond which spectral parameters are not plotted.

The long time constant characteristic of cultural sources could be exploited when exploring for fine grained sulphides in their vicinity. Identification might be made on the basis of time constant alone.

4. SUFFIELD, QUEBEC

Figure 4 shows the IP/resistivity results for one line in the area of the Suffield mine, Sherbrooke, Quebec. A pole-dipole array with an "a" spacing of 100 feet was used.

The resistivity low and associated chargeability high west of the base line suggest massive conductor. This is supported by the long time constant. This interpretation is correct. This is the area where a graphitic phyllite outcrops. This unit is known to be conductive and may be mapped using EM techniques.

There is a subtle IP response in the area of station 300E. There is no parallel variation in apparent resistivities and an interpretation without access to the spectal information might have passed over this part of the pseudosection.

The spectral parameters however suggest that this may be an area of fine grained disseminated sulphides. The Cole-Cole amplitude M is as large at 300E as over the graphities. This suggests an equal amount of polarizable material. This information is not available from single slice (or phase or PFE) presentation. The M7 results at 300E are as uninteresting as they appear because the time constant is so short. The decay is faster than would be seen with a long time constant source. The amplitude is depressed at M7.

The area around station 300E was identified as one for further investigation. Drilling immediately to the north of station 300E revealed fine grained disseminated sulphides. The locally high resistivities were explained by silicification.

5. JELLICOE DEPOSIT, ONTARIO

In 1983, the Ontario Geological Survey sponsored a series of geophysical surveys over known gold deposits in the Beardmore-Geraldton greenstone belt. Part of this work involved IP surveys 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 50m 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 25m and n=1 to 5. The results over one survey line are shown in pseudosection form in Figure 5. The apparent resistivity, eighth-slice chargeability, Cole-Cole time-constant, chargeability amplitude, and exponent values are shown in contoured pseudosection form.

The deposit is centered at station 450S 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 chargeability amplitude has amplified the anomaly over the deposit. As in the earlier examples, the amplitude M is a more reliable indicator of the volume percent metallic sulphides. The single slice (or phase or PFE) is less reliable. Variations therein can be caused by changes in grain size alone.

6. AVERAGE CHARGEABILITY

Figure 6 shows the results from a survey in the Casa Berardi area in which the M7 presentation showed little obvious variation and therfore no clear indication of areas of greater interest.

The lowest pseudosection shows the average of all ten slices. Where the eighth slice (M7) is of 380ms width, all ten lices occupy a window width of 1760ms. This is more than a fourfold increase in time averaging. A two times increase in signal to noise results. Subtle variations in chargeability are amplified and areas of possible interest are more easily identified.

In some ways, the average chargeability shown here is the chargeability parameter with the greatest signal to noise ratio possible. The survey operator is concerned with noise in the decay. Power or measuring time requirements are hence more severe than would be seen if looking at the average alone. The high quality of the average chargeability data is a result of the care needed to make IP measurements accurate enough to be used for spectral analysis.

CONCLUSIONS

The spectral paramters have been shown to be usefull compliment to the traditional chargeability data. This is particularly true where it is important to separate fine grain disseminated sulphides from their coarse grained equivalents. This is important in gold explortion as it is common to find gold associated with fine grained sulphides.

The calculated spectral parameter M is a more reliable indicator of the presence of metallic sulphides. The time constant reflects grain size. Fine grained disseminated sulphides may yield little or no IP response when viewed through the non-spectral measurement of single slice (or PFE or phase). Spectral analysis corrects this problem and the risk of missing interesting targets is less.

The spectral parameters may be used to separate cultural responses from those due to bedrock sources. The ratio of slices from time domain surveys is not equivalent to spectral analysis and the use of ratios will lead to errors where the ratio is related to the time constant or grain size. In addition, the ratio ignores the true chargeability amplitude which is used to indicate the concentration of disseminated sulphides.

The type of source discrimination seen with time domain spectral IP is not possible when measuring a single IP quantity such as a particular slice, PFE or phase at one frequency. These methods are restricted to a measurement of a quantity which is a mixture of source characteristics such as volume percent metallic sulphides and grain size. There is no way to extract each separately and the interpretation of such data is done and recommendations made while lacking important information.

The time domain spectral IP method does not suffer this limitation. The argument for spectral IP is particularly strong given that there is little effect on production rates when using the instrumentation, analysis software and field methods used for the results shown herein.

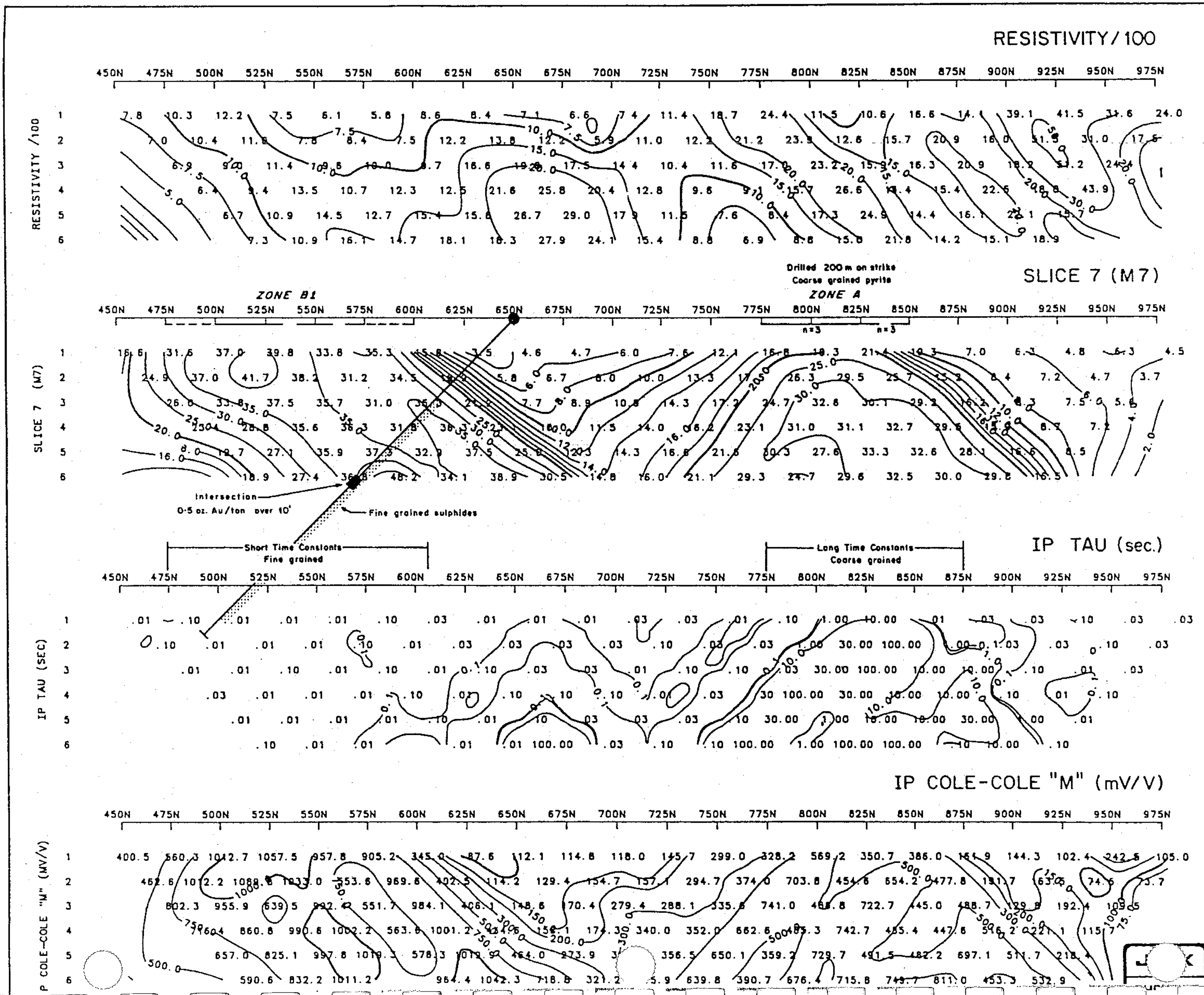

RESISTIVITY/100
SLICE 7 (M7)
ZONE B1
ZONE A
Drilled 200 m on strike
Coarse grained pyrite
Intersection
0·5 oz. Au/ton over 10'
Fine grained sulphides
IP TAU (sec.)
Short Time Constants
Fine grained
Long Time Constants
Coarse grained
IP COLE-COLE "M" (mV/V)
450N 475N 500N 525N 550N 575N 600N 625N 650N 675N 700N 725N 750N 775N 800N 825N 850N 875N 900N 925N 950N 975N

Fig. 1

Fig. 2

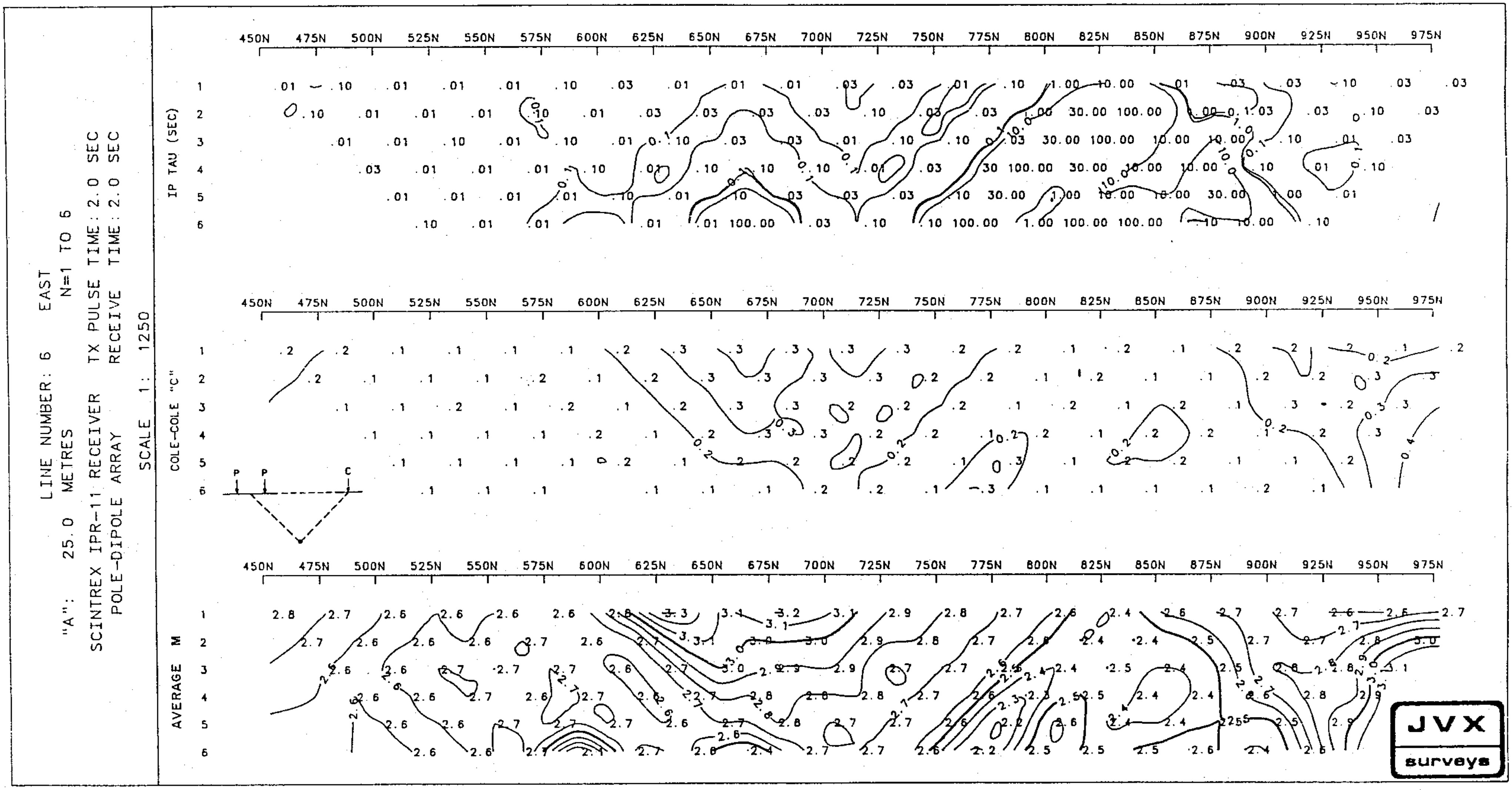
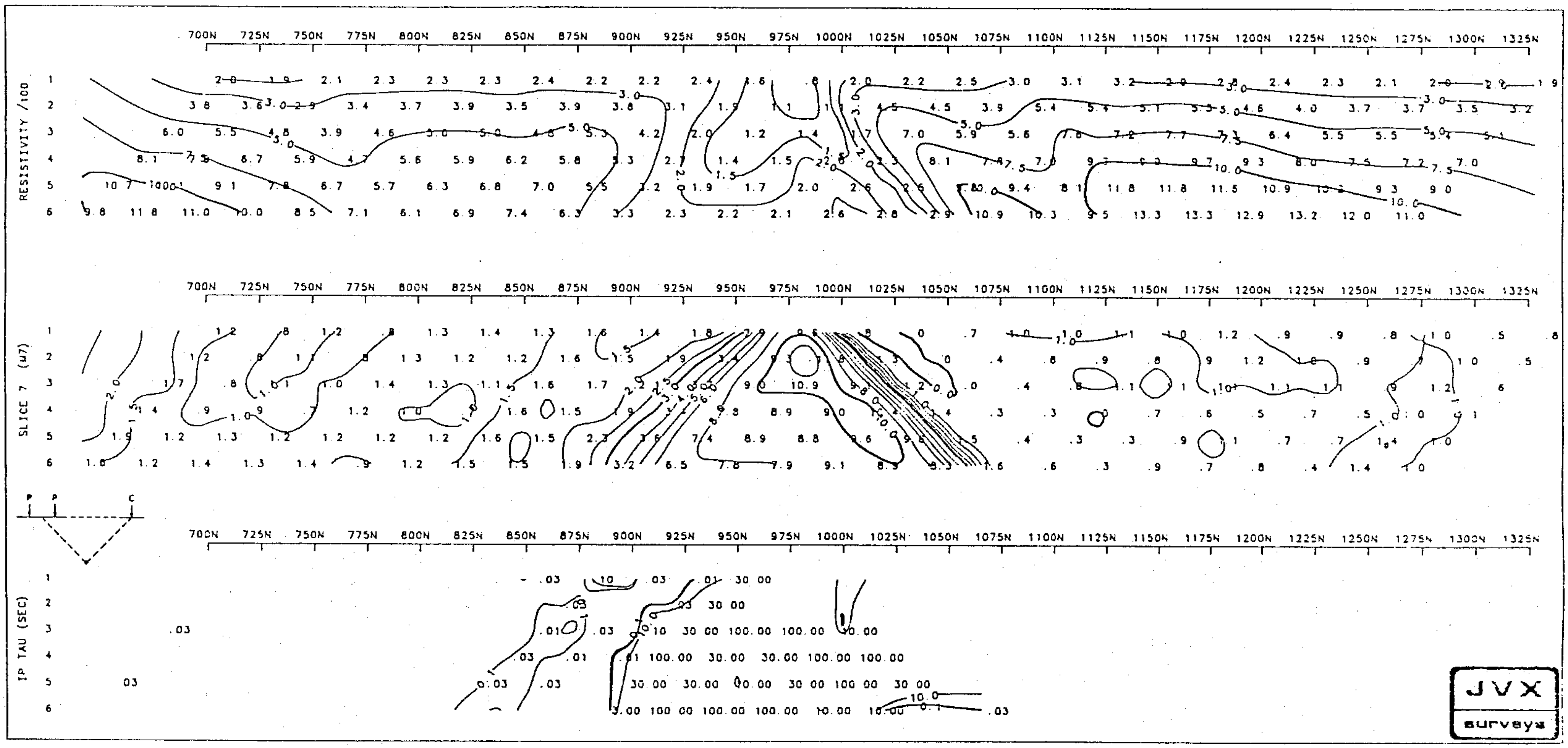


Figure 2

Fig. 3



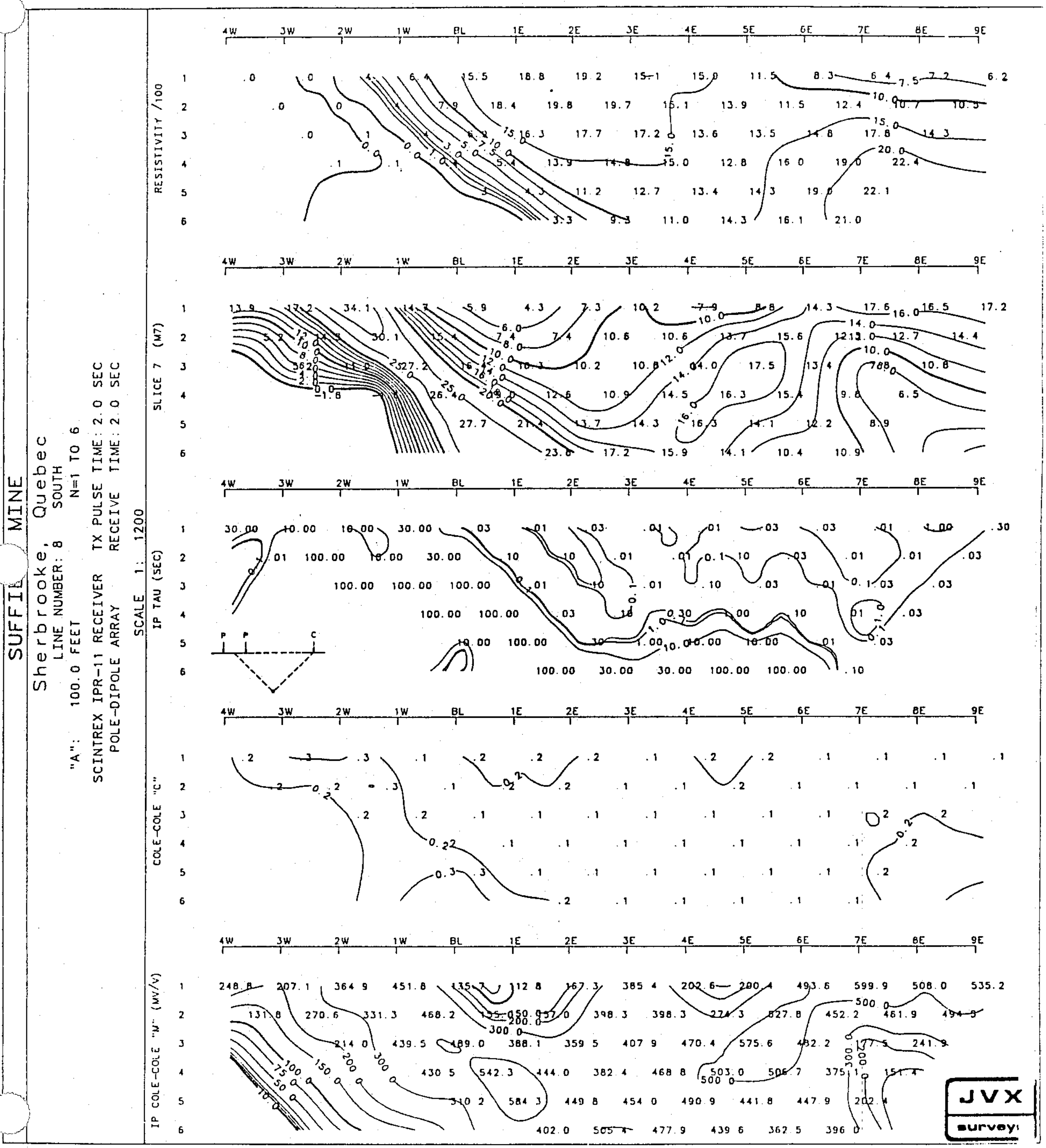

SUFFIELD MINE
Sherbrooke, Quebec
LINE NUMBER: 8 SOUTH
"A": 100.0 FEET N=1 TO 6
SCINTREX IPR-11 RECEIVER TX PULSE TIME: 2.0 SEC
POLE-DIPOLE ARRAY RECEIVE TIME: 2.0 SEC
SCALE 1: 1200
4W 3W 2W 1W BL 1E 2E 3E 4E 5E 6E 7E 8E 9E
RESISTIVITY /100
SLICE 7 (M7)
IP TAU (SEC)
COLE-COLE "C"
IP COLE-COLE "M" (MV/V)
P P C
JVX
surveys

Figure 4

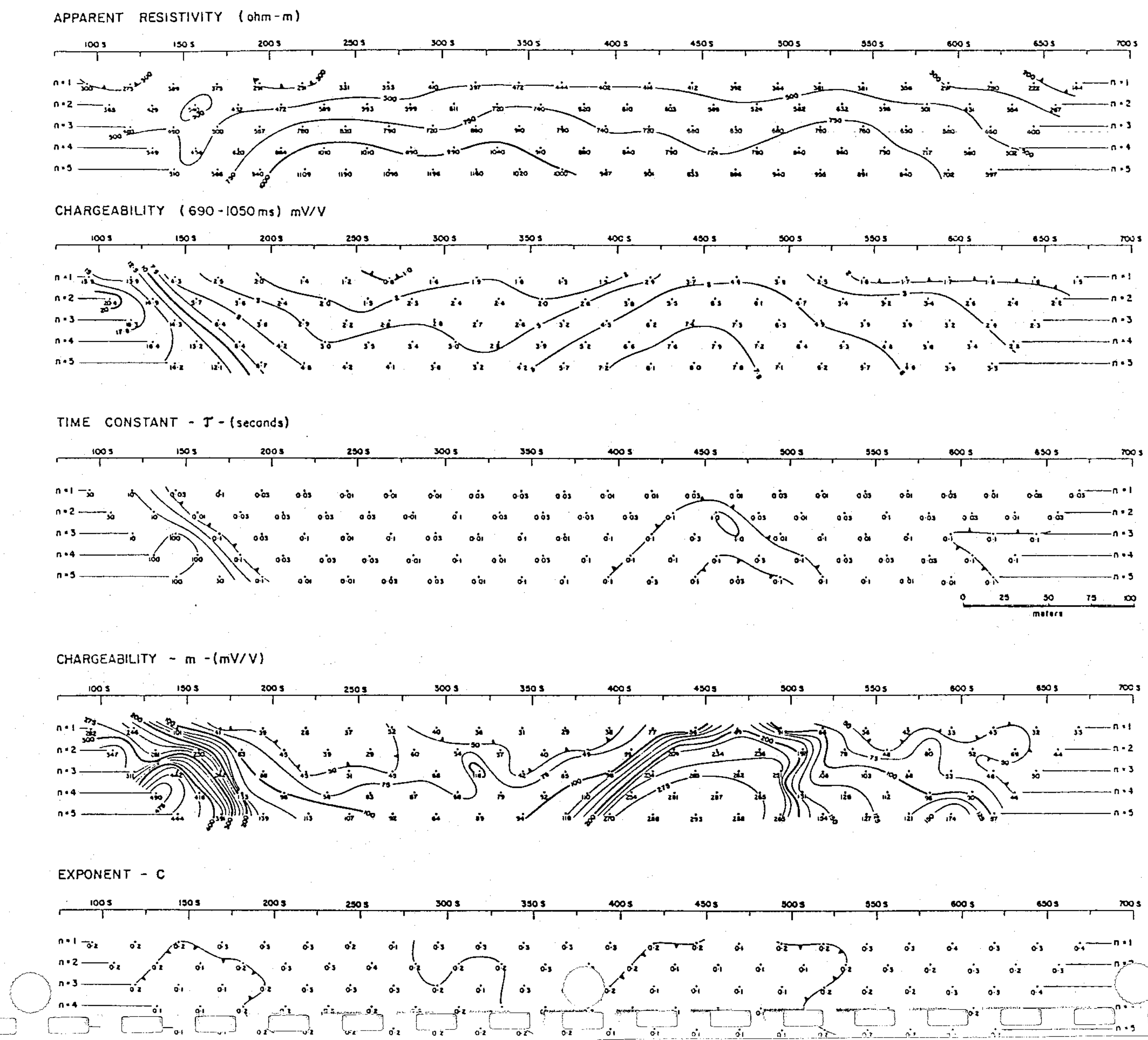

APPARENT RESISTIVITY (ohm-m)
CHARGEABILITY (690-1050 ms) mV/V
TIME CONSTANT - τ - (seconds)
CHARGEABILITY - m - (mV/V)
EXPONENT - C
100 S
150 S
200 S
250 S
300 S
350 S
400 S
450 S
500 S
550 S
600 S
650 S
700 S
n=1
n=2
n=3
n=4
n=5
0
25
50
75
100
meters

Fig. 5

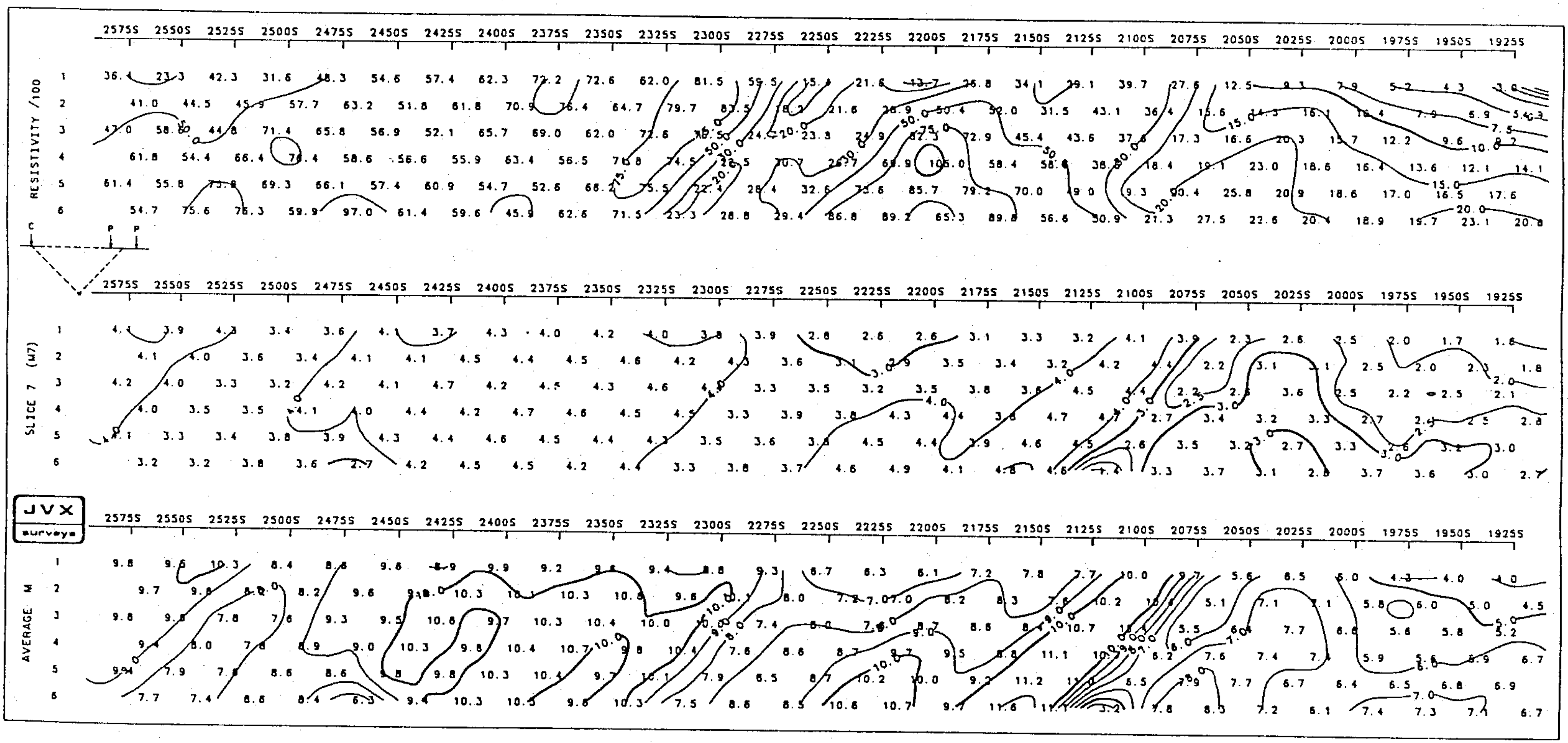

2575S 2550S 2525S 2500S 2475S 2450S 2425S 2400S 2375S 2350S 2325S 2300S 2275S 2250S 2225S 2200S 2175S 2150S 2125S 2100S 2075S 2050S 2025S 2000S 1975S 1950S 1925S
RESISTIVITY /100
SLICE 7 (M7)
AVERAGE M
C P P
JVX
surveys

Fig. 6