ANNUAL REPORT
E. L. 2835 HELEN SPRINGS, N.T.
FOR YEAR ENDED 25.6.84

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1. Plan showing location of RRMIP Geophysical Surveys. l:84,000
1. **Summary**

The following work was undertaken on E.L. 2835 during the current year.

1.1. RRMIP orientation survey October 1983 by Scintrex Pty. Ltd.
1.2 Diamond Search by Ashton Mining Pty. Limited.
1.3 Detailed RRMIP survey by Scintrex - in progress.

2. **RRMIP Orientation Survey**

Scintrex conducted a trial survey from 21st to 30th October 1983. A total of 5 arrays were completed, one with a current dipole of 1800 metres, the remainder of 1500 metres reading an effective are of 900m x 800m.

(See Appendix 1)

The test survey was conducted over the Willieray Fault area immediately south of Mt. Willieray.

The survey outlined two zones - an eastern zone about 1100 metres wide of high resistivity with one strong meridional conductor - probably a horst zone of older quartzites - flanked on the west by a more conductive zone which may be caused by McArthur Group sediments.

The eastern resistive zone appears to be strongly cross faulted and reflects a complex horst zone of older quartzites similar to the Emu Fault in the McArthur region.

3. A diamond search of the area was conducted by Joint Venture partners Ashton Mining Ltd. These activities will be reported separately.

4. **Geology**

Some mapping was conducted during the laying out of the RRMIP grids. The most significant outcrops occur on the Hunter Creek Grid near Hunter Creek about 1800m east of the Hunter Fault. Here sucrosic dolomites with abundant radiating pseudomorphs after (?) gypsum identical in appearance to the Coxco Dolomite member of the Teena Dolomite are overlain by thin bedded siltts which contain pink potassic beds interpreted as water lain tuffs. This latter horizon is tentatively interpreted as the stratigraphic equivalent of the W Fold Shale member of the Barney Creek Formation. The high quartz silt component fits in with the previous interpretation of the area being the southern margin of the McArthur Basin where the sediments contain a higher wind blown aeolian fraction.
4. **Geology (cont'd)**

These sediments dip gently west then steepen to 60° to 70° west before passing below cover of (?) Nathan Group dolomitic silts and silty dolomites.

The HYC Pyritic Shale Member of the Barney Creek Formation, if present, would overlie these tuffaceous silts and would be also covered by the (?) Nathan Group unconformity to the west.

5. **Detailed RRMIP Survey**

Access track preparation, Base Line and Grid layout was initiated in late May. A Scintrex RRMIP crew commenced pegging and reading on 13th June. No results have been received yet.

6. **Future Programme**

6.1 Complete RRMIP Survey. This involves initially seven 1500 x 1500 metre arrays in the Hunter Creek area and 8 arrays also 1500 x 1500 metres in the Willieray area.

6.2 Diamond Drilling. Testing of significant RRMIP anomalies will be initiated before the end of the dry season.

7. **Expenditure**

To be advised.
A REPORT ON
PATHFINDER RAPID RECONNAISSANCE
MAGNETIC INDUCED POLARIZATION SURVEYS
AT HELEN SPRINGS,
NEAR RENNER SPRINGS, NORTHERN TERRITORY
ON BEHALF OF
CLIFFORD MINERALS LIMITED
IN ASSOCIATION WITH
TECHNOMIN AUSTRALIA N.L.
Summary

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Discussion of Results

Conclusions

Appendices: Data Presentation

Brief Description of Method, and Meaning of Parameters

MIP Method

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3. Interpretation Plan
PRIVATE AND CONFIDENTIAL

A REPORT ON
PATHFINDER RAPID RECONNAISSANCE
MAGNETIC INDUCED POLARIZATION SURVEYS
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DECEMBER, 1983
NT-033R
SUMMARY

A series of five HRMIP test arrays were surveyed over the southern section of the Willieray fault zone as a test of the efficiency and feasibility of using HRMIP as a semi-regional mapping tool for the area.

The work showed that the method can be effectively applied to the area on a most effective basis.

While further detailing is required, anomalies of the NYC and Mississippi Valley types have been detected. It is considered desirable, however, that further surveys be carried out north along the Willieray fault zone and Hunter Creek area prior to any investigation by drilling.
INTRODUCTION

Between 21st and 30th October, 1983, Scintrex Pty. Ltd. executed a series of five test arrays over an area situated on the southern section of the Willieray Fault zone. These surveys were carried out at the request of Mr. P. Ho, Chairman of Clifford Minerals Limited. The actual site for the survey was chosen by Mr. D. Ward who undertook the detailed mapping and evaluation of the area.

The crew was comprised of Scintrex operator Mr. P. Brown, B.Sc., and second operators Mr. R. Laver and Mr. R. List. The crew pegged and read the lines. Mr. D. Ward initiated the surveys on site, first identifying the location.

For those unfamiliar with the method, the attached appendices give descriptions of the parameters measured and their meaning; the method and data presentation.
DISCUSSION OF THE OBJECTIVES OF THE SURVEY AND SURVEY PROCEDURES

The area over which the survey was undertaken is part of a larger area which has been identified by Mr. D. Ward, Consulting Geologist for Clifford Minerals Limited, as being potential for McArthur River HYPD and Mississippi Valley (MV) type deposits. The sediments, age and palaeogeography, together with structural setting, are considered similar to the McArthur River area.

The objectives of the present survey were to (a) assess the feasibility of utilising the RRMIP method to the search for HYPD and MV type deposits (Note: the method has been successfully tested over HYPD and has played a primary role in locating MV deposits in the type area).

(b) Carry out a limited survey over an accessible section of the area prior to the wet as a 'pathfinder' survey in preparation for the larger scale surveys to be carried out in the 1984 field season.

The target, being of substantial area, requires large current dipoles, preferably 1 to 3 kilometres, in order that the target mineralisation is 'small' with respect to the current dipole, or at least the target mineralisation has at least one of its edges within the grid area. Initially it was intended to employ the Scintrex 10 kilowatt (TSQ-4) RRMIP transmitter, but because of the mobilisation costs for such a small survey, it was decided to attempt the task using a 3 kilowatt (TSQ-3) unit which is considerably lighter.

Fortunately, due to the high bulk resistivities of the host rocks, and the lack of appreciable surface conductivity, 3Hz was able to be employed as the energising frequency, which maximised the possible current dipole. Also, for the bulk of
the survey, geomagnetic conditions were abnormally quiet.

In practice the first array attempted was 1800 metres. This proved to be at the limit of tolerable noise, so the remaining four arrays employed a 1500 metre dipole.

The survey crew consisted of two readers and two peggers. In practice it took one four man day and one two man day to peg one array which could then be read in one day. This relationship will have to be borne in mind when larger arrays are contemplated.

The 5000E baseline was pegged every 150 metres using a star picket, with 50 metre metal fence droppers along lines. Some cutting of the waist high to shoulder high scrub was necessary, and obviously slowed progress.
DISCUSSION OF RESULTS

Only brief comments on the geophysical data are made below. It is hoped that appropriate comments will be added by Mr. D. Ward of D. Ward & Associates with respect to the location of the site of this pathfinder survey, and the possible geological meaning of the geophysical data.

The five reconnaissance arrays had current dipoles emplaced as follows:

1W  23650N and 25450N at 5000E  1800 metres
2W  22950N and 24450N at 5000E  1500 metres
3E  22950N and 24450N at 4200E  1500 metres
4E  23750N and 25250N at 4200E  1500 metres
5E  22375N and 23875N at 4600E  1500 metres

The energising frequency was 3Hz with readings taken on 150 metre spaced lines every 50 metres along lines.

The magnetometric resistivity (MMR) data divides the survey area into a number of specific zones. The most significant event is a conductor axis which can be traced from about 4850E/23650N sinuously to beyond 4900E+ on line 25000N. On array 1 the MMR reaches +130% on the centre section (4800E/24550N) and on the array boundary (24100N/4850E) where it reaches +230%. Note the MMR values are lower by an order of magnitude on the 2W overlap line due to the very short effective strike of the conductor axis with respect to the large current dipole. Also it could be that the conductor axis plunges north. North of 24400N the asymmetry of the anomaly suggests a steep east dip, while in the southern section, 24100N (+150 metres) the asymmetry suggests a steep west dip. These interpreted
dip directions presuppose the actual conductor source to be sharp sided with respect to the enclosing rocks. The form of the MMR data also suggests a depth extent to the source in excess of 300 metres+. The conductor shows good contrast (at 130%) with the enclosing rocks. In this geological setting, limestones, dolomites and sandstones (and the like) would be expected to make up the bulk of the underlying rocks, and these are generally extremely resistive (5,000 to 20,000 ohm-metres). Thus features such as faults (open) brecciated zones, and the like, would be expected to cause MMR responses such as this feature. Also, as the rocks over this feature are considered to have quite flat dips, and MMR being insensitive to horizontal layering, clearly implies this feature to be due to a fault zone.

A very weak continuation of this feature may be present from about 4750E/23200N to 4750E/22750N.

Note: both the above conductors are relative conductors, and show contrasts in bulk resistivity rather than conductors in the electromagnetic sense.

To the east of the above conductors, extremely resistive rocks underlie the survey area. Two very broad areas of high, broad bulk resistor axes can be identified. The most northerly runs from 5250E/25000N to 5250E/24100N. A sub-parallel axis was recorded between 5150E/24250N to about 5050E/23650N to 4850E/22750N. The MMR values along the axis range from -35% to -60%, but after the conductor axis is allowed for, the bulk resistivity of the zone 500 metres+ east of the conductor axis, can be considered to be of the order of -40% in the south, to -30% in the north.
Whereas the MMR data to the east of the conductor axis shows the underlying rocks to be very uniform along the north south strike, to the west of the conductor the continuity along the supposed north south (+) strike is very 'blocky'. The break in continuity along strike suggests grid east west faults as follows:

a) between lines 24400N and 24550N from 4600E to 3700E, and

b) along line 23800N between the same coordinates

Generally the relative resistivity is high for up to 800 metres west of the conductor axis, until a series of weak to very weak conductor axes was defined between 3900E/23350N and 4050E/24850N (see interpretation map for details). These, at least in part, appear disrupted by the supposed east west dislocations.

In all the above comments on MMR, it should be recognised that STEEPLY DIPPING features such as faults and the EDGES of horizontal features (rather than horizontal features themselves) will be emphasised.

The relative phase shift (RPS) parameter indicates the relative bulk internal polarization levels of the underlying geological units (providing they are not horizontal infinite plates with respect to the current dipole for each array). Basically two types of RPS response have been defined on the survey grid. The first is lenticular and typical of either steeply dipping lenses (perhaps MV type deposits), and the second, sub-areal zones of interior polarization which arise from relatively chargeable sections which may represent sub-horizontal lenses (MYC targets?).

The most substantial response was defined in the north-east quadrant of array 1, and is open to the north and east. The amplitude is up to +0.5° above background.
The source could be a sub-horizontal zone of higher chargeability. Depth to source is difficult to gauge, but a guess is 150 metres\(^+\). Surface electrical soundings to confirm the axis' interest, and to ascertain depth to the source may be desirable prior to any investigatory drilling. A second sub-areal zone of higher chargeability was defined on, and west of, the conductor axes and to the south of the east-west dislocation along line 23800N. Again the levels are about +0.5° RPS above background. As with the chargeable region on the north-east quadrant of array 1, the edges of the anomaly are neither sharp nor well defined. This could be due either to a fall-off in chargeable content for scores (if not hundreds) of metres, and/or the depth to source at the edge of the 'chargeable plate' source.

A number of specific axes were defined, and each is briefly commented on below. A number are inferred to be present on the boundary between arrays (A1 to A3) which will require confirmation by smaller detailed arrays. Also, when looking at linear features whose strike length is small (i.e. 200 metres \(\pm\)) with respect to the current dipole (1500 metres), the amplitude of the smaller response will be depressed. Thus these smaller linear features may have greater importance than their small amplitude would suggest.

A1 and A2 ..... An axis of actual and inferred higher internal polarization was defined on the extreme western flank of array LW. This response tends to be confirmed by the data on the adjacent array 4E, to the west. However, since the energising cable was east for array 4, and west for array 1, some caution may be required, although closures are implied by the data.
### Table

<table>
<thead>
<tr>
<th>Line</th>
<th>Station</th>
<th>RPS</th>
<th>MMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>25000N</td>
<td>+0.4°</td>
<td>+15%(+)</td>
</tr>
<tr>
<td>A1</td>
<td>24850N</td>
<td>+0.6°</td>
<td>+11%</td>
</tr>
<tr>
<td>A1</td>
<td>24700N</td>
<td>+0.4°</td>
<td>+12%</td>
</tr>
<tr>
<td>A2</td>
<td>24550N**</td>
<td>+0.6°</td>
<td>+12%</td>
</tr>
<tr>
<td>A2</td>
<td>24400N</td>
<td>+0.7°</td>
<td>+12%</td>
</tr>
</tbody>
</table>

* above background  
** best response

Overall the zone is complex and clearly associated with more resistive rocks. Thus the source is either disseminated in origin or may even be semi-massive but highly silicified (so effectively rendering the body 'geophysically' disseminated). This latter case is the signature of MV type deposits observed over known deposits in this environment. The depth to source is difficult to gauge, but the current sources are as great as 200 metres. Further work would be required to clarify this.

A3 ..... At 4670E on 23950N and 24100N (on the overlap of four arrays), a zone is implied which is about +0.5° above background. Little material change in the accompanying resistivity indicates the source to be disseminated, while the inferred centre of current depth is 150 metres(+). Again detailed work would be required to confirm this response.

A4 and A5 ..... Two small lenticular, essentially single line RPS anomalies, each of about +0.4° to +0.5° above background, were defined at 4600E and 4750E
on lines 23650N and 23500N respectively. Although the amplitudes are small, the limited strike length may enhance their interest. Again (unfortunately) detailing will be required to clarify the location and form.

A6 and A7 ..... These two responses, each about +0.4° above background, and each in excess of 200 metres in strike length, are best seen on line 23800N centred at 5150E and 5350E. Their form suggests a west dip and a current centre of about 150 metres. The most westerly is definitely associated with a marked resistor axis, while the easterly zone lies on a transition between resistive (west) and conductive (east) rocks. These sources lie some 400 metres to 600 metres east of the conductive zones in the central section of the area.
CONCLUSIONS

A - WITH RESPECT TO DATA

1. Large areas of anomalous internal polarization have been located in the north-east and south-west of the area. This anomaly is of the same form as that expected from HVC type mineralisation at depth.

2. A series of type A and type B responses have been defined, the form of which is akin to MV type deposits. Further detailing work will be required to confirm this.

B - WITH RESPECT TO EQUIPMENT

3. Large current dipoles of 2 kilometres to 3 kilometres rather than the 1500 metre dipoles used in this survey would be desirable. This would require a TSQ-4 (10 kilowatt) transmitter.

4. The conditions during the survey were very dry, and thus some transmitter efficiency was lost, particularly in sandy areas. It is recommended that work be carried out as close to the end of the wet as possible, to maximise transmitter power.

C - WITH RESPECT TO PEGGING

5. It is recommended that as many as four peggers be employed to peg out grids ahead of the reading crew. The area, while reasonable for RRMIP surveys, will require pegging and cutting, and this (the least cost section of the work) will
be rather more costly than the average surveys in the Kalgoorlie region.

On balance I would favour pegging under supervision and direction of the
gophysical party chief, rather than pegging well ahead of the survey operations.

D - FROM A GEOLOGICAL STANDPOINT

6 While the anomalies defined in the test surveys are of the MV and NV type,
it would seem advantageous to the project to survey at least five to ten
arrays further north along the Willieray fault, and in the Hunter Creek area,
prior to decisions being take as to specific drilling sites. This would enable
a better selection of targets to be made, and certainly a better feel for the
area to be acquired.

In summary, the work to date has shown that the RRMIP is capable of making good
progress in the region. As the form of the targets is known, the geology prospective
and the area now familiar, work this coming year should be efficiently carried out.

Respectfully submitted on behalf of:

SCINTEX PTY. LTD.

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Geophysicist
APPENDIX

DATA ACQUISITION AND PRESENTATION
DATA ACQUISITION AND PRESENTATION

Data Recorded:-

The following parameters were recorded:

- \( H_p \), the incident magnetic field due to the current flow in the current dipole
- \( RPS \), the magnetic induced polarization effect at each station by reference to the Relative Phase Shift of the primary and third harmonic.
- \( PFE \), the magnetic induced polarization effect by reference to the Percent Frequency Effect observed from the relative amplitudes of the first and third harmonics.
- The offsets for \( RPS \) and \( PFE \) for each array.
- The energising current \( (I) \) and the frequency of energisation.

Data Processing:-

The data has been computed and the following parameters have been calculated for each station.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMR</td>
<td>Magnetometric resistivity</td>
</tr>
<tr>
<td>( H_N )</td>
<td>Normalised horizontal magnetic field</td>
</tr>
<tr>
<td>( H_u )</td>
<td>Geometric factor</td>
</tr>
<tr>
<td>RPS</td>
<td>Relative phase shift (in °)</td>
</tr>
<tr>
<td>PFE</td>
<td>Percent frequency effect (in %)</td>
</tr>
<tr>
<td>HSQ/I</td>
<td>Secondary field (derived from RPS)</td>
</tr>
<tr>
<td>HSP/I</td>
<td>Secondary field (derived from PFE)</td>
</tr>
<tr>
<td>PFE/RPS</td>
<td>Ratio, an indication of the presence of coupling.</td>
</tr>
</tbody>
</table>
Data Presentation:

The data has been displayed in table form with the selected parameters of MMR, RPS and HSQ/I being shown in computer printergraph format by array.

In addition MMR and RPS have been contoured and presented at the scale of 1:2500, and an interpretation plan has been compiled from these parameters.

The MMR and RPS plates show the array number. The centres of the arrays are shown with a circle, while the suffix after the array number denotes the position of the electrode wire with respect to the array. The size of the current dipole is given in hundreds of metres by the figure below the array number.
APPENDIX

BRIEF DESCRIPTION OF METHOD AND MEANING OF PARAMETERS
SCINTREX

METHOD

A brief and simple description of the method is given below for those unfamiliar with the basic principles behind the Rapid Reconnaissance Magnetic Induced Polarization (RRMIP) method. However, it is strongly recommended that the enclosed appendix be studied in detail for a more complete description of the method, and for those who are to make a geophysical assessment of the data, it is recommended that the papers referred to in the appendix be read also. The references therein give the current major papers dealing with MMR and MIP methods by various authors.

There are two significant electrical properties of rocks and ore bodies which are of great assistance in identifying zones of potential economic interest. The first is resistivity. This can be described as the resistance of a rock to the passage of electric current through it. Obviously those sections which are less resistive will allow greater quantities of current to flow than those which are more resistive. Massive sulphides zones, fault zones, zones of deeper and more intense oxidation and graphite horizons, are examples of units which will allow greater quantities of current to pass. In RRMIP, the measurement of resistivity is made with a very sensitive horizontal field magnetometer. This senses the volume of current flowing in the section below by virtue of the fact that current is simply the number of electrons flowing, and each of these electrons carries a magnetic field with it as it moves. Thus the magnetic field observed by the magnetometer is proportional to the current flowing through the volume of overburden and rock below the sensor. This measurement is called Magnetometric Resistivity (MMR). Positive values define areas of relative conductors, and
negative values areas which are relatively resistive. This property can be used as a method for tracing rocks having different resistivities beneath conductive overburden, as well as to define specific conductors which may of themselves be of potential economic interest.

The second and more significant property is known as induced polarization. This phenomenon involves the storage of some of the electrical energy at the grain boundaries of sulphide (or graphite) grains, and the water contained between grain boundaries in rocks and ore bodies. If a pulsed current is used, the sulphide (or graphite) zones will charge during periods of current flow, and discharge during periods when the current ceases to flow. It is this discharge of stored energy which is the induced polarization effect, and the magnetic sensor is sufficiently sensitive to define these minute magnetic fields. The magnetic induced polarization effects are measured in terms of Relative Phase Shift (RPS). Positive values denote internal polarization from within sulphides or graphite, while negative values generally denote the discharge of the polarization effect external to the source.

The reason for a magnetic sensor being used rather than simple electrical contact with the surface of the ground is that the conductive surface areas effectively mask the major changes in resistivity (XMR) beneath the conductive surface layer, and invariably either completely short out the induced polarization effect, or render it unrecognisable against background noise. The current is injected into the ground through current electrodes placed from 1 to 3 kilometres apart. These large current electrodes enable current to penetrate the weathering into the fresh rocks below that hold the sulphides which are the subject of our exploration search.
MIP Sensor

Magnetic field due to current flow

Current

EIP potential dipole

Current

Disseminated chargeable source

Sum of magnetic field due to whole current flow below

Primary Equipotential surface

Primary current path

Primary magnetic field

Primary current path

Fig. 1
EIP & MIP
DISCHARGE OF INDUCED POLARIZATION

MIP Sensor

Sum of internal and external fields

EIP potential dipole

Dissociated chargeable source

Magnetic field due to external polarization (Hx)

Magnetic field (Hx-) due to internal polarization

Internal polarization

External polarization

Secondary equipotential surface

Fig 2
THE PHYSICAL MEANING OF RRMIP PARAMETERS

A summary of the main characteristics of each of the features highlighted in the interpretation map follow in order that the reader can fully appreciate the geological implications of the data.

Conductor Axes

These represent the axes of the MMR conductor. To be significant they must have (i) a significant cross-sectional area conductivity contrast with the immediate enclosing rocks, and (ii) a significant strike length with respect to the current dipole used to energise the array. A diminution of either (i) or (ii) with respect to background resistivity of the rocks, or current dipole respectively, will result in a diminution of the observed response.

One further consideration with respect to the magnitude of the response is that should the current dipole be 'small' and the conductivity width of the overburden 'great', then a diminution of response will occur also. (For details see MIP appendix, page 12, fig 7.)

One major point to bear in mind is that horizontal layering will not be observed on the MMR, while lateral changes will be emphasised.

Resistor Axes

These represent the axes of the significant MMR resistors, which in turn represent the area of the most resistive rock units. All the remarks above for conductors apply also to the resistor axes.
Contacts

Where significant gradients are observed in the MMR data, a line has been drawn along the inflexion point (or approximately so, allowing for various 'local' distortions). This line will, for vertical dipping bodies show the approximate location, and certainly the strike length of major rock type changes.

Dislocations

These are located on the interpretation maps to emphasise a significant along strike discontinuity in both MMR and RPS features. They represent faults, flexures in strike direction or perhaps lensing of significant resistors and conductors.

Internal Polarization Axes

These represent above background zones of anomalous internal polarization. They are caused by segregations of sulphides, graphite and more rarely, by serpentine, mafic mineral content and magnetite.

These features can be distorted by electromagnetic coupling, by current channelling particularly when MMR curves show a steep (25° to 30°) angle with the energising current, and by wire effects should the energising frequency be excessive with respect to the conductivity width of the overburden.

On the flanks of arrays, the precise location of the axes may not necessarily be mapped, but can be inferred. In such cases additional limited detail work is required. Where this is done, the axes can be identified.
Significance of the Three HRMIP Parameters, MMR, RPS and HSQ/I

As discussed elsewhere, the positive MMR values denote the relative bulk conductors, while the negative values denote relative bulk resistors. The positive RPS values emphasise internal polarization within low current density areas, while positive HSQ/I values emphasise internal polarization within high current density areas.

(Please refer to the papers for further explanation.)
THE PRESENT APPLICATION
OF THE MAGNETIC INDUCED POLARIZATION (MIP) METHOD
IN THE TIME AND FREQUENCY DOMAIN

INTRODUCTION

Since the Magnetic Induced Polarization (MIP) method was introduced into Australia some six years ago, very considerable field experience has been gained. The purpose of these comments is to discuss the application of the method, the form of the responses observed, and how the standard anomaly forms are generated. This is a simple non-mathematical description designed to enable the geologists to visualise just how the energising and induced polarization current's flow in the ground, and how to interpret these in a qualitative sense, for it is the geologist who is far better qualified to interpret this data in a structural context. It is the author's opinion that MIP data is more often simple, simpler and more diagnostic to interpret than EIP or EM data in the conductive conditions which exist over much of Australia's land mass.

The uniqueness of the MIP Method ......

It is essential to grasp the very basic differences between the magnetic mode of acquiring induced polarization data (MIP) and the more conventional electrical mode (EIP). As even geophysicists of some experience have had difficulty in appreciating the full significance of this method, it is necessary to state in simple terms some of the unique attributes of the method.

1. Conventional EIP data monitors ONLY the current flow AT THE SURFACE generated by the storage of charge (IP effect) WITHIN the body. With MIP both the current flow OUTSIDE, but more importantly INSIDE the chargeable
source, are **DIRECTLY MONITORED**. Thus the external (EIP) polarization from mineralisation **NEED NOT NECESSARILY COME TO THE SURFACE** for it to be monitored.

2 - In conventional EIP, the transfer of the induced polarization signal from the source mineralisation to the *surface* involves a considerable loss of energy by "friction" and "chemical reactions" en route, whereas for MIP, as the movements in current *at depth* are monitored *from depth* via their associated magnetic fields, very much less loss of energy is involved. Thus, the fall off in response with distance from a chargeable source is very much less as seen with MIP than that seen with EIP.

3 - With conventional EIP methods, the external induced polarization effect is monitored via two potential electrodes placed some distance apart (commonly 25 to 100 metres), effectively averaging the response over this distance. However, as the MIP sensor is about 60 centimetres in length only, in the MIP method it is essentially a point source measurement which improves resolution very considerably.

4 - Where conventional EIP techniques are applied to highly conductive overburden/oxidation regions, the multi-layering within this zone very considerably reduces or even eliminates the EIP signal en route to the surface. With MIP, both primary and secondary (IP) current flow within this zone has **NO MATERIAL INFLUENCE** on the data. Thus the problems of "masking" are eliminated with MIP.

5 - As the EIP induced polarization signal flows from source to surface, the medium through which it passes not only reduces its amplitude (see 2 above), but also modifies the form of the signal. Thus the decay form observed at the surface will tend to be that of the medium rather than the source. However, as the MIP monitors the magnetic field from the decay *within* the source itself, no such distortion in the *internal* polarization decay form can be expected.

6 - The EIP method is essentially a measurement of absolute levels of apparent resistivity and chargeability as observed at the surface. However, the **MIP**
method measures the relative properties of chargeability and resistivity, and is thus more sensitive to those differences.

7 - In the EIP method, the electric field is often severely distorted by local and often insignificant inhomogeneities in resistivity. However, as the primary (resistivity) and secondary (IP) magnetic field measurements are summed over a large volume of rock, they are not distorted or masked by local inhomogeneities.

A Definition of Terms ..... 

before going into the detailed qualitative discussion of the principles of operation, it is best to define the terms used in the description.

**Energisation:** The process by which current is introduced into the volume of rock which is the subject of the survey. **Primary Current Flow:** The flow of current through this medium as a result of this energisation. **Primary Magnetic Field ($H_p$):** The magnetic field generated by virtue of the primary current flow in the subsurface.

**Induced Polarisation Effect:** The "condenser like" storage of energy on an electronic/electrolytic boundary, for instance on sulphide/electrolyte boundaries. **Internal Polarization:** The induced polarization effect within the body, which is the source of all induced polarization phenomenon, whose discharge is always in the OPPOSITE DIRECTION to the primary current flow which caused it.

**External Polarisation:** The induced polarization effect which flows outside or external to the causative source which is always of the same sign as it is in the same direction as the energising primary current. **Secondary Magnetic Field ($H_s$):** This is the magnetic field caused by the flow of secondary currents within (internal) and outside (external) of the causative source.

**Decay Form ($\Delta M$):** This term describes the decay of the energy stored within the body. It may be more rapid than "normal" or slower than "normal". (A detailed description follows on Page 9).
Comparison of the Electrical and Magnetic Modes of Acquiring Induced Polarization Data

By far the most meaningful way in which to visualise the nature of MIP (and indeed EIP) data, is to consider the energy storage concept and to look at the primary current flow pattern and the resultant equipotential field caused by this energising current, and then the consequent secondary current flow pattern and its associated secondary potential field caused by the decay of the energy stored on electronic/electrolytic contact boundaries, which is known as induced polarization. As this is most easily visualised in the time domain, this description is confined to that domain.

Energisation Process ..... Normally current is applied to the volume to be sampled by means of two electrodes placed semi-parallel to the expected strike of the target mineralisation. In the diagram shown in Figure 1, the fine solid lines represent the current flow pattern so generated. The dashed faint lines represent the equipotential surfaces (lines in the section).

In the electrical mode, the two potential electrodes (see Figure 1) will measure the resistivity of a volume of material defined by the equipotential surfaces which are always at right angles to the current flow.

Energy Storage Process ..... The material through which the current passes will store some portion of the energy in a way determined by the properties of the storage material. The amount of energy stored will depend on the total area of the sulphides (or graphite etc.) presented to the current, and thus, the greater this surface area with respect to the volume of material, the greater will be the energy stored. Finely disseminated material will store substantially more energy than coarse grained material.

The Discharge of Stored Energy ..... On cessation of the energising current flow, the energy stored by the chargeable source will discharge internally within the source as shown by the solid arrows in Figure 2, and externally around the body in the medium surrounding the source as shown by the solid heavy lines in Figure 2. These currents are respectively known as internal and external current flow. The former is of negative sign as it is in the opposite direction to the original energising current, and the latter is of positive sign as it is in the same
MIP Sensor

Magnetic field due to current flow

Current

EIP potential dipole

Current

Disseminated chargeable source

Primary Equipotential surface

Primary current path

Sum of magnetic field due to whole current flow below

Primary magnetic field

Primary current path

Fig 1
EIP & MIP
Discharge of Induced Polarization

MIP Sensor

Sum of internal and external fields

EIP potential dipole

Magnetic field due to external polarization

Magnetic field due to internal polarization

Internal polarization

Disseminated chargeable source

Secondary equipotential surface

External polarization

Fig 2
direction as the energising current.

In the electrical mode, only the discharge external to the body is investigated. In Figure 2 the thick solid lines show this discharge together with the equipotential surfaces (thick broken lines) which this current imposes. As with the charging process these surfaces must be at right angles to the current lines which impose them. The potential electrodes will therefore measure the stored energy (chargeability) as seen via the secondary equipotential field. It is important to note that (i) this is NOT the same volume as the resistivity measurements and (ii) it is NOT the original IP signal as stored by the body, but a measurement distorted and processed by the environment through which it has passed.

In the magnetic mode a very sensitive magnetometer (Scintrex MFM-3) is used to "sense" the horizontal component of the magnetic field due to the current flow both inside and outside of the source material. This is possible because each electron which flows in the ground carries with it an associated magnetic field. This magnetic field will pass unhindered through the environment and thus both the discharge internally and externally to the source can be monitored on the surface.

The Form of MIP Anomalies ......

In the MIP method, the energising field is normalised with respect to the energising current electrodes. Details of this procedure are given later in this paper. In the description Figures 3 to 6, the magnetic field due to the primary passage of the energising field \( H_\infty \), can be regarded as "relative bulk conductivity" plotted upwards. In those figures, internal polarization (which is negative in sign because it flows in the opposite direction to the energising current), is plotted upwards, while external polarization (which flows in the same direction as the energising current and is therefore positive in sign) is plotted downwards.

The enclosed Figure 3 demonstrates the theoretical form of an MIP anomaly from a source which has no electrical contrast with the enclosing material, but has the property of retaining charge. (In nature such anomalies are in fact observed from the ilmenite fraction within heavy mineral deposits in beach sands.)
THEORETICAL MODEL

CHARGEABLE SOURCE
NO RESISTIVITY CONTRAST

TYPE A

CHARGEABLE SOURCE
RESISTIVE SOURCE

NOTE

+ External current flow into plane of paper

- Internal current flow out of plane of paper

Fig 3
Energisation is along strike, into the plane of the paper. In all figures the current flow direction is represented by arrows, with dots representing current flow out of the plane of the paper, and crosses represent the current flow into the plane of the paper.

In Figure 3, over the source, the magnetometer will "see" a surplus of internal (negative) current flow, while on the flanks of the body, the external (positive) current flow will become predominant. The "head and shoulders" MIP anomaly shown is always seen over all sources. It is the distortions in shape, form and zero level that yield vital information as to conductivity of the source, conductivity of the environment above and about the source, the depth to the source and the nature of the mineralisation in and around the source.

TYPE 'A' (Figure 3) ..... shows the typical anomaly form over a chargeable source which is more resistive than the surrounding medium. In such cases the normal "head and shoulders" anomalies coincident with a depression in the $H_N$ are observed. An example of such an anomaly form is chalcopyrite/pyrite in quartz veins itself within a more resistive conductive rock unit.

TYPE 'B' (Figure 4) ..... In this case the chargeable source has no resistive contact with the enclosing material. This example is very similar to the theoretical model. An example of such an anomaly form would be over disseminated sulphides within a homogeneous rock unit.

TYPE 'C' (Figure 4) ..... In this case the source of the chargeable material is itself more conductive than the enclosing rock type. When the observed $H_N$ values are less than 180% - 200%, a normal "head and shoulders" anomaly is observed over the source. In practice, observed $H_N$ values rarely exceed 150% of normal.

TYPE 'D' (Figure 5) ..... In this most important anomaly form which invariably is associated with massive sulphides which are both conductive and electrically continuous, a massive sulphide must be surrounded by a disseminated halo within more resistive host rocks. In this case the disseminated sulphides will naturally store the induced polarization charge far more efficiently than the massive electrically continuous core. Thus, on completion of the energisation process.
TYPE B
CHARGEABLE SOURCE
HOMOGENEOUS

TYPE C
CHARGEABLE SOURCE
CONDUCTIVE

NOTE:
+ External current flow into plane of paper
• Internal current flow out of plane of paper

Fig 4
the charge stored within the disseminated halo will preferentially discharge through the conductive massive sulphide core. This effect has NEVER been observed where $H_N$ values have been less than 160% of normal. This anomaly form due to its high $H_N$ and coincident predominantly external (positive) current flow, is diagnostic when observed. An example of such a response is the Mt. Windarra pyrrhotite/nickel/copper deposits in Western Australia.

**TYPE 'E' (Figure 5) ....** A distorted MIP response curve is generated when a polarizable body is located on a contact between rocks of quite different resistivities. This is rather common in Western Australian nickel deposits. In such a case the return polarization current flow will be concentrated in the more highly conductive rock type instead of being symmetrically distributed on both sides of the body. The resultant MIP response is an asymmetric curve, with its internal (negative) maximum lying on the more resistive side of the body and the external (positive) current peak lying on the more conductive side. Sometimes the asymmetry is so large that the "crossover" is almost directly over the polarizable body. The $H_N$ peak is shifted over the conductive rock side of the polarizable body.

**Composite Anomalies .....**

As can readily be appreciated, the above examples 'A' to 'E', represent single simple bodies. In the field, more often than not, the sources vary in composition and therefore in chargeability and resistivity across strike, along strike and down dip. For example, while the form of Type 'C' and Type 'D' anomalies are very different in appearance, the geological situation which gives rise to them requires relatively little change in conductivity to materially change their form from 'C' to 'D'.

In the interpretation of MIP therefore, the electrical characteristics of known 'Type Deposits' similar to those being sought, together with local information as to the possible range of structure in the area, is of primary importance. In other words, geological input is often of greater importance than quantitative geophysical data.
SCINTREX

TYPICAL M.I.P. ANOMALY FORMS

TYPE D
CHARGEABLE SOURCE
VERY CONDUCTIVE WITH
DISSEMINATED HALO

TYPE E
CHARGEABLE SOURCE
ON CONTACT BETWEEN
TWO ROCK TYPES OF
DIFFERING RESISTANCE

NOTE
+ External current flow
  into plane of paper
- Internal current flow
  out of plane of paper

Fig 5
The Alternative Way of Acquiring MIP Data ......

The initial work in Australia was carried out in the Time Domain, and the chargeability was measured in terms of milligamma/gamma. In the Frequency Domain, a single operating frequency of either, 3, 1, 0.3 or 0.1 Hz with a frequency stability of better than 0.01% is transmitted. The induced polarization effect is then measured in terms of the first and third harmonic of the fundamental frequency in Relative Phase Shift (RPS) which to the first approximation is free of electromagnetic coupling effects, or as Percent Frequency Effect (PFE).

The relationship between these modes of measurement of the induced polarization phenomenon in the magnetic induced polarization method is as follows:-

<table>
<thead>
<tr>
<th>Domain</th>
<th>Time</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>IPR-8 (or 10)</td>
<td>IPRF-2</td>
</tr>
<tr>
<td>Units</td>
<td>milligamma/gamma</td>
<td>Degrees(°)</td>
</tr>
<tr>
<td>equivalence</td>
<td>10 milligamma/gamma</td>
<td>1.5°</td>
</tr>
</tbody>
</table>

It is important to note that in common with the electrical mode of measurement, the induced polarization effect will be identical regardless of the way in which the measurement is made, providing always that (i) the frequencies of energisation and (ii) the geometry of the energising current electrodes and sensor remain the same with respect to the body.

The Polarity of EIP and MIP Anomalies ......

The polarity of the three ways in which the induced polarization effect can be measured varies, depending on which mode (magnetic or electric) or which domain (Time or Frequency) we are operating in. The table below sets out the differences in detail.
### Mode of Measurement

<table>
<thead>
<tr>
<th>Domain</th>
<th>Parameter</th>
<th>EIP: External Polarization Dominating over Body</th>
<th>MIP: Internal Polarization Dominating over Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Chargeability</td>
<td>positive</td>
<td>negative</td>
</tr>
<tr>
<td>Frequency</td>
<td>Relative Phase Shift (RPS)</td>
<td>negative</td>
<td>positive</td>
</tr>
<tr>
<td>Frequency</td>
<td>Percent Frequency Effect (PFE)</td>
<td>positive</td>
<td>negative</td>
</tr>
</tbody>
</table>

* For Type 'A', 'B' and 'C' anomalies only

"Noise" and its influence on MIP Data ......

The "noise" in magnetic induced polarization data is essentially relatively minor variations in the earth's magnetic field which decreases in amplitude as the equator is approached. In the Time Domain where the IP Phenomenon is summed over a relatively long period, the influence of a "noisy" magnetic field is maximum. In the Frequency Domain, the time required to acquire a single reading is very considerably less, hence the noise component is also less.

The following table derived from field experience shows the primary magnetic field (Hp) required in order to take a meaningful measurement of the induced polarization effect for the time and frequency domain.

For time domain these are:

- Hp 6 gamma (plus)  Accuracy of M Reading: +0.2 milligamma/gamma
- Hp  4 gamma          +0.4 milligamma/gamma
- Hp  2 gamma (minus)  an educated guess!

For frequency domain (at 3Hz)

- Hp 1 gamma (plus)    Accuracy of PFE and RPS: +0.05% or +0.05°
- Hp 0.6 gamma         +0.10% or +0.10°
- Hp 0.4 gamma (minus) an educated guess!

Note: for lower frequencies, higher Hp is required.
The Importance of Decay Curve Information......

Considering the time domain first, fine grained mineralisation absorbs the charge rapidly, and once the passage of the energising current is stopped, the stored charge is rapidly discharged. If the mineralisation is effectively coarse grained (i.e. either coarse grained as such, or agglomerates of finer grain), the charging and consequent discharging will be much slower. Only with MIP is the actual decay within the source monitored, therefore major differences in decay characteristics can be observed. Figure 6 shows how this is accomplished using the IPR-8 time domain receiver. In sketch (A), DF represents the energising pulse, while the rapid decay form is due to fine grained material discharge, and the slow decay form is due to coarse grained mineralisation. You will note from the figure that the rapid decay form has a greater amplitude to start with. This is due to the fact that as the IP effect depends on the total surface area of the sulphides present, the disseminated material per sulphide volume present will give a greater IP effect.

Normally three "slices" are measured which are shown in Figure 6 as \( M_1, M_2 \) and \( M_3 \). The red decay form included in Figure 6A is the 'normal' or 'average' decay form usually observed over normal rocks. The IPR-8 processes the data by dividing this normal decay into each of the slices \( M_1, M_2 \) and \( M_3 \). This is done so that any deviation from 'normal' is readily apparent. Figure 6B displays the result of this processing of data. The rapid decay form (e.g. fine grained disseminated) will result in \( M_1 > M_3 > M_5 \), while the slow decay form (e.g. coarse grained massive, but not necessarily electrically continuous) will result in \( M_1 < M_3 < M_5 \).

The \( \Delta M \) parameter is a shorthand display of the decay form: \( \Delta M = |M_3| - |M_1| \). Thus, when this quantity is positive it implies coarse grain size, and when negative implies fine grain size for a given mineral.

Where a substantial range in chargeability is recorded in an area, it is necessary to normalise the decay factor \( \Delta M \) by the amplitude of the chargeability. This is done by dividing \( \Delta M \) by \( M_3 \) and multiplying the factor by 100%.

The normalised decay form \( \Delta M_n \) is:

\[
\Delta M_n = \frac{|M_3| - |M_1|}{M_3} \times 100\%
\]

and displays the variation in decay form from 'normal' in percent.
(A) DECAY AS OBSERVED BY IPR-8 MIP RECEIVER PRIOR TO PROCESSING

EP (energising pulse)

rapid decay (fine grained source)

M1 M3 M5

normal' decay

slow decay (coarse grained materials)

(B) DECAY AS OBSERVED BY IPR-8 MIP RECEIVER AFTER NORMALISATION FOR A "NORMAL" DECAY FORM

EP

rapid decay (fine grained) M1 > M3 > M5

"normal" M1 = M3 = M5

slow decay (coarse grained) M1 < M3 = M5

Fig 6
This decay form can be seen by varying frequency domain measurements over a wide frequency. For a slow decay form, MIP data acquired at a lower frequency will be relatively larger in amplitude than that acquired at higher frequencies, while conversely for fast decay forms the MIP will be emphasised by higher energising frequencies.

Electromagnetic Coupling ......

In common with electrical induced polarization magnetic induced polarization can be subject to electromagnetic coupling. In the time domain this can readily be identified by abnormal distortions in the decay curve, a typical example would be where:

\[ M_1 \ll M_3 \approx M_5 \]

In the frequency domain the magnetic induced polarization effect is read in both RPS and PFE. The former is free of electromagnetic coupling to a first approximation, while the latter is not. Therefore an observation of the variation of the RPS and PFE from their theoretical relationship of \(18^\circ \text{PFE} + 1.6^\circ \text{RPS} \) can warn of the presence of EH coupling.

The Influence of the Size of the Current Dipole ......

The current dipole is normally placed parallel to the expected strike of the mineralisation. This array will couple best to lenticular bodies with depth extent and with a strike extent of about one-third the size of the current dipole or larger. Therefore, to maximise the "focus" of the current dipole for "small" bodies, small current dipoles should be employed. From an operational point of view the current dipole is normally about three to five times the expected length of the target ore body.

A more important influence on the determination of the current dipole size is the depth and intensity of oxidation. The deeper and/or the more intense the oxidation, the larger the current dipole must be to get a significant proportion of the current to penetrate the freshrock target volume.

Current Penetration into Freshrock Through Conductive Overburden ......

The MIP method was developed for conductive overburden situations we encountered
in the Kalgoorlie nickel belt in the late 1960's. As we saw the problem then, there were two quite separate problems. The first was to energise the volume of rock that the geologist wished to search and the second was to obtain at the surface a meaningful signal which did indeed represent the electrical characteristics of the underlying freshrocks and ore zones.

Basically the first part of the problem was capable of solution even in the late 1960's. Electrodes down holes and/or large generators with large current dipoles were (and are) capable of deep energisation. Nigel Edwards in his paper with Howell in Geophysics Vol. 41-6A page 1172 demonstrates this point well in Figure 3 reproduced below.

![Diagram](image)

Fig. 3. The function $f(a)$ which determines the percentage of current remaining in conductive, thin surface layer above a resistive half-space.

The vertical axis represents the percentage of the current remaining in the overburden, while the horizontal axis represents $f(a)$.

\[ \alpha = 2S\rho_2/L \]

Where $S$ is the conductivity thickness product of the overburden and $\rho_2$ the resistivity of the freshrock and $L$ the current dipole. This can be rewritten as $\alpha = 2\rho_2/\rho_1 \times d/L$ where $\rho_1$ and $\rho_2$ are the resistivities of the overburden/oxidation and freshrock respectively, and $d$ and $L$ are the depth of oxidation and the currents dipole respectively. For ease of field use it can be recast as a series of curves for different ratios of $\rho_1/\rho_2$ to show percentage current penetration of the freshrocks for the various ratios of $d/L$ (Figure 7).

In practice electrical soundings will yield diagnostic information as to the bulk resistivity ($\rho_1$) and thickness ($d$) of the weathered zone. As the resistivities of rock types are known and can be reasonably estimated for any area if drill hole information is not available, $\rho_2$ can be reasonably estimated. As an example, take an area where the overburden/oxidation has a bulk resistivity ($\rho_1$) of 50 ohm-metres, and a depth ($d$) of 25 metres over bedrock ($\rho_2$) known to average 2000 ohm-metres. Thus $\rho_2$ will equal about 40 $\rho_1$, therefore for 40% of the current generated to penetrate the bedrock the current dipole is required to be 50 times
the depth of oxidation of 25 metres, i.e. \(25 \times 50 = 1250\) metres. (Figure 7)

Data Processing and Presentation ..... 

For large scale reconnaissance surveys carried out in the frequency domain (known as rapid reconnaissance magnetic induced polarization - RRMIP), the data is processed by computer and presented in terms of RPS, PTE, MMR, \(H_N\), HSQ/I and HSP/I, some of which are presented as line printer graphs (usually RPS, MMR and HSQ/I). For ease of interpretation and for structural information, RPS and MRF are normally also contoured, generally at the scale of 1:2500.

In the time domain, the chargeability, \(M\), together with \(H_S\) and \(H_N\) are usually hand plotted. The generally smaller size of the current dipoles (500 ±100 metres) precludes a meaningful contour presentation in most cases. Again, a scale of 1:2500 is favoured.

Field Procedures ..... 

Most (but not all) fieldwork to date has been carried out using gradient arrays as shown in Figure 8. In practice the current dipole \(L\) is laid parallel to strike and varies up to 500 metres for time domain surveys and 3000 metres in the case of frequency domain (RRMIP) surveys. From each gradient set-up a block some 0.6 kilometres in strike length by about 0.4 kilometres in width can be surveyed. The line interval depends on the minimum strike length of the target zone, while the reading intervals along lines are normally about 25 to 50 metres.

In the time domain some 40 to 60 stations can be read per operator in good conditions while the figure in the frequency domain is about 100 to 120 per operator per day. Normally two operators are used.

From a practical point of view, as MMR/MIP is a magnetic field method, it necessarily depends on strong current flow. Thus the method works best in areas which are conductive rather than those which are highly resistive. Areas where MIP/MMR appears to have been particularly useful are Kalgoorlie, Western Australia, western New South Wales, north-west Queensland and northern Australia, always in areas of conductive overburden.

\* See page 15
Edwards Array ..... 

Edwards has developed a multi-source MMR/MIP sounding array designated the Edwards array (Edwards & Howland-Rose, 1979). The array is designed to ascertain the depth to source and depth to the centre of current flow for infinite slabs, and are used to follow-up in detail significant features located on reconnaissance surveys.

The configuration of the array is shown in Figure 9. The main features are (i) an infinite current electrode $C_2$ placed along strike, (ii) close electrodes $C_1^1$ to $C_1^N$ placed at distances $y$ along strike, (iii) the MFM-3 sensor is placed at various stations along $x$. For each location the Hp and RPS readings are taken for each current electrode separation $C_1^N$ to $C_2$. The data is then computed and plotted either as profiles or as pseudosections as shown in Figure 9. In this figure each data point is plotted in the pseudosection with the horizontal distance $x$ along the survey line against $y$ the distance of the close current electrodes $C_1^N$ from the survey line $X$. It must be emphasised that the Edwards multi-source array is a very recent development, the first field data having been acquired in late 1979 over Elura (Howland-Rose, 1980).

As yet there are few computer models and those available (Edwards & Howland-Rose, 1979) are for tabular infinite bodies. Therefore the comments must necessarily be descriptive. The significant factors are considered to be the relative values of interior and exterior polarization, for should induced polarization be uniform, no anomalism will be observed. Similarly should the resistivity be uniform, the expected MMR will be zero. Variations in resistivity alone will not produce an MIP response (Howland-Rose et al, 1980, p.41). The MIP method will be sensitive only to lateral inhomogeneities (Howland-Rose et al, 1980, p.40) which, in most circumstances where steep dipping rocks occur is the significant factor.

Units and Parameters ..... 

A - Measurements of relative resistivity of the earth for gradient array:

The MIP sensor senses the horizontal magnetic field due to the passage of the primary current in the ground. Unlike ELP resistivity data, it sums all current to depth by virtue of its magnetic field. The field at any point in the survey area (Hp), must be adjusted for the position of the current dipole. The formula for the calculation of the normal ($H_{Norm}$) field at any point is:-
\[ H_{\text{Norm}} = 100 \left( \frac{y + l}{x^2 + (y + l)^2} - \frac{y - l}{x^2 + (y - l)^2} \right) \]

Where \( l \) is current in amps, \( y \) is distance from the centre line and, \( x \) is the distance from centre line joining the electrodes, and \( 2l \) is the distance between electrodes.

\( H_N \), the normalised horizontal field is given by the expression:

\[ H_N = \frac{H_p \times 100\%}{H_{\text{Norm}}} \]

\( H_p \) is expressed in percent variation from normal, normally being either a homogeneous underlying resistivity or any complex horizontal layering. Normal will be 100%.

\( \text{MNR} \), the magnetometric resistivity is given by the expression:

\[ \text{MNR} = \frac{H_p - (H_N \times l)}{400} \times 100\% \]

\( \text{MNR} \) is expressed in percent variation from normal, 0 being normal. This parameter will tend to emphasise conductivities in regions of high current density.

\( B \) - Measurements of Relative resistivity of the earth for a multi-source (Edwards) array:

\[ B_{\sigma} (\%) = \frac{B^\sigma - B^D}{B^m} \times 100\% \]

Where \( B^\sigma = B^m - B^D \)

and \( B^D = \frac{1001 y_1}{(x^2 + y_1^2)} - \frac{1001 y_2}{(x^2 + y_2^2)} \)

\( y_1 \) = distance of station from \( C_1 \) parallel to \( Y \) axis, \( y_2 \) = distance to \( C_2 \) parallel to \( Y \) axis, \( x \) = distance from centre line, \( B^\sigma \) = anomalous field, \( B^m = \) measured
field and $B^F = n_{\text{mag}}$ field (see Figure 9)

**C - Measurements of the Induced Polarization Effect**

In the time domain chargeability ($M$) is measured in terms of milligamma/gamma.

In the frequency domain two independent measurements of chargeability are taken.

(i) **RPS, Relative Phase Shift**, is given by the expression:

$$\text{RPS} = \frac{\theta_F}{\theta_{3F}}$$

where $\theta_F$ and $\theta_{3F}$ are the phase shifts of the fundamental and third harmonic of the transmitted square wave.

(ii) **PFE, Percent Frequency Effect**, is given by the expression:

$$\text{PFE} = \frac{A_F - 3A_3}{3A_3} \times 100\%$$

where $A_1$ and $A_3$ are amplitudes of the fundamental and third harmonic of the transmitted square wave.

**D - Derived Parameters**

In areas of large variations in current density due to conductivity inhomogeneities, or close to electrodes it is more meaningful to present the secondary current magnetic fields due to polarization effects. These derived parameters will emphasize induced polarization effects in areas of high current density whereas the original induced polarization data in terms of $M$, PFE or RPS will emphasize induced polarization effects in areas of low current density.

It should be noted that by examining the induced polarization phenomenon in terms of chargeability ($M$, RPS or PFE) and by means of the secondary magnetic field, we can observe induced polarization effects from both high and low current density areas.

In the time domain the secondary field is calculated as follows:
Field setup

Pseudosection plotting format

plotting point

Fig. 9

MULTI-SOURCE (EDWARDS) ARRAY
where I is the current in amps, and H is the chargeability of the i-th slice of the decay curve.

In the frequency domain these secondary fields are termed:

(i) Quadrature change $HSQ/I$

$$HSQ/I = \frac{H_p}{I} \sin \theta \times 1000, \quad (\theta = \frac{RPS}{2})$$

(ii) In-phase change $\Delta HSP/I$

$$HSP/I = \frac{H_p}{I} \times \frac{PTE}{100} \times 1000$$

Both $HSQ/I$ and $\Delta HSP/I$ are expressed in milligamma/amp of primary current strength.

Final Comment ..... 

The above remarks briefly outline the present procedures in the execution, computation and interpretation of Magnetic Induced Polarization data in the time and frequency domain. It is recommended that the reader should now study the papers listed in the "References" to obtain a more comprehensive understanding of the method.

A.W. HOWLAND-ROSE, MSc, DIC, AMAus IMM, FSIS.
REFERENCES

Magnetic Induced Polarization


Rapid Reconnaissance Magnetic Induced Polarization (RRMIP)


Decay Form


Instrumentation

SEIGEL, H.O., and BRCIC, I., 1976. Frequency domain IP measurement using harmonically related components. Scintrex Applications Brief, 76-1

Scintrex manual on IPR-8 time domain receiver.