CRA EXPLORATION PTY LTD

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GOODPARLA EL 1092, N.T.
PINE CREEK BASIN
ANNUAL REPORT FOR 1981

submitted by: Ian A. Cook
accepted by: W.H. Johnston
date: November 1981
copy to: CRA Limited - Melbourne
N.T. Dept. of Mines & Energy

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APPENDIX I Drill Logs 1981 Drilling

APPENDIX II Rapid Reconnaissance Magnetic Induced Polarisation Test Survey - contractors report
1. SUMMARY
Drilling in the oxide zone of mineralisation at the Namoona prospect failed to intersect economic mineralisation. Infill drilling proved the mineralisation to be poddy.

2. INTRODUCTION
Title to Goodparla EL 1092 was granted to CRA Exploration Pty Limited on the 22 December 1976 by the N.T. Administration. Location of EL 1092 is shown on Plan NTd 1543.

Exploration carried out by CRAE within Goodparla EL during the first year of tenure has been described by Wills, 1978 (CRAE Report No.9158) during the second year of tenure; by Ikstrums 1979, (CRAE Report No.9526) during the third year of tenure; by Ikstrums and Steemson 1980, (CRAE Report No.9985) and during the fourth year of tenure by Ikstrums 1981 (CRAE Report No.10509). Exploration in the latter half of 1981 is described in this report.

3. CONCLUSIONS
The 1981 drilling of the Namoona prospect, in the oxide zone, failed to intersect an economic tonnage of secondarily enriched silver ore. Previous drilling in the non oxidised zone also failed to intersect viable tonnages of adequate grade mineralisation.

A rapid reconnaissance magnetic induced polarisation survey was carried out over the Namoona mineralisation during September 1981. The contractors comments are included in Appendix II of this report along with the contractors plans NTd 1769 and NTd 1770. This survey failed to delineate any further mineralisation.
4. 1981 DRILLING

A drilling programme was carried out at the Namoona prospect during the 1981 field season, to test for secondary enriched silver in the oxide zone. Initially a five hole diamond drilling programme was designed for the prospect. Due to poor core recovery in the oxide zone, the drilling technique was altered to drill and ream and then to reverse circulation. Several holes were re-drilled.

Drill holes DD81ND30, DD81ND31, RD81ND34 and RD81ND35 were drilled into the oxide zone of mineralisation above holes 78ND3 and 78ND9 (10200N) (see Plan No.NTd 853). RD81ND34 was a re-drill of DD81ND30 and RD81ND35 was a re-drill of DD81ND31.

Drill holes RD81ND32, RD81ND33 and RD81ND36 were drilled into the oxide zone of mineralisation above diamond drill hole 78ND1 (10400N), (see Plan No.NTd 851). RD81ND36 was a re-drill of RD81ND33, which was abandoned due to drilling difficulties.

Drill hole RD81ND37 (10300N) was an infill hole to test the strike uniformity of the mineralisation. This showed the poddy nature of the mineralisation, (see Plan No.NTd 1771).

Detailed drill logs with assay results are given in Appendix I. Summary logs of the 1981 drill holes are given below.

4.1. Summary Logs

DD81ND30 intersected the target zone at 15 metres R.L.

A summary log is:-

0 - 6m  Orange red and tan clays with vein quartz
6 - 18m Well laminated shales, oxidised, some remnant vein quartz
18 - 21m Rhyolite
21 - 24m Gossanous rhyolite tuff
24 - 26m Gossanous shales
26 - 28m Red brown ferruginous shales
E.O.H.

DD81ND31 intersected the target zone at the 30 metre R.L.

A summary log is:
0 - 23.4 m Highly weathered shales quartz veining common
23.4 - 26.7 m Gossanous limonitic shales with vein quartz
26.7 - 28.1 m Rhyolite
28.1 - 29.8 m Shale with vein quartz
29.8 - 30.8 m Gossan with pyromorphite
30.8 - 34.7 m Gossanous shale with abundant quartz veining
34.7 - 42.75m Weathered yellow brown shales with occasional hemimorphite veining
42.75 - 44.5 m Fresh black shale
E.O.H.

RD81ND32 drilled on section 10.400 N intersected the lode at 13 m R.L.

A summary log is:-
0 - 11.2m Oxidised shales with vein quartz
11.2 - 12.4m Rhyolite
12.4 - 23.0m Shales gossanous/ferruginous
23.0 - 29.6m Shales ferruginous
E.O.H.

RD81ND33 drilled on the same section intersected lode material at 22 m and 24 m R.L.'s

A summary log is:-
0 - 23 m Oxidised shale with quartz veining
23 - 28 m Gossanous shales
28 - 30 m  Rhyolite
30 - 33.5 m  Gossanous shales
30.5 - 34.0 m  Rhyolite

E.O.H.

RD81ND34 is a re-drill of ND30 on section 10,200N intersected the lode at 15 m R.L.

A summary log is:-

0 - 14 m  Weathered shale with minor quartz veins
14 - 17 m  Rhyolite
17 - 28.5 m  Gossanous shales with relict sulphide on bedding planes. Limonite and zinc oxides common

28.5 - 29.0 m  Black shale

E.O.H.

RD81ND35 drilled by reverse circulation intersected the lode at 22 m R.L. on section 10200N.

A summary log is:-

0 - 26.7 m  Weathered shales with vein quartz becoming gossanous below 23 m.
26.7 - 28.1 m  Rhyolite
28.1 - 42.75 m  Gossanous shale with secondary lead quartz and limonite veining
42.75 - 43.5 m  Black shale

E.O.H.

RD81ND36 was drilled by reverse circulation on section 10.400 and intersected the lode at 20 m R.L.

A summary log is:-

0 - 28.3 m  Weathered shales with gossanous limonite quartz veining increasing below 21 m
28.3 - 31.5 m  Rhyolite
31.5 - 33.6 m  Gossanous shale
33.6 - 34.5 m  Rhyolite with some secondary lead minerals
34.5 - 42.5 m  Gossanous shale with secondary Pb and Zn minerals.

42.5 - 43.5  Fresh black shale.

E.O.H.

RD81ND37 drilled on section 10.300N intersected the lode at 20 m R.L.

A summary log is:

0 - 21.7 m  Weathered shale with vein quartz
21.7 - 23 m  Rhyolite
23 - 24 m  Weathered shale
24 - 37 m  Highly gossanous shale
38 - 40 m  Black shale

E.O.H.

4.2. Drilling Results

Drilling of the oxide zone showed the grades of Ag, Pb and Zn to be variable and generally sub-economic.

The significant assays of these holes are listed below:

DD81ND30
21-26 m (5m)  2.25% Pb, 22ppm Ag

DD81ND31
29.8 - 30.8 (1m)  2.43% Pb, 245ppm Ag
32.4 - 34.0 (1.6m)  8.0% Pb, 34ppm Ag

RD81ND32
10-14m (4m)  3.5% Pb, 147ppm Ag
17-19m (2m)  9.6% Pb, 97ppm Ag

RD81ND33
25-29m (4m)  2.28% Pb, 136ppm Ag
33-34m (1m)  1.56% Pb, 150ppm Ag
RD81ND34
13-15.5m (2.5m) 5.6% Pb, 142ppm Ag
21.5 - 24.5m (4.5m) 1.73% Pb, 139ppm Ag

RD81ND35
29-32m (3m) 2.10% Pb, 135ppm Ag

RD81ND36
36.5-37.5m (1m) 2.26% Pb, 57ppm Ag

RD81ND37
29-30m (1m) 1.62% Pb, 107ppm Ag

4.3. Drilling
Initially the diamond drilling technique was to be employed at the Namoona prospect. Ground conditions, however made good core recovery difficult and this method was abandoned after drilling DD81ND31. RD81ND32 and RD81ND33 were drilled by rock roller with casing being advanced behind the drill bit to prevent contamination. Although this method gave excellent samples it was slow and the depth of drilling was inhibited by the shear strength of the casing. Finally the reverse circulation technique was employed and holes RD81ND34, RD81ND35, RD81ND36 and RD81ND37 were drilled in this way.

4.4. Discussion
All previous holes drilled in this part of the Goodparla EL have intersected the zone of interest in the sulphide zone. These holes have been reported in previous annual reports. Assays ranged in value between 1.3% Pb, 503ppm Ag (78ND1 3.2m width) 1.2% Pb 75ppm Ag (78ND9 3.2m width) and 79ND25 which was barren. These holes showed the poddy nature of the mineralisation in the sulphide zone.
The 1981 drilling was based upon the premise that some enrichment, of the zone of mineralisation, may have occurred in the oxide zone, and a small open cut situation may have been viable. See Plan No. NTd 1723 for plan and long section. The holes drilled showed the silver mineralisation in particular to be poddy, variable in grade and narrow in width. The lead and zinc mineralisation tended to have a more constant grade, but well below economic extraction levels.

I.A. COOK
5. REFERENCES

1). Wills, K.J. 1978
   Annual Reports. Moline EL 1091, Goodparla EL 1092, Frances Creek EL 1093, George Creek EL 1094, Pine Creek Basin N.T. CRAE Report No.9158

2). Wills, K.J. 1979

3). Ikstrums, J.P. 1979

4). Ikstrums, J.P. 1980

5). Ikstrums, J.P. 1981

6. KEYWORDS

Lead, zinc, silver, drill-diamond, drill-rotary, drill-reverse circulation.

7. LOCATION

Mt Evelyn SD53-5 1:250 000 Geological map sheet

8. LIST OF PLANS

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DRILL LOGS
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For 29.5 m
Survey 29 m, 59°-044', mag.
No logged for natural gamma.
**DRILL CORE**

**Sample No.**

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<td>Qrtz, molybdenite, milky, quartz crystal</td>
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<td>Bleached reddish white shale, finely laminated</td>
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<td>Shale, finely laminated, gaseous appearance</td>
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<td>Lithology essentially unknown, some</td>
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<td>No recovery, Change of red color, indicated lithology change at 1230 metres, possibly gabbro</td>
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**SPECIAL FEATURES**

- **DEATH, ALTERATION, MINERALIZATION**
- **ELECTRICITY**
- **MINERALIZATION**

**SUMMARY**

- **Gabbro, molybdenite, yellow.**
- **Shale, weathered**
- **Bleached, reddish, cream, clay laminites**

**SPECIAL COMMENTS**

- **Emerald-grade, red breccia.**
- **Rhyolite, cream colored, fine grained.**

**logged by:** Tim Coak

**DATE:** 16/11/2001

**SHEET 1 OF 1**
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**Summary:**
- Varies in color from brown to bleached white to yellow in a random manner.
- Colour intervals observed.
- Variously colored, extremely weathered shales.

**Special Features:**
- Colour varies from brown to bleached white to yellow in a random manner.
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**Special Comments:**
- Hole capped 33m
- HG casing sheared whilst reaming
- 9m of casing plus shoe bit abandoned in hole
- Hole logged for gamma (natural) - indicated rhyolite at 28-30m and 33-35m.
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Notes:
- Shale
- Rhyolite
- Mineralised shales
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**SPECIAL FEATURES**

- Weather, Alteration, Fracturing
- Veins, Mineralization

- **Sample**
  - No.
  - From (m)
  - To (m)
  - Rec (m)

- **ASSAY VALUES**
  - Pb
  - Zn
  - Ag
  - Cu

- **NOTES**
  - Core description includes various geological features such as shales, rhyolite, and quartz veins.
  - Special comments indicate drilling and capping procedures.

---

**SUMMARY**

- Shales with various shades of brown, grey, and black.
- Rhyolite 28.3-31.5 m.
- Assay values provide a range of metallic concentrations.

**LOGGED BY**

- Ken Cook

**DATE**

- 29/1/1981

---

**PROJECT**

- Namoono - Goodpasture F.L.

**HOLE No.**

- RD81ND3

**DEPT**

- 43.5 m
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| 29-40 |             |           |              |                  |                  | 41         | 17       | 40     | 45     | 40.9, 8.6, 4.9, 2.3 |

**SPECIAL COMMENTS:**
- Shale, fine-grained, finely laminated, slightly gassanous in parts, 39-40: Shale, black, carbonaceous, poor grade.

**SUMMARY AND SPECIAL COMMENTS:**
- Shale, fine-grained, finely laminated, slightly gassanous, 21-7-23: Rhyolite, 22-34: Shale, moderately yellow to pale brown, greyish, occasional pale white bands, highly gassanous from 24 to 37 metres.
Topography Approximate

RD81ND37
10300N, 2663E
Azimuth 046 mag
Inclination 60°

Level of Oxidation

Mineralised Unit

EOH 40m

29-30m
1.52% Pb
107 ppm Ag

C.R.A. EXPLORATION PTY LIMITED
NAMOONA PROSPECT N.T.
DRILL SECTION RD81ND37

Reference S053-5
Geologist TAC Scale 1:200
Report No. 10965
Drawn SRJ SEA Date Nov 1981
Prop No. NTd1777
RAPID RECOONNAISSANCE MAGNETIC INDUCED POLARISATION TEST SURVEY - CONTRACTORS REPORT
COMMENTS ON

A RAPID RECONNAISSANCE

MAGNETIC INDUCED POLARIZATION TEST SURVEY

OVER THE NAMOONA PROSPECT

NEAR GOODPARLA STATION, NORTHERN TERRITORY

ON BEHALF OF

C.R.A. EXPLORATION PTY. LIMITED

IN ASSOCIATION WITH

TECHNOMIN AUSTRALIA N.L.
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A RAPID RECONNAISSANCE
MAGNETIC INDUCED POLARIZATION TEST SURVEY
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BY

A.W. HOWLAND-ROSE
MSC, DIC, AUSIMM, FGS,
GEOPHYSICIST

SYDNEY, N.S.W.          OCTOBER, 1981
                           NT - 030R
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Appendix 'MIP'

Contour Plans for MMR and RPS for all arrays and HSQ/1 for arrays 1 and 5
SUMMARY

An RRMIP test survey over the Namoona prospect in the Northern Territory on behalf of C.R.A. Exploration Pty. Limited has yielded some fascinating, if ambiguous results. While the section of the grid bordered by 10200N-10500N and 2600E to 2800E is certainly anomalous having high relative internal polarization, the detailed comparisons between test arrays leads to inconsistent conclusions. A broad north south conductor having a multiple source and low conductivity contrast was recorded through this anomaly and has slightly lower conduction in the vicinity of the higher polarization. This might indicate that the causative sulphides (or graphite?) may have been accompanied by solution which locally increases the resistivity of the enclosing rocks.
INTRODUCTION

A short test survey was carried out over the Namoona prospect as part of a series of RRMIP test surveys carried out for C.R.A. Exploration Pty. Limited by Scintrex Pty. Ltd. on authorisation from Technomin Australia N.L.

The field work, consisting of 3 double operator days, took place between 8th and 11th September, 1981, and was carried out by Mr. P. Brown, B.Sc., and Mr. P. Rogers, B.Sc. Crew and vehicles were provided by C.R.A.

A record of the work is appended to this report.
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 sulphide 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 (MMR) 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.
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 harmonics.
- 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 (\( 1 \)Hz)

In addition, a total magnetic field survey (uncontrolled) was also carried out.

Data Processing:-

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

- MMR Magnetometric Resistivity
- \( H_N \) Normalised horizontal magnetic field
- \( H_u \) Geometric factor
- RPS Relative Phase Shift (in °)
- PFE Percent Frequency Effect (in %)
- HSQ/I Secondary field (derived from RPS)
- HSP/I Secondary field (derived from PFE)
- PFE/RPS ratio, an indication of the presence of coupling.
Data Presentation:-

The data has been displayed in table form with the selected parameters of MMR, RPS and HSQ/1 being shown in computer printergraph format by array.

In addition, the parameters of MMR and RPS have been contoured and presented at the scale of 1:2500. HSQ/1 is contoured for arrays 1 and 5 at the same scale. RPS is printed in red, MMR in blue and HSQ/1 in black.

The array prefix M, R or H refers to the data being MMR, RPS or HSQ/1 respectively, while the suffix W or E denotes the current loop lies to the west or east respectively. The figure below the array number depicts the array size in hundreds of metres, while the circle denotes the array centre. In the case of array 4, the current line is drawn in as the electrodes were incorrectly positioned at an angle*. (This data is wholly suspect, but presented for completeness.)

* Unfortunately CRA field personnel connected the electrodes incorrectly and the error was not discovered until array completed.
DISCUSSION OF RESULTS

The geology and type of deposit are unknown to the author, as are the results of any testing carried out on the results of a time domain magnetic induced polarization survey carried out in June, 1978 and discussed in Scintrex report NT-021 dated July, 1978 by the author.

The present programme was designed by C.R.A., and unfortunately due to absence overseas, no input was possible from the author.

Each of the five arrays surveyed is discussed in order of descending current dipole size.

Array 5E Electrodes at 9500N and 11100N on 2700E
Current: 2.7 amps Frequency 1Hz

The MMR data shows a simple pattern with a broad bulk conductor having a width of about 240 metres trending about grid north south through the survey grid. Most lines show evidence that the broad conductor consists of a multiple source, for example, on line 10400N three discrete (minor) maxima are seen at 2680E, 2760E and 2840E. Between lines 10300N and 10400N the inferred resistance of the underlying broad conductor is slightly less than to the north and south, however, this minor change would not normally be considered significant.

The RPS data is in sharp contrast to the MMR in that a complex pattern emerges. Finally, the whole area has a relatively high internal polarization (anomalous)
level of about +4.00° RPS. The PFE/RPS ratio does not imply significant
coupling to be present, and no wire effect is observed, therefore it would
appear that this high background must represent a high chargeability background
overall in the rocks underlying this array.

Unfortunately the survey lines are not sufficiently close to allow a detailed
interline correlation, but what is clear is that between and on lines 10300N
and 10400N, a significant increase in internal polarization was noted. Approximately
above +5.00° RPS could be considered to be the anomalous section, and this
approximately coincides with the slightly reduced level within the broad
multiple conductor which trends grid north south through the area.

The most significant anomaly occurs on line 10300N and broadly correlates with
the conductor axis. The best manifestation is +5.60° centred at 2640E, with
a secondary maximum at or east of 2800E. These two anomalies lie either side
of the axis of the bulk conductor. This data does not allow any depth to
source estimate.

HSQ/I was also contoured. This data shows greater anomalism of about 17
milligamma/amp between about line 10500N and line 10200N centred along an
axis at about 2650E with the suggestion of a second axis at 2775E on line
10300N.

Array 1E     Electrodes at 9800N and 10800N on 2700E
              Current 3.6 amps  Frequency 1Hz

The MMR data shows a very similar pattern to that observed with the 1.6 kilometre
array, the axis being at 2700E+ on all lines.
The RPS data on the other hand is a complex picture. While lines 10300N and 10400N are more internally polarized than the lines to the south, so too is 10500N. Also, the pattern of this polarization in detail bears little resemblance to that seen on the 1.6 kilometre array. It is difficult to explain this in terms of array focus alone, although this may be so on the northern line 10600N.

The HSQ/1 contour plan shows greater levels for HSQ/1 above line 10200N and continues across line 10600N. The axis is at about 2700E. As would be expected HSQ/1 from arrays 1 and 5 are compatible.

**Array 2E**

**Electrodes at 10000N and 10600N on 2700E**

Current 2.9 amp, Frequency 1Hz

The MMR data over the three lines surveyed shows a simpler pattern with a conductor trending just west of grid north south. The maxima of about +30% MMR was seen at 2720E on 10200N, 20700E on 10300N and at 2660E on 10400N. The amplitude is somewhat reduced from the 50%+ seen on previous arrays, presumably due to overburden dilution.

The RPS data again shows a higher than normal background, this time +1.00° RPS (+). The anomalous responses here occur on the eastern flanks of the lines with a maximum being inferred at about 2900E. As low amplitude internal polarization responses were recorded on line 10300N at 2800E and 2880E(#5E), this data would imply a west dip to that source, and would imply a 50 to 60 metre maximum depth to the source. The anomalies seen, however, are small with respect to background, while the data is insufficient to gauge their merit.
Array 3E  Electrodes at 10800N and 9800N on 2900E

Current 3.1 amps  Frequency 1Hz

In this experiment the current electrode was displaced some 200 metres east of that used on the 1000 metres array (1E). For the three lines surveyed this has had the effect of shifting the low amplitude broad conductor eastwards by 100 metres to about 2800E. The amplitude is considerably reduced from +50% plus on the array centred at 2700E to 35% (+) on this array. (A shift in current axis for a shift in current dipole as observed here is most unusual and has not been observed elsewhere where the experiment has been carried out.)

The RPS data shows a high background of about +2.00°, while generally higher values were recorded west of 2700E of up to +0.80° above background and lower values by 0.50° to the east thereof. An internal polarization axis of about +0.80° above background trending about grid 025° was recorded from about 2625E on 10300N to about 2660E on 10400N. While this feature tends to confirm the presence of the anomaly located on the 1.6 kilometre array at this point, the displacement in maxima could imply an east dip to the source. A similar but low amplitude anomaly was inferred at about this location on array 2E also, however, no specific local anomaly was recorded on 1E at this point, although the section was anomalous as such.

Array 4E  Electrodes at 2500E/10800N and 2900E/9800N

This array was incorrectly placed due to a fieldhand's error, but is presented for completeness.

The MMR data shows results quite inconsistent with all other data, in part
perhaps due to the angle of the sensor to the direction of the current dipole (i.e. 22°)

The RPS data is also suspect, however, this shows the central section from 2600E to 2700E to be of greater internal polarization than to the east or west. This agrees with the results seen on arrays 5, 3 and particularly 2, but not 1.

No further comment on this array is warranted.
CONCLUSIONS

1. While the MMR data is for the most part consistent between arrays, the RPS data is, quite frankly, not understood by the author.

2. The most convincing data is the data from the 1.6 kilometre array which shows an internal polarization anomaly of significant contrast to be present at about 2650E on 10300N. Each of the other arrays tends to confirm various aspects of this data, but never is a wholly consistent picture seen.

3. The change in form observed on change of current dipole does not form a regular sequence as is normally observed for current dipole changes. Only a complex structure, horizontal layering or cross structures in other areas have been considered to cause some of the features observed.

The author looks forward to being able to study these fascinating results with the geological truth.

Respectfully submitted on behalf of:

SCINTREX PTY LTD.

A.W. HOWLAND-ROSE, MSc, DIC, AUSIMM, FGS.

GEOPHYSICIST
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 currents 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 than not, 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 these 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 Polarization 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 Polarisation 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
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EIP & MIP ENERGIZATION

Magnetic field due to current flow

Disseminated chargeable source

Primary Equipotential surface

Primary current path

Primary magnetic field

Sum of magnetic field due to whole current flow below

EIP potential dipole

Current

Fig. 1
SCINTREX

EIP & MIP
DISCHARGE OF INDUCED POLARIZATION

MIP Sensor

Sum of internal and external fields

EIP potential dipole

Disseminated chargeable source

Magnetic field due to internal polarization ($H_a$)

Internal polarization

Magnetic field due to external polarization ($H_s$)

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 $H_N$, can be regarded as "relative bulk conductivity" plotted upwards. In these 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,
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TYPICAL M.I.P. ANOMALY FORMS

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 180% 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 (RFS) 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 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>IPR-8 (or 10)</td>
<td>IPRF-2</td>
</tr>
<tr>
<td>Units equivalence</td>
<td>milligamma/gamma</td>
<td>degrees(°)</td>
</tr>
<tr>
<td></td>
<td>15 milligamma/gamma</td>
<td>1.6°</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:

- \( H_p \) 6 gamma (plus) \( \pm 0.2 \text{ milligamma/gamma} \)
- 4 gamma \( \pm 0.4 \text{ milligamma/gamma} \)
- 2 gamma (minus) an educated guess!

For frequency domain (at 3Hz)

- \( H_p \) 1 gamma (plus) \( \pm 0.05\% \) or \( \pm 0.05^\circ \)
- 0.6 gamma \( \pm 0.10\% \) or \( \pm 0.10^\circ \)
- 0.4 gamma (minus) an educated guess!

Note: for lower frequencies, higher \( H_p \) 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), EP 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 M₁, M₃ and M₅. 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 M₁, M₃ and M₅. 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 M₁ > M₃ > M₅, while the slow decay form (e.g. coarse grained massive, but not necessarily electrically continuous) will result in M₁ < M₃ < M₅.

The ΔM parameter is a shorthand display of the decay form: \( \Delta M = |M₅| - |M₁| \).
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 ΔM by the amplitude of the chargeability. This is done by dividing ΔM by M₃ and multiplying the factor by 100%.

The normalised decay form \( \Delta Mₐ% = \frac{|M₅| - |M₁|}{M₃} \times 100\% \)
and displays the variation in decay form from 'normal' in percent.
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**VEHICLE(S) Supplied By Client:**
Supplied by Client. (Delete if SPL supplied)

**METHOD:** ARZIP (Test)

**SURVEY LOCATION:** Coonamble Station (Warronga)

**FIELD ADDRESS:** Somewhere in NJ

**CLIENT:** CRA.

**CREWLEADER:** Pete Brown

**OFFICE DATE** | **OP. 1 TPSX** | **OP. 2 TPSX** | **TYPE OF WORK (ARRAY, LINE SECTIONS, ETC.)** | **No. of Obs'ns** | **Profile Length** | **Vehicle and KM** | **EQUIPMENT** | **OK u/s** |
--- | --- | --- | --- | --- | --- | --- | --- | --- |
**SUN** | 6TH |  |  |  |  |  |  |  |
**MON.** | 7TH |  |  |  |  |  |  |  |
**TUES** | 8TH | 1P; \(1/2 P_2\) |  | 116 | 2400 m |  |  |  |
**WED.** | 9TH | 1P; 1P_2 |  | 185 | 4000 m |  |  |  |
**THUR** | 10TH | 1P; 1P_2 |  | 155 | 2700 m |  |  |  |
**FRI.** | 11TH | \(3/4 P; 4/3 T\) |  | 68 | 1500 m |  |  |  |
**SAT.** | 12TH |  |  |  |  |  |  |  |

**PERSONNEL:**

**FUNCTION:**

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>S M T W T S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pete Brown</td>
<td>Crew Leader</td>
<td>J J J J J J</td>
</tr>
<tr>
<td>Peter Keers</td>
<td>Operator</td>
<td>J J J J J</td>
</tr>
<tr>
<td></td>
<td>Assistant</td>
<td>J J J J J</td>
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</tbody>
</table>

**REMARKS:**

- Two Good Measurements Were Supplied By CRA. More With Two Vehicular, Most of The
- Arrays Were Set Up By Two Assistants. Array No. 4 Was Set Up Incomplete
- All Arrays Taken At P.B. Using Noisy/Coarse Window

Operations: Accounts: Client: Crew Leader:  

Please check (✓) days worked, (x) days not worked
(A) DECAY AS OBSERVED BY IPR-8 M.I.P. RECEIVER PRIOR TO PROCESSING

(E.P. (energising pulse))

rapid decay (fine grained source)

"normal" decay

slow decay (coarse grained material)

M₁ M₃

(B) DECAY AS OBSERVED BY IPR-8 M.I.P. RECEIVER AFTER NORMALISATION FOR A "NORMAL" DECAY FORM

(E.P.)

rapid decay (fine grained) M₁ > M₃ > M₅

"normal" M₁ = M₃ = M₅

slow decay (coarse grained) M₁ > M₃ > M₅

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:

\[ M_3 \ll M_5 \]

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 1%PFE + 1.6%RPS can warn of the presence of EM 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 $f(\alpha)$ which determines the percentage of current remaining in a 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 the $f(\alpha)$. $\alpha = 2\rho_2/L$

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 current 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 × 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, PFE, MMR, H_N, HSQ/I and HSP/I, some of which are presented as line printergraphs (usually RPS, MMR and HSQ/I). For ease of interpretation and for structural information, RPS and MMR 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 (I) is laid parallel to strike and varies up to 600 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
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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 C2 placed along strike, (ii) close electrodes C11 to C1n 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 C1n to C2. 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 z along the survey line against y the distance of the close current electrode C1n 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 EIP 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:-
\[ H_{\text{Norm}} = 100I \left( \frac{y + l}{x^2 + (y + l)^2} - \frac{y - l}{x^2 + (y - l)^2} \right) \]

Where \( I \) 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:

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

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

MMR, the Magnetometric Resistivity is given by the expression:

\[ \text{MMR} = \frac{H_p - (H_u \times I)}{400I \times l} \times 100\% \]

MMR 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:**

\[ \text{MMR (\%)} = \frac{B^a \times 100}{1001} \left( \frac{y_1}{y_2} - 1 \right) \]

Where \( B^a = B^m - B^p \)

and \( B^p = \frac{100y_1}{(x^2 + y_1^2)} - \frac{100y_2}{(x^2 + y_2^2)} \)

\( y_1 = \text{distance of station from } C_1 \text{ parallel to } Y \text{ axis, } y_2 = \text{distance to } C_2 \text{ parallel to } Y \text{ axis, } x = \text{distance from centre line, } B^a = \text{anomalous field, } B^m = \text{measured} \)
field and \( B^p \) = normal 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:-

\[
\text{RPS} = 3\theta_f - \theta_{3f}
\]

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:-

\[
\text{PFE} = \frac{A_1 - 3A_3}{3A_3} \times 100\%
\]

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 **emphasise** induced polarization effects in areas of high current density whereas the original induced polarization data in terms of \( M \), PFE or RPS will **emphasise** induced polarization effects in areas of low current density.

It should be noted that by examining the induced polarization phenomenon in terms of chargeability \((M, \text{RPS or PFE})\) 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:
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C1

45°

C2

L (CURRENT DIPOLE LENGTH)

STRIKE DIRECTION

GRADIENT ARRAY

Fig 8
Field setup

Pseudosection plotting format

\[ \times \] plotting point

Fig. 9

MULTI-SOURCE (EDWARDS) ARRAY
SCINTREX

\[ H_{Si} = \frac{H_p}{I} \times M_i \times 100 \text{ (milligamma/amp)} \]

where \( I \) is the current in amps, and \( M \) 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 \( AHSP/I \)

\[ AHSP/I = \frac{H_p}{I} \times \frac{PFE}{100} \times 1000 \]

Both \( HSQ/I \) and \( AHSP/I \) 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, AM Aus IMM, FGS.
SCINTEX

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.