

SCINTREX

OPEN FILE

A REPORT ON
 RECONNAISSANCE MAGNETIC INDUCED POLARIZATION SURVEYS
 OVER THE BOCO SIDING AREA
 WITHIN E.L. 17/88, QUE RIVER, TASMANIA
 ON BEHALF OF
 SAMISEN PTY. LTD.

89-3016

MINES	
File Ref.	EL17/88
27 SEP 1989	
Doc. Ref.	
Action Officer	Initials
LETTER	
25. 9. '89	
REFERS	
Resubmit to	Date

MICROFILMED

SCINTREX

PRIVATE AND CONFIDENTIAL

A REPORT ON
RECONNAISSANCE MAGNETIC INDUCED POLARIZATION SURVEYS
OVER THE BOCO SIDING AREA
WITHIN E.L. 17/88, QUE RIVER, TASMANIA
ON BEHALF OF
SAMISEN PTY. LTD.

BY

A.W. HOWLAND-ROSE
MSc, DIC, FIMM, FAusIMM, FAIG, FGS, CEng.
GEOPHYSICIST

SYDNEY, N.S.W.

MAY, 1989
TAS-125

SCINTREX**CONTENTS**

Summary	
Introduction	Page 1
Aims and Objectives of the Survey	Page 2
Discussion of Results	Page 3
Conclusions and Recommendations	Page 8

Appendices: Extract from Licence Application
RMIP Method

Plates:

- 1 MMR Contour Plan
- 2 RPS Contour Plan
- 3 MMR Contour Plan - Edwards Array - Line 6000N
- 4 RPS Contour Plan - Edwards Array - Line 6000N
- 5 MMR Contour Plan - Edwards Array - Line 5600N
- 6 RPS Contour Plan - Edwards Array - Line 5600N
- 7 Interpretation Plan

*SUMMARY*

An RMIIP survey was carried out over a section of the Boco Siding grid within EL 17/88, Que River on behalf of Samisen Pty. Ltd.

Some seven internal polarization anomalies of note were defined, which are interpreted to be due to polarizable material within sources which show little resistive contrast to the enclosing rocks.

Six of the above anomalies are recommended for one or two gravity lines using the Scintrex electronic self-levelling, microprocessor controlled gravity meter. Those anomalies found to be gravity anomalies will be recommended for testing by drilling.

SCINTREX

Page - one

INTRODUCTION

At the request of Mr. I. Shulman, Chairman of Samisen Pty. Ltd., Scintrex Pty. Ltd. carried out a reconnaissance magnetic induced polarization survey over a section of the Pancontinental grid at Boco Siding over 24 production days between 15th February and 13th March, 1989. The crew consisted of Mr. P. Brown, BSc., geophysicist/party leader, Mr. R. Laver, Mr. P. Eagleton and Mr. M. Evans. Over the section surveyed, the grid had to be rehabilitated, and intermediate (100 metre) lines had to be cut and pegged. Unfortunately, there has been significant tree growth since the original surveys were undertaken in 1977. While a chain saw was used, all possible was done to minimise injury to vegetation.

The author visited the site on 14th April, 1989.

SCINTREX

Page - two

AIMS AND OBJECTIVES OF THE SURVEY

The area of the survey is covered by a variable thickness of fluvo-glacial sediments which are known to be quite conductive. The argument is contained in Appendix 1 (Licence Application Item -7 ppl-6).

The area surveyed was selected on the basis of:

- 1 inferred permissive geology
- 2 relatively easy access

The objectives of the survey were to define polarizable areas both relatively conductive and otherwise, with a view to drilling such targets **providing** they showed a mass surplus.

It is intended to check the anomalies defined using a Scintrex CG-3 microprocessor based electronic self-levelling gravity meter for this purpose as soon as same is available. Only such a meter will be able to take satisfactory readings in the swampy ground at Boco.

SCINTREX

Page - three

DISCUSSION OF RESULTS

Some eight reconnaissance arrays having current dipoles of 1200 - 1400 metres placed along strike were surveyed on the old Pancontinental grid between grid coordinates 4200N and 7100N and between 2600E and 4700E. The areas selected were chosen on a basis of permissive geology, and all things being equal, relatively easy access and minimal requirement for line cutting.

The MMR data displayed on Plate 1, shows a range in values from +100% to -50%, with the majority of axes and boundaries trending approximately grid 340° to 360°.

On the whole, the area appears to be relatively resistive, with the exception of a wedge of higher conductivity in a complex form between 3600E and 3900E on line 4200N, narrowing to 3950E on line 4200N. Within this "wedge", high local conduction to +100% MMR was recorded. This is the only area of truly relatively high conduction recorded in the area surveyed.

In addition to the grid 340° to 360° general trend noted on the major MMR features, a strong suggestion of a north-west south-east (\pm) series of dislocations can be seen. These often (but not always), imply local displacements. Although large areas of "relatively resistive" or "relatively conductive" show general continuity over many hundreds of metres, there are no clear "marker" horizons as such, which could be used to identify structural trends. This, however, would be entirely consistent with the variable nature (both across and along strike) of the underlying volcanic pile.

One feature, a very strong **apparent** resistor, extends from 4600E/6500N to 4500E/5300N. This is in fact due to current flowing in the HEC earth return wire above a high power cable along this "anomaly". This cable has influenced the data for 75 metres either side of the high power line.

SCINTREX

Page - four

The bulk of the RPS data shows a variation within each array of about 1.0° RPS, with the vast majority of events being of limited amplitude, and of very limited strike length.

Zone 1

The only real exception to the above, was a series of higher polarization values extending from line 6200N at 3225E striking and broadening grid south to line 5700N at 3300E ±50 metres. A single feeler line to 3200E on 5400N implies a continuation in that direction. (Note, this anomaly was not further defined by an additional array to the south of 7E due to the requirement for extensive line cutting)

The significant maxima are summarised below:

<u>Array</u>	<u>Line</u>	<u>Station</u>	<u>High/background</u>	<u>Maximum Depth</u>
7/3	6100N	3200E	1.5/0	75 metres (±)
7/3	6000N	3200E±	1.9/0.6	100 metres
7/3	5900N	3250E	1.2/0.5	60 metres

All the above are confirmed to be of interest due to array overlap (arrays 3E and 7E) although **in detail** the responses are different. This difference is due to both geological and instrument "noise" - the latter due to the soft surface.

<u>Array</u>	<u>Line</u>	<u>Station</u>	<u>High/Background</u>	<u>Maximum Depth</u>
1E	5900N	3175E	2.4/0.5	50 metres ?
		3275E	2.1/0.5	40 metres ?
	5800N	3225E	1.5/0.5	50 metres?
		3288E	1.0/0.5	60 metres
	5700N	3250E(?)	1.8/0.65	50 metres+
		3325E	1.5/0.65	50 metres(?)
	5400N	3275E	1.9/0.5	50 metres (?)
		3350E	1.0/0.4	50 metres (?)

SCINTREX

Page - five

The above anomalies are considered valid in spite of a ± 0.2 geological/instrument noise level superimposed thereon (assessed from the spread in readings **and** the variation in the PFE/RPS ratio).

This response is associated with generally resistive rocks ($-40\% \pm$) as against more "average" rocks to the east, i.e. $-20\% (\pm)$.

An Edwards array was carried out on line 6000N between 3100E and 3300E. This confirms the source to be resistive, and relatively chargeable, and, if anything, implies a dip to the east.

Zone 2

To the east of Zone 1, a narrow anomaly of moderate amplitude above background ($+0.8^\circ$ RPS \pm) was recorded for over 500 metres between 3450E/5600N ($+1.2^\circ$ RPS) to 3350E/5900N ($+1.6^\circ$ RPS) and thence to 3325E/6100N. The higher polarization in this zone shows little correlation with any feature on the MMR, and thus a source of disseminated origin within generally resistive rocks is interpreted. The maximum depths to source are not considered to be greater than 50 to 75 metres.

Zone 3

Of the many moderate internal polarization responses of marginal interest, Zone B is worthy of comment. A 1.6° RPS response was defined at 3800E on line 5600N with markedly smaller responses on adjacent lines. The anomaly occurs on a near zero (if "noisy") background, and lies on a resistivity change (i.e. perhaps close to a contact). The maximum depth to the top of the source is guesstimated at 60 metres \pm .

An Edwards Array suggests the source lies close to a conductive/resistive contact, which is inferred to dip east. The RPS data from the Edwards Array is complex and implies a polarizable source east of the 3800E maximum seen on the gradient array data.

SCINTREX

Page - six

Zone 4

A further moderate internal polarization anomaly extends from 3500E/5200N to 3575E/4700N, crossing line 4800N at 3550E where it reaches $+1.7^\circ$ RPS, and line 5100N at 3525E where it reaches $+1.2^\circ$ RPS. The latter two sites are the better responses on the 500 metre strike length of the zone. As with most of the significant responses, the polarization lies within relatively resistive rocks. In this case, the MMR shows slight increases in resistance by about -5% over the already highly resistive background of -45% MMR. The narrow nature of the response again suggests a relatively shallow depth to source, namely, 50 to 65 metres (\pm).

Zone 5

This zone rises to $+1.0^\circ$ RPS against background for about 600 metres between 3425E on line 4700N and 3475E on line 5300N. The best defined section was on line 5100N at 3450E where the maximum depth to source appears to be of the order of 60 metres \pm . A wholly disseminated source is interpreted, as no material changes in the already high resistivities were seen.

Zone 6

A well defined 400 to 500 metres long moderate internal polarization response was defined between 3475E/4900N and 3500E/4500N, with maxima of $+1.4^\circ$ RPS on line 4800N at 3500E and -0.5° ($+0.5$ against background) at 3475E/4600N. As no really significant change in MMR was noted over the strike of this zone, the source must again be disseminated (or electrically discontinuous) polarizable material.

Zone 7

A moderate to weak amplitude zone was recorded discontinuously between 3950E/6500N and 3925E/5300N. Overall, the zone appears to cut across the

SCINTREX

Page - seven

strike of the country as seen from the MMR, however, superimposed thereon, there is often a local reduction in resistivity of about 5%.

SCINTREX

Page - eight

CONCLUSIONS AND RECOMMENDATIONS**Zone 1**

- 1 A significant series of internal polarization responses over an inferred strike length of at least 700 to 900 metres has been defined.
- 2 Distinct maxima to 3 to 4 times the $0.5^\circ \pm$ RPS background have been defined, **but** subject to a geologic and/or instrument noise envelope of $\pm 0.2^\circ$ RPS.
- 3 On three lines the anomaly is confirmed on two adjacent arrays and is not due to wire effect.
- 4 The anomalism is associated with a **resistive** host. A relatively conductive or neutral MMR could normally be expected from a volcanogenic base metal sulphide body.

It is recommended that a series of short gravity lines be run over the anomaly to ascertain the gravity field over this response.

Zone 2

The proposed gravity survey should cross this anomaly on lines 5600N and 5900N, the latter in conjunction with the work on Zone 1.

Zone 3

While the reconnaissance data has shown a significant if moderate single line response (with extensions to 200 metres \pm strike length), the Edwards Array data has not confirmed its interest. This, together with the limited strike length decreases the interest of this response. Nevertheless, a few gravity stations across the anomaly are warranted.

SCINTREX

Page - nine

Zone 4

The source should be further investigated by the proposed gravity survey to ascertain the mass of the source relative to the enclosing rocks. A disseminated **or** electrically discontinuous source is the suggested generator of the observed anomaly.

Zone 5

Again, the essentially disseminated or electrically discontinuous polarization source is worthy of investigation by a gravity traverse.

Zone 6

A single gravity line centred over 3500E/4800N is recommended (to be carried out in conjunction with zone 4 on the same line).

Zone 7

This anomaly is not recommended for further work.

General Conclusions

- 1 In spite of the noise level of up to $\pm 0.2^\circ$ RPS, a number of distinct anomalies of significant strike length have been defined over the limited section of the Boco grid so far surveyed.
- 2 All the responses so far defined, have sources which are inferred to be either disseminated, or, if massive, electrically discontinuous. For the most part, they lie within generally resistive areas and show little contrast with the enclosing rocks. Disseminated pyrite and pyrite/sphalerite/galena are possible sources.

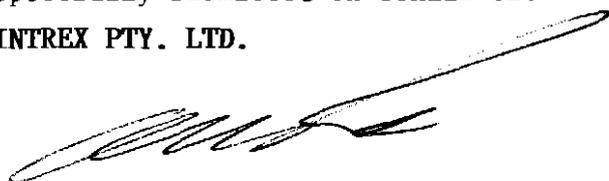
SCINTREX

Page - ten

- 3 It is recommended that Zones 1 to 6 be surveyed over one or two lines on each anomaly with the Scintrex CG-3 electronically self-levelling gravity meter prior to drill target selection, as it is argued that only those zones showing a significant gravity anomaly are capable of being of potential economic interest.

Respectfully submitted on behalf of:

SCINTREX PTY. LTD.



A.W. Howland-Rose, MSc, DIC, FIMM, FAusimm, FAIG, FGS, CEng.

Geophysicist

Summary of Aims, Exploration Philosophy, Exploration Programme

The basic objectives of Samisen Pty. Ltd. in applying for the old Bulgobac Licence 12/72 (less the EZ Pancontinental excision) is to search for, and if successful, develop, ore bodies of the Rosebery-Que River-Hellyer type.

To this end, the company will:

- 1 Engage the services of such consultants and contractors as will achieve this objective. Those presently in mind include Scintrex Pty. Ltd. and Earth Resources Aust. Pty. Ltd.
- 2 Employ the Scintrex RMIP geophysical technique (which was designed specifically for layered conductivity situations), which, after detailing, will be followed by such drilling as will be required to identify the sources of anomalies.
- 3 Emphasis will be given in the first year to the Boco grid with other sections of the exploration licence receiving geological assessment in preparation for geophysical surveys either late in the first year or in the second year period.

As the exploration problem is to meaningfully search beneath the glacial cover, it follows that the initial approach will have to be geophysical. It is argued elsewhere in this application that (i) the main problem is conductive layering within the glacial overburden and (ii) this problem will be solved by the use of the recently upgraded RMIP technique. Those involved in the direction and execution of this programme have extensive experience in its application to areas having far more severe conductive layering problems. The first phase to be carried out as early as weather permits will consist of a comprehensive RMIP survey of the initial area of greatest interest, i.e. the Boco grid.

Should magnetic induced polarization and conductivity anomalies be located, detailing by other relevant geophysical methods will be carried out, followed by drilling to identify those sources.

It is intended that the initial programme outlined above will be carried out as rapidly as weather and equipment availability allow.

Our preliminary studies and advice suggest that emphasis should first be placed on the Boco grid providing that the methods employed are seen to be successful in locating significant sulphides (whether or not they be economic) under the glacials, then the approach will be employed elsewhere within the exploration area.

During our initial period (i.e. first 12 months) geological evaluation and some additional mapping will be carried out in other areas which have received attention in the past, namely, in the Silver Hills and Que River grid areas. This will involve a study of the available airborne and gravity data for the area as a whole.

SCINTREX

ITEM 7 - 2

Providing the weather is kind, it is hoped to carry out RMIP on the Boco grid, and drilling of any significant anomalies located wholly within the first year.

Work in the second year will be dependent upon the results obtained in the first year's work. It is our policy to make an evaluation of the area rapidly and if unsuccessful, to withdraw promptly.

A more detailed argument for the application of the RMIP technique to the licence follows:

Introduction

The author, A.W. Howland-Rose, has been familiar with the area, and particularly the geophysical exploration carried out in the area since 1975. The initial gradient EIP work and all subsequent EIP work, failed to obtain reasonable and consistently reliable data from the rocks beneath the glacial cover. It would appear that UTEM surveys similarly failed (in the limited area covered) to produce significant responses. The author has over the years, retained his keen interest in the special problems of the area, particularly the Boco section, and is now in a position to suggest a meaningful geophysical solution to the difficult problem of obtaining a representative consistent response from the subglacial subcrop.

These notes represent a simplified argument for the use of RMIP as the prime exploration tool. A number of papers are appended which will provide further information on the method and its application.

Nature of the Mineralisation Sought

The mineralisation sought at Bulgobac is the classic Rosebery-Que River-Hellyer exhalative submarine volcanic type. The various intrinsic geophysical characteristics which can be expected from such deposits can be summarised as follows:

1. Pyritic haloes: Polarizable, but not truly conductive with little or no contrast with the enclosing rocks.
2. Cu Pb-Zn pyrite: Polarizable, and depending on the quantity and mode of occurrence of copper (and pyrrhotite if present) can be conductive to the degree that electromagnetic methods are capable of detecting such bodies. Hellyer and the copper rich lode at Que River are such examples.
3. Zn Pb(Cu) pyrite: Induced polarization would be the main signature, with very little resistivity contrast. The zinc rich lode at Que River is a good example.

1 and 3 have similar resistivity, EM and polarization signatures.

As a general rule, even massive pyrite when not associated with pyrrhotite or chalcopyrite is not conductive. However, quite minor quantities (0.5%±) of chalcopyrite (and even less of pyrrhotite) can increase the conductivity by many orders of magnitude. Sphalerite, on the other hand, is not only not conductive, but acts as a "blocking agent", and tends to prevent conduction in an otherwise

conductive mineral assemblage. Overall, galena tends to behave like pyrite, but with greater local conduction.

Nature of the Environment

The induced polarization work carried out over the Boco grid consisted of wide spaced gradient array electrical induced polarization in the time domain, with dipole-dipole electrical induced polarization in both the time and frequency domain.

These surveys clearly demonstrated that:

The area suffered from problems akin to those typical of the Kalgoorlie region, namely, conductive overburden. It is important to completely understand how this problem affects the results of the induced polarization survey. The main points are:

- 1 The use of large energising electrodes will increase the penetration of current into the bedrock, as figure 1 clearly demonstrates. While the enclosed paper entitled The Present Application of the Magnetic Induced Polarization Method explains this in detail on pages 12 and 13, at Boco if we assume the current dipoles for gradient array of 1000 metres and for dipole-dipole of 100 metres and 20 metres, then the amount of current penetrating the subcrop through 50 metres of glacials, assuming the ground has a 20 ohm-metres resistivity and the bedrock a 2000 ohm-metres resistivity is illustrated by the following table:

Dipole (L)	1000 metres	100 metres	20 metres
$l/2$	100	100	100
Glacial depth (d)	50 metres	50 metres	50 metres
L/d	20	2	0.5
percentage of current density in bedrock will be			
	33%(±)	5%	<1%

Thus, to energise the bedrock, large current dipoles are mandatory.

Contrary to subsequent comment on the efficacy of the gradient surveys, the significantly higher resistivities seen on the gradient rather than the dipole-dipole, demonstrate clearly that current penetrated the bedrock. Simply stated, the observed apparent resistivities are higher than the resistivities recorded from the overlying glacials!

- 2 The main problem of obtaining meaningful signal relates to layering within the conductive overburden. By its very nature, the glacial overburden can be expected to consist of fluvo-glacial deposits of various sorts, including varied clays, and glacial material. Essentially, layering can be expected. The real problem is not the energisation discussed in (1) above, but the return signal from the subcrop. Should the glacials above the subcrop be of uniform resistivity even if this is low, then the induced polarization from a source can easily be recorded at surface, as shown in Figure 2. If, however, the layered glacial sequences show alternations of markedly different resistivities, then a "shorting out" will occur which will result in reduced or no signal returning to surface. Thus, while some sections of the area covered by the gradient array will be valid, others will be subject to this "shorting out" or "masking" phenomenon.

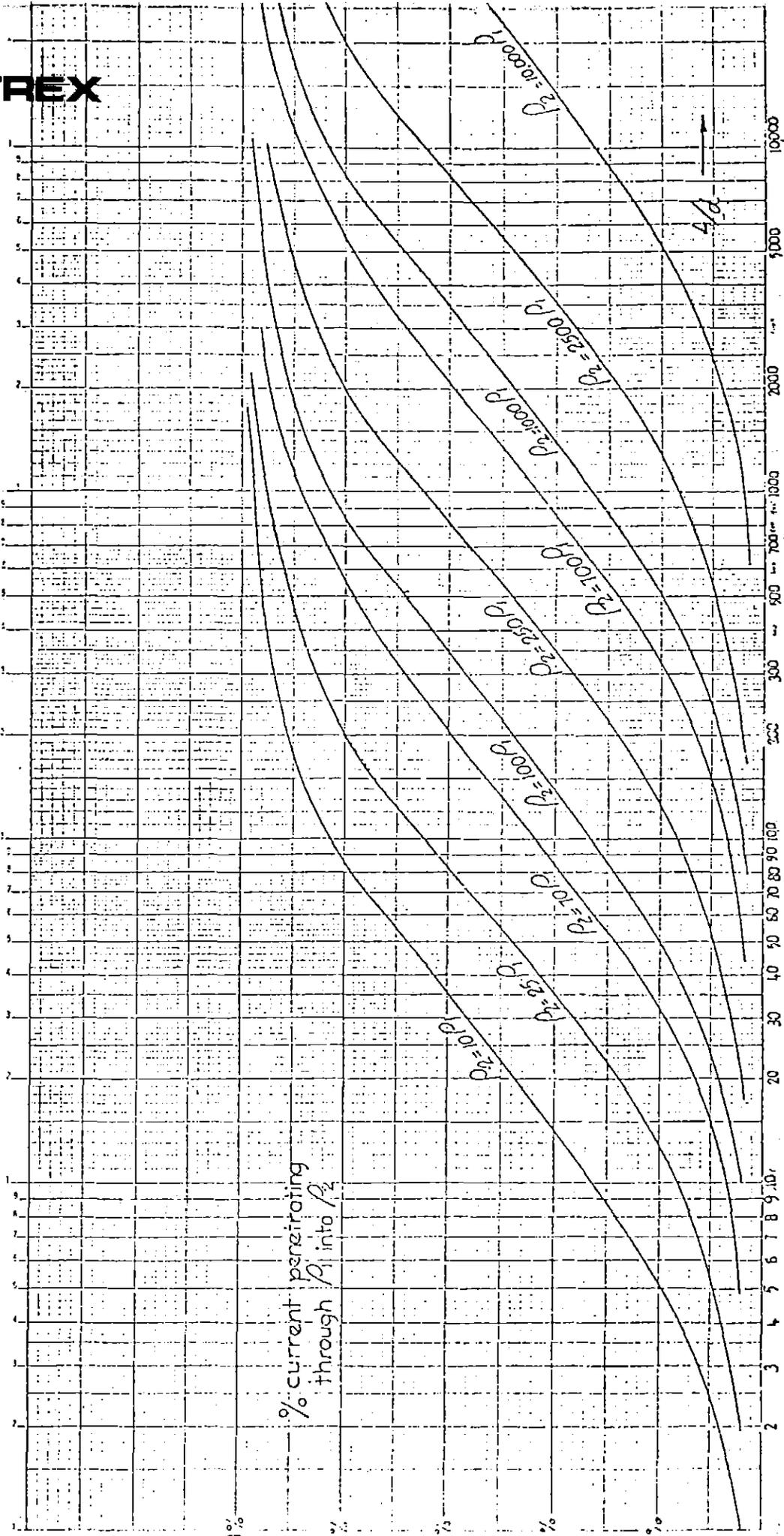
017

SCINTREX

SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490

591018

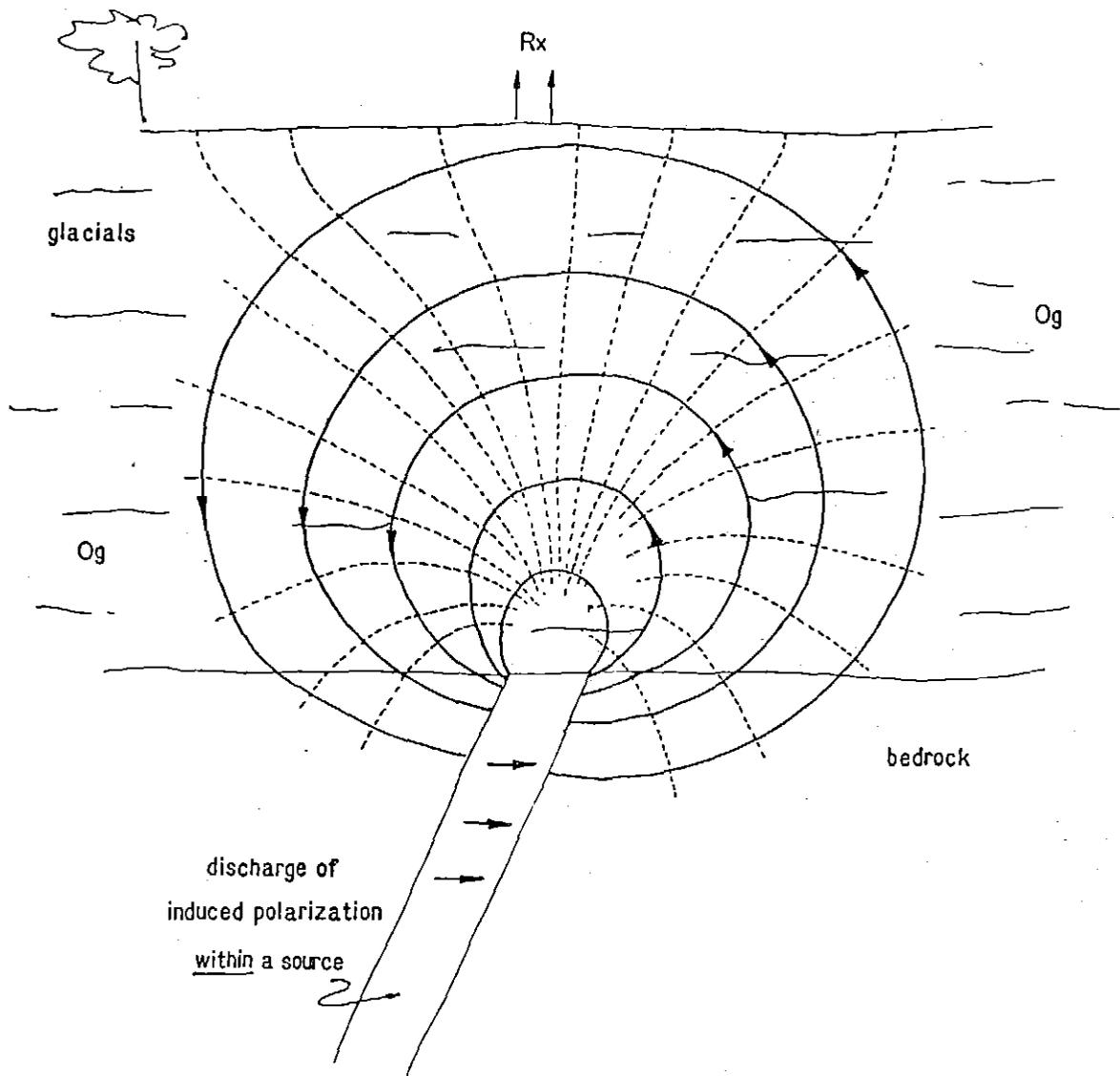
SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490
SCHEMATICALLY 46 3490



% current penetrating through R_1 into R_2

FIG. 1

SCINTREX



Discharge of an induced polarization source under fairly uniform but conductive overburden - the signal is not unduly attenuated

Fig. 2

SCINTREX

ITEM 7 - 4

In the gradient surveys run at Boco, the low polarization over large sections of resistivity data, including high resistivity areas, demonstrate that the signature from the bedrock was subject to a variable degree of attenuation. In the circumstances at Boco this occurred in a number of ways:

(a) By differential masking (Figure 3)

In this case the induced polarization effect in body A discharges into the glacials, but is short circuited in the more conductive clays above. In the case of body B the glacials above are uniform in which case the signal can be picked up at surface. In practice a continuum between case A and B is seen at Boco. Thus the reliability of EIP at Boco must be in serious doubt.

b) By differential subcrop burial (Figure 4)

In this case, assuming no layering within the glacials, the bedrock having intrinsically higher polarization than the glacials (e.g. 15 millivolts/volt against 5± millivolts/volt) the induced polarization profile will reflect the bedrock.

Of course, adding the complexity of differential layering will further complicate the picture at surface.

The Proposed Solution

The first phase will emphasise a geophysical approach and will consist of employing the Rapid Magnetic Induced Polarization (RMIP) method. (Which is essentially magnetic induced polarization executed in the frequency domain. The enclosed papers describe the salient features of this method). This method has the following benefits in the glacial covered areas of the prospect.

- 1 Large current dipoles (1000+ metres) will allow penetration of the bedrock beneath the glacial overburden.
- 2 The resultant primary energising horizontal magnetic field will not be influenced by horizontal layering (see enclosed papers) and will emphasise differences in resistivity of the underlying rock units, especially as the current dipole will be placed along strike
- 3 The secondary (induced polarization) field will be similarly read using the same magnetometer, and since the secondary electrical fields will be received directly via their associated magnetic field, they will be unaffected by masking.

The equipment for the RMIP survey will consist of:

Energisation:

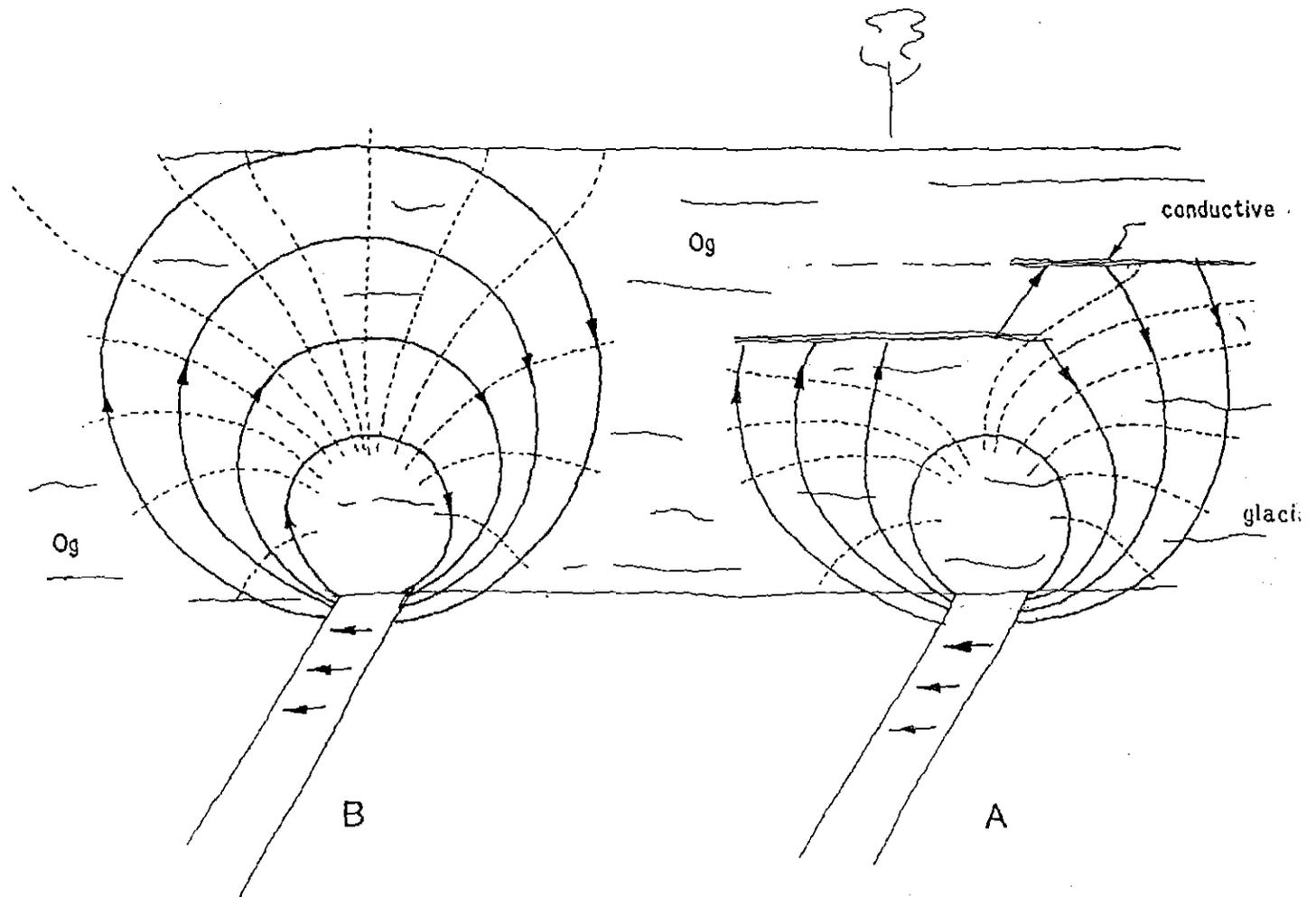
Scintrex TSQ-4 Time/frequency domain transmitter (10Kw) powered by a trailer mounted Volkswagen motor generator.

The transmitter will be crystal controlled by a Scintrex HSC-2 crystal clock.

SCINTREX

(a)

Differential masking



In the case of two identical induced polarization sources,
conductive clays above 'A' will 'short out' the return signal
while in the case of 'B' the signal will not be materially affected

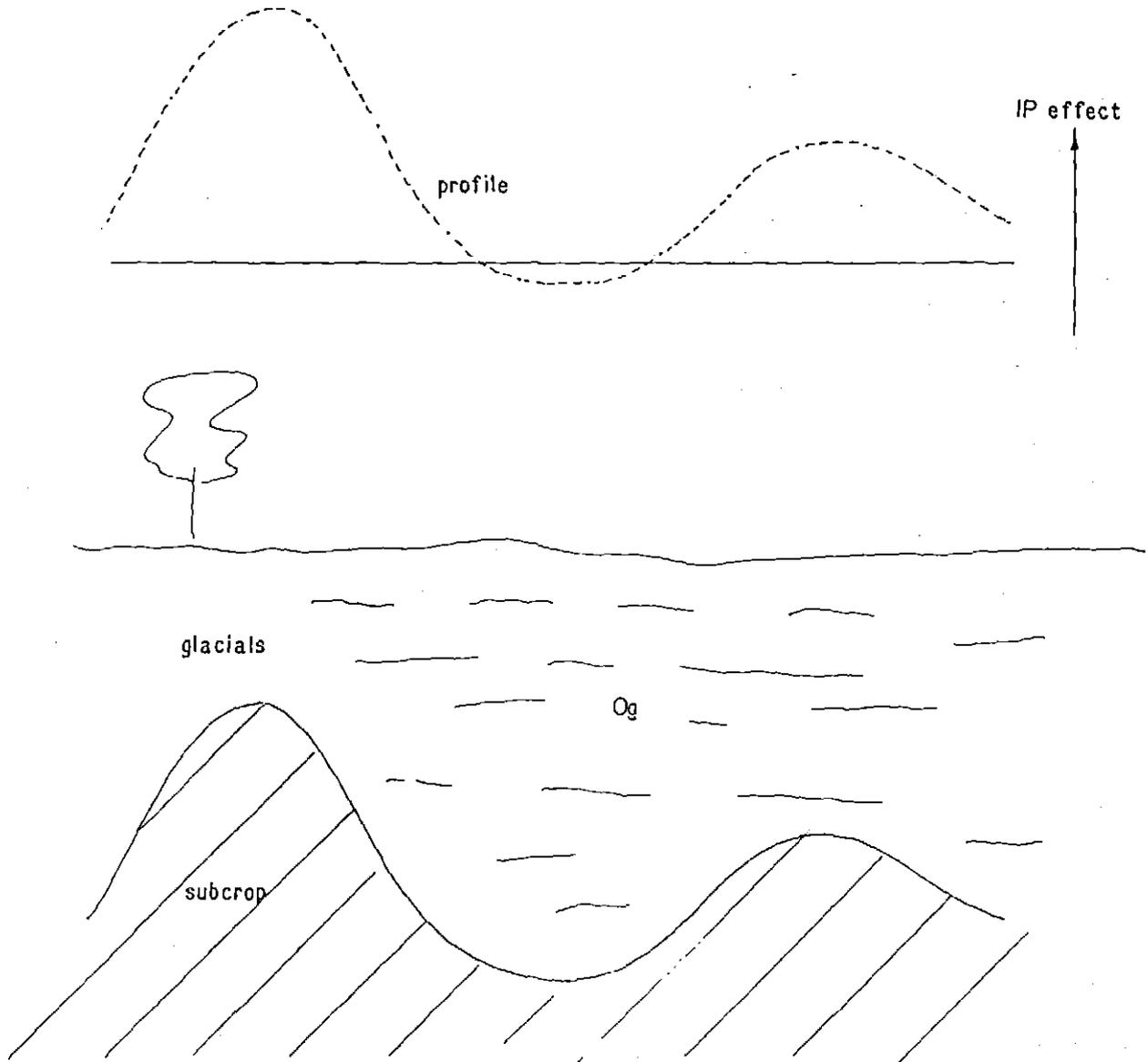
Fig. 3

021

SCINTREX

(b)

By differential subcrop burial



The induced polarization effect will reflect the subcrop where the cover has a fairly uniform (if low) resistivity

Fig. 4

SCINTREX

ITEM 7 - 5

Field Reading:

The sensor will be a Scintrex MFM-3 horizontal field magnetometer connected into a Scintrex IPRF-3/IGS RMIP receiver. (It should be noted that the latter was developed by Scintrex for I. Shulman's then Technomin group.)

Should significant anomalies typical of sulphides be located, these may be detailed as follows:

- a) multi-electrode method known as "Edwards Array" to ascertain source dip, depth and depth extent.
- b) gravity, using the new auto-levelling Scintrex gravity meter CG-3 which in the boggy ground of the grid will allow highly accurate readings due to an electronic levelling system.
- c) Electrical soundings to assist in subcrop depth strata assessment
- d) limited seismic profiling.

The following specification sheets for equipment are enclosed:
TSQ-4, MFM-3, IPRF-3, CG-3.

Budget for the Geophysical Work

RMIP, assuming that the grid to be carried out will consist of about 60 kilometres of line, and assuming that this will take about 50 days to survey (including some additional fill-in lines) a cost estimate of \$50,000 is made.

RMIP and gravity detail,
say 10 days at \$1000/day = \$10,000

Rehabilitation of grid
say \$15,000

Summary: Rehabilitation of grid	\$15,000
RMIP	\$50,000
Detailing	\$10,000
Interpretation, field	
visits, data processing	<u>\$15,000</u>
	\$90,000

Conclusions

- 1 The gradient array carried out at Boco achieved penetration of the glacial cover by the energising current, but was only partially successful in obtaining meaningful data due to layering in the glacials.
- 2 Notwithstanding the above, it is highly significant that drill holes BBP207, BBP208 and BBP209, all picked on gradient array induced polarization anomalies, were the first and most significant drill intersections found on the grid. Target descriptions and intersections made extracted from the EZ report (after Mill, Hanson, 1978) were as follows:

SCINTREX

ITEM 7 - 6

"Target Description:
Designed to test IP gradient anomalies

BBP IP Gradient anomalies

207 XVI 12 millisec. Charg/Resist High
208 III broad charge to 18 m.secs low Res.
209 XIII broad charge to 18 m.secs moderate res.

Results

BBP 207: Siliceous tuffs, dissemination and fracture pyrite, up to 3% sulphur max 250 ppm Pb, 2500 ppm Zn.

BBP 208: Pink porphyries and interbedded tuff/seds ending in ash flow tuffs.

Patchy vein and dissem. pyrite max 2% sulphur, 1450 ppm Pb, 2600 ppm Zn.

BBP 209: Ash flow tuffs, Auto Bx porphyries, sheared siliceous tuffs.

Rare pyrite at depth but network fe/mn veinlets, max 150 ppm Pb 4000 ppm Zn, 3% sulphur (but patchy)."

- 3 The similarity of the alteration zone to Rosebery and Que River (referred to in reports but not discussed here at length) at Boco, together with the obviously ineffective geophysics and geochemistry in covered areas, suggests that sections of the EL should receive priority attention.
- 4 The RMIP method is ideally suited to the problem, and together with suitable detailing and gravity/seismic work, would be expected to delineate any significant mineralisation present in the area. In this respect it is important to be able to detect both zinc rich mineralisation which would be non-conductive and polarizable and copper rich mineralisation which would be both polarizable and conductive.

SCINTREX

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

SCINTREX

Page - two

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 Polarization:- 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 (ΔM):- 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).

SCINTREX

Page - four

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*

SCINTREX

EIP & MIP ENERGIZATION

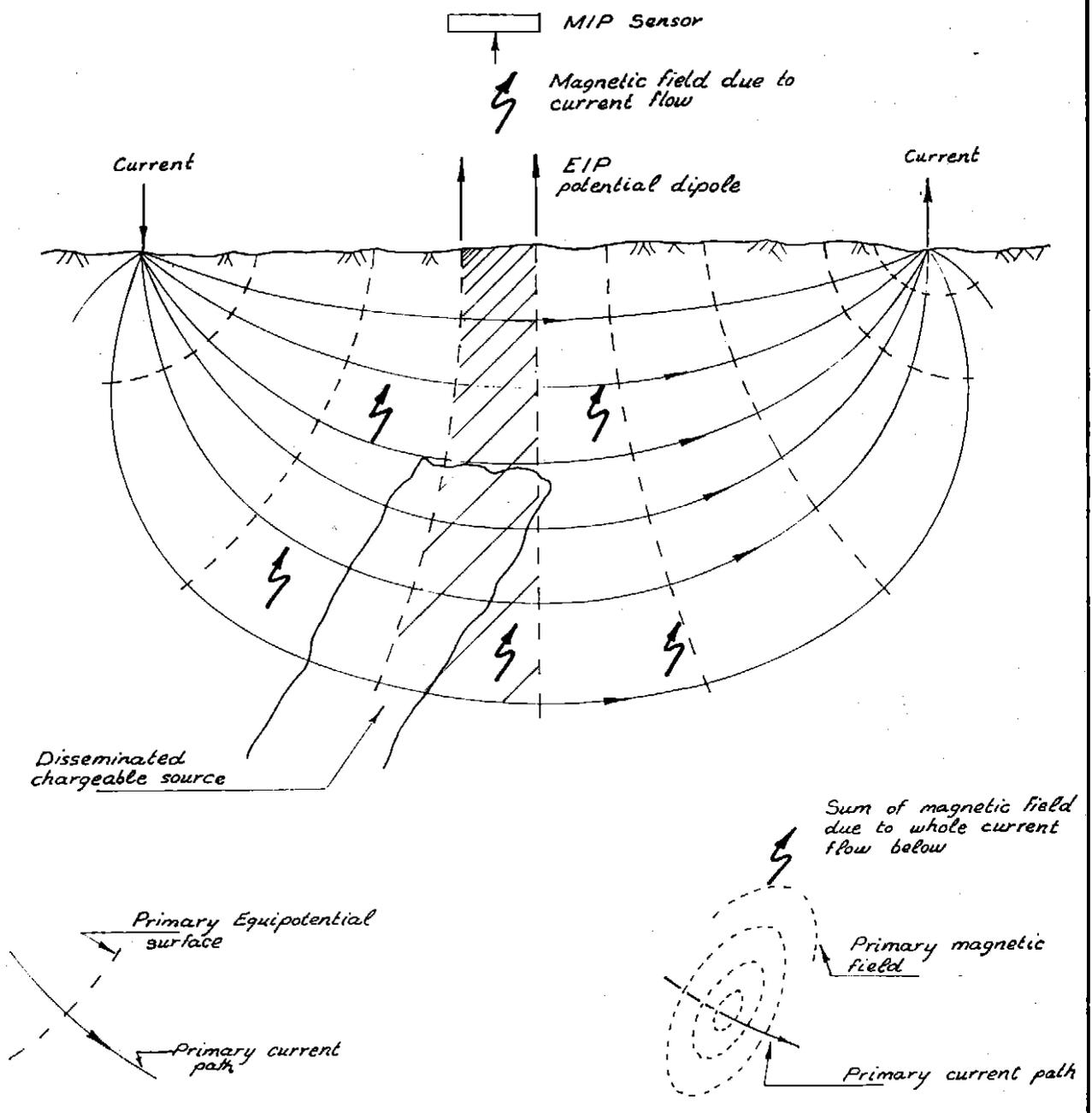


Fig. 1

EIP & MIP DISCHARGE OF INDUCED POLARIZATION

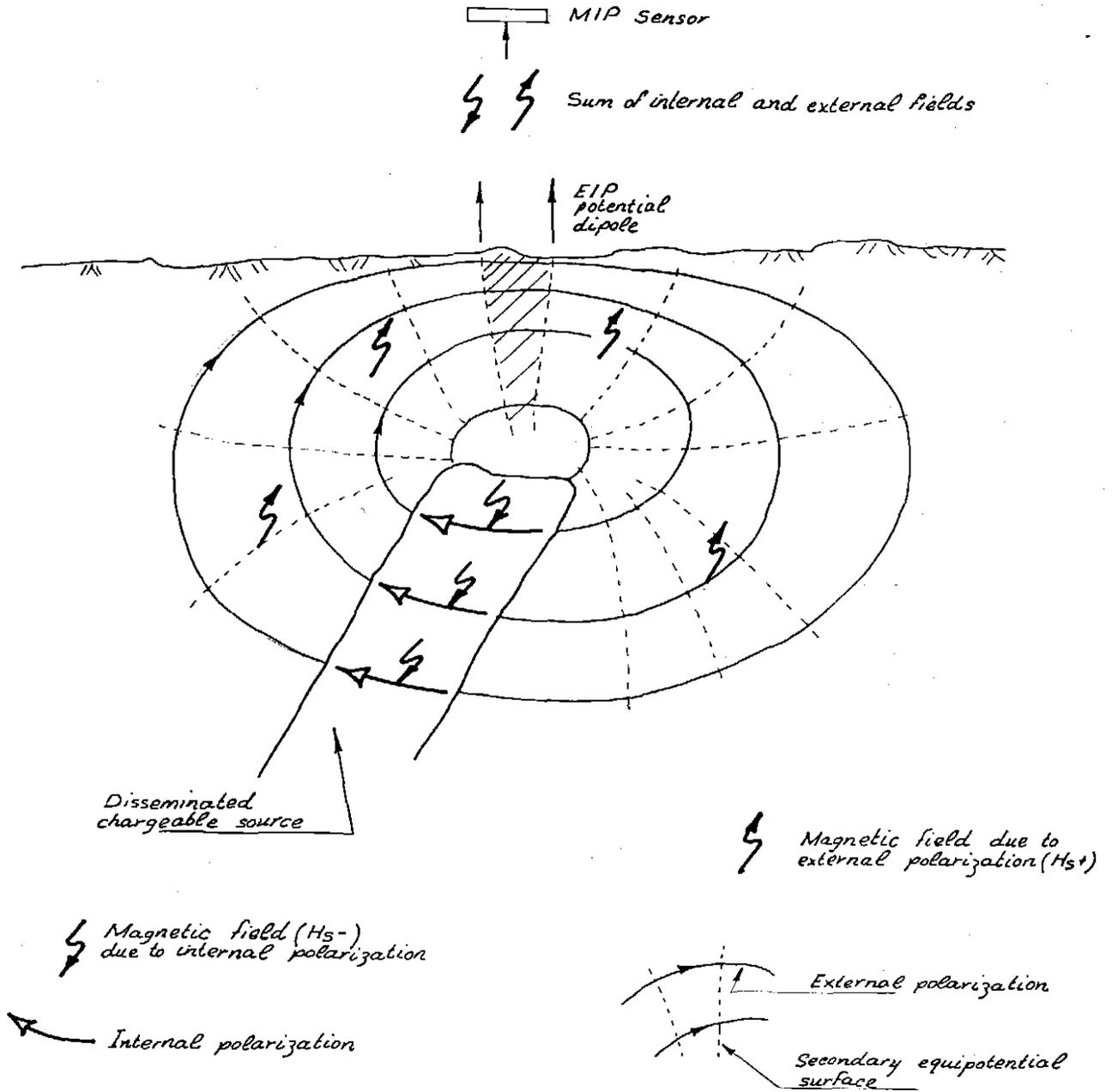


Fig 2.

SCINTREX

Page - five

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.)

SCINTREX

Page - six

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.

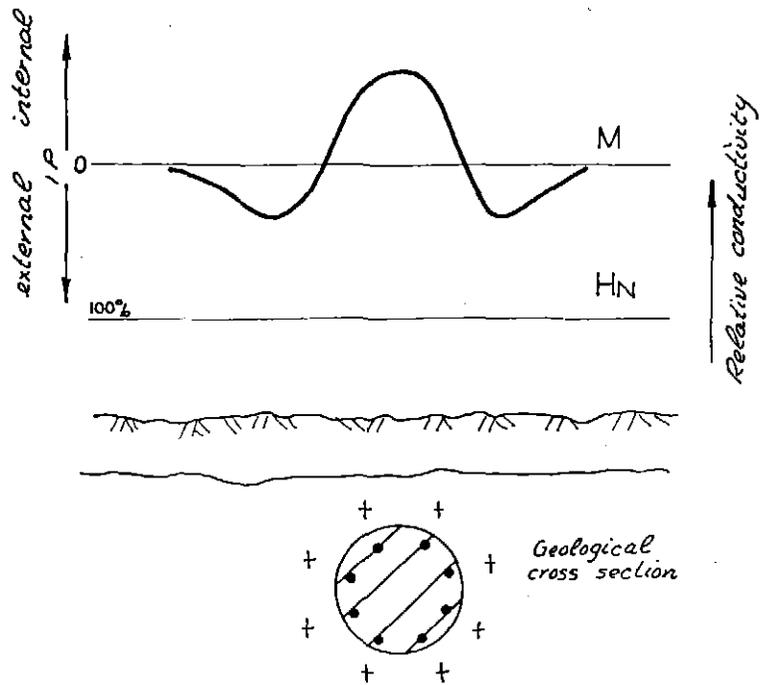
TYPE 'D' (Figure 5) In this most important anomaly form which invariably is associated with massive sulphides which are both conductive and electrically continuous, a massive sulphide *must* be surrounded by a disseminated halo within more resistive host rocks. In this case the disseminated sulphides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

SCINTREX

TYPICAL M.I.P ANOMALY FORMS

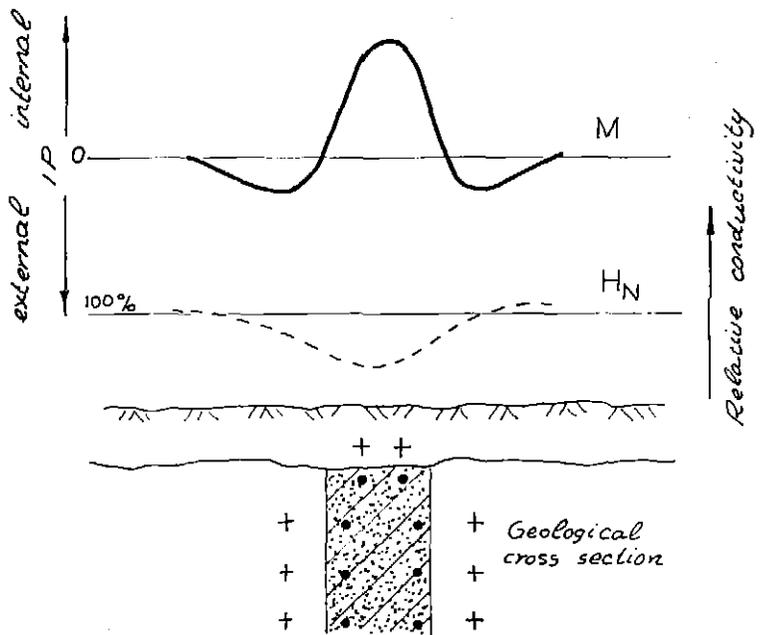
THEORETICAL MODEL

CHARGEABLE SOURCE
NO RESISTIVITY CONTRAST



TYPE A

CHARGEABLE SOURCE
RESISTIVE SOURCE

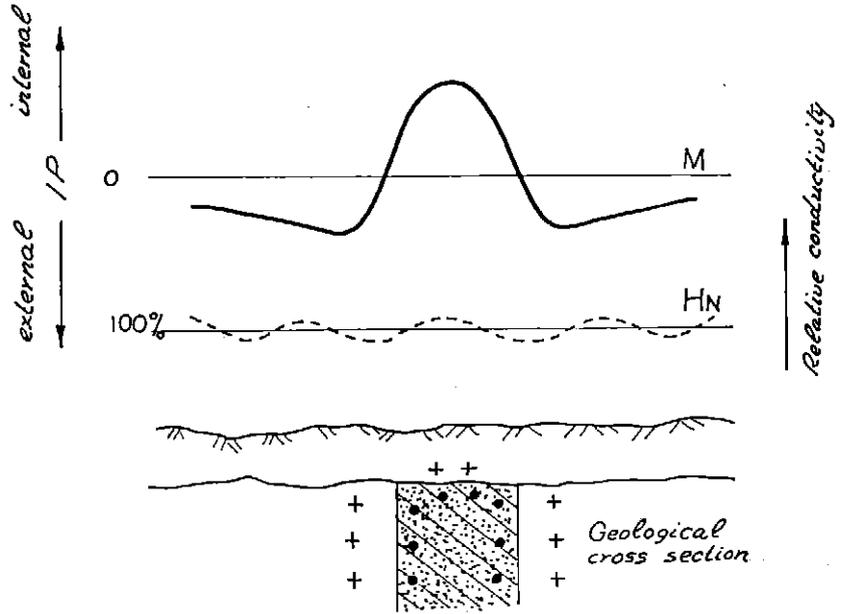


NOTE:

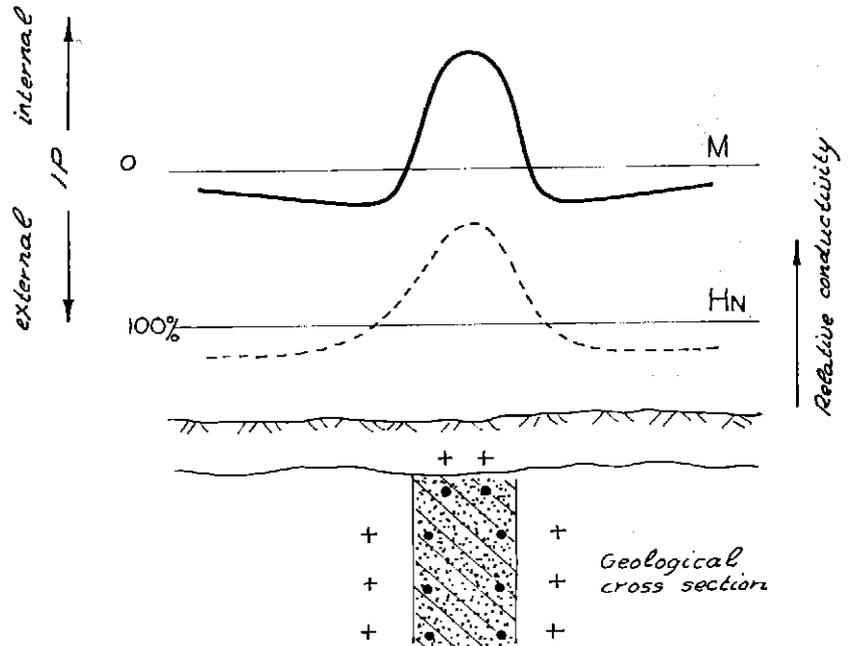
- + External current flow into plane of paper
- Internal current flow out of plane of paper

Fig. 3

TYPE B
 CHARGEABLE SOURCE
 HOMOGENOUS



TYPE C
 CHARGEABLE SOURCE
 CONDUCTIVE



NOTE:

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

Fig 4.

SCINTREX

Page - seven

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'.

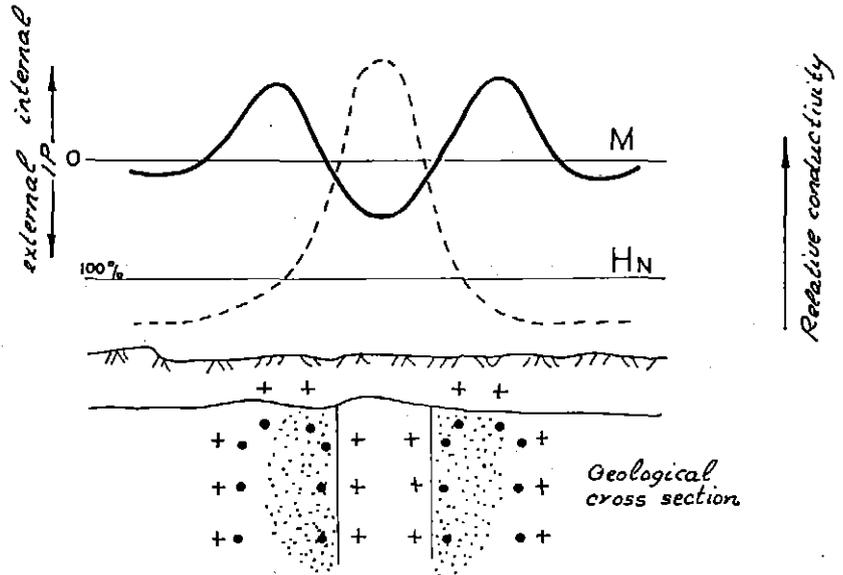
In the interpretation of MIP therefore, the electrical characteristics of known 'Type Deposits' similar to those being sought, together with local information as to the possible range of structure in the area, is of primary importance. In other words, geological input is often of greater importance than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

SCINTREX

TYPICAL M.I.P ANOMALY FORMS

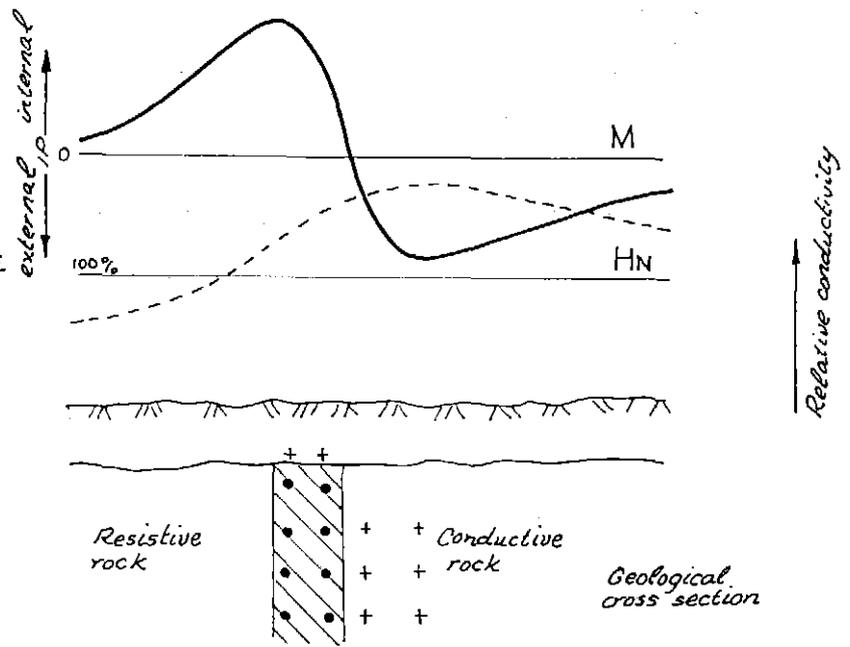
TYPE D

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.

SCINTREX

Page - eight

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:-

Domain	Time	Frequency	
Equipment	IPR-8 (or 10)	IPRF-2	
Units	milligamma/gamma	degrees(°)	Percent Frequency Effect (%)
equivalence	15 milligamma/gamma \equiv	1.6° \equiv	1%

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.

SCINTREX

Page - nine

Domain	Parameter	Mode of Measurement	
		EIP External Polarization Dominating over Body	MIP Internal Polarization Dominating over Body*
Time	Chargeability	positive	negative
Frequency	Relative Phase Shift (RPS)	negative	positive
Frequency	Percent Frequency Effect (PFE)	positive	negative

* 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:

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

For frequency domain (at 3Hz)

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

Note: for lower frequencies, higher Hp is required.

SCINTREX

Page - ten

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 M_1 , M_3 and M_5 . 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_3 and M_5 . 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 ΔM parameter is a shorthand display of the decay form: $\Delta M = |M_5| - |M_1|$. 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 ΔM by the amplitude of the chargeability. This is done by dividing ΔM by M_3 and multiplying the factor by 100%.

The normalised decay form $\Delta M_n\% = \frac{|M_5| - |M_1|}{M_3} \times 100\%$

and displays the variation in decay form from 'normal' in percent.

SCINTREX

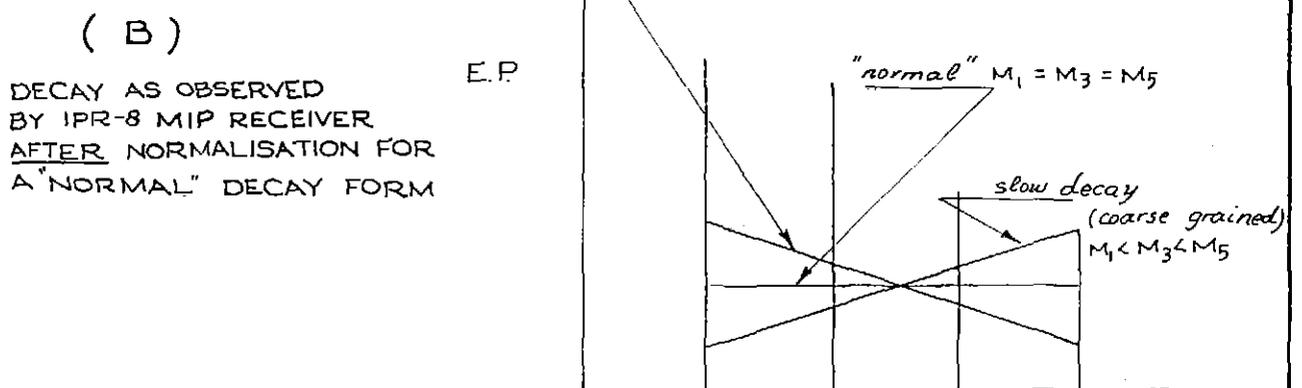
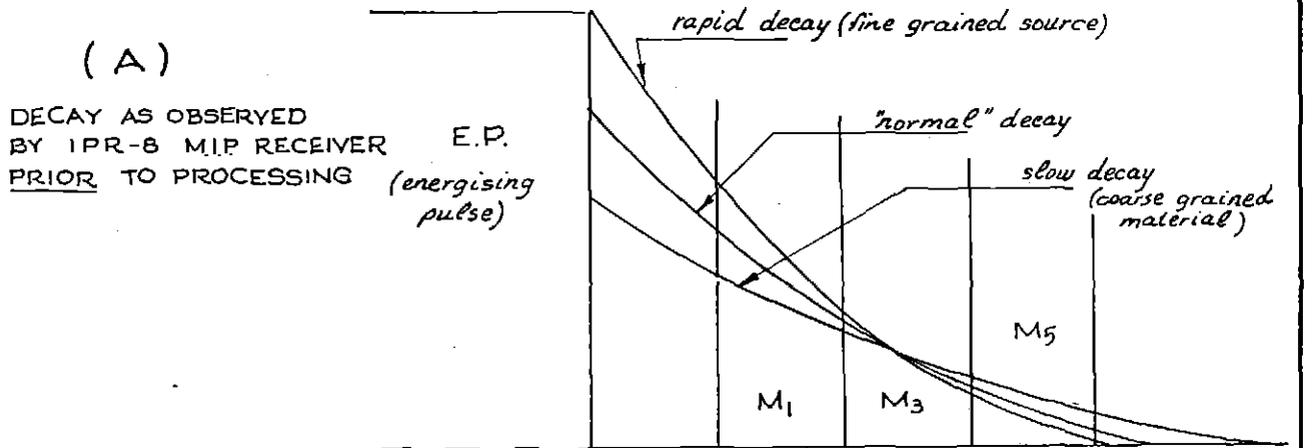


Fig 6.

SCINTREX

Page - eleven

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 $1\%PFE + 1.6^\circ RPS$ 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.

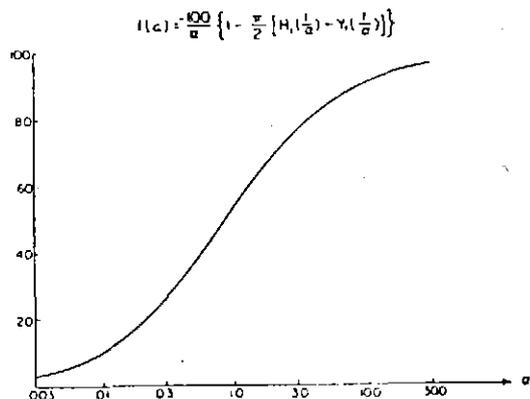


FIG. 3. The function $f(\alpha)$ which determines the percentage of current remaining in a conductive, thin surface layer above a resistive half-space.

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

$$\alpha = 2S\rho_2/L$$

Where S is the conductivity thickness product of the overburden and ρ_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 ρ_1 and ρ_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 ρ_1/ρ_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 (ρ_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, ρ_2 can be reasonably estimated. As an example, take an area where the overburden/oxidation has a bulk resistivity (ρ_1) of 50 ohm-metres, and a depth (d) of 25 metres over bedrock (ρ_2) known to average 2000 ohm-metres. Thus ρ_2 will equal about 40 ρ_1 , therefore for 40% of the current generated to penetrate the bedrock the current dipole is required to be 50 times

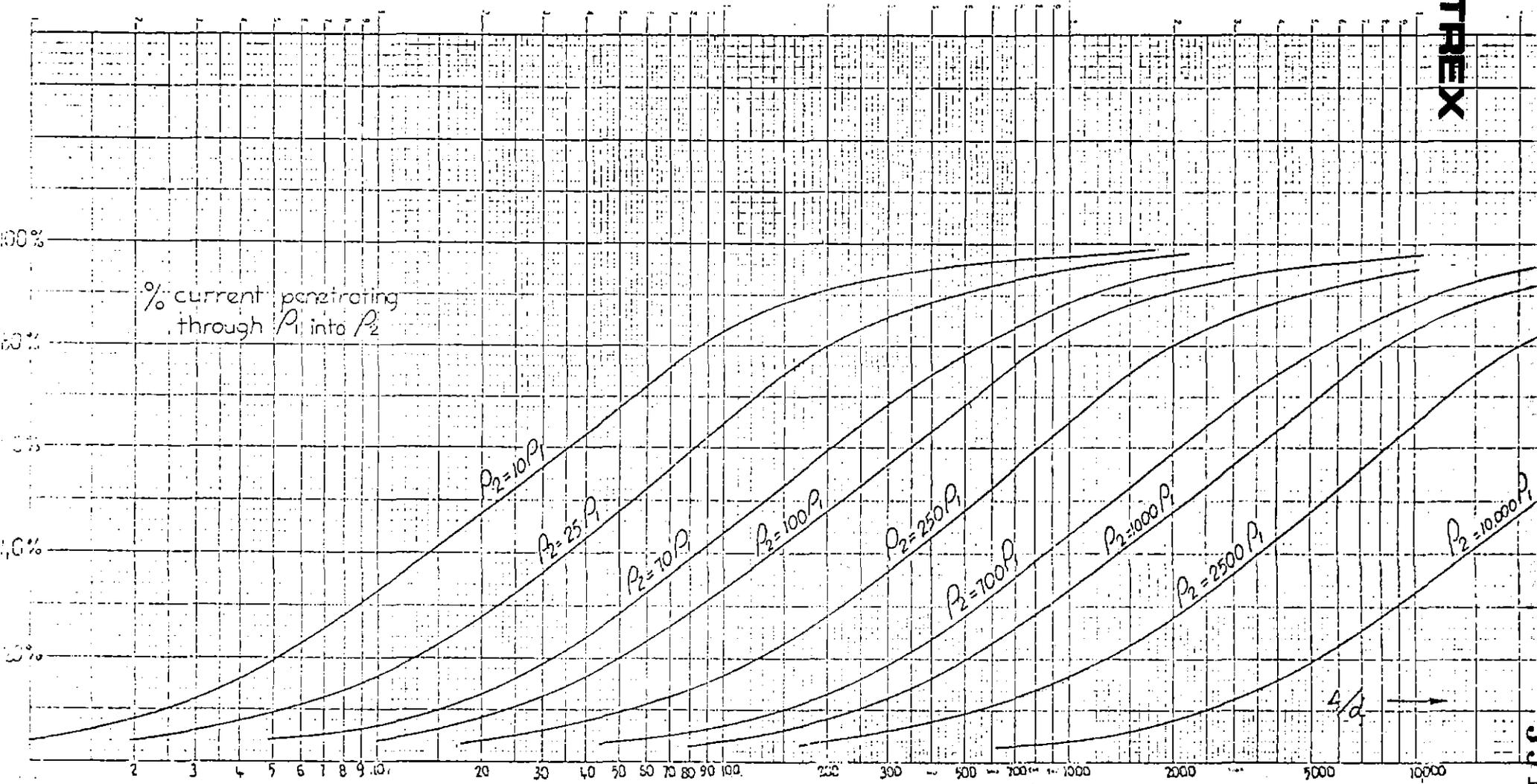
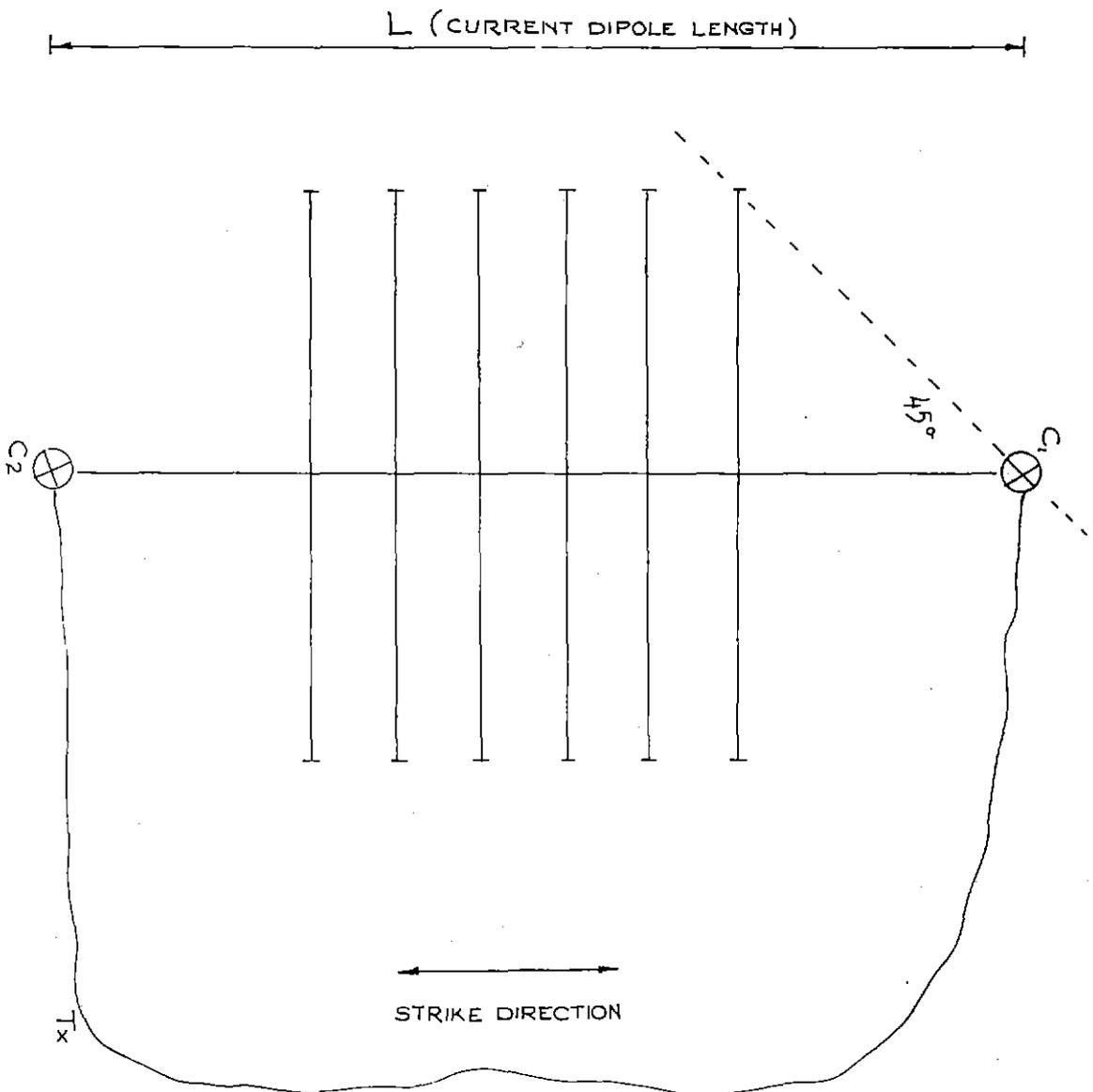


FIG. 7

SCINTREX



GRADIENT ARRAY

Fig 8

SCINTREX

Page - thirteen

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, 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 \pm 100 metres) precludes a meaningful contour presentation in most cases. Again, a scale of 1:2500 is favoured.

Field Procedures

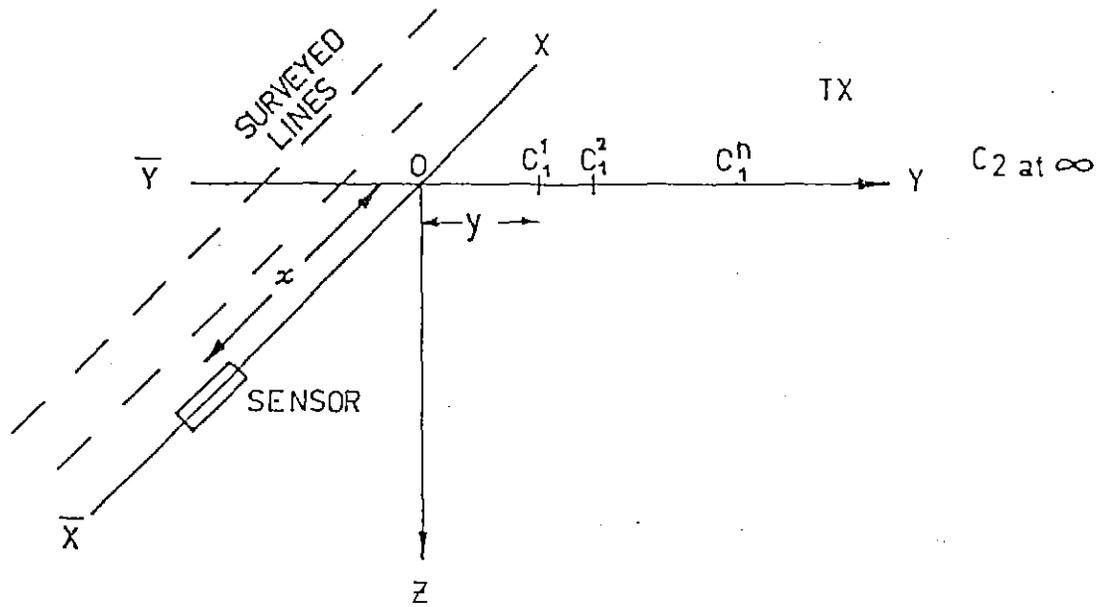
Most (but not all) fieldwork to date has been carried out using *gradient arrays* as shown in Figure 8. In practice the current dipole (L) is laid parallel to strike and varies up to 600 metres for time domain surveys and 3000 metres in the case of frequency domain (RRMIP) surveys. From each gradient 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.

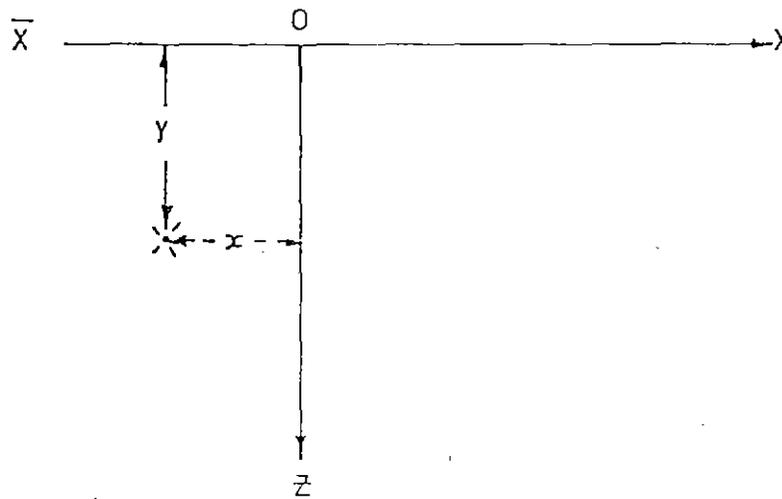
From a practical point of view, as MMR/MIP* is a magnetic field method, it necessarily depends on strong current flow. Thus the method works best in areas which are conductive rather than those which are highly resistive. Areas where MIP/MMR appears to have been particularly useful are Kalgoorlie, Western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

* See page 15

SCINTREX



Field setup



Pseudosection plotting format

\ast plotting point

Fig. 9

MULTI-SOURCE (EDWARDS) ARRAY

SCINTREX*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 χ . For each location the H_p 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 electrode C_1^n from the survey line χ . 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:*

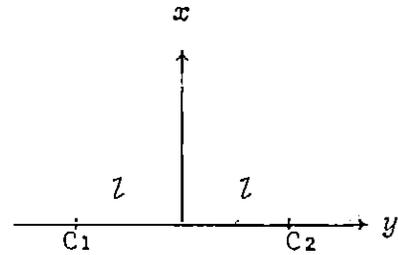
The MIP sensor senses the horizontal magnetic field due to the passage of the primary current in the ground. Unlike EIP resistivity data, it sums *all* current to depth by virtue of its magnetic field. The field at any point in the survey area (H_p), must be adjusted for the position of the current dipole. The formula for the calculation of the normal (H_{Norm}) field at any point is:-

SCINTREX

Page - fifteen

$$H_{\text{Norm}} = 100I \left[\frac{y+l}{x^2 + (y+l)^2} - \frac{y-l}{x^2 + (y-l)^2} \right]$$

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:-

$$\text{MMR} = \frac{H_p - (H_u \times I)}{\frac{400I}{2l}} \times 100\%$$

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:-*

$$\text{MMR} (\%) = \frac{B^a \times 100}{\frac{100I}{y_1} - \frac{100I}{y_2}}$$

Where $B^a = B^m - B^p$

$$\text{and } B^p = \frac{100Iy_1}{(x^2 + y_1^2)} - \frac{100Iy_2}{(x^2 + y_2^2)}$$

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^a = anomalous field, B^m = measured

SCINTREX

Page - sixteen

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:-

$$RPS = 3\theta_f - \theta_{3f}$$

where θ_f and θ_{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:-

$$PFE = \frac{A_1 - 3A_3}{3A_3} \times 100\%$$

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, 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:

049

SCINTREX

Page - seventeen

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

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 $\Delta HSP/I$

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

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, FGS.

SCINTREX

REFERENCES

Magnetic Induced Polarization

EDWARDS, R.N. and HOWLAND-ROSE, A.W., 1979. Modern EM & IP exploration techniques *Australian Mineral Foundation, V.III, Sections a & b, pp.607-748*

HOWLAND-ROSE, A.W., LINFORD, J.G., PITCHER, D.H., and SEIGEL, H.O., 1980. Some recent magnetic induced polarization developments. *Geophysics, V.45, Parts I & II pp.37-74.*

SEIGEL, H.O., 1974. The magnetic induced polarization method. *Geophysics, V.39, pp. 321-339.*

HOWLAND-ROSE, A.W., 1980. Early electrical and magnetic induced polarisation surveys over the Elura ore body - results and comments. *A.S.E.G. Bulletin, 1980 (In publication).*

Rapid Reconnaissance Magnetic Induced Polarization (RRMIP)

EDWARDS, R.N. and HOWELL, E.C., 1976. A field test of the magnetometric resistivity (MMR) method. *Geophysics, V.41, pp.1170-1188.*

EDWARDS, R.N., and GOMEZ-TREVINO, E., 1979. MMR2D A programme to compute the magnetometric resistivity (MMR) anomalies of two dimensional structures. *Unpublished Report, Macquarie University.*

GOMEZ-TREVINO, E., and EDWARDS, R.N., 1979. Magnetometric resistivity (MMR) anomalies of two-dimensional structures. *Geophysics, V.44, pp.947-958*

HOWLAND-ROSE, A.W., 1980. Magnetometric resistivity and frequency domain magnetic induced polarization test surveys using gradient and multi-source arrays over the Elura ore body. *A.S.E.G. Bulletin, 1980 (In Publication).*

Decay Form

GEDDE, R.W., and HOWLAND-ROSE, A.W., 1970. Adapting IP to W.A. conditions. *Southern Miner, V.1, No.26, pp.14-22.*

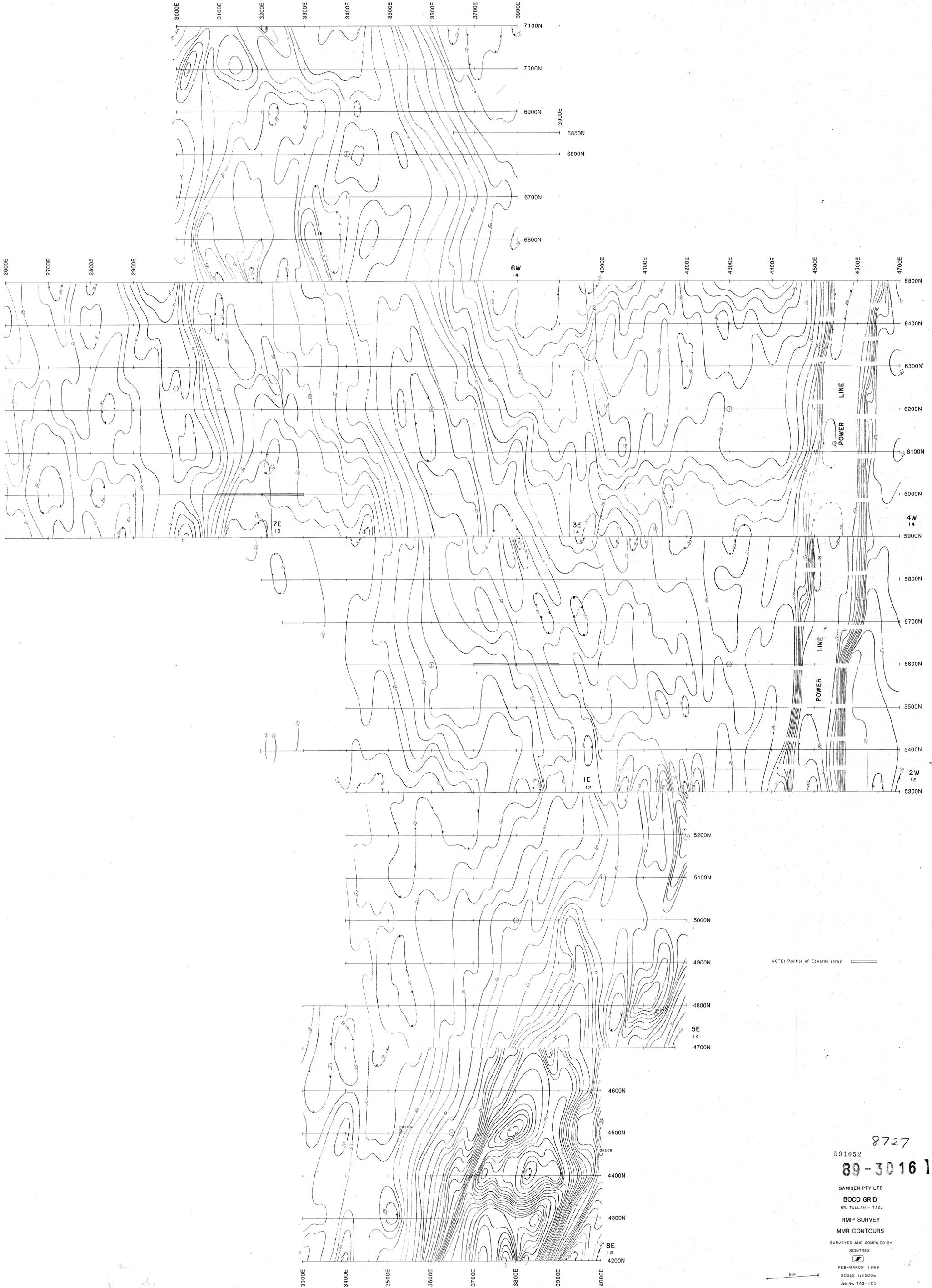
SWIFT, C.M., 1973. The L/M parameter of time-domain IP measurements - A computational analysis. *Geophysics, V.38, pp.61-67.*

WAIT, J.R., 1958. A phenomenological theory of induced electric polarization. *Canadian Journal Physics, V.37, pp.1634-1644.*

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.

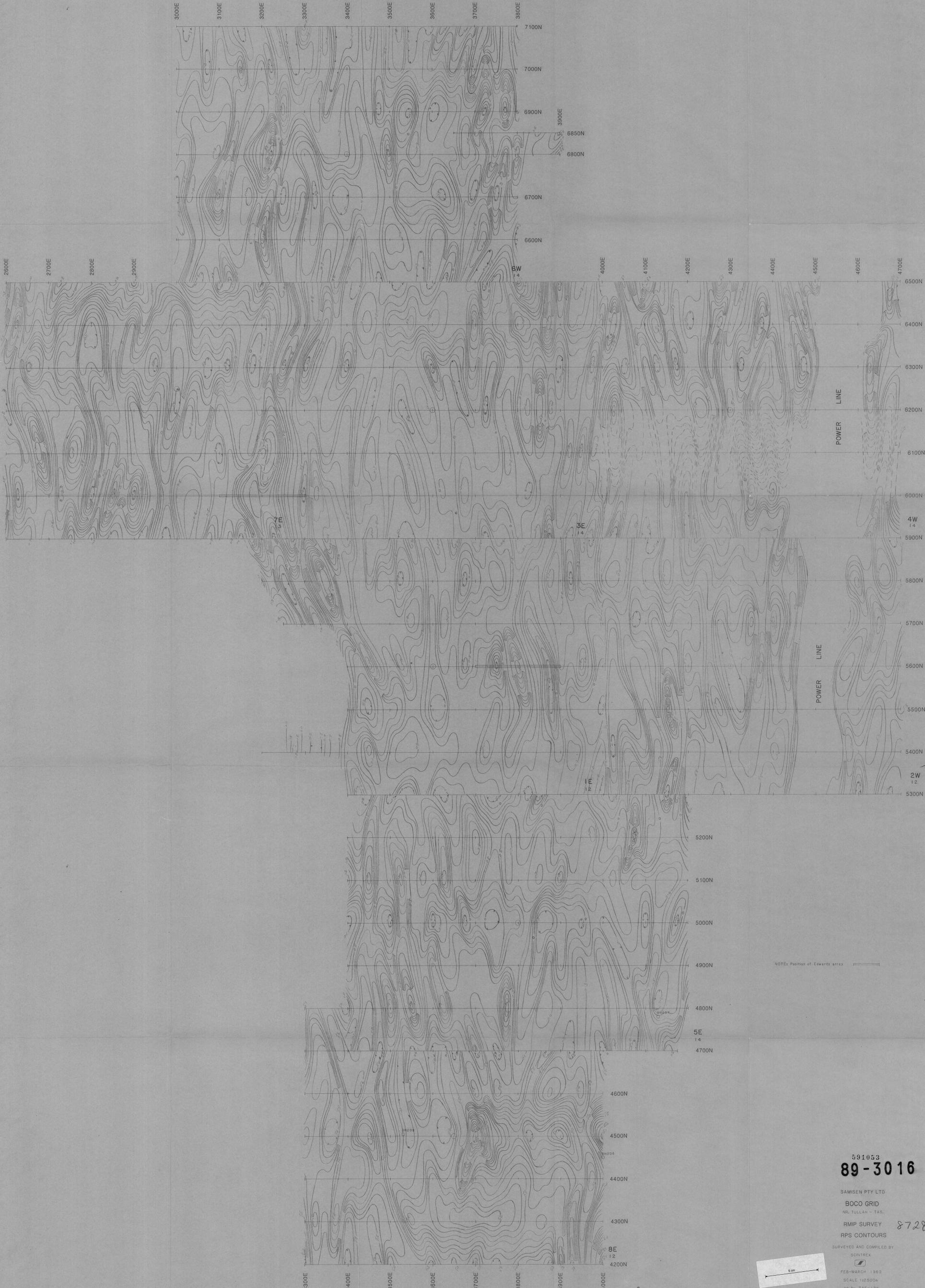


NOTE: Position of Edwards array

8727
 591052
89-3016 1

SAMISEN PTY LTD
 BOCO GRID
 NR. TULLAH - TAS.
 RMP SURVEY
 MMR CONTOURS
 SURVEYED AND COMPILED BY
 SCINTREX
 FEB-MARCH 1989
 SCALE 1:2500m
 Job No. TAS-125





NOTE: Position of Edwards array

591053
89-3016

SAMISEN PTY LTD
BOCO GRID
NR. TULLAH - TAS.
RMP SURVEY
RPS CONTOURS

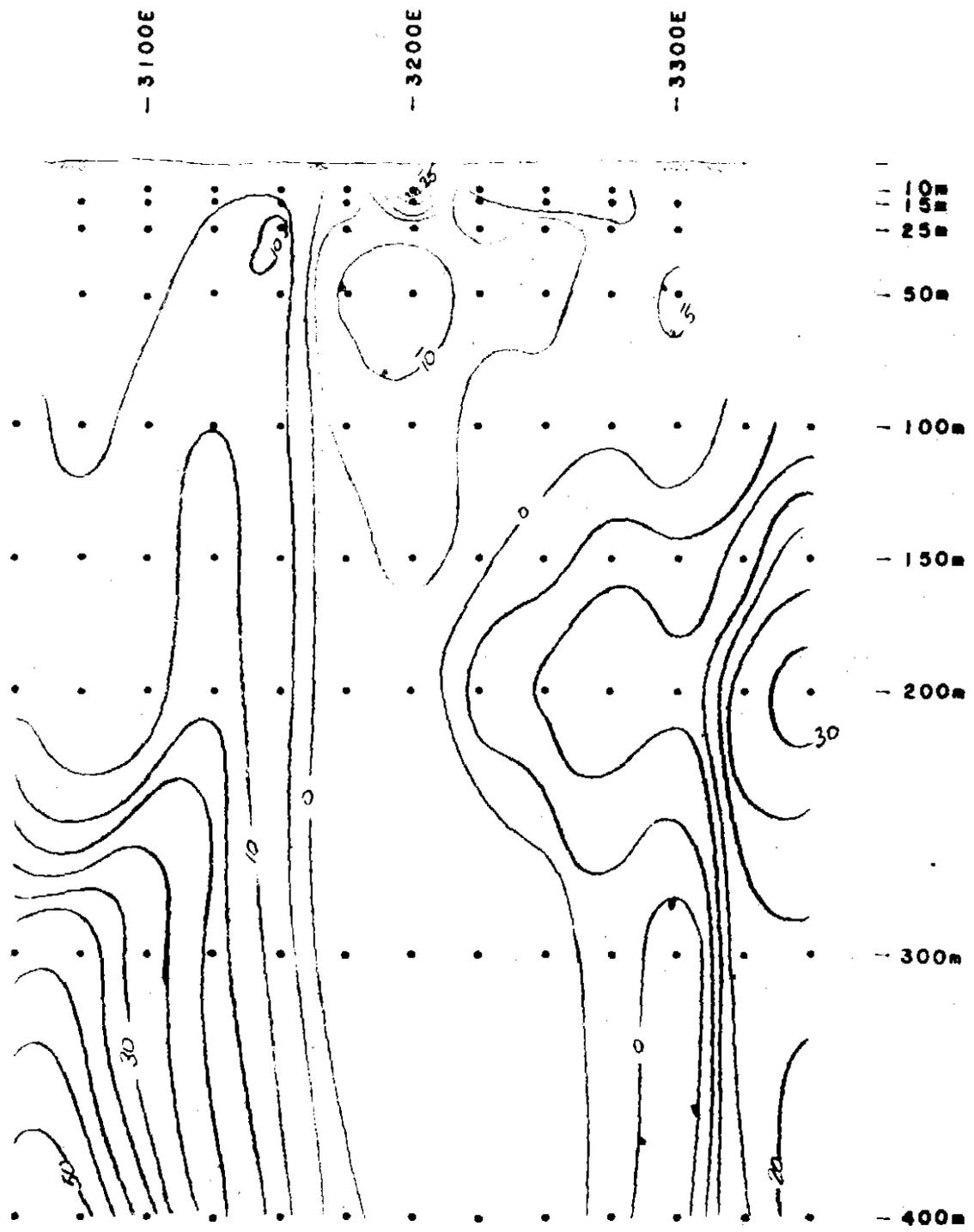
8728

SURVEYED AND COMPILED BY
SCINTREX
FEB-MARCH 1965
SCALE 1:2500m
Job No. T45-125



8729
Line 8000N
MMR

591054



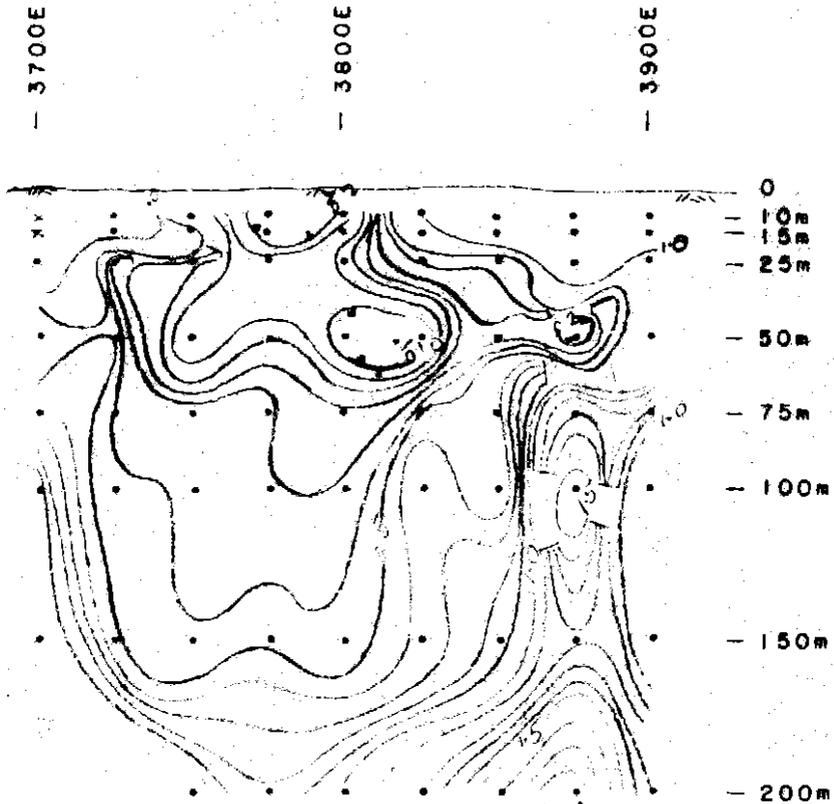
Edwards array
TAS-125

8730

591055

Line 5600N

RPS



Edwards array

TAS-125

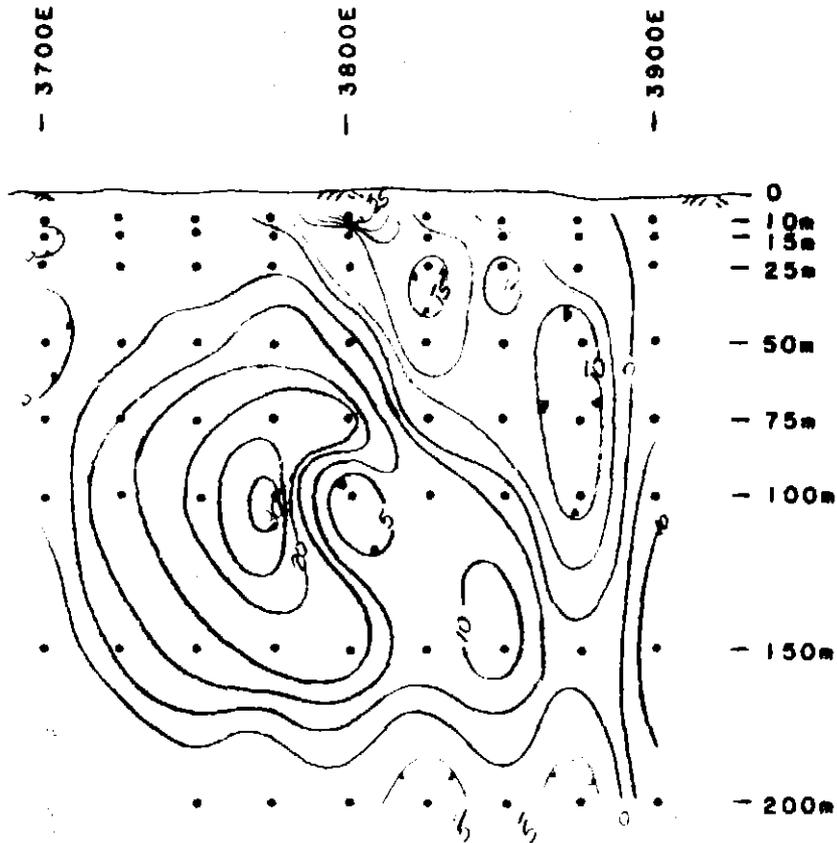
Plate 4

8731

591056

Line 5600N

MMR



Edwards array

TAS-125

8732

591057

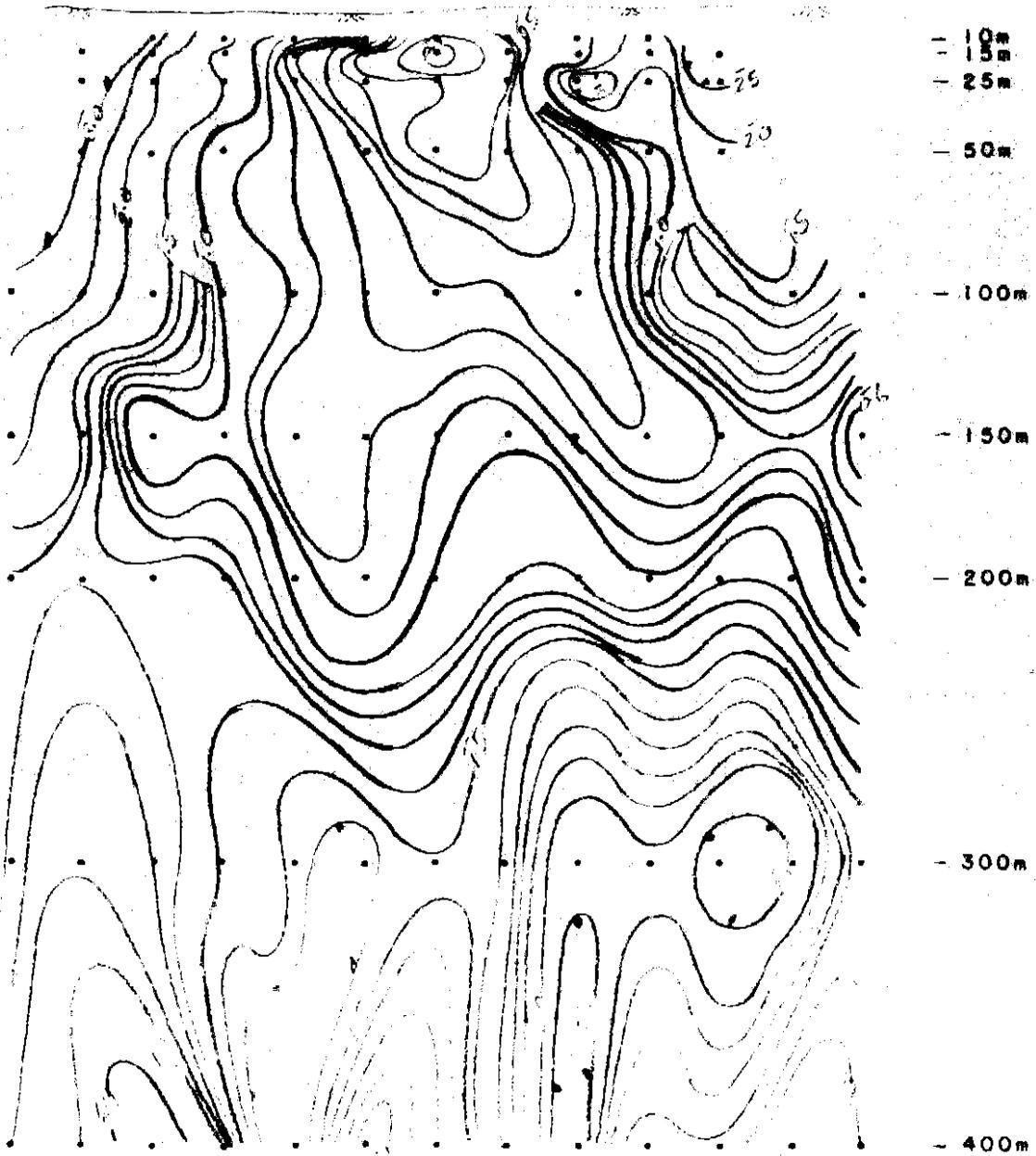
Line 6000N

RPS

- 3100E

- 3200E

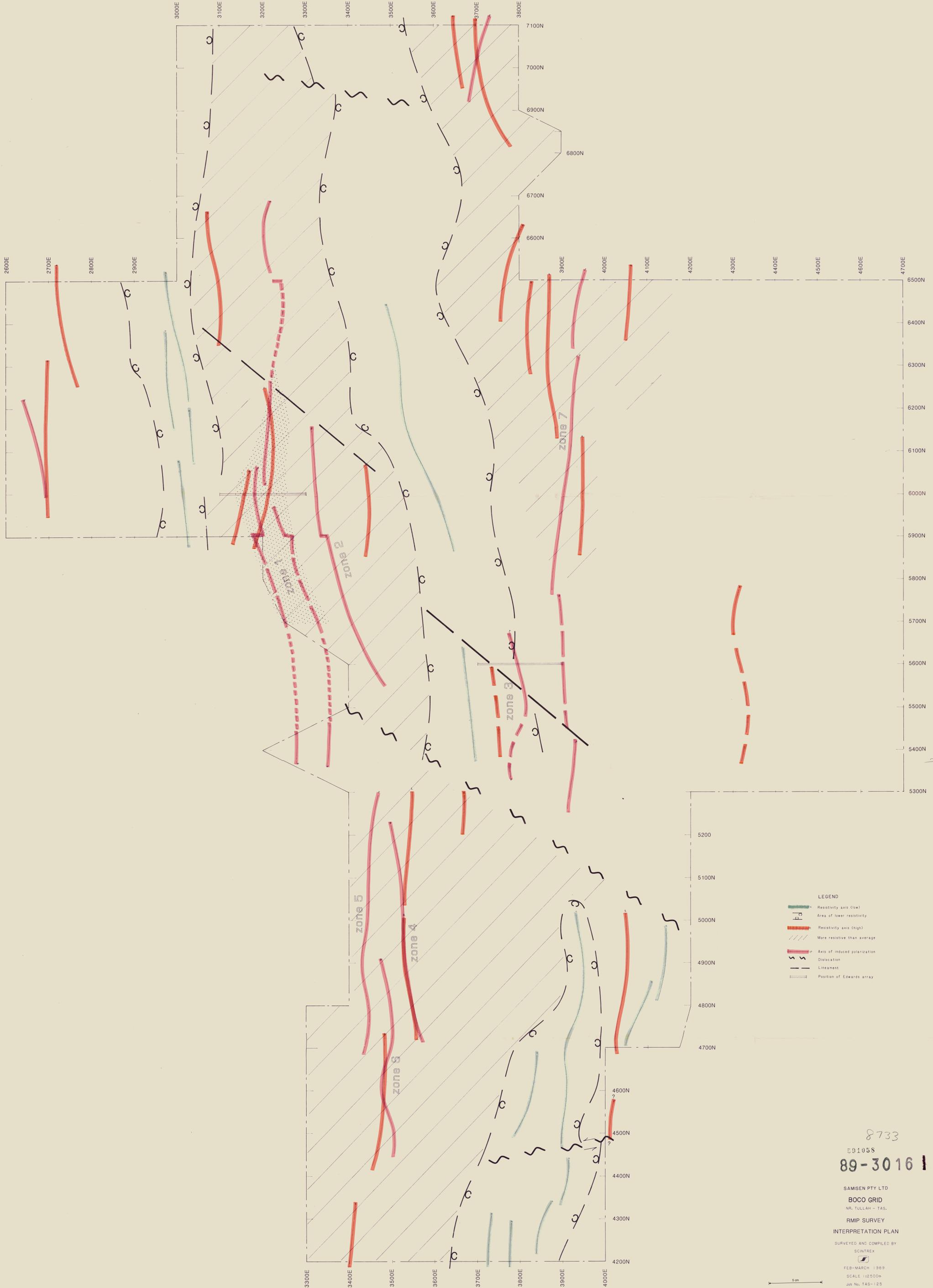
- 3300E



Edwards array

TAS-125

Plate 6



8733
 89-3016

SAMISEN PTY LTD
 BOCO GRID
 NR. TULLAH - TAS.
 RIMP SURVEY
 INTERPRETATION PLAN
 SURVEYED AND COMPILED BY
 SCINTREX
 FEB-MARCH 1989
 SCALE 1:25000
 JOB No. TAS-125