296001

MITRE GEOPHYSICS PTY LTD

MINERAL EXPLORATION AND ENGINEERING CONSULTANTS

BUGGS LANE   ELLIOTT   TASMANIA 7325   PHONE 004-363143

NOTES ON SOME EM METHODS

FOR GROUND FOLLOW-UP OF DIGHEM ANOMALIES

FOR

MT. LYELL MINING AND RAILWAY COMPANY LIMITED

AND

ELECTROLYTIC ZINC COMPANY OF AUSTRALASIA LIMITED
West Coast Mines

BY

DR. J.R. BISHOP

EZ-ML/MG81/06

JUNE, 1981

CONTENTS

LIST OF FIGURES

SUMMARY

Five EM systems in regular use in Australia are briefly described and their suitability for Dighem follow-up in Tasmania commented on.

Incomplete testing of the Horizontal Loop EM system, Max-Min, suggests that this method will be most suitable for the ground follow-up of Dighem anomalies. Although it is considered not to be as sensitive as time domain systems such as Sirotem or (Crone's) pulse EM, it is expected to be quite adequate for location of even the small trace excursions that do not rate as Dighem anomalies. Other systems such as the VLF method are quicker and cheaper to use but may have inadequate penetration and respond more readily to unwanted conductors such as faults.

AIMS AND INTRODUCTION

Anomalies defined by an airborne survey require locating on the ground. Normally a grid is pegged over the expected location of the anomaly, and a detailed ground survey made. Failure to find the anomaly (as has often been experienced) may be due to a false anomaly (i.e. noise), poor positioning, or use of the wrong follow-up method.

Any anomaly detected by an airborne EM system operating at 900Hz with a coil spacing of less than 10m (e.g. Dighem) should be detectable by any (modern) ground EM system. Therefore the main consideration will be ease of operation. There are however other factors, and these are discussed in the comments below on five ground EM units in use in Australia.

EM systems may be either frequency or time domain. Time domain is a more recent development and methods employing this technology are generally capable of detecting deeper and smaller targets. But theoretically the two domains are equivalent, and one reason for time domain's apparent superiority may be that less (recent) effort has been put into developing frequency domain methods. (The Max-Min system is a recent exception; however, from initial tests over a massive sulphide body at Mt. Bulga, Orange N.S.W., it appears

that it too, is inferior to time domain systems.)

The airborne EM system, Dighem, has been used by many mining companies exploring on the West Coast of Tasmania and the following is a brief description of some of the EM systems available for ground follow-up.

EM METHODS

FREQUENCY DOMAIN

Frequency domain methods may use either naturally occuring fields (e.g. the magnetotelluric method), remote fields (e.g. the VLF method) or transmit their own fields (e.g. Max-Min).   All these fields are sinusoidal EM waves of various frequencies.   Generally the various methods serve different, though overlapping purposes.

1.   VLF

VLF stands for Very Low Frequency and it refers to radio waves used for communications with under-water submarines.   Geophysically it is a very high frequency (around 20,000Hz), which means that it will respond to features such as swamps, faults, contacts etc., as well as massive sulphides.   The high frequency also means that its penetration will be much less than other methods, although in the typically resistive host rocks of the Mt. Read Volcanics, VLF is theoretically capable of detecting ore bodies at depths of up to 100m *   (assuming a host rock of at least 1,000-ohm-m).   The system uses the transmitting stations of the American military communications network (e.g. Japan; Hawaii; NW Cape, Australia); and being merely a receiver for a remote-source EM field, it is the simplest, quickest and cheapest method to use.   The parameter measured is the tilt of the (resultant) field; some instruments also measure the quadrature component; others the field strength.

*   The penetration of an EM system is usually equated to the skin depth, which is defined as the depth at which an EM wave has been attenuated by 1/e, i.e. by about 37%. Skin depth is approximately equal to $500\sqrt{\frac{\rho}{f}}$ where ρ is the resistivity of the rock and f is the operating frequency.

2.   Horizontal Loop (e.g. Max-Min).

The horizontal loop method (also called the Slingram method) transmits its
own field.   It consists of two loops with a connecting cable between them.
The method is very sensitive to topographic variations and changes in coil
separations.   To make corrections for these changes, lines should be pegged
at equal horizontal intervals.   The Max-Min system's five operating fre-
quencies and various possible coil separations ensure that a wide range of
conductors may be detected.   The parameters measured are usually the inphase
and out-of-phase response (with reference to the transmitted field) expressed
as a percentage of the transmitted field.

3.   Dip-Angle

This EM system measures the same parameter as the VLF system (the tilt of
the resultant field), however it transmits its own field.   Problems of
topography are overcome by each coil acting as, alternatively, receiver and
transmitter.   Often the system is used 'broadside' whereby the traverses
are made with the coils on adjacent lines rather than one behind the other
(there is no connecting cable).   Two people are needed to operate the system
and progress should be about the same as the Horizontal Loop system.   The
method has been used for Dighem follow-up in Tasmania to the satisfaction
of the company concerned, although the contractor stated that it had its
problems.   These may have been instrumental, since the equipment used was
old.   With modern equipment (if such exists), the method should be quite
suitable, however like the VLF method, a tilt angle is measured and no
quantitative interpretation can be made.

TIME DOMAIN

Time domain methods all employ their own energising field, which is some
sort of pulse and it is the decay of this pulse which is measured.   A
similar description applies to time domain IP; however, the difference (in
measurement) between the two is in the time interval measured.   For IP,
the decay may be measured from 500 to 2000 msec or more.   In EM, the decay may
be measured from nearly zero to perhaps 20 msec, although more recent models
are extending the time measured to over 100 msec (e.g. Sirotem goes to 180 msec).
The parameter measured in time domain systems is usually microvolts per Amp
(μV/A).

4.   Pulse EM

This is the name given to a time domain EM system marketed by Crone Geo-
physics, which may be used with either a large transmitting loop (e.g. 100m x
100m square loop) or a small loop (e.g. 9m diameter circular loop).   The
receiver monitors eight channels with each channel measuring progressively
later sections of the decay curve.   Since later channels are equivalent to
lower frequencies, late channel responses mean greater penetration and/or
conductivity.

The small loop would be quite adequate for following up airborne EM anomalies
and since the loop is (can be?) open ended, it should be possible to use,
even in fairly thick scrub.   The equipment is heavy (it includes a heavy
duty 12 volt battery) and requires 3 people to operate it.

A version of this method is used for down-hole EM logging.

5.   Sirotem

This is the latest time domain system to come on the market and is Australian
designed and manufactured.   It was primarily designed for use in areas of
deep weathering and/or conductive overburden.   It is usually used with a
large (100m x 100m) 2-wire loop which transmits and receives, but a small
hand-held receiver is now available.   A logging version is being developed.

CONCLUSIONS AND RECOMMENDATIONS

The VLF method would, in all likelihood, detect the cause of a Dighem
anomaly, however the response may be obscured by faults, contacts, etc..
The occurrence of (near) surface veins, too small to be seen by the Dighem
system, may also mask a deeper, larger conductor.

The lower frequencies of the Max-Min system ensures that geologic noise is
not such a problem.   The effects of vein conductors near the surface could
probably be overcome by using a large loop separation and a small station
spacing.

Figure 1 shows the responses of VLF, Max-Min and Dighem surveys over excellent conductors (Colebrook Hill). The VLF shows three main conductors centred approximately at 374,910E, 375,045E and 375,130E. The coincidence of magnetic anomalies with the VLF anomalies at Colebrook Hill confirmed that the VLF responded to pyrrhotite mineralisation and not faults, contacts, etc.. There are four Max-Min lows, centred at 374,660E, 374,910E, 375,065E and 375,180E. The western Max-Min anomaly has no corresponding VLF response (the anomaly is poorly defined since the survey finished 40m to the west), but there is excell-ent agreement with two of the VLF anomalies and a 50m discrepancy with the third. The VLF method gives the best resolution; differences between the Max-Min and the VLF may be due to interference effects in the Max-Min results, from the other (near surface) conductors.

The largest Dighem anomaly (920A of Sheet 2) is situated between the VLF anomaly at 375,130E and the Max-Min anomaly at 375,180E. This anomaly has an off-scale coplanar (whale-tail) in-phase response and a 210 ppm co-axial (standard) in-phase response. The conductance is 138 mhos, giving it the highest grade of 6 ($\geq$100). The strongest VLF and Max-Min anomalies are at 375,045E and 375,060E respectively; no Dighem anomaly was recorded in this area, however a close examination of the results (e.g. the responses in the first anomaly recognition channel, No. 35) suggests that an anomaly, swamped by anomaly 920A (Sheet 2), does occur here. This reinterpretation anomaly 'M' closely corresponds with the strongest VLF and Max-Min anomalies and is on an alignment of anomalies, marked on the Dighem plans, defined by responses on several lines to the north and south of 920.

The third conductive zone defined by VLF and Max-Min at 374,910E has no corresponding Dighem anomaly, the nearest being 'a possible' 70m to the west. Other Dighem possible anomalies have been picked at 375,260E and 375,430E, again not corresponding with any VLF or Max-Min responses (the latter is covered by VLF only). Other Dighem anomalies were picked beyond the coverage of the ground EM surveys.

If the strongest Dighem anomaly were moved west about 100m to correspond with the strongest VLF and Max-Min anaomalies, then the 'M' anomaly would roughly correspond with the 374,910E ground responses and the possible anomaly A (Sheet 2) would nearly coincide with the 375,130/180E ground responses. Thus it seems possible that the Dighem anomalies in this area have been plotted

about 100m to the east of their true positions. A more thorough exam-
ination will be done later, comparing all flight lines with the VLF and Max-
Min results, however the example illustrates the point that appropriate ground
methods must be used to accurately locate anomalies from airborne surveys.

With regard to the other systems discussed above, the dip angle method
(assuming a system of recent design is available) would not give the detailed
information of Max-Min, but also it should not give any false anomalies
due to topographic effects. The system would perhaps be a little easier
to use than Max-Min in thick scrub or on poorly cut lines, but progress
should be much the same.

At least one company in Tasmania has tried to locate Dighem 'X' type anomalies
using their own 'in-house' . EM system; it was not an unqualified success.
This may have been due to false anomalies rather than inadequate equip-
ment. Location of even smaller trace excursions that do not rate Dighem
'anomaly status' will be even more difficult, and such methods as PEM and
Sirotem may be needed. However, it is expected that genuine anomalies,
however slight, should be detectable by a Max-Min type system and the more
cumbersome time domain systems should only be used when searching for subtle
targets not detectable from the air. Included in this definition of
subtle targets would be the situation referred to earlier of thin veins of
sulphides masking deeper, more massive mineralisation; the large receiving/
transmitting loop configuration used by Sirotem may act so as to reduce the
surface effects and so may be useful for defining conductors in 'noisy'
environments.

J.R. BISHOP
JUNE, 1981

JRB/amd

APPENDIX

Results of some Max-Min surveys on the West Coast of Tasmania.

The Max-Min system is a Horizontal Loop or Slingram-type system which con-
sists of two coils, one transmitting, the other receiving. A reference
cable between the two enables in- and out-of-phase measurements to be made
(usually as a percentage, either 0% of 100%, or the transmitted field; for
the Max-Min system it is 0%).   The response over a steeply-dipping
tabular conductor is shown in Figure A1.

This type of system is very sensitive to changes in the coil geometry,
i.e., the coils must always be kept in the same plane, and coil separation
should be kept constant (only the in-phase channel is affected by these
factors).   So critical is the need for constant distance, that the use of
the reference cable for monitoring the separation is not sufficient in
areas of variable topography (slight changes in distance occur at breaks
in the slope) and lines should be surveyed with constant horizontal distances;
a correction is then later made for the slope.   (The received field strength
is inversely proportional to the cube of the distance, thus a variation of
1m using a coil separation of 100m will give a 3% anomaly.)   Figure A2
shows the effect of change in coil spacing and attitude.

The name Max-Min refers to the possible coil configurations.   In the hor-
izontal loop configuration (normally used) the loops are maximum coupled;
the receiving coil may be turned 90° and the coils are then minimum coupled
(not normally used, but can assist in resolution of multiple bodies).   The
system may also be used for reading dip-angle (vertical loop), however this
system is not useful in areas of variable terrain since the coils cannot both
act as receiver and transmitter (see comments on dip-angle EM in the report).
The equipment is manufactured by Apex Parameters Ltd., Canada.

a)   Max-Min follow-up survey over a grade 1 Dighem anomaly.
The Dighem anomaly is over a pyrite body of approximately 10 million tonnes.
The body is approximately 100m wide x 250m long, and outcrops (the Selina
western pyrite body).

The Dighem results are shown in Figure A3. The in-phase conductive anomaly has been swamped by a magnetic response. However from the ground follow-up, it is unlikely that the in-phase response would be any larger than the out-of-phase response (11 ppm). The significant out-of-phase anomaly shows the body to be a poor conductor and hence the grade of 1. Figure A4 shows the well defined Max-Min response (although note the difference in scale between this and the Figure 1 results) along line 128N about 50m north of the Dighem anomaly. The larger out-of-phase response confirms the Dighem grading and the increase in amplitude with increase in frequency suggests a shallow source. An attempt at a quantitative interpretation gave a conductance one order of magnitude lower than the Dighem estimate of 3 mhos. However there is some interference to the mineralisation anomaly by conductive surface conditions to the west (swamp and/or moraine); this led to a dip calculation of about 30°W rather than the actual near-vertical dip. The Dighem interpretation gave a depth of 38m, assuming a vertical dyke.

b) Max-Min follow-up of a Turam anomaly over a moraine covered fault zone. Figure A5 shows two Turam profiles from a RioTinto survey of the late 1950's. The anomalies are over a faulted contact between the Owen Conglomerate and Comstock Tuffs of the Tyndall Group. Glacial moraine covers the fault and extends further to the west. The Turam anomaly is strong, but poorly sampled (100ft station interval).

RTAE's

Figure A6 shows the Max-Min results from a line which crosses line 4800S at the Turam anomaly (the two lines are at an angle of 26°). The lack of response at frequencies either side of the Turam frequency (440 Hz) and the stronger out-of-phase response at 3555 Hz suggest that the Turam anomaly was caused by the return current (a grounded cable was used) concentrating in the surface moraine and/or fault zone. The Max-Min survey has shown that there is no significant conductor in the area.

c) A Max-Min profile over a Rosebery Pb-Zn massive sulphide vein. This profile was taken along line 5,375,000mN, which is north of a small, disused open-cut on Mt. Black (north of the present open cut). A massive sulphide vein of pyrite with sphalerite and galena outcrops on the line at 378,555mE; it is about 1m wide and dips about 60°E. The 1m width persists

to a depth of at least 100m, but it eventually broadens and is 7-8m wide at 300m.   In the open cut, pyritic black shales occur immediately on the hanging wall for about 60m.   To the east of these are massive pyroclastics.

The Max-Min survey used a 100m coil spacing with a 20m reading interval. Two minima were recorded, about 60m apart; the dominant one to the east, with a weaker one to the west.   The eastern low coincides with the centre of the wide band of black shales; the weaker low is some 20-25m to the west of the mineralisation and is over (siliceous) footwall schists.   The results also show a strong 'regional' effect, the in-phase values on the eastern end of the profile being still very negative.

The western minimum maybe due to the receiver being directly on outcropping black slates (assuming the receiver was to the east); and the 'regional' may be due to the transmitter being on or very near to these slates (a topo-graphic effect may also be contributing, although the profile was apparently pegged at equal horizontal intervals).   Certainly there is no low directly associated with the mineralisation; detailed surveying over this narrow vein is needed to see if the mineralisation is sufficiently conductive to respond to this method.   This site is an excellent one for the testing of geophys-ical methods and equipment.   In particular, tests could be made to see whether the ore-body might be distinguishable, geophysically, from the black slates.

d)   Pulse EM (Crone PEM) response near the Hercules Mine.
Figure A8 shows a weak PEM anomaly over mineralisation beneath line 8S, south of the Hercules Mine.   A Max-Min survey was carried out over this line, however the results were such that the instrument was thought to be faulty.   (Two spacings, 200ft and 300ft were read, and anomalies were obtained in quite different positions.   Also, for each spacing, the pro-files of the five frequencies were nearly identical).   The line is to be resurveyed in the 1981/82 field season and the results will be added to this report.
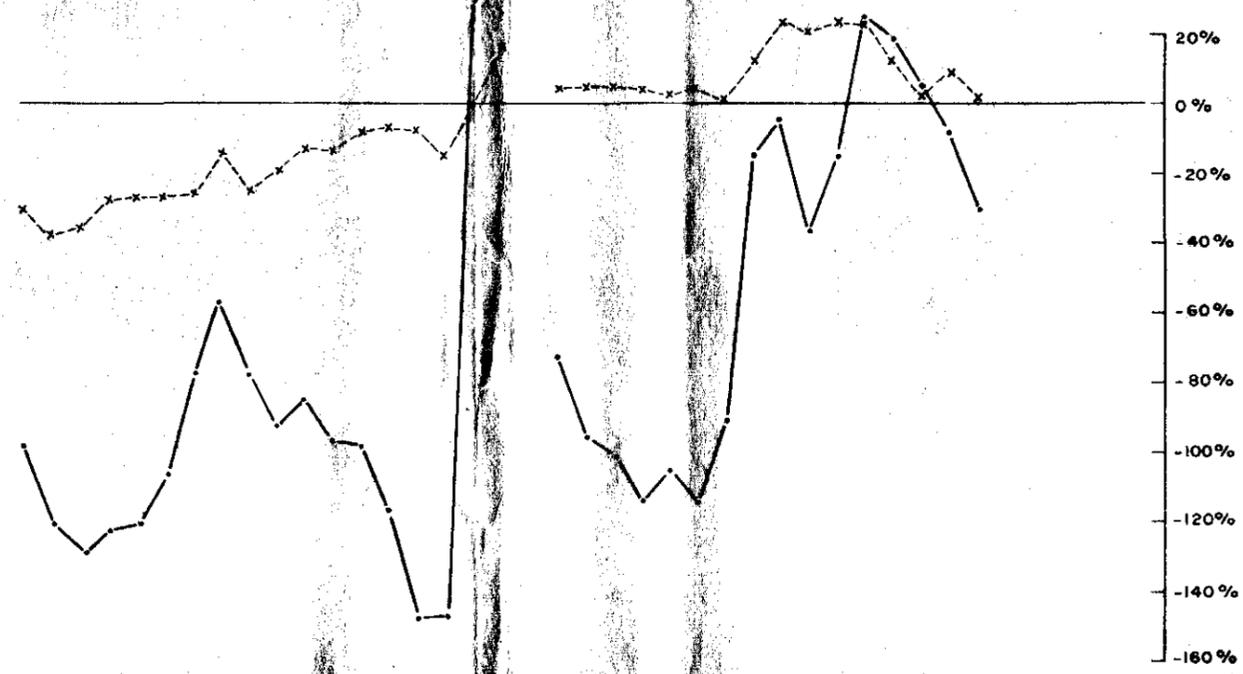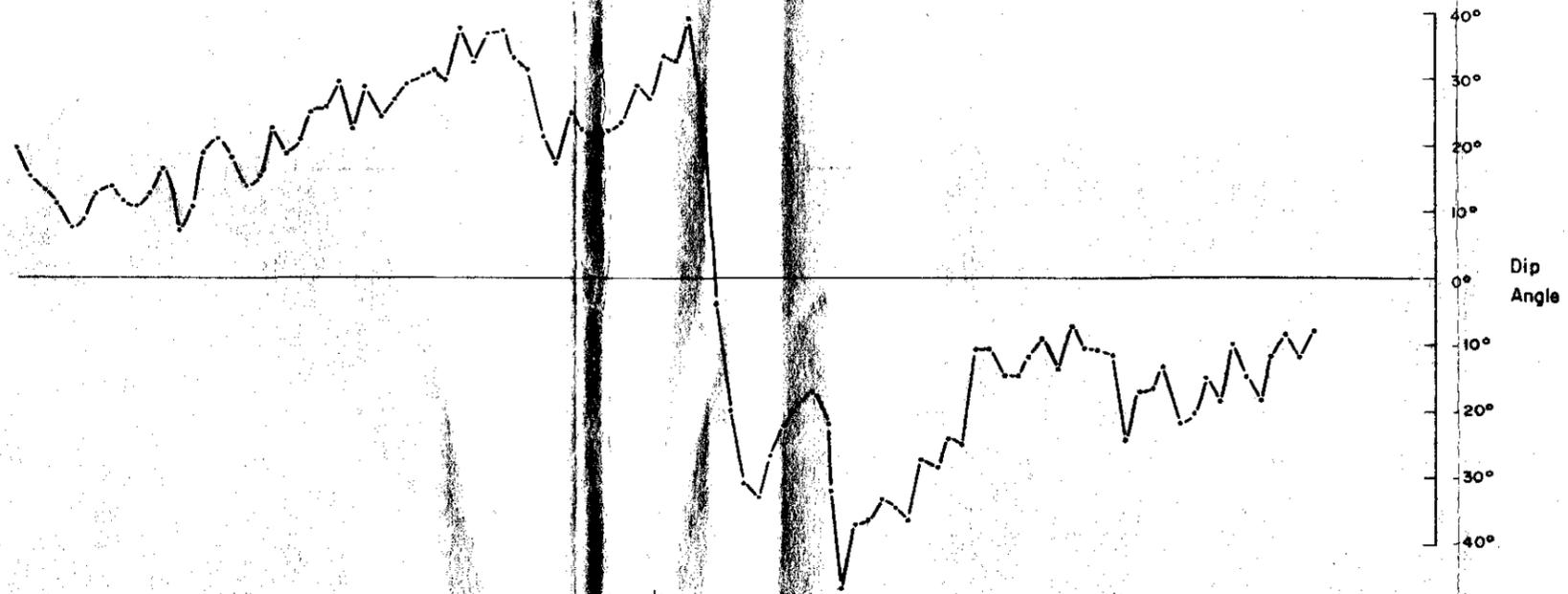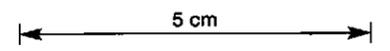
VLF, Max.-Min. and Dighem Anomalies Line 5,371,700 N — Colebrook Hill
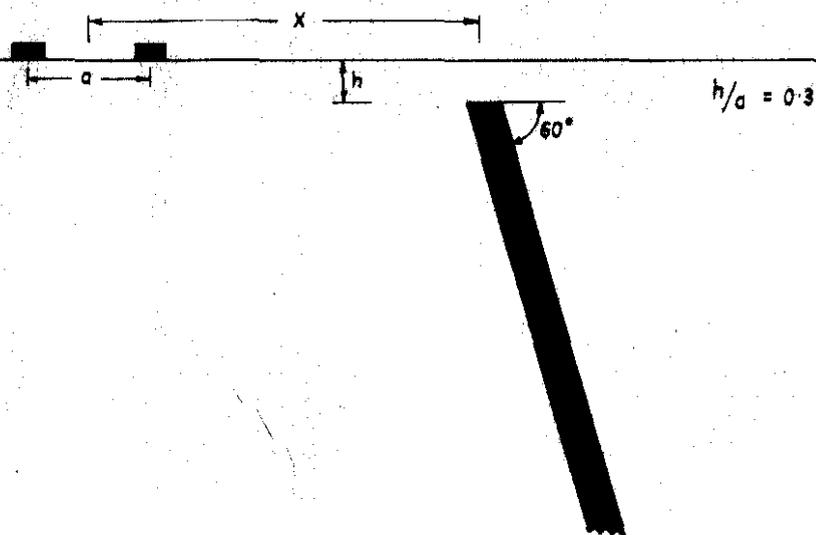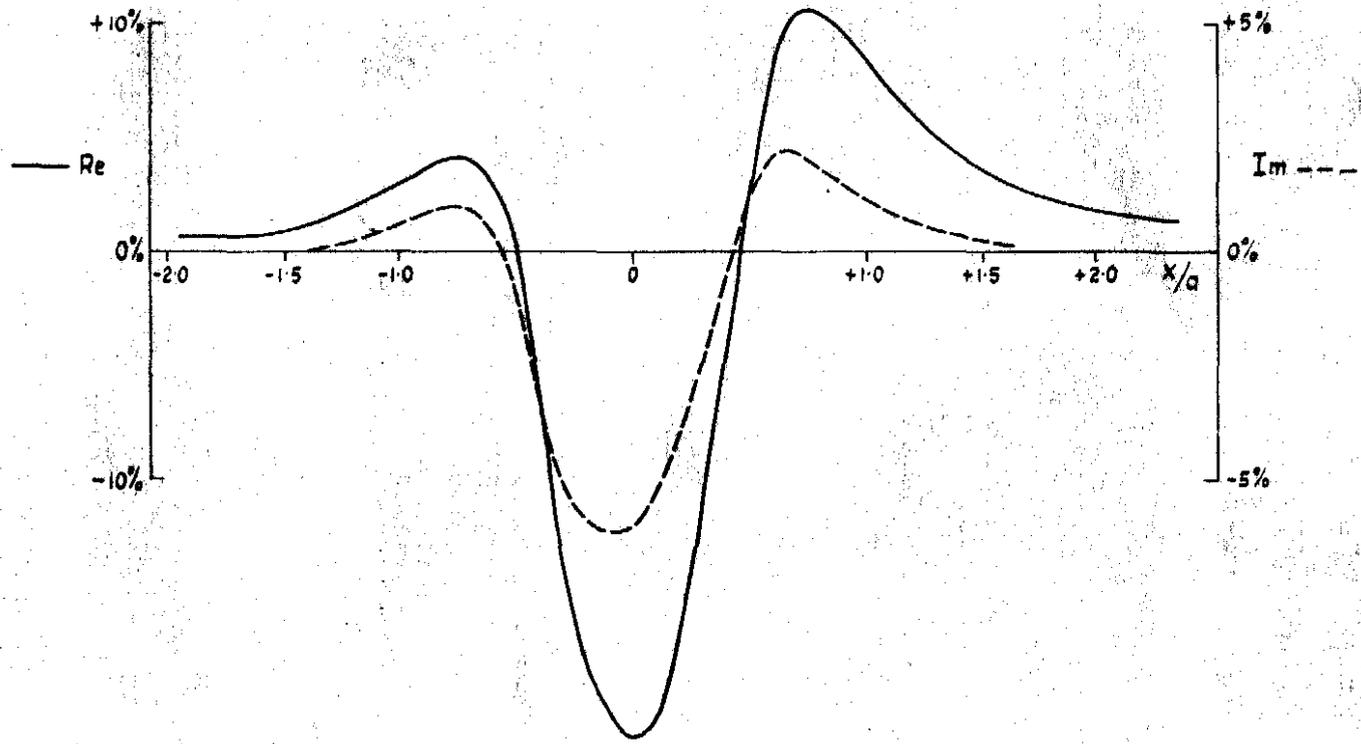
NOTES: Results from a model
experiment using a
good conductor (zinc)
in an insulating
host (air).
frequency = 3600 Hz.

model parameters
$\theta \mu \omega a \delta = 29.7$
$a = 10 cm$
$\delta = 0.82 mm$
$\theta = 12.76 \times 10^6 \; mho/m.$

$h/a = 0.3$

MITRE GEOPHYSICS PTY. LTD.

HORIZONTAL LOOP E.M. RESPONSE

OVER A STEEPLY DIPPING CONDUCTOR

DRAWN J.B	SCALE	FIG. A1
TRACED T.G.D.S	DATE March 1981	

888 Hz

Measured (true) tilt = 45%
Readings were then taken
with tilts of 0,10,20,30,40%
and 45% repeated.
50m coil separation.

tilt (of Tx & Rx)
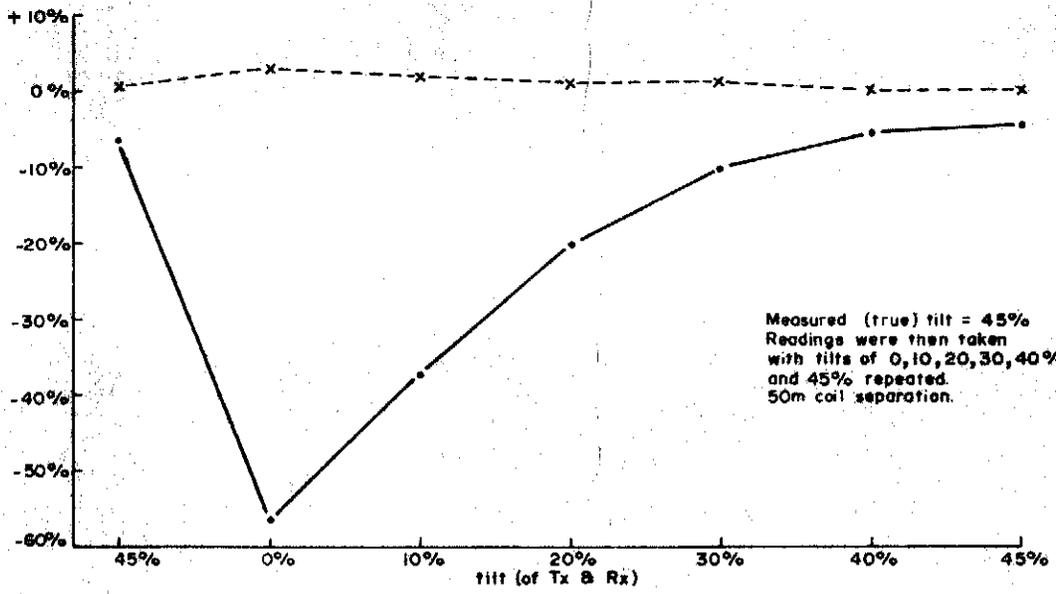
(a) Response to changes in tilt:receiver and transmitter
with the same tilt.

3555 Hz

True tilt 0%
50m coil separation

Coils parallel / 0% tilt — Rx 5% tilt towards Tx (Tx 0% tilt) — Tx 10% 'sideways' (Rx 0% tilt) — Tx 20% 'sideways' (Rx 0% tilt)
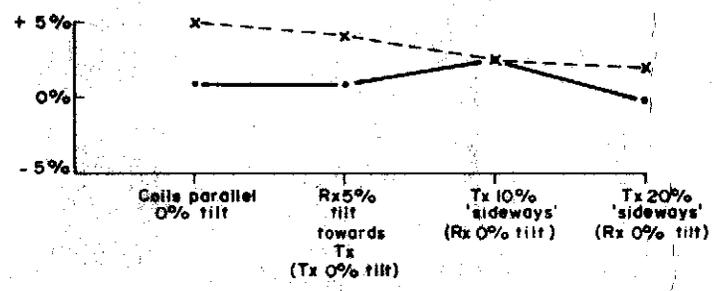
(b) Response to changes in tilt:receiver and transmitter
with different tilts.

3555 Hz

(tilt 0%)

KEY

●————● Real

x—————x Imag.

50m · 49m · 48m
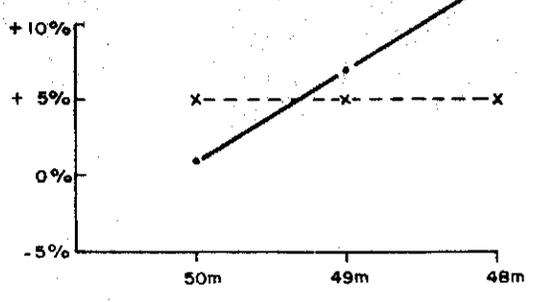
(c) Response to changes in coil separation.

MITRE GEOPHYSICS PTY. LTD.

Responses to Changes
in tilt and coil separation.
(Line 23N East Tyndall Grid)

DRAWN: J.B.	SCALE:	
TRACED: T.G.D.S.	DATE: May, 1981	**FIG.A2**

29C016

magnetics

100 ft.

altitude

100 gammas
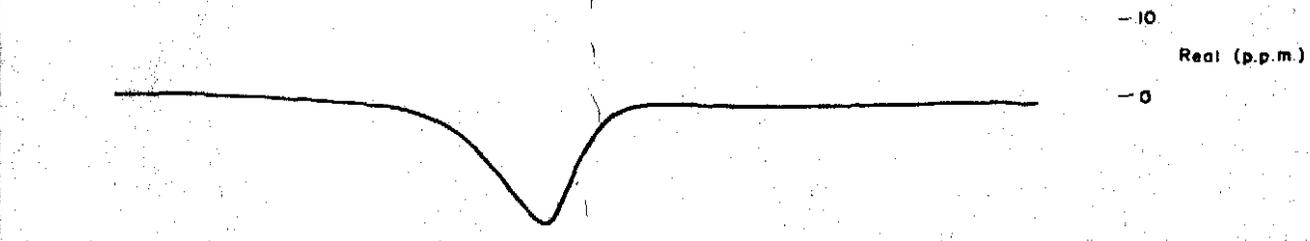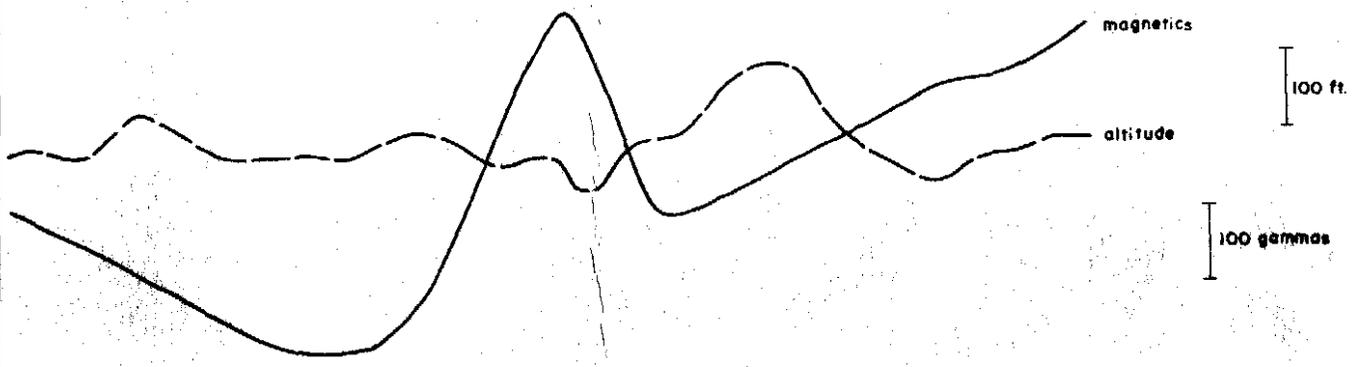
—10

Real (p.p.m.)

—0

Co-axial (Standard) coils

—10

Imag. (p.p.m.)

—0

—10

Real (p.p.m.)

—0

Coplanar (wholetail) coils

—10

Imag. (p.p.m.)

—0

Flight Line No.120

1093   1092 1091   1090 Fiducial No.
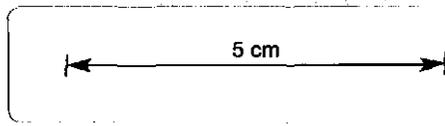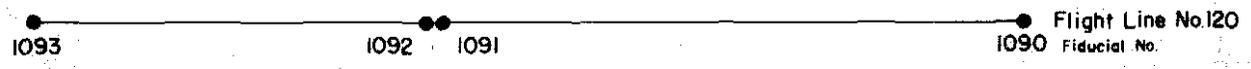
MITRE GEOPHYSICS PTY. LTD.

Dighem Results
over the Selina
pyrite body.

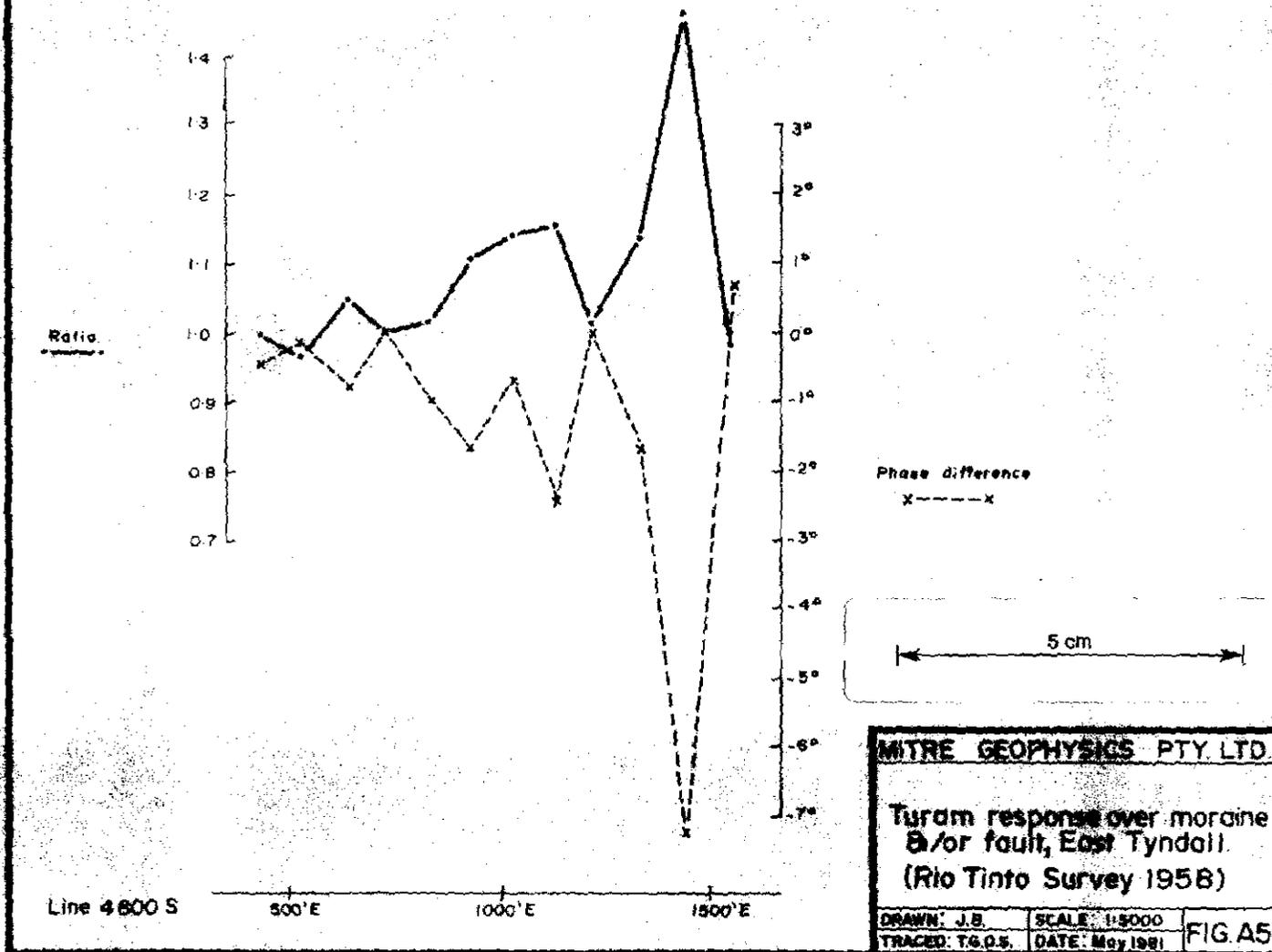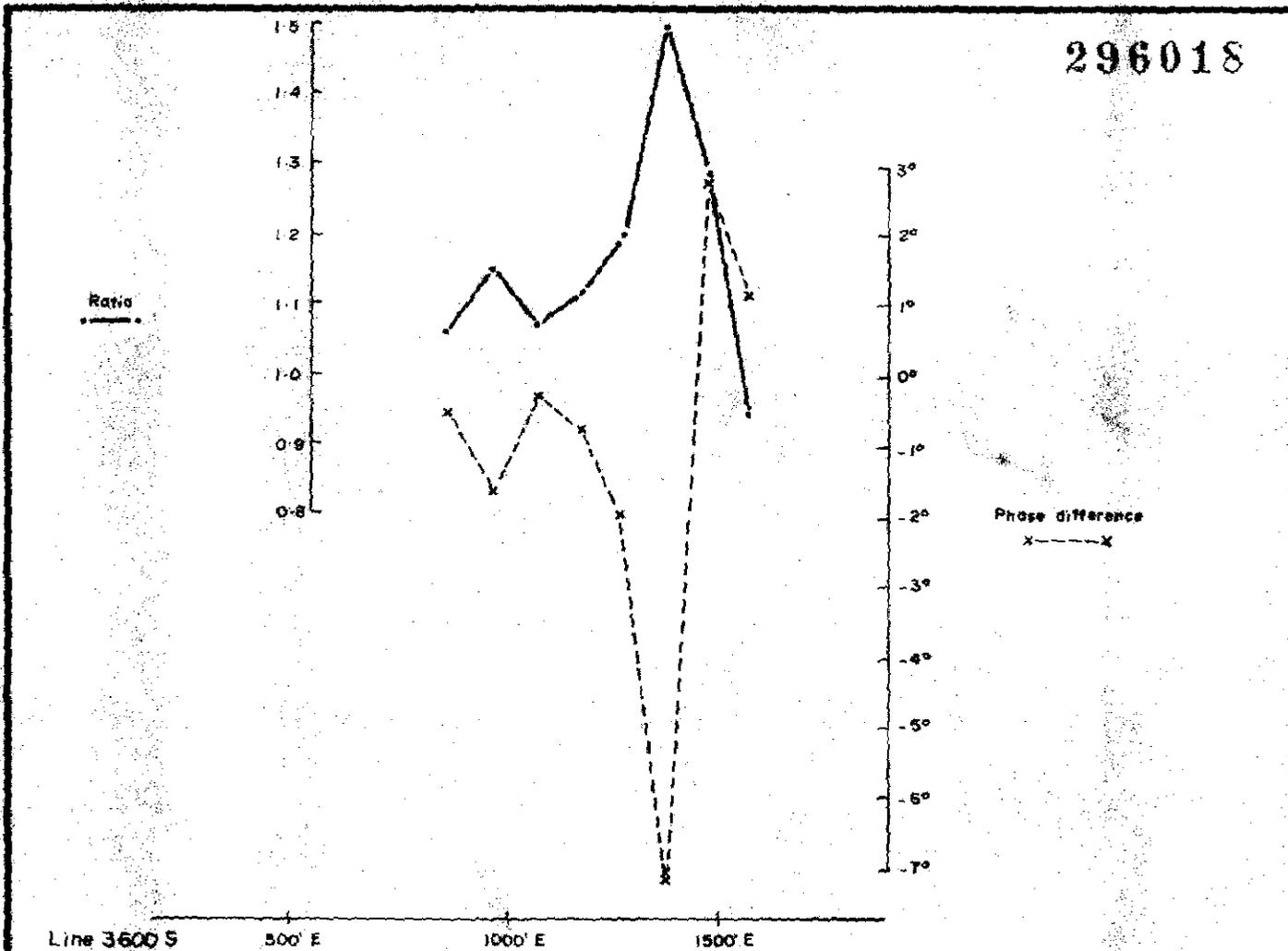| DRAWN: J.B. | SCALE: 1:10,000 | FIG. A3 |
| TRACED: T.G.D.S. | DATE: May 1981 | |

5 cm
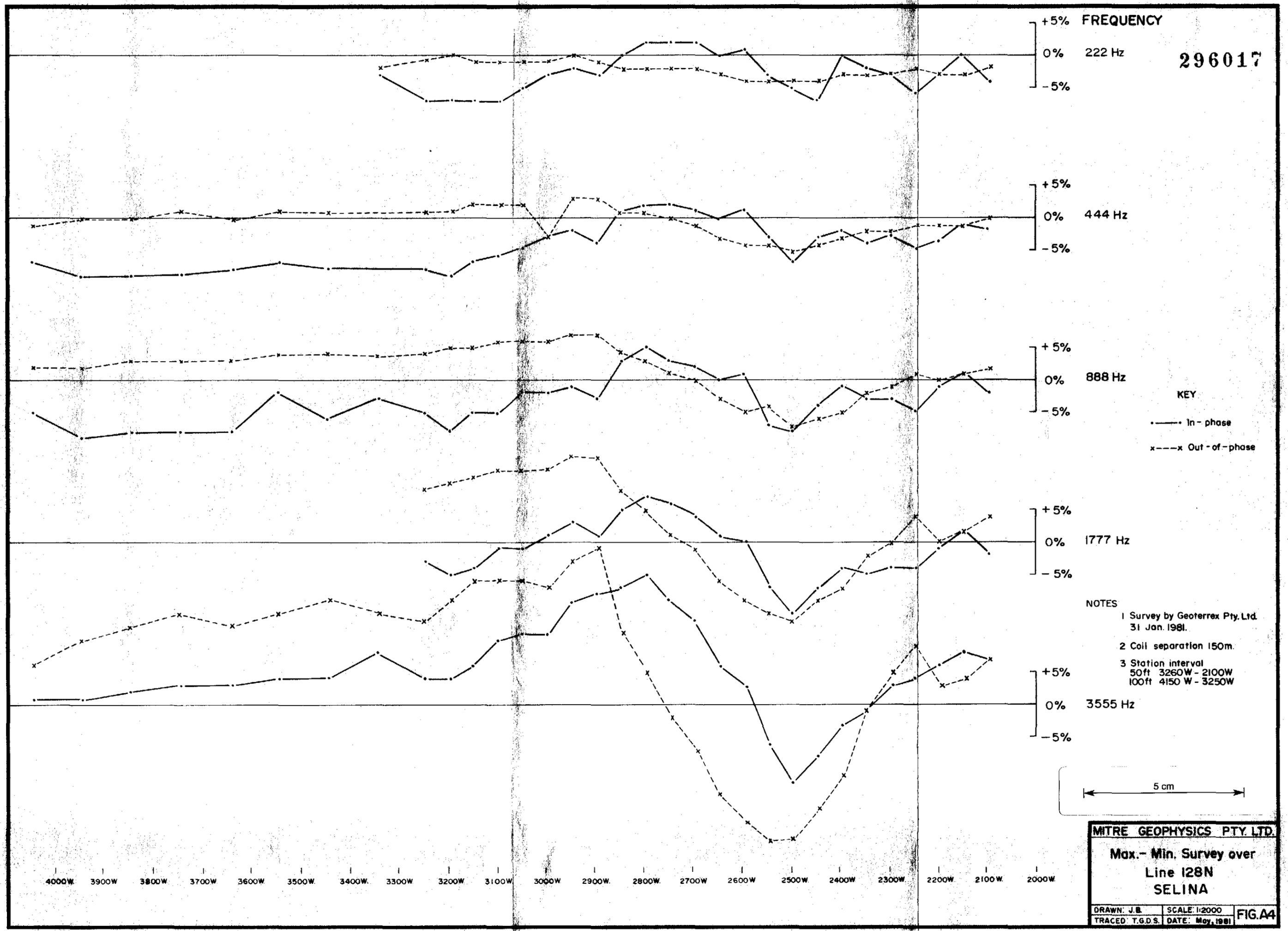
Max.- Min. Survey over Line 128N SELINA

Turam response over moraine &/or fault, East Tyndall. (Rio Tinto Survey 1958)

MITRE GEOPHYSICS PTY LTD

DRAWN: J.B.   SCALE: 1:5000
TRACED: T.G.O.S.   DATE: May 1981   FIG. A5

FREQUENCY

+5%
0%   222 Hz
-5%
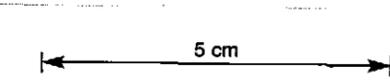
+5%
0%   444 Hz
-5%

+5%
0%   888 Hz
-5%

+5%
0%   1777 Hz
-5%

+5%
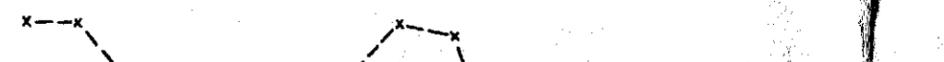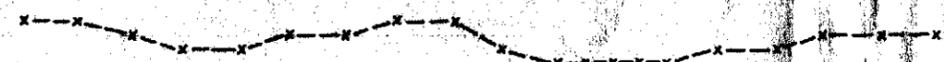0%   3555 Hz
-5%

KEY

•—• in - phase

x—x Out - of - phase

NOTES

1 Survey by Geoterrex Pty Ltd
  30-31 Jan 1981

2 Coil separation 150m

3 Station spacing 50 ft (15m)

| 0 | 100E | 200E | 300E | 400E | 500E | 600E | 700E | 800E | 900E | 1000E | 1100E. feet |

5 cm

MITRE GEOPHYSICS PTY. LTD.

EAST TYNDALL GRID
Horizontal loop (Max.- Min.)
E.M. Survey
LINE 23 N.

DRAWN J.B.	SCALE 1:2000	
TRACED T.O.S.	DATE March 1981	FIG. A6

FREQUENCY

+20%
+10%
0 — 222 Hz
-10%
-20%
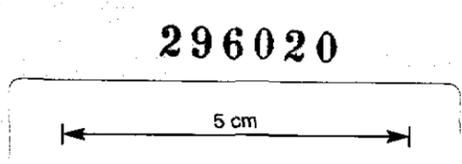
+20%
+10%
0 — 444 Hz
-10%
-20%

+20%
+10%
0 — 888 Hz
-10%
-20%
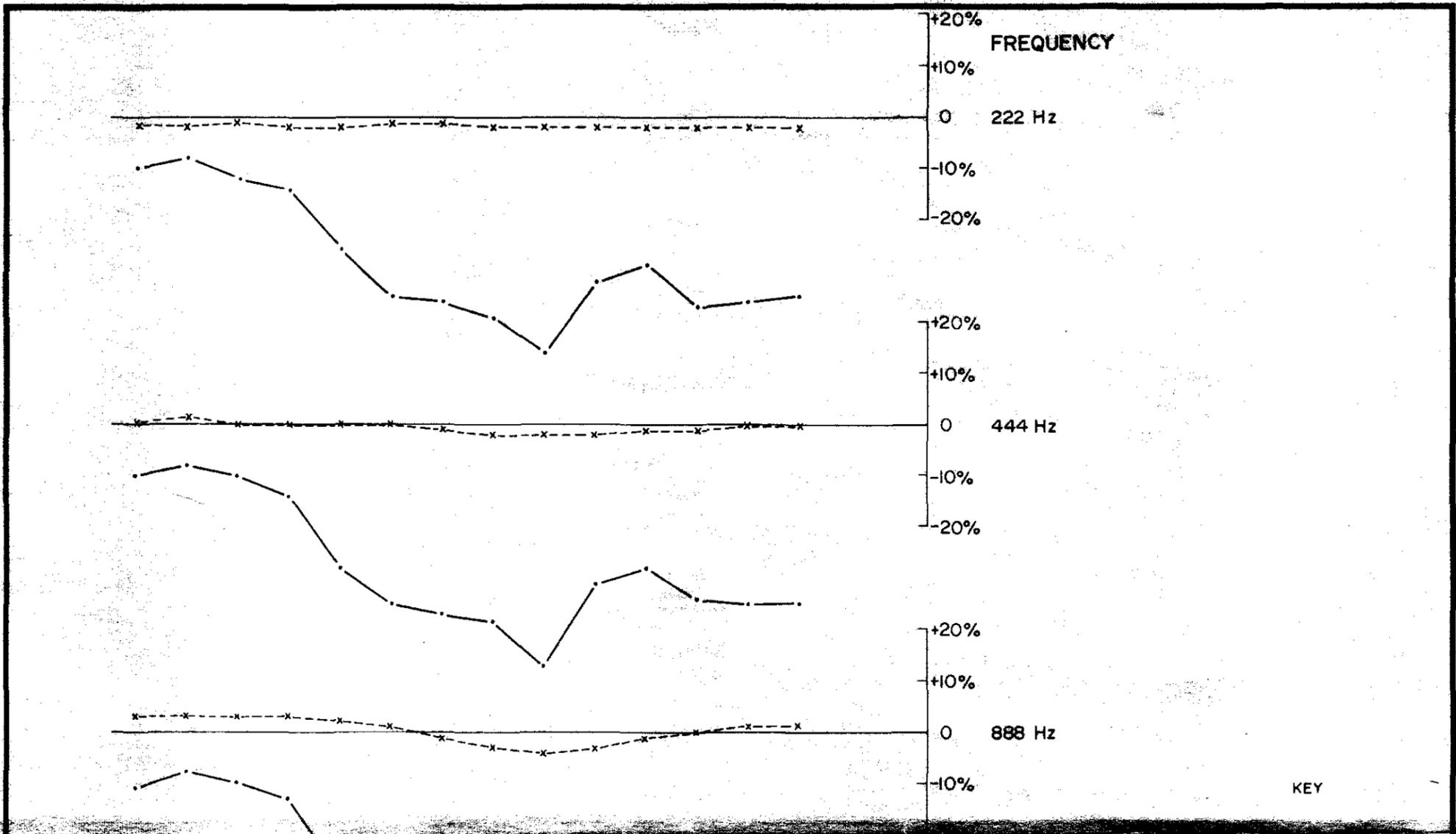
KEY

x——x Out-of-phase

NOTES
Coil spacing 100m
(horizontally corrected)

+20%
+10%
0 — 1777 Hz
-10%
-20%

+20%
+10%
0 — 3555 Hz
-10%
-20%

Topographic Profile
5,375,000 N.

Massive
pyroclastics

black slate

Cherty F/W
pyroclastics

pyritic
host
rocks

Pb-Zn massive
sulphide vein.
~1m. thick.

378,420 E   378,460 E   378,500 E   378,540 E   378,580 E   378,620 E   378,660 E   378,700 E   378,740 E
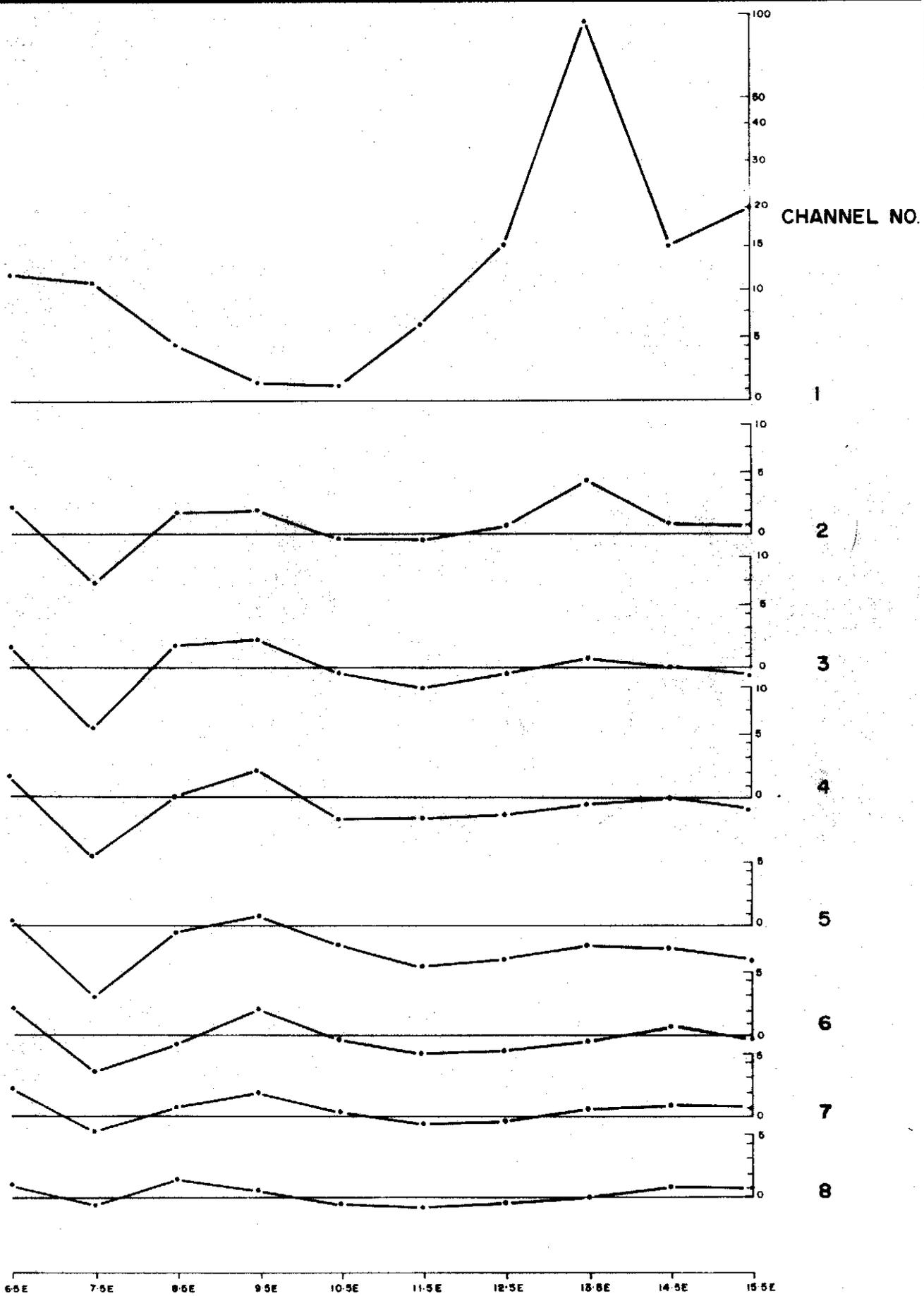
296020

5 cm
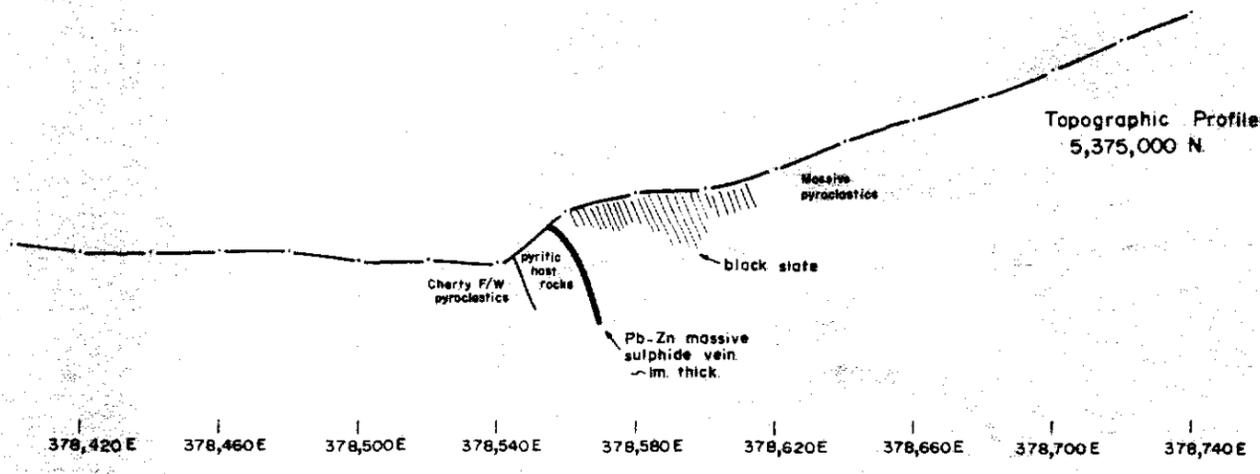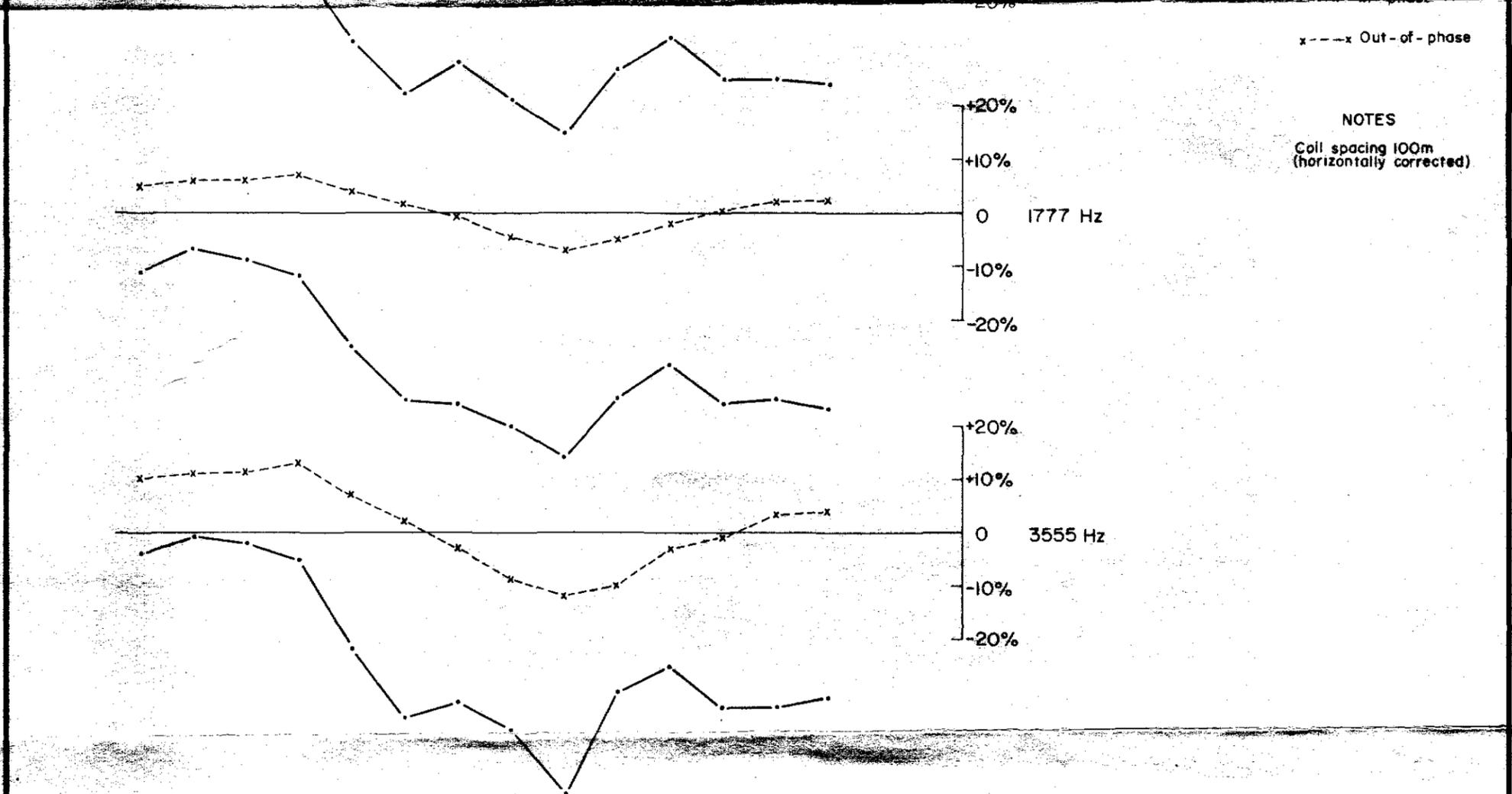
MITRE GEOPHYSICS PTY. LTD.
Max.- Min. profile over
Line 5,375,000 N
near Rosebery open-cut.

| DRAWN: J.B. | SCALE: 1:2000 | FIG. A7 |
| TRACED: T.D.S. | DATE: May, 1981 | |

CHANNEL NO.

NOTES: Survey by Geoterrex,
February 1977
Tx - Rx spacing = 100ft.

5 cm

296021

MITRE GEOPHYSICS PTY. LTD

Pulse E.M. Survey over
Hercules Mine
Line 8S

| DRAWN: J.B. | SCALE 1:2000 | FIG.A8 |
| TRACED: T.G.D.S. | DATE: May 1981 | |