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NOTES ON
PROPOSED HELICOPTER E.M. SURVEYS
AND
SELECTION OF PAPERS

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SCINTREX PTY. LTD.

GEOPHYSICAL CONSULTANTS AND CONTRACTORS

6th June, 1977 Sydney

Mount Lyell Mining & R'way Co. Ltd.,
Queenstown Tasmania

Attention: Mr. K. Reid, Chief Geologist
Mr. R. Mears, Senior Exploration Geologist
Mr. A. Walters, Geologist

Dear Kerry, Russell and Andy,

re: Helicopter EM Surveys in the
Mt. Read Volcanics

This is a very preliminary note on the above subject with some background information on the subject.

1 - The Nature of the Mineralisation

Without "naming names", you will be aware of my considerable knowledge of the geophysical nature of known lead-zinc-copper occurrences in Tasmania, and indeed, in Australia. In general, these deposits cannot really be considered to be "conductive" as a whole in the conventional sense. Pyrite-lead-zinc assemblages are not generally conductive, and such bodies, even when the conductive sulphides make up to 20%+ of the volume, have bulk resistivities of tens to hundreds of ohm-metres rather than fractions of ohm-metres. However, the addition of copper to such an assemblage (i.e. significant pyrite 15%+), has the effect of increasing the conductivity markedly.

In your own experience, this can be seen in the results from Henty Fault zone, and Cape Horn, where copper is related to conductivity. It is said that this is true also at MacIntosh River where the "copper body" is very much less resistive than the lead-zinc body.

Now this relationship also holds true for all lead-zinc

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Page - two

mineralisation in Broken Hill, Western Australia, Queensland, etc. That is, pyrite-lead-zinc mineralisation when lean in copper, while being less resistive (i.e. 10 - 100 ohm-metres) than the enclosing rock types (generally thousands of ohm-metres) *are not* conductive in the electromagnetic sense.

2 - Conclusions from Above

i.....It is therefore concluded that an airborne EM system will only locate those bodies which are truly "conductive", which based on extensive down hole and core measurements clearly means those bodies which carry copper.

ii.....It also follows that because the bodies are not "super conductive" a *higher* frequency should be used to energise them. This is more fully explained below, but in brief, "the higher the frequency used, the less conductive the zone requires to be to produce a significant response".

iii.....As one experience within the Mt. Read volcanics shows, other geologic units can produce anomalous responses in most respects similar - namely, shales.

iv.....Also button grass plains and *some* moraines are seen as *weakly* conductive sheets.

In summary then, the argument for using HEM will be in a search for the copper bearing pyrite-zinc-lead bodies and should be a "first pass" operation only, and should not be considered to rule out the occurrence of pyrite-lead-zinc bodies *lean* in copper.

3 - Practical Considerations - Terrain

Much of the area you wish to cover is undoubtedly rough from a terrain point of view. Now it is essential that the EM system to be used should be placed as close to the ground as possible. This necessarily means a helicopter in Tasmania. Now there are

two possibilities; Turair, which uses a fixed loop laid on the ground by the chopper, and operates at 200 cps or 400 cps, and HEM-701 which operates on *in phase* and *out of phase* at 1800 cps.

In a previous note (copy enclosed) I have gone into details on the difference between Turair and HEM. In that memo, I came to the conclusion that because of the terrain problem, Turair would be the superior method. However, there may be merit in using HEM at the *higher frequency*, providing a number of other measures are carried out also...

a.....close line spacing of 100 metres, bearing in mind the essentially limited strike manifestation of these deposits (e.g. MacIntosh River). As HEM could be as much as *half* the Turair cost, this could be considered cost effective.

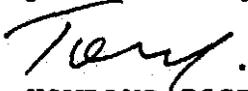
b.....in areas where the terrain does not permit terrain clearance sufficiently low for adequate coverage in both directions, the survey may have to be flown in *one direction* only.

c.....in certain "shadow" areas, difficult to get to by any other means, lines should be flown parallel to terrain (e.g. in the Henty River area ?)

In the letter referred to above, there are some comparable cost estimates of about \$11.^x20 per kilometre for HEM-701 and about \$25.^x00 per kilometre for Turair.

I will talk with my colleagues in Perth and follow up with a further note and contract proposal for your consideration in the next two weeks. It will take some time to get accurate costings, but I think the above estimates will do for budgetary purposes. Not included is mobilisation, but perhaps we can get one or two others interested.

Best personal regards,


A.W. HOWLAND-ROSE
MANAGING DIRECTOR

AWHR:LK

* probably a bit low!

9th October, 1974 Sydney

Mount Lyell Mining & R'way Co. Ltd.,
Queenstown Tasmania 7467.

Attention: Mr. K. Reid, Mr. K. Wells

Dear Kerry and Keith,

re: The Search for Rosebery-Hercules Deposits in
the 50-70 Square Miles of West Tyndall

I was pleased to be able to debate with you the pros and cons of the various geophysical approaches to apply in your forthcoming exploration for Rosebery/Hercules type deposits in West Tyndall.

I set down some of my thoughts on the subject based on work carried out over similar deposits not only in your region, but elsewhere.

1 - Basic Considerations

a) The Area

The facts as I understand them are:

- (i) The area is rugged
- (ii) The area of interest covers 50 - 70 square miles
- (iii) Much of the area would be covered with moraine and/or non-residual soils.

b) The Type Mineralisation

The geophysical characteristics of the type mineralisation are as follows:

- (i) Although the sulphides invariably have a "massive" appearance, as often as not they are not electrically continuous, and therefore do not conduct well and do not form electromagnetic targets.
- (ii) When these deposits are conductive, they are "weak" to "moderate" in strength, as would be expected from the

005
 Page - two

mineralisation. (The phrase "weak" refers to their conductivity and not the size of the anomaly).

- (iii) Quite frequently only a portion of the body will in fact conduct sufficiently well to form an electromagnetic conductor therefore frequent line spacing is a considerable advantage. It is not logical to use the usual concept of "line spacing of 2/3 of the strike length of body", but "2/3 of the expected strike length of the conduction within the body". This is a very important consideration, ~~as for~~ although these bodies are not as conductive as visual inspection may suggest (see (i) above) they are often conductive in part.
- (iv) The deposits are surrounded by a significant disseminated pyritic halo as seen via their associated induced polarization responses, particularly along strike, but also across strike.
- (v) Although not a geophysical characteristic, but certainly of great significance, is the fact that all bodies of this type carry mercury within the economic portion of the mineralisation within the range 5 ppm to in excess of 50 ppm. In Canada, Europe and apparently Australia, mercury can be quite clearly detected within the non-residual soils and moraines in quantities 10 to 100 times greater than the detection limit the HGG-3.

a
~~pr~~ The Available Airborne Systems ↓

Assuming that one phase of the search programme is to explore for either (1) Those Pb/Zn/Cu bodies which are conductive and/or (2) the bodies which show some conduction within their strike length, the following airborne electromagnetic systems are available in Australia at this time:

- (i) Scintrex HEM-701
- (ii) McPhar
- (iii) Geotrex Input
- (iv) Scintrex Turair

Each system has characteristics which make it eminently suited for the detection of deposits having certain geophysical characteristics

Page - three

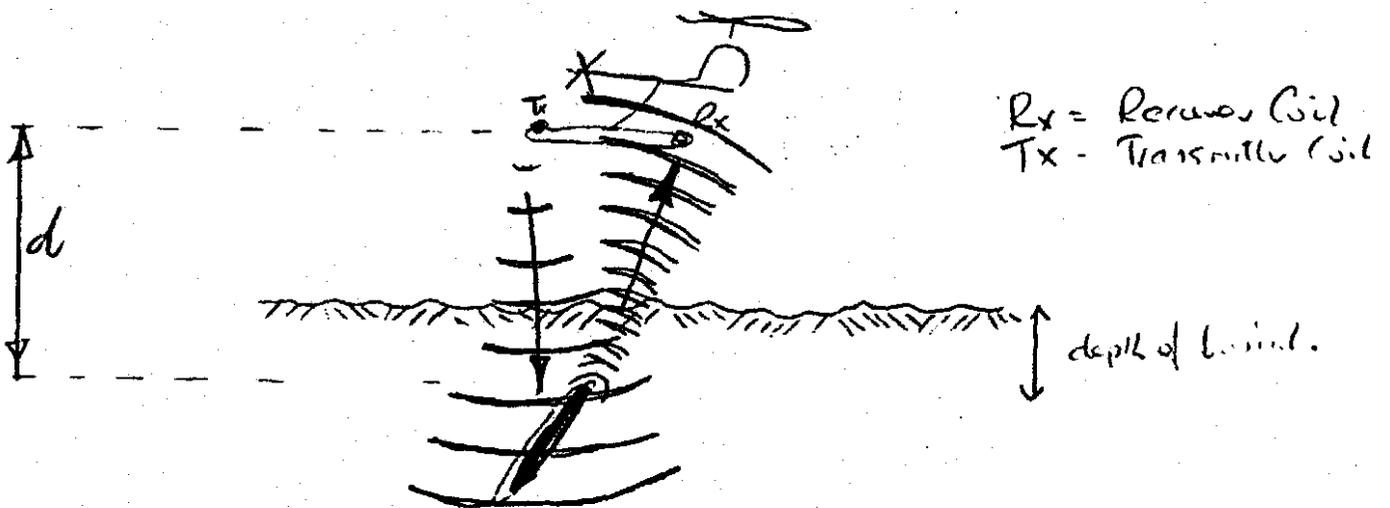
and these are reviewed in detail in the attached list of papers. Very briefly summarising their characteristics, the Scintrex 701 and McPhar 400 type are of similar character in that they are both moving source systems, where the transmitter and receiver are carried in the helicopter, and both are frequency domain systems. These systems are reviewed in detail in Enclosure I (pages 2 and 3, etc.) The Input system employs a large aircraft (Canso) with a towed bird. (See also Enclose I, pages 2 and 3)

(a) Moving Source systems (a) Terrain Depth of Burial

The essential problem with all the above systems in the Tasmanian context is that the transmitter/receiver system must be within 200-300 feet of the target mineralisation or the system cannot respond. Bearing in mind the necessary terrain clearance problems, the helicopter is unable to maintain a bird/surface clearance of 100 feet, which would be essential for penetration of 200 feet below surface. Any increase in height above this limit would reduce the search depth accordingly.

Turair, however, is fundamentally quite different as the system was developed for the sole purpose of deep penetration in areas of rugged terrain. The transmitting loops are laid on the ground as at Lake Selina and only the sensing device is towed by the helicopter. The importance of this distinction is reviewed in detail in the accompanying papers, but as summarised in the diagrams set out below:-

Moving Source Systems (i), (ii) and (iii)

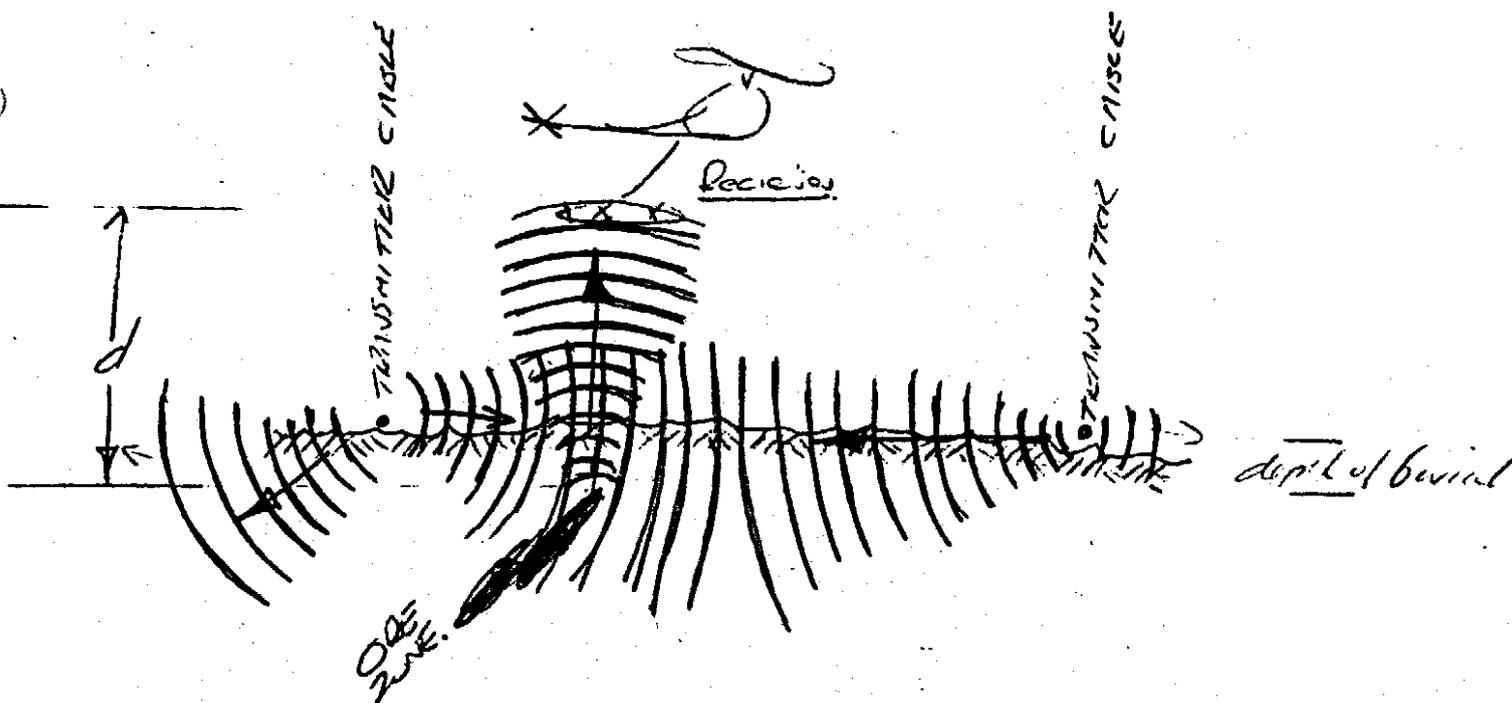


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 Page - four

In the above the transmitter (red) sends out the signal which energises the body at depth (black). The body's response (green) then is monitored by the receiver coil. The response then will tend to vary as $1/d^4$ to $1/d^6$, where 'd' is the distance between the receiver/transmitter and the energising system.

In the case of Turair, however, the way in which measurements are taken are quite different, as the following diagram shows:

Turair (Fixed Source) System (iv)



In this case the energising source is on the ground and a strong energising field is guaranteed to a depth of 500 metres by the large motor generator used. The only variable now, is the distance of the receiver from the body, and in this case the response will be as $1/d^2$.

Where the differences in response become critical is for deeply buried

bodies, and in areas where the terrain simply precludes the chopper from getting a moving source system close enough to the ground. By way of illustrating this point, for a moving source system if the distance is doubled the signal strength drops to 1/16th to 1/32nd of its strength, while for fixed source systems the fall off is only 1/2. This is quite clearly illustrated in the example over Whundoo (W.A.) shown in Enclosure 2, page 22, a discovery in Manitoba, Enclosure 2, page 19 and in Enclosure 4. In a nutshell, this is why you should use Turair rather than a moving source system if EM is to be considered in your terrain conditions. *where terrain and/or depth of burial are major considerations*

I could "rave on" further, however, I've really covered the most important points, for further details please see the enclosed papers. I strongly recommend that you read Enclosures 1, 2 and particularly 3, (The latter because it is an independent view by Cominco, which in the current MacIntosh discovery is significant - apparently the local branch haven't seen the paper!)

2 - The Recommended Approach

After our conversations in Queenstown last Thursday, I have given considerable thought to the problem and would make the following recommendations for your programme. These employ two quite distinct techniques for reconnaissance work and should be carried out concurrently.

Mercury Reconnaissance Survey - As our conversations revealed, across-strike walking traverses will have to be cut for mapping purposes over the area of interest. It would therefore be a simple exercise to collect mercury soil samples at 50 metre intervals along these traverses as they are cut. I would suggest a 2 kilometre interval between traverses to commence with, and then come back and put in intermediate traverses at 1 kilometre intervals. I would suggest that this work be commenced as soon as possible so as to give as much consideration to additional follow-up work as early in the season as possible. Samples can be run by us on the mainland or in Tasmania when we are there.

009
Page - six

Basic consideration suggest, and practical survey work confirms, that anomalous mercury in the soils will be seen over a wide area surrounding a deposit and in certain conditions, down slope of a deposit. The target size will be at least 300 metres wide and 1 kilometre to 1½ kilometres in length.

I seem to remember your estimate of the traverse cutting at about \$7500.00, while I estimate the analysis of the samples at about \$500.00 at 100 metres intervals and at the recommended 50 metre station intervals, \$1000.00

Turair Survey - There certainly is a case for using an electromagnetic method in the search for Rosebery/Hercules type mineralisation on the grounds that

- (i) about half of the bodies are conductive to some degree and/or
- (ii) some of the bodies are conductive over some sections within the bodies.

Working on the above premises then, any airborne EM survey must

- (i) have lines spaced at such a distance apart as to maximise the detection of type (ii) above and
- (ii) use a system which will not be unduly influenced by the topography in such a way to render the data acquisition ineffective.

Clearly then, Turair is the only system which meets these specifications

My recommendation therefore is that if airborne EM is to be used, then make sure what is done will be effective. In other words I favour using Turair, but would advise against the other three systems including our own Scintrex HEM-701.

3 - Costing of the Above Proposals

a - Mercury Survey: The cost of in-situ mercury analysis is \$180.00 per day for the hire of operator and equipment. An average of 180 samples can be analysed per diem.

Page - seven

b - A contract and cost estimate in enclosed both for Turair and HEM making the following assumptions:

- (i) The area to be flown is 50 square miles
- (ii) The line spacing is 400 feet, i.e. the total line mileage is about 660 miles.

In both cases I would advise you to consider the data acquisition and the data processing phases separately.

Personally I consider the exercise of flight path recovery, analysis, drafting etc., a futile operation if there are no significant anomalies I suggest you process only those areas which are indicated to be of interest.

Should you wish to adopt this somewhat unconventional approach we could amend the Turair contract accordingly, as it at present includes flight path recovery.

I have also assumed that you would also require measurements of the magnetic field to be made. I certainly advise this.

A precise (within +10m) positioning system can be hired which will literally pin point anomaly positions. The additional cost of such a system is estimated at about \$6000.00 (See attached explanatory material).

Helicopter charges vary between \$200-\$240 per day plus \$120-\$180 per hour. Inquiries made with regard to Tasmania suggest a rate of \$200 per day and \$130 per hour with a small mobilisation charge.

Data Acquisition Cost - HEM

HEM-701 type surveys are of course considerably cheaper as they involve less flying due to no loop laying and of course no wire. A contract proposal for this is enclosed

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Page - eight

70km/day

Cost Estimate (1000 Kilometres)

5 production and standby days at \$300.00	\$ 1500.00
1000 km at \$4.00 per kilometre	\$ 4000.00
Flight path recovery at \$1.00 per kilometre	\$ 1000.00

Less.

Helicopter

5 days at \$220.00/day	\$1100	
28 hours at \$130 (inc fuel)	<u>\$3640</u>	
(35 km per hour flight time)		<u>\$ 4740.00</u>
		<u>\$11240.00</u>

Data acquisition to compilation stage ..

\$11.20 per line kilometre (\$18.00 per line mile)

Data Acquisition Cost - Turair

The data acquisition cost based on recent surveys employing the enclosed format was as follows: (per loop)

Daily charge	\$ 800.00
Helicopter charges \$240 per diem & 5 hours at \$130	\$ 890.00
Mileage charge 270 km at \$16.00 (400' line spacing)	\$ 4320.00
Cost of wire (4 x 3 km)	<u>\$ 750.00</u>
	<u>\$ 6760.00</u>

or approximately \$25.00 per kilometre (\$40.00 per line mile) for data acquisition and flight path recovery. For more intense line spacing this figure would of course increase.

Therefore the data acquisition can be carried out over the 660 line miles at a cost of approximately \$40 x 660 - \$26,400.

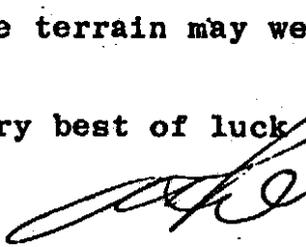
In both the above, mobilisation is additional and final report costs can be estimated at \$1000 - \$1500, providing results warrant. It is also assumed that the magnetics will not be contoured.

I sincerely trust that the above analysis together with the costings and contracts will assist you in your deliberations.

Page - nine

Summing up, a thorough approach would include mercury soil sampling and Turair. I don't favour HEM as even if the target is conductive, the terrain may well preclude its detection.

Very best of luck in your studies!


A.W. Howland-Rose
Managing Director

AWHR:LK

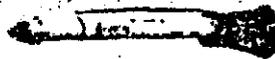
Enclosures:

- 1 - Airborne Electromagnetic Systems, Bosschart & Pemberton
- 2 - Turair, Bosschart and Seigel
- 3 - Deeply Penetrating Surveys in Northern Manitoba - Tikkanen
- 4 - Turair- The State of the Art
- 5 - Advances in Deep Penetration Airborne EM Methods, Bosschart, Seige
- 6 - Comparison Scintrex HEM-701 and Input
- 7 - The Scintrex HEM-701 EM System in Perspective, Bosschart, Campbell
- 8 - Mini Ranger System

013

AIRBORNE

ELECTROMAGNETIC SYSTEMS



R. A. Bosschart,

R. H. Pemberton,



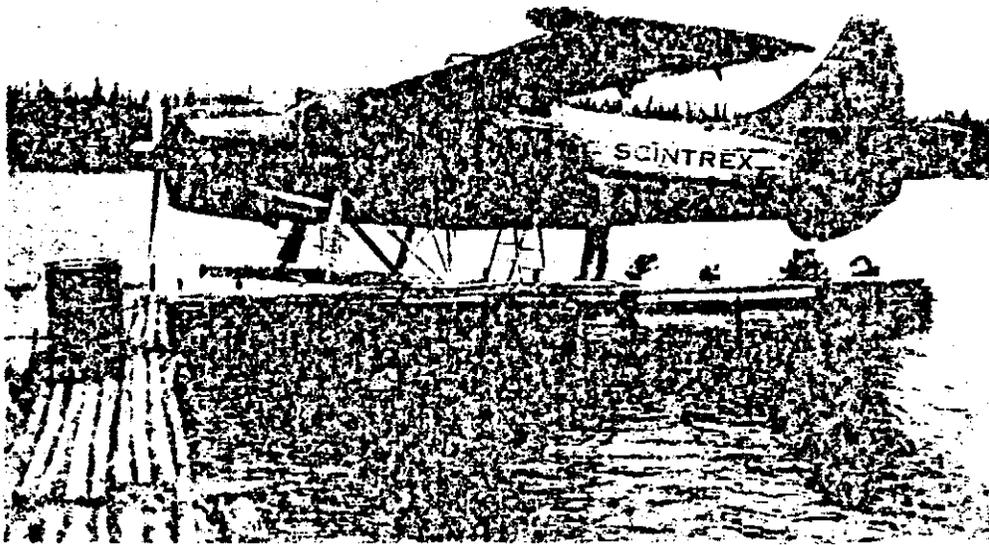
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Scintrex Otter aircraft carrying Electromagnetometer, Magnetometer and Radioactive Spectrometer.

Applications and limitations of AIRBORNE ELECTROMAGNETIC SYSTEMS in mineral exploration

R.A. Bosschart,*

R.H., Pemberton,*

The first successful airborne electromagnetic (AEM) system was introduced in Canada in 1950, and by 1955 a number of systems were in operation. This new prospecting method produced remarkably rapid rewards and proved its value by leading in succession to the discoveries of the Heath Steele ore body in New Brunswick (1953), the Thompson nickel deposit in Manitoba (1955), the Mattagami Syndicate copper-zinc deposit in NW Quebec, the Poirier and Joutel copper-zinc deposits in the same area (1958), the Texas Gulf copper-silver-zinc deposit in Kidd Township, Central Ontario (1962), and others.

Notwithstanding the adage that mine finding is a combination of science, art and luck, and not necessarily in that order, and that the AEM methods employed were not equally valuable or in all cases properly employed, the record has been impressive enough to establish AEM surveying as a first line base metal prospecting tool. As a result we have, to date, seen the development of some 24 different AEM systems.

As seems to be traditional in the geophysical industry, the basic nature of these systems is hidden behind a colourful array of abbreviations and code numbers which are incomprehensible to the uninitiated. Although many systems differ in minor details only, some differences are of crucial significance and have to be fully understood in order to evaluate the suitability of methods for particular search problems. Several writers (e.g. Pemberton, 1962; Ward, 1957, 1967) have sorted and classified the different systems, and their pattern will be followed.

Basically most of the AEM systems employ moving source configurations comparable to moving source systems used on the ground, such as the horizontal loop system. The main factor limiting the sensitivity of these ground systems, i.e. noise arising from the differential movement between transmitter and receiver, is even more significant in airborne systems, where appreciably higher sensitivities are required. Two differ-

ent solutions have been used to overcome this problem: the rigid boom and the towed bird system. In the first, transmitter and receiver are attached to a mechanically rigid structure: the airframe, or a towed boom. Coil separations are of necessity limited, usually between 20ft and 70ft, but because of the high mechanical rigidity, secondary fields can be measured in complex components with great accuracy. In some systems the noise level is lower than 5 parts per million of the primary field at the receiver, even when the structure is moving at normal airspeeds under average turbulence conditions.

In the towed bird systems the transmitter is attached to the aircraft and the receiver usually towed behind and below on a 400-500-ft long cable. The relative movement between the two during flight results in random real component distortion that is at all times too high to permit the detection of the real component response of subsurface conductors. In order nevertheless to obtain diagnostic information, some systems measure the largely unaffected imaginary (quadrature) component at two discrete frequencies (Hunting Canso, Lockwood, McPhar) or compare different components at the receiver which are affected at the same rate by the movements of the receiver platform relative to the transmitter (Inco, ABEM Rotary Field). In the only time-domain AEM system (INPUT) the movements of the receiver are of little significance, because transmission and reception are separated in time.

RIGID BOOM SYSTEMS

All present rigid boom systems measure complex components at a single frequency. The difference between systems is mainly in coil configuration, coil separation, and in operating frequency.

The Nucom system. The Nucom system (Fig. 1a) developed by American Metals in 1955, was the first rigid boom system. It employed a 20-ft bird towed on a 100-ft cable by a helicopter, containing transmitter

* Scintrex Limited.

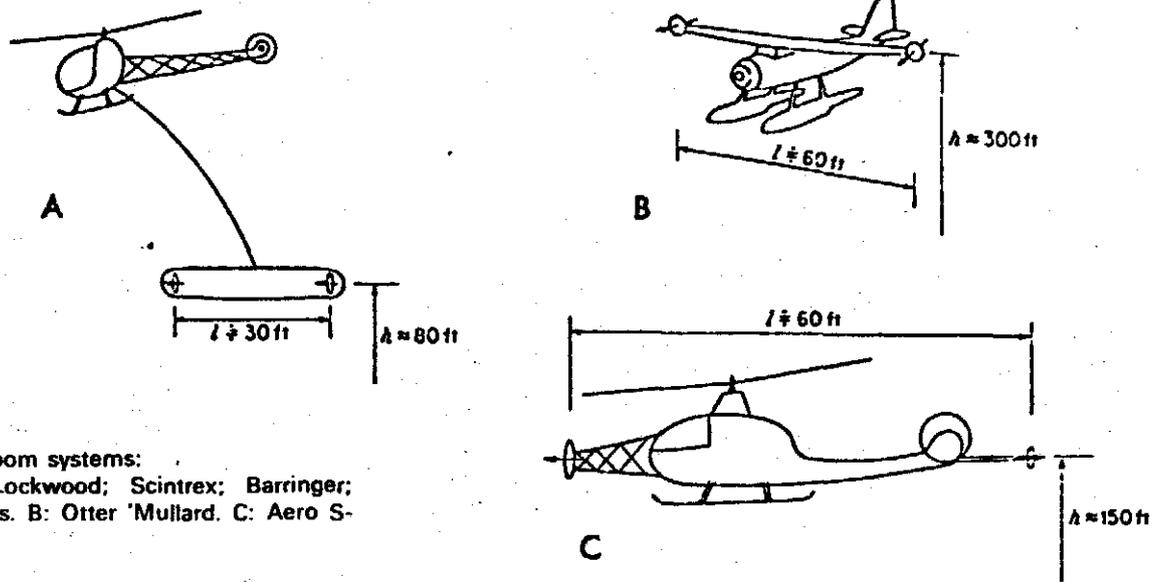


Fig. 1. Rigid boom systems:
 A: Nucom; Lockwood; Scintrex; Barringer;
 H.E.M. systems. B: Otter 'Mullard. C: Aero S-
 55. D: T.G.S.

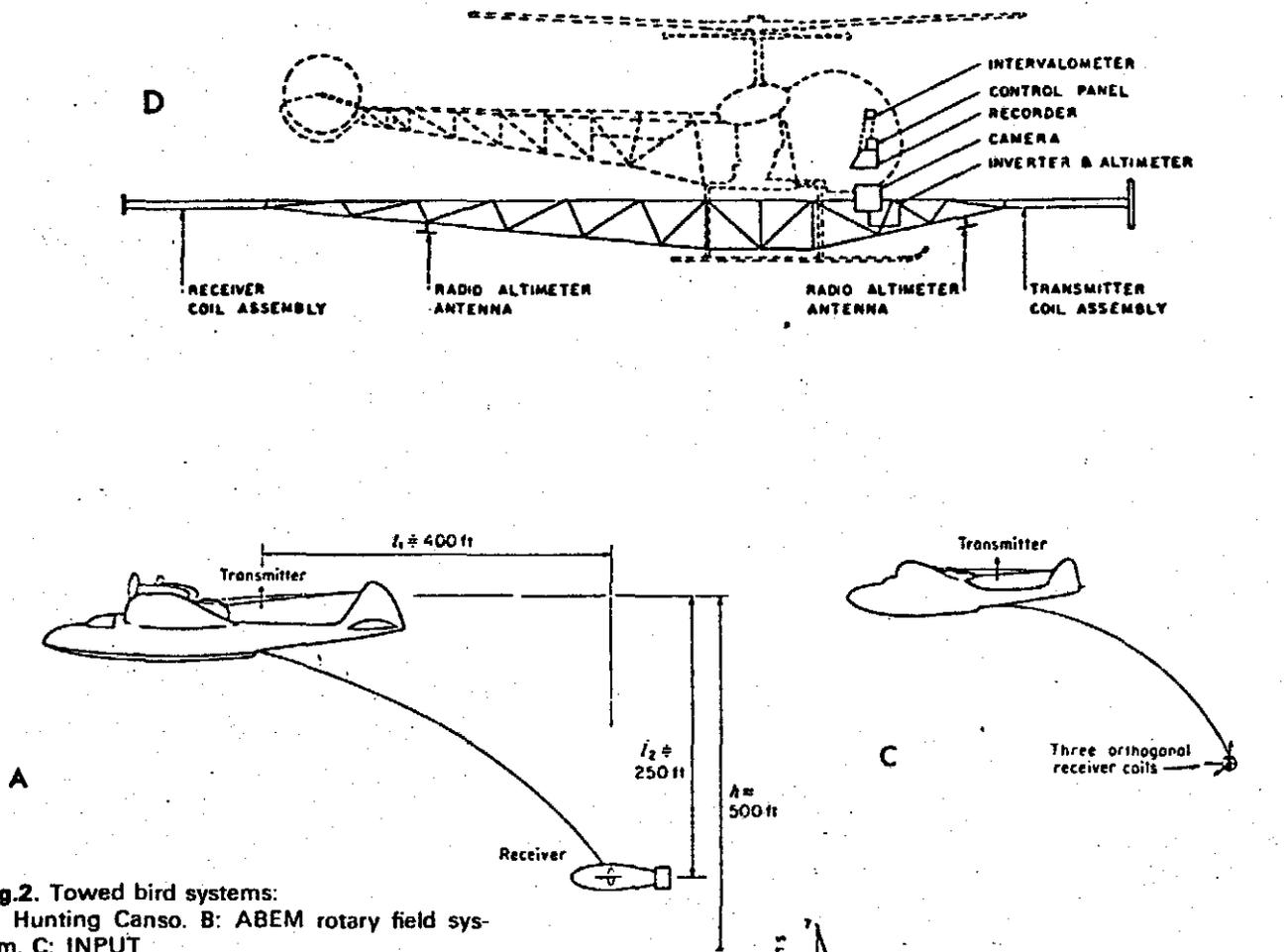
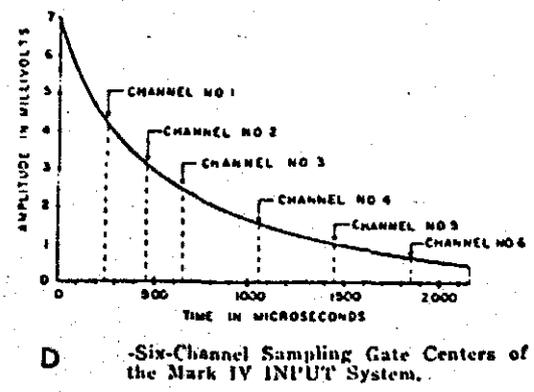


Fig. 2. Towed bird systems:
 A: Hunting Canso. B: ABEM rotary field system. C: INPUT



D: Six-Channel Sampling Gate Centers of the Mark IV INPUT System.

and receiver in a coaxial configuration with the axis in the direction of flight and measured real and imaginary components at a frequency of 1000Hz. The noise level was relatively high, resulting in limited depth of exploration. The system is no longer in active use.

The Aeromagnetic Surveys (presently Lockwood) helicopter system. The Aeromagnetic Surveys helicopter system was developed shortly after the Nucom system and is very similar, the only difference being a higher (4000Hz) operating frequency. In 1962 the coil separation was increased to 30ft whereby the sensitivity was increased. The system is in active use, although the high operating frequency limits its applicability in the presence of conducting overburden.

The Mullard system. Rio Tinto Mining introduced the Mullard system in 1956. Transmitter and receiver are mounted in a vertical coplanar orientation on the wing-tips of a DeHavilland Otter STOL aircraft (separation 62ft) (Fig.1b) and the system measures complex components at an operating frequency of 320Hz. After four years operation it was taken over by Canadian Aero Service. It is now operated by Canadian Aero Mineral Surveys Limited. A second unit is at present operated by Scintrex Limited.

The Canadian Aero S-55 system. The Sikorsky S-55 helicopter mounted system was introduced at the same time as the Mullard system. Transmit and receive coils were mounted coaxially in the flight direction fore and aft of the helicopter, whereby a separation of 60ft was achieved (Fig.1c). Operating frequency was 390Hz, and the parameters measured are real and imaginary components. Although excellent, the system was obsolete because of the high cost and poor performance of the S-55 helicopter compared with modern turbo-helicopters.

The Varian TGS system. The Varian TGS system, first employed in 1959, was very similar to the S-55 system. The coaxial transmit and receive coils were mounted on a 50-ft rigid boom carried between the skids of a Bell G-2 helicopter (Fig.1d). Operating frequency was 400Hz, and complex components were measured. Although very successful, the unit has not been operated since a fatal crash a few years ago in which a geophysicist and a pilot were killed.

The Scintrex HEM-701 system. The Scintrex helicopter system, introduced in 1967, is similar to the Nucom and Lockwood systems (Fig.1a) but for a different frequency (1600Hz) and a lower noise level (3-5 ppm).

The Barringer system. The Barringer helicopter system, although superficially similar, differs from other systems in employing a zero coupled coil configuration. The transmit coil axis is aligned in the flight direction, the receive coil axis is vertical. Operating frequency is 100Hz, and complex components are measured.

TOWED BIRD SYSTEMS

Towed bird systems include both continuous wave and pulse-transient electromagnetic systems. The continuous wave systems measure either differential complex components, imaginary (quadrature) responses at two discrete frequencies or, as in the case of the Input system, time varying characteristics of secondary electromagnetic field effects.

The Inco system. The International Nickel Company of Canada introduced the first operating AEM system in 1950. The Inco system utilizes a transmitter as well as a receiver consisting of two orthogonal coils, which are coupled coaxial and coplanar respectively. Typically, three frequencies within a range of 100Hz to 2500Hz are transmitted, and the measurements at the receiver include the amplitude difference between the received signals as well as direct amplitude changes in the coplanar and coaxial coupled coils. Phase relations may be recorded as well, to aid in the interpretation of the response recorded on the main channel. The receiver is towed on a 500-ft cable resulting in approximately 400-ft horizontal separation in flight. Misalignment noise is the main limiting factor and precludes utilization of the system in turbulent weather. Under favourable conditions the depth of exploration is good and the data permit a determination of the relative merits of detected conductors. The system has recently been adapted to Twin Otter jet turbine aircraft.

The ABEM system. A.B. Elektrisk Malmletning in Sweden in 1955 developed the "rotary field" system. This system was flown in Canada in 1956 by ABEM (Canada) Ltd. and later, until 1960, by Lundberg Explorations. The preferred version of the system requires two separate aircraft, one carrying the transmitter and the other the receiver (Fig.2b). Relative in-phase and imaginary responses at 880Hz are measured in two orthogonal transmit and receive coils, usually separated by a distance of 500-800ft. Under favourable conditions good depth penetration is obtained. Operational costs are relatively high because two aircraft have to be employed. The system is in active use.

The Hunting Canso. In 1956 Aeromagnetic Surveys, predecessor of the Hunting Survey Company, introduced into Canada a dual frequency imaginary component measuring system which had been developed in Finland. This system, which used exciting frequencies of 400Hz and 2300Hz, comprised a horizontal transmitter and a vertical receiver with its axis in the flight direction, towed in a bird on a 400-500ft cable (Fig.2a). Sensitivity of the system was approximately 2000 parts per million. The limitations of quadrature measurements, particularly the failure to detect massive sulphides, obsoleted the system and it was phased out of service in Canada by 1960. Lockwood Survey Corporation has attempted in 1968 to revive it by offering a transistorized version of the original instrumentation, mounted in a smaller aircraft. Otherwise it has remained the same.

McPhar F-400 system. During the latter part of 1968 McPhar developed a dual frequency out-of-phase measuring system similar to the original Aeromagnetic or Hunting system except for the exciting frequencies. The McPhar F-400 version operates at 340Hz and 1070Hz. The receiver is carried in a bird towed at the end of a 400-ft cable. The principal difference between this system and the Hunting Canso system is that the transmit coil is in a vertical position so that the transmit and receive systems are flown in a maximum coupling configuration.

INPUT system. The Input system constitutes a rather radical departure from the conventional continuous wave inductive AEM system. The unit, at present mounted in a Canso (PBY) fixed-wing aircraft (Fig.2c), utilizes a large horizontal external transmitting loop through which an electromagnetic pulse of 1.5millisecond duration is generated at a repetition

rate of 3.5ms. After the cessation of this pulse, the time varying characteristics of the decay of the eddy currents and their associated secondary EM fields are measured. The receive coil, with its axis in the direction of flight, is carried in a towed bird at the end of a 500-ft cable. The voltage obtained in the receive coil is sampled at six increasing delay times which vary from 300microseconds for the first channel to 1900microseconds for the sixth channel (Fig.2d). The responses of bodies of lower conductivity appear only in the first two or three channels, those of high conductivity sources become detectable in the later channels.

The Input system has overcome one of the basic handicaps of continuous wave AEM systems, namely the necessity of measuring weak secondary fields in the presence of primary excitation fields which are many orders of magnitude stronger. The transient secondary field effects are separated in time from the primary field and orientation variations between the transmitting and receiving coils do not affect the limiting noise levels of the system.

PASSIVE AND FIXED SOURCE AEM SYSTEMS

Two types of airborne systems can be called passive because they employ external fields as the primary source. The AFMAG system employs the natural audio frequency magnetic fields arising from atmospheric discharges and several recently developed systems use the signals transmitted by military VLF radio stations.

(a) *The AFMAG system.* The airborne version of the AFMAG system (Ward, 1960) records the tilt of the plane of polarization of natural magnetic fields arising from atmospheric discharges at two different frequencies. For instance, 90 and 330Hz (fixed-wing version), 150 and 590Hz (towed bird version) have been used. Notwithstanding initial high expectations the system has proved to be unsuitable for the location of sulphide bodies. It is at present used occasionally for structural mapping.

(b) *VLF systems.* Since the establishment of a world-wide network of powerful VLF radio transmission stations with frequencies ranging from 15 to 27kHz several ground and airborne receiver systems have been developed in an attempt to utilize these fields for the mapping of ground conductivity. Typically they measure relations between pairs of field components, e.g. the ratio of horizontal and vertical components (McPhar KEM), the relative phase angle (Ronka), the ratio of (vertical) electric and (horizontal) magnetic fields (Barringer Radiophase), or the gradients of phase and amplitude of the horizontal field (Scintrex Deltair).

These and several similar systems have only recently been introduced and some are still in the experimental phase.

SEMI-AIRBORNE SYSTEMS

Methods utilizing a large fixed source on the ground, combined with an airborne receiver, have been used off and on. In the past the source was usually a long grounded wire and only the amplitude of the horizontal component was measured. As a result geological noise was high and resolution poor.

At present, experiments are being carried out with an airborne Turam system using large inductive sources and measuring amplitude and phase gradients from a light helicopter, which is also utilized to lay out the primary loop. It is expected that this system (Scintrex Turair) will have considerably better penetration (600ft) than present airborne surveys (rarely better than 300ft) and will have an application in areas with very heavy overburden, rough topography or tall forest.

SIGNAL AND NOISE

Although AEM methods are employed on a limited, mostly experimental, scale for the mapping of geological features, e.g. in aid of ground water exploration, their primary application is in the search for base metals. Thus, in the present context, signal is referred to as the response of target conductors (mineralized bodies), and noise as all other recorded responses. Among the latter the two most important sources are system noise and geologic noise. System noise may arise from many parts of the aircraft or installation, but the main cause is usually configuration instability, which results in variations in mutual coupling between transmitter and receiver which creates random noise, mainly the real component. Geologic noise may arise from any geological conductor. The most common source of geologic noise on the Precambrian Shield is conducting overburden.

To evaluate individual systems, their response over a variety of expected conductor arrays should be investigated. Data for a proper comparison of all relevant characteristics are, however, rarely available and we usually have to be satisfied with an evaluation based on the theoretical response above one of the more common conductor arrays. Most useful is perhaps to examine the combined response to an "homogeneous earth" model (overburden) and a "conducting half plane" model (steeply dipping mineralized zone).

The response of AEM systems over the former is governed by the induction parameter $\alpha = \mu\omega\sigma(\rho^2 + h^2)$ and over the latter $\alpha = \mu\omega\sigma(\rho^2 + h^2)^{1/2}$ (Ward, 1967) (in which μ = permeability, σ = conductivity, ω = frequency, ρ = half plane thickness, ρ = coil separation, h = height). Thus the height h of the system above the conductor as well as the coil separation ρ and the frequency ω are operating parameters i.e. characteristics of the systems that can be varied to modify the response. Since the values of ρ and h are much larger for towed bird systems than for rigid boom systems, the induction parameter of the former above overburden is in typical cases 30 to 40 times larger than for rigid boom systems using the same frequency, but only 5 to 6 times larger above the mineralized sheet.

In practice this means that above this common type of conductor array geologic noise is much lower in rigid boom systems, which therefore have a much more favourable signal to noise ratio than towed bird systems. Figure 3 illustrates this point. In this example the rigid boom system has been given a frequency five times the frequency of the towed bird system so that the mineralization has the same induction number in both systems. The overburden response in the towed bird system falls in an area where real and imaginary components have appreciable amplitudes. The same overburden gives rise to very low real and imaginary amplitudes for the rigid boom configuration, notwithstanding the five-times higher frequency.

When geologic noise is low, system noise will take over as the main factor limiting signal detectability. It primarily affects the real part of the field (amplitude or in-phase component) and in towed bird systems, where instability is an inherent problem, methods other than the direct comparison of real and imaginary components have to be used for the determination of conductor characteristics. In the Inco and ABEM methods components at the receiver are compared without direct reference to the primary field. In the former the differences between amplitudes of three frequencies are measured, in the latter the difference between real and imaginary components in two orthogonal coils. A more common solution, which was introduced in the

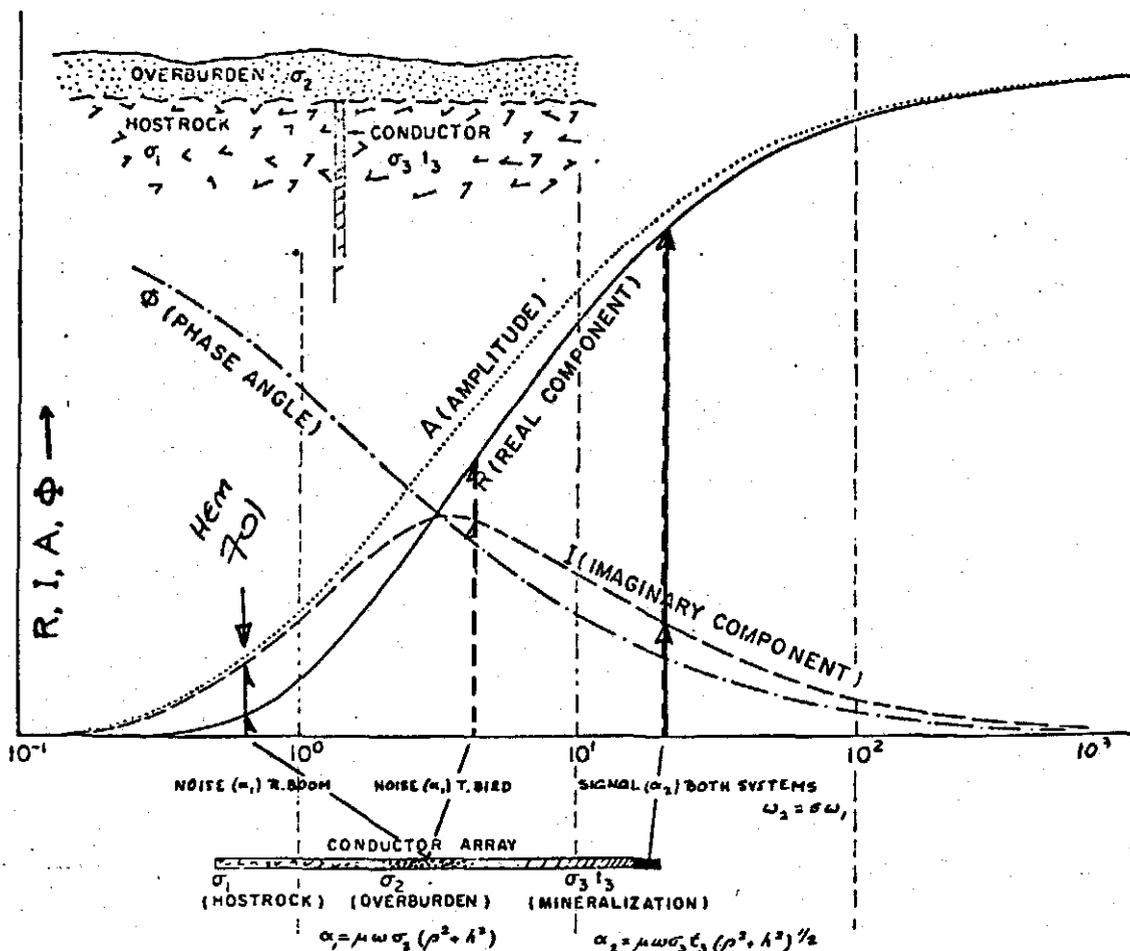


Fig.3. Signal to noise relations; towed bird and rigid boom systems

Hunting Canso system and after its demise revived by Lockwood and in the F-250 and F-400 McPhar systems, is to compare the imaginary component at two different frequencies. This approach has the advantage of simplicity; the imaginary component is relatively unaffected by instability, and it can be directly referred to the primary field.

A distinct disadvantage is that the range of detectable conductors is limited. As Ward (1967) puts it, these systems have a narrow "window" of acceptable conductivity-width products. Above a certain value of the latter the response of both operating frequencies disappears below the noise level. Although not to the same degree, all imaginary component systems are blind to geological conductors of high conductivity, including many massive ore-bodies. In addition, the ability to discriminate, within this narrow window, between mineralization and conducting overburden, is more restricted, in comparison with methods measuring real components.

System noise is usually specified in parts per million of the primary field at the receiver. (Typical noise figures given for towed bird systems fall between 500 and 4000ppm and for rigid boom systems between 3 and 50ppm.) These noise figures thus are a function of a particular configuration, and unless they are converted to some common base, offer little basis for direct comparison. Moreover, such noise levels are usually established under favourable conditions. As individual systems behave quite differently in turbulent air these figures are also of questionable value in evaluating true operational noise levels.

The Input system, when it measures the time derivative of the decay function with a sampling time of 2 milliseconds and a repetition rate of 3.5ms can be compared to a broadband imaginary component measuring system with the fundamental repetition rate of 285Hz as the lowest represented frequency. Thus, the system can be expected to have, as the two frequency imaginary systems, a limited window of acceptable conductivity-width products. Because of the lower frequency, higher conductivity-width products will be accepted, but a more important difference can be expected to result from the much better signal to noise ratio.

System noise is very low, although apparently atmospheric and airframe noise may reach nuisance levels in the last channels. Geologic noise created in the higher frequency ranges is separated in stages through the different sampling gates and the response from target conductors has to overcome only the noise level at the representative frequency of the gate.

The factors ρ and h for this system are relatively large and, depending on the conductivity of the overburden, geologic noise may still be a factor to consider, even at the last gate.

The response of target conductors decreases with increasing conductivity-width product and it depends on the combined level of geologic and system noise at the last gates whether the signal will be detectable. Little information is available regarding these signal to noise levels, but the system generally appears in essence to have limiting factors similar to conventional systems. Experience has indicated that it is capable of

a working subsurface exploration depth of at least 300ft. Under favourable conditions it may perhaps be capable of greater penetration.

SIGNAL RATE OF FALL-OFF

The signal rate of fall-off with increasing height of a particular system deserves more attention than it is usually given. Rigid boom systems inherently have a steeper rate of fall-off than towed bird systems, but appreciable difference also exists between members of each group, mostly as the result of coil configuration.

In general, maximum coupled systems (coaxial, coplanar) have a more favourable rate of fall-off over steeply dipping bodies than minimum coupled systems (plane of receive coil perpendicular to plane of transmit coil). Hedstrom (1959) has shown the difference be-

tween the Rotary field system and the Hunting Canso system based on model experiments (Fig.4a). The former system is fully coupled, the latter approaches a minimum coupling.

A similar difference has been observed in the results of test flights over the Whistle Mine with two superficially rather similar rigid boom systems, The Barringer Helicopter EM and the Scintrex HEM-701 systems (Fig.4b). The former system is zero coupled, the latter maximum coupled. The rate of fall-off curves represent information published by both companies after these tests. A lower noise level (1-3ppm) is claimed for the Barringer system, versus 3-5ppm for the Scintrex system, but since the rate of fall-off for both systems seems equally steep at this low signal level this will not result in much gain. In fact these curves indicate

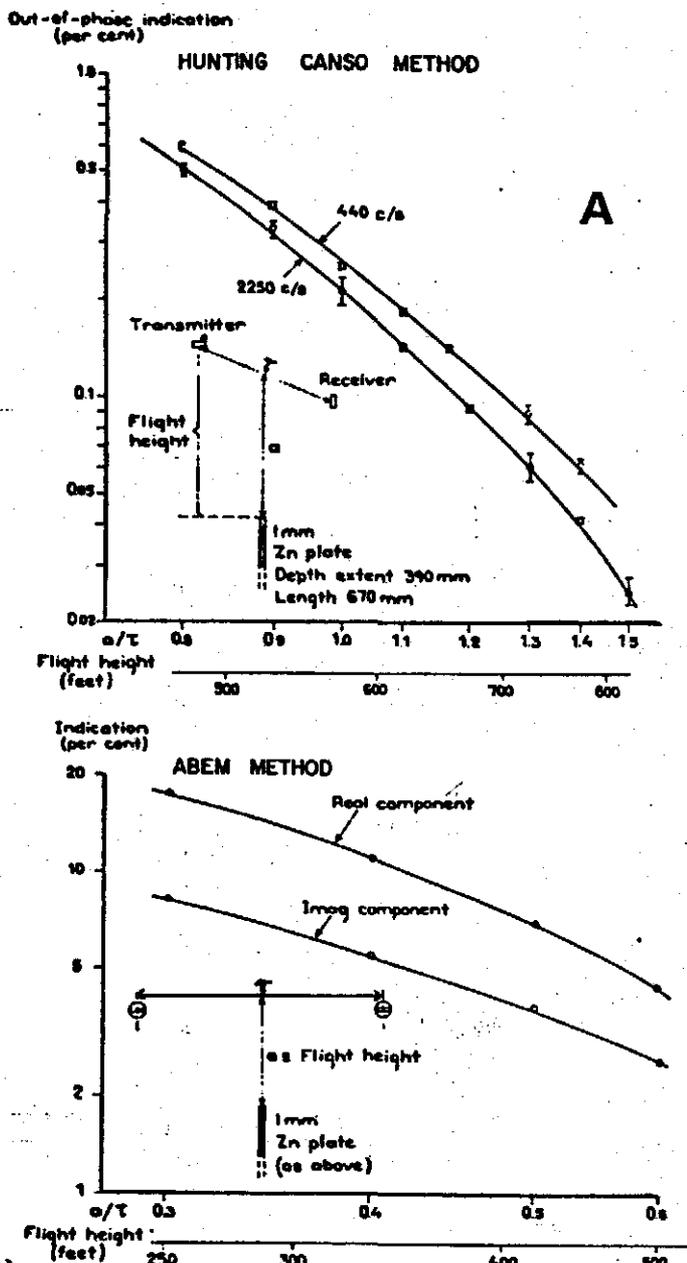
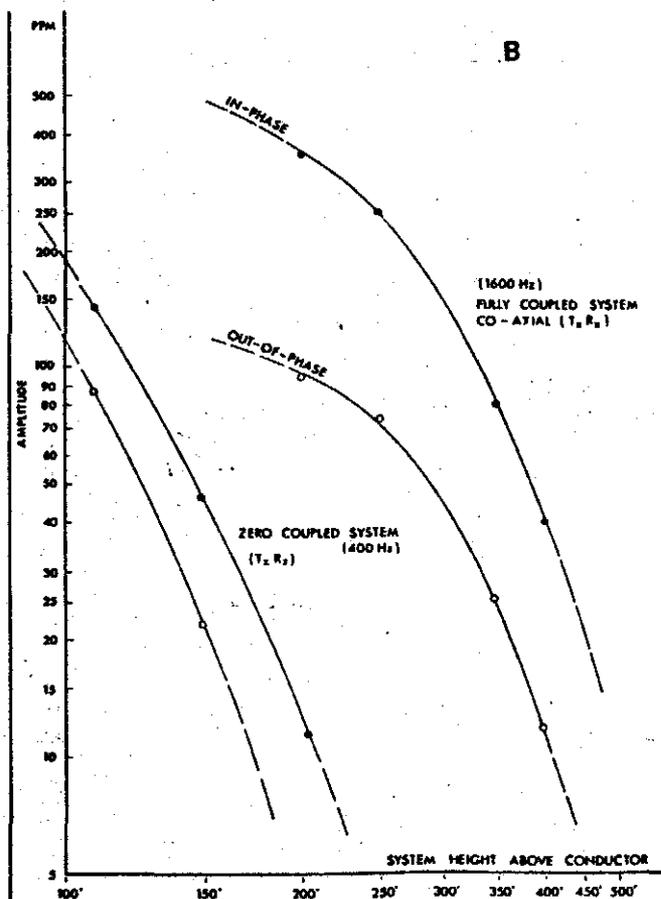


Fig.4. Signal rate of fall-off of maximum coupled and minimum coupled systems. A: Hunting Canso vs ABEM. B: Barringer vs Scintrex HEM 701 system



that not much further penetration can be achieved with present rigid boom systems by decreasing the system noise level.

Both examples demonstrate the advantage of maximum coupled systems in this respect. It should be noted however that before any conclusions as to the difference in penetration can be made, the geologic noise characteristics of the systems should be taken into account as well.

DEPTH OF EXPLORATION

It is customary to present as the depth of exploration of an AEM system the maximum height at which the response of a near surface conductor at increasing flight altitude is still clearly detectable above the noise

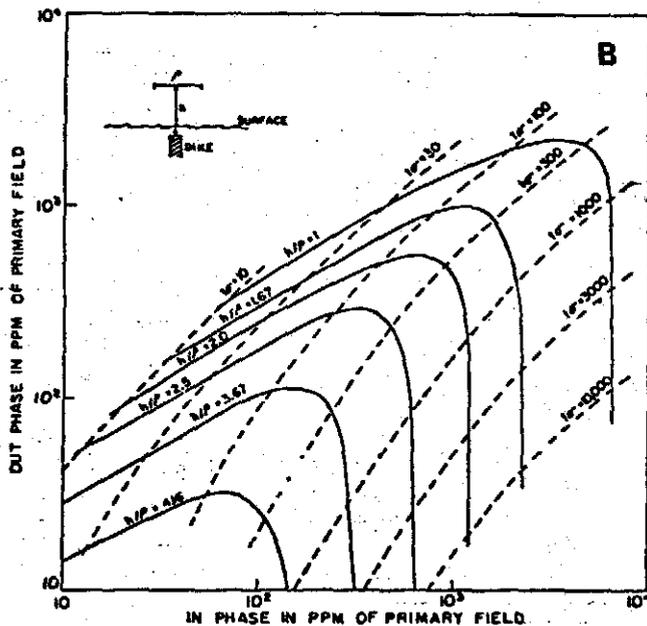
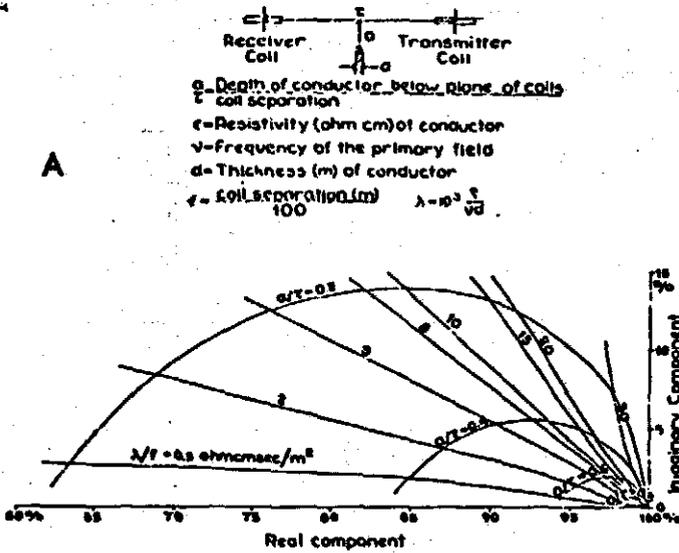
level. In this way only the free air rate of fall-off and the most favourable system noise are taken into account. Needless to say, this is not necessarily equivalent to flying at low survey altitudes, in more turbulent air, and with the full spectrum of geologic noise present. Under the latter conditions it would appear that none of the present-day systems achieve a working depth of exploration significantly better than 300ft subsurface and many have considerably less useful penetration.

Because they are least susceptible to turbulence and geologic noise, the low frequency rigid boom fixed-wing and helicopter systems and the Input system will give the most consistent exploration depth under a wide variety of conditions. The high frequency helicopter systems are more sensitive to geologic noise and their penetration may be reduced in overburden areas.

Towed bird systems such as the Inco and ABEM methods are very sensitive to turbulence. For this reason the receiver in the latter is preferably mounted on a second aircraft rather than in a bird. All the towed bird imaginary component systems are particularly sensitive to geologic noise, which may in many cases drastically reduce the exploration depth.

Fig.5. Interpretation diagram for AEM data.

A: Argand diagram ABEM. B: Newmont-Aero interpretation diagram



RESOLUTION

The resolution of AEM systems, i.e. the ability to distinguish adjacent sources, decreases with increasing height and coil separation; height being in the majority of cases the main determining factor. Rigid boom systems thus can be expected to have better resolution than the other airborne systems.

TERRAIN PERFORMANCE

Terrain performance is, of course, mainly determined by the aircraft type, particularly its rate of climb. Towed bird systems are inherently unsuitable for use in other than relatively flat topography. Helicopter systems, particularly when carried by the present powerful turbo jet helicopters, can be used successfully in almost any kind of terrain. They are, however, somewhat slower and more expensive to operate.

INTERPRETATION

Airborne surveying is usually regarded as a reconnaissance function and the significance of quantitative interpretation at this stage is often underestimated. Usually, however, far more conductors will be located than can economically be examined on the ground, and it is highly desirable to distinguish potential ore conductors from probably uneconomical conductors, in order to narrow down the number of targets for subsequent ground follow-up.

Such a discrimination may be aided by a comparison of pattern and location with other geophysical or geological information, but the most relevant basis for discrimination are the conductivity-width products of the individual conductors. The ability to readily yield this information is of major importance in evaluating airborne systems.

The results of rigid boom systems measuring real and imaginary amplitudes, can be easily interpreted in terms of conductivity-width products by means of Argand or similar diagrams (Fig.5) and the obtained values can in most cases be used directly for conductor discrimination.

The results of towed bird systems are usually more difficult to interpret. Schemes of varying complication and usefulness have been designed and published for most methods. Because the survey height h is often smaller than the separation p , h has a rather larger effect on the induction parameter, and the results have

to be corrected accordingly before they can be used for conductor discrimination. Generally interpretation of towed bird data requires more experience and expert knowledge.

Input results appear to be readily interpretable in terms of relative conductor merit. Persistence through the consecutive channels can be taken as a reliable guide. Determination of conductivity-width products has, to the writer's knowledge, not been attempted, and it would seem in view of the inherent discrimination of the system, unnecessary for routine interpretation.

LIMITATIONS OF AFMAG AND VLF SYSTEMS

So far, little has been said about the capability of the AFMAG system and the new VLF systems.

Applications and limitations of AFMAG, based on considerable experience with the method, have been discussed in an article by Ward et al in 1966. Among the limitations, it was found that the system responds to broad surface resistivity variations, sulphide deposits were difficult or impossible to locate because of the small response relative to the many faults, shears and carbonaceous horizons that were delineated, and dual frequency interpretation was found to be meaningless in distinguishing conductors of different conductivity-width product.

These findings bear out conclusions that can be drawn from a consideration of the response curves shown in Figure 6. Since the transmitter receiver separation ρ is infinitely large, it would be expected that notwithstanding the low frequencies the induction parameters over both homogeneous earth and half plane would be large enough to move the response of the entire conductor array over to the saturated part (far right), where the real response is flat and the imaginary part negligible. Conductivity, except when extremely low, will have no effect on the response and thus, inversely, it is impossible to distinguish any part of the conductor array, be it massive mineralization, overburden, shear zones or formational conductors, by means of the response characteristics. The observed amplitudes will, of course, be controlled by size and geometry. Frequency reduction, to move the conductor array back into the area of diagnostic response would have to go considerably lower than the present range of the system, and this seems impossible.

It is worth remembering that initially AFMAG was intended and expected to be a new tool for the exploration for massive sulphides with an exploration depth far in excess of conventional methods.

The experience with AFMAG seems to have largely been lost on the present promoters of VLF radio systems.

Typical statements, recurring in the descriptive write-ups of VLF systems are e.g. "... conductivity-size and attitude can be estimated from the shapes of the dip angle profile and the relative amplitudes. . ." "The technique. . . operates in the VLF band where high sensitivities are obtained to variations in rock conductivity". "It is apparent that there is a wealth of information to be obtained from terrain conductivity measurements and equipment that can map such conductivity has multiple applications in geophysical surveying, engineering assessments and mineral exploration". ". . . has proven its ability to pick up anomalies at greater depth than conventional geophysical methods".

The VLF systems are comparable to AFMAG except for 50 to 100 times higher operating frequencies. The relevant induction parameters are thus accordingly larger, moving the response still further into saturation.

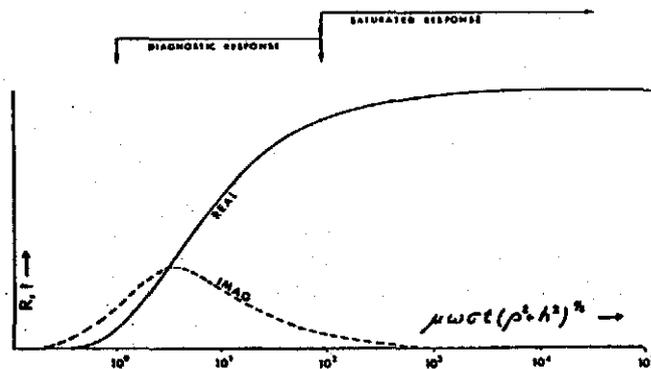


Fig.6. Response of AEM system over half plane with increasing transmitter-receiver separation and frequency

Not even the widest conductivity contrast in geologic materials, except perhaps in a narrow range of very high resistivities, will affect this over-saturated response. Amplitude variations recorded in these systems will be almost entirely due to dimensional and geometrical factors, to transitions from conducting to non-conducting materials, or to system noise.

Under usual glacial clay overburden conditions the penetration of VLF signals will be very small. Conditions have to be favourable indeed to map subsurface features. Significant applications in mineral exploration, no matter how indirect, are not credible and even the usefulness of VLF measurements as a tool for structural mapping seems questionable.

CAVENDISH TOWNSHIP TEST FLIGHTS

It is rarely possible to compare the results of different AEM methods over the same target. A series of conductors in Cavendish township, Ontario has recently been used by several companies to test AEM equipment (Fig.7). The main interest in this test area is its proximity to Toronto, otherwise it is rather inadequate to test system capability. The conductors occur in a series of parallel bands in an area mapped as limestone. They are relatively small, shallow and of medium to poor conductivity and their nature unknown to the writers. The overflights are as closely comparable as possible, but particularly in view of the smallness of the targets, significant differences may nevertheless be expected. Certain general observations can be made, however.

Conductors A, B, and C are clearly shown as individual zones in the F-400 towed bird and HEM-701 rigid boom systems. In the Input results B is not clearly detectable, which may be caused by different traverse location. Conductivity of A and C can be determined from all these systems, with comparable results. B shows a much poorer conductor in the HEM-701 than in the F-400 trace. The conductivities of A, B and C fall well within the two-frequency imaginary window.

It is left to the interested reader to try and locate these conductors on the AFMAG and VLF traces. On the latter, indeed, anomalies occur which roughly coincide with C and AB; but this is hardly surprising because distortion is virtually continuous throughout. Without previous knowledge as to their occurrence these conductors could not have been selected. For all practical purposes these anomalies fall within the geologic noise.

It should be noted that the data shown have been

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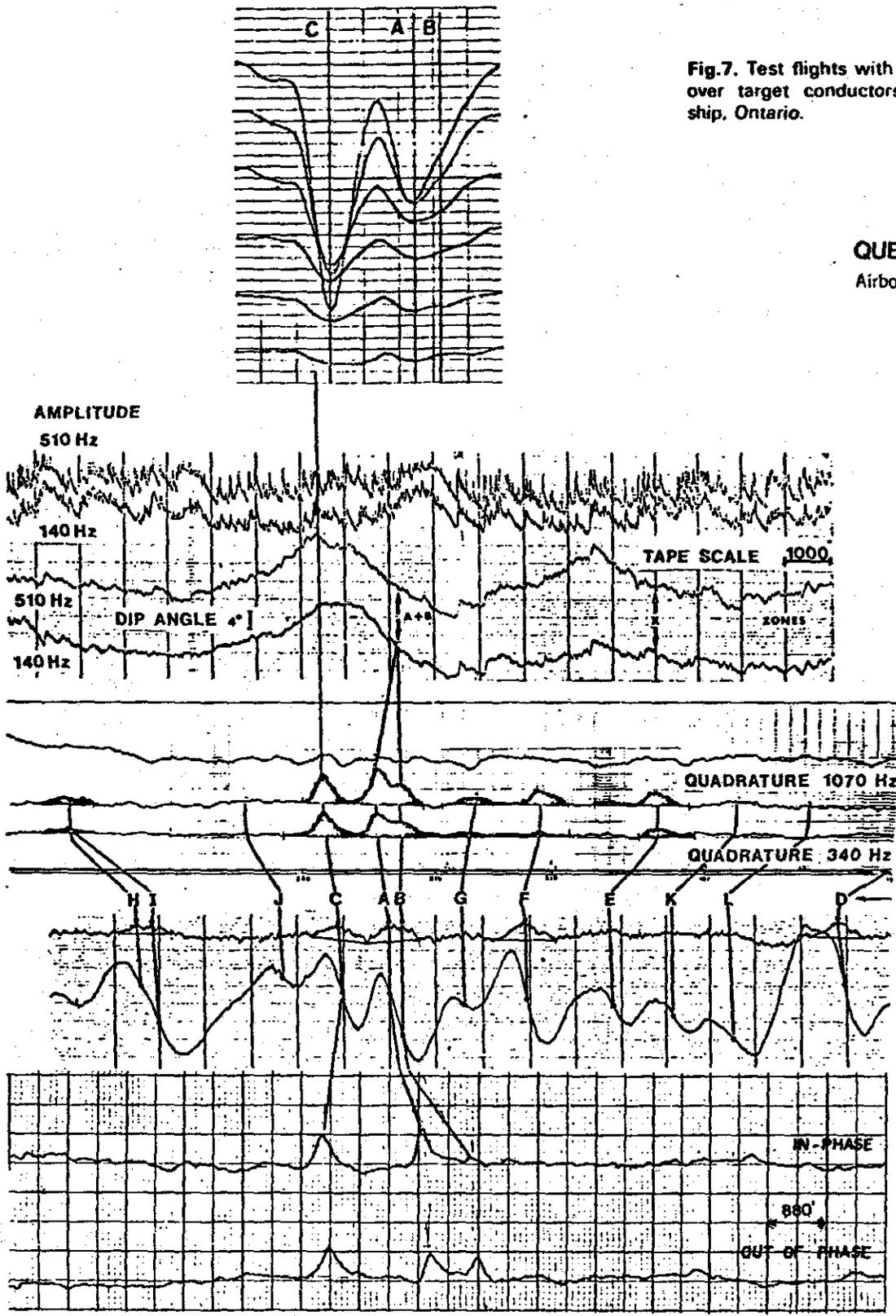


Fig.7. Test flights with different AEM systems over target conductors in Cavendish Township, Ontario.

QUESTOR SURVEYS
Airborne Mk V Input

- McPHAR
AFMAG
600' ALT.
- McPHAR
F-400
TOWED BIRD SYSTEM
TWO-FREQUENCY
OUT-OF-PHASE
450' ALT.
- McPHAR
KEM
RADIO FREQUENCY SYSTEM
500' ALT.
BALBOA
24.0 kHz
- SCINTREX
HEM-701
RIGID BOOM SYSTEM
200' ALT.
1600 Hz

used by the different companies as publicity material and thus may be considered representative.

CONCLUSION

All present AEM systems have their limitations, and their applicability varies with geologic and topographic conditions. Some methods are more versatile than others, but no single present method will solve all our search problems.

Complex component measuring rigid boom systems such as the Mullard (Otter) system and the helicopter systems, and towed bird systems such as the Inco system, the ABEM system and the INPUT system have won general acceptance both on technical and economic grounds. It would seem questionable whether the recent revival of two frequency imaginary component systems will last, in view of their limited detection capability. The VLF "prospecting" systems will, in

the writer's opinion, contribute confusion rather than any tangible benefits to mineral exploration.

It should be stressed that the principal cost of an airborne program is the actual flying cost and not the amortization cost of the geophysical equipment, and that ground follow-up is costly and should be taken into consideration at the initiation of the program. Thus, there is a good case for paying a premium dollar for a premium AEM system.

Airborne geophysics has helped to find many new ore bodies since World War II, but not enough new mines are added annually to keep pace with the world's increasing metal consumption. If we are to increase our present rate of discovery existing systems have to be refined and new and more effective techniques added.

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Applications and limitations of

AIRBORNE ELECTROMAGNETIC SYSTEMS

in mineral exploration

by R.A. Bosschart and R.H. Pemberton,
Scintrex Ltd., Toronto.

The following comments have been received by Mining in Canada in response to the article on Airborne Magnetic Methods by R.A. Bosschart and R.H. Pemberton which appeared in our May, 1969, issue (Page 19). The authors' replies to these rebuttals will be published in the next issue.

From N. Paterson, a Toronto consulting geophysicist:

There is no subject that can cloud one's objectivity more than airborne E.M. Why this is so is not clear, for the most one-sided opinions are often expressed by those of broad experience who have nothing to lose through impartiality. Lately, in reviews published by McLaughlin, Ward, and others, we have seen a trend towards objectivity that has been most refreshing. The article in the May issue sets a new low in one-sided reporting that cannot be allowed to stand on record as an acceptable statement of geophysical opinion.

The review of airborne E.M. methods by *Mining in Canada* is timely in view of current increased activity and recent instrumental developments. The classifications of systems and their physical descriptions are adequately set out in the article. Most of this material can be found, however, in more detailed articles such as those by Pemberton, Ward and McLaughlin. The newer systems, particularly the new helicopter rigid-boom

systems and the airborne VLF systems, of greatest interest to readers, are only given limited description.

Following the classification and description of systems, the writers judge methods individually against a series of criteria such as depth of exploration, resolution and interpretation. They then compare systems and give them an overall rating for mineral exploration work. In this area they are of course entitled to their opinion, as it is difficult to agree on the relative importance of the various operating parameters. However, opinions should be based on facts, and it is on the basis of some rather questionable observations that the writers conclude:

1. That natural field or passive systems such as AFMAG and VLF have little application in structural mapping and no application at all to base metal prospecting;
2. That imaginary component (quadrature) systems are obsolete and inferior to rigid-boom systems for mineral exploration.

Let us examine the observations on which these conclusions are based:

1. Observation

Lack of popularity of the AFMAG system is attributed by the writers to the inability to distinguish between good conductors and poor conductors, and also because "it has proven unsuitable for the location of sulphide bodies".

Fact

In fact, much of the lack of popularity comes from the unreliability of the AFMAG natural field, rendering AFMAG surveying chancy and therefore expensive. The method is an excellent tool for structural mapping and has been proven to be capable of recognizing massive sulphide bodies of moderate size to a remarkable depth. Its low frequency enables it to operate in areas of high conductivity and deep weathering.

The VLF method also responds to massive sulphide bodies at considerable depth, and is useful for both structural mapping and mineral exploration in all but the highest conductivity areas. Even in parts of the Canadian Shield where glacial overburden is typically 50 - 100 feet thick, the VLF method appears to have useful application. By comparison of direction and amplitude of the two phase components we may well be able to distinguish certain geometrical parameters.

Because of the extremely high values of response parameter, both the AFMAG and VLF methods naturally respond almost equally to all geological conductors of large dimensions. To help distinguish between these anomalies, steps are being taken to computerize methods of data reduction and analysis. This will allow the interpreter to screen the anomalies rapidly for certain pre-

scribed geometric characteristics as well as correlation with topographic, geologic, or other geophysical parameters. Alternatively, the interpreter may wish to "filter" his data in order to present a series of maps emphasizing conductors of different apparent strike, dip, depth, vertical dimension, or any combination of these. In structural mapping, the lack of selectivity of these systems may in fact be their greatest advantage.

2. Observation

The writers present an interesting comparison of results over a series of conductors in Cavendish Township, Ontario. The AFMAG and VLF results, obtained and published by McPhar, show a remarkably close correlation with the known geology, and the results of a towed-bird airborne E.M. survey. No correlation is recognized by the writers, who attribute the anomalies to "geologic noise"; further, they state that the nature of the conductors is unknown to them.

Fact

As one who is well acquainted with the area and with the various E.M. systems employed in this comparison, I can state unequivocally that the anomalies are real and that they would have been recognized in a reconnaissance survey. Furthermore, certain other anomalies some distance away from the main zone, that show on both AFMAG and VLF records (and on the imaginary component towed-bird survey also), but do not register on the rigid-boom helicopter survey, are also real and may in fact be of economic significance.

So far as the nature of the anomalies is concerned, at least two have been drilled, and sulphides have been proven to be the cause.

3. Observation

The writers refer to imaginary component towed-bird systems such as the Hunting/Lockwood and McPhar two-frequency systems in such terms as "obsolete", "phased out service", "service" and "demise", and question whether "the recent revival of two-frequency imaginary component systems will last".

Fact

In fact, the popularity of these systems has been gaining rather than dropping during the period mentioned by the writers. Here are a few pertinent facts:

- The method, first invented in Finland, is still in use by this country's Geological Survey for routine mapping and exploration work.

- The method was selected by the Newmont/Sharritt Gordon interests as their "in-house" system for reconnaissance surveys in the Canadian Shield, over the rigid-boom method actually developed by Newmont. The system has succeeded in discovering the Fox Lake orebody and several other deposits of potential interest.

- A major U.S. mining company with a rapidly expanding and highly sophisticated

exploration program, after careful study, rated the two-frequency imaginary component method first in their choice of preferred E.M. systems for reconnaissance work.

- McPhar Geophysics, pioneers in Canadian E.M. technology, as recently as 1968 chose the same method over other possible methods for their F-400 series airborne E.M. system. Obviously this contractor does not share the opinion of the writers regarding obsolescence.

4. Observation

The writers raise the old bogey, long since exposed and discredited, that imaginary component systems are incapable of detecting "good conductors".

Fact

In 1959, I presented theoretical, experimental and field evidence that such a claim was ridiculous and challenged critics of the method to mention a single massive sulphide body that had too high a conductivity to respond. Needless to say the challenge has not been taken up.

It is certainly true that the imaginary component of the electromagnetic response has a limited "aperture", but by the use of more than one frequency, this aperture can be made arbitrarily large. The effective aperture of the Hunting/Lockwood system, in terms of the conductivity-width product of a half plane conductor, is 0.1 to 250 mhos. Tests with the method over 15 massive sulphide orebodies in Canada show a total spread of from 2 to 12 mhos. Experience with electromagnetic systems on such excellent conductors as the Texas Gulf deposit at Timmins and the West McDonald orebody at Noranda, suggests that the practical upper limit on conductivity-width is about 50 mhos, well within the central part of the imaginary component response curve.

To readers of *MINING IN CANADA* a statement such as "the limitations of quadrature measurements, particularly the failure to detect massive sulphides, obsoleted the system" is bound to cause a reaction. It would be interesting to know how many massive sulphide bodies have been drilled by readers as a result of surveys by this system since 1955.

5. Observation

The writers make the common mistake of confusing unwanted geologic response with unwanted geologic anomaly. They point out that towed-bird systems typically respond to over-burden thirty times better than do rigid-boom systems, whereas anomalies from vertical sheets are only five times better.

Fact

What they fail to mention is that overburden response is not in itself a problem, but variation in response at swamp edges, buried bedrock ridges and channels, in the bandwidth of orebody anomalies is a very serious problem indeed. These geologic anomalies are caused by departures from a half-space

conductivity model and are noticeable on systems of all geometries. Certain rigid-boom systems produce anomalies over swamp edges that are more difficult to recognize than the broader feature obtained over the centre by a towed-bird configuration.

The reason for lower geologic noise in most rigid-boom systems has nothing to do with coil geometry, but is the result of a smaller coil separation, leading to a lower response factor and a lower response to the poorer conductors.

Geologic anomalies, particularly those arising from the overburden or weathered layers, are certainly a problem in airborne electromagnetic surveying. The best means of handling the problem is to lower the frequency as much as possible and to record sufficient frequencies or components that the geometric and conductivity parameters of the conductors can be effectively distinguished and separated.

6. Observation

The writers criticize towed-bird systems for their rapid decrease of anomaly with height, and attribute this to the effect of minimum coupling between coils.

Fact

In fact, all imaginary component systems known to me are maximum coupled. The decrease in anomaly with height is almost entirely a function of coil separation rather than geometry. (The example used by the writers is an exception; the other pair of minimum coupled coils in the Barringer rigid-boom system produces the same fall-off with height as does the maximum coupled pair). Since towed-bird systems have larger coil separations than rigid-boom systems, the fall-off is less rapid and the penetration is greater. The two-plane ABEM system has the greatest coil separation of the active field airborne systems and therefore suffers the least attenuation with height. Natural field systems such as AFMAG and VLF have very little decrease in anomaly with height, except in the case of relatively small conductors.

Issue could be taken with a number of other statements by the writers, but the above points would seem to be the most serious. In conclusion, I wish to say that my comments are prompted out of a desire to put certain facts clearly on record. There is sufficient confusion at present surrounding the choice of geophysical methods, that unnecessary and inaccurate criticism of proven techniques must be avoided at all costs.

From V. Ronka, president of Geonics Ltd, Toronto:

I feel it necessary to comment on the article for two reasons. One is the

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disturbingly low technical and general accuracy and the regrettable lack of objectivity in a paper claiming to be a broad review of airborne EM methods. The lack of objectivity is, of course, quite understandable when the reader is aware that the author is an employee of one of a number of companies engaged in the hotly competitive geophysical instrumentation and services industry. Unfortunately the author's commercial association was not indicated anywhere. Indeed, his name did not even appear with the article itself and he was only identified in the index. With regard to greater objectivity I can only suggest that *Mining in Canada* restrict future articles of this nature to authors with a somewhat more impartial and less commercially biased viewpoint.

The second reason for my comment is that the author has vehemently attacked two particular methods with which I have been closely associated, the airborne dual-frequency imaginary component EM-system and the VLF-method of electromagnetic exploration.

With regard to the dual-frequency system I shall not subject the reader to involved technical discussion, but state that the author's main assumption (that hoary, old, discredited argument) that imaginary component systems are incapable of detecting good conductors is quite incorrect. Extensive experience and tests have shown that natural orebodies have much flatter response curves than the ones shown in the article. The argument that massive ores would not show up with this system has simply not been borne out in practice.

Surprisingly the author praises the merits of the INPUT system which is in effect equivalent to a multiple-frequency imaginary component system and has a similar coil geometry.

As a final word on the two-frequency system, it certainly appears to have had a much greater success ratio in mine location than those boosted by the article.

It is on VLF systems that the author is least factual. To literally hundreds of VLF equipment users, including a high proportion of major mining and exploration companies, the VLF-method most certainly does not "contribute confusion rather than any tangible benefits" but has proved to be an effective and valuable electromagnetic tool. Regardless of the author's personal conclusion, the fact is that VLF has established itself as one of the major geophysical methods.

There are limitations as well as advantages to the VLF-method, as there

are to any geophysical method. It is the proper appreciation of the principles of data interpretation which must contribute to the success of any method. The author draws certain conclusions from a VLF profile flown over a series of conductors in Cavendish Township, Ontario. What the author refers to as "geologic noise", the professional interpreter would call anomalies and search for the geological meaning of the data. The author ignores the possibility that the VLF-method may have located real conductors that the other methods missed. Evidence strongly suggests that these conductors do exist in the area flown.

Also the Cavendish VLF profile shown measures in effect only the in-phase (real) component of the vertical magnetic field and does not indicate the complete parameter capabilities of VLF systems. For example Geonics' VLF equipment measures both the in-phase (real) and out-of-phase (imaginary) component of the vertical magnetic field. Both together provide the geophysicist with an essential aid to VLF interpretation.

There are quite a number of other statements in the article that warrant detailed rebuttal to correct the author's rather one-sided opinions, but I shall just mention one more—his particular emphasis on the merits of a frequency of 1600 Hz for use in helicopter towed-bird EM systems. An identical but competing system (which incidentally I designed in 1955 and has been in operation ever since) is criticized for its frequency of 4000 Hz which according to the author "limits its application in the presence of conducting overburden." Actually in practice this difference in frequency has quite a negligible effect. Again the author falls into the same error mentioned in the dual-frequency argument since he neglects the factor that most natural orebodies have much flatter response curves than he indicates.

There are not too many articles concerning geophysical methods and instrumentation published in Canada, and *Mining in Canada* is to be commended for initiating these. However, the mining and exploration industry would be better served if the articles presented a broader view of professional opinion.

From D.M. Wagg and A.R. Rattew,
Geotrex Ltd., Ottawa.

R.A. Bosschart and *Mining in Canada* are to be complimented for the excellent article appraising in objective terms the many airborne E.M. systems available to the Canadian mining industry. The discussion

of signal and noise, signal rate of fall-off, depth of exploration, and interpretation puts the critical considerations clearly before the reader. Those of us who are involved intimately in the application of airborne E.M. can appreciate R.A. Bosschart's candid approach. We are sure that we will frequently have occasion to refer users to this article.

There are a few specific points which we would like to make:

1.—The second Muillard system, (page 21) was developed jointly by Scintrex Ltd. and Geotrex Ltd. and is also available to the industry through Geotrex.

2.—Our recent experience operating the Barringer INPUT system in Africa enables us to add something regarding geological noise, penetration capability and interpretation.

Conductive soils are much more common in Africa than in the Canadian Precambrian, so the geological noise level is typically higher. We find, however, that on the basis of conductivity discrimination and the use of anomaly shape criteria, we can effectively differentiate the conductor types and select sulphide targets. The broadband aspect of INPUT is an advantage in the sense that it provides the interpreter a great deal of information to work with. It seems that, with the exception of large salt concentrations, surficial conductivity rarely results in a geological noise level which is serious enough to inhibit the effective use of the system.

We have established under actual survey conditions that the maximum effective penetration for our particular INPUT installation is 650 ft subsurface. The target was a shallow plunging, long, highly conductive massive sulphide body in a resistive environment. It was followed down plunge to a drilled depth of 650 ft. In areas of higher geological noise level and for poorer targets, the effective penetration is certainly less, but we have concluded that in many environments the "working penetration" of INPUT is substantially in excess of 300 ft.

3.—While agreeing that the resolution capability of INPUT is inherently inferior to that of fixed-coil systems, we contend that any experienced INPUT interpreter would recognize the profile over B and C in Fig. 7 as a clear signature of a double conductor.

The article on

Applications and limitations of airborne electromagnetic systems in mineral exploration.

by R.A. Bosschart and R.H. Pemberton, published in the May 1969 issue of Mining in Canada, brought forth detailed critiques by several readers. The rebuttals were published in the July/August issue of Mining and Canada.

In this issue we give the authors the opportunity to answer the criticism.

Reply to N.R. Paterson

When we prepared our paper, Applications and Limitations of Airborne Electromagnetic Systems in Mineral Exploration, we found surprisingly diverging opinions as to the capabilities of the different airborne electromagnetic systems. We confess to having purposely taken a rather conservative stand, in particular in regard to some recently introduced systems, in order to stimulate comments on this very current topic.

While we thus appreciate Dr. Paterson's eagerness to make his contribution, we regret his neglect of the ground rules of objective discussion. Our conclusions were based on a careful consideration of properly researched material and our reasoning was explained and illustrated, so that it could be followed and verified. Yet, rather than support his objections with evidence of comparable substance, he has merely labelled our conclusions "observations" and his own gratuitous statements "fact" and further lightened his effort by misquoting us whenever convenient.

Re 1. The first "observation" may serve as an example. We quoted verbatim from Ward et al 1966, "... Among the limitations it was found that ... sulphide deposits were difficult or impossible to locate, etc. ... which has significantly different implications than Dr. Paterson's reading.

Under the heading "fact" we are told that "... The (Afmag) method is an excellent tool for structural mapping and has proved to be capable of recognizing massive sulphide bodies of moderate size at remarkable depths. Its low frequency enables it to operate in areas of high conductivity and deep weathering." A similar, if somewhat deflated claim is made for VLF methods.

Surely such statements require the support of unambiguous evidence. They imply excellent selectivity, which we have demonstrated to be impossible when the induction parameter is very large.

In the next paragraph we find "... Because of the extremely high values of the response parameter, both the Afmag and VLF methods naturally respond almost equally well to all geological conductors of large dimensions. ... and somewhat further" ... the lack of selectivity of these systems may in fact be their greatest advantage."

Logic is not Mr. Paterson's forte. If we are to believe him, these systems have (a) the advantage of being selective and (b) the advantage of being non-selective.

Re 2. We defined signal and noise within the context of mineral exploration. Whether any of the anomalies in Cavendish Township were "real" or "recognizable" was never a criterion, but rather whether they represented "signal" or "noise" as defined. Conductors A, B and C which reflect

sulphide mineralization were classed as signal, the remainder as (geological) noise. The VLF results "show a remarkably close correlation with the known geology" because they strongly respond to all geological conductors and this is precisely why the signal from target conductors is masked. The method is "out of focus" for mineral prospecting.

The location and nature of the conductors which were presumably not recorded in the HEM survey have not been specified by Dr. Paterson and the statement as such is meaningless. We hope he noted the different horizontal scale of the HEM traverse, which covered little more than conductors A, B and C.

Re 3. Between 10 and 15 years ago the two-frequency phase-shift (Hunting-Canso) system was employed for 90% or more of all contract AEM surveys in Canada. During some years possibly as much as 100,000 line miles may have been flown with this system.

This present year AEM contract surveys will amount to more than 150,000 line miles, of which some 100,000 line miles will be flown with complex component rigid boom systems and the remainder with the INPUT towed bird system. To our knowledge, no substantial mileage has been contracted for imaginary component systems and it seems unlikely to even exceed 5% of the total.

Re 4. The 1959 publication Dr. Paterson refers to was, like his present one, a series of comments on a paper on airborne electromagnetic methods; in

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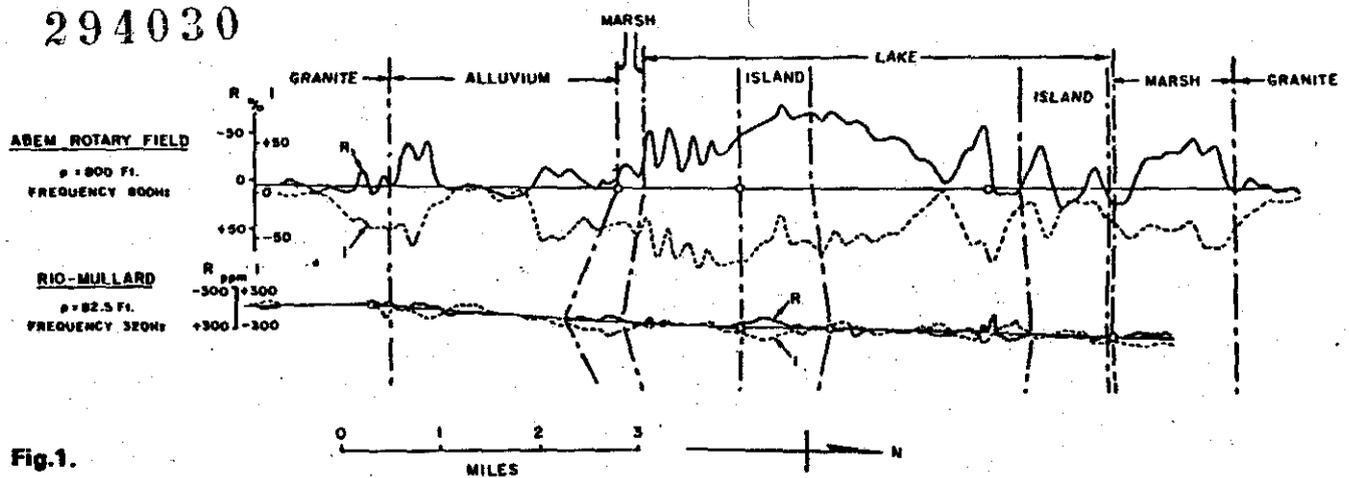


Fig. 1.

A comparison between the response of a "towed bird" and a "rigid boom" AEM system over Lake Marsh and Alluvium—Seita, East Africa. (After Mackowiecki, King and Cratchley, 1967)

that particular case by Messrs. Hedstrom & Parasnis. These writers raised the same "old bogey" that the two frequency phase-shift system was incapable of detecting bodies of high conductivity. Few readers of the 1958-59 discussion will, we think, agree with Dr. Paterson that he managed to expose and discredit this contention and proved it ridiculous. As to the unanswered "challenge", Dr. Paterson, in those comments, conceded that large bodies of 1-2 ohmcm resistivity would give very little out-of-phase response, but concluded that such bodies did not normally occur in nature. He did not know of any conductors which had failed to respond to the Hunting airborne method because of too low a resistivity.

In 1961 we published a paper, dealing in particular with the resistivities of geological conductors, in which we demonstrated with examples of seven sulphide bodies in Ontario and Quebec, that conductors of such low resistivities are of frequent occurrence. The paper was not intended to discredit a useful prospecting method and we, therefore, did not emphasize that all seven sulphide bodies had been traversed by the Hunting-Canso airborne system and that none had caused a detectable response. We thought that someone as keenly interested as Dr. Paterson and as well informed about the areas covered by the airborne surveys, would be able to draw this conclusion himself.

Similar examples can be found in other areas. For instance, a comparison of the airborne results with the results of later ground follow-up and the location of presently known mines in New Brunswick, reveals a number of undetected sulphide bodies.

Perhaps the inherent shortcomings of this method are best illustrated by the discovery history of the Poirier mine. An area including the ore deposit was covered by a two frequency phase-shift airborne survey in 1958. A fair amount

of conductive distortion was recorded, which was apparently caused by the overburden. No conductors of significance were indicated in the location of the present mines and accordingly, no ground follow-up was undertaken in this area.

One year later the same area was flown with the Mullard-Rio Tinto system and five pronounced anomalies were obtained (Boniwell and Dujardin, 1964) which led directly to the discovery of the Poirier mine.

It cannot be flatly stated that, in any of the above examples the body had "too high a conductivity to respond". These conductors probably all caused some response, but in all cases this response was too small to be detected above the local geological noise level.

We agree that theoretically the window of detectable conductivity-width products of multifrequency imaginary systems can be made arbitrarily large, but in this case we are dealing with one particular version and its characteristics. In this version the upper limit, in practice, is around 50 mhos which, combined with a high sensitivity to overburden-conduction, reduces its capability as a tool for mineral prospecting.

Re 5. The mistake of confusing "unwanted geologic response" with "unwanted geologic anomaly" must be common indeed. We hope one day Dr. Paterson will reveal to us how to distinguish the two, but as both are "unwanted," we are prepared to wait.

Equally difficult to relate to our statements concerning the difference in overburden response between various AEM systems is the soliloquy that follows this strange remark. We wonder whether Dr. Paterson actually read this part of our paper.

Rather than try to sort out the truisms and errors, we refer to fig. 1, which shows the results of test surveys with a

towed bird and rigid boom system (the towed bird Rotary Field system (T-R separation 800 ft. frequency 800 Hz) and the rigid boom Riv. Mullard system (T-R separation 82.5 ft. frequency 320 Hz) respectively) obtained by Mackowiecki, King and Cratchley over a sequence of bedrock and overburden formations in East Africa. These results clearly illustrate the difference in response, which is mainly due to the 10x larger separation. A minor difference results from the 2x higher frequency of the ABEM system.

Re 6. Point 6 is again a misquotation. We did not criticize towed bird systems anywhere for their rapid decrease of anomaly with height. Further, where we compared the two rigid boom systems we referred to the field results over the Whistle Mine published by Barringer Research, which were obtained with a system comprising only one pair of zero coupled coils. If other tests indeed showed identical rates of fall-off for maximum and zero coupled coil pairs, they would be of extraordinary interest and we wonder why Dr. Paterson does not show them. Of course, we would then be left without an explanation why the maximum coupled HEM 701 system displays so much more favourable a rate of fall-off.

We are frankly disappointed that Dr. Paterson's comments did not shed any new light on present day AEM systems, but concerned mainly a version of the multi-frequency imaginary AEM method. Without denying its unquestionable merits as a prospecting tool in the past, this system appears to us to have been overtaken in recent years by more capable systems, with fewer limitations.

Reply to V. Ronka

It is a time-worn stratagem to avoid a confrontation with verity by attacking the motives and integrity of an opponent, in the expectation to discredit

his ideas by inference. Mr. Ronka in his opening remarks concerning our commercial bias and our unwillingness to identify ourselves, makes an inexcusable, if inept effort to subvert, rather than answer the questions raised in our article.

Mr. Ronka suddenly becomes reticent, however, when it comes to facts. He does not want to bother the reader with "involved technical discussion." But perhaps readers of technical articles would rather be bothered with "involved technical discussion" than with platitudes. He vaguely refers to "extensive experience and tests" which he purports to have shown that "natural ore bodies have much flatter response curves than the ones shown in the article" and further echoes Dr. Paterson's statement that "the argument that massive ores would not show up with this system has simply not been borne out in our practice." Why does Mr. Ronka not show this "extensive experience and tests" and these "much flatter response curves?" If the latter are indeed materially different from ours (and thus from most response curves shown in the geophysical literature) he has made a discovery with far reaching implications and he should not keep this to himself.

If he had actually studied the results of all surveys carried out with the Hunting-Canso method in Canada and compared these with later ground follow-up surveys and the presently known locations of sulphide bodies, as his smug statement concerning the infallibility of the method would imply, he would not have missed the many examples we have quoted in our reply to Dr. Paterson. A review of the results in the areas we have mentioned, may help him regain some objectivity.

The INPUT system

After his accusation of commercial bias it must be a surprise to Mr. Ronka that we recognize the merits of the INPUT system. The statement that the Hunting-Canso system can be equated with the INPUT system because both have the same coil configuration and can be classed as multi frequency imaginary component systems, is a

representative sample of Mr. Ronka's ability to judge the capabilities of airborne EM systems.

HEM systems

Except in the brief method description, we have not mentioned, let alone put "particular emphasis", on the frequencies of helicopter EM systems. It is, however, not difficult to observe from our response curves, the advantage of the 2.5 times lower frequency of the Scintrex system. In the case of overburden of medium conductivity the in-phase response can easily be 2 - 2½ times larger in the 4000 Hz system, hardly a "negligible effect". But presumably Mr. Ronka refers to his own "much flatter response curves" which he does not produce.

VLF systems

In his defense of the system he pioneered, Mr. Ronka is, if possible, still less specific, and he barely rises to the level of his own sales promotion literature. We learn that "To literally hundreds of VLF equipment users . . . the VLF method . . . has proved to be an effective and valuable electromagnetic tool" and ". . . the fact is that VLF has established itself as one of the major geophysical methods". As to the Cavendish Township results, Mr. Ronka, like Mr. Paterson, misses the definition and significance of "signal" and "noise" in mineral prospecting and also talks about "real" conductors. "Real" conductors include such sources as fault zones, overburden, lake bottom sediments, telephone lines and rails, for instance, as well as sulphide deposits. We did not really ignore the possibility that the VLF method may have located "real" conductors that other methods missed. We are convinced of it; in fact, we even maintain that it sees little else than conductors other methods miss and that this is the very reason why the method is not suitable for mineral prospecting.

CONCLUSION

In our article we expressed doubts as to the validity of VLF surveys for mineral prospecting. We demonstrated clearly why we entertained these doubts. The response at those high values of the

induction parameter (infinite separation, very high exciting frequency) is close to saturation and has, therefore, lost its value as a means to discriminate between bodies of different conductivity. Dimensional and geometrical relations govern the response under these conditions.

Two protagonists of the VLF method have rushed to its defense; one of them the designer of the first VLF instruments. They have shown considerable annoyance that the applicability of the method was being questioned, as if this were blasphemy. But they have not attempted to answer our questions. Where are the firm criteria to establish the range of applicability of the method? Can any of the "experts" contribute response diagrams or demonstrate in any other way in what ranges conductivity discrimination will be feasible and where not? Or, failing this, demonstrate, not suggest, how information concerning the geometric characteristics of target conductors can be obtained, and subsequently how, on the basis of such information, potentially desirable and undesirable conductors can be distinguished? How, without this knowledge, can we claim that these methods have an application in mineral prospecting?

Reply to D.M. Wagg and A.R. Rattew

We apologize for having omitted Geotrex Ltd. in connection with the second Mullard system.

The writers refer to experience with the INPUT system in Africa which demonstrates the advantages of the broadband aspects of the method as well as its great potential penetration.

Convincing case history showing these particular capabilities of the INPUT method has not been published as yet and we hope that the writers will fill this gap within the near future.

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"Discovery and Exploration of the Poirier Ore Deposit" C.I.M.M.; Bulletin Sept. 1964.

L.Z. Mackowiecki, A.J. King and C.R. Cratchley
"A Comparison of Selected Geophysical Methods in Mineral Exploration"
Occasional Paper #2 Geophysical Division, Overseas Geological Survey

R.A. Bosschart "On the Occurrence of Low Resistivity Geological Conductors"
Geophysical Prospecting Vol IX (1961)

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TURAIR



BY
ROBERT A. BOSSCHART
AND
HAROLD O. SEIGEL

SCINTREX LIMITED

♦ A SCINTREX DEVELOPMENT, PATENTS PENDING IN ALL MAJOR COUNTRIES.

A

SEMI-AIRBORNE ELECTROMAGNETIC METHOD
FOR DEEP MINERAL EXPLORATIONINTRODUCTION

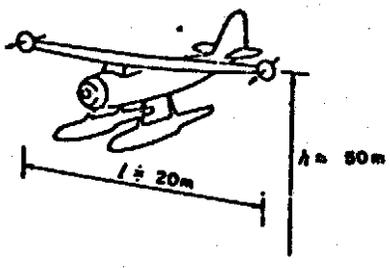
The applicability of airborne electromagnetic methods to base metal exploration has been well established by the record of ore bodies discovered by these methods over the past two decades. The main factors limiting the effectiveness of these methods are their useful depth of exploration, the surface topography and the nature and thickness of the materials overlying the potentially ore-bearing rocks. In many areas, deep overburden or weathering, sometimes combined with topographic relief or high tree growth, keep the horizons of interest beyond the range of the classical electromagnetic prospecting systems. The best of these achieve, under favourable conditions, a penetration of little more than 100 m subsurface and in rough terrain this depth is considerably reduced.

In Canada, although much of the Precambrian host rock has only light glacial cover, platform deposits of Paleozoic and younger ages cover the basement southwest of Hudson Bay and southwest of a line joining the Great Lakes and Great Bear Lake. Topographic relief is, for instance, a major obstacle to airborne prospecting in British Columbia and some areas in Eastern Canada. In the Western United States, problems of deep oxidation are often added to those of relief and cover and still further southward in subtropical and tropical countries, a heavy residual soil cover and deep oxidation frequently occur in combination with rough topography and a high tree cover.

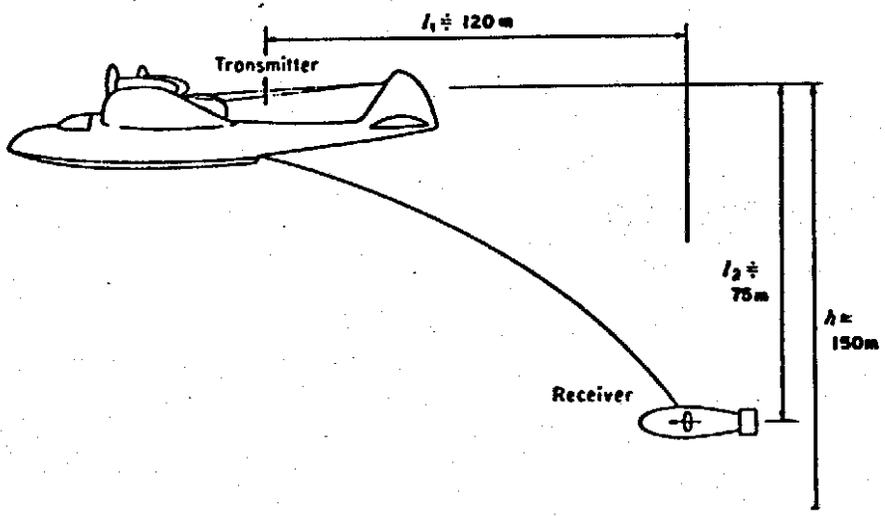
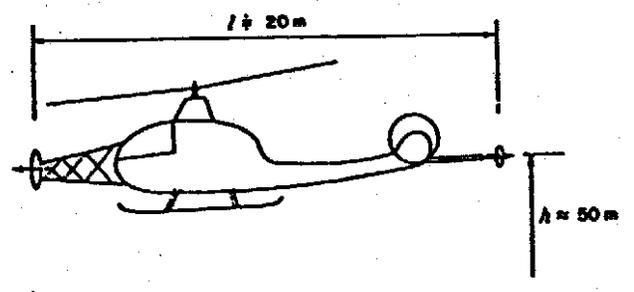
To conduct effective electromagnetic prospecting under these conditions requires exploration depths far in excess of 100 m, as well as the ability to maintain small terrain clearances in areas of rough topography. It is unlikely that the needed gain in capability can be attained through improvement of the classical AEM methods.

Two passive and a number of active AEM systems are in use at present. The passive field methods (AFMAG, VLF) provide, in practice, neither adequate exploration depth nor sufficient discrimination for direct exploration and they can be left out of consideration. The active systems are all of the moving source and receiver type, in stable or unstable form, i.e. transmitter and receiver are either in a mechanically rigid configuration or else differential movement is permitted to take place between the two.

The stable configurations inherently have small transmitter - receiver separations and are mounted on helicopters or light STOL fixed-wing aircraft, or suspended on a rigid boom below a helicopter. The unstable configurations tend to have larger transmitter - receiver separations and are mounted in larger aircraft, trailing the receiver in a bird on a tow cable (Figure 1).



Stable Configuration
Electromagnetic
Systems



Unstable
Electromagnetic
Measuring Configuration.
Towed Bird System

Figure 1

If we consider their capabilities, leaving aside such matters as discrimination and resolution, stable configurations obviously have the edge in terrain performance. In the better systems, instrumental and mechanical noise are now at the lowest levels obtainable with present components and materials. Beyond a depth of 100 m the response rate of fall-off is between the third power (for sheet-like bodies) and the sixth power (for spherical bodies), so that even marginal improvements in penetration can only be achieved through major reductions of the already very low noise levels. This configuration seems to have been developed close to its ultimate penetration potential.

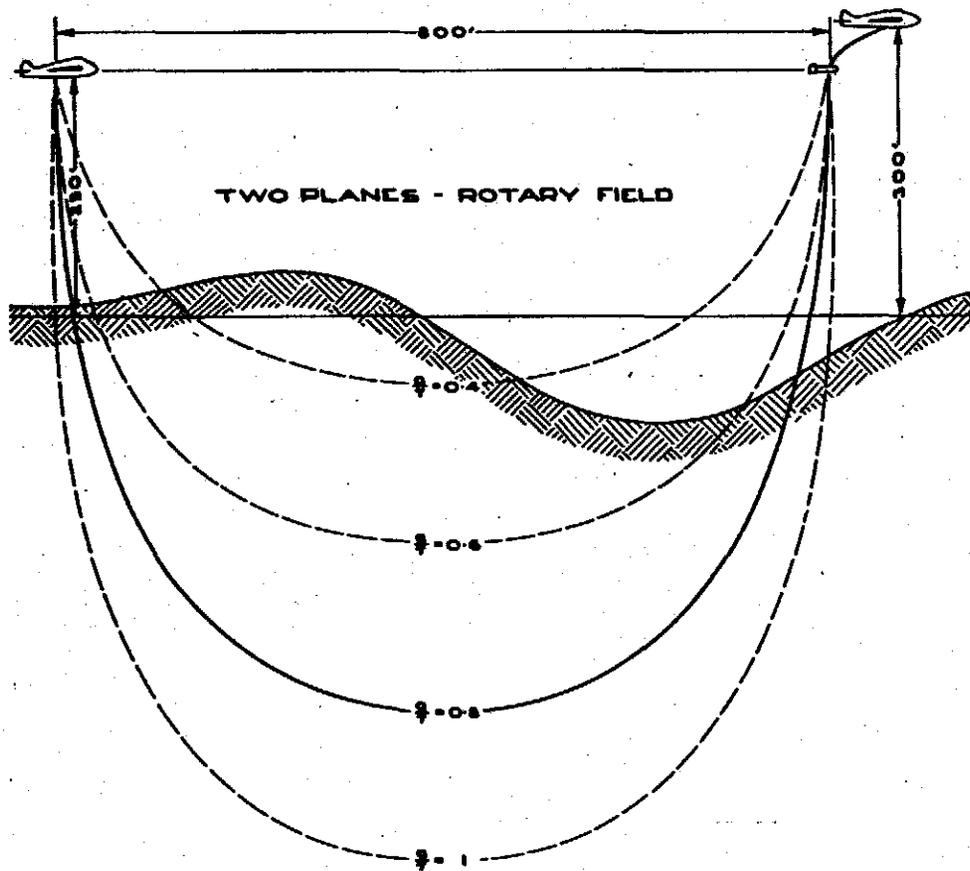
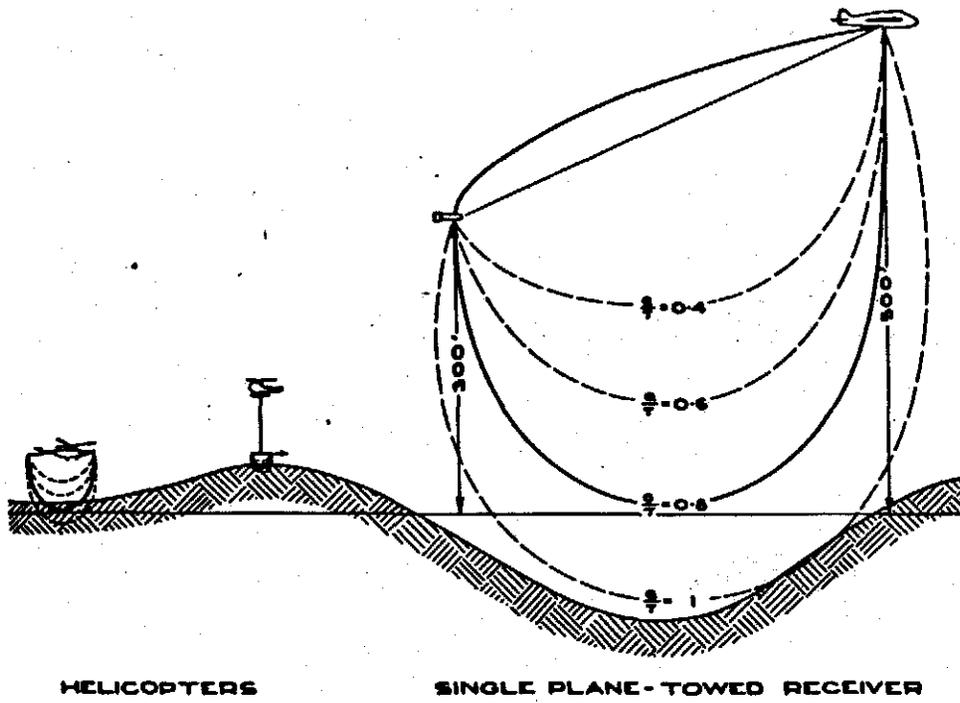
Unstable systems have a less favourable terrain performance, but they are often credited with better penetration because of the larger transmitter - receiver (T-R) separations. This concept is often based on studies of the characteristics of this configuration in free space. It can be shown experimentally that the response of a conductor (e.g. steeply dipping half plane) can be increased by increasing the T-R separation and it has, as a result, become a well established concept that large separations can be equated with deep penetration. The idea is shown in a popular form, which could be called the "skipping rope" concept, in Figure 2.

In this view only large separation systems are pictured as capable of significant depth of penetration and the problem of deep exploration is reduced to simply developing systems with large T-R separations. The idea was carried farthest in the ABEM two plane Rotary Field system which could be employed at a separation as large as 400-500 m. The expected deep penetrations were, however, never achieved either by the Rotary Field or by other large separation methods. The basic concept has a major flaw, namely, the infrequency of free space conditions. The geo-electrical analogy between the initial model and actual geophysical conditions is, in practice, quite inadequate.

The model of a target conductor in free space rarely, if ever, applies. Usually, and certainly where large exploration depths are needed, the target conductors are surrounded or overlain by material of finite resistivity, which also responds to the electromagnetic energization. With increasing separation the response parameters of both the target conductor and the medium or cover increase but because of the geometry the latter increases much faster.

The response parameter of a steeply dipping half plane in a moving source configuration is $\mu w \rho t (\rho^2 + h^2)^{\frac{1}{2}}$ (Ward, 1967) in which μ = permeability, w = frequency, ρ = conductivity, t = half plane thickness, ρ = T-R separation and h = height above conductor.

The induction number of a homogeneous earth is $\mu w \rho (\rho^2 + h^2)$ (Ward, 1967).



DIAGRAMS ILLUSTRATING E.M. FIELD PENETRATIONS
 USING
 DIFFERENT RECEIVER - TRANSMITTER COMBINATIONS
 RETURN SIGNAL (R) VARIES WITH $\frac{R}{T}$ RATIO,
 WHERE: Q = HEIGHT OF FLIGHT ABOVE CONDUCTOR
 T = TRANSMITTER - RECEIVER SPACING

Figure 2

03.

If we increase the separation ρ from 10 m to 150 m (which, in practice, also necessitates an increase of h from e. g. 40 m to 120 m) the half plane (signal) response parameter increases five times, whereas the homogeneous earth (geological noise) response parameter increases some 20 times.

The geological environment of the target and its geo-electrical characteristics will, therefore, determine whether an increase in T-R separation will increase or decrease the signal/noise ratio. If the environment is conductive the signal to noise ratio will, at a certain point, begin to decline with further separation and the exploration depth will from thereon diminish.

In other words, for every search problem there is an optimum separation which will result in the best signal to (geological) noise ratio, as there is an optimum frequency; or, more generally, for every search problem there is, within the range of dimensions and frequencies we are presently considering, an optimum separation \times frequency product which will result in the best signal to noise ratio and, therefore, the best penetration.

The following example is shown to illustrate the deterioration of the signal/noise ratio which in a common geological environment may result from an enlarged T-R separation.

Figure 3 (Mackowiecki et al) shows two test traverses over a sequence of geologic features, with the ABEM Rotary Field system ($\rho = 260$ m, $h = 100$ m, 800 Hz) and the Rio-Mullard system ($\rho = 26$ m, $h = 60$ m, 320 Hz). The signal level of the response of a conducting half plane at a depth of 10 m subsurface is indicated, as well as the tolerable noise level, (i. e. when the noise exceeds this level, the conductor becomes for all practical purposes undetectable).

It can be observed that this large, shallow target would be undetectable in more than 90% of the Rotary Field traverse because of the high geological noise level. In the Rio-Mullard survey it would be detectable over the full length of the traverse because the geological noise is well below the tolerance level. The Rotary Field system has a separation \times frequency product far too high for the geo-electrical conditions in this area and the focus has shifted to a very unfavourable signal/noise ratio.

The focus could be improved by either shortening the separation or lowering the frequency or both, as the Rio-Mullard results demonstrate.

The above considerations show and practical experience in recent years has confirmed, that the depth of exploration of classical moving source

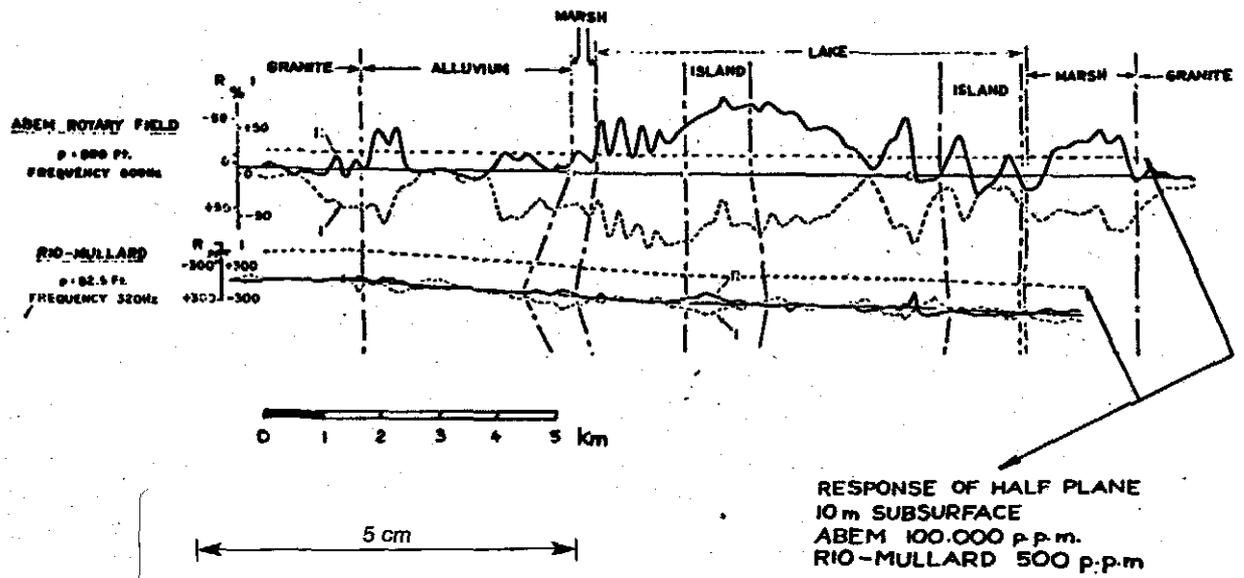


Figure 3

AEM systems in a normal geological environment is limited and that no easy remedies, such as simply increasing the coil separation, are available. Even if we assume that unstable moving source systems can and will be further improved, for instance by measuring in-phase components and employing lower frequencies, these improvements will not happen overnight and they will result in only modest gains in penetration. The large gains that deep exploration requires can only be achieved through a different approach.

THE TURAIR METHOD

It has long been recognized in the ground application of electromagnetic methods that much greater exploration depths can be obtained with systems using fixed energizing sources than with moving source and receiver systems. This advantage is mainly due to differences in scale between the two types of survey configurations.

The length of the receiver traverses in a fixed source survey suggests, to many people, large transmitter-receiver separations, but actually the latter are relatively small compared to the size of the energizing layouts. If we, for instance, consider an inductive Turam configuration, the measurements are carried out within one transmitting loop diameter and thus in an almost uniform primary field, which falls-off at a rate little more than the inverse first power of the distance. In Figure 4 the relative response rate of fall-off with depth of typical moving source and fixed source methods are compared. In the former, the fall-off is inversely as the 3rd power at a depth equal to the coil separation. In the latter method the response falls-off at a rate between the 1st and 2nd power.

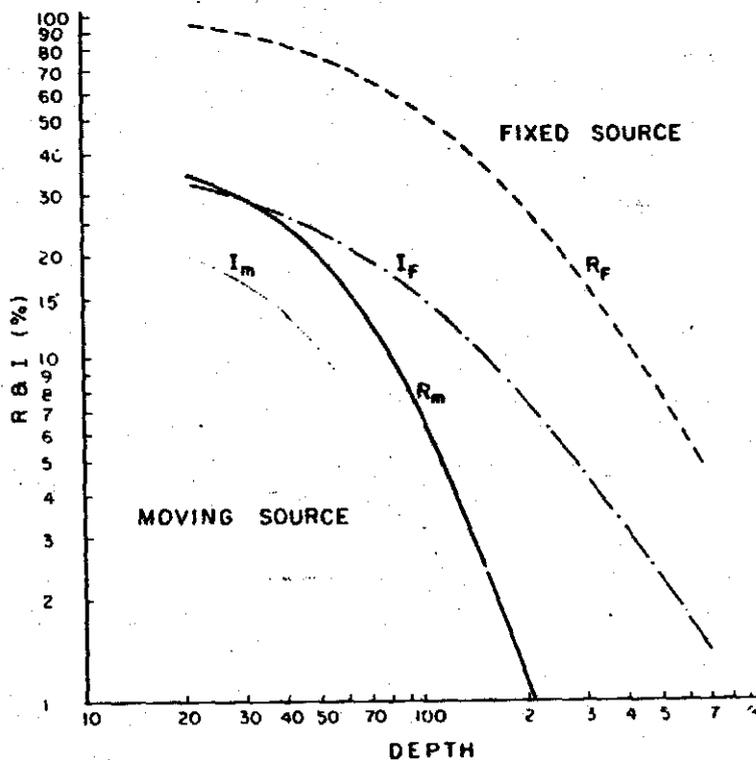


Figure 4

A representative range of target conductors (strike length varying from 100 to 1000 m) is shown in Figure 5a. In moving source configurations, all or most of these represent conducting half planes, but at the different scale of the fixed source configuration, they all appear as finite bodies. As a result, their response to moving source configurations does not vary appreciably with size but in a fixed source system the response may increase more than 400% over this range (Figures 5b, c).

In a moving source configuration, the largest target conductors are hardly more detectable than the smaller ones. The fixed source configuration has the advantage that the larger the conductor, the stronger will be its response and the greater the depth at which it will be detectable.

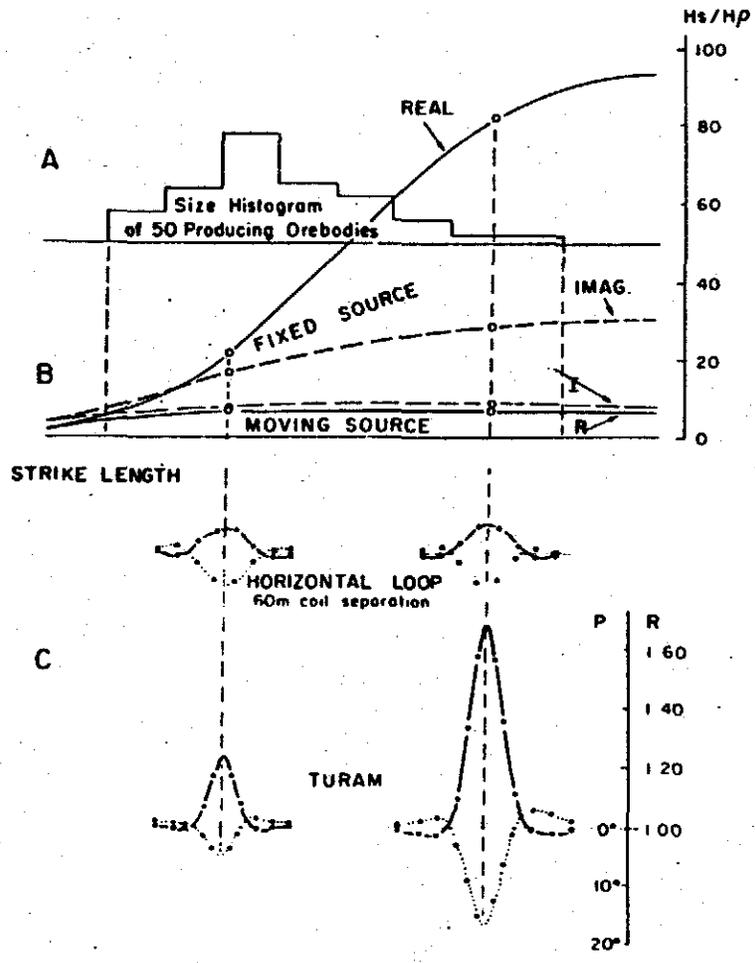
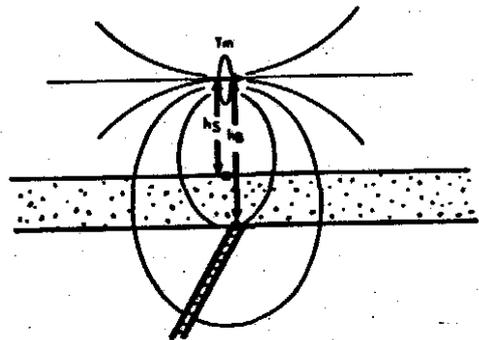
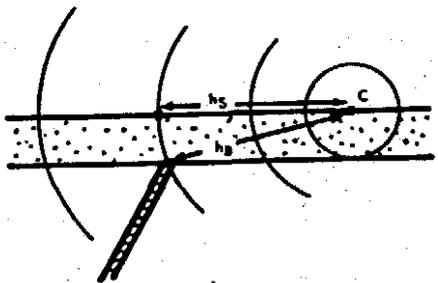


Figure 5

Another advantage results from the energization pattern and is particularly significant in areas of thick cover. Under such conditions a moving source system tends to emphasize overburden conductors because these are much closer to the source and the energizing field falls off at the 3rd power of the distance. In a fixed source system the energizing field is of almost equal strength at the location of near-surface or bedrock conductors (Figure 6) and overburden conductors are not emphasized by the energizing pattern.



MOVING SOURCE



FIXED SOURCE

Figure 6

Further, if the cover is extensive and homogeneous in thickness and conductivity, the electromagnetic response of this cover is constant over its entire area for a moving source configuration (assuming a constant terrain clearance of the airborne electromagnetic system). With fixed source energization

most of the current drains toward the edges and may leave the central portion almost neutral. Figure 7 shows this for a relatively limited horizontal conductor, both in the form for field measurements and in a model duplication. Only the edges are distorted; toward the central portion very little distortion is apparent.

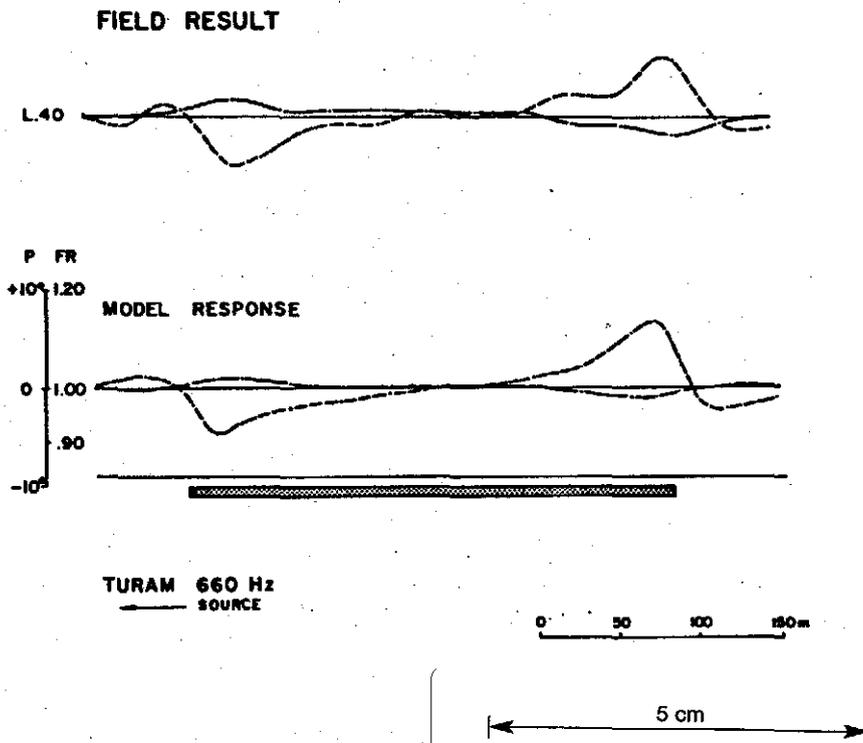
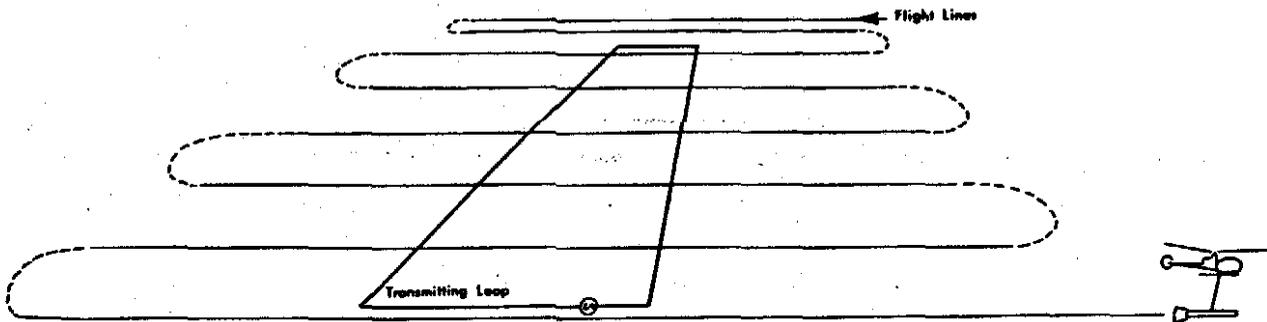


Figure 7

To combine these inherent advantages of the fixed source configuration with the speed and efficiency of airborne measurements, the Turair system employs transmitting layouts of large dimensions on the ground and a receiver system carried by a helicopter or light aircraft. Traverses

are usually flown across this source, as shown in Figure 8, i.e. measurements are made both outside and inside the transmitting loop.

The receiver system measures the horizontal gradient of the vertical and/or horizontal field by means of pairs of coils mounted in a bird towed by a helicopter, or attached to a fixed-wing aircraft.



TURAIR
FLIGHT LINES & LOOP LAYOUT

Figure 8

PRIMARY FIELD

Typical transmitting loop dimensions are 3 x 3 or 3 x 5 km. When a helicopter is used to carry the receiver system, it is also employed to lay out the transmitting loop from the air. For this purpose, a special cable dispensing device has been developed. Alternatively, the loop can be laid out by vehicle, where the country permits or by hand, and a light fixed-wing aircraft used to fly the receiver. A motor driven generator, supplying 2-4 amps of current is used to energize the loop. Any frequency between 100 and 800 Hz can be selected to suit the geologic conditions in specific areas.

Inductive primary sources are generally preferred. Grounded sources will usually cause galvanic current to flow through the investigation area, which will tend to result in increased overburden response. Moreover, as this current is in-phase and of random quantity and direction, it will impair quantitative interpretation, particularly conductor discrimination based on amplitude/phase relations.

In exceptional areas, grounded sources could be useful, for instance, to conductively energize bodies which, because of their geometry, cannot be sufficiently energized inductively to become detectable.

RECEIVING SYSTEM

The receiving system comprises two coils or two pairs of coils rigidly mounted in a coplanar and/or coaxial configuration. The separation may vary from 3 - 10 m. The ratio of the field strengths and the phase differences of the alternating magnetic field at the two coils are measured by means of a compensator and recorded in analogue or digital form. The sensitivity of the receiving system is 0.1% amplitude and 0.1° phase difference.

The receiver is normally flown at a 30-50 m ground clearance. It should be noted that since the response rate of fall-off is low, the receiver elevation is not critical. In fact, when near-surface conduction is high, the signal to noise ratio and thus the detectability of deep conductors can often be improved by increasing the terrain clearance.

INTERPRETATION

The field results of Turair measurements are basically similar to the results of ground Turam measurements, which gives the Turair method the benefit of proven and established quantitative interpretation procedures. (Bosschart, 1964).

In fixed source configurations, response parameters are simpler than in moving source configuration; neither transmitter-receiver separation, nor the height above the conductor have any effect on the character of the response at this scale. A typical Turair response diagram is shown in Figure 9 which shows the variation of real and imaginary components of the response with the factor $F\sigma t$ (F = frequency, σ = conductivity, t = thickness), for a tabular "thin" conductor of finite dimensions. A Turair coil separation of 5 m has been assumed as well as a depth of burial of 100 m to the upper edge of a 300 m square, tabular body dipping at 60° from the horizontal.

It has been shown earlier (Bosschart, 1964) that the conductor size variations affect the response characteristics and that they do so in a manner different from variation of the response parameter and that, therefore, a size factor cannot simply be incorporated in the response parameter. Thus, in order

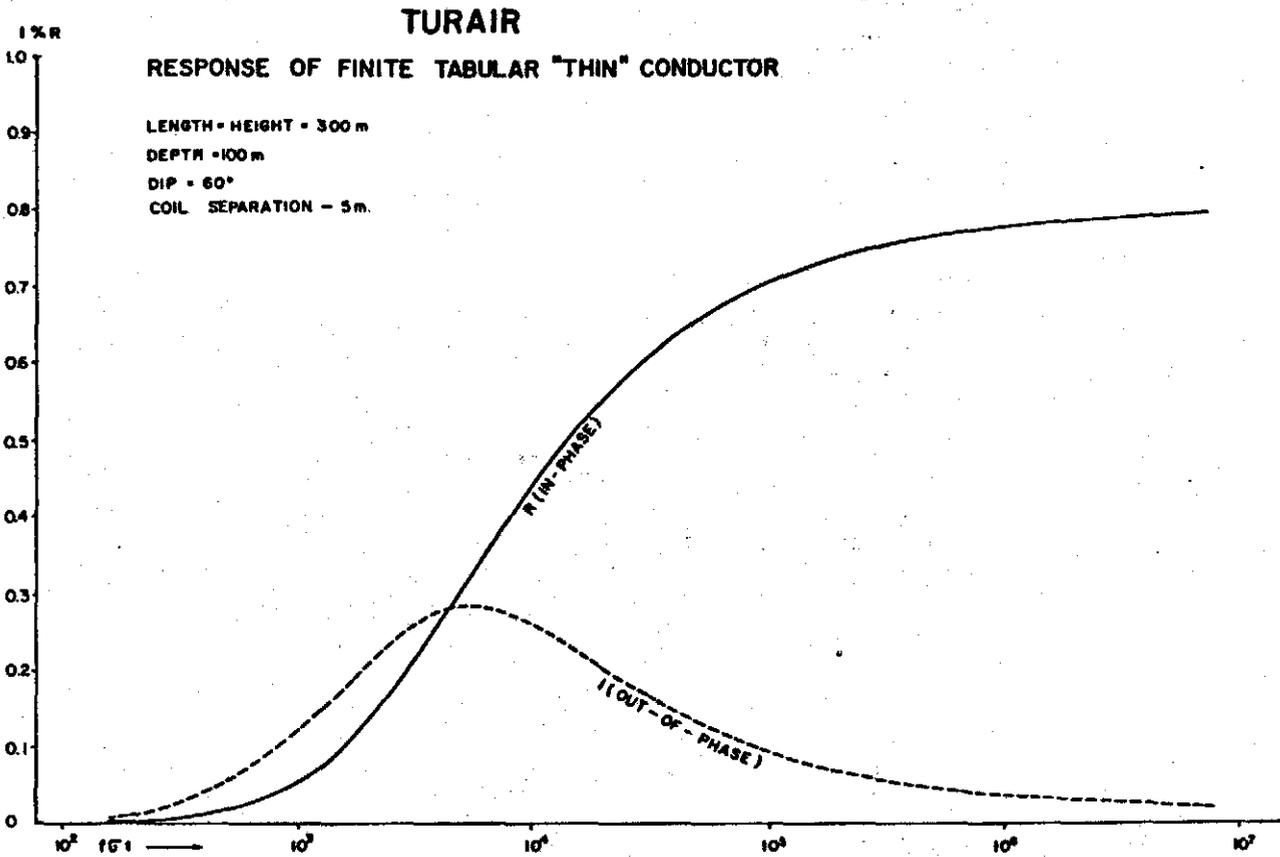
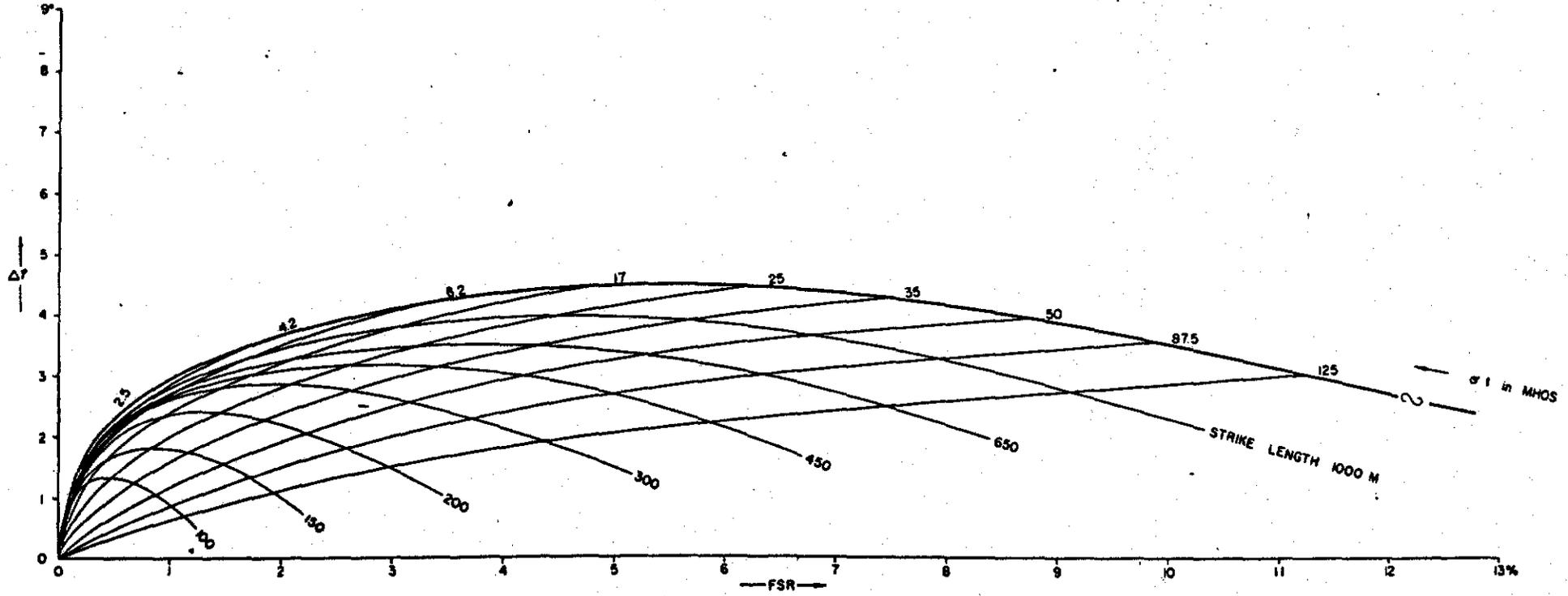


Figure 9

to determine Gt values from field data, composite nomograms have to be employed which incorporate size as well as response parameter variation. For the direct interpretation of Turair anomalies, a series of response diagrams for tabular "thin" conductors of dimensions ranging from 100 m strike length x 100 m depth extent, to infinite dimensions have been combined into a complex Argand diagram which is shown in Figure 10. Whereas this



TURAIR
 400 CPS
 RESPONSE / SIZE DIAGRAM
 TABULAR "THIN" CONDUCTOR

Figure 10

diagram applies for a particular coil separation and height of flight, the value of ζt can be derived directly from the relative amplitudes of field strength ratio and phase anomalies for all coil separation and heights of flight. The strike length of the conductor (which for bodies of more than $1/2 L$ depth extent is the determining size factor), can be determined from the anomalous pattern and is significant in determining it. Geometric changes such as depth, strike and dip, affect the amplitudes but not their mutual relations and thus have no effect on the determination of the ζt product.

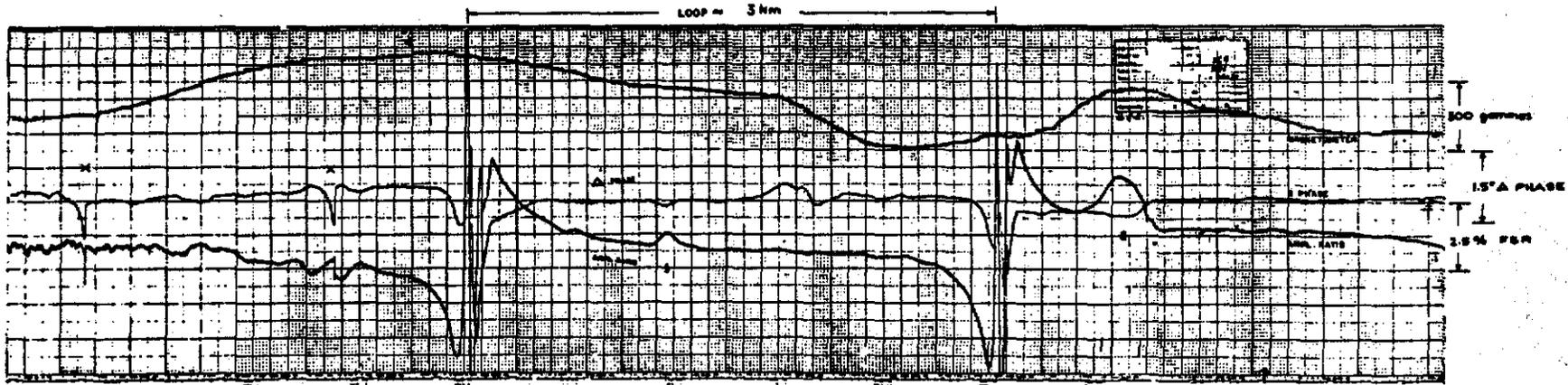
FIELD RESULTS

The Turair results shown below in Figures 11 to 16 were selected because the anomalies were followed up on the ground and subsequently drilled; because sulphide conductors were found and the initial interpretation was confirmed in detail and, most important in the present context, because these sulphide bodies were detected under a cover which is impenetrable to any other AEM method and barely within the range of the Turam ground EM method.

The survey was located on the projected SW extension of the Manitoba nickel belt, where the basement is covered by more than 100 m of Paleozoic formations (limestones, dolomites, sandstones, etc.) and relatively shallow Quaternary deposits.

Figure 11 is the record of a 400 Hz Turair and magnetometer traverse across a 3 km x 3 km source. The location of the latter is marked by two zones of very strong field reversals. Two distinct anomalies occur on this record, both indicating good conductivity. The first one, a small anomaly inside the loop, is due to a source at a depth less than 50 m, i. e. in the Paleozoic and of no immediate interest. The second anomaly is much stronger and shows a depth of approximately 240 m (or 200 m subsurface) and a ζt value of 180 mhos, indicating very high conductivity. There is a coincident magnetic expression of 170 gammas yielding the same interpreted depth. Figure 12 shows a parallel traverse $1/2$ mile outside the same transmitting loop, where the primary field gradients are almost constant. The anomaly in the centre portion is probably caused by an extension of the conductor shown in Figure 11. The indicated depth is approximately 270 m (or 230 m subsurface) and $\zeta t = 16$ mhos, indicating much lower conductivity. The field strength ratio shows a distinct current - return current pattern which suggests a wide, banded conductor. The anomaly has a coincident 70 gammas magnetic expression, indicating the same interpreted depth.

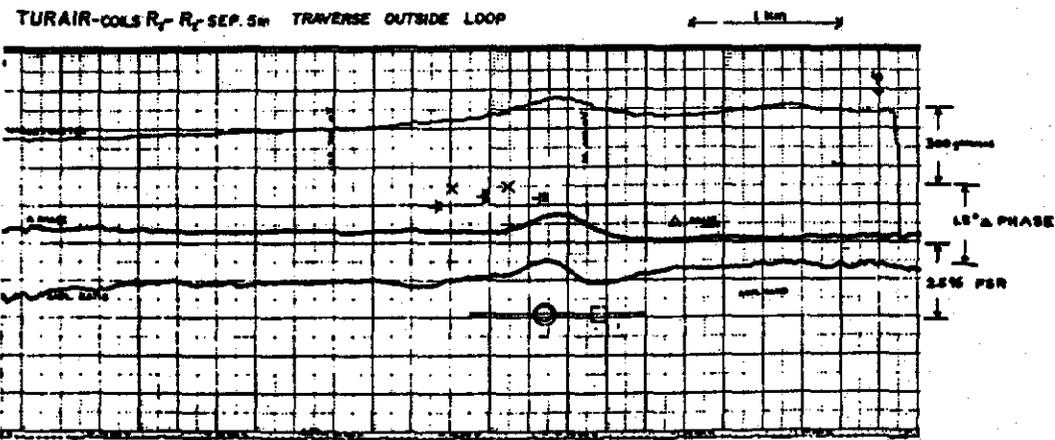
This conductive zone, which extends over a number of traverses, some of which are shown in Figure 13 was investigated on the ground by a magnetometer and Turam EM survey. The ground survey generally confirmed the conductor and the interpretation of the airborne traces. It is, however, worth



TURAIR - COILS R_1-R_2 - SEP. 5m

Figure 11

- 16 -



TURAIR-COILS R_1-R_2 SEP. 5m TRAVERSE OUTSIDE LOOP

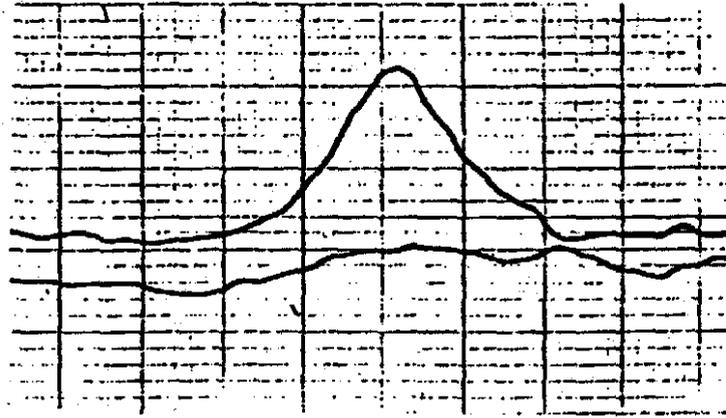
Figure 12

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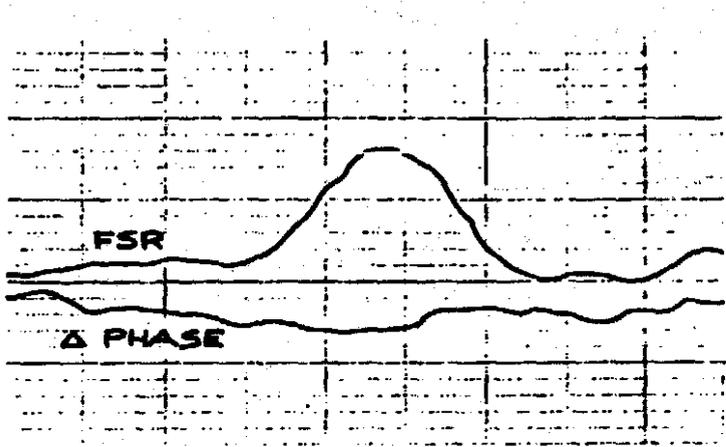
TURAIR 400 Hz
N. MANITOBA

ANOMALY # 1 294049

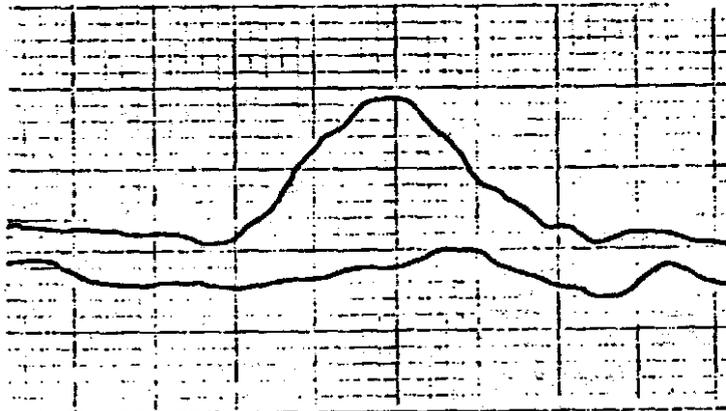
L 109 N



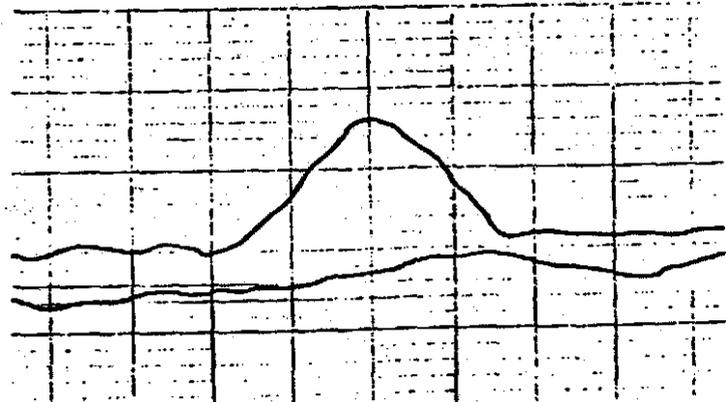
L 108 S



L 107 N



L 106 S



0 200 400 m

Figure 13

5 cm

noting that the ground Turam survey, although a 60 m coil separation was used, produced rather inconclusive results because of the near surface field distortion (Figure 14) which renders the signature of the deep conductor difficult to recognize. In fact, the ground EM results would not by themselves have formed a sufficiently reliable basis for further exploration. In contrast, the geological noise is hardly noticeable in the airborne results which consistently show a high (approximately 10:1) signal to noise ratio, notwithstanding the 30-40 m higher elevation of the receiver.

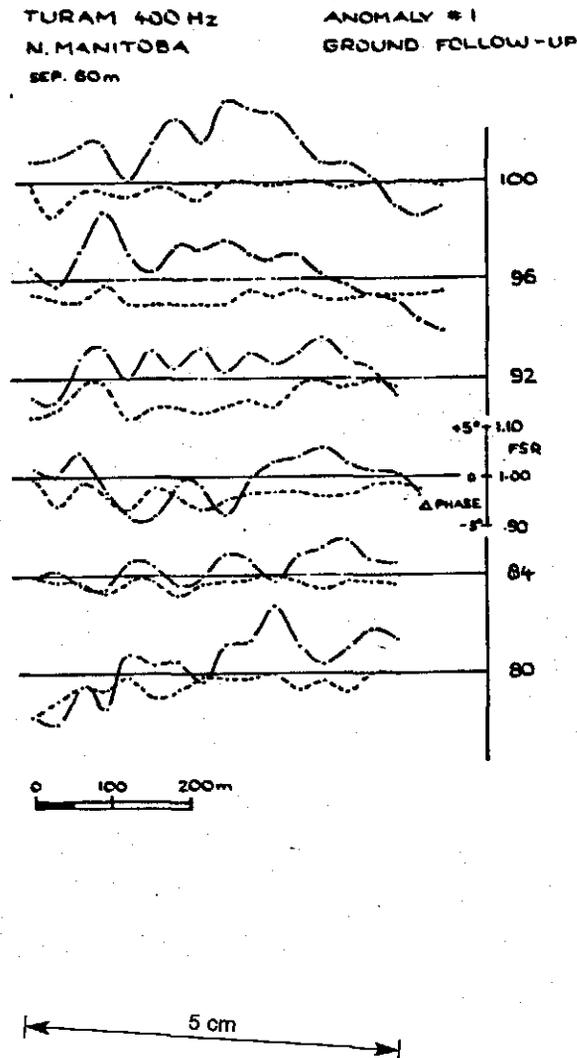


Figure 14

The drilling results of both traverses with the relevant airborne and ground sections are shown on Figures 15 and 16.

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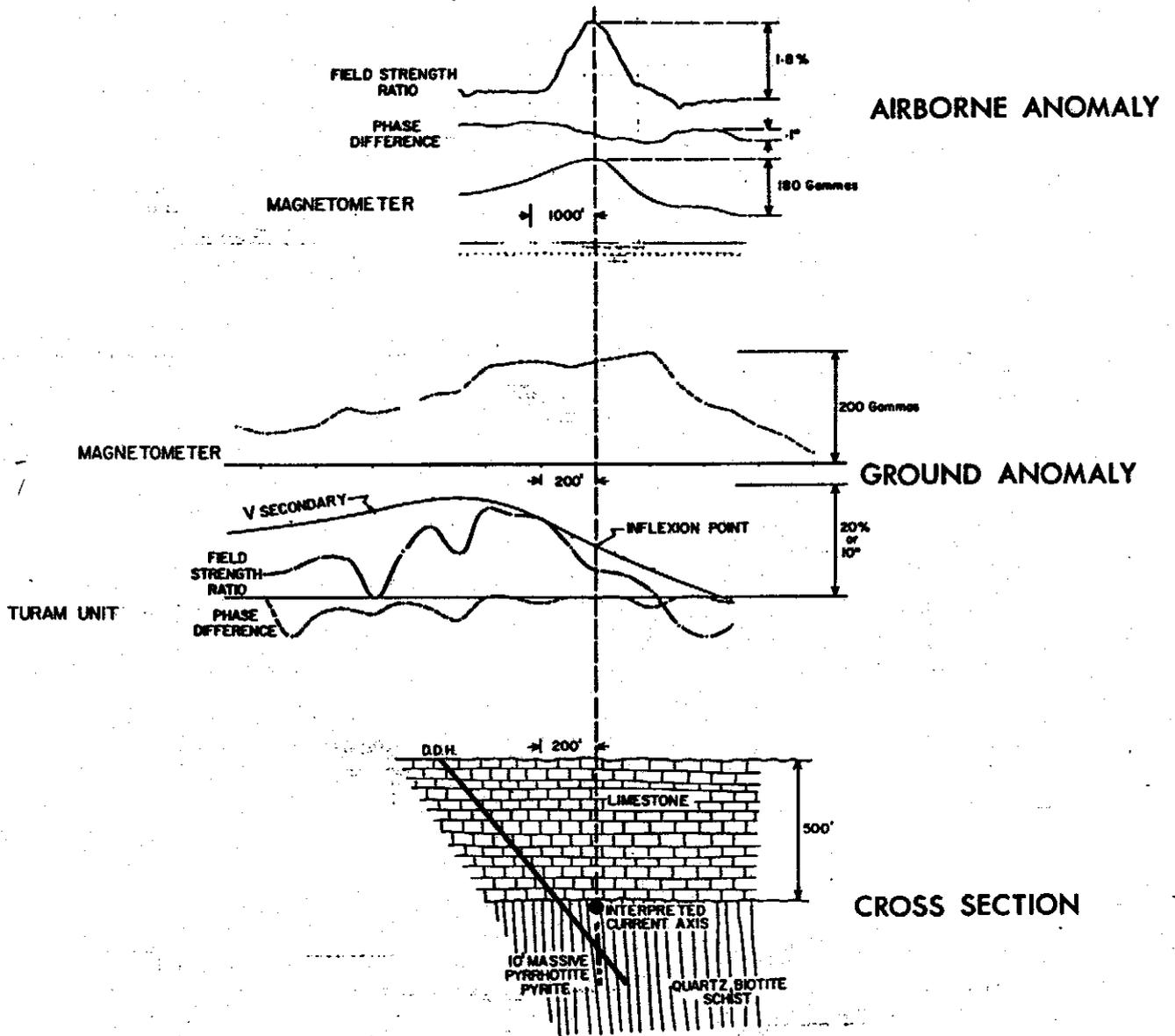
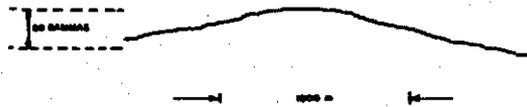


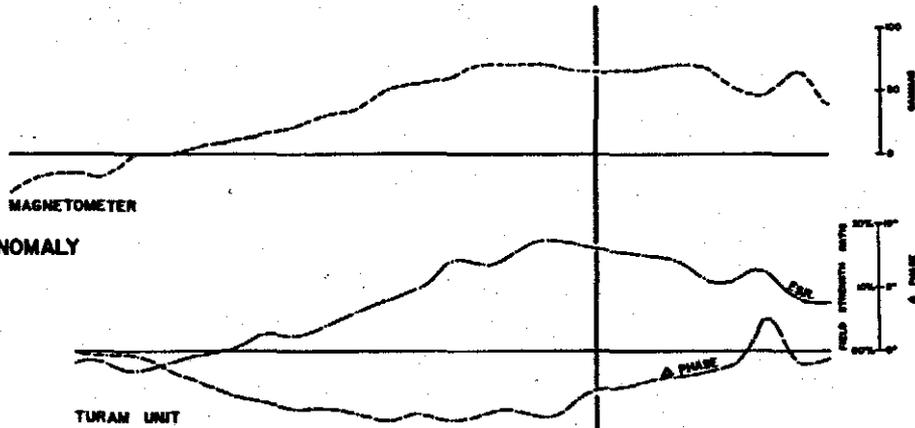
Figure 15

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TURAIR



GROUND ANOMALY



TURAM UNIT

CROSS SECTION

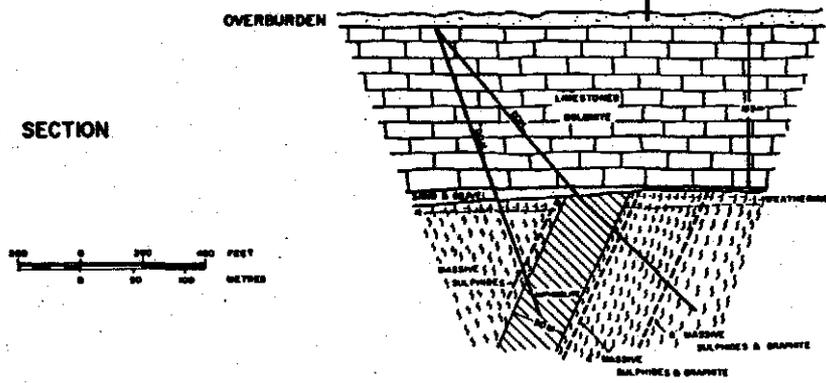


Figure 16

5 cm

The first hole intersected, at approximately 210 m depth, a 3 m wide zone of concentrated pyrite-pyrrhotite mineralization under 160 m of Paleozoic cover, thus confirming the high ρt value and the depth calculated from the airborne data.

Drilling of the second anomaly intersected a 120 m wide zone consisting of, in sequence, a narrow band of sulphides, a 50 m wide zone of partly serpentinized amphibolites, another narrow (1 m) sulphide zone, 40 m gabbro and a 3 m wide zone of pyrite-graphite mineralization under 185 m of Paleozoic formations. In addition, the upper 30 m of the basement were weathered and leached bringing the total cover to a thickness of 215 m. These results again confirmed the depth and the low ρt value calculated from the airborne data, as well as the wide, banded nature of the conductor.

Some examples of surveys in Western Australia are shown in Figures 17 and 18 and these display characteristics different from the previous examples. In all these surveys, the energizing loop was laid out around the target area and the measurements carried out inside the loop. Damping of the electromagnetic field in the weathered cover is often too high for reasonably long traverses to be measured outside the loop. In both locations the anomalies are characterized mainly by phase distortion, with much less distortion in the field strength. Conductivity of the mineralized zones generally appears to be low.

Figure 17 presents two traverses, in opposite directions, over a conductor in a host rock of ultrabasic formations of Archean age. The indicated depth is approximately 90 m subsurface which is probably the depth of oxidation. The conductor displays very low ρt values, 3.5 mhos and 2.5 mhos respectively. This conductor has not yet been further identified and could equally well be an ionically conducting fault zone or poorly conducting sulphides. The reversal of the amplitudes between the two traverses is due to the opposing directions of measurement.

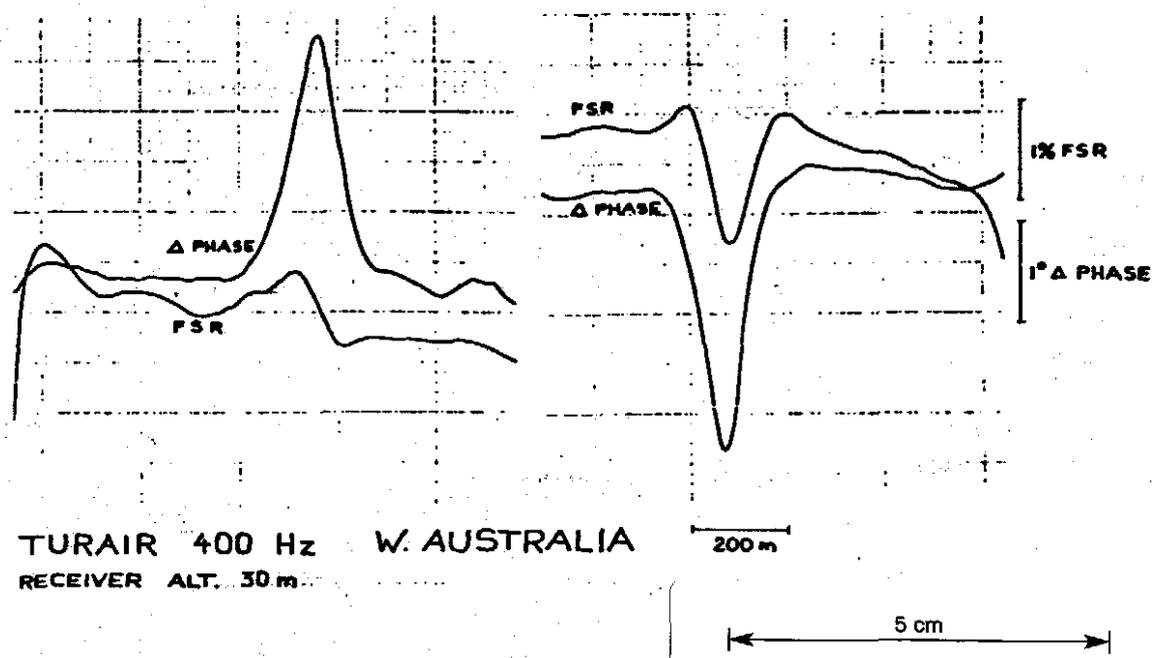


Figure 17

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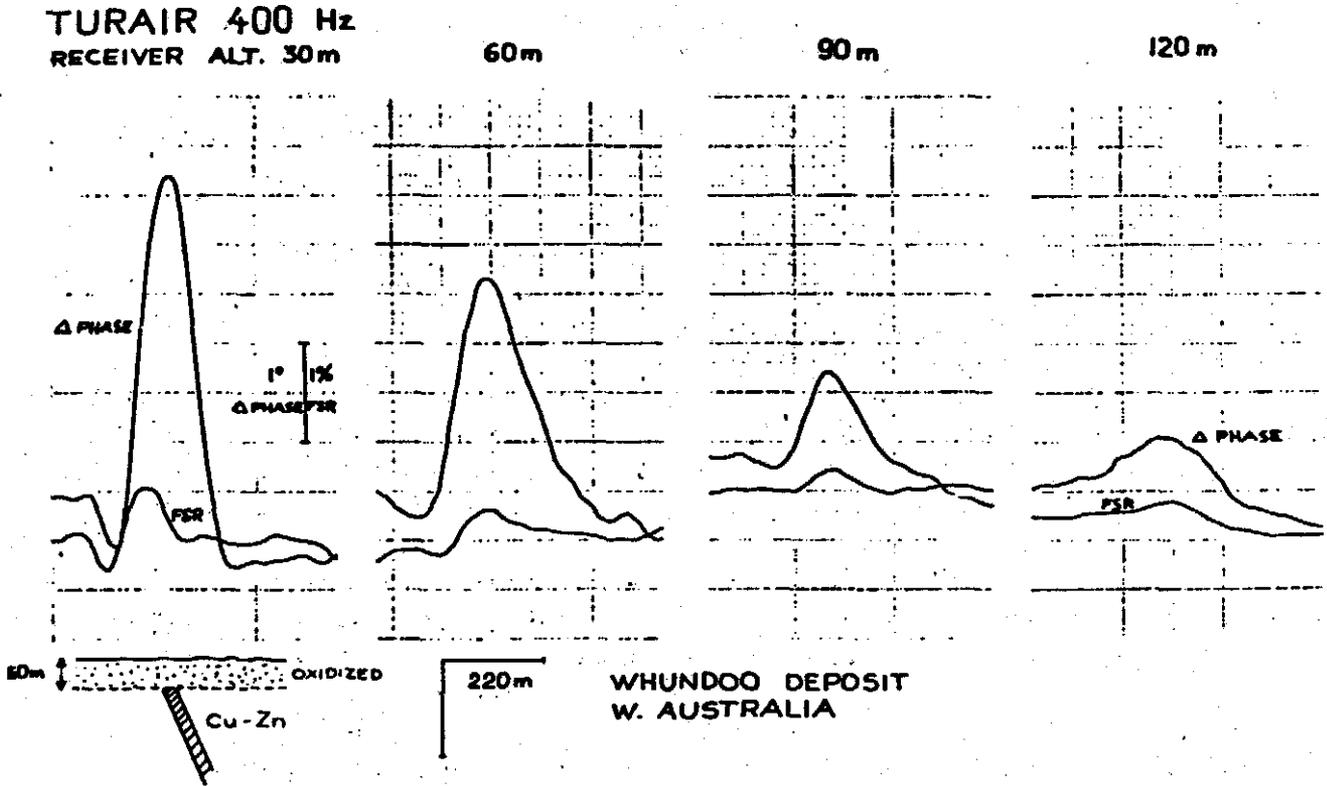


Figure 18

Figure 18 presents a survey over known conditions, the Whundoo deposit in NW Australia. Although the mineralization consists of a 10 m wide zone of Cu, Zn, pyrite mineralization, the conductivity appears to be very low ($\rho t = 2$ mhos) possibly due to the fact that the sulphide mineralization occurs in the form of discrete lenses. Traverses were made at increasing altitudes from 60 m to 165 m bird altitude, a level where the F.S.R. distortion has largely disappeared, but the phase difference anomaly is still clearly discernable (Figure 18) for the surface materials. On this basis, one may estimate the effectiveness of the standard AEM systems in detecting this target.

055

Earlier resistivity measurements in the area gave values of about 90-100 ohms. The surface σt would reasonably be estimated to be between 0.2 and 0.5 mhos, i. e. the difference between the target conductor and cover σt is less than one order of magnitude. In an unstable moving source configuration the response parameter of the cover would actually be larger than of the target conductor and it would, therefore, be unlikely that the deposit would be detectable at all with such a system, unless a much lower than usual exciting frequency would be used. In a stable moving source system the response parameter of the cover could be slightly smaller than of the target, and the latter might just be detectable at a lower receiver altitude. Neither system would be an effective exploration tool in this environment; even if the depth of oxidization would stay within 60 m throughout the area.

OPERATIONAL EFFICIENCY

Under average conditions a primary field loop of 3 x 5 km can be laid down by helicopter and the transmitter positioned within little more than one hour. By vehicle or by hand more time is required.

A line spacing of 200 m has been found most efficient for the majority of search problems. Economic ore deposits may have strike lengths of 200 m and even less and to detect such targets, particularly when they are deeply buried, requires a line spacing not much larger than the minimum strike length. Moreover, larger line spacings do not represent significant savings because less profile can be measured per loop layout. Subject to local conditions some 200-300 line km of profile (at 200 m intervals) can usually be surveyed from one source loop; the total operation of positioning and measuring covering about one day's field work.

THE MERITS OF DEEP EXPLORATION

The Turair system has been developed for the specific purpose of deep electromagnetic exploration. It has been shown that a sufficiently significant increase in capability cannot be achieved through improvement of the classical moving source AEM methods, which have been developed close to their effective penetration potential. To attain substantial improvement in exploration depths, electromagnetic techniques employing fixed primary sources have to be used.

There are two aspects of this increased depth of penetration. The first and more obvious, relates to areas of heavy overburden, thick sedimentary cover, oxidation or bad topography. The results obtained thus far in such areas of deep cover, have confirmed the feasibility and effectiveness of airborne fixed source gradient measurements and they have, moreover, shown that the airborne application has considerable advantages in sensitivity and penetration over ground fixed source measurements because of a strong reduction of

the geological noise level. For instance, the results in Northern Manitoba, in places where relatively homogeneous overburden conditions prevail, show that the Turam method could detect bedrock conductors under a maximum of 200 m of cover. Over the same conductors the Turair anomalies show a better than 6:1 signal/noise ratio, indicating that they would be detectable to a depth approaching 300 m. The maximum depth reached in the same area with an AEM moving source system (INPUT) has been 125 m (Tikkanen, 1970).

An equally important aspect of the ability to achieve significantly greater depths of exploration is the possibility of discovering truly "blind" ore bodies, even where little overburden exists. Up to the present time our primary concern in airborne electromagnetic prospecting has been the ability to penetrate the unmineralized covering formations or oxidization zone and to be able to detect bodies outcropping at basement surface. It is worthwhile, however, to examine the significance of the Turair method in terms of the probability of detecting sulphide deposits at depths in excess of those achievable with other AEM systems, even where the latter systems adequately penetrate the overburden.

For a multi-million ton massive sulphide base metal ore body, which is to be mined by underground methods, there is little effective difference in the mining costs per ton whether mining starts at the base of the overburden or at 1000' in depth. As the history of exploration on the Lake Dufault property in Quebec has demonstrated readily, rich ore deposits occurring at even one-half mile in depth are very desirable prizes indeed and fully warrant being put into production. An exploration depth of 300' imposed by the airborne electromagnetic systems currently available, is certainly not the maximum depth to which one would like to explore under present day economics of underground mining.

It is legitimate to ask, however, what is the probability of additional ore deposits being found by an airborne electromagnetic technique which has a significantly greater depth of detectability of 300'? The appropriate probability considerations are related to (a) the mode of origin of the ore deposits in question, (b) the size, shape and physical properties of the ore deposits, (c) their present attitude (dip and plunge directions) and (d) the thickness of overburden or later formations overlying the favourable horizon and (e) the amount of "geologic noise" in the area.

Some assumptions have to be made about these factors in order to arrive at the appropriate probabilities. The first assumption is that the ore deposits are essentially strata bound (meaning generally of tabular form with a thickness far less than their other two dimensions in the plane of the favourable horizon), of roughly equal dimension in this plane and highly conducting. Such deposits would include the majority of the massive copper-zinc

and nickel deposits in Archean rocks (see "Metallogenic Relationships in the Abitibi Belt, Canada; a Model for Archean Metallogeny" by Hutchison, Ridler and Suffel, C.I.M. Bulletin, April 1971, pages 48-57) and massive lead-zinc deposits in carbonate rocks of the Paleozoic age, throughout the world.

As more information is developed from each mining camp containing one of these types of deposits, the emerging picture reveals that the deposits are associated with a particular stratum or strata and are probably of volcanic exhalative origin laid down in shallow seas and subjected to later burial and metamorphism. A series of such deposits commonly occurs in an area, laid down originally on a gently undulating surface but later subjected to structural deformation to a greater or lesser extent. In most Precambrian shield areas of Canada, for example, the once essentially flat lying horizons are now very steeply dipping. The ore deposits are assumed to lie in a random distribution on the original horizon or horizons in which they were laid down, to have been subjected to random structural deformation and to have been cut by a perfectly random surface which, today, forms the present bedrock surface. The surface may then be covered by later sediments (e.g. Paleozoic) and by a skin of overburden of greater or lesser thickness.

The analysis of a large number of massive sulphide base metal deposits of the Canadian and Baltic Precambrian Shields, as shown on Figure 5a, indicates that such bodies have a median strike length of about 1000'. Since the present ground surface is a perfectly arbitrary one in respect of the original surface of deposition, on a statistical basis, one may assume that the bodies are essentially equi-dimensional in plan and dip extent. The old mining adage of 'as in strike so in dip' is probably based upon "seat of the pants" experience with this fact. In the case of an individual deposit, the present surface strike length may be much greater or much less than its dip extent, however. We will, therefore, use as a mathematical model a series of highly conducting bodies approximately 1000' in diameter, randomly distributed in a more or less contorted plane. If the average thickness of such a body was 50' this would represent approximately 5 million tons of ore. This contorted plane lies in a random location relative to the present ground surface.

Under normal conditions, a Turair anomaly of the order of .2% or greater in field strength ratio is usually sufficient for detection purposes. The typical 1000' diameter highly conducting tabular body discussed above, is shown in Figure 19 to give rise to .4% field strength ratio anomaly at a distance equal to its diameter above its nearest edge if steeply dipping. A Turair anomaly of the order of 0.2% is to be expected at a depth equal to twice its diameter (2000') if flatly dipping. Under conditions of reasonable geological noise, it is fair to say that the typical massive sulphide ore deposits which we have defined above are detectable to at least 1000' in depth of burial above their uppermost point regardless of its orientation.

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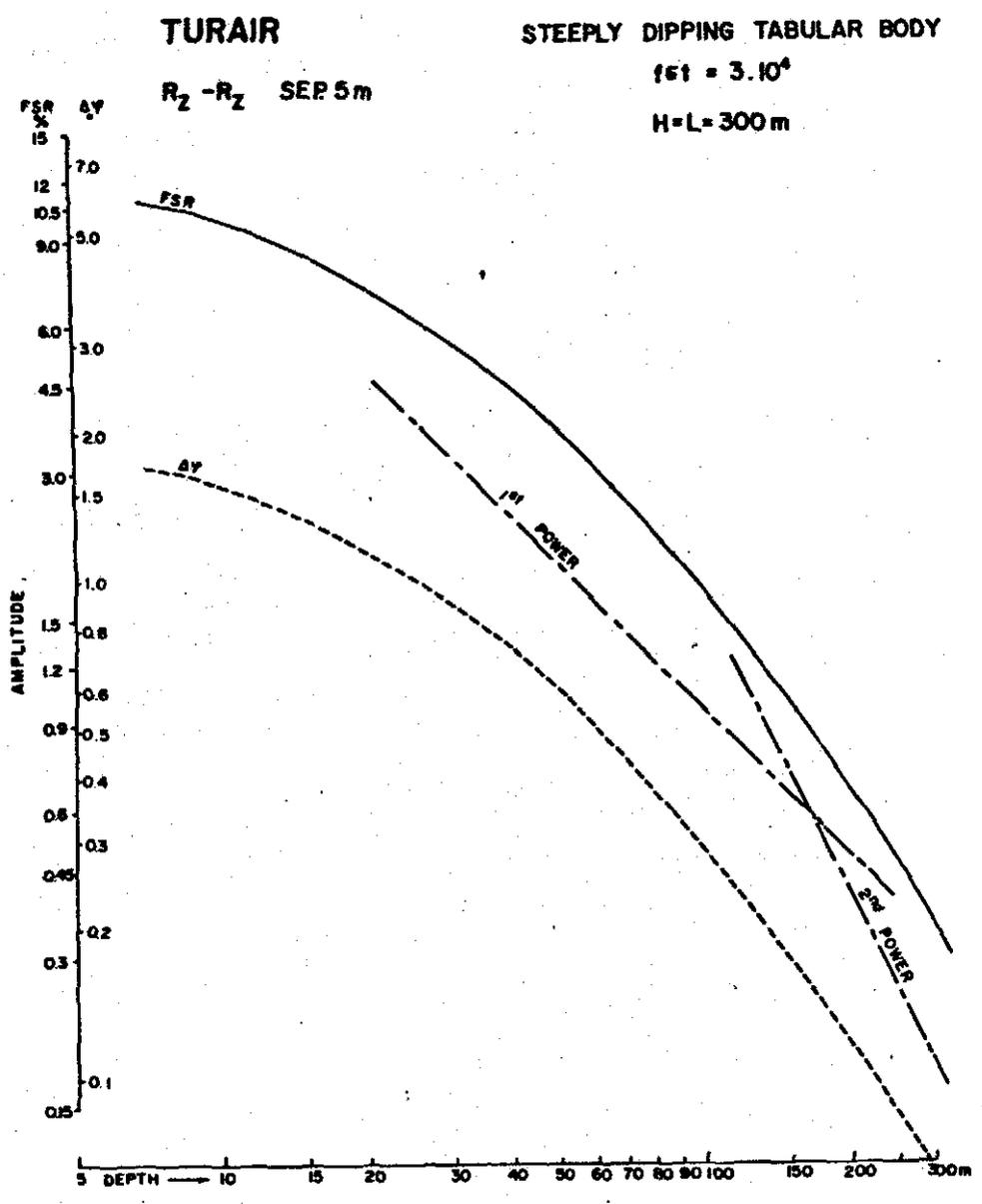


Figure 19

Let us now compare the relative probability of the top edge of such a body coming within 1000' below the ground surface with the probability of it coming within 300' of the ground surface (Figure 20).

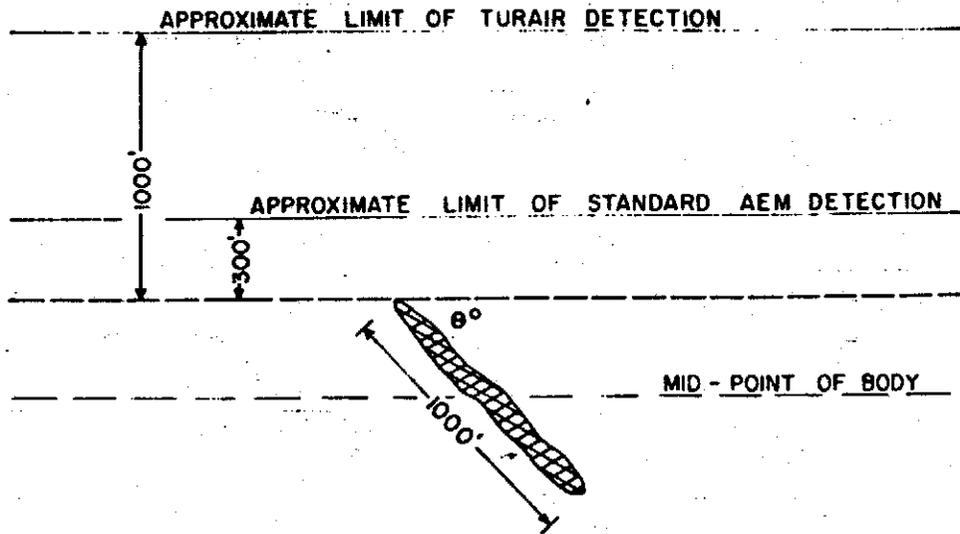


Figure 20

We will assume that the body, if it comes to the present bedrock surface, is at least one-half intact, that is that no more than half has been removed by erosion, so that a substantial body still remains. The relative detection probabilities of the Turair and the standard AEM systems may be established by comparing the probability of the ground surface cutting within 1000' of anywhere between the upper edge and the mid-point of the body with the probability of it cutting within 300' of the same region, ignoring for a moment, the effect of overburden or later sediments which are devoid of probability of containing these ore deposits. The relative probabilities then become $(1000' + 500' \sin \theta) / (300' + 500' \sin \theta)$ where θ is the dip of the body out of the horizontal. This relative probability factor is equal to 3.3 for $\theta = 0^\circ$, 2.1 for $\theta = 45^\circ$, and 1.9 for $\theta = 90^\circ$. On this simple basis, ignoring the effect of overburden, there is at least an equal chance for a sulphide deposit to lie between 300' and 1000' in depth as there is between 0' and 300' of the ground surface.

The probabilities for Turair are improved still further by the presence of overburden. The resultant probabilities may be expressed by multiplying the appropriate non-overburden probabilities, referred to above, by the relative vertical thicknesses of bedrock which are included in the achievable depth of penetration of each of the respective systems. In the case

060

of the Turair this would be $(1000' - H)$ where H is the thickness of overburden in feet and in the case of standard AEM systems $(300' - H)$. In an area containing 150' of barren cover of any sort, a further probability bias of the order of 5.7 in favour of Turair will result.

In summary, at least twice as many "typical" ore bodies would, statistically, be detectable by Turair to 1000' depth as by standard airborne electromagnetic systems to 300' depth, even where no appreciable overburden is present. If substantial overburden cover exists, this detectability ratio can readily achieve a factor of 10. There are immediate implications in respect of the merits of renewed exploration in areas where such deposits are already known and where the favourable horizons have been reasonably well established and can be defined as to their surface expression with some assurance. It is not at all necessary to restrict such exploration to areas of thick overburden or other sedimentary cover, although appreciable thicknesses of barren cover would greatly enhance the relative probability of detection by a Turair system.

Because of its lower efficiency and mobility the Turair method is not economically competitive with other AEM systems when the search problem requires only relatively moderate exploration depths. Its application is more useful (1) where the capability of other systems is limited because of extreme overburden, sedimentary cover, weathering or topographic relief or (2) in areas of special geological interest where the increased depth capabilities increase the probability of discovery of (blind) ore bodies. Because of the fixed source configuration the Turair method is less affected by near-surface conductivity than moving source methods and it can, moreover, be applied with much lower exciting frequencies (100-800 Hz). As a helicopter-borne system it can operate in mountainous terrain where it further has the significant advantage over other AEM methods that the height over target has (1) less effect on the exploration depth and (2) no effect on the response parameter.

The data obtained can be interpreted accurately in terms of current axis location (subject to flight path recovery), depth and conductivity-width values, using well established techniques.

In brief, the Turair method has provided a very useful tool for reconnaissance exploration for deeply buried base metal deposits.

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TURAIR - THE STATE OF THE ART

The applicability of airborne electromagnetic methods to base metal exploration has been well established by their discovery record the past two decades.

Differences in opinion occur in when to use a particular system. In practise the "conventional systems" (In-Phase/Out-of-Phase, Dual Frequency, Input) have proven to be able to detect economically mineable sulphides up to maximum depths of 300 ft. to 400 ft.

- In areas where
- strong relief (British Columbia, Tasmania);
 - heavy, sometimes conductive overburden (parts of Ontario and Quebec);
 - extensive thickness of Paleozoic sediments (Hudson Bay Lowlands, Manitoba);
 - deep weathering (S. W. United States, Tropics, Sub-Tropics, parts of Australia);
 - high trees (jungle)

require the need for greater exploration depth, such systems are not adequate. The same applies in established mining camps when the exploration geologist needs to probe to depths much greater than any previously executed electromagnetic surveys.

A fixed source system and especially its airborne version, TURAIR, is then the answer. Due to different scaling factors TURAIR has the advantage over conventional systems to extend exploration depths by a factor of 2 to 3.

During the last two years the electronics of the TURAIR equipment, the wire layout device, operational procedures and interpretation techniques have been improved to such an extent that surveys can be executed with great ease.

TURAIR costs compare very favourably with any other airborne EM method when one considers the total volume of rock explored. In comparison with ground methods on projects of, for example 50 line miles, TURAIR can be less expensive, yield data quickly and probe deeper.

Case histories from Ontario and Quebec (heavy overburden), British Columbia and Tasmania (strong relief, Manitoba (extensive Paleozoic sediments), S. W. United States and Western Australia (deep weathering) prove that TURAIR is capable of detecting targets up to depths of 600 ft. subsurface. Free air altitude tests show still clear responses up to 1400 ft. height. The signal to noise ratios in the above cases are 10:1 and 5:1 respectively, suggesting that similar targets can be readily detected to depths of 1000 ft.



Turair® is the deepest penetrating electromagnetic system in the world.



The Turair system, with magnetometer, in action

What is the deepest sulphide body you ever found by airborne electromagnetics?

If your answer is more than 200' you are one of the few!

Not so long ago you could be happy with this answer, knowing that this was as deep as could be achieved. Are you aware that you can now get much more?

A new approach

Conventional airborne electromagnetic systems have been developed close to their maximum penetration capability. Under ideal conditions the best among them may detect conductors to depths between 300' and 400'. To break through this threshold a new approach was needed.

Scintrex has developed an airborne method which is capable of exploration depths down to 1000'. We have called our new method TURAIR®.

What is Turair®?

Turair is airborne Turam.

You know that Turam is the deepest penetrating ground electromagnetic method and the only one that performs well in rugged topography. Turair has even better response characteristics and sensitivity plus the speed and economy of airborne surveying.

We have flown many thousands of line miles in Canadian and Australian Precambrian terrain. Turair has also been flown successfully in rugged mountainous terrain in British Columbia, western U.S.A. and Tasmania, where most conventional airborne electromagnetic systems have difficulty flying close enough to the target to achieve detection.

How deep?

Unlike other methods, the main limitation on Turair's depth of penetration is the size of the conducting target. The bigger they are, the deeper we can find them! Ideally, we can detect a tabular disc-shaped body when its upper edge is as deep as its diameter. Tests we have done above out-cropping bodies show clear responses at 1400' height.

On survey, we have detected sulphide bodies buried under 600' of cover. The strength of some of these anomalies confirms that they would have been found at much greater depths.

Is Turair® expensive?

On the basis of cost per volume of rock explored, Turair is probably cheaper than any other method. Since it is helicopter borne and requires a ground transmitter, Turair may cost more on a line mile basis — but that is only part of the picture.

For moderate size targets (say, 5 million tons) Turair's useful depth of exploration and coverage between lines is two to three times greater than any other system — and it is even better for larger bodies. You may pay more per line mile, but you

will reap the benefits of greatly increased penetration into bedrock — where it really counts!

Where should you use Turair®?

In some areas one or more of the following conditions prevail:

1. The overburden is especially thick;
 2. the host rock is covered by younger rocks;
 3. topography is rugged;
 4. the tree cover is high; or
 5. there is deep tropical weathering.
- Turair is a must for such areas.

Even where the above conditions do not occur there may be reason to expect blind ore deposits at depth, for instance, on a favourable horizon. Turair is the only reconnaissance system capable of finding sulphide conductors at depths beyond 400'.

If you have reason to be especially keen on an area, give it a thorough test — give it Turair.

Want to know more about Turair®?

We would be pleased to discuss the possible application of Turair to your exploration problem. Chances are we can show you results obtained under similar conditions elsewhere.

BRANCHES AND AGENTS: Ankara, Athens, Calcutta, Caracas, Denver, Djakarta, Frankfurt, Johannesburg, Lagos, Lima, London, Mexico City, Montreal, Perth, Pretoria, Quezon City, Rio de Janeiro, Salt Lake City, Sydney, Tokyo, Vancouver.

222 Sndercroft Rd., Concord, Ont.
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Phone or write — Dr. Harold O. Seigel will be glad to talk to you or send you further information.



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HEM-701
Helicopter-borne
Electromagnetic
System in Perspective

by R. A. Bosschart
and G. Campbell



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THE SCINTREX HEM-701
HELICOPTER-BORNE ELECTROMAGNETIC SYSTEM
IN PERSPECTIVE

by R. A. Bosschart and G. Campbell*

* Scintrex Limited, Concord, Ontario.



INTRODUCTION

The Scintrex HEM-701 system is a helicopter-borne moving source electromagnetic prospecting system measuring in-phase and out-of-phase components of a 1600 Hz field. Transmitter and receiver are mounted 10 m apart in a rigid coaxial configuration in a long tubular bird, which is towed about 30 m below the helicopter (Figure 1).



Figure 1: HEM-701 System in Flight

067



During the past four years, the system has been extensively used for base metal exploration in many areas around the world and its capability under a wide variety of conditions is by now well established.

Some advantages, such as terrain performance, appear to be generally recognized, but others, e.g. the high resolution or the low sensitivity to conducting overburden, seem not to be well understood. Moreover, appearances have helped create a belief that, compared to other AEM systems, helicopter electromagnetic systems are lightweight, second order exploration tools, which can achieve only limited exploration depths.

The purpose of the present article is to compare the performance of the HEM-701 system with other AEM systems under normal survey conditions. This may seem obvious, but it has become customary in recent years to compare AEM systems on the basis of an artificial combination of a free space environment and an arbitrary noise level. As the presence of a conducting cover or host rock has a different effect on different AEM systems, the extrapolation of free space performance to a normal field survey for the purpose of comparison is usually misleading and it is particularly so when short separation and large separation methods are compared.

GENERAL

Active EM systems traditionally fall into two distinct groups, namely, stable ("rigid boom") and unstable ("towed bird") systems (Figure 2). The former, including the Scintrex Otter equipped with the Rio-Mullard EM system and the Scintrex helicopter-borne HEM-701 systems, employ a transmitter and receiver mounted on a mechanically rigid structure, such as the airframe, or in a tubular survey "bird" and are normally flown at terrain clearances of 30 - 60 m. Unstable configuration systems, viz INPUT, 2-Frequency Phase Shift and Rotary Field systems have the transmitter mounted on the aircraft and a receiver towed below and behind the aircraft on a long (usually \approx 120 m) cable; normal terrain clearance is 135 - 150 m.

In comparison with the helicopter systems, it is tempting to portray the unstable systems as powerful, heavyweight and, therefore, more effective exploration tools, inferring that their large transmitter-receiver separations as opposed to the short separations of the stable systems (9 - 19 m) indicate a much greater depth penetration potential.

The capability of airborne electromagnetic methods is, however, determined by other factors.

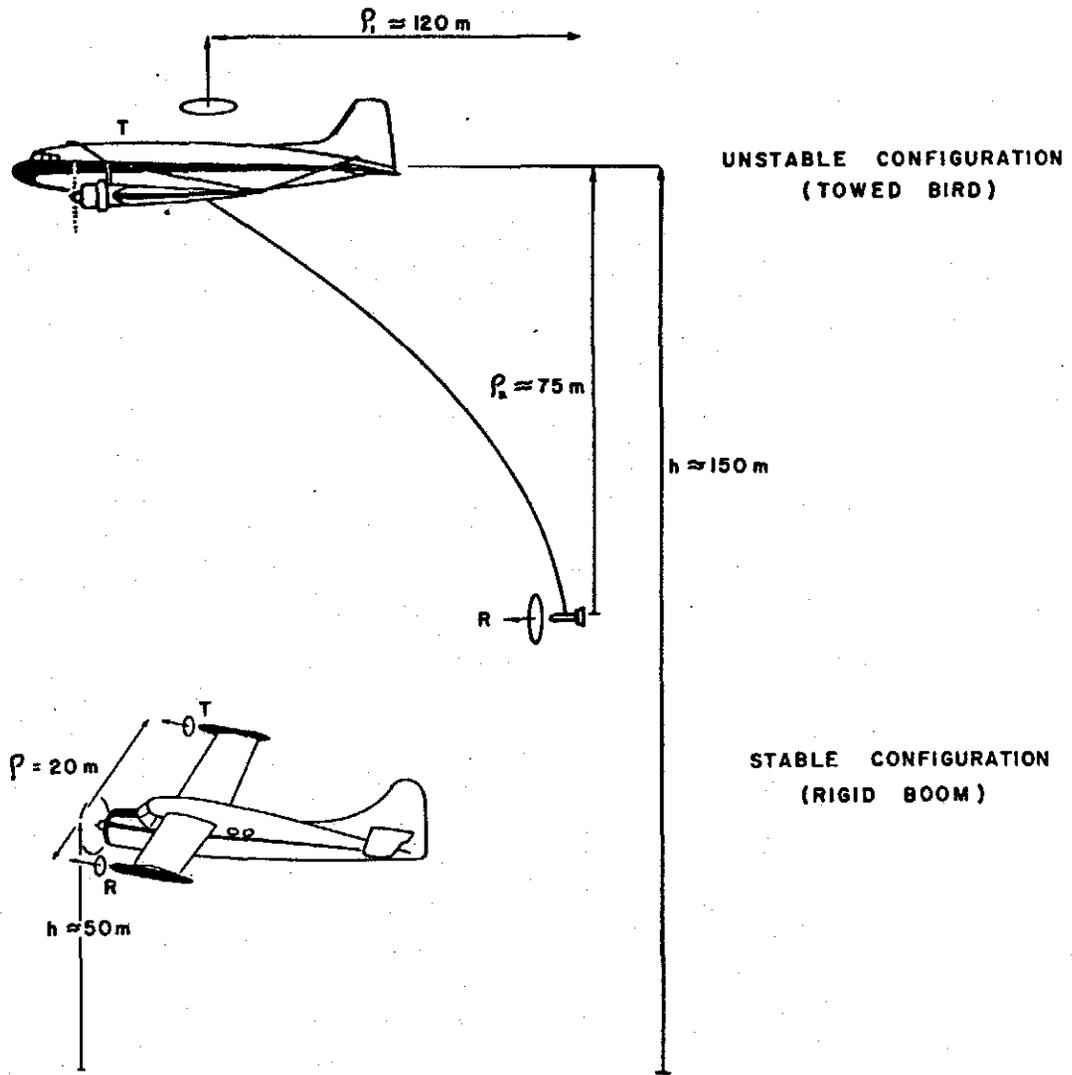


Figure 2: Typical Stable and Unstable Airborne Electromagnetic Systems

Power and Weight:

Airborne electromagnetic prospecting is not a brute force problem. In continuous wave systems the application of power to the energizing field will proportionally increase noise as well as signal. Since the exploration depth depends on the signal to noise ratio, it can only be increased by independently enhancing signal or reducing noise. Modern electronics provide extremely light and sensitive transmitter-receiver combinations, which easily bridge the required distances. Power represents weight and bulk. In modern systems power is, therefore, kept as low as is compatible with a proper functioning of the measuring system. Thus, in the HEM-701 system, full use has been made of state-of-the-art electronics to achieve a combination of high sensitivity and low weight.

06



Unstable systems generally have to employ large fixed-wing aircraft because they require large transmitting coil moments to function. For instance, the INPUT system requires a transmitting coil surface and concentrations of power in the pulses that can only be obtained by using relatively large aircraft such as the PBY Canso or the Skyvan. Such aircraft have a low rate of climb, which is compounded by the presence of the towed receiver and they can, of course, only be used for surveys in relatively level terrain.

Helicopters can operate at low terrain clearances in areas of strong topographic relief. The HEM-701 system has been used successfully in the most rugged parts of the Cordilleran.

Transmitter - Receiver Separation

Experience with the earliest geo-electrical methods, which were galvanic or potential methods, showed that generally their penetration increased with expansion of the measuring configuration. When, at a later stage, electromagnetic methods came into use, this concept was initially transposed without questioning to the new techniques, including airborne electromagnetic methods.

The nature of the electromagnetic response of geological conductors in different measuring configurations, as well as the field evidence accumulated in recent years shows, however, that the old rule of thumb, simply relating penetration to separation, does not hold.

To the contrary, in many typical target environments, short separation methods are superior to large separation systems in both depth of exploration and in resolution.

Potential Depth of Exploration:

The potential depth of exploration of different AEM methods is sometimes estimated, for the purpose of comparison, by representing the target conductor as a vertical sheet of infinite dimensions (half plane) in free air and comparing this response with an estimated operational noise level of the measuring system.

On this basis, figures for potential exploration depths have been arrived at, which vary as widely as 69 m (Ward 1967) and 285 m (Paterson 1971) for the INCO system, 100 m (Ward) and 370 m (Paterson) for the Rotary Field system, 89 m (Ward) and 60 m (Paterson) for the HEM-701 system. Typically most of the variation is in penetration estimates for large separation systems, where less agreement is found regarding noise levels. It is noteworthy that no field evidence has ever been produced to support penetration beyond Ward's conservative estimates, although most of these systems have been actively used for more than

a decade. In fact, the free air case rarely applies to actual field conditions and the exploration depth of stable and unstable systems is differently affected by a change to a geo-electrically more complex environment.

The Natural Search Problem

In nature, few target conductors occur in a non-conductive environment. In many potential exploration regions, the target conductors are covered by an extensive horizontal conductive layer, e. g. glacial till (in northern regions) or a deep zone of weathering (in tropical regions). Thus, the typical search problem is more accurately represented by a combination of horizontal and vertical conductors. The detectability of target conductors with stable or unstable measuring configurations is in that event considerably different from the free air case. From the mathematical expressions of the response of horizontal and vertical conductors it can be seen that the horizontal conductor produces a much stronger masking effect in large separation systems than in short separation systems (Bosschart and Pemberton, 1969).

Most useful is perhaps to examine the combined response to a "homogeneous earth" model (overburden) and a "conducting half plane" model (steeply dipping mineralized zone).

The response of AEM systems over the former is governed by the induction parameter $a = \mu\omega\sigma(\rho^2 + h^2)$ and over the latter $a = \mu\omega\sigma t(\rho^2 + h^2)^{\frac{1}{2}}$ (Grant & West, 1965) (Ward, 1970) (in which μ = permeability, σ = conductivity, ω = frequency, t = half plane thickness, ρ = coil separation, h = height). Thus the height h of the system above the conductor as well as the coil separation p and the frequency ω are operating parameters i. e. characteristics of the systems that can be varied to modify the response. Since the values of p and h are much larger for unstable systems than for stable systems, the induction parameter of unstable systems above overburden is in typical cases 30 to 40 times larger than for stable systems using the same frequency, but it is only 5 to 6 times larger above the mineralized sheet. Or, in other words, larger coil separations and heights result in a converging of the induction parameters of the formations representing signal and noise respectively, smaller separations and heights cause diverging of the induction parameters. In practice, this means that in stable systems (e. g. HEM-701) geologic noise is generally much better separated from the target response than in unstable systems. Figure 3 illustrates this point. In this example, for the purpose of comparison, the stable system has been given a frequency five times the frequency of the unstable system in order to give the mineralization the same induction number in both systems. The overburden response in the unstable system falls in an area where real and imaginary components have appreciable amplitudes. The same overburden gives rise to very low real and imaginary amplitudes in the stable configuration, notwithstanding the five-times higher frequency.



Briefly, conducting overburden is much more transparent to short separation stable systems, such as the HEM-701 or the Rio-Mullard system, than to large separation unstable systems such as the INPUT, Rotary Field or 2-Frequency Phase Shift system.

Response Amplitude, Potential Value and Detectability

A particularly significant and often overlooked difference between methods measuring both amplitudes and phase components and methods measuring phase components only, is that with the former the main component (amplitude) increases with increasing potential economic value of the target conductor (concentration, thickness, size) (Figure 3). The same figure shows that with phase measuring systems, after an initial rise the phase response begins to decrease with increasing potential value of the conductor. In practice, this point is for all present systems reached at modest conductivities and dimensions. Not only may highly conducting large bodies become entirely undetectable, but even before that point is reached the exploration depth for such targets is gradually reduced because of the diminishing response.

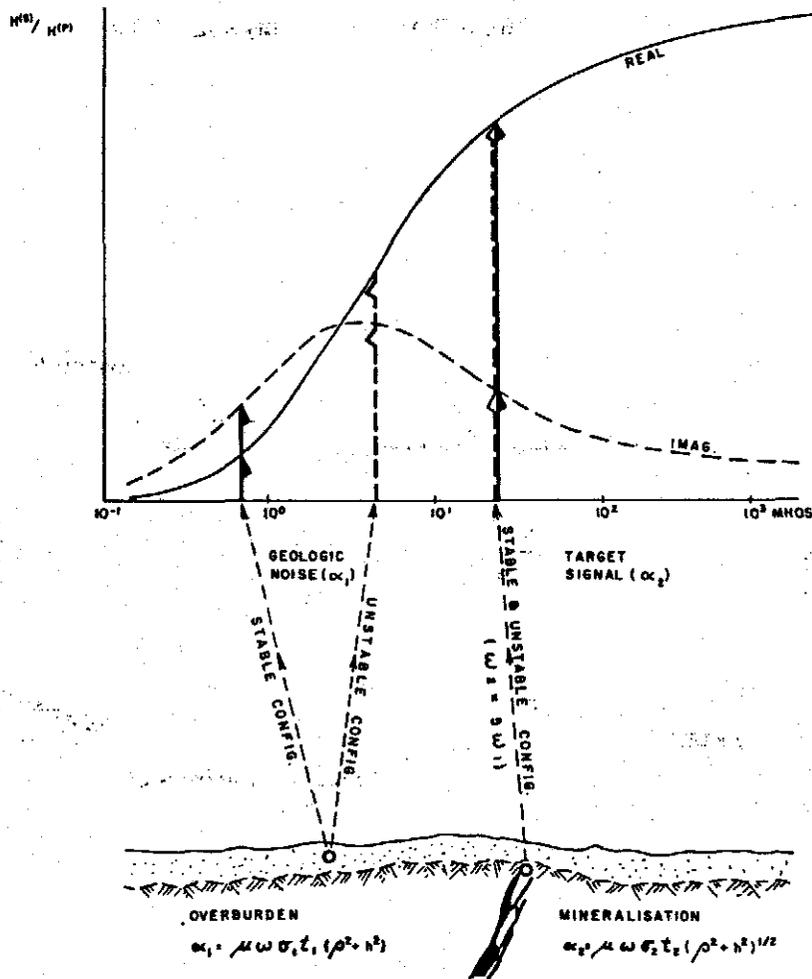


Figure 3: Signal/Noise Relations Stable and Unstable Systems



All unstable configurations, with the exception of the Rotary Field system, but including the INPUT method, are subject to this significant limitation.

Field Experience

The above conclusions, which were based on theoretical considerations, have been borne out in a number of AEM surveys where large separation and short separation methods were both used and where appreciable overburden or weathering was present.

For instance, test surveys with several different AEM systems in Kenya (Mackowiecki, et al) have shown that the short separation (24 m) Rio-Mullard system was far more effective under the geological conditions in that area than the Rotary Field system (separation 240 m). The latter showed excessive sensitivity to surface conduction whereas the Rio-Mullard system showed virtually no geologic noise. An example of one traverse with both systems is shown in Figure 4, on which for comparison also is shown the response of a large conducting body at 10 m subsurface. This conductor, which can be considered a typical target, is detectable throughout the short separation (Rio-Mullard) traverse, but it is undetectable in most of the large separation (Rotary Field) profile.

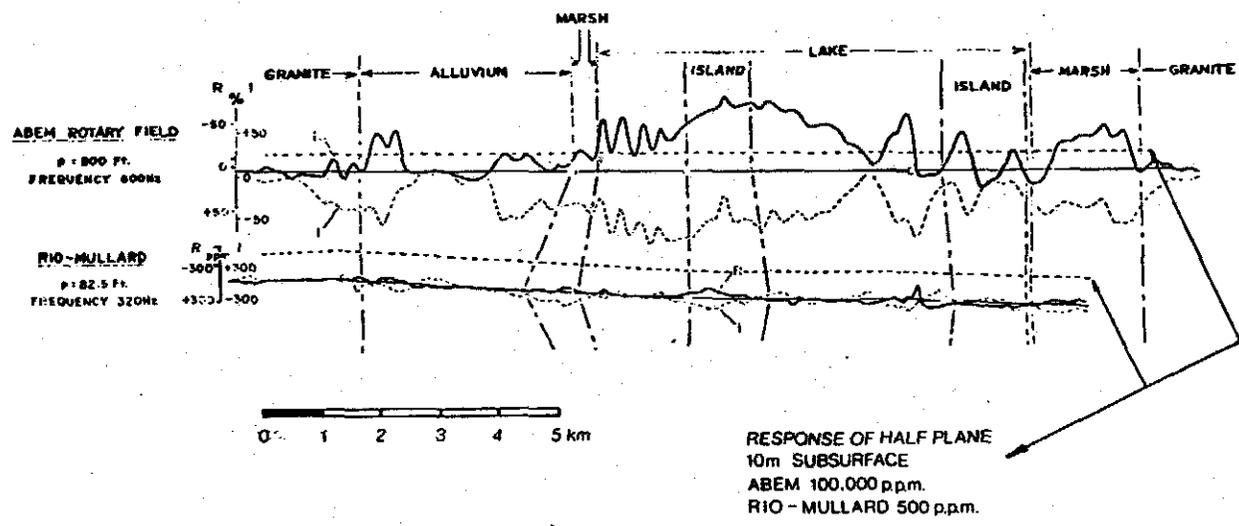
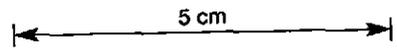


Figure 4: A Comparison Between the Response of a Stable and an Unstable AEM System over Lake Marsh and Alluvium--Seita, East Africa



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During "Operation Hard Rock" in India, where both the INPUT system and the stable configuration Aero Canso system were used, it was found that in areas of significant cover the INPUT system was usually more severely restricted by the presence of overburden than the Aero system. In Surinam and Guyana where a number of areas were surveyed with the INPUT system the penetration has generally been disappointing. In this weathered tropical environment the depth of exploration was rarely found to exceed 30 m and these surveys did not result in any mineral discoveries.

Resolution

The resolution of AEM systems, i. e. their ability to distinguish between adjacent bodies and detect conductivity differences independent of linear dimensions, improves with decreasing terrain clearance and coil separation. Stable systems, therefore, provide inherently better resolution than unstable ones.

Unstable systems, because of their scale, tend to emphasize large conductive features while sacrificing resolution. Often the diagnostic criteria are affected by conductor size, which may result in the downgrading of the smaller discrete conductors. As massive sulphide deposits are generally among the latter, this is an undesirable feature. Most unstable systems will not yield a significant anomaly over conductors having strike lengths under 120 m, which rules out the detection of an important category of potential ore deposits. This lack of resolution of unstable systems, besides involving the risk of missing ore bodies entirely, always necessitates more intensive and costly ground follow-up.

The short coil separation and small terrain clearance of the HEM-701 system enhances resolution. The orientation of the coils ($T_x - R_x$) minimizes the response of horizontal conductors (e. g. overburden, swamps) and emphasizes the response from steeply dipping conductors, which are usually of potential interest.

To illustrate the difference in resolution, a comparison of the INPUT discovery anomaly over the Sturgeon Lake deposit (Ontario) with a later HEM-701 test survey is shown in Figures 5, 6 and 7.

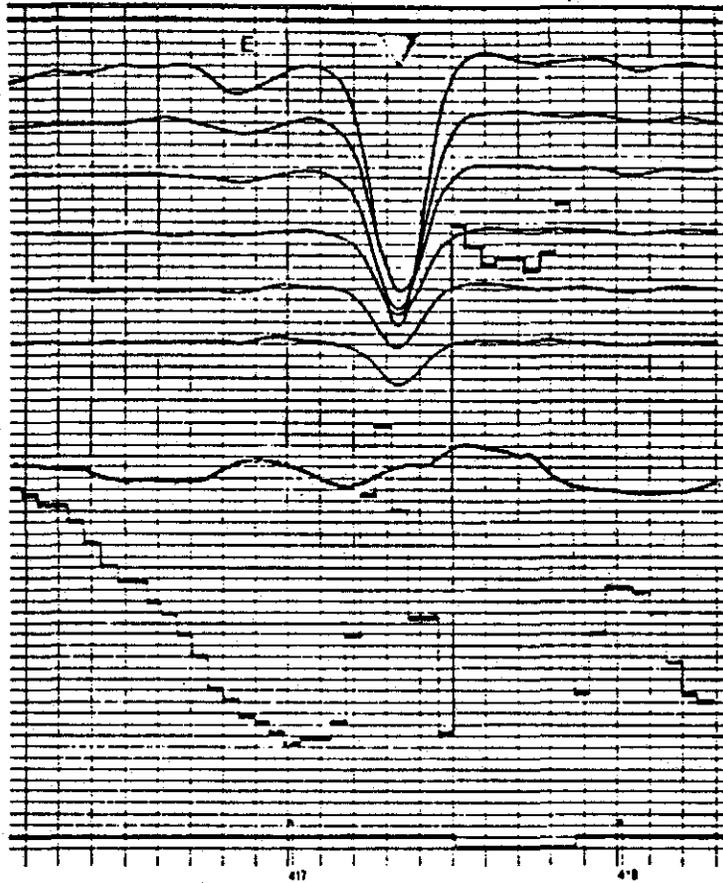


Figure 5: Sturgeon Lake INPUT Discovery Anomaly

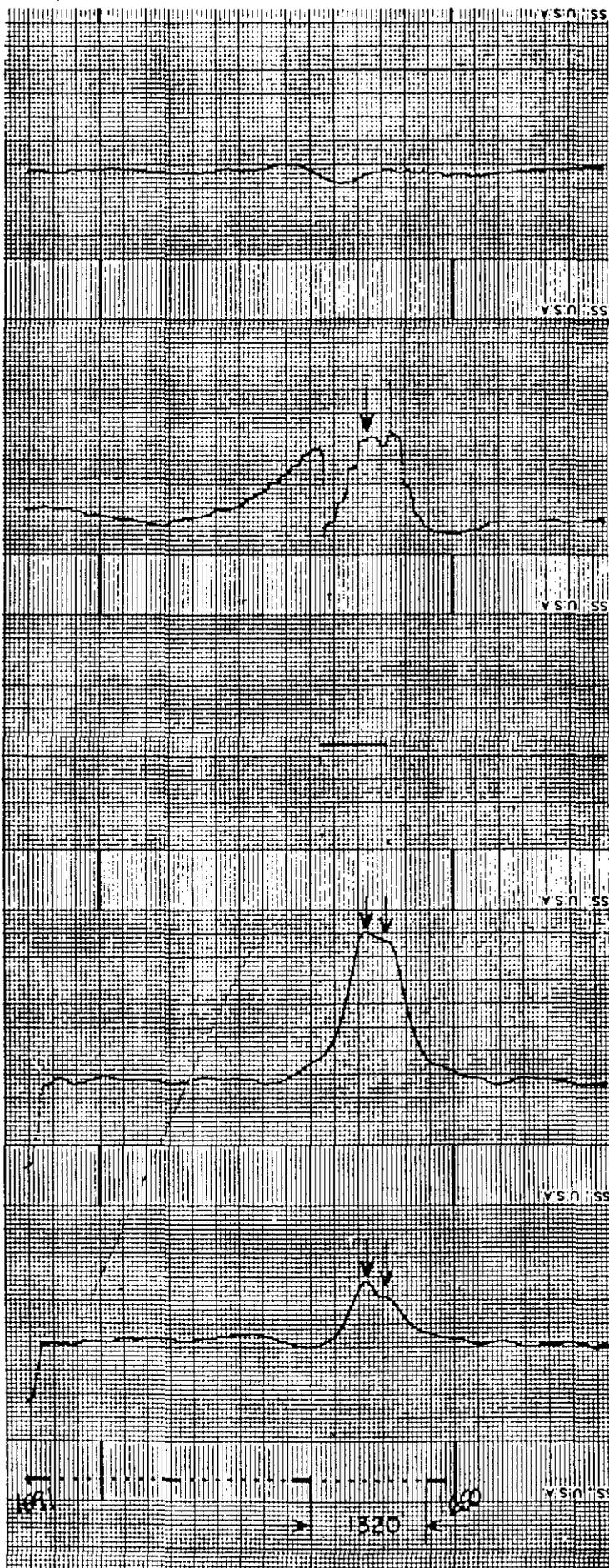


Figure 6:
Sturgeon Lake HEM-701
Test Survey Results

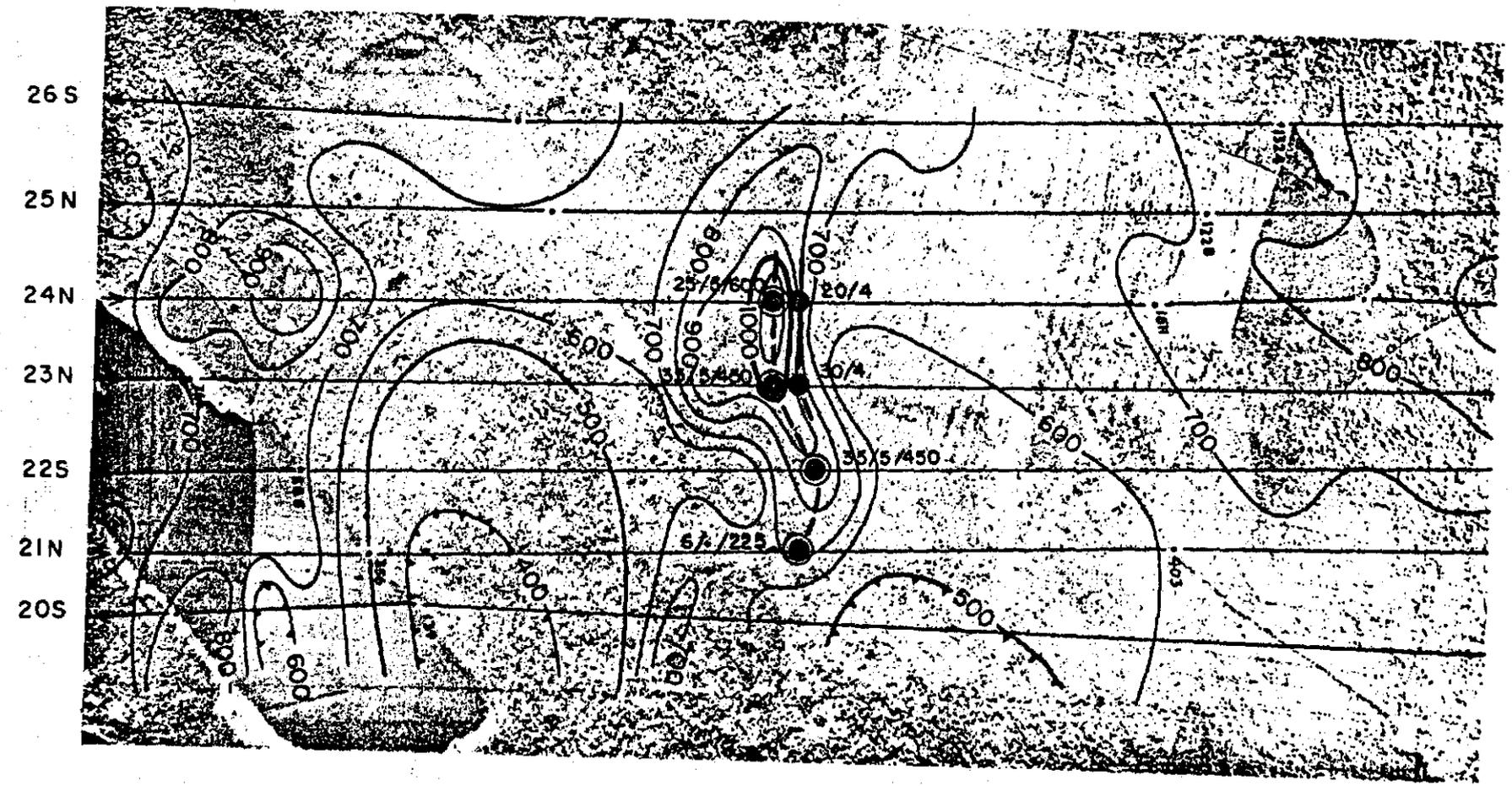


Figure 7: Sturgeon Lake HEM-701 Test Survey Results



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Whereas the INPUT anomaly is single, the HEM-701 anomalies clearly resolve two conductors (60 m apart) in keeping with the true configuration of the ore body, which comprises two bands of concentrated mineralization. The HEM-701 data shows strong, clear responses in both the in-and out-of-phase channels, indicating that this system is properly focussed on target conductors of the conductivity and size of this type of ore deposit.

Figure 8 shows the rate of fall off curve derived from overflying the ore zone at various altitudes, which indicates that the HEM-701 can detect similar small conducting bodies in the same environment at depths of up to 75 m subsurface.

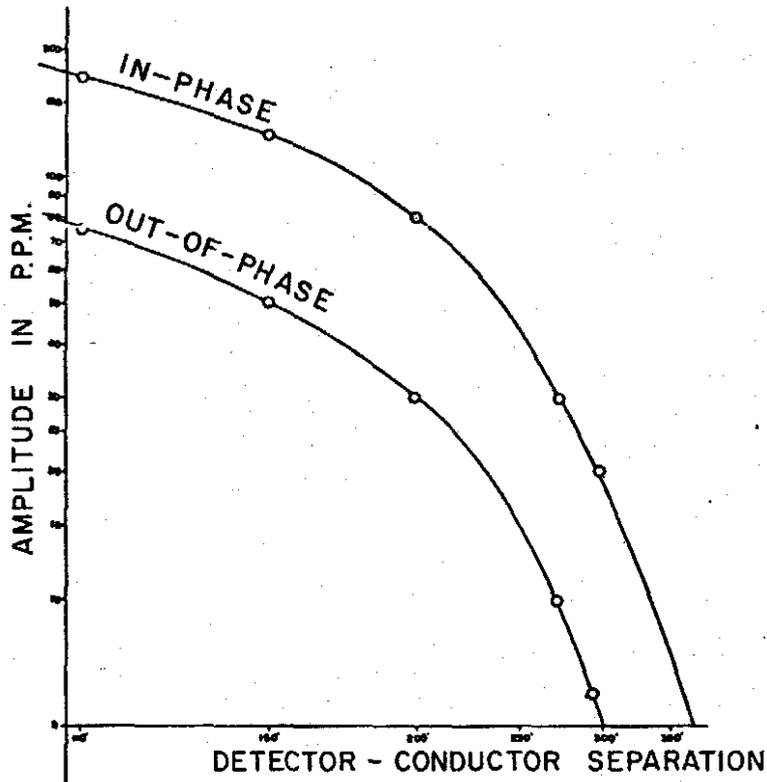


Figure 8: Sturgeon Lake HEM-701 Rate of Fall-Off Curves

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A second example of the high resolution of the helicopter system is shown in Figure 9, which presents a series of test flights with the HEM-701 over the Louvicourt deposit, Quebec. This conductor has a very small strike length (40 m) and medium to poor conductivity. It is as a result undetectable with an unstable AEM system and presents at best an elusive target for a short separation stable system. The presence of a nearby power line compounds the problem. The HEM-701 results show readily identifiable anomalies, well separated from the power line response. The low in-phase/out-of-phase ratio (< 0.7) shows the poor conductivity of the body, the best section of which graded only ten percent per volume of conducting sulphides (chalcopyrite and pyrite).

Interpretation of Data

The effectiveness of an airborne system is to a significant degree determined by the interpretability of the observed anomalies. The interpretation of in-phase and out-of-phase component data, such as obtained by the HEM-701 has been extensively studied and is well established. Conductivity width products (σt) can be directly determined from the amplitude relations, e. g. by means of Argand or similar diagrams, and there is extensive literature on the subject. Figure 10 shows a typical interpretation diagram, from which it is possible to determine conductivity-width products and estimate the depth of burial of the conductor. Use of the (σt) parameters allows us to distinguish potential ore conductors from probably uneconomic conductors and thus reduce the amount of ground follow-up work.

The interpretation of unstable configuration AEM data requires generally more complex schemes and is inherently more ambiguous, because of the already mentioned affect of size on conductivity discrimination and because, with the exception of the Rotary Field method, the results refer to the out-of-phase part of the response only, which is far less diagnostic. As to the INPUT (time-domain) system, efforts to establish a truly quantitative interpretation procedure have not yet been successful. Thus more of the weight of sorting conductors has to be shifted to ground follow-up, resulting in higher costs and more time losses in that exploration phase.

Multi-System Surveying

When the airborne EM measurements have to be combined with other geophysical measurements (Figure 11) the advantages of small terrain clearance become particularly important. A magnetic survey flown with the sensor between 30 - 60 m shows considerably more detail of value

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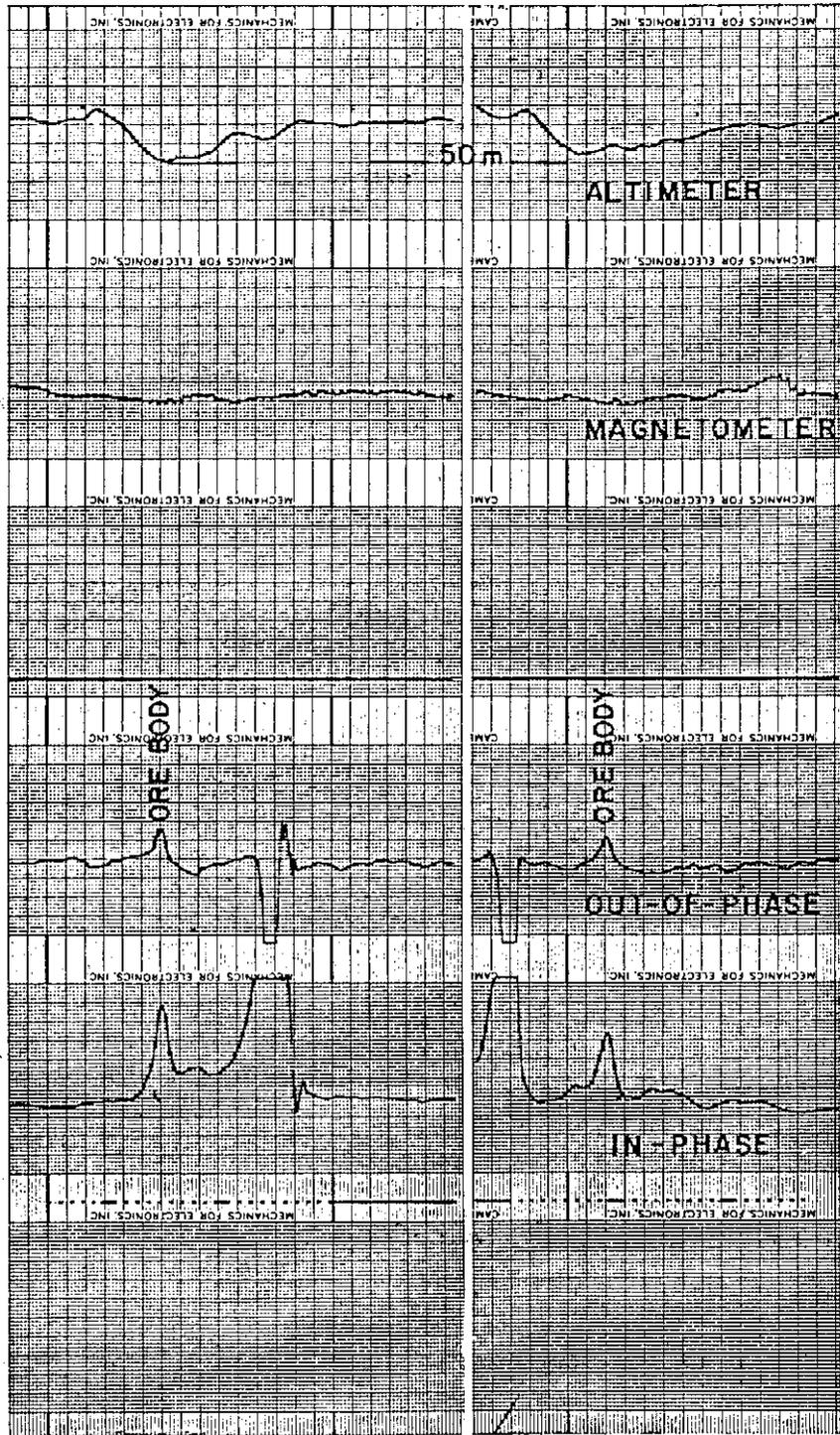


Figure 9: Louvicourt, Quebec, HEM-701 Test Survey Results

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SCINTREX HEM - 701

VERTICAL COAXIAL COILS 30' SEPARATION
FREQUENCY = 1600 cps.

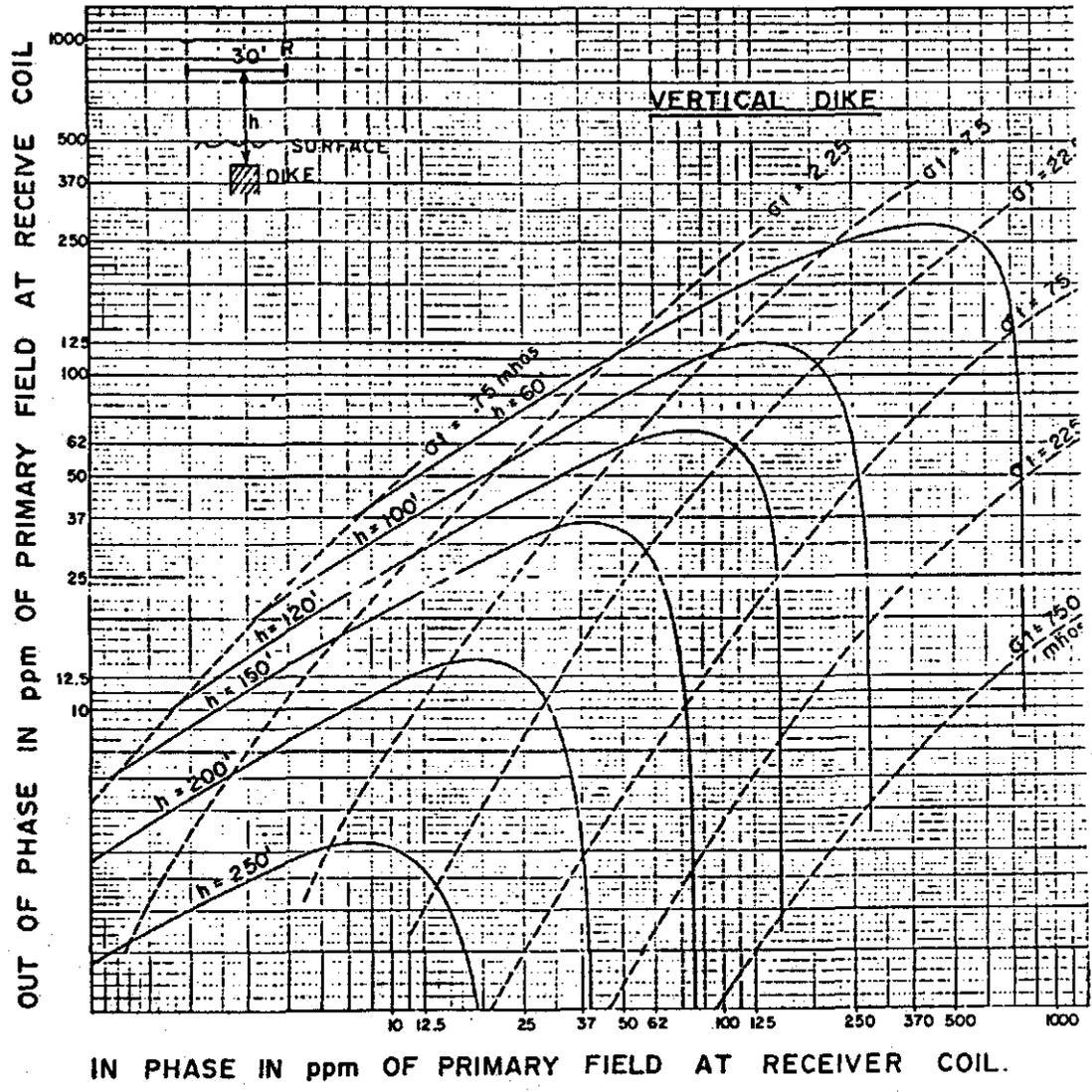


Figure 10: Interpretation Diagram HEM-701

084

in ore prospecting than one flown with the sensor at 120 - 150 m, the evaluation with unstable configuration AEM systems. Many of the low intensity local anomalies caused by significant pyrrhotite concentrations as well as the fine grain of the magnetic pattern over contacts, alteration zones and other potential loci of ore deposition are lost at the higher survey altitude.

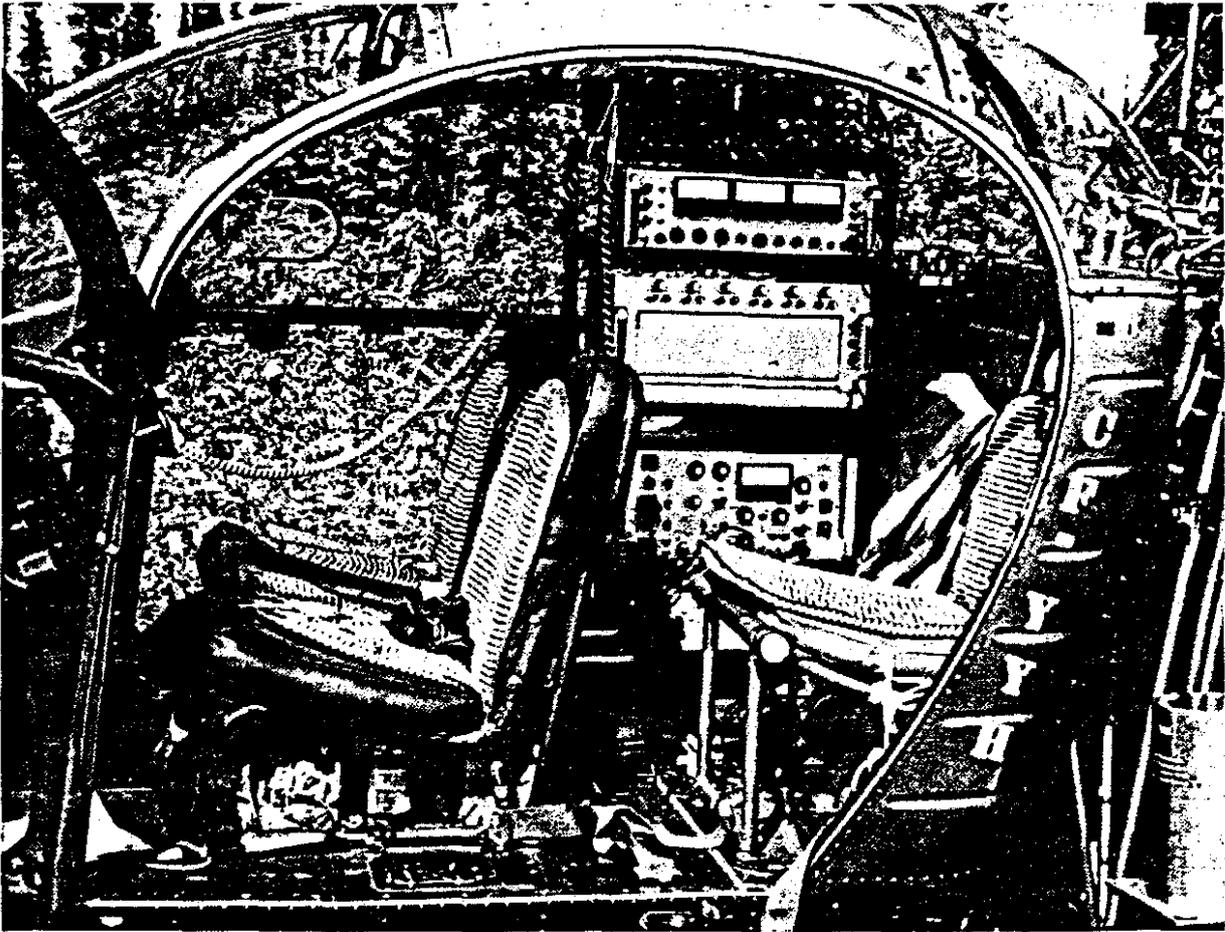


Figure 11: Typical Multi-System Installation

Targets of economic interest in airborne radiometric prospecting are primarily high energy point sources of gamma radiation, the responses of which decrease very rapidly as the source-sensor distance (altitude) is increased. Both theory and practice have shown that the successful detection and recognition of point sources in airborne radiometric prospecting demands a small terrain clearance, generally not exceeding 100 m (Figure 12). Greater flight altitudes cannot be compensated for by employing larger detector volumes as both the signal (from the target source) and the noise (determined by regional background level) will be increased at the same time.

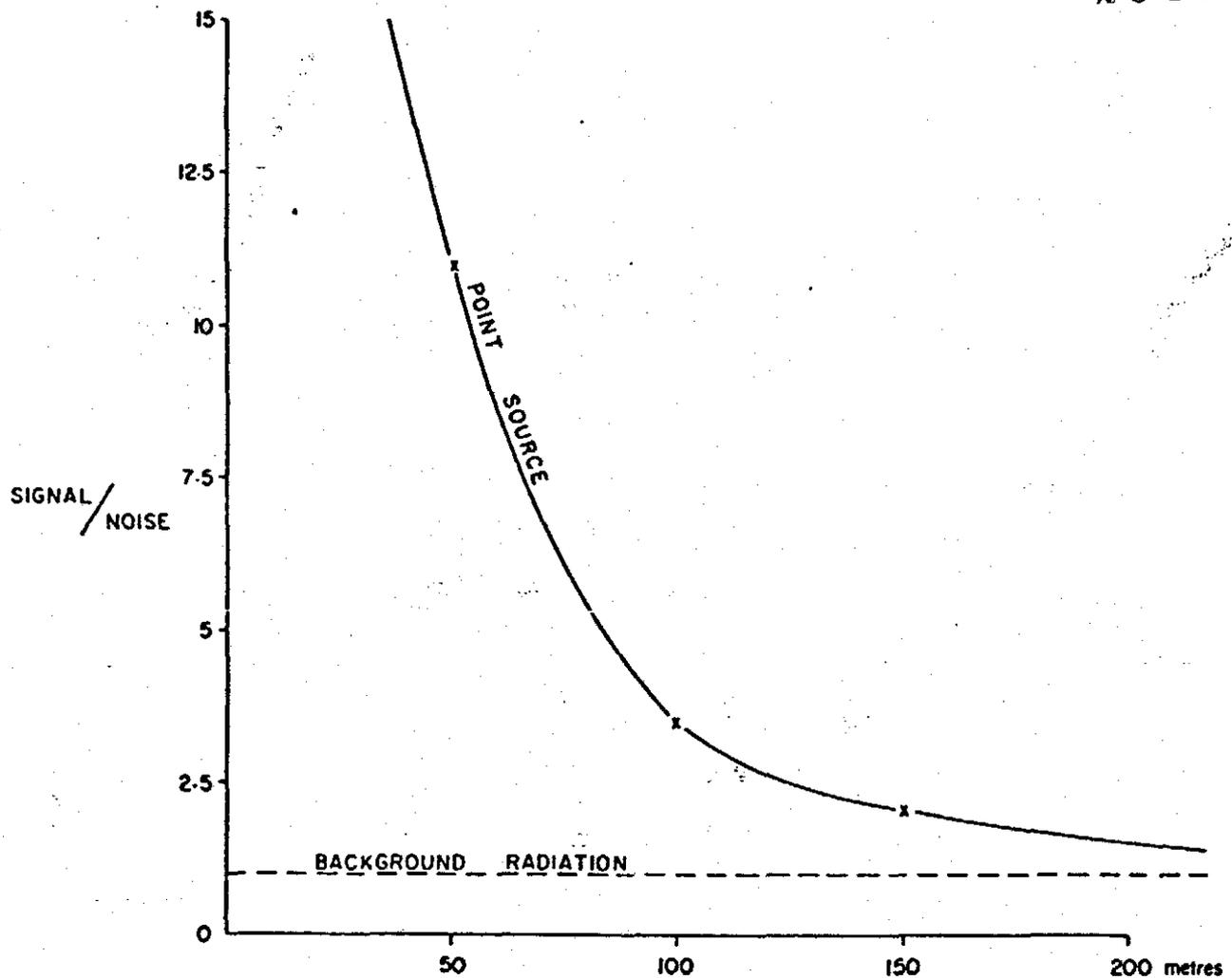


Figure 12: Radiometric Point Source and Background Radiation Decline of Signal/Noise Ratio with Increasing Terrain Clearance

Thus, detailed magnetometer and radiometric measurements can be very well combined with helicopter EM surveys but they lose much of their effectiveness when used at greater terrain clearances. Radiometric spectrometer measurements particularly are incompatible with unstable configuration AEM systems because the response of point sources disappears into background radiation at altitudes of 120 - 150 m.

In general, all auxiliary geophysical methods will tend to lose much of the resolution required for the detection of typical ore targets at altitudes over 100 - 120 m.

The inherent suitability for multi-system applications is another major advantage of the small survey altitude of the HEM-701 system.

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Operational Flexibility

The HEM-701 system can be installed and removed from chartered helicopters in a matter of hours. Often aircraft available close to the survey area can be employed, thus saving the high cost of mobilizing specially equipped aircraft over long distances.

Apart from its obvious application in major surveys over large areas the combined system lends itself well to detailed, (say 500 ft. line separation) systematic surveys over comparatively small areas of interest, e. g. a narrow, elongated contact zone, say 2 x 10 miles; here, the system possesses a definition approaching that of the equivalent ground survey and has a 40 - 50 times faster rate of production, while total costs will be lower than those of the ground survey.

SUMMARY AND CONCLUSION

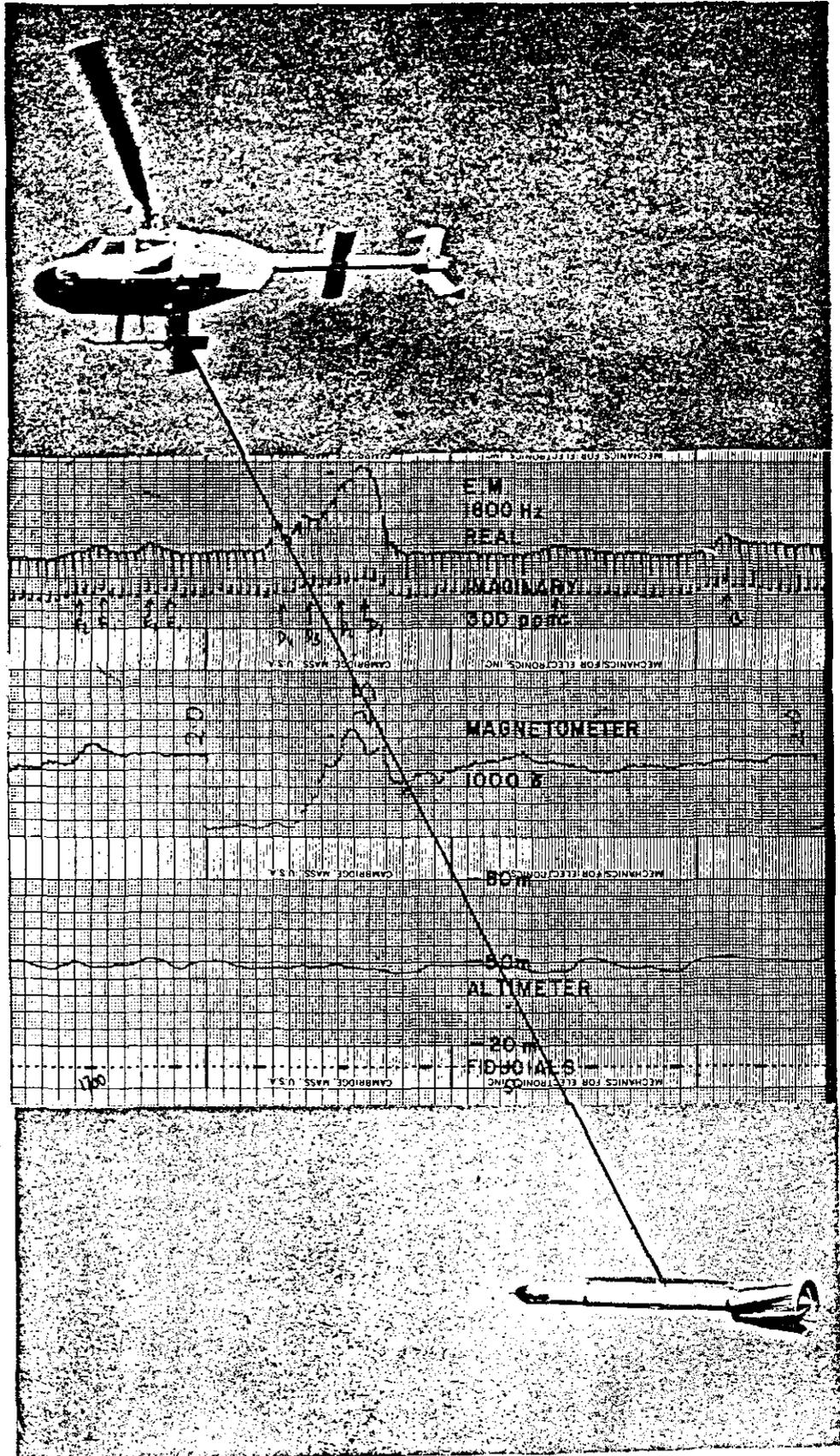
The foregoing considerations show that, appearances notwithstanding, the HEM-701 system is a more versatile and under many geological conditions a more powerful tool for base metal prospecting than ostensibly more powerful systems such as INPUT, Rotary Field, 2-Frequency Phase Shift and other unstable systems.

In summary, the method has significant advantages in the following respects; in weight and terrain performance; in signal to geologic noise ratio and the resulting exploration depth in the presence of conducting overburden; in spatial resolution and the discrimination between conductor characteristics; in the direct relation between potential target value and response amplitude; in data interpretation and economy of ground follow-up, in suitability for multi-system surveying and in operational flexibility.

January, 1972

SCINTREX HEM-701 AND INPUT

AIRBORNE ELECTROMAGNETIC SYSTEMS



INTRODUCTION

Based on its record of ore body discoveries during the last two decades, airborne electromagnetic surveying has established itself as a first line base metal prospecting tool. In principle, AEM surveys aim at mapping the distribution of sub-surface electrical conductors with a view to directly locating (potentially economic) massive sulphide deposits, which generally show highly conducting properties. The actual geophysical instrumentation techniques employed in locating conductors from the air are many and diverse, but most are of the classical moving source and receiver type. Two of the most successful and widely accepted systems (on a world-wide basis) are the Scintrex HEM-701 helicopter-borne rigid boom system (see Figure 1) and the INPUT system.

The helicopter-borne system is acknowledged to have the edge in terrain performance, as witnessed by its successful operations in the North American Cordillera, the Chilean Andes and the escarpment areas in Southern Africa, where the demand for a small terrain clearance in rugged areas can only be met by using jet powered helicopters.

The INPUT system has a much inferior terrain performance, but it is often credited with better penetration because of its longer source and receiver separation, and, in truth, because of its innovative appeal.

This comparison of the Scintrex HEM-701 and INPUT systems is aimed at making known some of the less well publicized merits of the former system. The procedure adopted has been to realistically evaluate the responses of both systems, to the geo-electrical parameters of the target itself and to its geological environment, thereby avoiding the ideal target in free air case, a situation which occurs only in laboratories and case histories.



A COMPARISON OF THE SCINTREX HEM-701 AND INPUT SYSTEMS

AEM systems traditionally fall into two distinct groups, namely the rigid boom and towed bird systems (Figure 2). The former, including the Scintrex Otter equipped with the Rio Mullard EM system and the Scintrex helicopter-borne HEM-701 systems, etc. etc. employ a transmitter and receiver mounted on a mechanically rigid structure, such as the airframe, or in a tubular survey "bird" and are normally flown at terrain clearances of 100' - 200'. Towed bird systems, viz INPUT, have the transmitter mounted on the aircraft and a receiver towed below and behind the aircraft on a long (INPUT = 450') cable; normal terrain clearance is 450'.

In comparison with the helicopter systems, proponents of the INPUT method portray it as a powerful, heavyweight and therefore more effective exploration tool, inferring that its large (450') transmitter-receiver separation as opposed to that of the helicopter system (30') indicates a much greater depth penetration potential. However, the following statements place these points in perspective.

a) POWER AND WEIGHT

INPUT is a time domain EM system, as opposed to other AEM systems which operate in the frequency domain; for it to work at all, high concentrations of power are required in the pulses, and to supply this power requires weight and bulk, reflected in the use of the Canso aircraft as transport vehicles. Now, in continuous wave systems (viz HEM-701) the application of power to the energizing field increases noise as well as signal; as the exploration depth is solely dependent on the signal to noise ratio a simple brute force approach is not adequate, and the depth potential can only be enhanced by relatively decreasing the noise. Thus, in the HEM-701 system, power is kept as low as is compatible with the proper functioning of the measuring apparatus (resulting in a light weight receiver-transmitter combination) while full use of state of the art electronics achieves a high sensitivity, giving exploration depths compatible with those of INPUT. Sensitivity of the system is such that changes in resultant field strength of as little as 3 parts per million, (i. e. 0.0003%) can be detected and accurately measured.

b) EFFECT OF TRANSMITTER-RECEIVER SEPARATION

There are several misconceptions as to the so called advantages of a large separation between transmit and receive coils. Points to consider are:

- I) The assigned "free air" depth potential (neutral environment)
- II) The natural search problem (conductive overburden) and
- III) The resolution potential of a system.



I) Free Air Depth Potential

Proponents of the INPUT system claim a vastly greater depth of penetration for their system as opposed to helicopter-borne methods. However, the old rule of thumb relating separation to depth potential, which was extrapolated unquestioningly from early geophysical ground galvanic (e.g. resistivity) surveys, has been shown not to apply in the field of airborne electromagnetics.

Extensive research into EM responses, plus the field evidence of recent years, has shown that the system's signal to noise ratio is the determining factor.

The potential depth of exploration of different AEM methods is sometimes estimated for comparative purposes, by representing the target conductor as a vertical sheet of infinite dimensions in free air, and comparing the response with the operational noise level of the measuring system.

*Ward, in his recent comprehensive study of AEM methods, has, using his free air case (i. e. target in neutral environment) assigned potential exploration depths of 370 ft. and 300 ft. the INPUT and the HEM-701 methods respectively.

Geophysical Contractors' claims for the depth penetration of their airborne EM systems usually originate in the practice of overflying a conductor of known depth, at gradually increasing flight altitudes, till the target response disappears. The total distance between EM sensor and conductor, at which a recognizable signal is just obtained, is then adjudged to be the penetration depth of that system; this of course is taking the "free-air" case ad absurdum, and the results pertain only to ideal cases.

However, in nature few targets occur in non-conductive environments, and it appears that in many environments short separation methods are superior to large separation systems in both depth of exploration and in resolution.

II) Natural Search Problem

In particular we believe the Scintrex HEM-701 unit to be ideally suited to the geological conditions existing in a large proportion of mining districts in the world, namely a highly conducting near surface material, generally having a limited thickness, overlying a resistive basement (viz. zones of weathering, leaching, in Southern Africa, S. W. States, highly conducting clays etc. in Australia).



Our rigid boom close coupled system is less affected by this conducting surficial material than is the INPUT system. Differences in the response parameter for the HEM-701 versus the INPUT system indicate that the geological noise, which is directly related to the surficial material, is considerably less for the former type of system. As a result, the response from any steeply dipping mineralized zone under such a layer may have a signal to noise ratio of between 5 and 8 times better than that recorded by the INPUT system - this deviation from the "free air" case results in a superior depth potential for the HEM-701 compared to INPUT, due to the deleterious "masking" effect on the latter.

This rather surprising result is reached by acknowledging that the typical search problem can be represented by a combination of horizontal (overburden) and vertical (steeply dipping mineralized zone) conductors. The mathematical expressions for the responses of AEM systems over horizontal (homogeneous earth model) and vertical (vertical dyke model) conductors have been derived by Ward, and are thus:

$$\text{Horizontal conductor, Response } \Delta = \mu \omega \sigma (p^2 + h^2)$$

$$\text{Vertical conductor, Response } \Delta = \mu \omega \sigma t (p^2 + h^2)^{\frac{1}{2}}$$

where

- μ = permeability
- σ = conductivity
- ω = frequency
- t = half plane thickness
- p = AEM coil separation
- h = height of AEM coils above conductor.

The parameters height (h), coil separation (p) and frequency (ω) are the operating characteristics of the systems that can be modified to vary the response.

Thus, for any AEM system we can define a "geological" or "environmental" signal to noise ratio (S/N) by forming the ratio of the vertical dyke response (signal) to the overburden response (noise); obviously, the greater the value of S/N , the less likelihood there is of the dyke response being masked by the overburden response, and the greater the effective depth of penetration.

$$\begin{aligned} S/N &= \frac{\text{Vertical dyke response}}{\text{Horizontal overburden response}} \\ &= \frac{\mu \omega \sigma_d t_d (p^2 + h^2)^{\frac{1}{2}}}{\mu \omega \sigma_o (p^2 + h^2)} \end{aligned}$$

where 'd' denotes dyke, and 'o' denotes overburden

$$S/N = \frac{\sigma_d t_d (p^2 + h^2)^{-\frac{1}{2}}}{\sigma_o}$$



Comparing these S/N values for the Scintrex HEM-701 (H) and INPUT (I), we can arrive at a qualitative figure of merit rating, M, which will be a relative measure of the extent to which target responses are masked by overburden responses in either system. Assuming the same environment for each system, then

$$M = \frac{\text{HEM-701 signal to noise ratio}}{\text{INPUT signal to noise ratio}}$$

$$M = \frac{[S/N]_H}{[S/N]_I} = \frac{\frac{\sigma_d t_d}{\sigma_o} (p_H^2 + h_H^2)^{-1/2}}{\frac{\sigma_d t_d}{\sigma_o} (p_I^2 + h_I^2)^{-1/2}}$$

$$= \left[\frac{p_I^2 + h_I^2}{p_H^2 + h_H^2} \right]^{1/2}$$

For the Scintrex HEM-701

$$p_H = 30 \text{ ft.}, \quad h_H = 100 \text{ ft.};$$

For INPUT,

$$p_I = 400 \text{ ft.}, \quad h_I = 300 \text{ ft.};$$

$$\therefore M = [25]^{1/2} = \underline{\underline{5}}$$

Thus, for the HEM-701 we have a signal to noise ratio some 5 times greater than for INPUT in the natural search problem, indicating that above this common type of conductor array, geological noise is much lower in rigid boom systems, allowing more ready identification of potentially economic targets. Figure 3 illustrates this point.

In this example, the rigid boom system has been given a frequency five times the frequency of the towed bird system so that the mineralization has the same induction number in both systems. The overburden response in the towed bird system falls in an area where real and imaginary components have appreciable amplitudes. The same overburden gives rise to very low real and imaginary amplitudes for the rigid boom configuration, notwithstanding the five times higher frequency.



091

Briefly, conducting overburden is much more transparent to the HEM-701 than to the INPUT system.

e.g. During "Operation Hardrock" in India, where Aero Service Corporation utilized both the INPUT and the Aero Canso systems, it was found that the INPUT method was much more severely restricted by the presence of overburden than the Aero (rigid boom, short separation) method. In fact, mainly because of this experience, Aero Service Corporation thereafter cancelled its INPUT licence and has further only employed rigid boom systems in airborne surveys.

Additionally, in Surinam and Guyana, a number of areas have been surveyed with the INPUT system. Ground follow-up has indicated that the penetration has generally been disappointing. Nowhere in these areas has the depth of exploration been found to exceed 100 ft. subsurface. As is well known, these surveys have not resulted in any mineral discoveries.

III) Resolution

Resolution relates to the behaviour of a system with respect to conductor length, and to the characteristic width of an anomaly, both of which are favoured by small scale systems. The large scale INPUT system strives to maximise anomaly amplitudes while sacrificing resolution; the largest anomalies are obtained from broad scale features such as swamps, and long bands of stratabound sulphides and graphite; these regional-type features are emphasized at the expense of the smaller discrete massive sulphide conductors.

In contrast, the vertical coil orientation of the HEM-701 minimizes responses from swamps etc., while accentuating responses from steeply dipping conductors (usually of potential interest).

While the INPUT system yields anomaly amplitudes dependent on conductor lengths, the HEM-701 yields anomalies equal in amplitude over targets of identical conductivity, irrespective of individual strike lengths. Consequently the INPUT method suffers from the disadvantages of downgrading discrete conductors (of possible economic interest) purely on the basis of length, and in fact, due to the large scale geometry of the system, INPUT will not yield an anomaly over conductors having strike lengths less than 400 ft. (economic base metal deposits having strike lengths smaller than this are quite common, viz. Tsumeb deposit, (S.W. Africa).



Figure 4 shows a series of test lines flown by the HEM-701 over the Louvicourt deposit, Quebec. This has a strike length of only 120 ft. but yields readily identifiable anomalies at regular survey altitudes; the low in-phase/out-of-phase ratio (0.7) testifies to the poorly conducting nature of the ore zone. (the best section of the ore zone graded only 10% by volume of conducting sulphides, namely chalcopyrite and pyrite.)

In addition, the INPUT system's usual preponderance of broad scale conductors and the merging of these anomalies with those from discrete conductors necessitates the familiar high costs of ground follow-up along with the increased risk of missing an orebody.

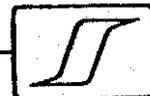
The small scale HEM-701 has a high resolution which allows identification of multiple conductor bands as close as 150' apart; the INPUT system, because of its larger coil separation and greater terrain clearance is unable to do this, resulting in ambiguities in interpretation.

Figure 5 shows the INPUT discovery anomaly over the Sturgeon Lake deposit, Ontario, Canada, while Figures 6 and 7 show the results of a Scintrex HEM-701 test survey over the same zone. Whereas the INPUT anomaly is single, the HEM-701 anomalies clearly resolve two conductors (200 ft. apart) in keeping with the true configuration of the ore body, which comprises two bands of concentrated mineralization. The HEM-701 data shows strong, clear responses in the in/out-of-phase channels, indicating that this system is focussed on finding mines, not mapping overburden.

Figure 8 shows the rate of fall off curve derived from overflying the ore zone at various altitudes, and indicates that the HEM-701 can detect ore bodies in the same environment at depths of up to 350 ft.

c) INTERPRETATION OF DATA

The effectiveness of an airborne system is to a significant degree determined by the interpretability of the observed anomalies. The interpretation of in-phase and out-of-phase component data, such as obtained by the HEM-701 has been extensively studied and is well established. Conductivity width products can be directly determined from the amplitude relations by means of phasor diagrams, and there is extensive literature on the subject. Figure 9 shows a typical phasor diagram, from which it is possible to determine conductivity width products and depth of burial of the conductor. Use of the σt parameters allows us to distinguish potential ore conductors from probably uneconomic conductors and thus decreases ground follow-up work.



The interpretation of INPUT data is entirely empirical, and efforts to establish truly quantitative interpretation schemes have as yet not been successful. This lack of quantitative interpretation is one of the reasons why conductors generally have to be sorted by follow-up ground surveys.

A further advantage of the HEM-701 system is that the calculated conductivity - thickness values are independent of flying height or depth of burial: weak responses from deeply buried strong conductors are not confused with weak responses from shallow poor conductors because the former will have larger conductivity - thickness products, (i. e. in-phase response > out-of-phase response.)

d) AIRBORNE RADIOMETRIC SURVEYING

Airborne radiometric surveys may either be oriented towards the direct detection of surface outcrops of uraniferous ores, or as a very valuable aid to geological mapping, wherein the relative contributions from the radio-elements are recorded and translated into trend maps.

Targets of economic interest in airborne radiometric prospecting are primarily high energy point sources of gamma radiation, the responses of which decrease very rapidly as the source-sensor distance (altitude) is increased. Both theory and practice have shown that the successful detection and recognition of point sources in airborne radiometric prospecting demands a small sensor terrain clearance, certainly not exceeding 300 ft. Greater flight altitudes cannot be compensated for by employing larger crystal detector volumes as both the signal (from the target source) and the noise (determined from regional background level) will be increased at the same time. Thus, the addition of a gamma ray spectrometer to the Scintrex helicopter-borne E.M. and magnetometer system produces a mutually compatible exploration system, in that the spectrometer sensors, (installed in-board the helicopter) will be flown at a mean terrain clearance of 200 ft., which is well within the altitude range for useful radiometric measurements.

Spectrometer installations are largely incompatible with the INPUT system, in that at the latter's normal terrain clearance of 350 - 450 ft. the response of most radioactive point sources disappears into the background radiation and the measurements lost much of their purpose.

A Scintrex GISA-4 four channel gamma ray spectrometer is usually flown along with the basic HEM-701 electromagnetic system. The former provides outputs of net uranium, net thorium, net potassium - 40 and total gamma radiations. Figure 10 shows a typical combined electromagnetic, magnetic and radiometric



094

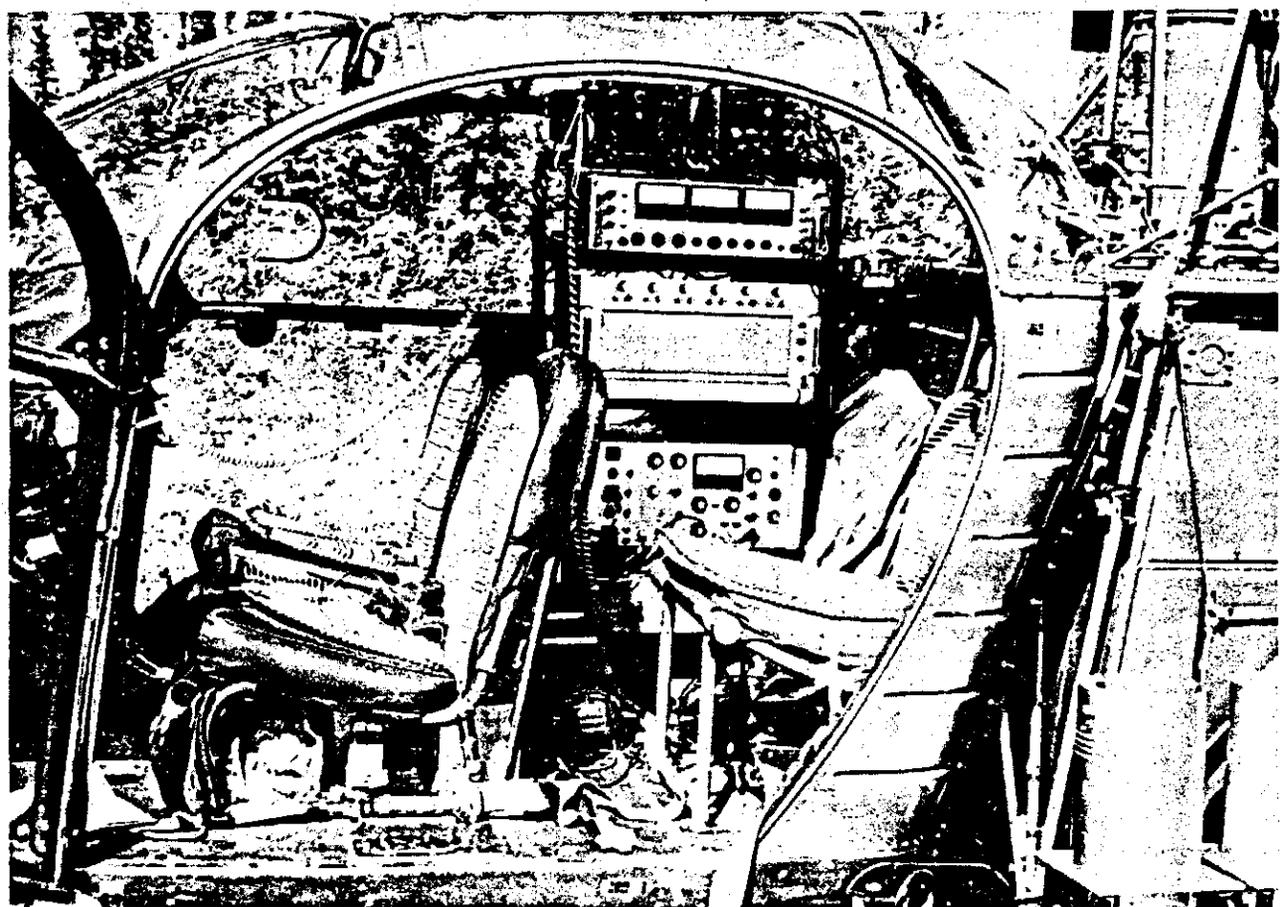
geophysical record; note should be made of the radiometric responses on channels 4 - 6 which amply demonstrate the advantages to be obtained in using 4 channels of radiometric information, as opposed to the one channel output of total count scintillometers. The anomaly reflects a combined uranium-thorium source, lacking in potassium-40, (i.e. not granites), typical of uraniumiferous deposits located in the Mississagi conglomerates of the Elliot Lake area, Ontario.

Thus, we believe that the basic Scintrex helicopter-borne EM system, allied with simultaneous recording magnetometer and spectrometer units, and operating at low terrain clearance, presents one of the most useful and mutually compatible rapid mineral exploration systems available today.

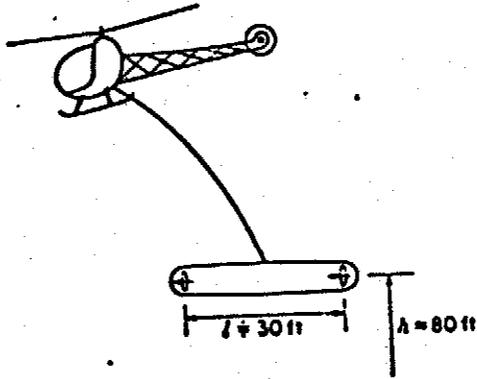
Apart from its obvious application in major surveys over large areas of imprecise geology, the combined system lends itself well to detailed, (say 500 ft. line separation) systematic surveys over comparatively small areas of interest e.g. a narrow, elongated contact zone, say 2 x 10 miles; here, the system possesses a definition approaching that of the equivalent ground survey and has a 40 - 50 times faster rate of production, total costs still being compatible, if not lower, than those of the ground survey. Additionally the portability of the equipment (allowing shipment by conventional aircraft) combined with its ease of installation into helicopters (maximum of two days) permits the use of local helicopters (as opposed to major ferry flights) and results in a minimum of mobilization costs.



FIGURE 1. COMBINED ELECTROMAGNETIC, MAGNETIC AND RADIOMETRIC SYSTEM, IN ALOUETTE II HELICOPTER. THE EQUIPMENT SHOWN IS, FROM TOP TO BOTTOM, A SCINTREX GISA-4 MULTICHANNEL SPECTROMETER, AN MFE SIX CHANNEL GRAPHIC RECORDER, A SCINTREX HEM-701 ELECTROMAGNETOMETER, AND A SCINTREX NPM-1 PROTON PRECESSION MAGNETOMETER.



SCINTREX HEM-701
RIGID BOOM SYSTEM



INPUT TOWED BIRD SYSTEM

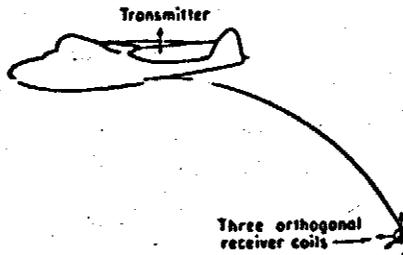
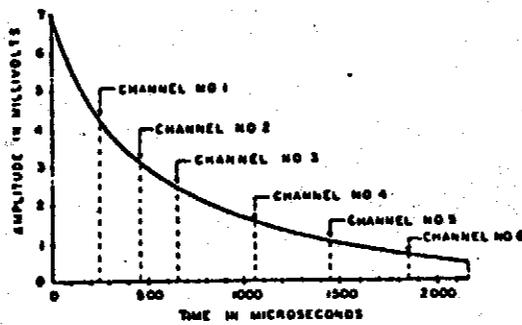
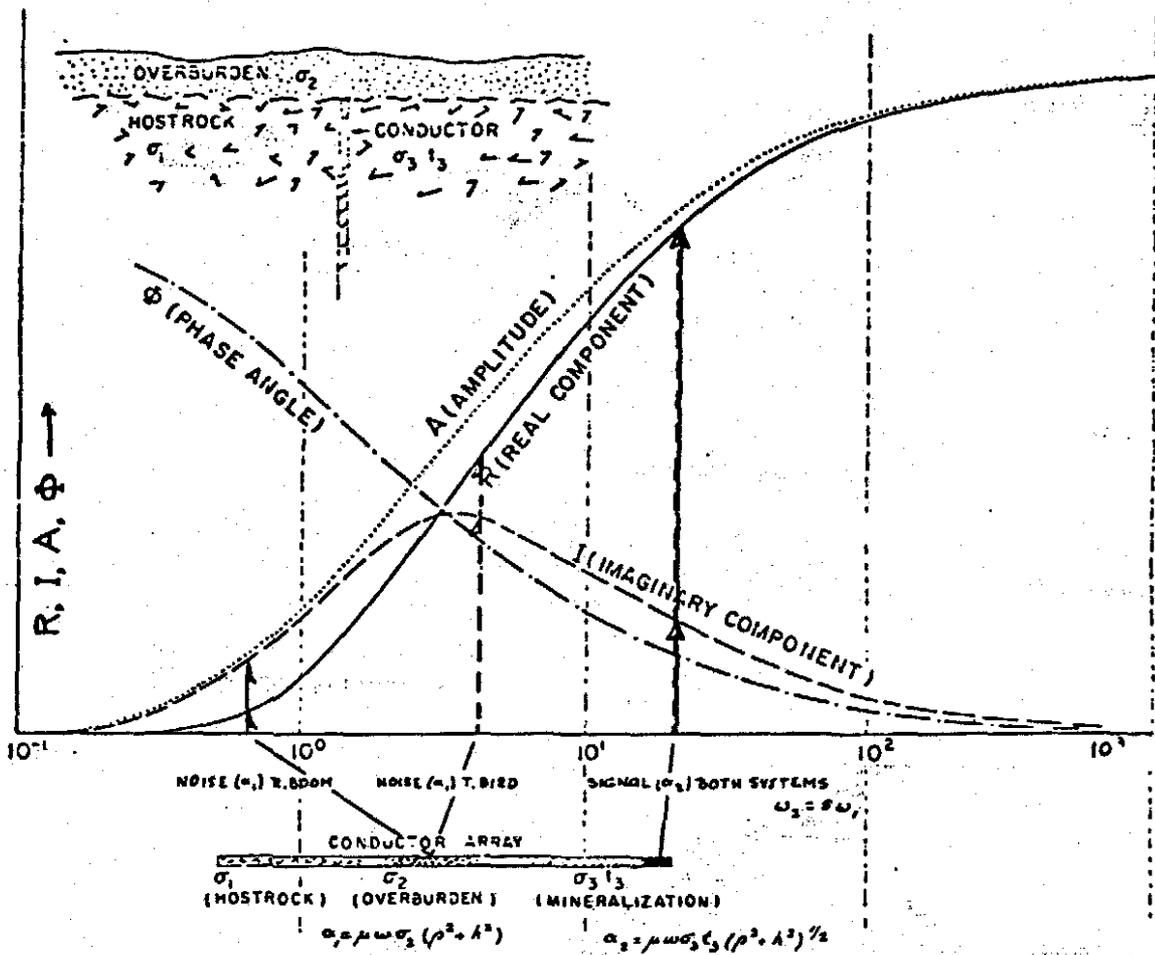


FIGURE 2



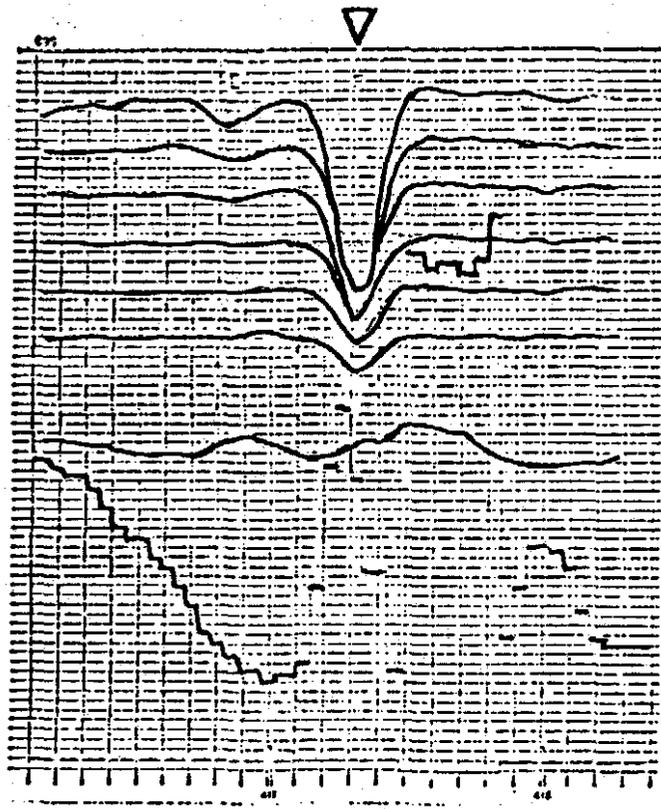
-Six-Channel Sampling Gate Centers of the Mark IV INPUT System.

FIGURE 3



Signal to noise relations: towed bird and rigid boom systems.

FIGURE 5. Sturgeon Lake - INPUT Discovery Anomaly

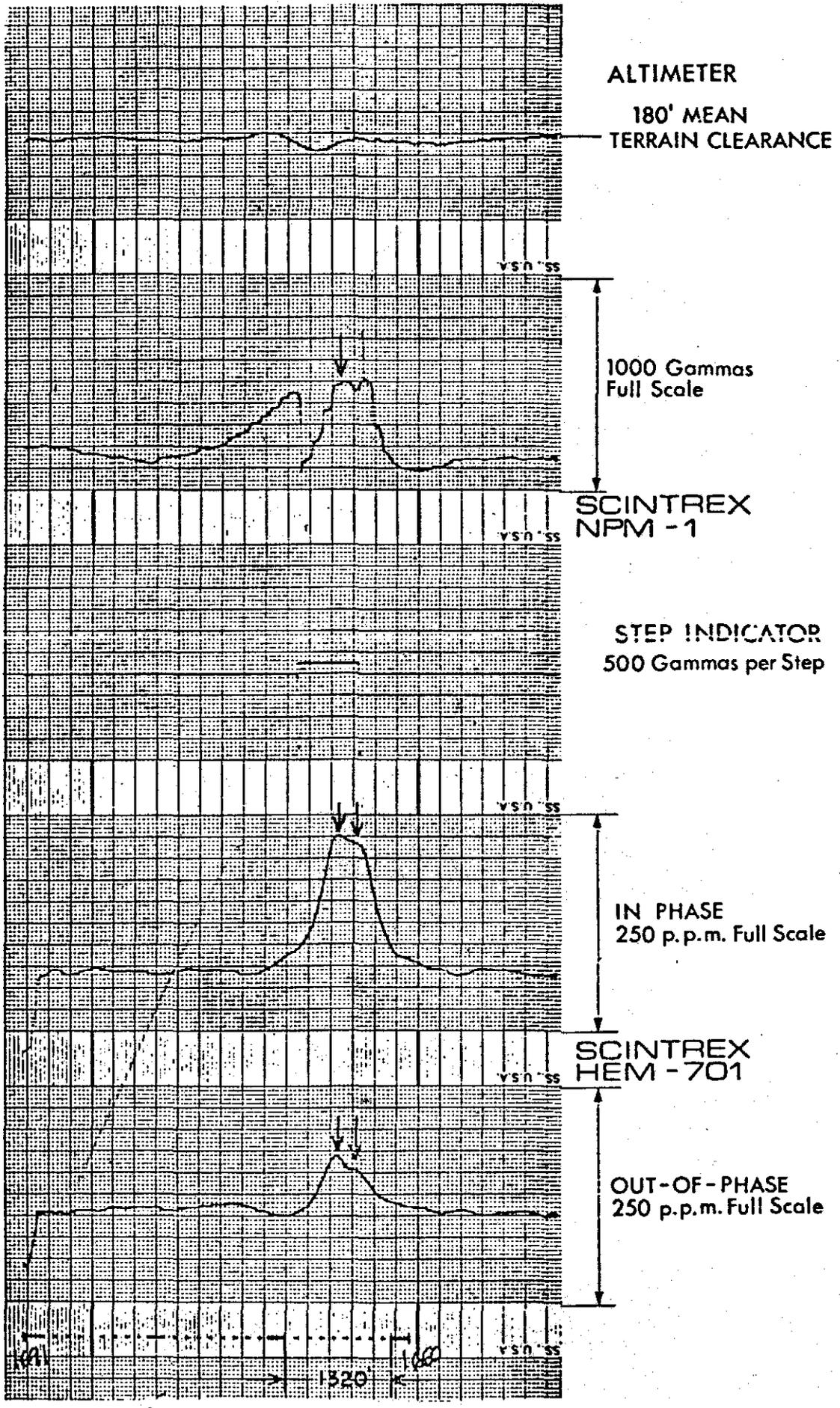


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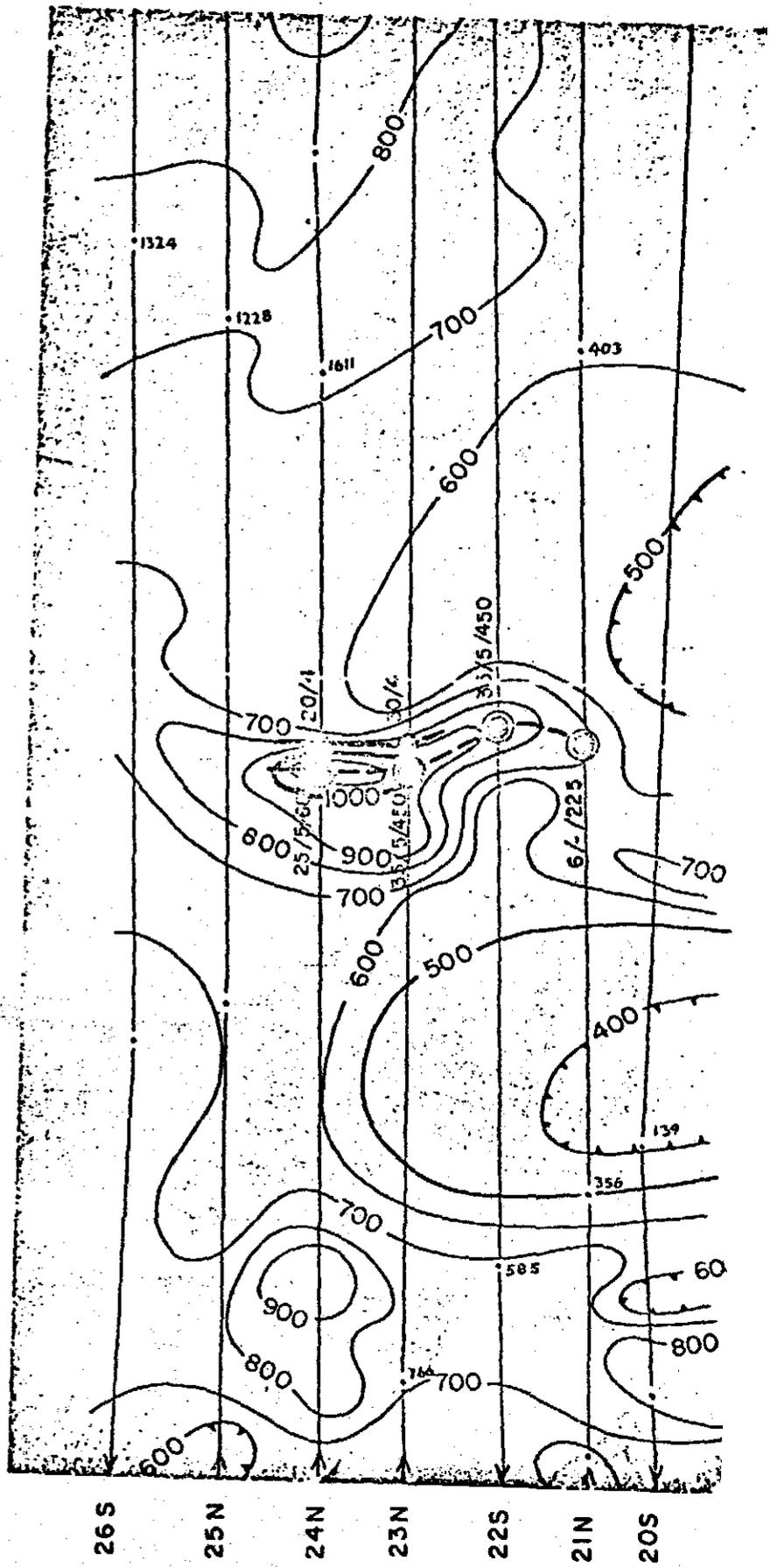
STURGEON LAKE - A CASE HISTORY

SCINTREX HEM-701 GEOPHYSICAL TRACES

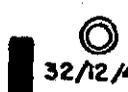
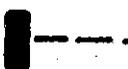


PRESENTATION OF AIRBORNE DATA

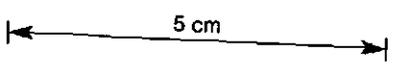
FIGURE 7



LEGEND:

-  21N FLIGHT LINE NUMBER, DIRECTION AND NUMBERED CONTROL POINT.
-  A.E.M. ANOMALY WITH MAGNETIC CORRELATION
32 ppm. / 12 ppm. / Magnetic Correlation
32/12/400 IN-PHASE / OUT-OF-PHASE / Amplitude in Gammas
-  CONDUCTOR AXIS
-  100 GAMMA MAGNETIC CONTOUR INTERVAL.

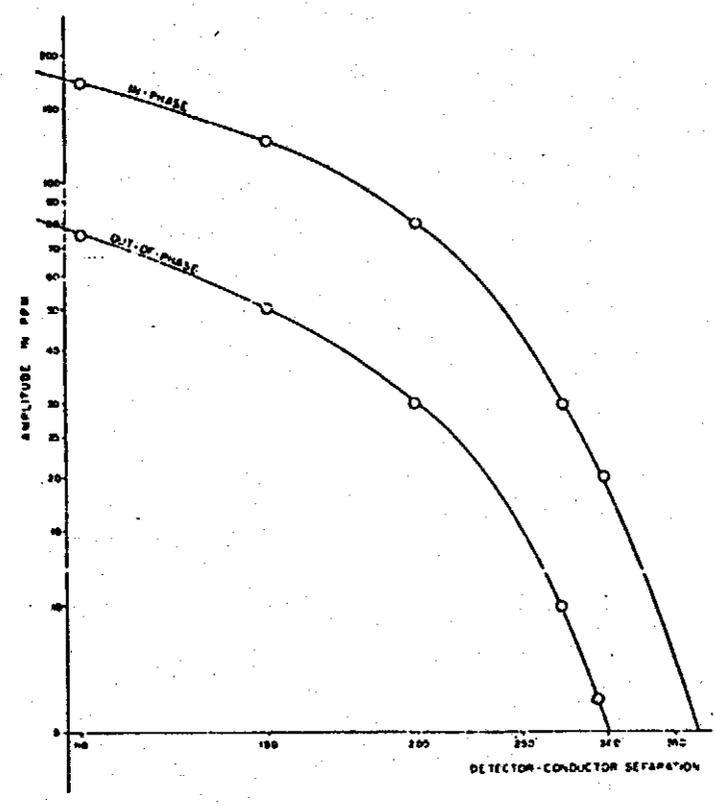
SCALE: 1" = 1320'



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FIGURE 8

STURGEON LAKE - A CASE HISTORY RATE OF FALL-OFF CURVES SCINTREX HEM-701



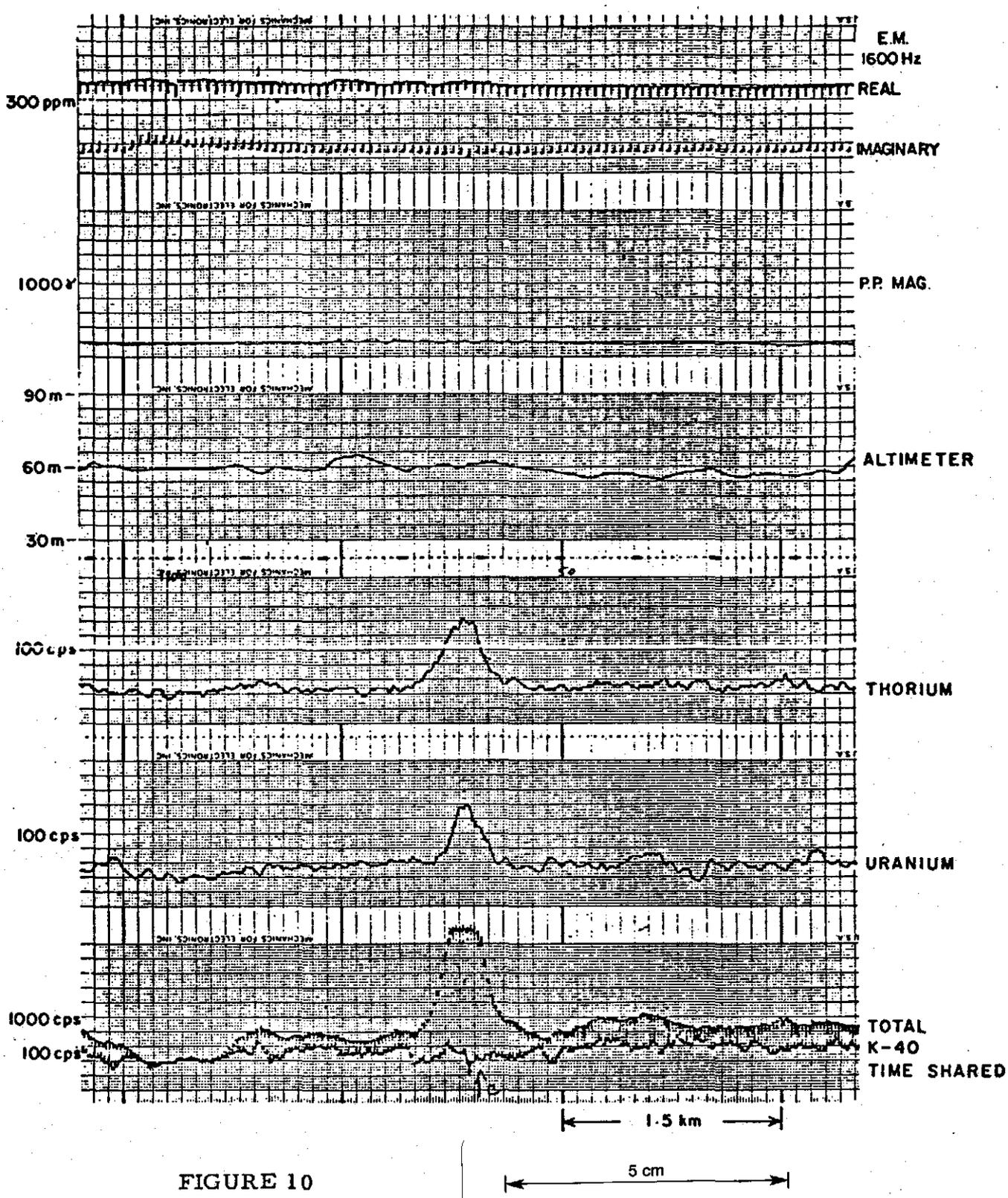


FIGURE 10

Record of Combined Electromagnetic, Magnetic and Radiometric System in Alouette II Helicopter. Radiometric Response.

Advances in Deep Penetration Airborne Electromagnetic Methods

R. A. BOSSCHART and
H. O. SEIGEL,
Canada

ABSTRACT

The Turair electromagnetic method has been developed in response to the need for a reconnaissance system to detect the presence of massive sulphide base metal deposits under conditions of depth of burial or topography which are beyond the capabilities of standard airborne electromagnetic techniques. The Turair is a fixed-source gradient detection system wherein the transmitter loop is often laid by helicopter and may be up to 16 kilometers in circumference. The receiver system consists of two similarly oriented coils, 2 to 5 m apart on a rigid boom, supported by either a helicopter or fixed-wing aircraft. Phase gradients and field strength gradients are measured. Depths of detection of sulphide deposits in excess of 150 meters subsurface have already been achieved by the Turair method and theoretically, for large targets, depths in excess of 300 meters are feasible under the proper conditions.

Because of its fixed source configuration, the Turair method is less affected by near-surface conductivity than moving-source methods and it can, moreover, be applied with lower exciting frequencies (100-800 Hz). As a helicopter system, it can operate in mountainous terrain where it further has the significant advantage over other AEM methods that the height over target has less effect on the exploration depth and no effect on the response parameter. Because of its lower efficiency and mobility it is not economically competitive with other AEM systems when the search problem requires only moderate exploration depths.

A further important application of the Turair method is in areas of special geological interest where the greater exploration depth increases the probability of discovering blind orebodies. Statistically, as is shown, at least twice as many "typical" orebodies will be detectable by a Turair system as by standard AEM systems, even in the absence of overburden. When substantial barren cover is present this detectability ratio will be many times higher. In areas where sulphide deposits are already known and the favourable horizons have been more or less well established, this high detectability ratio presents a strong reason for renewed exploration with the Turair system.

INTRODUCTION

THE APPLICABILITY of airborne electromagnetic methods to base metal exploration has been well established by their discovery record of the past two decades. The main factors limiting the effectiveness of these methods are their useful depth of exploration, the surface topography and the nature and thickness of the materials overlying the potentially ore-bearing rocks. In many areas, deep overburden or weathering, sometimes combined with topographic relief or high

Authors' addresses are given at the back of this book.

tree growth, keep the horizons of interest beyond the range of the classical electromagnetic prospecting systems. The best of these achieve, under favourable conditions, a penetration of little more than 100 m subsurface, and in rough terrain this depth is considerably reduced.

In Canada, although much of the Precambrian host rock has only light glacial cover, platform deposits of Paleozoic and younger ages cover the basement southwest of Hudson Bay and southwest of a line joining the Great Lakes and Great Bear Lake. Topographic relief is, for instance, a major obstacle to airborne prospecting in British Columbia and some areas in Eastern Canada. In the Western United States, problems of deep oxidation are often added to those of relief and cover and still farther southward, in subtropical and tropical countries, a heavy residual soil cover and deep oxidation frequently occur in combination with rough topography and a high tree cover.

To conduct effective electromagnetic prospecting under these conditions requires exploration depths far in excess of 100 m, as well as the ability to maintain small terrain clearances in areas of rough topography. It is unlikely that the needed gain in capability can be attained through improvement of the classical AEM methods.

Two passive and a number of active AEM systems are in use at present. The passive field methods (AFMAG, VLF) provide, in practice, neither adequate exploration depth nor sufficient discrimination for direct exploration and they can be left out of consideration. The active systems are all of the moving source and receiver type, in stable or unstable forms, i.e. transmitter and receiver are either in a mechanically rigid configuration or else differential movement is permitted to take place between the two.

The stable configurations inherently have small transmitter-receiver separations and are mounted on helicopters or light STOL fixed-wing aircraft, or suspended on a rigid boom below a helicopter. The unstable configurations tend to have larger transmitter-receiver separations and are mounted in larger aircraft, trailing the receiver in a bird on a tow cable.

If we consider their capabilities, leaving aside such matters as discrimination and resolution, stable configurations obviously have the edge in terrain performance. In the better systems, instrumental and mechanical noise are now at the lowest levels obtainable with present components and materials. Beyond a depth of 100 m the response rate of fall-off is between the third power (for sheet-like bodies) and the sixth power (for spherical bodies), so that even marginal improvements in penetration can only be achieved through major reductions of the already very low noise levels. This configuration seems to have been developed close to its ultimate penetration potential.

Unstable systems have a less favourable terrain performance, but they are usually credited with better penetration because of the large separation between transmitter and receiver. Indeed, in free space, the response of a typical target (e.g. a conducting half-plane) relative to the primary field increases with increasing T-R separation. In practice, however, the free space condition rarely applies. Usually the target conductors occur under a conducting cover (alluvial or glacial formations, weathered layer, etc.) or in a conducting environment which also responds to the electromagnetic energization. As a result of the geometry the response from the environment, which is usually called geological noise, increases faster with the transmitter-receiver separation than the signal from the target conductors. Thus the signal/noise ratio will begin to decrease beyond some optimum separation, or, in a more general way, beyond some optimum value of the separation x frequency product.

As field experience has shown (e.g. Mackowiecki, King and Cratchley) this optimum value is readily exceeded by most present unstable systems under quite common geological conditions. Unstable systems, as a result, have not so far provided us with very much greater exploration depths than stable systems. Even if we assume that unstable moving source systems can and will be further improved, for instance by measuring in-phase components and employing lower frequencies, these improvements will not happen overnight and they will result in only modest gains in penetration. The large gains that deep exploration requires can only be achieved through a different approach.

THE TURAIR METHOD

It has long been recognized in the ground application of electromagnetic methods that much greater exploration depths can be obtained with systems using fixed energizing sources than with moving-source and receiver systems. This advantage is mainly due to differences in scale between the two types of survey configurations.

The length of the receiver traverses in a fixed source survey suggests, to many people, large transmitter-receiver separations, but actually the latter are relatively small compared to the size of the energizing layouts. If we, for instance, consider an inductive Turam configuration, the measurements are carried out within one transmitting loop diameter and thus in an almost uniform primary field, which falls off at a rate little more than the inverse first power of the distance. In Figure 1 the relative response rate of fall-off with depth of typical moving source and fixed source methods are compared. In the former, the fall-off is inversely as the 3rd power at a depth equal to the coil separation. In the latter method the response falls off at a rate between the 1st and 2nd power.

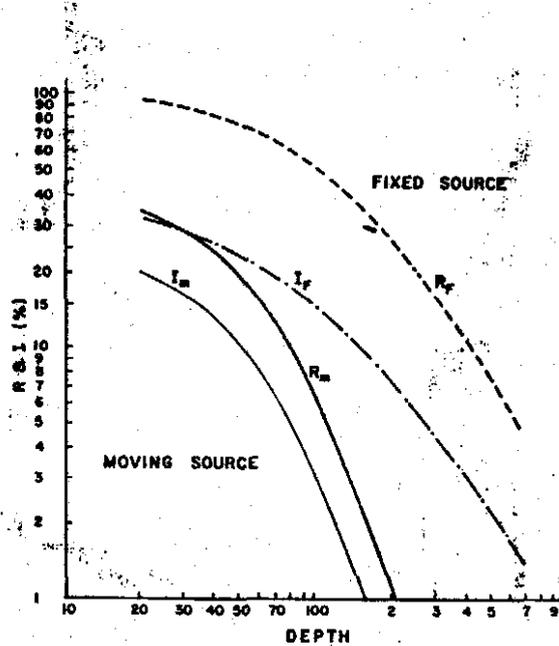


FIGURE 1 — Rate of response fall-off with depth for typical moving-source and fixed-source systems.

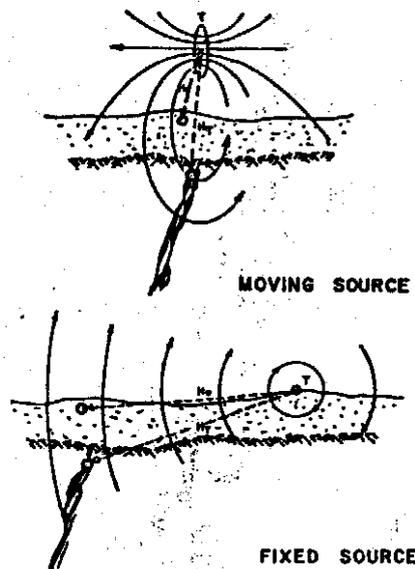


FIGURE 2 — Energizing pattern of moving-source and fixed-source configurations. Relative energization distances to surface conductors (H_s) and target conductors (H_r).

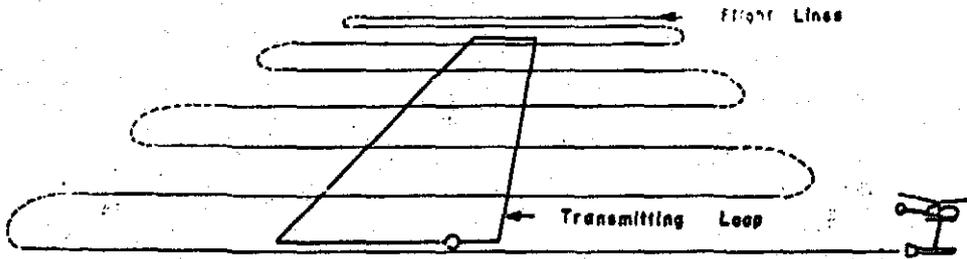


FIGURE 3 — Typical Turair survey layout.

Statistics of tabular base metal ore deposits in Precambrian Shield areas indicate a median length of about 250 m. In moving-source configurations, all such bodies over about 150 m in length give the same limiting response. As a result, their response to moving-source configurations does not vary appreciably with size, but in a fixed-source system the response will increase steadily with increasing body size out to about 2000 m in length, with a potential further increase in amplitude of as much as 400%.

In a moving-source configuration, the larger target conductors are hardly more detectable than the smaller ones. The fixed-source configuration has the advantage that the larger the conductor, the stronger will be its response and the greater the depth at which it will be detectable.

Another advantage results from the energization pattern and is particularly significant in areas of thick cover. Under such conditions, a moving-source system tends to emphasize overburden conductors because these are much closer to the source and the energizing field falls off at the 3rd power of the distance. In a fixed-source system the energizing field is of almost equal strength at the location of near-surface or bedrock conductors (Fig. 2) and, therefore, does not enhance overburden response.

To combine these inherent advantages of the fixed-source configuration with the speed and efficiency of airborne measurements, the Turair system employs transmitting layouts of large dimensions on the ground and a receiver system carried by a helicopter or light aircraft. Traverses are usually flown across this source, as shown in Figure 3, i.e. measurements are made both outside and inside the transmitting loop.

The receiver system measures the horizontal gradient of the vertical and/or horizontal field by means of pairs of coils mounted in a bird towed by a helicopter, or attached to a fixed-wing aircraft.

Primary Field

Typical transmitting loop dimensions range from 3 x 3 to 10 x 5 km. When a helicopter is used to carry the receiver system, it is also employed to lay out the transmitting loop from the air. For this purpose, a special cable-dispensing device has been developed. Alternatively, the loop can be laid out by vehicle, where the country permits, or by hand and a light fixed-wing aircraft used to fly the receiver. A motor-driven generator, supplying 2-4 amps of current, is used to energize the loop. Any frequency between 100 and 800 Hz can be selected to suit the geologic conditions in specific areas.

Inductive primary sources are generally preferred. Grounded sources will usually cause galvanic current to flow through the investigation area, which will tend to result in increased overburden response. Moreover, as this current is

in-phase and of random quantity and direction, it will impair quantitative interpretation, particularly conductor discrimination based on amplitude/phase relations.

In exceptional areas, grounded sources could be useful, for instance, to conductively energize bodies which, because of their geometry, cannot be sufficiently energized inductively to become detectable.

Receiving System

The receiving system comprises two coils or two pairs of coils rigidly mounted in a coplanar and/or coaxial configuration. The separation may vary from 3 to 10 m. The ratio of the field strengths and the phase differences of the alternating magnetic field at the two coils are measured by means of a compensator and recorded in analogue or digital form. The sensitivity of the receiving system is 0.1% amplitude and 0.1° phase difference.

The receiver is normally flown at a 30-50-m ground clearance. It should be noted that because the response rate of fall-off is low, the receiver elevation is not critical. In fact, when near-surface conduction is high, the signal-to-noise ratio and thus the detectability of deep conductors can often be improved by increasing the terrain clearance.

Interpretation

The field results of Turair measurements are basically similar to the results of ground Turam measurements, which gives the Turair method the benefit of proven and established quantitative interpretation procedures (Bosschart, 1964).

In fixed-source configurations, response parameters are simpler than in moving-source configurations; neither transmitter-receiver separation nor the height above the conductor have any effect on the character of the response at

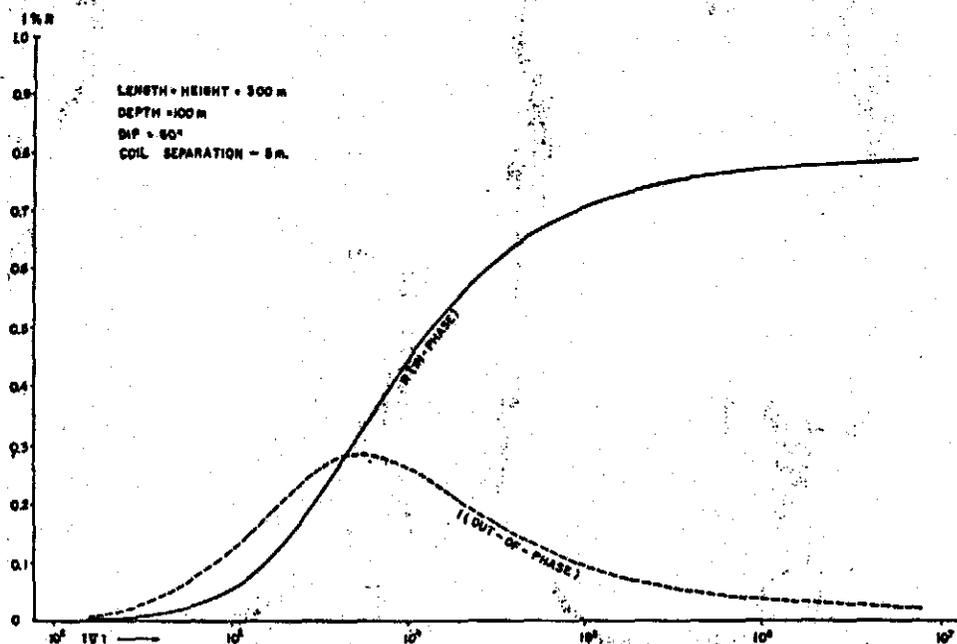


FIGURE 4 — Response of a finite tabular conductor in a Turair configuration (R_x — R_y , 5 m).

this scale. A typical Turair response diagram is shown in Figure 4, which shows the variation of real and imaginary components of the response with the factor $f\delta t$ (f = frequency, δ = conductivity, t = thickness), for a tabular "thin" conductor of finite dimensions. A Turair coil separation of 5 m has been assumed as well as a depth of burial of 100 m to the upper edge of a 300-m-square, tabular body dipping at 60° from the horizontal.

It has been shown earlier (Bosschart, 1964) that the conductor size variations affect the response characteristics and that they do so in a manner different from variation of the response parameter and that, therefore, a size factor cannot simply be incorporated in the latter. Thus, in order to determine δt values from field data, composite nomograms have to be employed which incorporate size as well as response parameter variation. For the direct interpretation of Turair anomalies, a series of response diagrams for tabular "thin" conductors of dimensions ranging from 100-m strike length by 100-m depth extent to infinite dimensions have been combined into a complex Argand diagram. From this diagram the value of δt can be derived directly from the relative amplitudes of field strength ratio and phase anomalies for all coil separations and height of flight. The strike length of the conductor (which for bodies of depth extent more than $\frac{1}{2}$ their length is the determining size factor) can be determined from the anomalous pattern and is significant in determining it. Geometric changes such as depth, strike and dip, affect the amplitudes but not their mutual relations and thus have no effect on the determination of the δt product.

Field Results

The Turair results shown below in Figure 5 were selected because the anomalies were followed up on the ground and subsequently drilled; because sulphide conductors were found and the initial interpretation was confirmed in detail and, most important in the present context, because these sulphide bodies were detected under a cover which is impenetrable to any other AEM method and barely within the range of the Turam ground EM method.

The survey was located on the projected SW extension of the Manitoba

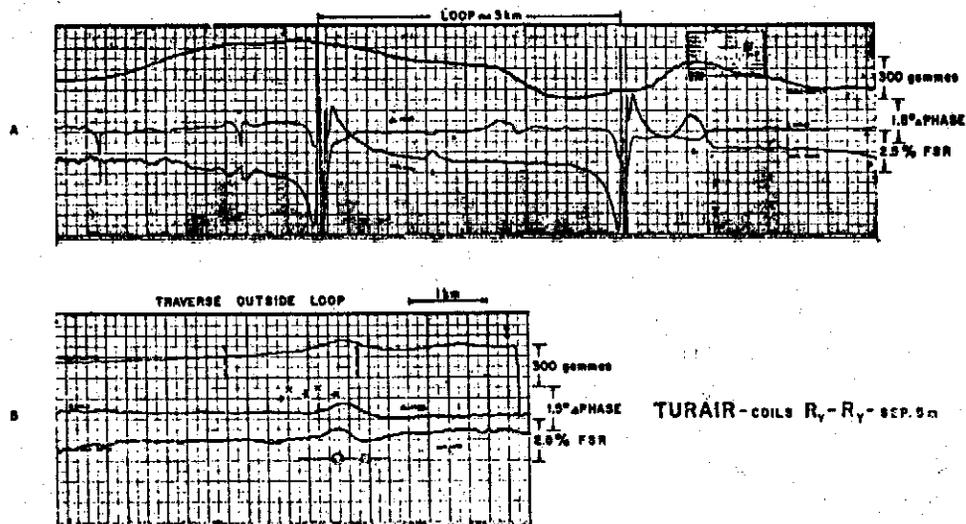


FIGURE 5 — Combined Turair and magnetometer survey, Manitoba, Canada.

nickel belt, where the basement is covered by more than 100 m of Paleozoic formations (limestones, dolomites, sandstones, etc.) and relatively shallow Quaternary deposits.

Figure 5a is the record of a 400-Hz Turair and magnetometer traverse across a 3 km x 3 km source. The location of the latter is marked by two zones of very strong field reversals. Two distinct anomalies occur on this record, both indicating good conductivity. The first one, a small anomaly inside the loop, is due to a source at a depth less than 50 m, i.e. in the Paleozoic and of no immediate interest. The second anomaly is much stronger and shows a depth of approximately 220 m (or 180 m subsurface) and a δt value of 180 mhos, indicating very high conductivity. There is a coincident magnetic expression of 170 gammas yielding the same interpreted depth. Figure 5b shows a parallel traverse $\frac{1}{2}$ mile outside a transmitting loop, where the primary field gradients are almost constant. The indicated depth is approximately 250 m (or 210 m subsurface) and $\delta t = 16$ mhos, indicating much lower conductivity. The field strength ratio shows a distinct current-return current pattern which suggests a wide, banded conductor. The anomaly has a coincident 70-gamma magnetic expression, indicating the same interpreted depth.

The conductive zone of Figure 5a which extends over a number of traverses, some of which are shown in Figure 6a, was investigated on the ground by a magnetometer and Turam EM survey. The ground survey generally confirmed the conductor and the interpretation of the airborne traces. It is, however, worth noting that the ground Turam survey, although a 60-m coil separation was used, produced rather inconclusive results because of the near-surface field distortion (Figure 6b) which renders the signature of the deep conductor difficult to recognize. In fact, the ground EM results would not by themselves have formed a sufficiently reliable basis for further exploration. In contrast, the geological noise is hardly noticeable in the airborne results, which consistently show a high (approximately 10:1) signal-to-noise ratio, notwithstanding the 30-40 m higher elevation of the receiver.

The drilling results of the traverses shown in Figure 5 with the relevant airborne and ground sections are shown on Figures 7a and 7b.

The first hole intersected, at approximately 210 m depth, a 3-m-wide zone of concentrated pyrite-pyrrhotite mineralization under 160 m of Paleozoic cover, thus confirming the high δt value and the depth calculated from the airborne data (Fig. 7a).

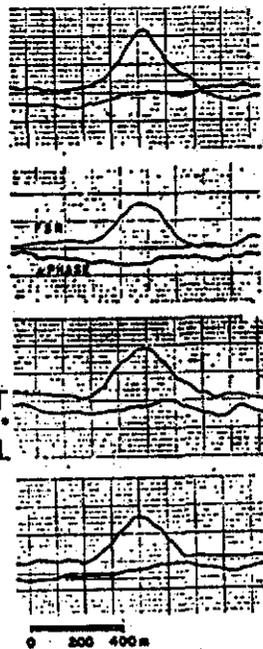
Drilling of the second anomaly intersected a 120-m-wide zone consisting of, in sequence, a narrow band of sulphides, a 50-m-wide zone of highly altered amphibolites, another narrow (1 m) sulphide zone and a 3-m-wide zone of pyrite-graphite mineralization under 180 m of Paleozoic formations. In addition, the upper 20 m of the basement was weathered and leached, bringing the total cover to a thickness of 200 m. These results again confirmed the depth and the low δt value calculated from the airborne data, as well as the wide, banded nature of the conductor (Fig. 7b).

Some examples of surveys in Western Australia are shown in Figures 8a and 8b and these display characteristics different from the previous examples. In all these surveys, the energizing loop was laid out around the target area and the measurements carried out inside the loop. Damping of the electromagnetic field in the weathered cover is often too high for reasonably long traverses to be measured outside the loop. In both locations the anomalies are characterized mainly by phase distortion, with much less distortion in the field strength. Conductivity of the mineralized zones generally appears to be low.

112

A. TURAIR AEM

$R_1 - R_2, 8m$



B. TURAM EM

$R_1 - R_2, 80m$

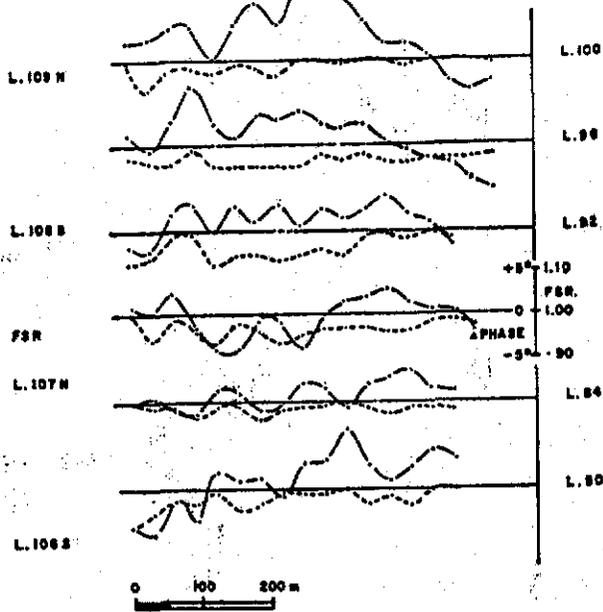
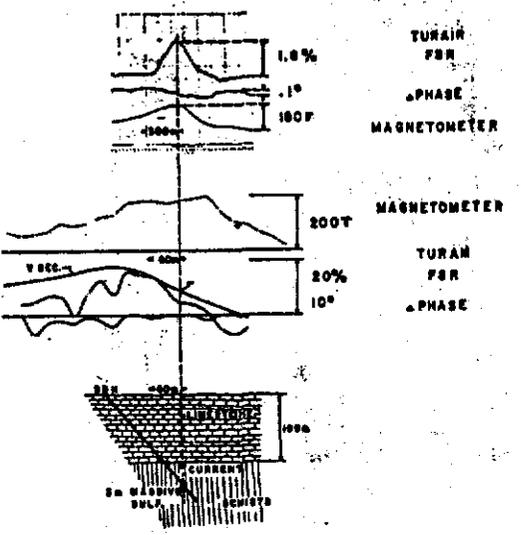


FIGURE 6 — Turair survey (A) and Turam ground follow-up (B), Manitoba, Canada.

A. ANOMALY # 1



B. ANOMALY # 2

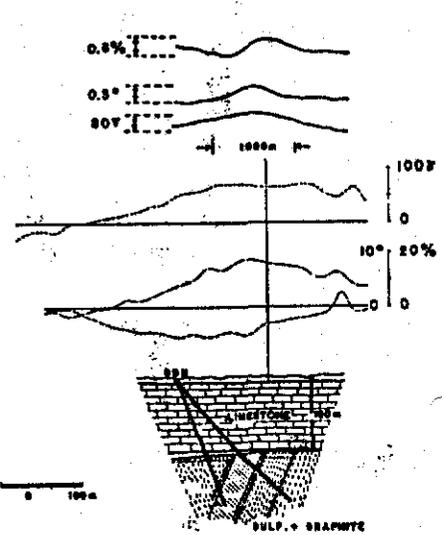
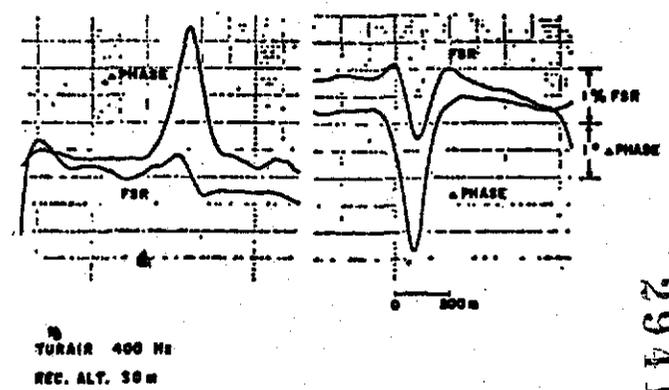


FIGURE 7 — Turair and magnetometer survey, ground follow-up and drilling results, Manitoba, Canada.

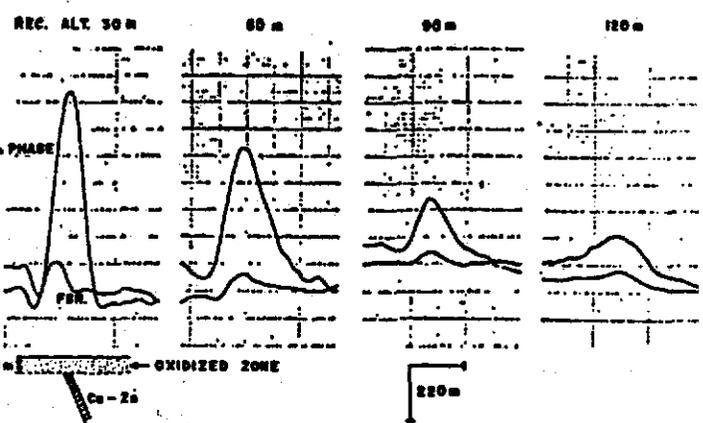
Figure 8a presents two traverses, in opposite directions, over a conduct in a host rock of ultrabasic formations of Archean age. The indicated depth approximately 90 m subsurface, which is probably the depth of oxidation. Tl conductor displays very low δt values, 3.5 mhos and 2.5 mhos respectively. Th conductor has not yet been further identified and could equally well be an ionics ly conducting fault zone or poorly conducting sulphides. The reversal of t amplitudes between the two traverses is due to the opposing directions of mea urement.

Figure 8b presents a survey over known conditions, the Whundoo deposit NW Australia. Although the mineralization consists of a 10-m-wide zone of C Zn, pyrite mineralization, the conductivity appears to be very low ($\delta t = 2$ mhos possibly due to the fact that the sulphide mineralization occurs in the form (

A. W. AUSTRALIA



TURAIR 400 Hz
REC. ALT. 30 m



B. WHUNDOO DEPOSIT

FIGURE 8 — Turair survey results, Western Australia.

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discrete lenses. Traverses were made at increasing terrain clearances from 60 m to 165 m bird altitude, a level where the F.S.R. distortion has largely disappeared, but the phase difference anomaly is still clearly discernible.

OPERATIONAL EFFICIENCY

Under average conditions, a primary field loop of 3 x 5 km can be laid down by helicopter and the transmitter positioned within little more than one hour. By vehicle or by hand, more time is required.

A line spacing of 200 m has been found most efficient for the majority of search problems. Economic ore deposits may have strike lengths of 200 m and even less, and to detect such targets, particularly when they are deeply buried, requires a line spacing not much larger than the minimum strike length. Moreover, larger line spacings do not represent significant savings because less profile can be measured per loop layout. Subject to local conditions some 200-300 line km of profile (at 200-m intervals) can usually be surveyed from one source loop; the total operation of positioning and measuring covers about one to two day's field work.

THE MERITS OF DEEP EXPLORATION

The Turair system has been developed for the specific purpose of deep electromagnetic exploration. It has been shown that a sufficiently significant increase in capability cannot be achieved through improvement of the classical moving-source AEM methods, which have been developed close to their effective penetration potential. To attain substantial improvement in exploration depths, electromagnetic techniques employing fixed primary sources have to be used.

There are two aspects of this increased depth of penetration. The first and more obvious relates to areas of heavy overburden, thick sedimentary cover, oxidation or rough topography. The results obtained thus far in such areas of deep cover have confirmed the feasibility and effectiveness of airborne fixed-source gradient measurements and they have, moreover, shown that the airborne application has considerable advantages in sensitivity and penetration over ground fixed-source measurements because of a strong reduction of the geological noise level. For instance, the results in northern Manitoba, in places where relatively homogeneous overburden conditions prevail, show that the Turair method could detect bedrock conductors under a maximum of 200 m of cover. Over the same conductors the Turair anomalies show a better than 6:1 signal/noise ratio, indicating that they would be detectable to a depth approaching 300 m. The maximum depth reached in the same area with an AEM moving-source system (INPUT) has been 125 m (Tikkanen, 1970).

An equally important aspect of the ability to achieve significantly greater depths of exploration is the possibility of discovering truly "blind" orebodies, even where little overburden exists. Up to the present time our primary concern in airborne electromagnetic prospecting has been the ability to penetrate the unmineralized covering formations and to be able to detect bodies outcropping at basement surface. It is worthwhile, however, to examine the significance of the Turair method in terms of the probability of detecting sulphide deposits at depths in excess of those achievable with other AEM systems, even where the latter systems adequately penetrate the overburden.

For a multi-million-ton massive sulphide base metal orebody, which is to be mined by underground methods, there is little effective difference in the mining costs per ton whether mining starts at the base of the overburden or at 1000 ft. in depth. As the history of exploration on the Lake Dufault property in

Quebec is fully warranted by the shallow depth to ground level. What borne electrical detectability of original propylitic thickness "geologic importance". To be made abundant distortions with the result large number that the rocks would not be through probably by burial periods of

The which new of a large median random such a good correlation field structure the anomaly

Under 0.2% regression of 0.2% defined,

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24th IGC,

Quebec has demonstrated, rich ore deposits occurring at even $\frac{1}{2}$ mile in depth fully warrant being put into production. An exploration depth of 100 m, imposed by the standard airborne electromagnetic systems, is certainly not the maximum depth to which one would like to explore under present-day economics of underground mining.

What are the chances that additional ore deposits will be found by an airborne electromagnetic technique which has a significantly greater depth of detectability than 100 m? The probability considerations are related to the mode of origin of the ore deposits in question and their resulting size, shape and physical properties, as well as their present attitude (dip and plunge directions). The thickness of the cover overlying the ore-bearing formations and the amount of "geologic noise" it generates in the particular electromagnetic system are also important.

To arrive at the appropriate probabilities some assumptions have to be made about these factors. The first is that the ore deposits are essentially strata-bound disc-shaped bodies of good conductivity, randomly distributed in formations which, as the result of tectonic movement, have been tilted and later, as the result of erosion, have been cut by an arbitrary plane. The analysis of a large number of sulphide deposits of the Canadian and Baltic Shields has shown that the majority of the massive copper-zinc and nickel deposits in Archean rocks would fit this description (Hutchinson, Ridler and Suffel, 1971) and so would many massive lead-zinc deposits in carbonate rocks of Paleozoic age throughout the world. The pattern fits the existing theory of a sedimentary, probably volcanic-exhalative origin of these deposits in shallow water, followed by burial, tectonic upheaval, subsequent regional metamorphism and finally long periods of surface erosion.

The original deposition horizons are thus cut by a perfectly random plane, which now forms the present bedrock surface. An examination of the dimensions of a larger number of sub-outcropping sulphide deposits shows that they have a median strike length of approximately 300 m, which confirms, considering the random attitude, the assumed disc shape. Given an average thickness of 15 m, such a body would represent approximately 5 million tons of ore and, assuming good conductivity, such a body, when steeply dipping, would give rise to a 0.4% field strength ratio anomaly at a depth equal to its diameter. With flatter dips the anomaly will be larger.

Under conditions of low geologic noise a field strength ratio distortion of 0.2% represents a detectable anomaly. Assuming an average geologic noise level of 0.2% (as in Figure 5) the typical massive sulphide bodies, which we defined, are detectable to at least 300 m depth of burial, regardless of orientation.

To determine the relative detection probabilities of the Turair and the standard AEM methods we compare the probability of the ground surface cutting within 300 m of anywhere between the upper edge and the mid-point of the body, with the probability of it cutting within 90 m of the same region. (Of the bodies cut by the present bedrock surface we leave out of consideration, for the sake of simplicity, those of which more than half has been removed by erosion.) This results in $(300 + 150 \sin \Theta)$ versus $(90 + 150 \sin \Theta)$, where Θ is the dip of the body from the horizontal. For $\Theta = 0^\circ$ the ratio is 3.3, for $\Theta = 45^\circ$ the ratio is 2.1 and for $\Theta = 90^\circ$ it is 1.9. Thus, in the absence of overburden there is at least an equal chance for a sulphide deposit to lie between 90 m and 300 m depth as there is between 0 m and 90 m of the ground surface. When overburden is present its (barren) depth H has to be subtracted from the potential penetration, i.e. in the case of the Turair system we would obtain 300-H, versus 90-H for the

standard AEM system, resulting in a further probability bias in favour of the Turair system. For instance, in an area covered by 50 m of overburden, the relative detection probability of the Turair system versus the standard AEM systems would increase to approximately 5.7 (Fig. 9).

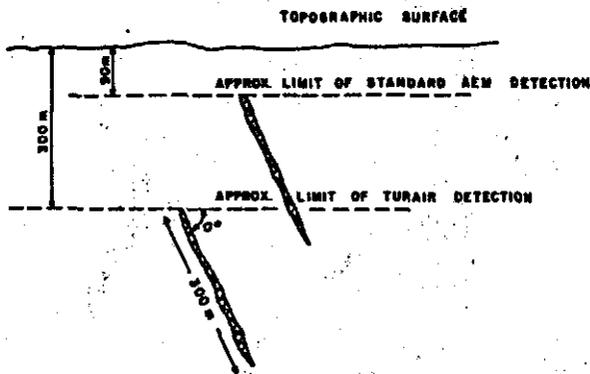


FIGURE 9 — Approximate limits of standard AEM and Turair detection of a steeply dipping tabular body of 300 m mean diameter.

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Advances in Airborne E

R. A. BOSSCHART
H. O. SEIGEL,
Canada

ABSTRACT

The Turair et a reconnaissance under conditions of standard airborne detection system with coils, 2 to 5 m apart. Phase gradient of sulphide deposits the Turair method are feasible under

Because of its near-surface conditions with lower excitation in mountainous methods that the effect on the economically only moderate

A further geological interest covering blind orebodies will be in the absence of ratio will be maximum and the favourable ability ratio present

INTRODUCTION

THE APPLICATION has been with The main factor depth of exploration the materials overburden or

Authors' address

116

Toronto, April 1970.

by G.D. Tikkanen, Ass't. Chief Geologist, Cominco Ltd.

DEEPLY PENETRATING SURVEYS IN NORTHERN MANITOBA

by

G. D. Tikkanen, Cominco Ltd.

SUMMARY:

The southwesterly projection of the Manitoba nickel belt beneath Paleozoic cover provides an excellent area for the application and testing of deeply penetrating surveys.

Examples of survey and drilling results show that sulphide bodies can be detected at depths of 400 to 500 feet.

INTRODUCTION:

Deeper searches have been of great interest to man throughout the years, ever since man first realized that valuable ores do not always crop out at the surface of earth, but can be hidden by soil or other types of overburden, water, or even barren rock. The first deep searches were likely made by following known orebodies underground, and discovering related hidden ores. Geological understanding and extrapolation led to searches by pits and shafts in areas of interest. Eventually, development of the diamond drill and geophysical surveys permitted widespread and relatively cheap searches, but usually only to relatively shallow depths.

Deep searches for massive or near massive sulphide bodies have been difficult because these bodies are small targets, compared to iron orebodies or porphyry coppers.

The whole concept of penetration is fundamental to any discussion of deeply penetrating surveys. One of the questions most frequently asked of geophysicists, concerning a survey is: "What is the penetration?"

The apparently evasive and unsatisfactory answers usually given this question are an honest reply to a question that should not be asked in general terms, but only in specific terms, when all parameters of the problem are defined. Limits cannot be put on penetration without definition of the target size. its response parameters, electronic and geological noise, and the characteristics of the survey method. To most geophysicists, adequate penetration, rather than ultimate penetration, is the more useful concept since it implies that recognizable responses are obtained throughout the area of survey over the type of target sought.

Although quite deep penetration, up to perhaps 300, 400 or 500 feet, has been demonstrated for particular ground survey methods in the past, the airborne EM methods, which have been so useful in rapidly searching very large areas of Canada, have only recently advanced sufficiently to provide useful information at depths greater than about 200 feet. The purpose of this paper is to show drill tested examples of responses from airborne and ground methods at depths down to 500 feet.

The projected southwestern extension of the Manitoba nickel belt provides a good test area, since the geophysical responses originate in the Precambrian rocks, which lie beneath Paleozoic dolomite and sandstone, which in turn is covered by unconsolidated overburden. Fig. 1 shows the location of the area of interest. Fig. 2 shows an isopachous map of the cover on the Precambrian surface.

The geology of the Manitoba nickel belt has been described by Zurbrigg and Manitoba government geologists. Essentially, sulphide bodies with and without nickel occur in both ultrabasics and gneisses. The orebodies show a rather remarkable linear arrangement. Apparently there is spatial relationship to a great zone of faulting.

The nickel deposits of the Manitoba belt are large, although small bodies also occur. The traditional search has been by electromagnetic and magnetic methods, followed by drilling.

METHODS:

This paper shows applications of Input and Turair airborne electro-magnetic methods, the Turam ground electromagnetic method, and the ordinary ground magnetic method.

The Input airborne method, as flown by Questor Surveys Ltd., has been described by Barringer Research Ltd. Essentially it is a time domain EM method whereby a transmitted pulse in the presence of a conductor generates a secondary field whose voltage is measured at six time intervals after cessation of the pulse. The method has the advantage of good penetration, achieved by measuring the secondary fields while the primary field is off.

The Turair method, developed by Scintrex Ltd., is an airborne application of the old Swedish Turam method. The Turam method has been described in detail by Bosschart.

In both airborne and ground applications a large loop is laid out on the ground. See Fig. 3. The loop's long dimension could be a few thousand feet or a few miles, with the width perhaps half the length. A motor generator connected to the loop generates a primary field, which in turn will cause secondary fields where conductive bodies are present. Two closely spaced coils are used to measure the gradient of the combined primary and secondary fields, as well as the phase shift between the coils. The primary field is known and its effect can be removed. The uniform primary field provides good penetration.

The ground surveys for Cominco were performed by Geosearch Consultants Ltd., using Swedish ABEM equipment. The Turair survey and associated ground Turam was performed by Scintrex Ltd., using their own equipment.

Ground magnetic surveys were made using Scintrex MF-1 fluxgate magnetometers.

RESULTS:

1) Interpretation:

The interpretation of the Input airborne results was straightforward and direct for the area concerned. The first channel was often quite disturbed, due to conductive overburden, but this disturbance diminished rapidly on the second channel. Obvious preference was given to well defined six channel anomalies.

The interpretation of Turam results had to provide discrimination between conductive overburden and real bedrock conductors. This is relatively easy, based on curve shapes and calculated depths. An example of a response interpreted as being caused by conductive overburden is shown in Example No.3, (Fig.6).

A second requirement of the Turam interpretation is the accurate determination of the location of the conductor. The location is commonly that of the maximum response of the reduced ratio, however when the conductor is near the primary source, or quite deep, the location is more accurately described by the inflection point of the secondary field.

The calculation of the secondary field has been described by Bosschart and by Lavoie, and is summarized below:

Calculation of Secondary Field:

let: n, n+1, n+2 indicate successive stations, away from the cable.

$F_n, F_{n+1}, F_{n+2} \dots$ be the primary field

$f_n, f_{n+1}, f_{n+1} \dots$ be the secondary field.

$\frac{F_n + f_n}{F_{n+1} + f_{n+1}}$ be the observed field ratio = $R_{n+\frac{1}{2}}$

$\frac{F_n}{F_{n+1}}$ be the normal primary field ratios = $R_{n+\frac{1}{2}}$

then: $(100\%) \frac{R_r}{R_n} =$ the reduced ratio = R_R

.. $R_{R_{n+\frac{1}{2}}} = \frac{F_n + f_n}{F_{n+1} + f_{n+1}} \cdot \frac{F_{n+1}}{F_n} \cdot 100\% = \frac{F_n + f_n}{F_n} \cdot \frac{F_{n+1}}{F_{n+1} + f_{n+1}}$

let: $V_T =$ the total field at each point, expressed in % of the normal field for that point.

$V_{T_n} = 100\% = \frac{F_n + f_n}{F_n}$

$V_{T_{n+1}} = \frac{F_{n+1} + f_{n+1}}{F_{n+1}} \dots 100\%$

.. $R_{R_{n+\frac{1}{2}}} = 100\% \cdot \frac{1}{V_{T_{n+1}}}$

so: $V_{T_{n+1}} = \frac{100\%}{R_{R_{n+\frac{1}{2}}}}$

and: $V_{T_{n+2}} = \frac{V_{T_{n+1}}}{R_{R_{n+1\frac{1}{2}}}}$ etc.

now: $V_S =$ secondary field, expressed in % of the field at the first point.

$V_S = \frac{f_n}{F_n} \cdot 100\%, \frac{f_{n+1}}{F_n} \cdot 100\%, \text{ etc.}$

also: V_N = normal field at any point, expressed in % of the field at the first point.

if: $V_{N_n} = 100\% = \frac{F_n}{F_n}$

then: $V_{N_{n+1}} = \frac{F_{n+1}}{F_n} \cdot 100\% = \frac{100\%}{R_{N_{n+\frac{1}{2}}}}$

$$V_{N_{n+2}} = \frac{F_{n+2}}{F_n} \cdot 100\% = \frac{100\%}{R_{N_{n+\frac{1}{2}}} \cdot R_{N_{n+1\frac{1}{2}}}}$$

by definition: $V_{S_{n+1}} = \frac{f_{n+1}}{F_n} \cdot 100\%$

$$= \left[\frac{F_{n+1}}{F_n} + \frac{f_{n+1}}{F_n} \right] 100\% - \frac{F_{n+1}}{F_n} \cdot 100\%$$

$$V_{S_{n+1}} = \frac{F_{n+1} + f_{n+1}}{F_n} \cdot 100\% - \frac{F_{n+1}}{F_n} \cdot 100\%$$

$$= \frac{F_{n+1}}{F_n} \cdot \left[\frac{F_{n+1} + f_{n+1}}{F_{n+1}} \cdot 100\% - 100\% \right]$$

$$\therefore V_{S_{n+1}} = \frac{V_{N_{n+1}}}{100} \left[V_{T_{n+1}} - 100\% \right]$$

A third requirement of the interpretation is to select those conductors having the best chance of being caused by sulphides. The conductivity can be determined from the ratio and phase responses, and in general the better sulphide intersections are associated with the better conductors.

2) Examples:

1. Input Airborne Electromagnetic Survey (Fig.4):

The Input records show a typical line of data in the Minago River area. The first and second channels are rather disturbed at the right side, caused primarily by conductive overburden. The trace shows anomalies which have been ground-checked and drilled. The cause was graphite and pyrite at depths ranging from 250 to 300 feet.

2. Turam Ground EM Survey at Two Frequencies (Fig.5):

This figure illustrates Turam results at frequencies of 220 c.p.s and 660 e.p.s. Most surveys done by Geosearch Consultants Ltd. for Cominco were performed at 660 c.p.s. The higher frequency shows larger responses over weaker conductors. This is an advantage in areas where the overburden is non-conductive, but in areas of conductive overburden, the response from the overburden is also increased.

3. Turam Survey over Overburden (Fig.6):

The survey shows a typical response over overburden. The results show steep gradients which are typical of conductive overburden.

4. Depth of Cover 180 Feet (Fig.7):

This moderately thickly covered conductor shows a very strong response. The drilling showed it to be pyrite and pyrrhotite.

The diagram shows the ratio, phase and the secondary field in percent of the normal field at an undisturbed point close to the cable, as well as the magnetic profile.

5. Depth of Cover 280 Feet (Fig.8):

This conductor, at a depth of 280 feet, still shows a very strong response. The drill hole showed it to be caused by graphite and pyrite.

6. Depth of Cover 320 Feet (Fig. 9):

This response is still well defined. The conductor was found to be caused by graphite and pyrite zones. The location is more precisely given by the secondary field.

7. Depth of Cover 380 Feet (Fig. 10):

This example shows that even at 380 feet, the Input method can show a conductor, although it is a weak response. The ground Turam response is well defined.

8. Depth of Cover 500 Feet (Fig.11):

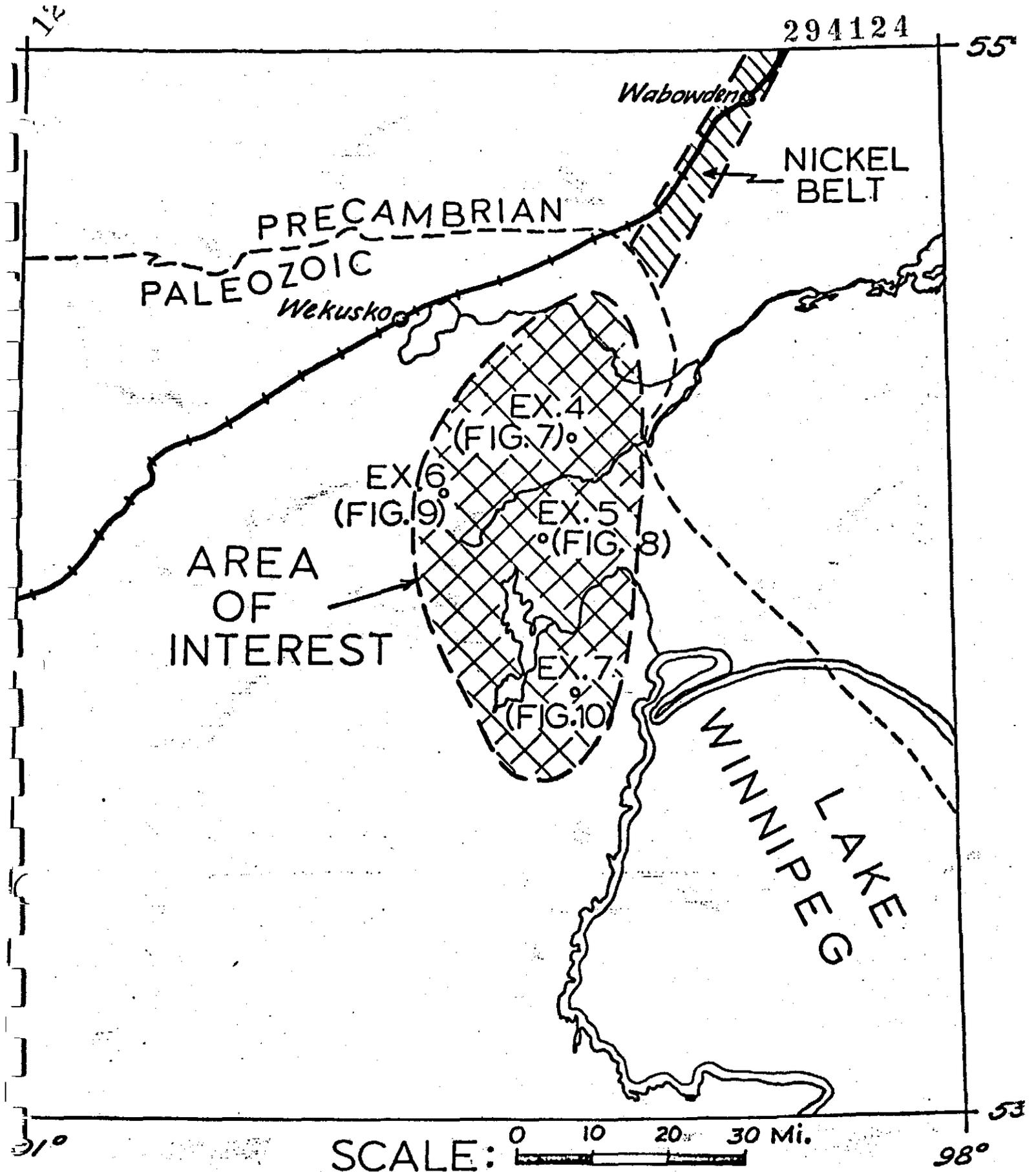
This case shows the Turair and ground Turam response from a conductor of pyrrhotite at a depth of 500 feet. The survey was done by Scintrex Ltd.

CONCLUSIONS:

- 1) Input and Turam electromagnetic surveys have located conductors at depths of at least 380 feet. At this depth the Input response is weak, and only marginally greater depths could be expected. The Turam response is still quite distinct, so that greater penetration, over a similar conductor, could be expected.
- 2) Turair and Turam have located a conductor at a depth of 500 feet. The airborne response is strong enough to expect detection of a similar conductor at even greater depths. The ground Turam response is also still significant at this depth.

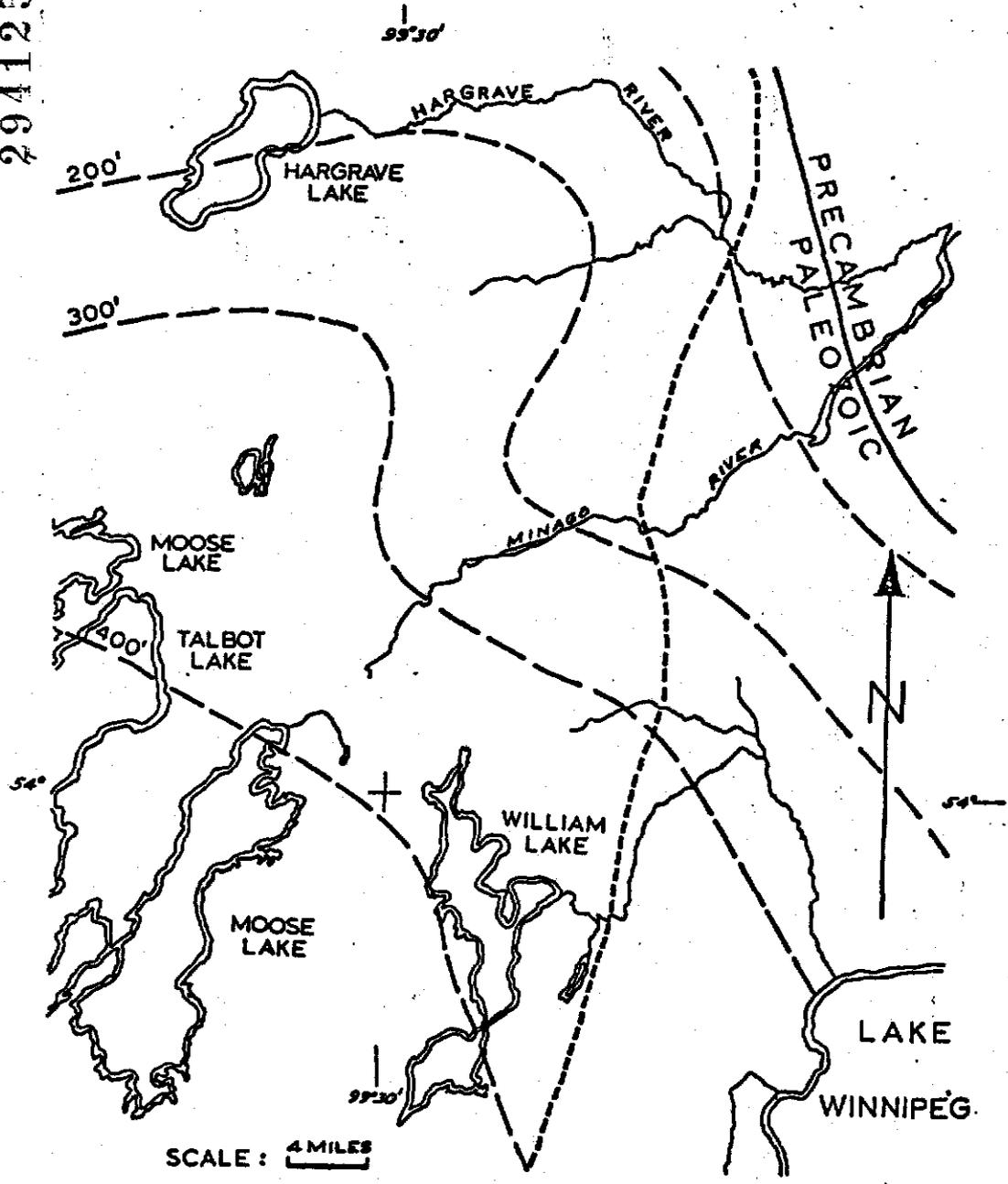
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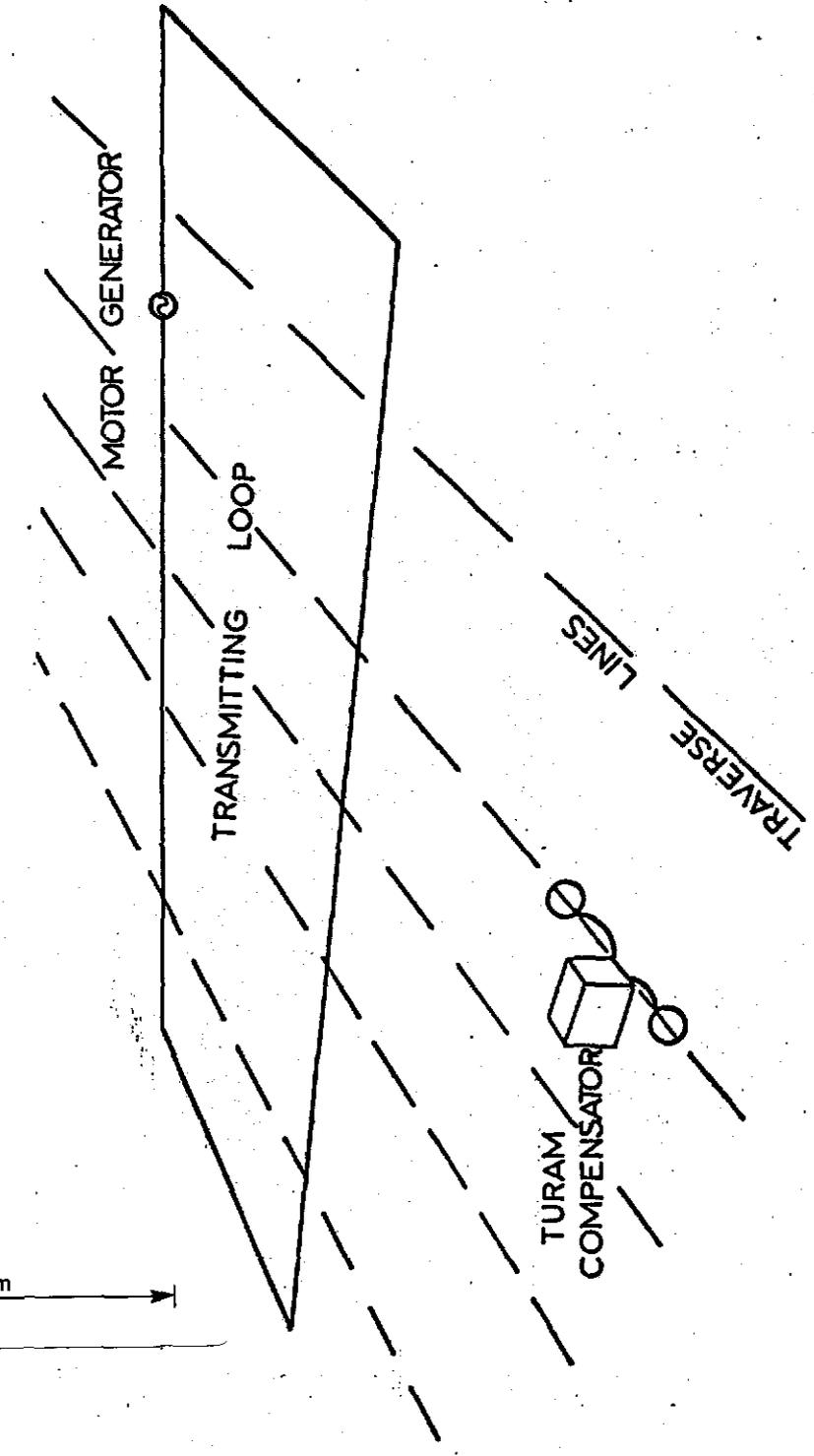
LOCATION MAP
FIGURE 1.

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MAP SHOWING THICKNESS OF COVER ON PRECAMBRIAN

FIGURE 2.



THE TURAM METHOD

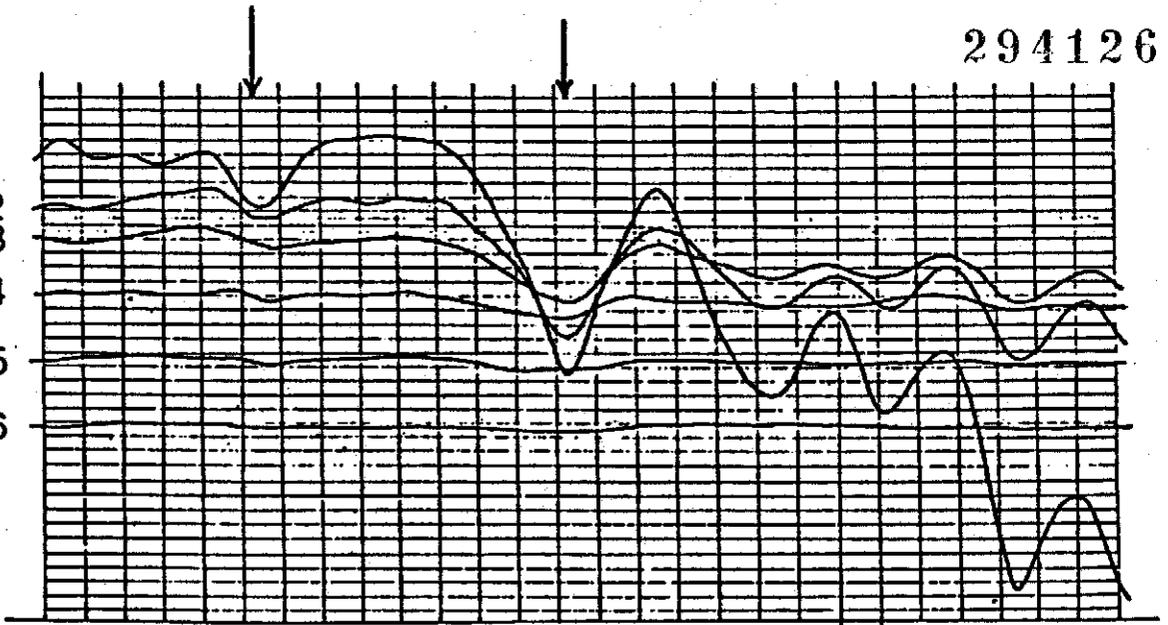
FIGURE 3.

125

127

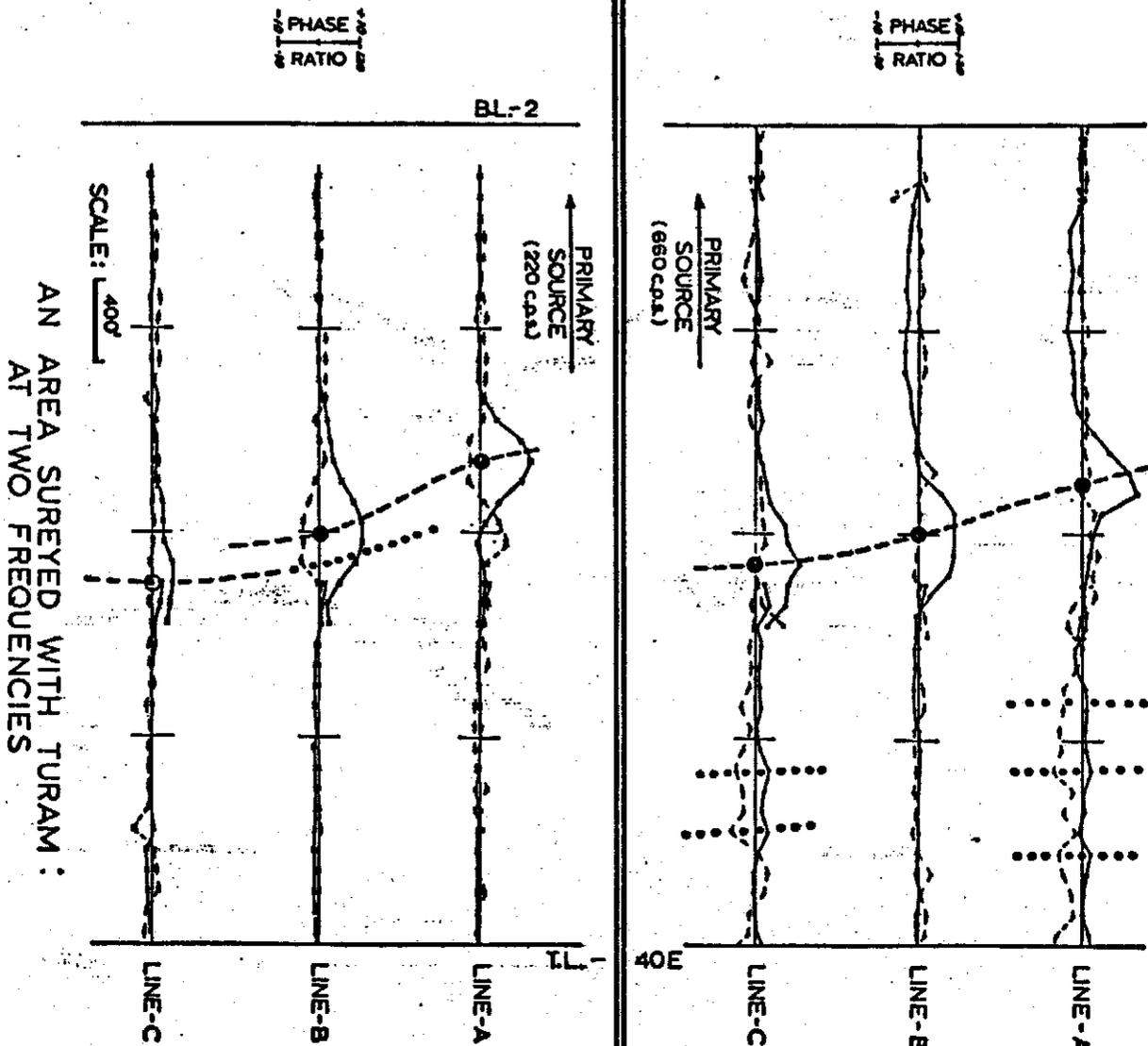
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CHANNEL 1
CHANNEL 2
CHANNEL 3
CHANNEL 4
CHANNEL 5
CHANNEL 6



INPUT AIRBORNE ELECTROMAGNETIC SURVEY

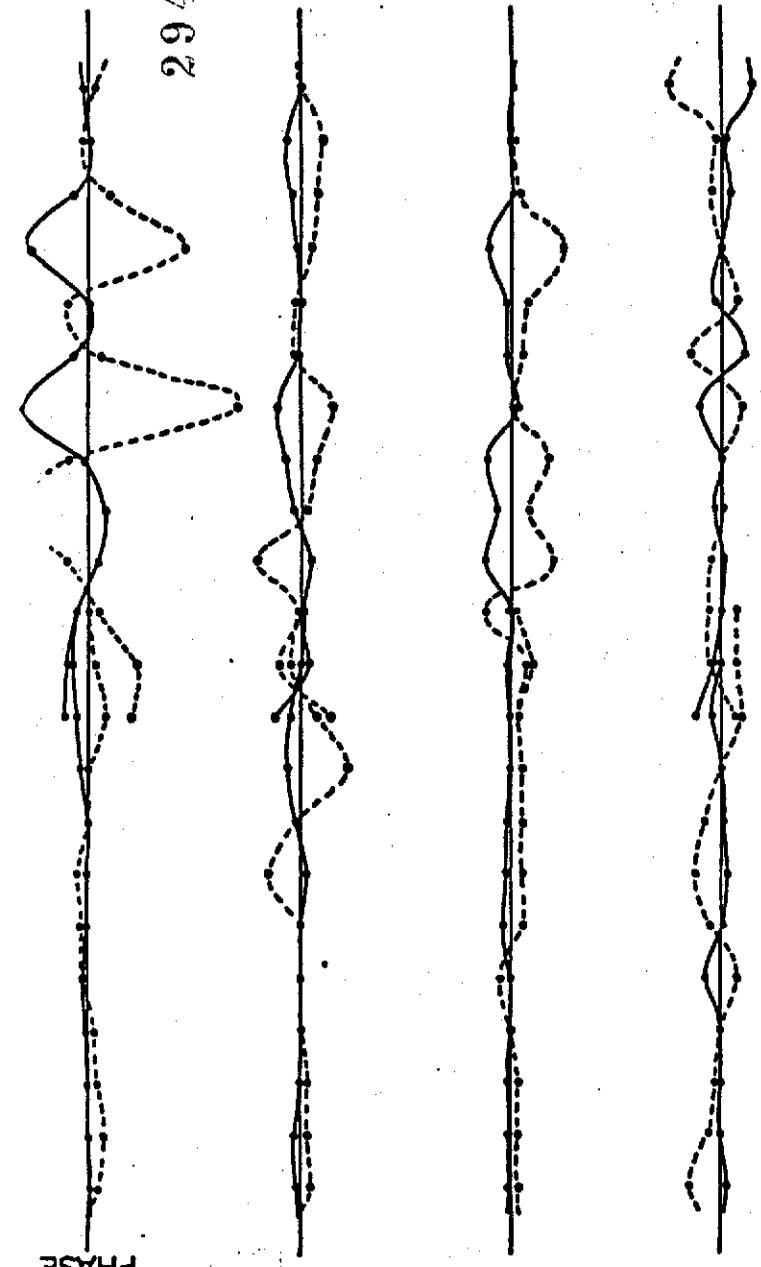
FIGURE 4.



AN AREA SUREYED WITH TURAM :
AT TWO FREQUENCIES

FIGURE 5.

5 cm



TURAM RESPONSE INTERPRETED AS OVERBURDEN

SCALE: 200 ft. (660 c.p.s.)

FIGURE 6.

5 cm

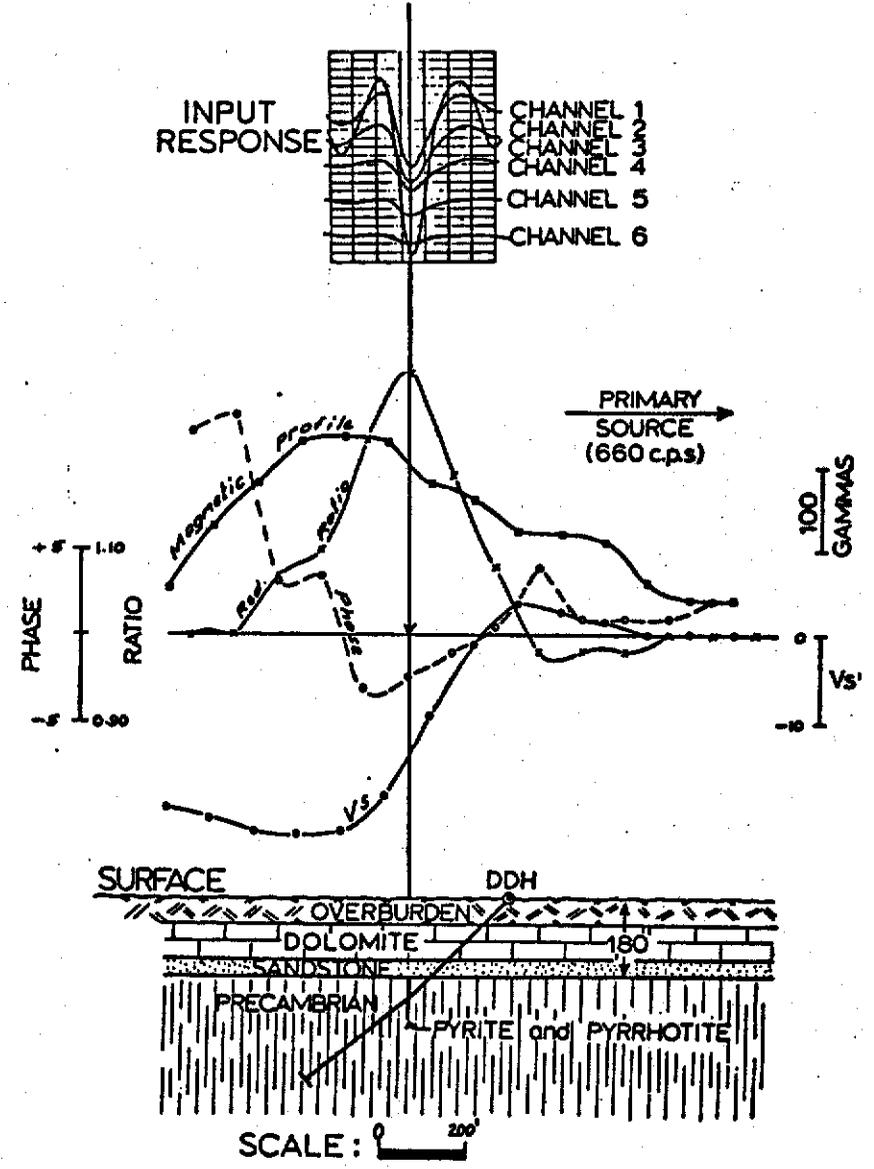


FIGURE 7

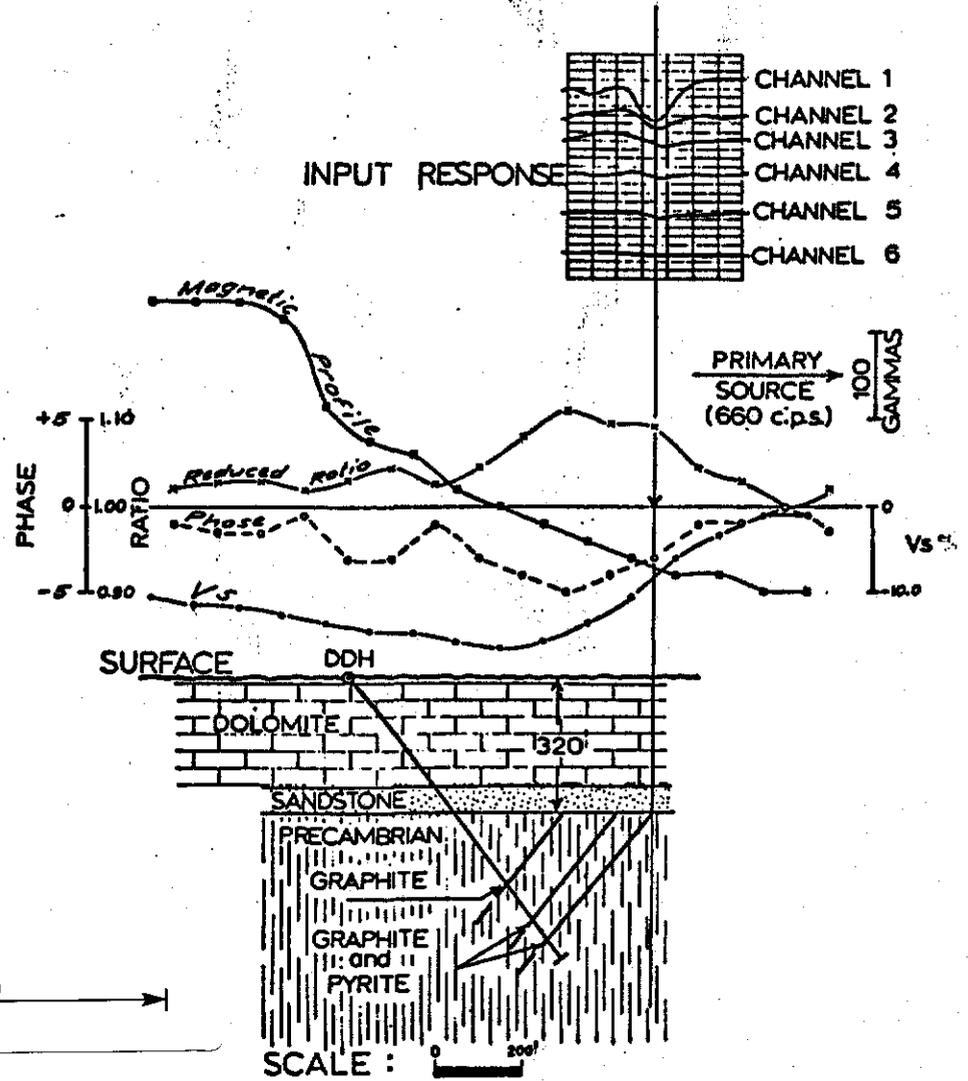
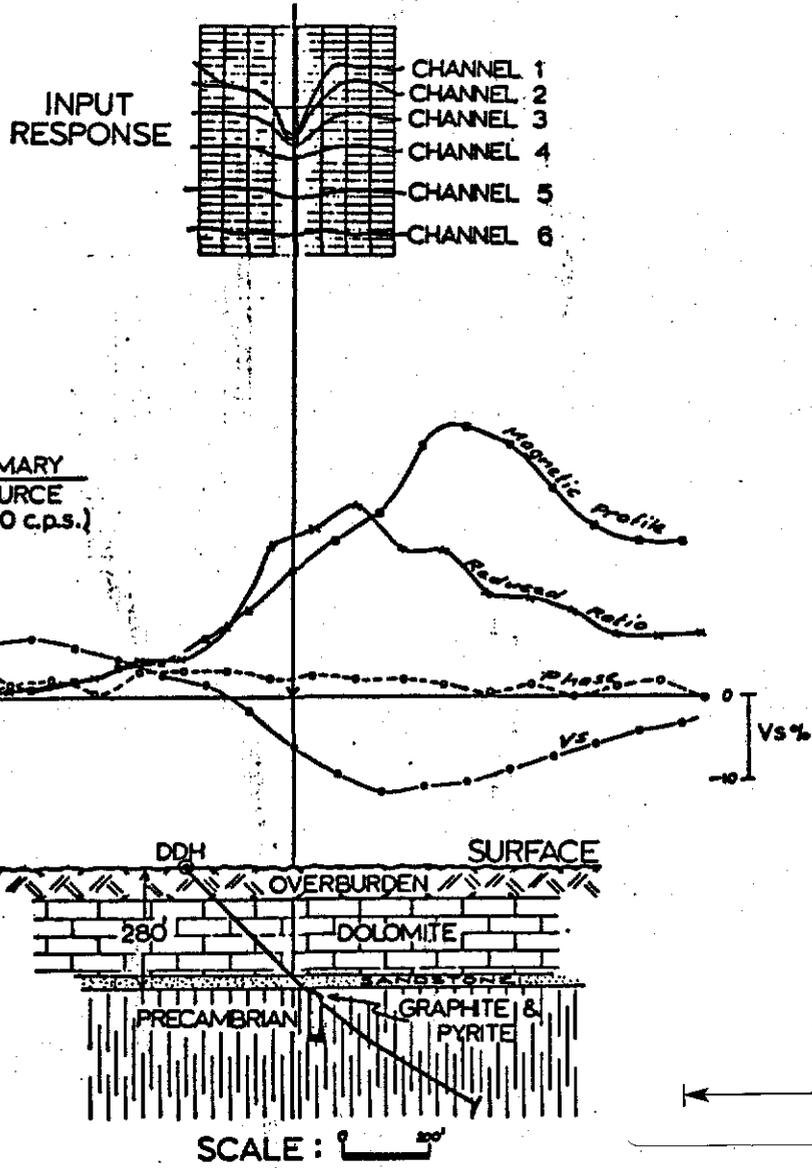


FIGURE 8.

294129

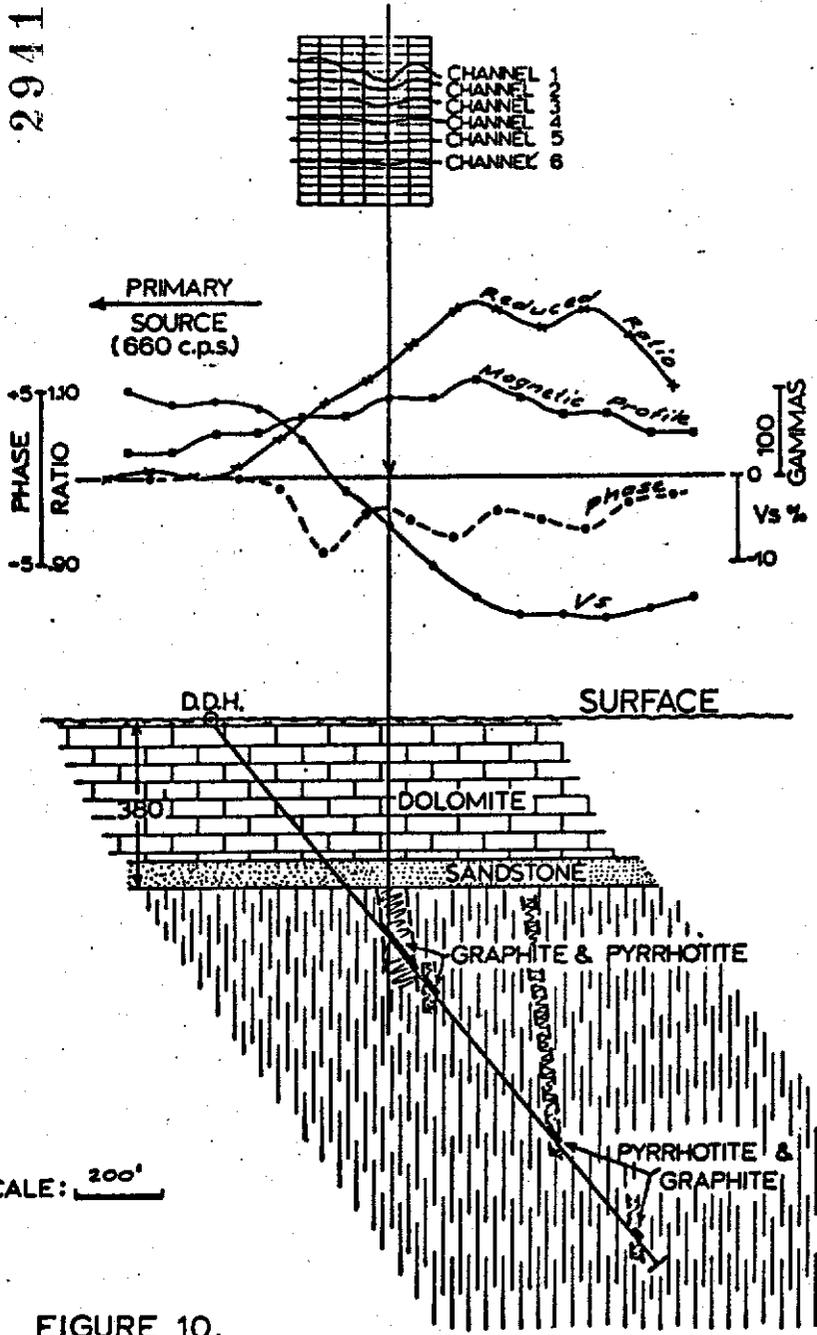


FIGURE 10.

TURAIR

A SCINTREX DEVELOPMENT
PATENTS PENDING IN ALL MAJOR COUNTRIES

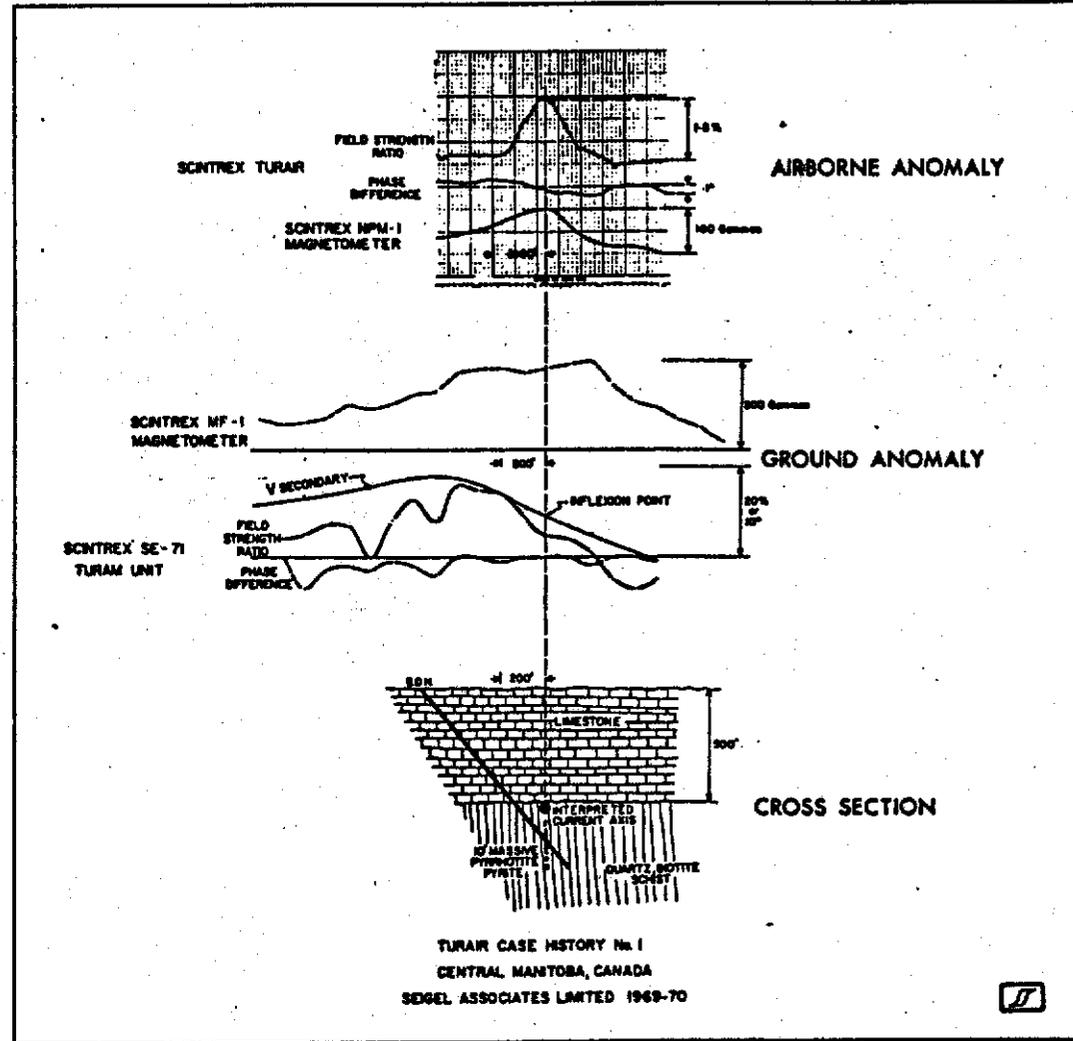


FIGURE 11.

5 cm

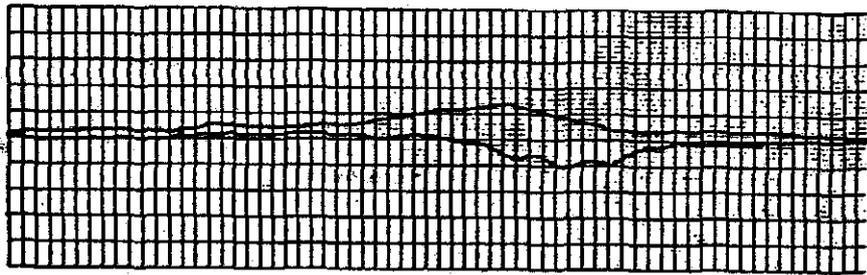
129

TURAIR

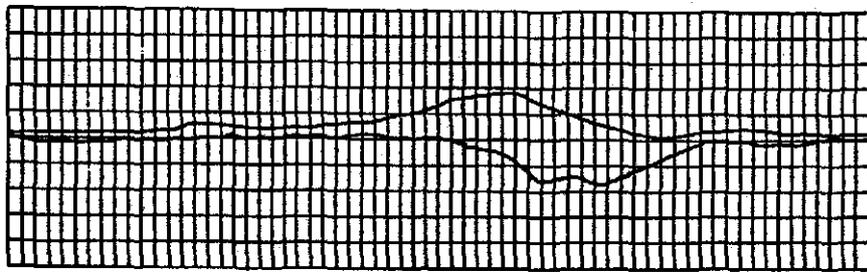
HIGH CLEARANCE

BIRD
HEIGHT

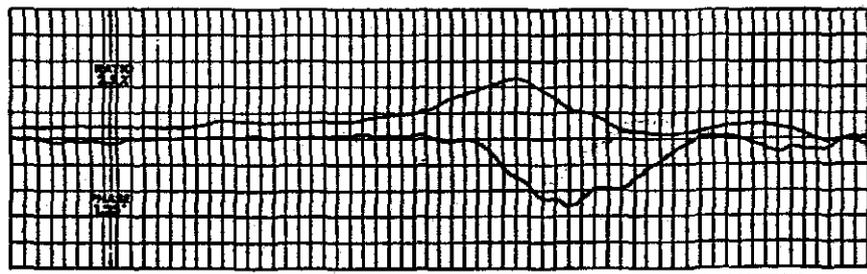
1400'



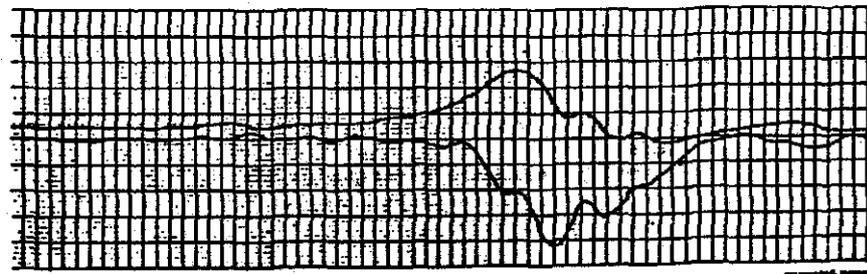
900'



700'



500'



137

Theory predicts that the fixed source Turair System is capable of much greater depth penetration than airborne electromagnetic systems which use moving sources. Altitude tests, wherein the free space distance between the receiver of an electromagnetic system and a given conductor is varied, are useful in indicating the maximum depth of burial at which the conductor might be detected. In practise, because bedrocks and overburden are always somewhat conductive, the depth of penetration is less than for free space conditions.

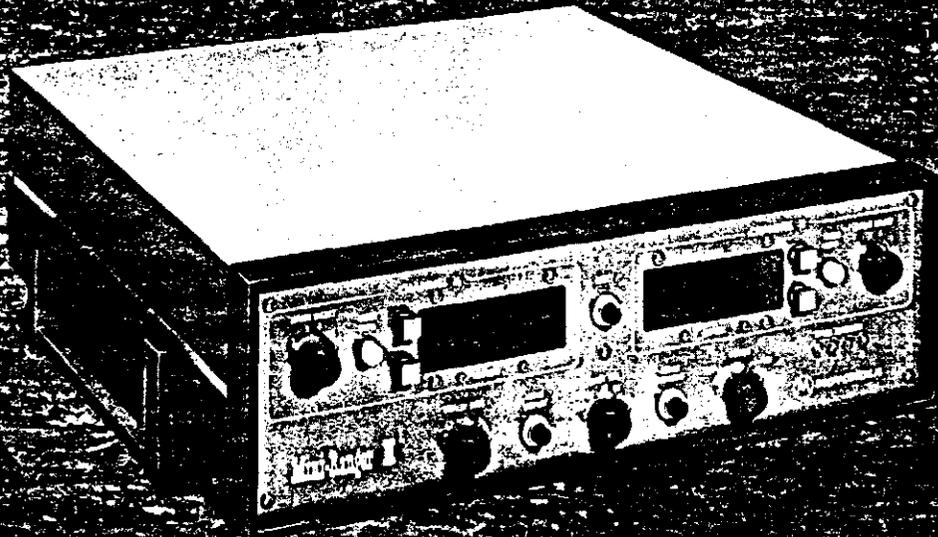
Although normal survey is about 200' the records shown here represent the 400 Hz responses of the Turair System flown at clearances ranging from 500' to 1400'. The conductor is banded, about 2500' in strike length and contains mainly pyrite, pyrrhotite and graphite. The conductivity-thickness product of the best part of the zone is 10 mhos and the overburden depth is less than 50'.

The anomaly is still discernable at 1400' clearance so that we may conclude that the Turair maximum (free space) detection depth of this conductor is in excess of 1400' (450 metres).

While no data are available for this conductor for other airborne electromagnetic systems, the free space detectability would fall far short of 1400'. For example, the theoretical free space detection depth for in-phase/quadrature systems would be between 300' and 400' depending upon coil spacing, frequency and noise level of the individual system.



motorola's
new



Mini-Ranger III

Meet the Mini-Ranger* III, Motorola's versatile new solution to the short-range positioning problem.

Like its field-proven predecessors, the Mini-Ranger III was designed to fill the need for a precise, cost-effective, short-range system for rapidly locating the position of a vessel, aircraft, or land vehicle.

The basic Mini-Ranger consists of a range console, receiver-transmitter, and omnidirectional antenna installed on the vessel or other mobile unit, and a pair of reference stations located at known ground or other fixed points up to 20 nautical miles away.

Incorporating dual-channel readouts and other new capabilities and options, the Mini-Ranger III is the outstanding performer in the low-cost radar positioning field.

The measured ranges to two reference stations are simultaneously and directly displayed in meters to a distance of 20 nautical miles with a probable accuracy of 3 meters. By conventional trilateration techniques, the operator can plot his precise position at any instant. In addition to this capability, the Mini-Ranger III provides a standard BCD output for operating peripheral devices, such as digital printers or computers.

The Mini-Ranger III can be installed in helicopters, airplanes, and land vehicles, as well as on any type of boat. A single system can be easily alternated between different types of vehicles. Operating at C-band, away from most radar frequencies, the system is virtually free from interference and the effects of atmospheric conditions.

HOW TO INSTALL

In a typical on-board installation, the range console is mounted in the pilot house, with the receiver-transmitter and omni antenna mounted as a unit to a mast or other high point above the boat's superstructure. Connecting the applied interconnecting and power source cables complete the installation, ordinarily in two hours or less.

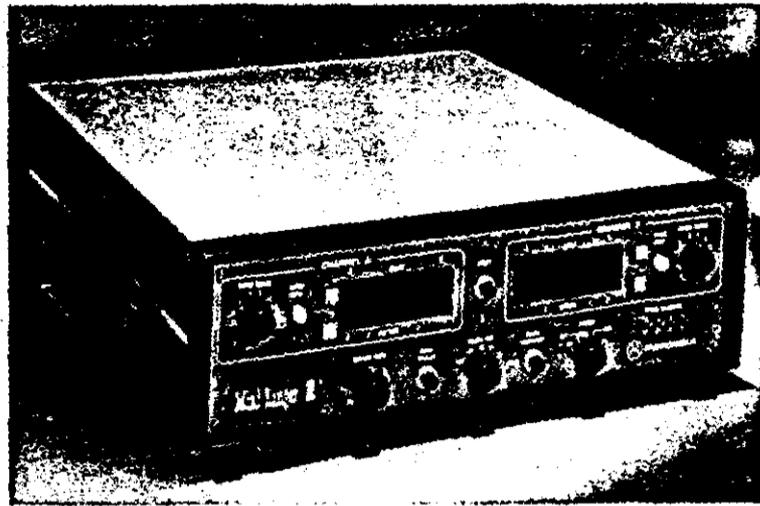
The compact reference stations can be set up and put into operation in minutes. Operating unattended, each reference station can function for a week on two 12-volt automobile batteries before recharging. Operation can be further extended by the use of a low-current module available as an option with the reference stations.

HOW TO OPERATE

The Mini-Ranger III is put into operation by turning the power switch to ON.

The reference stations are automatically selected by setting the Transponder Select switches on the range console to their preset codes. The return pulses from the reference stations are translated to range in meters and displayed directly, in digits, on the Range display. The Video Received lights indicate when the range display is updated.

Other controls and adjustments are available for "freezing" and "commanding" the displays, and for other special applications, including calibration. For example, the Hold Display button is depressed when the operator wishes to freeze, or retain, the last numerals on the displays so that they can be recorded or plotted. A back panel connection



allows this to be done automatically when peripheral equipment is being used, so that the range numbers do not change during the reading or recording time.

ECONOMICAL TO MAINTAIN

Solid-state construction throughout assures high reliability. Modular construction, with stripline interconnects that terminate in IC plugs, are used to facilitate repair and minimize down-time when trouble does occur.

STANDARD FEATURES

- Solid-state construction including LED displays provides ease in maintenance, reduced spare costs, and high reliability.
- Front panel calibration for each of four reference stations.
- Operator selection of reference station's range to be displayed.
- Range display can be "frozen" for accurate manual recording of display.
- Adjustable display update from 1 per second to 1 every 10 seconds.
- BCD output coded for identification of four reference station ranges.
- Updated range-on-command information available to operator as immediate display.
- 115 Vac or, 230 Vac, 50 to 400 Hz input power.
- Long life magnetron transmitting tubes.



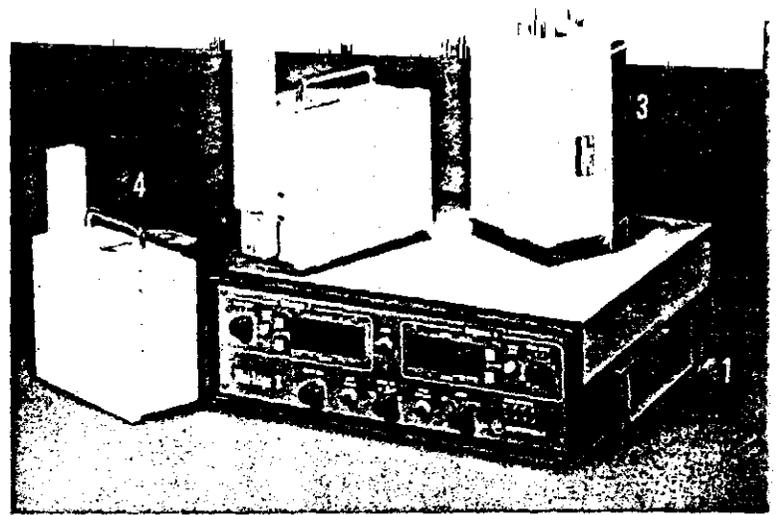
40 Nautical Mile Range. Requires high gain antennas for the reference stations. The same accuracy is retained, i.e., a probable accuracy of ± 3 meters.

Increased Accuracy. Requires addition of signal strength indicator. Reports of 1 meter accuracy have been received with this option. The signal strength indication is available as BCD data.

Four-Code Commutation. Requires additional circuit card and display code lamps. Automatic interrogation of four reference stations in sequence is performed.

Range Averaging. The standard system averages five valid replies. The option averages a selectable number of replies (10, 20, 40 or 75) to provide more repeatable range readings.

Multi-User. Allows more than one mobile unit to operate with a common set of reference stations.

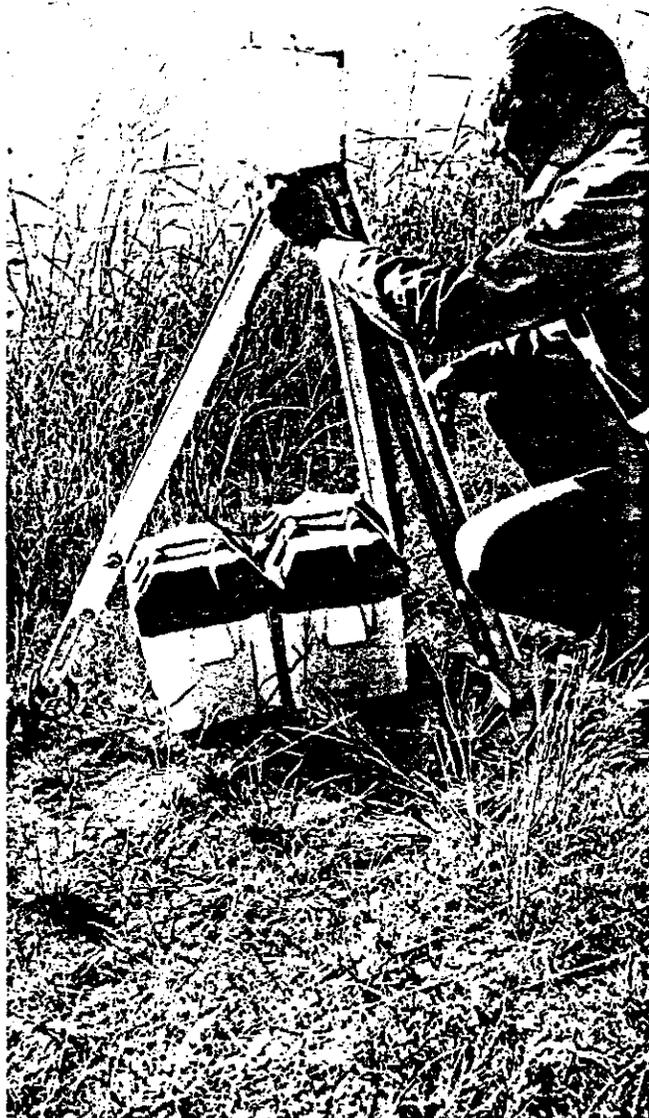


1. Range Console

2. Omni Antenna

3. Receiver-Transmitter

4. Reference Stations



Power Sources. The standard 115-volt, 50 to 400 Hz, power supply can be readily converted to 230-volt, 50 to 400 Hz operation by positioning a switch on the power supply module. By merely interchanging the module, 24-volt dc operation can be achieved.

X-Band Operation. This option allows the customer to use X-band transponders he may already own. Also, by using a rotating scanner antenna, operating ranges of 50 to 100 nautical miles may be achieved.

19-Inch Rack Adaptor. A kit is designed to mount the range console in 19-inch racks.

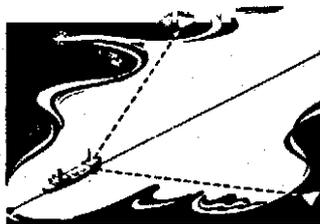
Splashproof Transit Case. Designed to mount the 19-inch rack panel configuration of the range console, the basic display can be supplied in a splashproof transit case.

Range Measurement Units. The standard range indication is in meters. Optional range readout units are available for yards or feet.

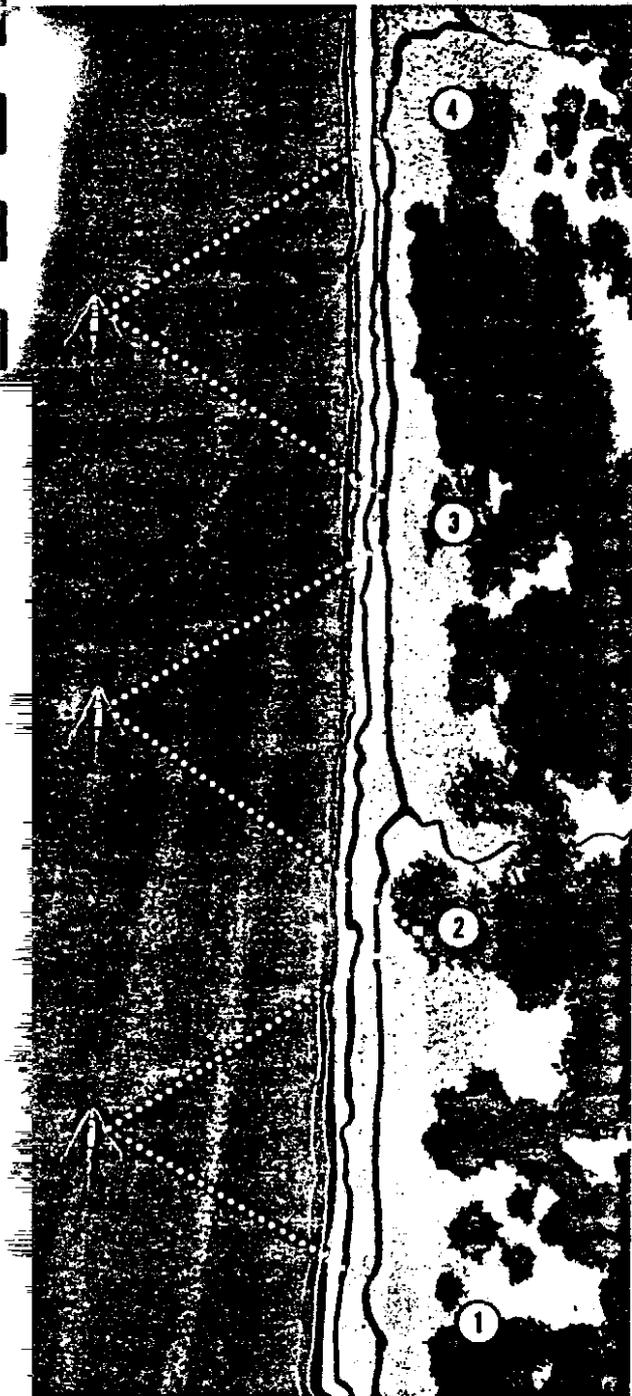
Built-In Test Evaluation (BITE). This is a readily installed feature for confidence test of the range console.

The Mini-Ranger III was designed to fill a gap in the short-range positioning spectrum — to answer a need in channel surveying, geophysical exploration, estuarine studies, harbor engineering, and related applications. Many of its features and options were suggested by users of Motorola's previous Mini-Ranger and Range Positioning Systems. In addition to innumerable satisfied commercial users of the Mini-Ranger are the following U. S. Government activities and services:

- National Oceanographic and Atmospheric Administration
- United States Navy
- U. S. Army Corps of Engineers
- Argonne Laboratories



For surveying a coastline or river, up to four reference stations can be installed. The survey boat begins its run using the first two stations. When reaching the maximum range of the first station, that channel is switched to the third station. As the run proceeds, stations three and four are used. Manual switching can be eliminated by use of the four-code commutation option.



- Frequency Range 5400 to 5600 MHz
- Range (line of sight) 20 nautical miles
(20-100nm with available options).
- Probable Range Error 3 meters at 20 nautical miles
- Coding Four selectable codes utilizing pulse spacing
- Range Readout Units Meters, standard
Yards, optional
Feet, optional
- Range Readout Selection Channels A and B (dual simultaneous readout)
- Range Output to Peripherals BCD, TTL, +8421 parallel
- Operating Voltage Range Console 115/230 volt, 50-400 Hz
24-30 vdc (plug-in option)
- Reference Stations 24-30 vdc
- Antennas
Mini-Ranger III Omni-directional, 25° elevation
- Reference Stations 13 dB Sector type, 75° azimuth, 15° elevation
- Operating Temperature Ranges
Range Console 0 to +50° C
Receiver-Transmitter -40 to +60° C
Reference Stations -54 to +71° C

Component	Size (in.)	Weight	
		DC	AC lbs
Range Console (Table Mount)	17x18x5.5	28	32
Transit Case for Range Console	21x18x6	21 lbs	
Receiver-Transmitter	6.25x9.25x6.5	5 lbs w/brkts	
Reference Station	5.5x10.25x6.5	5 lbs less ant.	

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