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REPORT NO. 705

DIGHEM^{II} SURVEY

OF

FOLLDAL AREA, NORWAY

FOR

FOLLDAL VERK A/S

BY

DIGHEM LIMITED

TORONTO, CANADA
JANUARY 29, 1982

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SUMMARY

A DIGHEM^{II} electromagnetic/resistivity/magnetic survey totalling 51 line-km was flown in the Folldal area of Norway in September, 1981.

The environment within the survey area was generally resistive providing good contrast with about ten linear bedrock conductors detected by the survey. All the conductors trend in a northeasterly direction. This trend parallels the magnetic structure of the area and several of the conductors show marked magnetic correlation.

LOCATION MAP

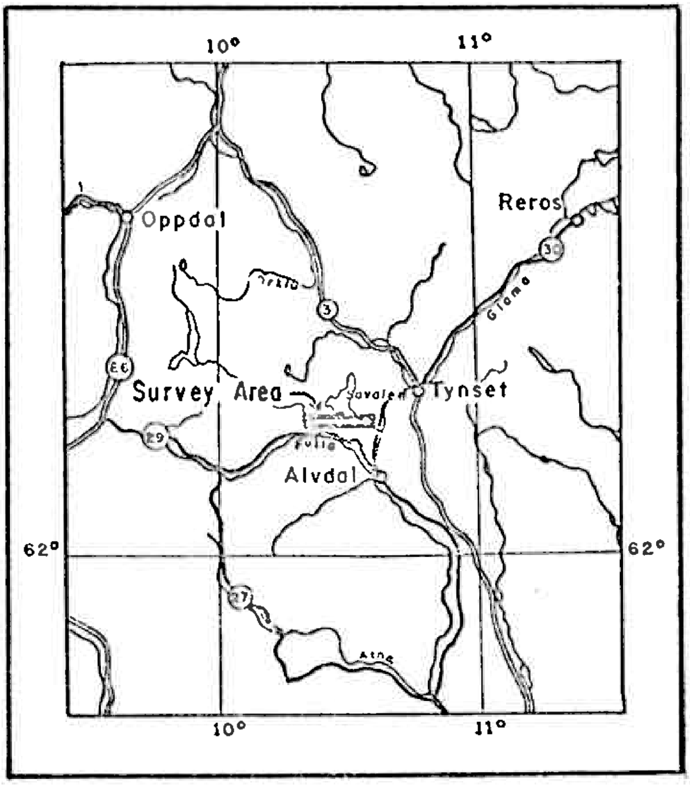

Figure 1 Scale 1:1,500,000

The Survey Area

CONTENTS

INTRODUCTION

A DIGHEM^{II} survey of 51 line-km was flown with a 250 m line-spacing for the Folldal Verk A/S on September 13, 1981 in the Folldal area, Norway (Figure 1).

The Lama I-VIOC turbine helicopter flew with an average groundspeed of 110 km/h and EM bird height of 35 m. Ancillary equipment consisted of a Sonotek PMH-5010 magnetometer with its bird at an average height of 50 m, a Sperry radio altimeter, Geocam sequence camera, Barringer 8-channel hot pen analog recorder, and a Sonotek SDS 1200 digital data acquisition system with a DigiData DPS 1100 9-track 800-bpi magnetic tape recorder. The analog equipment recorded four channels of EM data at approximately 900 Hz, two ambient EM noise channels (for the coaxial and coplanar receivers), and one channel each of magnetics and radio altitude. The digital equipment recorded the EM data with a sensitivity of 0.20 ppm/bit and the magnetic field to one gamma/bit.

Appendix A provides details on the data channels, their respective noise levels, and the data reduction procedure. The quoted noise levels are generally valid for wind speeds up to 35 km/h. Higher winds may cause the system to be grounded because excessive bird swinging produces difficulties in flying the helicopter. The swinging results from the 5 m^2 of area which is presented by the bird to broadside gusts. The DIGHEM system nevertheless can be flown under wind conditions that seriously degrade other AEM systems.

ELECTROMAGNETICS

DIGHEM electromagnetic responses fall into two general classes, discrete and broad. The discrete class consists of sharp, well defined anomalies from discrete conductors such as sulfide lenses and steeply dipping sheets of graphite and sulfides. The broad class consists of wide anomalies from conductors having a large horizontal surface such as flatly dipping graphite or sulfide sheets, saline water-saturated sedimentary formations, conductive overburden and rock, and geothermal zones. A vertical conductive slab with a width of 100 m would straddle these two classes.

The vertical sheet (half plane) is the most common model used for the analysis of discrete conductors. All anomalies plotted on the electromagnetic map are interpreted according to this model. The following section entitled Discrete conductor analysis describes this model in detail, including the effect of using it on anomalies caused by broad conductors such as conductive overburden.

The conductive earth (half space) model is suitable for broad conductors. Resistivity contour maps result from the use of this model. A later section entitled Resistivity mapping describes the method further, including the effect of using it on anomalies caused by discrete conductors such as sulfide bodies.

Discrete conductor analysis

The EM anomalies appearing on the electromagnetic map are interpreted by computer to give the conductance (i.e., conductivity-thickness product) in mhos of a vertical sheet model. DIGHEM anomalies are divided into six grades of conductance, as shown in Table I. The conductance in mhos is the reciprocal of resistance in ohms.

Table I. EM Anomaly Grades

Anomaly Grade	Mho Range
6	≥ 100
5	50 - 99
4	20 - 49
3	10 - 19
2	5 - 9
1	< 5

The mho value is a geological parameter because it is a characteristic of the conductor alone; it generally is independent of frequency, and of flying height or depth of burial apart from the averaging over a greater portion of the conductor as height increases.[1] Small anomalies from deeply buried strong conductors are not confused with small anomalies from shallow weak conductors because the former will have larger mho values.

Conductive overburden generally produces broad EM responses which are not plotted on the EM maps. However, patchy conductive overburden in otherwise resistive areas can yield discrete-like anomalies with a conductance grade (cf. Table I) of 1, or even of 2 for conducting clays which have resistivities as low as 50 ohm-m. In areas where ground resistivities can be below 1 ohm-m, anomalies caused by weathering variations and similar causes can have any conductance grade. The anomaly shapes from the multiple coils often allow such surface conductors to be recognized, and these are indicated by the letter S on the map. The remaining anomalies in such areas could be bedrock conductors. The higher grades indicate increasingly higher conductances. Examples: DIGHEM's New Insco copper discovery (Noranda, Quebec, Canada) yielded a grade 4 anomaly, as did the neighbouring copper-zinc Magusi River ore body; Mattabi (copper-zinc, Sturgeon Lake, Ontario, Canada) and Whistle (nickel, Sudbury, Ontario, Canada) gave grade 5; and DIGHEM's Montcalm nickel-copper discovery (Timmins, Ontario, Canada) yielded a grade 6 anomaly. Graphite and sulfides can span all grades but, in any particular survey area, field work may show that the different grades indicate different types of conductors.

Strong conductors (i.e., grades 5 and 6) are characteristic of massive sulfides or graphite. Moderate conductors (grades 3 and 4) typically reflect sulfides of a less massive character or graphite, while weak bedrock conductors (grades 1 and 2) can signify poorly connected graphite or heavily disseminated sulfides. Grade 1 conductors may not respond to ground EM equipment using frequencies less than 2000 Hz.

The presence of sphalerite or gangue can result in ore deposits having weak to moderate conductances. As an example, the three million ton lead-zinc deposit of Restigouche Mining Corporation near Bathurst, New Brunswick, Canada, yielded a well defined grade 1 conductor. The 10 percent by volume of sphalerite occurs as a coating around the fine grained massive pyrite, thereby inhibiting electrical conduction.

Faults, fractures and shear zones may produce anomalies which typically have low conductances (e.g., grades 1 and 2). Conductive rock formations can yield anomalies of any conductance grade. The conductive materials in such rock formations can be salt water, weathered products such as clays, original depositional clays, and carbonaceous material.

On the electromagnetic map, the actual mho value and a letter are plotted beside the EM grade symbol. The letter is the anomaly identifier. The horizontal rows of dots, beside each anomaly symbol, indicate the anomaly amplitude on the flight record. The vertical column of dots gives the estimated depth. In areas where anomalies are crowded, the identifiers, dots and mho values may be obliterated. The EM grade symbols, however, will always be discernible, and the obliterated information can be obtained from the anomaly listing appended to this report.

The purpose of indicating the anomaly amplitude by dots is to provide an estimate of the reliability of the conductance calculation. Thus, a conductance value obtained from a large ppm anomaly (3 or 4 dots) will tend to be accurate whereas one obtained from a small ppm anomaly (no dots) could be quite inaccurate. The absence of amplitude dots indicates that the anomaly from the coaxial coil-pair is 5 ppm or less on both the inphase and quadrature channels. Such small anomalies could reflect a weak conductor at the surface or a stronger conductor at depth. The mho value and depth estimate will illustrate which of these possibilities fits the recorded data best.

Flight line deviations occasionally yield cases where two anomalies, having similar mho values but dramatically different depth estimates, occur close together on the same conductor. Such examples illustrate the reliability of the conductance measurement while showing that the depth estimate can be unreliable. There are a number of factors which can produce an error in the depth estimate, including the averaging of topographic variations by the altimeter, overlying conductive overburden, and the location and attitude of the conductor relative to the flight line. Conductor location and attitude can provide an erroneous depth estimate because the stronger part of the conductor may be deeper or to one side of the flight line, or because it has a shallow dip. A heavy tree cover can also produce errors in depth estimates. This is because the depth estimate is computed as the distance of bird from conductor, minus the altimeter reading. The altimeter can lock on the top of a dense forest canopy. This situation yields an erroneously large depth estimate but does not affect the conductance estimate.

Dip symbols are used to indicate the direction of dip of conductors. These symbols are used only when the anomaly shapes are unambiguous, which usually requires a fairly resistive environment.

A further interpretation is presented on the EM map by means of the line-to-line correlation of anomalies, which is based on a comparison of anomaly shapes on adjacent lines. This provides conductor axes which may define the geological structure over portions of the survey area. The absence of conductor axes in an area implies that anomalies could not be correlated from line to line with reasonable confidence.

DIGHEM electromagnetic maps are designed to provide a correct impression of conductor quality by means of the conductance grade symbols. The symbols can stand alone with geology when planning a follow-up program. The actual mho values are plotted for those who wish quantitative data. The anomaly ppm and depth are indicated by inconspicuous dots which should not distract from the conductor patterns, while being helpful to those who wish this information. The map provides an interpretation of conductors in terms of length, strike direction, conductance, depth, thickness (see below), and dip. The accuracy is comparable to an interpretation from a high quality ground EM survey having the same line spacing.

An EM anomaly list attached to each survey report provides a tabulation of anomalies in ppm, and in mhos and estimated depth for the vertical sheet model. The EM anomaly list also shows the conductance in mhos and the depth for a thin horizontal sheet (whole plane) model, but only the vertical sheet parameters appear on the EM map. The horizontal sheet model is suitable for a flatly dipping thin bedrock conductor such as a sulfide sheet having a thickness less than 15 m. The list also shows the resistivity and depth for a conductive earth (half space) model, which is suitable for thicker slabs such as thick conductive overburden. In the EM anomaly list, a depth value of zero for the conductive earth model, in an area of thick cover, warns that the anomaly may be caused by conductive overburden.

Since discrete bodies normally are the targets of EM surveys, local base (or zero) levels are used to compute local anomaly amplitudes. This contrasts with the use of true zero levels which are used to compute true EM amplitudes. Local anomaly amplitudes are shown in the EM anomaly list and these are used to compute the vertical sheet parameters of conductance and depth. Not shown in the EM anomaly list are the true amplitudes which are used to compute the horizontal sheet and conductive earth parameters.

X-type electromagnetic responses

DIGHEM^{II} maps contain x-type EM responses in addition to EM anomalies. An x-type response is below the noise threshold of 3 ppm, and reflects one of the following: a weak conductor near the surface, a strong conductor at depth (e.g., 100 to 120 m below surface) or to one side of a flight line, or aerodynamic noise. Those responses that have the appearance of valid bedrock anomalies on the flight profiles are mentioned in the report. The others should not be followed up unless their locations are of considerable geological interest.

The thickness parameter

DIGHEM^{II} can provide an indication of the thickness of a steeply dipping conductor. The ratio of the anomaly amplitude of channel 24/channel 22 generally increases as the apparent thickness increases, i.e., the thickness in the horizontal plane along the flight line. This thickness is equal to the conductor width if the conductor dips at 90 degrees and strikes at right angles to the flight line. This report refers to a conductor as thin when the thickness is likely to be less than 3 m, and thick when in excess of 10 m. In base metal exploration applications, thick conductors can be high priority targets because most massive sulfide ore bodies are thick, whereas non-economic bedrock conductors are usually thin. An estimate of thickness cannot be obtained when the strike of the conductor is subparallel to the flight line, when the conductor has a shallow dip, when the anomaly amplitudes are small, or when the resistivity of the environment is below 100 ohm-m.

Resistivity mapping

Areas of widespread conductivity are commonly encountered during surveys. In such areas, anomalies can be generated by decreases of only 5 m in survey altitude as well as by increases in conductivity. The typical flight record in conductive areas is characterized by inphase and quadrature channels which are continuously active; local peaks reflect either increases in conductivity of the earth or decreases in survey altitude. For such conductive areas, apparent resistivity profiles and contour maps are necessary for the interpretation of the airborne data. The advantage of the resistivity parameter is that anomalies caused by altitude changes are virtually eliminated, so the resistivity data reflect only those anomalies caused by conductivity changes. This helps the interpreter to differentiate between conductive trends in the bedrock and those patterns typical of conductive overburden. Discrete conductors will generally appear as narrow lows on the contour map and broad conductors will appear as wide lows.

Channel 40 (see Appendix) and the resistivity contour map present the apparent resistivity using the so-called pseudo-layer (or buried) half space model defined in Fraser (1978)[2]. This model consists of a resistive layer overlying a conductive half space. Channel 41 gives the apparent depth below surface of the conductive material.

The apparent depth is simply the apparent thickness of the overlying resistive layer. The apparent depth (or thickness) parameter will be positive when the upper layer is more resistive than the underlying material, in which case the apparent depth may be quite close to the true depth.

The apparent depth will be negative when the upper layer is more conductive than the underlying material, and will be zero when a homogeneous half space exists. The apparent depth parameter must be interpreted cautiously because it will contain any errors which may exist in the measured altitude of the EM bird (e.g., as caused by a dense tree cover). The inputs to the resistivity algorithm are the inphase and quadrature components of the coplanar coil-pair. The outputs are the apparent resistivity of the conductive half space (the source) and the sensor-source distance. The flying height is not an input variable, and the output resistivity and sensor-source distance are independent of the flying height. The apparent depth, discussed above, is simply the sensor-source distance minus the measured altitude or flying height. Consequently, errors in the measured altitude will affect the apparent depth parameter but not the apparent resistivity parameter.

The apparent depth parameter is a useful indicator of simple layering in areas lacking a heavy tree cover. The DIGHEM^{II} system has been flown for the purpose of permafrost mapping, where positive apparent depths were used as a measure of permafrost thickness. However, little quantitative use has been made of negative apparent depths because the absolute value of the negative depth is not a measure of the thickness of the conductive upper layer and, therefore, is not meaningful physically. Qualitatively, a negative apparent depth estimate usually shows that the EM anomaly is caused by conductive overburden. Consequently, the apparent depth channel 41 can be of significant help in distinguishing between overburden and bedrock conductors.

Interpretation in conductive environments

Environments having background resistivities below 30 ohm-m cause all airborne EM systems to yield very large responses from the conductive ground. This usually prohibits the recognition of bedrock conductors. The processing of DIGHEM^{II} data, however, produces six channels which contribute significantly to the recognition of bedrock conductors. These are the inphase and quadrature difference channels (#33 and 34), the resistivity and depth channels (#40 and 41), the conductivity contrast channel (#42), and the product of the conductivity contrast and depth contrast channels (#44).

The EM difference channels (33 and 34) eliminate up to 99% of the response of conductive ground, leaving responses from bedrock conductors, cultural features (e.g., telephone lines, fences, etc.) and edge effects. An edge effect arises when the conductivity of the ground suddenly changes, and this is a source of geologic noise. While edge effects yield anomalies on the EM difference channels, they do not produce resistivity anomalies. Consequently, the resistivity channel aids in eliminating anomalies due to edge effects. On the other hand, resistivity anomalies will coincide with the most highly conductive sections of conductive ground, and this is another source of geologic noise. The recognition of a bedrock conductor in a highly conductive environment therefore is based on the anomalous responses of the two difference channels (33 and 34) and the resistivity channel (40). The most favourable situation is where anomalies coincide on all three channels.

Channel 41, which is the apparent depth to the conductive material, also helps determine whether a conductive response arises from surficial material or from a conductive zone in the bedrock. When this channel rides above the zero level on the electrostatic chart paper (i.e., it is negative), it implies that the EM and resistivity profiles are responding primarily to a conductive upper layer, i.e., conductive overburden. If channel 41 is below the zero level, it indicates that a resistive upper layer exists, and this usually implies the existence of a bedrock conductor.

The conductivity contrast channel (#42) highlights local resistivity lows. This channel, and the depth contrast (#43), both yield positive anomalies from conductors at depth. Channel 44 is the multiple 42*43 and it is highly sensitive to conductors at depth. The interpretation of channels 42 and 44 has to be done carefully, however, because they may also respond in a similar fashion to a local thickening in the conductive cover as, for example, over a buried river channel. Channels 42 and 43 are derived from channels 40 and 41 using digital filter techniques.

Channels 35, 36 and 42 are the anomaly recognition functions. They are used to trigger the conductance channel 37 which identifies discrete conductors. In highly conducting environments, channel 36 is deactivated because it is subject to corruption by highly conductive earth signals. Some of the automatically selected anomalies (channel 37) are discarded by the human interpreter. The automatic selection algorithm is intentionally oversensitive to assure that no meaningful responses are missed. The interpreter then classifies the anomalies according to their source and eliminates those that are not substantiated by the data, such as those arising from geologic or aerodynamic noise.

The resistivity map often yields more useful information on conductivity distributions than the EM map. In comparing the EM and resistivity maps, keep in mind the following:

(a) The resistivity map portrays the absolute value of the earth's resistivity.

(b) The EM map portrays anomalies in the earth's resistivity. An anomaly by definition is a change from the norm and so the EM map displays anomalies, (i) over narrow, conductive bodies and (ii) over the boundary zone between two wide formations of differing conductivity.

The resistivity map might be likened to a total field map and the EM map to a horizontal gradient in the direction of flight[3]. Because gradient maps are usually more sensitive than total field maps, the EM map therefore is to be preferred in resistive areas. However, in conductive areas, the absolute character of the resistivity map usually causes it to be more useful than the EM map.

Reduction of geologic noise

Geologic noise refers to unwanted geophysical responses. For purposes of airborne EM surveying, geologic noise refers to EM responses caused by conductive overburden and magnetic permeability. It was mentioned above that the EM difference channels (i.e., channel 33 for inphase and 34 for quadrature) tend to eliminate the response of conductive overburden. This marked a unique development in airborne EM technology, as DIGHEM^{II} is the only EM system which yields channels having an exceptionally high degree of immunity to conductive overburden.

Magnetite produces a form of geological noise on the inphase channels of all EM systems. Rocks containing less than 1% magnetite can yield negative inphase anomalies caused by magnetic permeability. When magnetite is widely distributed throughout a survey area, the inphase EM channels may continuously rise and fall reflecting variations in the magnetite percentage, flying height, and overburden thickness. This can lead to difficulties in recognizing deeply buried bedrock conductors, particularly if conductive overburden also exists. However, the response of broadly distributed magnetite generally vanishes on the inphase difference channel 33. This feature can be a significant aid in the recognition of conductors which occur in rocks containing accessory magnetite.

EM magnetite mapping

The information content of DIGHEM^{II} data consists of a combination of conductive eddy current response and magnetic permeability response. The secondary field resulting from conductive eddy current flow is frequency-dependent and consists of both inphase and quadrature components, which are positive in sign. On the other hand, the secondary field resulting from magnetic permeability is independent of frequency and consists of only an inphase component which is negative in sign. When magnetic permeability manifests itself by decreasing the measured amount of positive inphase, its presence may be difficult to recognize. However, when it manifests itself by yielding a negative inphase anomaly (e.g., in the absence of eddy current flow), its presence is assured. In this latter case, the negative component can be used to estimate the percent magnetite content.

A magnetite mapping technique was developed for the coplanar coil-pair of DIGHEM^{II}. The technique yields channel 50 which displays apparent weight percent magnetite according to a homogeneous half space model. The method can be complementary to magnetometer mapping in certain cases. Compared to magnetometry, it is far less sensitive but is more able to resolve closely spaced magnetite zones, as well as providing an estimate of the amount of magnetite in the rock. The method is sensitive to 1/4% magnetite by weight when the EM sensor is at a height of 30 m above a magnetitic half space. It can individually resolve steeply dipping narrow magnetite-rich bands which are separated by 60 m.

The EM magnetite mapping technique provides estimates of magnetite content which are usually correct within a factor of 2 when the magnetite is fairly uniformly distributed. EM magnetite maps can be generated when magnetic permeability is evident as indicated by anomalies in channel 50.

The EM magnetite algorithm is basically quite simple because a linear relationship exists between volume percent magnetite and the negative inphase response in ppm. This linear relationship is true for a fixed survey altitude when demagnetization effects are disregarded and when a fixed susceptibility-volume percent relationship is assumed. The technique in practice involves, first, correcting the actual EM response for variations in flying altitude and, second, calibrating the negative inphase ppms in terms of volume percent magnetite.

EM magnetite mapping provides another method of airborne geologic mapping. It thus joins resistivity mapping, magnetometer mapping, spectrometry, photogeology, etc., as a possible means by which geologic information can be obtained from airborne techniques. It is not nearly as useful in the general sense as the other airborne mapping techniques, but can be of value in cases where the magnetite content gives an indication of lithology.

Like magnetometry, the EM magnetite method maps only bedrock features, provided that the overburden is characterized by a general lack of magnetite. This contrasts with resistivity mapping which portrays the combined effect of bedrock and overburden.

MAGNETICS

The existence of a magnetic correlation with an EM anomaly is indicated directly on the EM map. An EM anomaly with magnetic correlation has a greater likelihood of being produced by sulfides than one that is non-magnetic. However, sulfide ore bodies may be non-magnetic (e.g., the Kidd Creek deposit near Timmins, Ontario, Canada) as well as magnetic (e.g., the Mattabi deposit near Sturgeon Lake, Ontario).

The magnetometer data are digitally recorded in the aircraft to an accuracy of one gamma. The digital tape is processed by computer to yield a standard total field magnetic map which is usually contoured at 25 gamma intervals. The magnetic data also are treated mathematically to enhance the magnetic response of the near-surface geology, and an enhanced magnetic map is produced with a 100 gamma contour interval. The response of the enhancement operator in the frequency domain is shown in Figure 2. The 100 gamma contour interval is equivalent to a 5 gamma interval for the passband components of the airborne data. This is because these components are amplified 20 times by the operator of Figure 2.

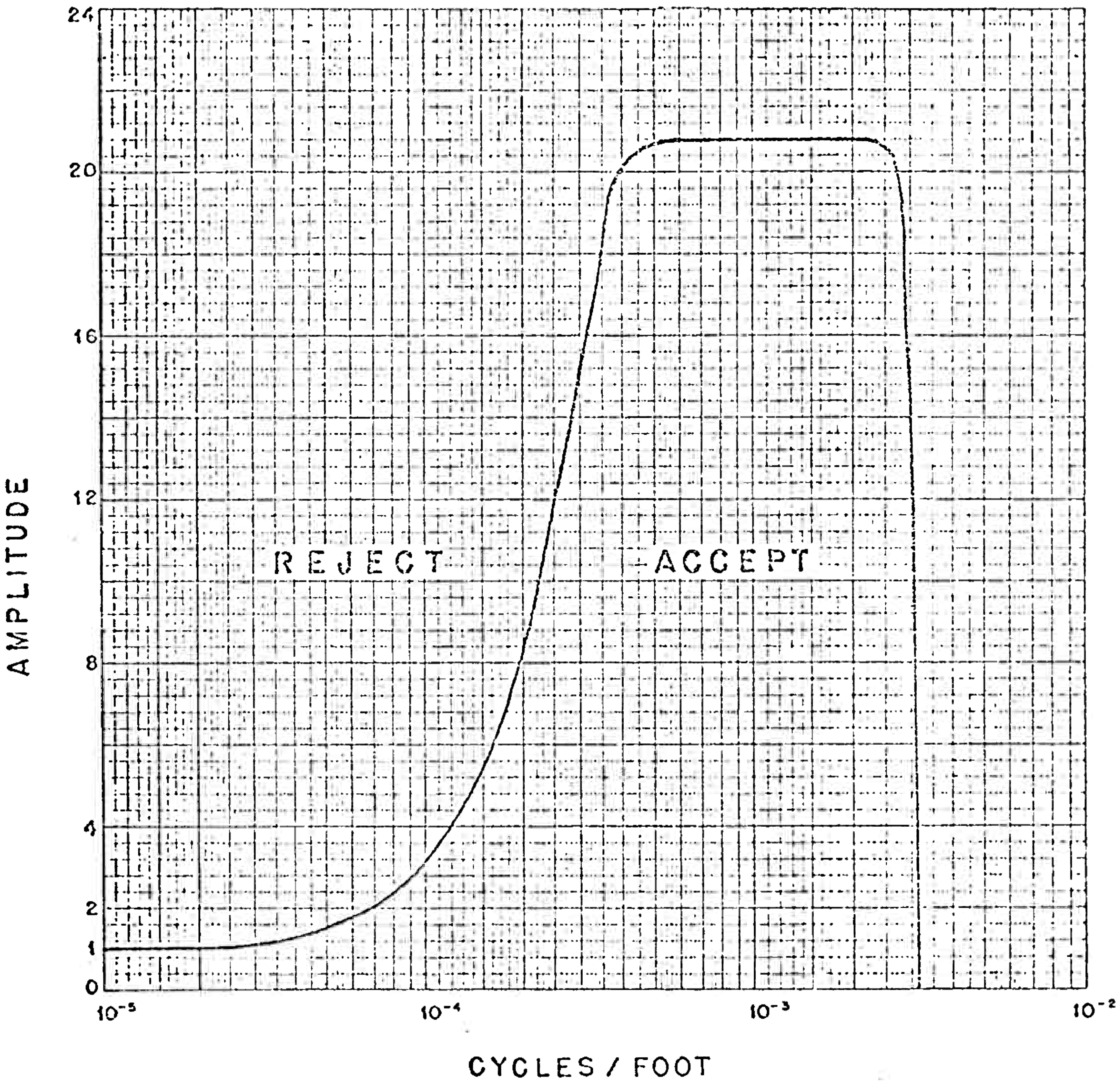

Figure 2 Frequency response of magnetic operator

The enhanced map, which bears a resemblance to a downward continuation map, is produced by digital bandpass filtering the total field data. The enhancement is equivalent to continuing the field downward to a level (above the source) which is 1/20th of the actual sensor-source distance.

Because the enhanced magnetic map bears a resemblance to a ground magnetic map, it simplifies the recognition of trends in the rock strata and the interpretation of geological structure. The contour interval of 100 gammas is suitable for defining the near-surface local geology while de-emphasizing deep-seated regional features.

CONDUCTORS IN THE SURVEY AREA

The electromagnetic map shows the location of the conductors and their interpreted conductance (i.e., conductivity-thickness product), depth and occasionally dip. Their strike direction and length are also shown when anomalies can be correlated from line to line. When studying the maps for follow-up planning, consult the anomaly listings appended to this report to ensure that none of the conductors are overlooked.

The survey consisted of four lines flown in an east-west direction totalling 51 km. The EM map indicates which anomalies are believed to be caused by cultural or surficial sources. Generally, such anomalies are not commented on below as the discussions are directed to identifying bedrock features.

The resistivity map indicates generally resistive country rock hosting several linear conductive zones with resistivities as low as 1 ohm-m which cut across the survey area in a northeasterly direction.

The magnetic map, and in particular the enhanced magnetic map, revealed a northeasterly striking magnetic trends within the area, basically coinciding with the strike direction of the low resistivity zones.

The survey was successful in detecting about ten linear bedrock conductors ranging in quality from an x-type response to a grade 6 anomaly, all striking across the area in a northeast direction. In addition, several isolated x-type responses were identified which also reflect bedrock conductors (e.g., 1xC, 1xD, 3xA). A group of closely spaced conductors at the eastern end of the survey has been resolved into five discrete features. All of them show direct magnetic correlation or occur on the flanks of prominent magnetic features. In addition, conductor 1F-4E appears to be dipping west.

It is of interest to note that the EM anomaly shapes of the bedrock conductor 1E-4D, found in the middle of the area, were distorted by the presence of magnetite. As a result, the calculated conductance of anomaly 4D may be overestimated.

At the western end of the survey, there is a group of widely spaced parallel bedrock conductors ranging in conductance from an x-type response to a grade 5 anomaly. Many of the anomaly shapes in this part of the area indicate a generally easterly dip for this group of conductors.

Respectfully submitted,
DIGHEM LIMITED

W.E.S Urquhart

Four map sheets accompany this report:

Electromagnetics	1 map sheet
Resistivity	1 map sheet
Magnetics	1 map sheet
Enhanced magnetics	1 map sheet

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A P P E N D I X   A

THE FLIGHT RECORD AND PATH RECOVERY

Both analog and digital flight records are produced. The analog profiles are recorded on green chart paper in the aircraft during the survey. The digital profiles are generated later by computer and plotted on electrostatic chart paper at 1:15,000 or at map scale, whichever is larger. The digital profiles, which may be displayed, are as follows:

Channel Number	Parameter	Scale units/mm
20	magnetics	10 gamma
21	bird height	3 m
22	vertical coaxial coil-pair inphase (freq #1)	1 ppm
23	vertical coaxial coil-pair quadrature (freq #1)	1 ppm
24	horizontal coplanar coil-pair inphase (freq #2)	1 ppm
25	horizontal coplanar coil-pair quadrature (freq #2)	1 ppm
26	VLF-EM total field	1 %
27	VLF-EM vertical quadrature	1 %
28	ambient noise monitor (coaxial receiver)	1 ppm
29	ambient noise monitor (coplanar receiver)	1 ppm
33	difference function inphase from channels 22 and 24	1 ppm
34	difference function quadrature from channels 23 and 25	1 ppm
35	first anomaly recognition function	1 ppm
36	second anomaly recognition function	1 ppm
37	conductance	1 mho
40	log resistivity (at freq #2)	.03 decade
41	apparent depth or thickness (at freq #2)	3 m
42	conductivity contrast (at freq #2)	arbitrary
43	depth contrast (at freq #2)	arbitrary
44	product 42*43 (at freq #2)	arbitrary
45	log resistivity (at freq #1)	.03 decade
46	apparent depth or thickness (at freq #1)	3 m
47	conductivity contrast (at freq #1)	arbitrary
48	depth contrast (at freq #1)	arbitrary
49	product 47*48 (at freq #1)	arbitrary
50	apparent weight percent magnetite	0.5%

The log resistivity scale of 0.03 decade/mm means that the resistivity changes by an order of magnitude in 33 mm. The resistivities at 0, 33, 67 and 100 mm up from the bottom of the chart are respectively 1, 10, 100 and 1000 ohm-m.

The fiducial marks on the flight records represent points on the ground which were recovered from camera film. Continuous photographic coverage allowed accurate photo-path recovery locations for the fiducials, which were then plotted on the geophysical maps to provide the track of the aircraft.

The fiducial locations on both the flight records and flight path maps were examined by a computer for unusual helicopter speed changes. Such changes may denote an error in flight path recovery. The resulting flight path locations therefore reflect a more stringent checking than is provided by standard flight path recovery techniques.

The following brief description of DIGHEM^{II} illustrates the information content of the various profiles*.

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*For a detailed description, see D.C. Fraser, Geophysics, v.44, p.1367-1394.

Single-frequency surveying

The DIGHEM^{II} system has two transmitter coils which are mounted at right angles to each other. Both coils transmit at approximately the same frequency. (This frequency is given in the Introduction.) Thus, the system provides two completely independent surveys at one pass. In addition, the digital profiles (generated by computer) include an inphase channel and a quadrature channel which essentially are free of the response of conductive overburden. Also, the EM channels may indicate whether the conductor is thin (e.g., less than 3 m), or has a substantial width (e.g., greater than 10 m). Further, the EM channels include channels of resistivity, apparent depth and conductance. A minimum of 14 EM channels are provided. The DIGHEM^{II} system gives information in one pass which cannot be obtained by any other airborne or ground EM technique.

Figure A1 shows a DIGHEM^{II} flight profile over a conductive ore body in Australia. It will serve to identify the majority of the available channels.

Channels 20 and 21 are respectively the magnetics and the EM bird height. Channels 22 and 23 are the inphase and quadrature of the coaxial coil-pair. This coil-pair is

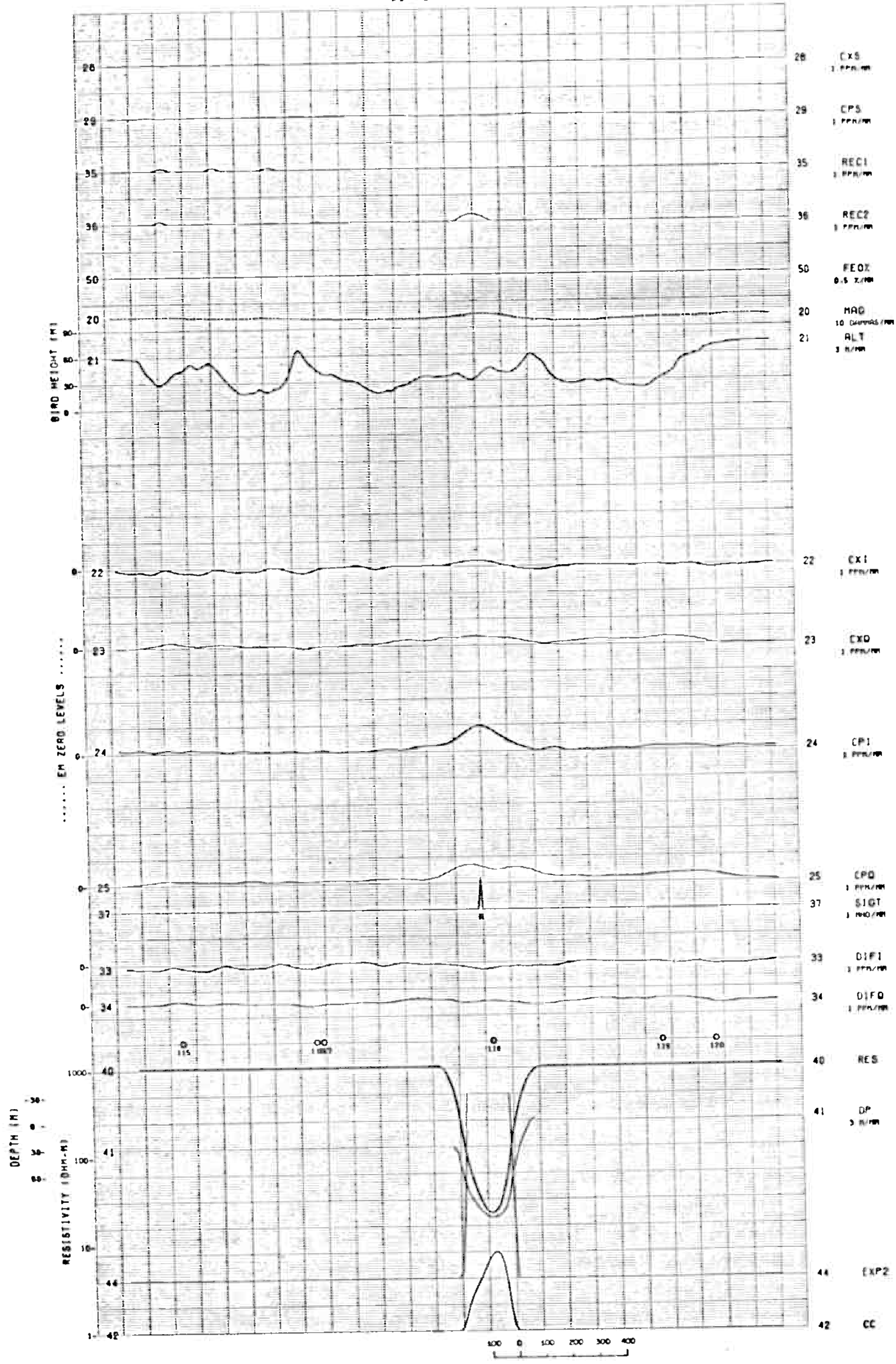

Fig. A1 DIGHEM^{II} digital profile.

equivalent to the standard coil-pair of all inphase-quadrature airborne EM systems. Channels 24 and 25 are the inphase and quadrature of the additional coplanar coil-pair.

Channels 33 and 34 are inphase and quadrature difference functions of the coaxial and coplanar channels. The difference channels tend to be free from the response of conductive overburden. Channel 37 is the conductance. The conductance channel essentially is an automatic anomaly picker calibrated in conductance units of mhos; it is triggered by the anomaly recognition functions shown as channels 35, 36, and 42.

Channel 40 is the resistivity, which is derived from the coplanar channels 24 and 25. The resistivity channel 40 yields data which can be contoured, and so the DIGHEM^{II} system yields a resistivity contour map in addition to an electromagnetic map, a magnetic contour map, and an enhanced magnetic contour map. The enhanced magnetic contour map is similar to the filtered magnetic map discussed by Fraser.*

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*Cdn. Inst. Mng., Bull., April 1974.

Channel 41 is the depth channel. A depth estimate which is negative will occur when conductive overburden exists. A negative depth estimate implies that the conductive material occurs above the daylight surface. This false estimate shows that the EM system has responded to the conductive surface material and had also sensed the underlying resistive rock. In Fig. A1, the positive depth estimate of about 100 m is close to the true depth for this bedrock conductor.

Channel 42 is the conductivity contrast which highlights resistivity lows. Channel 43 is the depth contrast, which usually is not plotted. Both channels 42 and 43 tend to yield positive responses over bedrock conductors at depth. Channel 44 is the multiple of channels 42*43. Consequently, channel 44 tends to yield large positive responses over bedrock conductors at depth. The interpretation of channels 42 and 44 has to be done with care, however, because they may also respond in a similar fashion to a local thickening in conductive cover, e.g., over a buried river channel.

Channel 50 provides an estimate of the percent by weight of magnetite. This computation is made whenever the coplanar inphase channel 24 is negative. The negative response shows that magnetic permeability exists.

Dual-frequency surveying

For surveys flown primarily for resistivity mapping, as opposed to EM surveying, the two transmitter coils may be energized at two well-separated frequencies (e.g., 900 and 3600 Hz). Apparent resistivity maps can be made independently for each frequency. The interpretation procedure involves comparing the apparent resistivity and apparent depth parameters at the two frequencies.

The use of two different coil-pair orientations (i.e., coaxial and coplanar) for dual-frequency resistivity mapping is an unorthodox procedure. However, as long as the current flow patterns are primarily horizontal, the different coil orientations do not influence the results. Wire fences and other cultural features will produce local deviations, because they usually respond preferentially to one or the other of the coil-pairs.

The difference channels 33 and 34, and the anomaly recognition channel 35, are not produced for dual frequence surveys. This is because the divergent frequencies of the two coil-pairs render them meaningless.

APPENDIX B

EM ANOMALY LIST

705 FOLLDAL BLOCK 1

LINE & ANOMALY	COAXIAL COIL REAL PPM	COAXIAL COIL QUAD PPM	COPLANAR COIL REAL PPM	COPLANAR COIL QUAD PPM	VERTICAL DIKE COND MHOS	VERTICAL DIKE DEPTH* M	HORIZONTAL SHEET COND MHOS	HORIZONTAL SHEET DEPTH M	CONDUCTIVE EARTH RESIS OHM-M	CONDUCTIVE EARTH DEPTH M
1A	43	51	68	100	11	0	3	35	16	15
1B	12	15	24	35	7	2	1	42	70	9
1C	15	29	47	88	6	0	3	28	19	7
1D	68	36	122	69	38	2	6	50	4	35
1E	0	0	3	4	3	73	1	157	569	54
1F	6	3	6	3	14	36	1	133	71	89
1G	21	10	31	16	27	11	5	73	7	54
1H	24	7	15	8	45	25	4	106	10	83
1I	116	46	254	120	63	0	12	25	1	16
2A	15	11	27	23	15	0	3	62	19	37
2B	6	13	20	28	5	0	2	59	25	32
2C	26	44	61	115	7	0	2	22	26	0
2D	50	18	77	30	56	5	5	74	6	56
2E	10	8	6	9	9	15	1	94	92	43
2F	46	15	68	25	62	4	9	59	2	45
2G	28	4	35	13	79	16	6	105	6	84
2H	30	9	36	23	37	8	7	83	4	65
2I	28	14	36	23	26	13	3	91	19	65
3A	25	13	35	41	14	4	2	50	36	21
3B	14	10	22	27	11	14	1	58	65	24
3C	11	13	36	33	10	0	3	45	17	23
3D	43	21	91	47	37	5	7	53	3	40
3E	1	2	8	4	6	43	3	144	27	109
3F	2	4	1	1	3	45	1	91	249	38
3G	16	9	17	11	20	26	2	90	52	54
3H	32	3	57	16	132	0	11	49	1	36
3I	14	8	29	13	19	0	6	71	6	52
3J	21	9	29	13	27	10	4	75	8	55
4A	19	13	24	25	14	5	1	55	74	18
4B	10	11	27	35	8	0	2	41	25	15
4C	17	7	27	24	19	15	2	73	33	43
4D	14	9	12	7	18	21	2	111	48	74
4E	13	6	11	7	23	35	1	92	75	51
4F	44	11	56	21	69	10	7	65	4	50
4G	28	11	26	16	33	4	4	69	9	48

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* M	COND MHOS	DEPTH M	RESIS OHM-M	DEPTH M
4H	18	5	26	16	34	17	2	92	30	63

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.