

DIGHEM^{III} SURVEY

OF THE

LABOUR DAY LAKE AREA, B.C.

FOR

FALCONBRIDGE LIMITED

BY

DIGHEM LIMITED

TORONTO, ONTARIO
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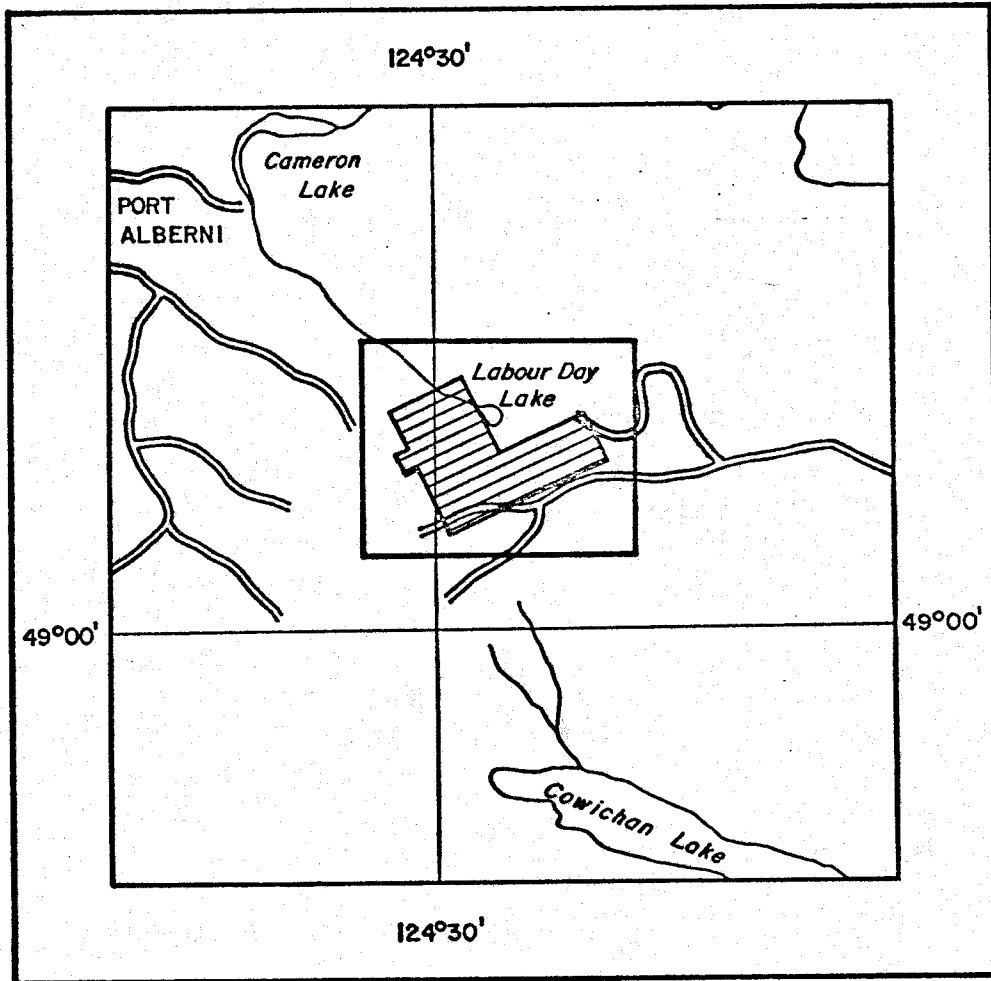
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SUMMARY AND RECOMMENDATIONS

A total of 235 km (146 miles) of survey was flown in February and March 1984, over a property held by Falconbridge Limited on Vancouver Island, B.C.

The survey outlined several discrete bedrock conductors associated with areas of low resistivity. Most of these anomalies appear to warrant further investigation using appropriate surface exploration techniques. Areas of interest may be assigned priorities for follow-up work on the basis of supporting geological and/or geochemical information.

LOCATION MAP



Scale 1:500,000

Figure 1
The Survey Area

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INTRODUCTION

A DIGHEM^{III} survey totalling 235 line-km was flown with a 200 m line-spacing for Falconbridge Limited, from February 14 to March 2, 1984, in the Labour Day Lake area of Vancouver Island, B.C. (Figure 1).

The CG-DEM turbine helicopter flew at an average airspeed of 70 km/h with an EM bird height of approximately 57 m. Ancillary equipment consisted of a Sonotek PMH 5010 magnetometer with its bird at an average height of 72 m, a Sperry radio altimeter, a Geocam sequence camera, an RMS GR 33 hot pen analog recorder, a Sonotek PMH 5010 digital data acquisition system and a DigiData 1640 9-track 800-bpi magnetic tape recorder. The analog equipment recorded four channels of EM data at approximately 900 Hz, two channels of EM data at approximately 7200 Hz, two ambient EM noise channels (for the coaxial and coplanar receivers), two channels of magnetics (coarse and fine count), and a channel of radio altitude. The digital equipment recorded the EM data with a sensitivity of 0.20 ppm at 900 Hz, 0.40 ppm at 7200 Hz, and the magnetic field to one nT (i.e., one gamma).

Appendix A provides details on the data channels, their respective sensitivities, and the flight path recovery procedure. Noise levels of less than 2 ppm are generally maintained 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 m² 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.

It should be noted that the anomalies shown on the electromagnetic anomaly map are based on a near-vertical, half plane model. This model best reflects "discrete" bedrock conductors. Wide bedrock conductors or flat-lying conductive units, whether from surficial or bedrock sources, may give rise to very broad anomalous responses on the EM profiles. These may not appear on the electromagnetic anomaly map if they have a regional character rather than a locally anomalous character. These broad conductors, which more closely approximate a half space model, will be maximum coupled to the horizontal (coplanar) coil-pair and are clearly evident on the resistivity map. The resistivity map, therefore, may be more valuable than the electromagnetic anomaly map, in areas where broad or flat-lying conductors are considered to be of importance.

In areas where magnetite causes the inphase components to become negative, the apparent conductance and depth of EM anomalies may be unreliable.

There are several areas where EM responses are evident only on the quadrature components, indicating zones of poor

conductivity. Where these responses are coincident with strong magnetic anomalies, it is possible that the inphase component amplitudes have been suppressed by the effects of magnetite. Most of these poorly-conductive magnetic features give rise to resistivity anomalies which are only slightly below background. These weak features are evident on the resistivity map but may not be shown on the electromagnetic anomaly map. If it is expected that poorly-conductive sulphides may be associated with magnetite-rich units, some of these weakly anomalous features may be of interest.

In some portions of the survey area, the extremely rugged topography forced the pilot to exceed normal terrain clearance for reasons of safety. It is possible that some weak conductors may have escaped detection in areas where the bird height exceeded 120 m. In difficult areas where near-vertical climbs were necessary, the forward speed of the helicopter was reduced to a level which permitted excessive bird swinging. This problem, combined with the severe stresses to which the bird was subjected, gave rise to aerodynamic noise levels which are slightly higher than normal. Several reflights were carried out to minimize these adverse effects.

SECTION I: SURVEY RESULTS

CONDUCTORS IN THE SURVEY AREA

The survey covered a single grid with 235 km of flying, the results of which are shown on the map sheets accompanying this report. Table I-1 summarizes the EM responses in the area with respect to conductance grade and interpretation.

The electromagnetic anomaly map shows the anomaly locations with the interpreted conductor shape, dip, conductance and depth being indicated by symbols. Direct magnetic correlation is also shown if it exists. The strike direction and length of the conductors are indicated when anomalies can be correlated from line to line. When studying the map sheets for follow-up planning, consult the anomaly listings appended to this report to ensure that none of the conductors are overlooked.

There are numerous EM anomalies which exhibit the characteristics of broad, flat-lying zones, some of which appear to be due to moderately deep, rather than surficial zones of weak conductivity. Although the difference channels (DIF I and DIF Q) are extremely valuable in

TABLE 1

EM ANOMALY STATISTICS OF THE LABOUR DAY LAKE AREA

CONDUCTOR GRADE	CONDUCTANCE RANGE	NUMBER OF RESPONSES
6	> 99 MHOS	0
5	50-99 MHOS	0
4	20-49 MHOS	0
3	10-19 MHOS	0
2	5- 9 MHOS	4
1	< 5 MHOS	48
X	INDETERMINATE	38
TOTAL		90

CONDUCTOR MODEL	MOST LIKELY SOURCE	NUMBER OF RESPONSES
B	DISCRETE BEDROCK CONDUCTOR	51
H	ROCK UNIT OR THICK COVER	39
TOTAL		90

(SEE EM MAP LEGEND FOR EXPLANATIONS)

distinguishing between near-vertical and flat-lying sources, bedrock conductors with shallow dips may not yield clearly defined anomalies on these channels. Such shallow dipping features, however, should be evident on the resistivity map. If the geological units in the area exhibit relatively shallow dips, some of the anomalies with an "H" classification may be of interest, particularly if the depth channels indicate these are not surficial (overburden) responses.

The total field magnetic map suggests an area of rather complex geology which strikes northwest-southeast in the northern portion of the survey area. South of line 1900, higher magnetic values are evident. The 56,500 nT magnetic contour outlines a major plug-like feature approximately 3 km in diameter, centered in the vicinity of anomaly 28xB'. East of this feature, there are two other magnetic units which strike north-northwest/south-southeast through anomalies 26xB' and 28G. A fourth, incomplete magnetic anomaly is situated beyond the eastern ends of lines 1 through 9. The rock units which give rise to these stronger anomalies all exhibit core material containing more than 1% magnetite. The negative inphase suppression of magnetite is clearly evident on the profiles for lines 2400 through 31.

Resistivities in the survey area are generally high, with only a few isolated areas exhibiting values of less

than 1,000 ohm-m. Most of the interesting EM anomalies are associated with these zones of moderate to low resistivity.

Anomalies 3xC-7A,
300B-4xA,
300A, 8A

Anomalies in this group are contained within a zone of moderate to low resistivity which extends in a southeasterly direction from anomaly 100A. With the exception of anomaly 300C, which exhibits a weak 20 nT magnetic correlation, the anomalies forming conductor axis 3xC-7A are associated with a relative magnetic depression. The CXI/CPI ratio of anomaly 300C suggests a parallel or off-line source which may indicate that the northwest extent of this conductor occurs at, or south of, line 300. The broad nature of anomalies 5A-7A and the apparent negative depth both tend to suggest overburden as a possible cause of this conductor; however, the weak difference channel responses and the offsets in CPI-CXI peaks suggest a probable wide bedrock source.

Anomaly 300B-4xA reflects a poor conductor of limited strike length which may be partially due to overburden. The sharpness of anomaly 300B, however, suggests a possible bedrock conductor. Anomaly 300A exhibits characteristics similar to 300B, and is located about 200 m to the southwest. Its relationship to a weak magnetic low suggests this anomaly could be due to a weakly conductive fault. Anomaly 8A is a weak, poorly-defined response which may also be due to thick conductive overburden.

Anomalies in this group are considered to be of low priority with the exception of anomalies 300C and 7A, both of which are associated with resistivity lows of less than 250 ohm-m.

Anomalies 6A-7xA,
15A-16A

Anomalies 6A-7xA and 15A-16A both reflect possible bedrock conductors of limited strike length. The

former occurs on the northern flank of a dike-like magnetic anomaly which extends from fiducial 975 on line 1 through fiducial 833 on line 10. The enhanced magnetic map suggests this narrow magnetic unit may extend southeast to fiducial 161 on line 2000 where it merges with a similar feature which extends from fiducial 573 on line 3, continuing southeast through fiducial 2290 on line 25. Anomaly 15A-16A is located on the western contact of the same magnetic unit which hosts anomaly 6A-7xA. Although both conductors consist of weak, poorly defined anomalies, they may reflect weakly mineralized contacts which could be of interest.

Anomalies 1100B, 1300A

A broad conductive unit is considered to be a likely cause of anomaly 1100B. The difference channel responses associated with anomaly 1300A are fairly flat,

suggesting a similar broad conductor, although the sharpness of 1300A tends to indicate a probable buried bedrock feature. Both anomalies are considered to be of moderately low priority, although they are associated with a subtle resistivity low.

Anomalies 1900A, 2200A

An interesting conductor of limited extent is indicated by anomaly 1900A. This isolated feature is situated on the northern edge of a strong magnetic anomaly and probably reflects mineralization associated with a geological contact. This anomaly warrants further work.

Anomaly 2200A reflects a moderately broad, weak conductor. Although the anomaly is located in a relatively non-magnetic area (between two prominent magnetic anomalies), the inphase suppression suggests this anomaly is associated

with a poorly conductive zone of magnetite. Both anomalies 1900A and 2200A are associated with subtle low resistivity anomalies which tend to enhance their significance.

Anomalies 23A-25A,
2400B,
27A-29A,
31A

Anomaly 23A-25A reflects a bedrock conductor with a strike length of about 1 km. This conductor appears to be fairly broad (or flat lying) in the vicinity of anomaly 23A, grading to a narrow (or steeply-dipping) zone towards the east. This conductor is associated with a moderately low resistivity zone which is paralleled by a northwest trending limb of magnetic material about 400 meters to the northeast. Anomaly 2400B reflects a possible bedrock conductor associated with the northern contact of this magnetic unit. The former conductor, 23A-25A, is associated with a moderately low resistivity anomaly.

Anomaly 27A-29A reflects a bedrock conductor associated with the southern contact of a moderately strong isolated magnetic anomaly. This conductor should be followed up, particularly in the vicinity of anomaly 28A which yields a direct magnetic correlation of 200 nT.

The broad, poorly defined anomalies 30A and 31A may also be related to the same geological horizon as indicated by the magnetic contours in the area.

Anomalies 28xB-31B,
25D-28xB',
25B, 27xA',
30E

Anomalies in this group are related to a strong magnetic anomaly which may reflect an intrusive plug. All anomalies are affected by magnetite, as evidenced by the negative inphase responses, which precludes accurate resistivity estimates. (The negative inphase gives rise to erroneously high resistivities.) The conductors generally appear to flank the stronger magnetic peaks suggesting

that the mineralized zones are associated with the contacts of the magnetite-rich units. Exceptions are anomalies 25B, 25D and 31B, which exhibit direct magnetic correlation. The broad rock unit which hosts these conductors appears to contain between 1% to 2.5% magnetite. (See FEO channels for lines 25 to 31.)

All conductors in this area appear to warrant follow-up.

Anomaly 2400xA-26xB

Anomaly 2400xA-26xB reflects a bedrock conductor associated with a well defined magnetic unit containing about 1% magnetite.

Anomalies 23xA, 25xA,
26xB'-28E
28D, 31E,
29E-30xC'

All anomalies in this group are associated with a moderately broad magnetic anomaly outlined by the 56,500 nT contour. This unit strikes northwest/southeast along the axis of conductor 26xB'-28E which is associated with peak

magnetic values of more than 57,000 nT.

Anomaly 29E-30xC', which may be an offset continuation of conductor 26xB'-28E, yields positive inphase results on the high frequency only, suggesting that this portion either contains less magnetite or is more highly conductive. (Although the effects of magnetite are independent of frequency, the 7200 Hz which can detect poorly conductive zones yields a positive inphase response, i.e., the effects of conductance exceed the negative effects of magnetic permeability at the higher frequency.) This phenomenon is exemplified by comparing anomalies 23xA and 31E, both of which exhibit direct magnetic correlation. The positive inphase associated with anomaly 31E gives rise to a low resistivity anomaly while 23xA does not.

All anomalies in this area are related to poorly conductive zones of magnetite and should be investigated, particularly if it is likely that the magnetic (intrusive?) host may have influenced mineral deposition in the area.

Anomaly 26C

Anomaly 26C reflects a bedrock conductor, probably of limited strike length, which is considered to be one of the more attractive targets in the Labour Day Lake area. The high CPI/CXI ratio suggests that the anomaly is due to a thick, moderately strong conductor or a narrower conductor which is parallel or to one side of the survey line. This conductor yields the strongest low resistivity anomaly in the survey area.

It is strongly recommended that further work be carried out to determine the strike direction, length and causative source of this interesting bedrock conductor.

Anomaly 30G-31F

A broad, weak bedrock conductor is indicated by anomaly 30G-31F. This feature may be open to the southeast.

Anomalies 26xD, 28G,
30xE

Anomalies in this group consist of isolated responses which are related to a major magnetic unit which strikes northwest/southeast through anomaly 28G. All anomalies are due to poorly conductive zones of magnetite.

In the general area south of line 2400, there are several broad quadrature responses which occur in areas where magnetite has suppressed the relative inphase responses. These have not been picked as EM anomalies as they do not meet the criteria for "discrete" bodies. The extent and uniformity of the magnetic units which host these subtle features tends to mask weak conductors within this environment. Some of these subtle features may also be of interest if the "magnetite associated" anomalies described herein prove to be related to economic mineralization.

SECTION II: BACKGROUND INFORMATION

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 200 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 analyzed 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.

Geometric interpretation

The geophysical interpreter attempts to determine the geometric shape and dip of the conductor. This qualitative interpretation of anomalies is indicated on the map by means of interpretive symbols (see EM map legend). Figure II-1 shows typical DIGHEM anomaly shapes and the interpretive symbols for a variety of conductors. These classic curve shapes are used to guide the geometric interpretation.

Discrete conductor analysis

The EM anomalies appearing on the electromagnetic map are analyzed by computer to give the conductance (i.e., conductivity-thickness product) in mhos of a vertical sheet model. This is done regardless of the interpreted geometric shape of the conductor. This is not an unreasonable procedure, because the computed conductance increases as the electrical quality of the conductor increases, regardless of its true shape. DIGHEM anomalies are divided into six

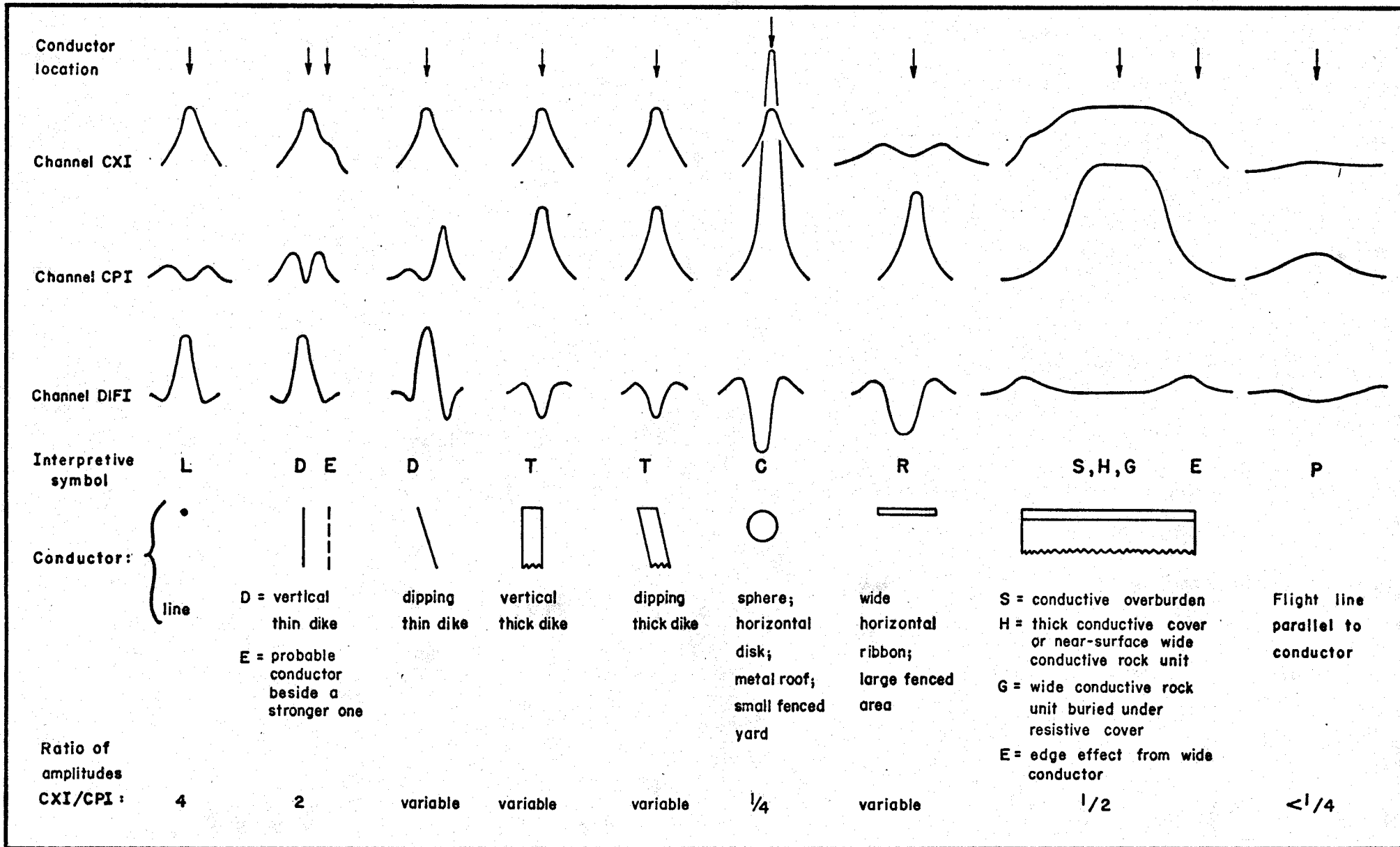


Figure II - 1

Typical DIGHEM anomaly shapes

grades of conductance, as shown in Table II-1. The conductance in mhos is the reciprocal of resistance in ohms.

Table II-1. EM Anomaly Grades

<u>Anomaly Grade</u>	<u>Mho Range</u>
6	> 99
5	50 - 99
4	20 - 49
3	10 - 19
2	5 - 9
1	< 5

The conductance 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 conductance values.

Conductive overburden generally produces broad EM responses which are not plotted on the EM maps. However, patchy conductive overburden in otherwise resistive areas

¹ This statement is an approximation. DIGHEM, with its short coil separation, tends to yield larger and more accurate conductance values than airborne systems having a larger coil separation.

can yield discrete anomalies with a conductance grade (cf. Table II-1) 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 10 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 conductors to be recognized, and these are indicated by the letters S, H, G and sometimes E on the map (see EM legend).

For bedrock conductors, the higher anomaly grades indicate increasingly higher conductances. Examples: DIGHEM's New Inco copper discovery (Noranda, Canada) yielded a grade 4 anomaly, as did the neighbouring copper-zinc Magusi River ore body; Mattabi (copper-zinc, Sturgeon Lake, Canada) and Whistle (nickel, Sudbury, Canada) gave grade 5; and DIGHEM's Montcalm nickel-copper discovery (Timmins, 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, 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, a letter identifier and an interpretive symbol are plotted beside the EM grade symbol. The horizontal rows of dots, under the interpretive symbol, indicate the anomaly amplitude on the flight record. The

vertical column of dots, under the anomaly letter, gives the estimated depth. In areas where anomalies are crowded, the letter identifiers, interpretive symbols and dots 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 conductance grade and depth estimate illustrates which of these possibilities fits the recorded data best.

Flight line deviations occasionally yield cases where two anomalies, having similar conductance 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 onto 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 conductance values are printed in the attached anomaly list 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 and dip, geometric shape, conductance, depth, and thickness (see below). The accuracy is comparable to an interpretation from a high quality ground EM survey having the same line spacing.

The attached EM anomaly list provides a tabulation of anomalies in ppm, conductance, and depth for the vertical sheet model. The EM anomaly list also shows the conductance and 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 10 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 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 the flight line, or aerodynamic noise. Those responses that

have the appearance of valid bedrock anomalies on the flight profiles are indicated by appropriate interpretive symbols (see EM map legend). The others probably do not warrant further investigation unless their locations are of considerable geological interest.

The thickness parameter

DIGHEM can provide an indication of the thickness of a steeply dipping conductor. The amplitude of the coplanar anomaly (e.g., CPI) increases relative to the coaxial anomaly (e.g., CXI) as the apparent thickness increases, i.e., the thickness in the horizontal plane. (The 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. Thin conductors are indicated on the EM map by the interpretive symbol "D", and thick conductors by "T". For base metal exploration in steeply dipping geology, thick conductors can be high priority targets because many massive sulfide ore bodies are thick, whereas non-economic bedrock conductors are often thin. The system cannot sense the thickness 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 EM 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 correct 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. The resistivity analysis also helps the interpreter to differentiate between conductive trends in the bedrock and those patterns typical of conductive overburden. For example, discrete conductors will generally appear as narrow lows on the contour map and broad conductors (e.g., overburden) will appear as wide lows.

The resistivity profile (see table in Appendix A) 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. The depth channel (see Appendix A) 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

² Resistivity mapping with an airborne multicoil electromagnetic system: Geophysics, v. 43, p. 144-172.

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 system has been flown for purposes 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 can be of significant help in distinguishing between overburden and bedrock conductors.

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.

(Resistivity = $1/\text{conductivity}$.)

(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 flight³. 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.

³ The gradient analogy is only valid with regard to the identification of anomalous locations.

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 discrete bedrock conductors. The processing of DIGHEM data, however, produces six channels which contribute significantly to the recognition of bedrock conductors. These are the inphase and quadrature difference channels (DIFI and DIFQ), and the resistivity and depth channels (RES and DP) for each coplanar frequency; see table in Appendix A.

The EM difference channels (DIFI and DIFQ) 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 conductive environment therefore is based on the anomalous responses of the two difference channels (DIFI and DIFQ) and the two resistivity channels (RES). The most favourable situation is where anomalies coincide on all four channels.

The DP channels, which give the apparent depth to the conductive material, also help to determine whether a conductive response arises from surficial material or from a conductive zone in the bedrock. When these channels ride above the zero level on the electrostatic chart paper (i.e., depth is negative), it implies that the EM and resistivity profiles are responding primarily to a conductive upper layer, i.e., conductive overburden. If both DP channels are below the zero level, it indicates that a resistive upper layer exists, and this usually implies the existence of a bedrock conductor. If the low frequency DP channel is below the zero level and the high frequency DP is above, this suggests that a bedrock conductor occurs beneath conductive cover.

Channels REC1, REC2, REC3 and REC4 are the anomaly recognition functions. They are used to trigger the conductance channel CDT which identifies discrete conductors. In highly conductive environments, channel REC2

is deactivated because it is subject to corruption by highly conductive earth signals. Similarly, in moderately conductive environments, REC4 is deactivated. Some of the automatically selected anomalies (channel CDT) are discarded by the geophysicist. 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.

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 DIFI for inphase and DIFQ for quadrature) tend to eliminate the response of conductive overburden. This marked a unique development in airborne EM technology, as DIGHEM 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 DIFI. 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 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. The technique yields channel "FEO" (see Appendix A) which displays apparent weight percent magnetite according to a homogeneous half space model.⁴ 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. Unlike magnetometry, the EM magnetite method is unaffected by remanent magnetism or magnetic latitude.

⁴ Refer to Fraser, 1981, Magnetite mapping with a multi-coil airborne electromagnetic system: Geophysics, v. 46, p. 1579-1594.

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 the magnetite channel FEO.

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.

Recognition of culture

Cultural responses include all EM anomalies caused by man-made metallic objects. Such anomalies may be caused by inductive coupling or current gathering. The concern of the interpreter is to recognize when an EM response is due to culture. Points of consideration used by the interpreter, when coaxial and coplanar coil-pairs are operated at a common frequency, are as follows:

1. Channels CXS and CPS (see Appendix A) measure 50 and 60 Hz radiation. An anomaly on these channels shows

that the conductor is radiating cultural power. Such an indication is normally a guarantee that the conductor is cultural. However, care must be taken to ensure that the conductor is not a geologic body which strikes across a power line, carrying leakage currents.

2. A flight which crosses a line (e.g., fence, telephone line, etc.) yields a center-peaked coaxial anomaly and an m-shaped coplanar anomaly.⁵ When the flight crosses the cultural line at a high angle of intersection, the amplitude ratio of coaxial/coplanar (e.g., CXI/CPI) is 4. Such an EM anomaly can only be caused by a line. The geologic body which yields anomalies most closely resembling a line is the vertically dipping thin dike. Such a body, however, yields an amplitude ratio of 2 rather than 4. Consequently, an m-shaped coplanar anomaly with a CXI/CPI amplitude ratio of 4 is virtually a guarantee that the source is a cultural line.

3. A flight which crosses a sphere or horizontal disk yields center-peaked coaxial and coplanar anomalies with a CXI/CPI amplitude ratio (i.e., coaxial/coplanar) of 1/4. In the absence of geologic bodies of this geometry, the most likely conductor is a metal roof or

⁵ See Figure II-1 presented earlier.

small fenced yard.⁴ Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

4. A flight which crosses a horizontal rectangular body or wide ribbon yields an m-shaped coaxial anomaly and a center-peaked coplanar anomaly. In the absence of geologic bodies of this geometry, the most likely conductor is a large fenced area.⁴ Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

5. EM anomalies which coincide with culture, as seen on the camera film, are usually caused by culture. However, care is taken with such coincidences because a geologic conductor could occur beneath a fence, for example. In this example, the fence would be expected to yield an m-shaped coplanar anomaly as in case #2 above. If, instead, a center-peaked coplanar anomaly occurred, there would be concern that a thick geologic conductor coincided with the cultural line.

⁴ It is a characteristic of EM that geometrically identical anomalies are obtained from: (1) a planar conductor, and (2) a wire which forms a loop having dimensions identical to the perimeter of the equivalent planar conductor.

6. The above description of anomaly shapes is valid when the culture is not conductively coupled to the environment. In this case, the anomalies arise from inductive coupling to the EM transmitter. However, when the environment is quite conductive (e.g., less than 100 ohm-m at 900 Hz), the cultural conductor may be conductively coupled to the environment. In this latter case, the anomaly shapes tend to be governed by current gathering. Current gathering can completely distort the anomaly shapes, thereby complicating the identification of cultural anomalies. In such circumstances, the interpreter can only rely on the radiation channels CXS and CPS, and on the camera film.

TOTAL FIELD 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, Canada) as well as magnetic (e.g., the Mattabi deposit near Sturgeon Lake, Canada).

The magnetometer data are digitally recorded in the aircraft to an accuracy of one nT (i.e., one gamma). The digital tape is processed by computer to yield a total field magnetic contour map. When warranted, the magnetic data also may be treated mathematically to enhance the magnetic response of the near-surface geology, and an enhanced magnetic contour map is then produced. The response of the enhancement operator in the frequency domain is illustrated in Figure II-2. This figure shows that the passband components of the airborne data are amplified 20 times by the enhancement operator. This means, for example, that a 100 nT anomaly on the enhanced map reflects a 5 nT anomaly for the passband components of the airborne data.

The enhanced map, which bears a resemblance to a downward continuation map, is produced by the digital bandpass filtering of 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

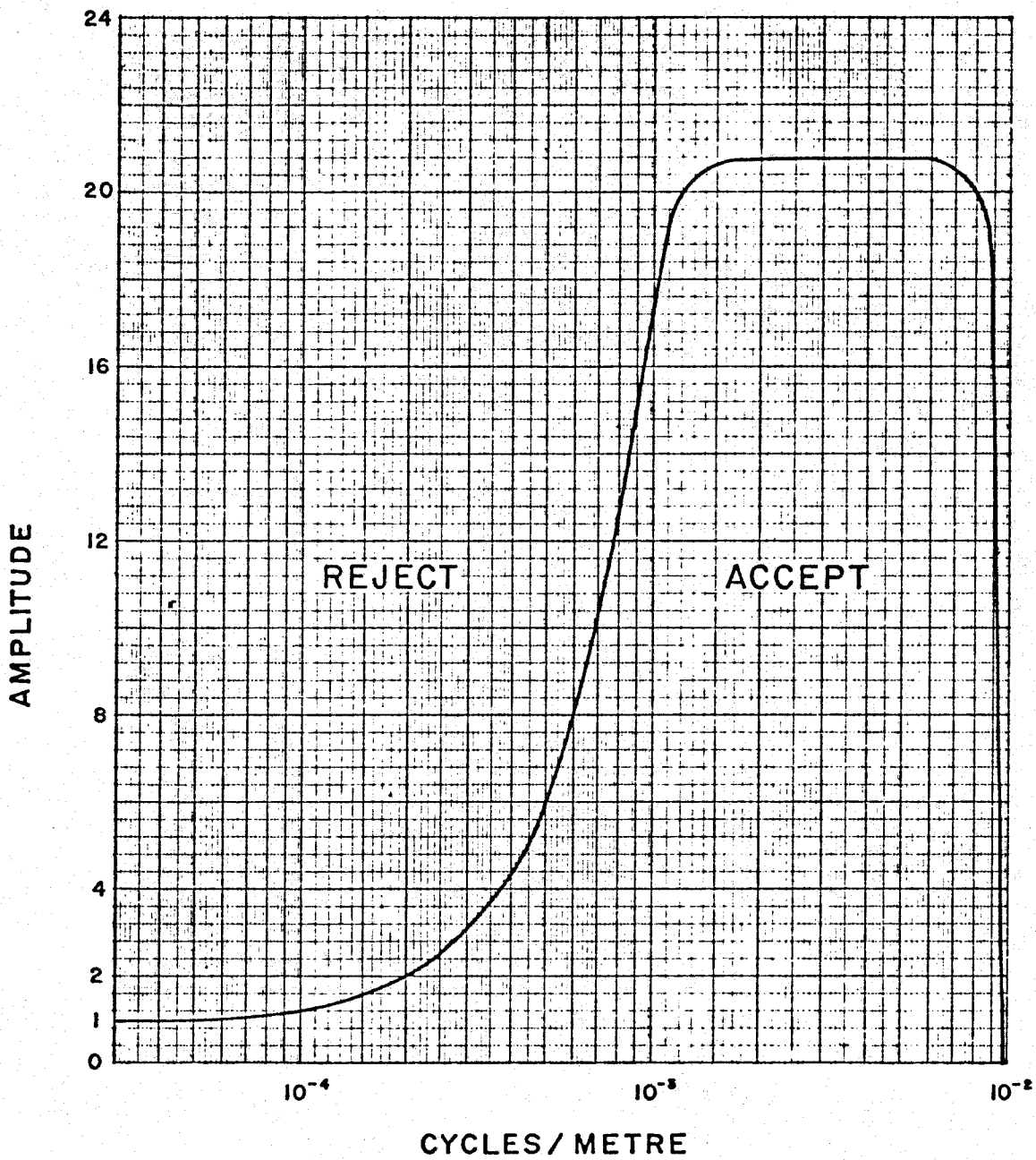


Figure II-2 Frequency response of magnetic enhancement operator.

geological structure. It defines the near-surface local geology while de-emphasizing deep-seated regional features. It primarily has application when the magnetic rock units are steeply dipping and the earth's field dips in excess of 60 degrees.

MAPS ACCOMPANYING THIS REPORT

Four map sheets accompany this report:

Electromagnetic Anomalies	1 map sheet
Resistivity	1 map sheet
Total Field Magnetics	1 map sheet
Enhanced Magnetics	1 map sheet

Respectfully submitted,
DIGHEM LIMITED



P.A. Smith
Geophysical Interpreter

STATEMENT OF QUALIFICATIONS

I, Paul A. Smith, of the City of Toronto, Province of Ontario, do hereby certify that:

1. I am a geophysical technician, residing at 65 Dogwood Crescent, Scarborough, Ontario M1P 3N5.
2. I have graduated from DeVry Technical Institute, Toronto (Electronics - 1962) and the Nova Scotia Land Survey Institute, (Cartography - 1966).
3. I have been actively engaged in geophysical exploration since 1962.
4. I am presently employed by Dighem Limited.
5. The statements made in this report represent my best opinion and judgment.

Dated at Toronto this 22nd day of March, 1984.



Paul A. Smith
Geophysical Interpreter

A P P E N D I X A

THE FLIGHT RECORD AND PATH RECOVERY

Both analog and digital flight records were produced. The analog profiles were recorded on chart paper in the aircraft during the survey. The digital profiles were generated later by computer and plotted on electrostatic chart paper at a scale of 1:15,000. The digital profiles are listed in Table A-1.

In Table A-1, 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, 100 and 133 mm up from the bottom of the digital flight record are respectively 1, 10, 100, 1,000 and 10,000 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 speed changes may denote

an error in flight path recovery. The resulting flight path locations therefore reflect a more stringent checking than is normally provided by manual flight path recovery techniques.

Table A-1. The Digital Profiles

Channel Name (Freq)	Observed parameters	Scale units/mm
MAG	magnetics	10 nT
ALT	bird height	3 m
CXI (900 Hz)	vertical coaxial coil-pair inphase	1 ppm
CXQ (900 Hz)	vertical coaxial coil-pair quadrature	1 ppm
CXS (900 Hz)	ambient noise monitor (coaxial receiver)	1 ppm
CPI (900 Hz)	horizontal coplanar coil-pair inphase	1 ppm
CPQ (900 Hz)	horizontal coplanar coil-pair quadrature	1 ppm
CPS (900 Hz)	ambient noise monitor (coplanar receiver)	1 ppm
CPI (7200 Hz)	horizontal coplanar coil-pair inphase	1 ppm
CPQ (7200 Hz)	horizontal coplanar coil-pair quadrature	1 ppm
<u>Computed Parameters</u>		
DIFI (900 Hz)	difference function inphase from CXI and CPI	1 ppm
DIFQ (900 Hz)	difference function quadrature from CXQ and CPQ	1 ppm
REC1	first anomaly recognition function	1 ppm
REC2	second anomaly recognition function	1 ppm
REC3	third anomaly recognition function	1 ppm
REC4	fourth anomaly recognition function	1 ppm
CDT	conductance	1 grade
RES (900 Hz)	log resistivity	.03 decade
RES (7200 Hz)	log resistivity	.03 decade
DP (900 Hz)	apparent depth	3 m
DP (7200 Hz)	apparent depth	3 m
FEO% (900 Hz)	apparent weight percent magnetite	0.25%

A P P E N D I X B

EM ANOMALY LIST

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	COAXIAL 900 HZ	COPLANAR 900 HZ	COPLANAR 7200 HZ	VERTICAL DIKE	HORIZONTAL SHEET	CONDUCTIVE EARTH						
ANOMALY/ FID/INTERP	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* M	COND MHOS	DEPTH M	RESIS OHM-M	DEPTH M
LINE 100 A 1526 H	(FLIGHT 2	10) 2	1	3	12	13	1	0	1	29	232	1
LINE 300 A 1416 B	(FLIGHT 1	10) 4	0	8	22	58	1	0	1	21	388	0
B 1412 B	1	4	0	8	26	66	1	0	1	24	173	3
C 1402 B	1	3	4	4	11	21	5	17	1	69	135	24
LINE 5 A 1705 B	(FLIGHT 1	10) 3	1	6	22	16	2	0	1	23	125	0
LINE 6 A 1860 B?	(FLIGHT 0	10) 1	0	1	7	6	1	0	1	96	170	64
B 1911 B	2	4	2	9	36	25	2	0	1	24	65	5
LINE 7 A 270 B	(FLIGHT 2	11) 11	4	23	67	94	1	0	1	19	78	4
LINE 8 A 512 B?	(FLIGHT 0	11) 1	2	4	11	9	1	0	1	27	101	2
B 534 H	1	2	3	4	16	7	3	0	1	51	128	27
LINE 10 B 843 H	(FLIGHT 0	11) 1	0	2	8	7	1	0	1	59	165	32
LINE 1100 A 1439 H	(FLIGHT 0	8) 1	0	2	6	9	1	0	1	44	796	3
B 1475 B?	1	3	1	6	22	11	3	0	1	55	59	36
C 1532 H	0	2	0	2	10	7	2	0	1	47	172	18
LINE 12 A 1276 H	(FLIGHT 1	8) 1	1	2	7	3	3	0	1	53	100	27
LINE 1300 A 1142 B	(FLIGHT 1	8) 6	1	11	33	77	1	0	1	21	215	0
B 1154 H	1	2	1	4	3	15	1	0	1	42	77	20
LINE 14 A 885 H	(FLIGHT 1	8) 1	1	2	6	4	2	0	1	19	270	0
LINE 15 A 731 B?	(FLIGHT 0	8) 1	0	2	7	7	1	0	1	45	470	8

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART
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ANOMALY/ FID/INTERP	COAXIAL 900 HZ		COPLANAR 900 HZ		COPLANAR 7200 HZ		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* M	COND MHOS	DEPTH M	RESIS OHM-M	DEPTH M
LINE 16	(FLIGHT 4)											
A 1016 B?	0	1	0	3	8	17	1	0	1	32	474	0
B 1085 H	0	1	1	2	6	8	1	11	1	113	159	83
LINE 1900	(FLIGHT 4)											
A 482 B	0	3	0	8	38	29	2	0	1	25	121	4
LINE 2000	(FLIGHT 6)											
A 149 H	0	2	0	3	7	22	1	0	1	10	1103	0
B 179 H	0	1	0	2	10	8	1	0	1	55	307	23
LINE 2200	(FLIGHT 6)											
A 548 B	2	2	0	6	11	36	1	0	1	36	458	7
LINE 23	(FLIGHT 3)											
A 715 B	2	3	2	7	17	40	1	0	1	36	278	11
B 725 H	1	2	2	3	10	23	1	0	1	61	153	35
C 761 H	1	0	1	2	7	11	1	4	1	57	522	23
LINE 2400	(FLIGHT 3)											
A 563 B	1	5	2	11	39	38	2	0	1	34	117	14
B 547 B?	0	3	0	2	3	18	1	0	1	1	2638	0
LINE 25	(FLIGHT 1)											
A 2262 B	0	3	0	6	25	52	1	0	1	26	388	1
B 2294 B?	0	0	0	0	0	4	1	0	1	114	8280	0
D 2316 B?	0	1	0	1	0	4	1	0	1	87	7422	0
LINE 26	(FLIGHT 1)											
C 1996 B	2	2	6	4	15	5	8	18	3	118	18	88
LINE 27	(FLIGHT 1)											
A 1745 B	1	4	1	7	30	49	1	0	1	24	279	0
LINE 28	(FLIGHT 1)											
A 1700 B	0	4	0	2	8	19	1	0	1	28	1006	0
D 1582 B?	0	1	0	1	0	13	1	0	1	11	5367	0
E 1557 B?	3	2	0	2	1	13	7	55	1	173	1035	0
G 1505 B?	0	1	0	1	1	10	1	0	1	78	8112	0
LINE 29	(FLIGHT 1)											
A 1272 B	1	2	0	2	7	25	1	0	1	26	1440	0

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ANOMALY/ FID/INTERP	COAXIAL 900 HZ		COPLANAR 900 HZ		COPLANAR 7200 HZ		VERTICAL DIKE	COND MHOS	DEPTH* M	HORIZONTAL SHEET		CONDUCTIVE EARTH	
	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM				COND MHOS	DEPTH M	RESIS OHM-M	DEPTH M
LINE 29	(FLIGHT 1)												
B 1307 B?	0	2	0	3	12	17	1	0	1	118	1035	0	
E 1401 B?	0	3	0	6	12	53	1	0	1	14	776	0	
LINE 30	(FLIGHT 1)												
A 1179 H	0	2	1	4	11	29	1	0	1	37	772	6	
C 1130 B?	0	1	0	2	9	14	1	0	1	176	1035	0	
E 1100 B?	0	0	0	0	0	3	1	0	1	68	6999	0	
G 1023 B?	0	3	0	5	7	42	1	0	1	11	1288	0	
LINE 31	(FLIGHT 1)												
A 732 B?	1	1	2	3	10	3	5	23	1	115	98	89	
B 764 B?	0	1	0	0	1	9	1	0	1	32	5567	0	
C 795 H	0	1	0	1	2	5	1	9	1	33	6093	0	
E 833 B?	0	1	0	2	11	13	1	8	1	37	470	7	
F 861 B?	0	3	0	5	15	26	1	0	1	32	270	8	
G 895 H	1	1	0	1	7	7	1	26	1	106	492	68	

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