REPORT ON A
COMBINED HELICOPTER-BORNE
MAGNETIC, ELECTROMAGNETIC
AND VLF-EM SURVEY
TRAIL PEAK BLOCK
PROVINCE OF BRITISH COLUMBIA
NTS 93 M/8

FOR

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MARCH 18, 1993

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J9321TP

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1. INTRODUCTION

This report describes an airborne geophysical survey carried out on behalf of Noranda Exploration Company, Limited by Aerodat Limited under a contract dated February 11, 1993. Principal geophysical sensors included a five frequency electromagnetic system, a high sensitivity cesium vapour magnetometer and a two frequency VLF-EM system. Ancillary equipment included a colour video tracking camera, a Global Positioning System for navigation, a radar altimeter, a power line monitor and a base station magnetometer.

The survey was carried out over a small block totalling about 3.5 sq. km. located approximately 90 km east northeast of Hazelton, B.C. Total survey coverage was approximately 12 line kilometres. The Aerodat Job Number is J9321.

This report describes the survey, the data processing, data presentation and interpretation of the geophysical results. Electromagnetic anomalies have been identified and appear on selected map products as EM anomaly symbols with interpreted source characteristics. Conductive areas of interest are indicated on an interpretation map with designation number or letter. Prominent structural features interpreted from the magnetic results are also indicated. Recommendations concerning areas with favourable geophysical characteristics are made with reference to this compilation/interpretation map.

2. SURVEY AREA

The survey area is located about 90 km east northeast of Hazelton just northeast of Babine Lake. Topography is shown on the 1:50,000 scale NTS map sheet 93 M/8. Local relief is moderate to rugged. Elevations range from 4,000 to 5300 feet amsl.

The survey area is shown in the attached index map which includes local topography and latitude - longitude coordinates. This index map also appears on all black line map products. The flight line directions and line spacings respectively were east-west and 400 m.

3. SURVEY PROCEDURES

The survey was flown on February 25, 1993. Principal personnel are listed in Appendix IV. A total of one survey flight was required to complete the project.

The aircraft ground speed was maintained at approximately 60 knots (30 metres per second). The nominal EM sensor height was 30 metres (100 feet), consistent with the safety of the aircraft and crew.

A global positioning system (GPS) consisting of a Trimble TANS GPS receiver plus the Polycorder data logger. Differential GPS data is processed in the field on a PC using software supplied by Trimble. One system is installed in the survey helicopter. This involves mounting the receiver antenna on the tail boom. A second system was used as the base station.

The UTM coordinates of survey area corners were taken from the published NTS maps. These coordinates are used to program the navigation system. A test flight was used to confirm that area coverage would be as required.

Thereafter the traverse lines are flown under the guidance of the navigation system. The operator also enters manual fiducials over prominent topographic features as seen on a topographic map. Survey lines which show excessive deviation were re-flown.

The magnetic tie lines were flown using visual navigation in areas of low topographic and magnetic relief. Aircraft position was taken from the navigation system.

Calibration lines are flown at the start, middle (if required) and end of every survey flight. These lines are flown outside of ground effects to record electromagnetic zero levels.

4. DELIVERABLES

The colour maps are delivered in four copies. The shadow maps are delivered in two copies. The colour maps are rolled and delivered in map tube(s).

A full list of all map types is given at the beginning of this report. A summary is given following:

MAP NO.   DESCRIPTION

         COLOUR

1   Total Field Magnetics
2   Vertical Magnetic Gradient
3A   Apparent Resistivity Contours - 800 Hz
3B   Apparent Resistivity Contours - 935 Hz
3C   Apparent Resistivity Contours - 4,175 Hz
3D   Apparent Resistivity Contours - 4,600 Hz
3E   Apparent Resistivity Contours - 32,000 Hz
4   VLF-EM Total Field
5A   HEM Offset Profiles - 800 Hz and 935 Hz
5B   HEM Offset Profiles - 4,175 Hz and 4,600 Hz
5C   HEM Offset Profiles - 32,000 Hz

5. AIRCRAFT AND EQUIPMENT

5.1 Aircraft

A ASTAR helicopter, piloted by G. Suthem owned and operated by Executive Helicopters
Ltd, was used for the survey. A. Sweet of Geonex Aerodat acted as navigator and equipment
operator. Installation of the geophysical and ancillary equipment was carried out by Aerodat.
The survey aircraft was flown at a mean terrain clearance of 60 metres (200 feet).

5.2 Electromagnetic System

The electromagnetic system was an Aerodat 5 frequency system. Two vertical coaxial coil
pairs were operated at 935 Hz and 4,600 Hz and three horizontal coplanar coil pairs at 800
Hz 4,175 Hz and 32 kHz. The transmitter-receiver separation was 7 metres. Inphase and
quadrature signals were measured simultaneously for the 5 frequencies with a time constant of
0.1 seconds. The HEM bird was towed 30 metres (100 feet) below the helicopter.

5.3 VLF-EM System

The VLF-EM System was a Herz Totem 2A. This instrument measures the total field and
vertical quadrature components of two selected frequencies. The sensor was towed in a bird
10 metres below the helicopter.

VLF transmitters are designated "Line" and "Ortho". The line station is that which is in a
direction from the survey area which is ideally normal to the flight line direction. This is the
VLF station most often used because of optimal coupling with near vertical conductors
running perpendicular to the flight line direction . The ortho station is ideally 90 degrees in
azimuth away from the line station.

The transmitters used were:

NLK, Jim Creek, Washington broadcasting at 24.8 kHz. (ortho)

NSS, Annapolis, Maryland broadcasting at 21.4 kHz. (line)

5.4 Magnetometer

The magnetometer employed was a Scintrex H8 cesium, optically pumped magnetometer sensor. The sensitivity of this instrument is 0.001 nanoTesla at a 0.2 second sampling rate. The sensor was towed in a bird 15 metres (50 feet) below the helicopter (45 metres (150 feet) above the ground).

5.5 Ancillary Systems

Base Station Magnetometer

An IFG-2 proton precession magnetometer was operated at the base of operations (Babine Lake Lodge) to record diurnal variations of the earth's magnetic field. The clock of the base station was synchronized with that of the airborne system to facilitate later correlation. Recording resolution was 1 nT. The update rate was 4 seconds.

External magnetic field variations were recorded on a 3" wide paper chart and in digital form. The analog record shows the magnetic field trace plotted on a grid. Each division of the grid (0.25") is equivalent to 1 minute (chart speed) or 5 nT (vertical sensitivity). The date, time and current total field magnetic value are printed every 10 minutes.

Radar Altimeter

A King KRA-10 radar altimeter was used to record terrain clearance. The output from the instrument is a linear function of altitude. The radar altimeter is checked after installation using a line marked off at intervals of 100, 150, 200 and 245 ft. A heavy weight is tied onto one end of the line. The helicopter moves up over the weight and the operator notes the radar altimeter reading at the 100, 150, 200 and 250 foot marks.

Tracking Camera

A Panasonic colour video camera was used to record flight path on VHS video tape. The camera was operated in continuous mode. The flight number, 24 hour clock time (to .01 second), and manual fiducial number are encoded on the video tape.

Global Positioning System (GPS)

The Global Positioning System is a U.S. Department of Defense program which will provide world-wide, 24 hour, all weather position determination capability . GPS consists of three segments:

- a constellation of satellites
- ground stations which control the satellites
- a receiver

The receiver takes in coded data from satellites in view and there after works out the range to each satellite. The coded data must therefore include the instantaneous position of the satellite relative to some agreed earth-fixed coordinate system.

The final satellite constellation will consist of 24 satellites with a proportion of the satellites acting as standby spares.

Analog Recorder

A RMS dot matrix recorder was used to display the data during the survey. Record contents are as follows:

Label	Contents	Scale
MAGF	Total Field Magnetics, Fine	2.5 nT/mm
MAGC	Total Field Magnetics, Course	25 nT/mm
VLT	VLF-EM, Total Field, Line Station	2.5% / mm
VLQ	VLF-EM, Vert. Quadrature, Line Station	2.5% / mm
VOT	VLF-EM, Total Field, Ortho Station	2.5% / mm
VOQ	VLF-EM, Vert. Quadrature, Ortho Station	2.5% / mm
CXI1	935 Hz, Coaxial, Inphase	2.5 ppm/mm
CXQ1	935 Hz, Coaxial, Quadrature	2.5 ppm/mm
CXI2	4,600 Hz, Coaxial, Inphase	2.5 ppm/mm
CXQ2	4,600 Hz, Coaxial, Quadrature	2.5 ppm/mm
CPI1	800 Hz, Coplanar, Inphase	10 ppm/mm
CPQ1	800 Hz, Coplanar, Quadrature	10 ppm/mm
CPI2	4,175 Hz, Coplanar, Inphase	10 ppm/mm
CPQ2	4,175 Hz, Coplanar, Quadrature	10 ppm/mm
CPI3	32,000 Hz, Coplanar, Inphase	20 ppm/mm
CPQ3	32,000 Hz, Coplanar, Quadrature	20 ppm/mm
RALT	Radar Altimeter	10ft/mm
PWRL	60 Hz Power Line Monitor	-

Data is recorded with positive - up, negative - down. This does not apply to the VLF data as seen on the analog records which is inverted.

The analog zero of the radar altimeter is 5 cm from the top of the analog record. A helicopter terrain clearance of 60 m (200 feet) should therefore be seen some 3 cm from the top of the analog record.

Chart speed is 2 mm/second. The 24 hour clock time is printed every 20 seconds. The total magnetic field value is printed every 30 seconds. The ranges from the radar navigation system are printed every minute.

Vertical lines crossing the record are operator activated manual fiducial markers. The start of any survey line is identified by two closely spaced manual fiducials. The end of any survey line is identified by three closely spaced manual fiducials. Manual fiducials are numbered in order. Every tenth manual fiducial is indicated by its number, printed at the bottom of the record.

Calibration sequences are located at the start and end of each flight and at intermediate times where needed.

Digital Recorder

A DGR-33 data system recorded the digital survey data on magnetic media. Contents and update rates were as follows:

DATA TYPE	RECORDING INTERVAL	RECORDING RESOLUTION
Magnetometer	0.2 s	0.001 nT
VLF-EM (4 Channels)	0.2 s	0.03%
HEM (8 Channels)	0.1 s	
coaxial		0.03 ppm
coplanar-865 Hz/4,175 Hz		0.06 ppm
coplanar -32 kHz		0.125 ppm
Position (2 Channels)	0.2 s	0.1 m
Altimeter	0.2 s	0.05 m
Power Line Monitor	0.2 s	-
Manual Fiducial		
Clock Time		

6. DATA PROCESSING AND PRESENTATION

6.1 Base Map

The base map is taken from a photographic enlargement of the NTS topographic maps. A UTM reference grid (grid lines usually every kilometre) and the survey area boundary were added. After registration of the flight path to the topographic base map, topographic detail and the survey boundary are digitized. This digital image of the base map is used as the base for the colour and shadow maps.

6.2 Flight Path Map

Global Positioning System

The GPS receiver takes in coded data from satellites in view and there after works out the range to each satellite. The coded data must therefore include the instantaneous position of the satellite relative to some agreed earth-fixed coordinate system.

A further calculation using ranges to a number of satellites gives the position of the receiver in that coordinate system (eg. UTM, lat/long.). The elevation of the receiver is given with respect to a model ellipsoidal earth.

Normally the receiver must see 4 satellites for a full positional determination (3 space coordinates and time). If the elevation is know in advance, only 3 satellites are needed. These are termed 3D and 2D solutions.

The position of the receiver is updated every second. The accuracy of any 1 second position determination is described by the Circular Error Probability (CEP) . 95% of all position determinations will fall with a circle of a certain radius. If the horizontal position accuracy is 25 m CEP for example, 95% of all trials will fall within a circle of 25 m radius centred on the mean. The system may be degraded for civilian use and the autonomous accuracy is then 100 m CEP. This situation is called selective availability (SA). Much of this error (due to principally to satellite position/time errors and atmospheric delays) can be removed using two GPS receivers operating simultaneously. One receiver acting as the base station, is located at a known position. The second remote receiver is in the unknown position. Differential corrections determined for the base station may then be applied to the remote station. Differential positions are accurate to 5 m CEP (for a one second sample). Averaging will reduce this error further.

Flight Path

The flight path is drawn using linear interpolation between x,y positions from the navigation system. These positions are updated every second (or about 1.5 mm at a scale of 1:20,000). These positions are expressed as UTM eastings (x) and UTM northings (y).

Occasional dropouts occur when the optimum number of satellites are not available for the GPS to make accurate positional determinations. Interpolation is used to cover short flight path gaps. The navigator's flight path and/or the flight path recovered from the video tape may be stitched in to cover larger gaps. Such gaps may be recognized by the distinct straight line character of the flight path.

The manual fiducials are shown as a small circle and labelled by fiducial number. The 24 hour clock time is shown as a small square, plotted every 30 seconds. Small tick marks are plotted every 2 seconds. Larger tick marks are plotted every 10 seconds. The line and flight numbers are given at the start and end of each survey line.

The flight path map is merged with the base map by matching UTM coordinates from the base maps and the flight path record. The match is confirmed by checking the position of prominent topographic features as recorded by manual fiducial marks or as seen on the flight path video record.

6.3 Electromagnetic Survey Data

The electromagnetic data were recorded digitally at a sample rate of 10 per second with a time constant of 0.1 seconds. A two stage digital filtering process was carried out to reject major sferic events and to reduce system noise.

Local sferic activity can produce sharp, large amplitude events that cannot be removed by conventional filtering procedures. Smoothing or stacking will reduce their amplitude but leave a broader residual response that can be confused with geological phenomena. To avoid this possibility, a computer algorithm searches out and rejects the major sferic events. The signal to noise ratio was further enhanced by the application of a low pass digital filter. This filter has zero phase shift which prevents any lag or peak displacement from occurring, and it suppresses only variations with a wavelength less than about 0.25 seconds. This low effective time constant gives minimal profile distortion.

Following the filtering process, a base level correction was made using EM zero levels determined during high altitude calibration sequences. The correction applied is a linear function of time that ensures the corrected amplitude of the various inphase and quadrature components is zero when no conductive or permeable source is present. The filtered and levelled data were used in the determination of apparent resistivity (see below).

6.4 Total Field Magnetics

The aeromagnetic data were corrected for diurnal variations by adjustment with the recorded base station magnetic values. No corrections for regional variations were applied. The corrected profile data were interpolated on to a regular grid using an Akima spline technique. The grid provided the basis for threading the presented contours. The minimum contour interval is 5 nT. A grid cell size of 25 m was used.

6.5 Vertical Magnetic Gradient

The vertical magnetic gradient was calculated from the gridded total field magnetic data. The calculation is based on a 17 x 17 point convolution in the space domain. The results are contoured using a minimum contour interval of 0.2 nT/m. Grid cell sizes are the same as those used in processing the total field data.

6.6 Apparent Resistivity

The apparent resistivity is calculated by assuming a 200 metre thick conductive layer over resistive bedrock. The computer determines the resistivity that would be consistent with the sensor elevation and recorded inphase and quadrature response amplitudes at the selected frequency. The apparent resistivity profile data was re-interpolated onto a regular grid at a 25 metres true scale interval using an Akima spline technique and contoured using logarithmically arranged contour intervals. The minimum contour interval is 0.1 log(ohm.m).

The highest measurable resistivity is approximately equal to the transmitter frequency. The lower limit on apparent resistivity is rarely reached.

6.7 VLF-EM

The VLF Total Field data from the Line Station is levelled such that a response of less than 0% is seen in non-anomalous regions. The corrected profile data are interpolated onto a regular grid using an Akima spline technique. The grid provided the basis for threading the presented contours. The minimum contour interval is 1%. Grid cell size is 25 m.

7. INTERPRETATION

7.1 Regional Geology

The survey area is located within the Intermontane Belt on the Skeena Arch. The belt is composed principally of eugeosynclinal volcanic and clastic rocks of Late Palaeozoic, Triassic and Jurassic age. Deformation consists of moderate folding, transcurrent boundary faults, thrusting and normal faulting.

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7.2 Magnetic Interpretation

The total field magnetic responses reflect major changes in the magnetite content of the underlying rock units. The amplitude of the magnetic responses relative to the regional background help to assist in identifying specific magnetic and non-magnetic units related to, for example, mafic flows or tuffs, mafic to ultramafic intrusives, felsic intrusives, felsic volcanics and/or sediments etc. Obviously, several geological sources can produce the same magnetic response. These ambiguities can be reduced considerably if basic geological information on the area is available to the geophysical interpreter.

In addition to amplitude variations, magnetic patterns related to the geometry of the particular rock unit also help in determining the probable source of the magnetic response. For instance, long narrow magnetic linears usually reflect mafic tuff/flow horizons or intrusive dyke structures while semi-circular features with complex magnetic amplitudes may be produced by local plug-like intrusive sources such as pegmatites, carbonatites or kimberlites.

The calculated vertical magnetic gradient assists considerably in mapping weaker magnetic linears that are partially masked by nearby higher amplitude magnetic features. The broad zones of higher magnetic amplitude, however, are severely attenuated in the vertical magnetic gradient results. These higher amplitude zones reflect rock units having magnetic susceptibility signatures. For this reason both the total and gradient magnetic data sets must be evaluated.

Theoretically the zero contour of the magnetic gradient map marks the contacts or limits of large magnetic sources. This applies to wide sources, greater than 50 metres, having simple slab geometries and shallow depth.(See discussion in Appendix I) Thus the gradient map also aids in the more accurate delineation of contacts between differing magnetic rock units.

The cross cutting structures, shown on the interpretation map as faults, are based on interruptions and discontinuities in the magnetic trends. Generally, sharp folding of magnetic units will produce a magnetic pattern indistinguishable from a fault break. Thus these structures have been designated as fold/fault features.

7.3 Magnetic Survey Results and Conclusions

To facilitate the following discussion of the magnetic results it is suggested that the interpretation map be compared with the total field and vertical gradient magnetic colour contour maps either as overlays or side by side.

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An interpretation map for this block is not warranted because of the limited geophysical coverage. Obviously a particular geological environment is being tested for its geophysical response or the survey covers a small claim block. The magnetics over the Trail Peak block show a high amplitude circular magnetic anomaly and peripheral weaker anomalies suggestive of a mafic intrusive plug source. There are some weak poor conductivity conductive responses either side of the major magnetic anomaly but there is no specific correlation with the magnetic responses.

7.4 Electromagnetic Anomaly Selection/Interpretation

Usually two sets of stacked colour coded profile maps of one coaxial and one coplanar inphase and quadrature responses are used to select conductive anomalies of interest. Selection of anomalies is based on conductivity as indicated by the inphase to quadrature ratios of the 935 Hz, and/or 4,600 Hz coaxial data, anomaly shape, and anomaly profile characteristics relative to coaxial and corresponding coplanar responses (see discussion and figure in Appendix I). It is difficult to differentiate between responses associated with the edge effects of flat lying conductors and actual poor conductivity bedrock conductors on the edge of or overlain by flat lying conductors. Poor conductivity bedrock conductors having low dips will also exhibit responses that may be interpreted as surficial overburden conductors. In such cases, where the source of the conductive response appears to be ambiguous, the anomaly is still selected for plotting. In some situations the conductive response has line to line continuity and some magnetic association thus providing possible evidence that the response is related to an actual bedrock source.

The calculation of the depth to the conductive source and its conductivity is based on the 935 Hz data using a thin vertical sheet model. The amplitude of the inphase and quadrature responses are used for the calculations which are automatically determined by computer. These data are listed in Appendix II and the depth and conductivity values are shown with each plotted anomaly. Further detailed discussion and illustration of the determination of these values is contained in Appendix I.

The selected anomalies are automatically categorized according to their conductivity and amplitude. The calculation of the conductivity of low amplitude anomalies can be very inaccurate. Therefore, anomalies having amplitudes below a certain level and/or low conductivity value are given a zero rating with the category increasing for increasing conductivity values that are statistically reliable.

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7.5 VLF Electromagnetic Survey

This high frequency type of survey, utilizing fixed government communication transmitter stations, tends to detect long strike length and/or surficial poor conductivity sources such as swamps, creeks and rivers. Conductors that are optimum coupled with the primary field will usually predominate over those with other strike directions. In some instances anomalies will be produced by variations in topographic relief. This appears to be the case for this survey where most of the VLF anomalies are associated with topographic highs.

## 7.6 Electromagnetic Survey Results and Conclusions

As mentioned in the section on the magnetic results, only weak poor conductivity responses were detected on the Trail Peak block.

8. RECOMMENDATIONS

Local geological information or the ore target model for the survey area was not made available to the author. The survey area is quite small but contains a local magnetic anomaly and some poor conductivity responses. The significance of the geophysical results is best assessed by Noranda personnel with more intimate geological knowledge of the areas.

Respectfully submitted,
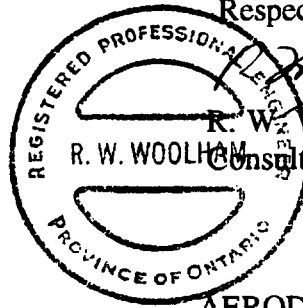
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for

AERODAT LIMITED

J9321

March 18, 1993

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APPENDIX I

GENERAL INTERPRETIVE CONSIDERATIONS

APPENDIX I

GENERAL INTERPRETIVE CONSIDERATIONS

Electromagnetic

The Aerodat four frequency system utilizes two different transmitter-receiver coil geometries. The traditional coaxial coil configuration is operated at two widely separated frequencies. The horizontal coplanar coil configuration is similarly operated at two different frequencies where at least one pair is approximately aligned with one of the coaxial frequencies.

The electromagnetic response measured by the helicopter system is a function of the "electrical" and "geometrical" properties of the conductor. The "electrical" property of a conductor is determined largely by its electrical conductivity, magnetic susceptibility and its size and shape; the "geometrical" property of the response is largely a function of the conductor's shape and orientation with respect to the measuring transmitter and receiver.
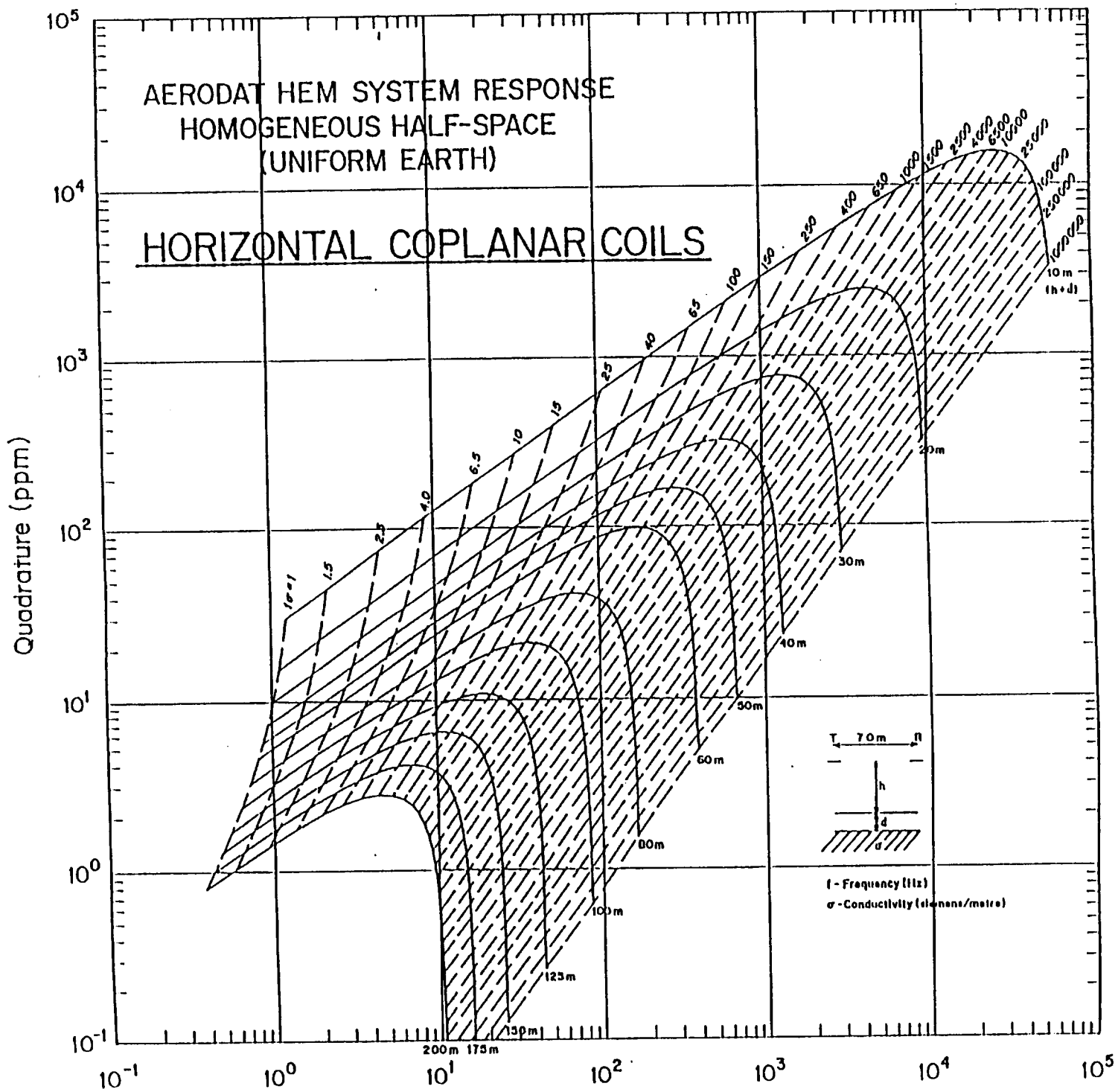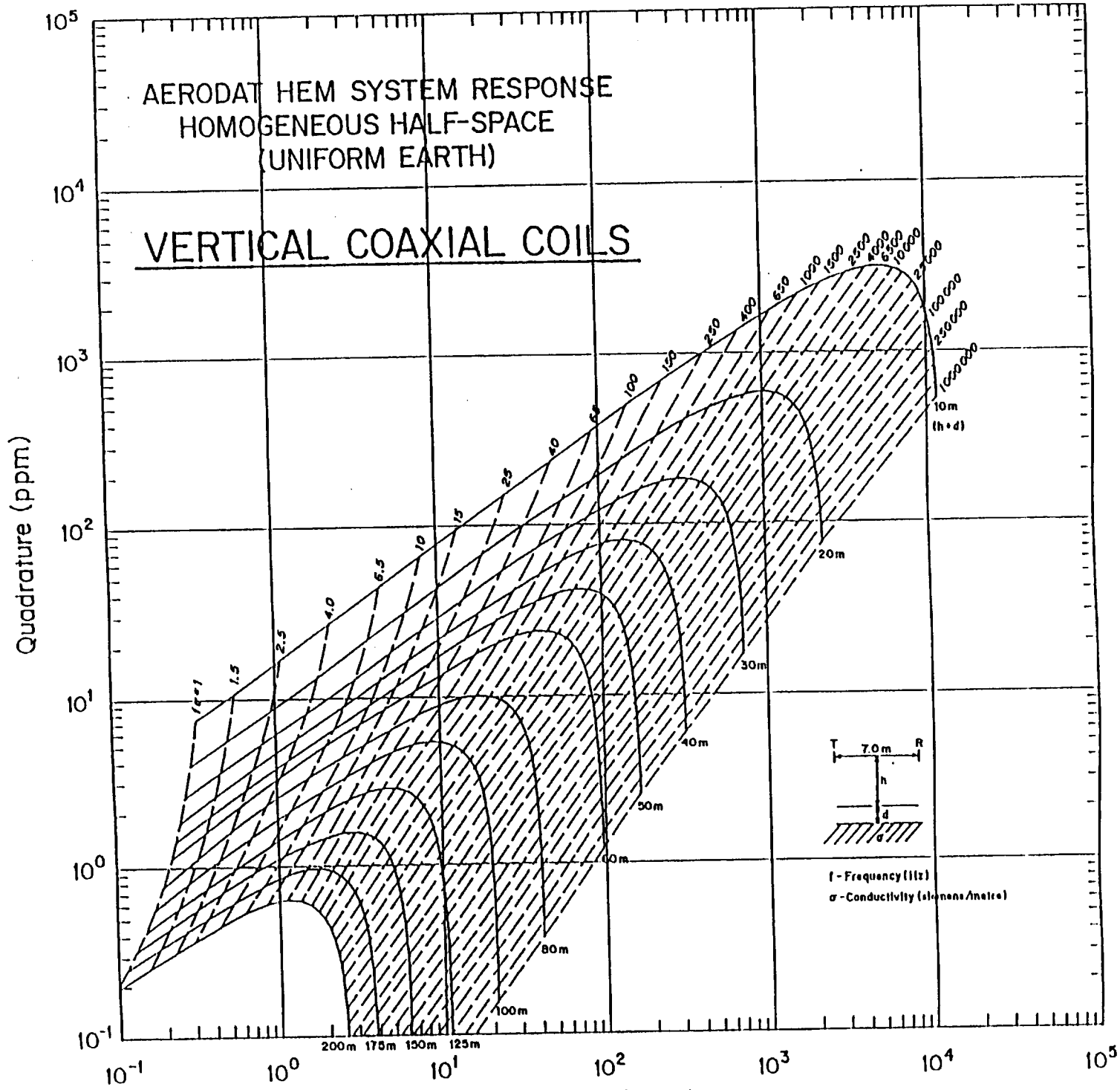
Electrical Considerations

For a given conductive body the measure of its conductivity or conductance is closely related to the measured phase shift between the received and transmitted electromagnetic field. A small phase shift indicates a relatively high conductance, a large phase shift lower conductance. A small phase shift results in a large inphase to quadrature ratio and a large phase shift a low ratio. This relationship is shown quantitatively for non-magnetic vertical half-plane and half-space models on the accompanying phasor diagrams. Other physical models will show the same trend but different quantitative relationships.
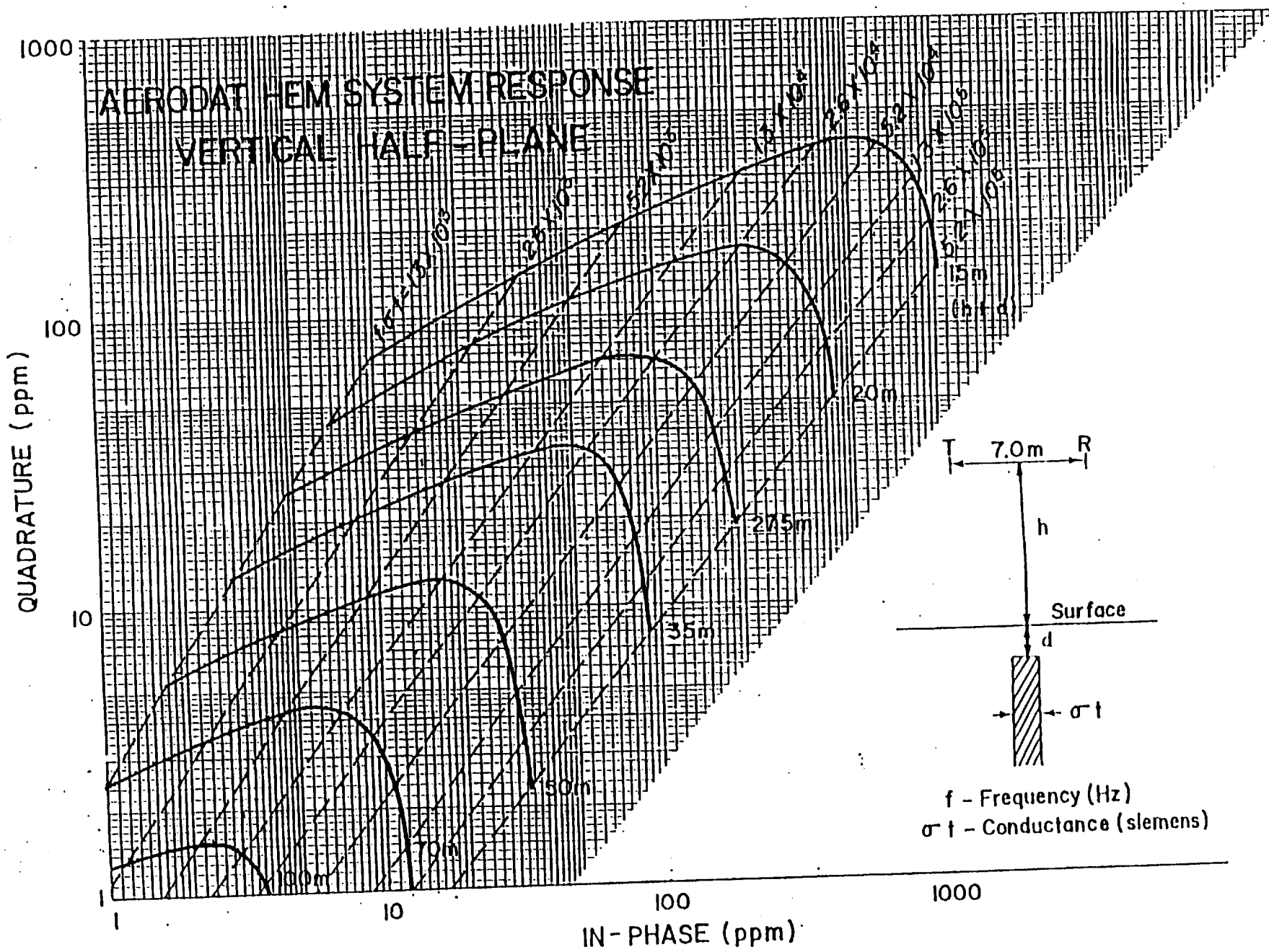
The phasor diagram for the vertical half-plane model, as presented, is for the coaxial coil configuration with the amplitudes in parts per million (ppm) of the primary field as measured at the response peak over the conductor. To assist the interpretation of the survey results the computer is used to identify the apparent conductance and depth of selected anomalies. The results of this calculation are presented in anomaly listings included in the survey report and the conductance and inphase amplitude are presented in symbolized form on the map presentation.

The conductance estimate is most reliable when anomaly amplitudes are large and background resistivities are high. Where the EM anomaly is of low amplitude and background resistivities are low, the conductance estimates are much less reliable. In such situations, the conductance estimate is often quite low regardless of the true nature of the conductor. This is due to the elevated background response levels in the quadrature channel. In an extreme case, the conductance estimate should be discounted and should not prejudice target selection.

The conductance and depth values as presented are correct only as far as the model approximates the real geological situation. The actual geological source may be of limited length, have significant dip, or may be strongly magnetic. Its conductivity and thickness may vary with depth

AERODAT HEM SYSTEM RESPONSE
HOMOGENEOUS HALF-SPACE
(UNIFORM EARTH)

HORIZONTAL COPLANAR COILS

AERODAT HEM SYSTEM RESPONSE
HOMOGENEOUS HALF-SPACE
(UNIFORM EARTH)

VERTICAL COAXIAL COILS

AERODAT HEM SYSTEM RESPONSE
VERTICAL HALF-PLANE

QUADRATURE (ppm)

IN-PHASE (ppm)

f - Frequency (Hz)
σ t - Conductance (siemens)

and/or strike and adjacent bodies and overburden may have modified the response. In general the conductance estimate is less affected by these limitations than is the depth estimate, but both should be considered as relative rather than absolute guides to the anomaly's properties.

Conductance in mhos is the reciprocal of resistance in ohms and in the case of narrow slab-like bodies is the product of electrical conductivity and thickness.

The higher ranges of conductance, greater than 2-4 mhos, indicate that a significant fraction of the electrical conduction is electronic rather than electrolytic in nature. Materials that conduct electronically are limited to certain metallic sulphides and to graphite. High conductance anomalies, roughly 10 mhos or greater, are generally limited to massive sulphides or graphites.

Sulphide minerals, with the exception of such ore minerals as sphalerite, cinnabar and stibnite, are good conductors. Sulphides may occur in a disseminated manner that inhibits electrical conduction through the rock mass. In this case the apparent conductance can seriously underrate the quality of the conductor in geological terms. In a similar sense the relatively non-conducting sulphide minerals noted above may be present in significant concentrations in association with minor conductive sulphides, and the electromagnetic response will only relate to the minor associated mineralization. Indicated conductance is also of little direct significance for the identification of gold mineralization. Although gold is highly conductive, it would not be expected to exist in sufficient quantity to create a recognizable anomaly. Minor accessory sulphide mineralization may however provide a useful indirect indication.

In summary, the estimated conductance of a conductor can provide a relatively positive identification of significant sulphide or graphite mineralization. A moderate to low conductance value does not rule out the possibility of significant economic mineralization.
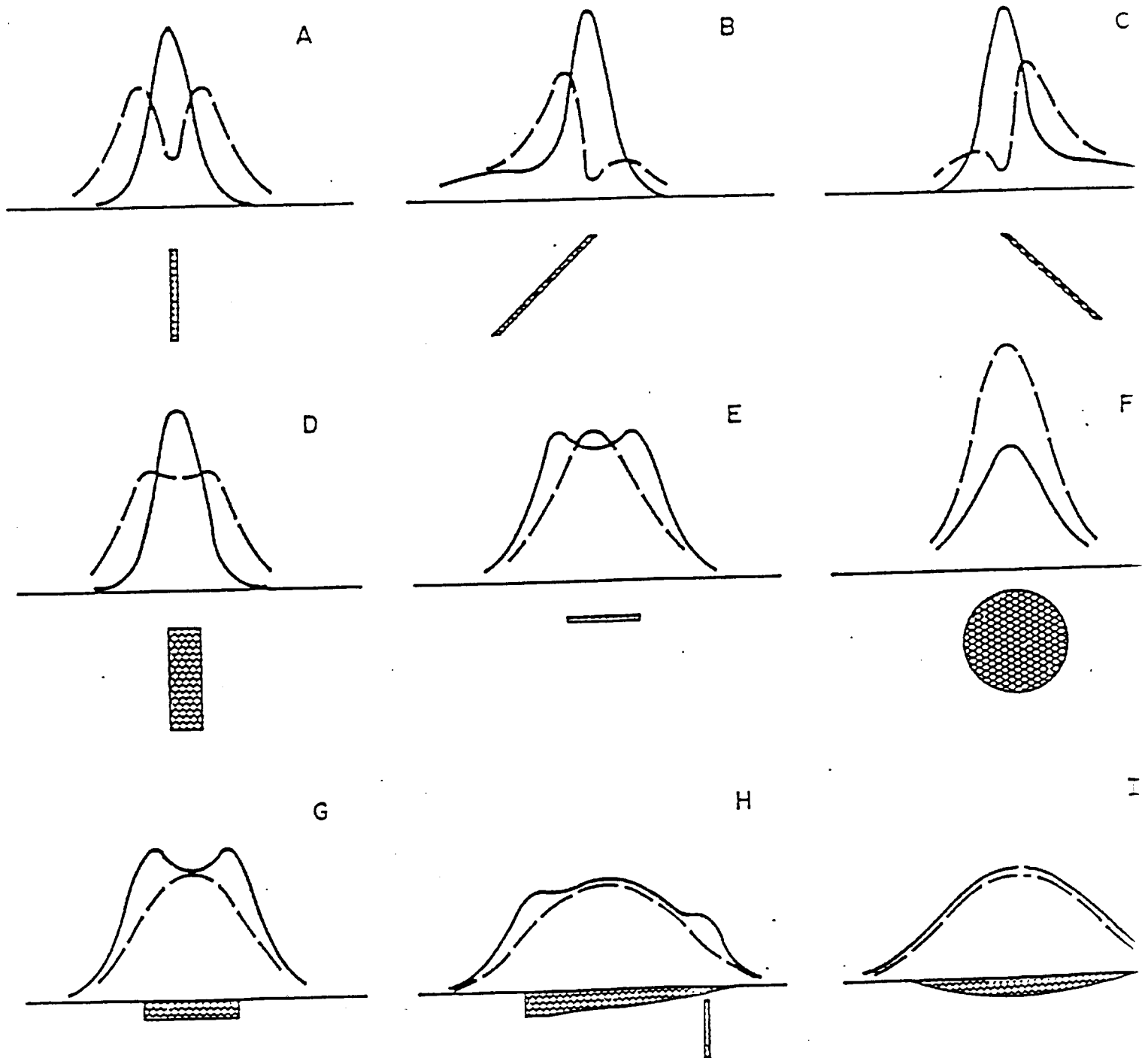
Geometrical Considerations

Geometrical information about the geologic conductor can often be interpreted from the profile shape of the anomaly. The change in shape is primarily related to the change in inductive coupling among the transmitter, the target, and the receiver. The accompanying figure shows a selection of HEM response profile shapes from nine idealized targets. Response profiles are labelled A through I. These labels are used in the discussion which follows.

In the case of a thin, steeply dipping, sheet-like conductor, the coaxial coil pair will yield a near symmetric peak over the conductor. On the other hand, the coplanar coil pair will pass through a null couple relationship and yield a minimum over the conductor, flanked by positive side lobes.(Profile A) As the dip of the conductor decrease from vertical, the coaxial anomaly shape changes only slightly, but in the case of the coplanar coil pair the side lobe on the down dip side strengthens relative to that on the up dip side.(Profiles B and C).

As the thickness of the conductor increases, induced current flow across the thickness of the

HEM RESPONSE PROFILE SHAPE AS AN INDICATOR OF CONDUCTOR GEOMETRY

———————— COAXIAL   vertical scale 1 ppm/unit

— — — — COPLANAR vertical scale 4 ppm/unit

conductor becomes relatively significant and complete null coupling with the coplanar coils is no longer possible.(Profile D) As a result, the apparent minimum of the coplanar response over the conductor diminishes with increasing thickness, and in the limiting case of a fully 3 dimensional body or a horizontal layer or half-space, the minimum disappears completely.

A horizontal conducting layer such as a horizontal thin sheet or overburden will produce a response in the coaxial and coplanar coils that is a function of altitude (and conductivity if not uniform). The profile shape will be similar in both coil configurations with an amplitude ratio (coplanar:coaxial) of about 4:1*.(Profiles E and G).

In the case of a spherical conductor, the induced currents are confined to the volume of the sphere, but not relatively restricted to any arbitrary plane as in the case of a sheet-like form. The response of the coplanar coil pair directly over the sphere may be up to 8* times greater than that of the coaxial pair.(Profile F)

In summary, a steeply dipping, sheet-like conductor will display a decrease in the coplanar response coincident with the peak of the coaxial response. The relative strength of this coplanar null is related inversely to the thickness of the conductor. A pronounced null indicates a relatively thin conductor. The dip of such a conductor can be inferred from the relative amplitudes of the side-lobes.

Massive conductors that could be approximated by a conducting sphere will display a simple single peak profile form on both coaxial and coplanar coils, with a ratio between the coplanar to coaxial response amplitudes as high as 8*.

Overburden anomalies often produce broad poorly defined anomaly profiles.(Profile I) In most cases, the response of the coplanar coils closely follows that of the coaxial coils with a relative amplitude ratio of 4*.

Occasionally, if the edge of an overburden zone is sharply defined with some significant depth extent, an edge effect will occur in the coaxial coils. In the case of a horizontal conductive ring or ribbon, the coaxial response will consist of two peaks, one over each edge; whereas the coplanar coil will yield a single peak.(Profile H)

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The Total Field Magnetic Map shows contours of the total magnetic field, uncorrected for regional variation. Whether an EM anomaly with a magnetic correlation is more likely to be

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The interpretation of contoured aeromagnetic data is a subject on its own involving an array of methods and attitudes. The interpretation of source characteristics for example from total field results is often based on some numerical modelling scheme. The vertical gradient data is more legible in some aspects however and useful inferences about source characteristics can often be read off the contoured VG map.

The zero contour lines in contoured VG data are often sited as a good approximation to the outline of the top of the magnetic source. This only applies to wide (relative to depth of burial) near vertical sources at high magnetic latitudes. It will give an incorrect interpretation in most other cases.
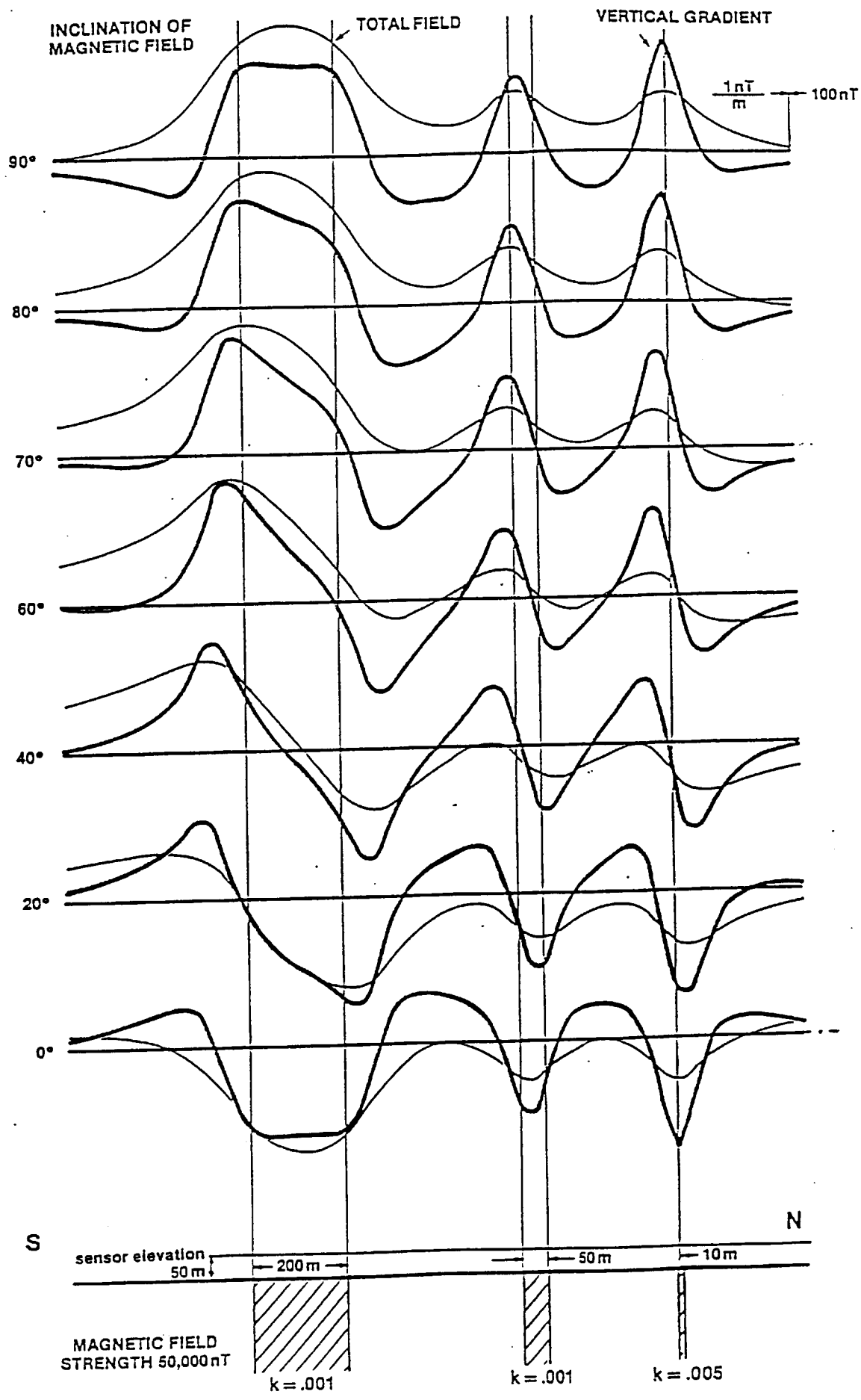
Theoretical profiles of total field and vertical gradient anomalies from tabular sources at a variety of magnetic inclinations are shown in the attached figure. Sources are 10, 50 and 200 m wide. The source-sensor separation is 50 m. The thin line is the total field profile. The thick line is the vertical gradient profile.

The following comments about source geometry apply to contoured vertical gradient data for magnetic inclinations of 70 to 80°.

Outline

Where the VG anomaly has a single sharp peak, the source may be a thin near-vertical tabular source. It may be represented as a magnetic axis or as a tabular source of measureable width - the choice is one of geological preference.

Where the VG anomaly has a broad, flat or inclined top, the source may be a thick tabular source. It may be represented as a thick body where the width is taken from the zero contour lines if the body dips to magnetic north. If the source appears to be dipping to the south (i.e. the VG anomaly is asymmetric), the zero contours are less reliable indicators of outline. The southern most zero contour line should be ignored and the outline taken from the northern zero contour line and the extent of the anomaly peak width.

INCLINATION OF MAGNETIC FIELD   TOTAL FIELD   VERTICAL GRADIENT

$\frac{1 nT}{m}$ → 100nT

90°
80°
70°
60°
40°
20°
0°

S   N

sensor elevation 50 m↓ |← 200 m →| |← 50 m →| |← 10 m →|

MAGNETIC FIELD STRENGTH 50,000 nT

k = .001   k = .001   k = .005

Dip

A symmetrical vertical gradient response is produced by a body dipping to magnetic north. An asymmetrical response is produced by a body which is vertical or dipping to the south. For southern dips, the southern most zero contour line may be several hundred meters south of the source.

Depth of Burial

The source-sensor separation is about equal to half of the distance between the zero contour lines for thin near-vertical sources. The estimated depth of burial for such sources is this separation minus 50 m. If a variety of VG anomaly widths are seen in an area, use the narrowest width seen to estimate local depths.

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The Herz Totem uses three coils in the X, Y, Z configuration to measure the total field and vertical quadrature component from two VLF stations. These stations are designated Line and Ortho. The line station is ideally in a direction from the survey area at right angles to the flight line direction. Conductors normal to the flight line direction point at the line station and are therefore optimally coupled to VLF magnetic fields and in the best situation to gather secondary VLF currents. The ortho station is ideally 90 degrees in azimuth from the line station.

The relatively high frequency of VLF (15-25) kHz provides high response factors for bodies of low conductance. Relatively "disconnected" sulphide ores have been found to produce measurable VLF signals. For the same reason, poor conductors such as sheared contacts, breccia zones, narrow faults, alteration zones and porous flow tops normally produce VLF anomalies. The method can therefore be used effectively for geological mapping. The only relative disadvantage of the method lies in its sensitivity to conductive overburden. In conductive ground the depth of exploration is severely limited.

The effect of strike direction is important in the sense of the relation of the conductor axis relative to the energizing electromagnetic field. A conductor aligned along a radius drawn from a transmitting station will be in a maximum coupled orientation and thereby produce a stronger response than a similar conductor at a different strike angle. Theoretically, it would be possible for a conductor, oriented tangentially to the transmitter to produce no signal. The most obvious effect of the strike angle consideration is that conductors favourably oriented with respect to the transmitter location and also near perpendicular to the flight direction are most clearly rendered and usually dominate the map presentation.

The total field anomaly is an indicator of the existence and position of a conductor. The response will be a maximum over the conductor, without any special filtering, and strongly favour the upper edge of the conductor even in the case of a relatively shallow dip.

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As noted, VLF anomaly trends show a strong bias towards the VLF transmitter. Structure which is normal to this direction may have no associated VLF anomaly but may be seen as a break or interruption in VLF anomalies. If these structures are of particular interest, maps of the ortho station data may be worthwhile.

Conductive overburden will obscure VLF responses from bedrock sources and may produce low amplitude, broad anomalies which reflect variations in the resistivity or thickness of the overburden.

Extreme topographic relief will produce VLF anomalies which may bear no relationship to variations in electrical conductivity. Deep gullies which are too narrow to have been surveyed at a uniform sensor height often show up as VLF total field lows. Sharp ridges show up as total field highs.

The vertical quadrature component over steeply dipping sheet-like conductor will be a cross-over type response with the cross-over closely associated with the upper edge of the conductor.

The response is a cross-over type due to the fact that it is the vertical rather than total field quadrature component that is measured. The response shape is due largely to geometrical rather than conductivity considerations and the distance between the maximum and minimum on either side of the cross-over is related to target depth. For a given target geometry, the larger this distance the greater the depth.

The vertical quadrature component is rarely presented. Experience has shown the total field to be more sensitive to bedrock conductors and less affected by variations in conductive overburden.
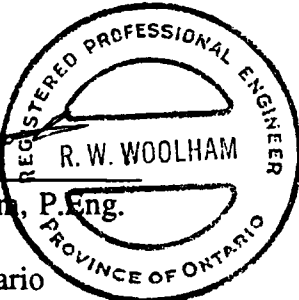

AERODAT LIMITED
June, 1991.

APPENDIX III

CERTIFICATE OF QUALIFICATION

I, Roderick W. Woolham of the town of Pickering, Province of Ontario, do hereby certify that:-

1.   I am a geophysicist and reside at 1463 Fieldlight Blvd., Pickering, Ontario, L1V 2S3

2.   I graduated from the University of Toronto in 1961 with a degree of Bachelor of Applied Science, Engineering Physics, Geophysics Option. I have been practising my profession since graduation.

3.   I am a member in good standing of the following organizations: The Association of Professional Engineers of the Province of Ontario (Mining Branch); Society of Exploration Geophysicists; South African Geophysical Association.

4.   I have not received, nor do I expect to receive, any interest, directly or indirectly, in the properties or securities of Noranda Exploration Company, Ltd. or any affiliate.

5.   The statements contained in this report and the conclusions reached are based upon evaluation and review of maps and information supplied by Aerodat.

6.   I consent to the use of this report in submissions for assessment credits or similar regulatory requirements.

R. W. Woolham, P.Eng.

Pickering, Ontario

March 18, 1993

APPENDIX IV

PERSONNEL

FIELD

       Flown   Feb. 24 to Feb 25, 1993

       Pilot(s)   G. Suthern

       Operator(s)   A. Sweet

OFFICE

       Processing   Sandra Takata
                        George McDonald

       Report   R. W. Woolham

APPENDIX I

GENERAL INTERPRETIVE CONSIDERATIONS

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GENERAL INTERPRETIVE CONSIDERATIONS

Electromagnetic

The Aerodat four frequency system utilizes two different transmitter-receiver coil geometries. The traditional coaxial coil configuration is operated at two widely separated frequencies. The horizontal coplanar coil configuration is similarly operated at two different frequencies where at least one pair is approximately aligned with one of the coaxial frequencies.

The electromagnetic response measured by the helicopter system is a function of the "electrical" and "geometrical" properties of the conductor. The "electrical" property of a conductor is determined largely by its electrical conductivity, magnetic susceptibility and its size and shape; the "geometrical" property of the response is largely a function of the conductor's shape and orientation with respect to the measuring transmitter and receiver.
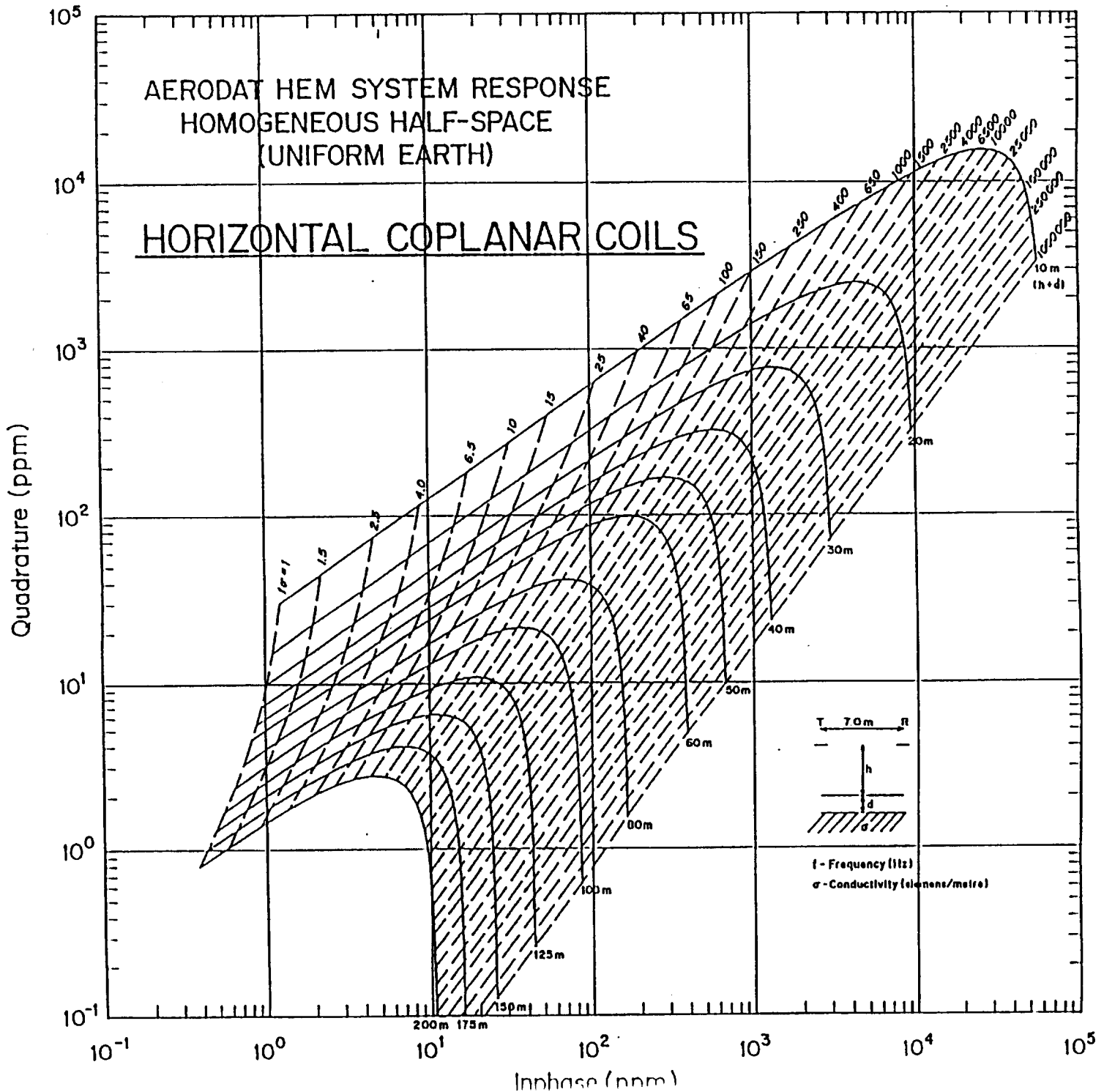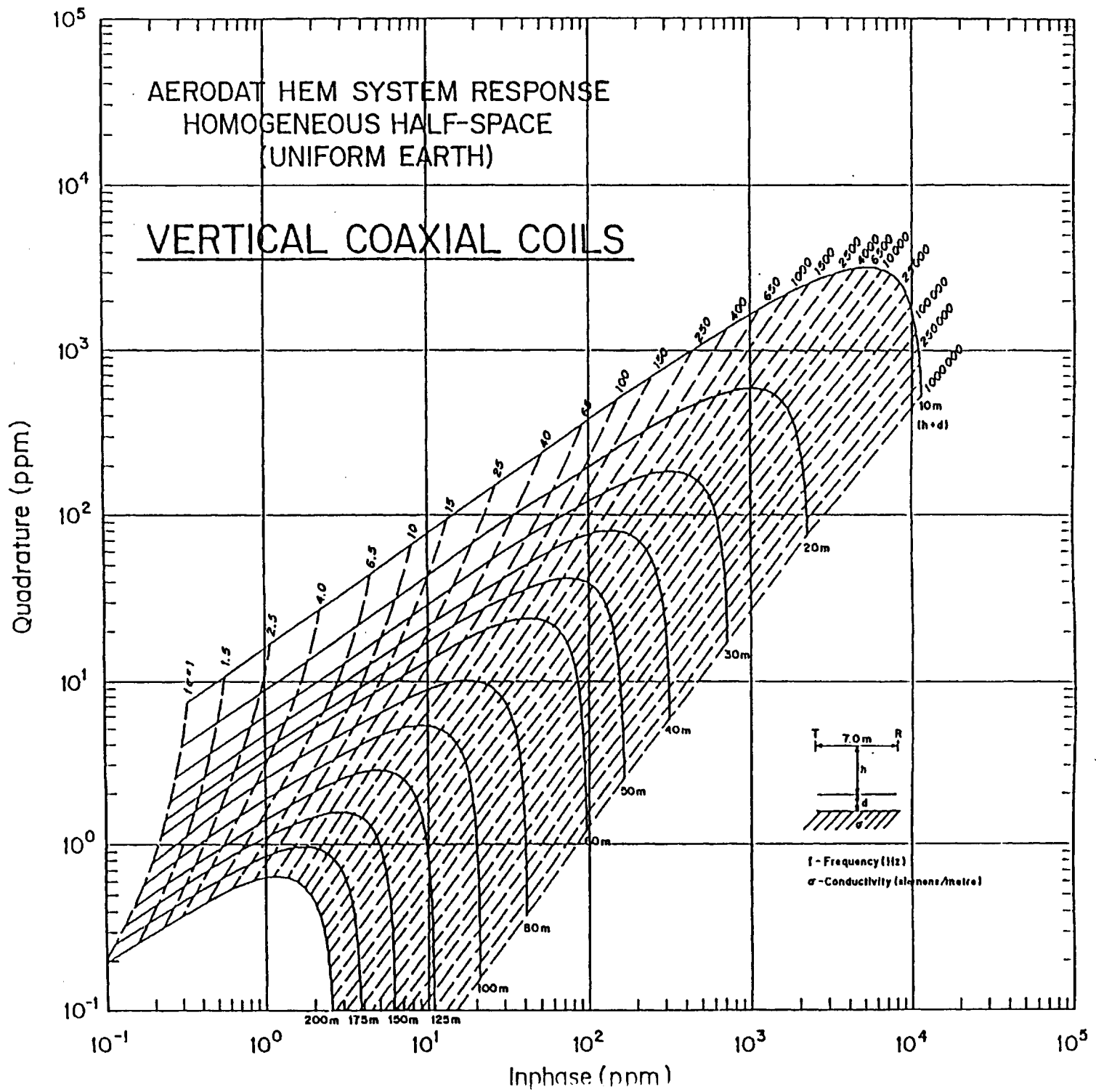
Electrical Considerations

For a given conductive body the measure of its conductivity or conductance is closely related to the measured phase shift between the received and transmitted electromagnetic field. A small phase shift indicates a relatively high conductance, a large phase shift lower conductance. A small phase shift results in a large inphase to quadrature ratio and a large phase shift a low ratio. This relationship is shown quantitatively for non-magnetic vertical half-plane and half-space models on the accompanying phasor diagrams. Other physical models will show the same trend but different quantitative relationships.
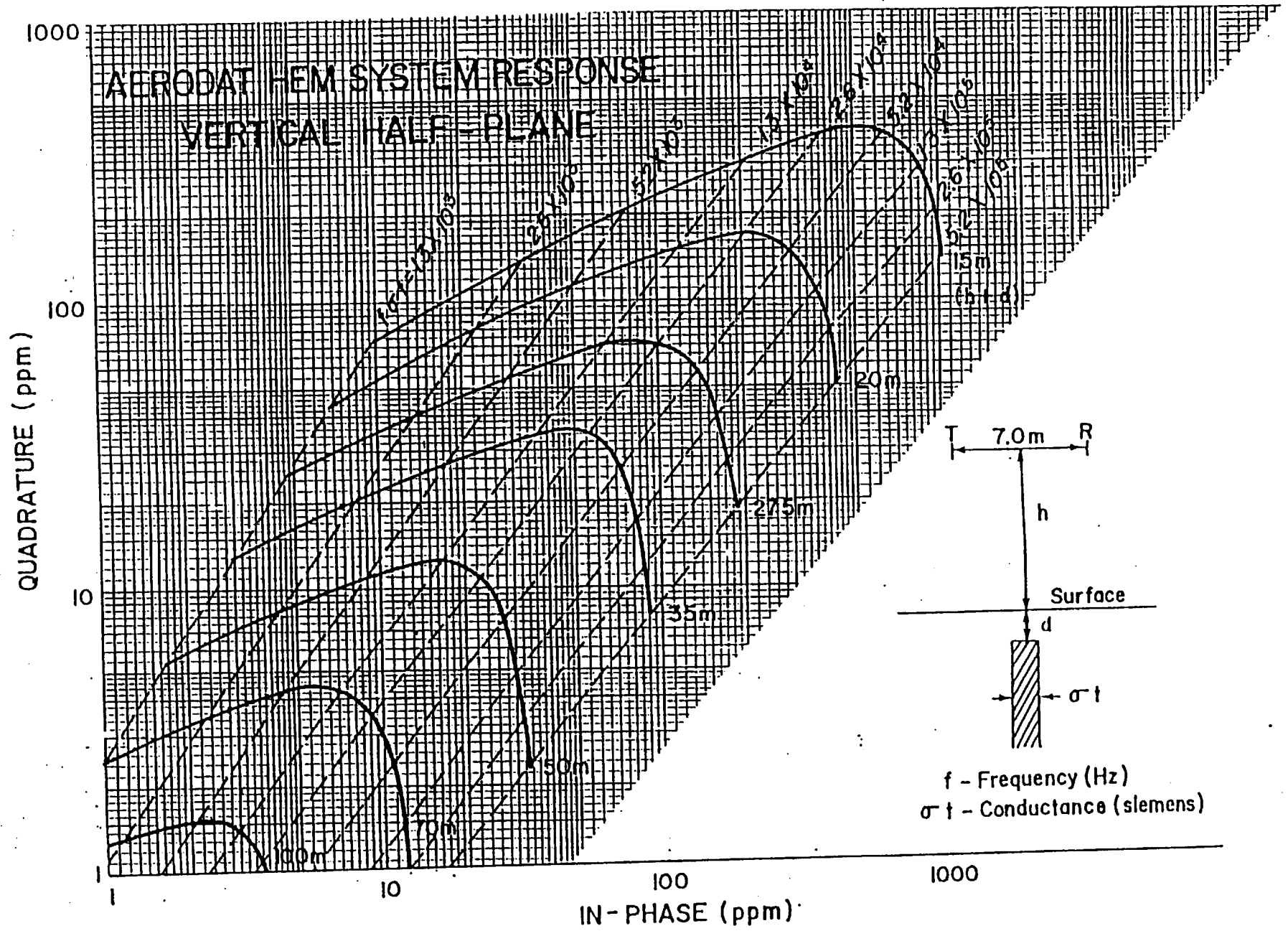
The phasor diagram for the vertical half-plane model, as presented, is for the coaxial coil configuration with the amplitudes in parts per million (ppm) of the primary field as measured at the response peak over the conductor. To assist the interpretation of the survey results the computer is used to identify the apparent conductance and depth of selected anomalies. The results of this calculation are presented in anomaly listings included in the survey report and the conductance and inphase amplitude are presented in symbolized form on the map presentation.

The conductance estimate is most reliable when anomaly amplitudes are large and background resistivities are high. Where the EM anomaly is of low amplitude and background resistivities are low, the conductance estimates are much less reliable. In such situations, the conductance estimate is often quite low regardless of the true nature of the conductor. This is due to the elevated background response levels in the quadrature channel. In an extreme case, the conductance estimate should be discounted and should not prejudice target selection.

The conductance and depth values as presented are correct only as far as the model approximates the real geological situation. The actual geological source may be of limited length, have significant dip, or may be strongly magnetic. Its conductivity and thickness may vary with depth

AERODAT HEM SYSTEM RESPONSE
HOMOGENEOUS HALF-SPACE
(UNIFORM EARTH)

HORIZONTAL COPLANAR COILS

AERODAT HEM SYSTEM RESPONSE
HOMOGENEOUS HALF-SPACE
(UNIFORM EARTH)

VERTICAL COAXIAL COILS

AERODAT HEM SYSTEM RESPONSE
VERTICAL HALF-PLANE

QUADRATURE (ppm) vs IN-PHASE (ppm)

T — 7.0m — R

h

Surface

d

σ t

f – Frequency (Hz)
σ t – Conductance (slemens)

and/or strike and adjacent bodies and overburden may have modified the response. In general the conductance estimate is less affected by these limitations than is the depth estimate, but both should be considered as relative rather than absolute guides to the anomaly's properties.

Conductance in mhos is the reciprocal of resistance in ohms and in the case of narrow slab-like bodies is the product of electrical conductivity and thickness.

The higher ranges of conductance, greater than 2-4 mhos, indicate that a significant fraction of the electrical conduction is electronic rather than electrolytic in nature. Materials that conduct electronically are limited to certain metallic sulphides and to graphite. High conductance anomalies, roughly 10 mhos or greater, are generally limited to massive sulphides or graphites.

Sulphide minerals, with the exception of such ore minerals as sphalerite, cinnabar and stibnite, are good conductors. Sulphides may occur in a disseminated manner that inhibits electrical conduction through the rock mass. In this case the apparent conductance can seriously underrate the quality of the conductor in geological terms. In a similar sense the relatively non-conducting sulphide minerals noted above may be present in significant concentrations in association with minor conductive sulphides, and the electromagnetic response will only relate to the minor associated mineralization. Indicated conductance is also of little direct significance for the identification of gold mineralization. Although gold is highly conductive, it would not be expected to exist in sufficient quantity to create a recognizable anomaly. Minor accessory sulphide mineralization may however provide a useful indirect indication.

In summary, the estimated conductance of a conductor can provide a relatively positive identification of significant sulphide or graphite mineralization. A moderate to low conductance value does not rule out the possibility of significant economic mineralization.
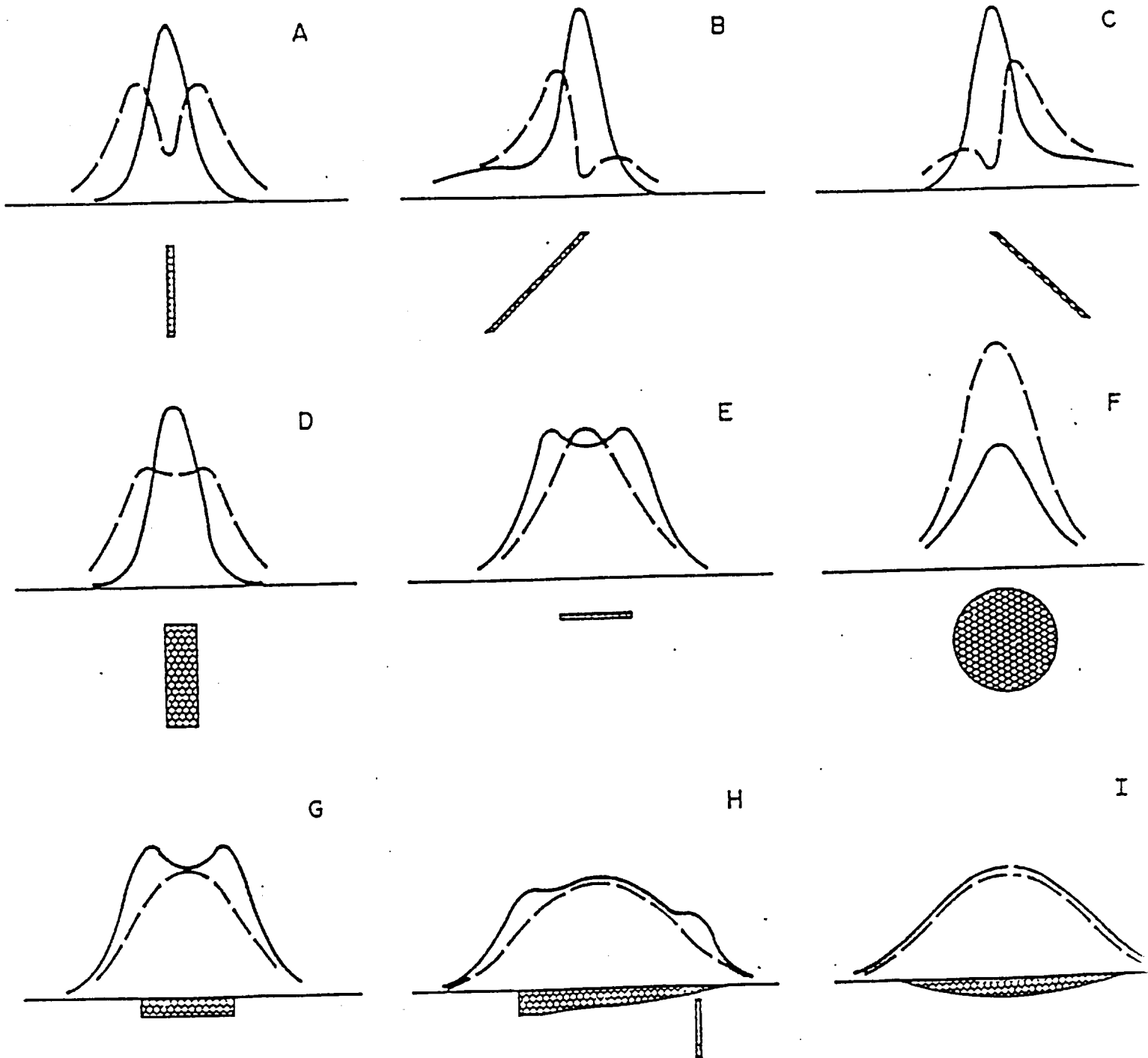

Geometrical Considerations

Geometrical information about the geologic conductor can often be interpreted from the profile shape of the anomaly. The change in shape is primarily related to the change in inductive coupling among the transmitter, the target, and the receiver. The accompanying figure shows a selection of HEM response profile shapes from nine idealized targets. Response profiles are labelled A through I. These labels are used in the discussion which follows.

In the case of a thin, steeply dipping, sheet-like conductor, the coaxial coil pair will yield a near symmetric peak over the conductor. On the other hand, the coplanar coil pair will pass through a null couple relationship and yield a minimum over the conductor, flanked by positive side lobes.(Profile A) As the dip of the conductor decrease from vertical, the coaxial anomaly shape changes only slightly, but in the case of the coplanar coil pair the side lobe on the down dip side strengthens relative to that on the up dip side.(Profiles B and C).

As the thickness of the conductor increases, induced current flow across the thickness of the

HEM RESPONSE PROFILE SHAPE AS AN INDICATOR OF CONDUCTOR GEOMETRY

COAXIAL   vertical scale 1 ppm/unit
COPLANAR vertical scale 4 ppm/unit

conductor becomes relatively significant and complete null coupling with the coplanar coils is no longer possible.(Profile D) As a result, the apparent minimum of the coplanar response over the conductor diminishes with increasing thickness, and in the limiting case of a fully 3 dimensional body or a horizontal layer or half-space, the minimum disappears completely.

A horizontal conducting layer such as a horizontal thin sheet or overburden will produce a response in the coaxial and coplanar coils that is a function of altitude (and conductivity if not uniform). The profile shape will be similar in both coil configurations with an amplitude ratio (coplanar:coaxial) of about 4:1*.(Profiles E and G).

In the case of a spherical conductor, the induced currents are confined to the volume of the sphere, but not relatively restricted to any arbitrary plane as in the case of a sheet-like form. The response of the coplanar coil pair directly over the sphere may be up to 8* times greater than that of the coaxial pair.(Profile F)

In summary, a steeply dipping, sheet-like conductor will display a decrease in the coplanar response coincident with the peak of the coaxial response. The relative strength of this coplanar null is related inversely to the thickness of the conductor. A pronounced null indicates a relatively thin conductor. The dip of such a conductor can be inferred from the relative amplitudes of the side-lobes.

Massive conductors that could be approximated by a conducting sphere will display a simple single peak profile form on both coaxial and coplanar coils, with a ratio between the coplanar to coaxial response amplitudes as high as 8*.

Overburden anomalies often produce broad poorly defined anomaly profiles.(Profile I) In most cases, the response of the coplanar coils closely follows that of the coaxial coils with a relative amplitude ratio of 4*.

Occasionally, if the edge of an overburden zone is sharply defined with some significant depth extent, an edge effect will occur in the coaxial coils. In the case of a horizontal conductive ring or ribbon, the coaxial response will consist of two peaks, one over each edge; whereas the coplanar coil will yield a single peak.(Profile H)

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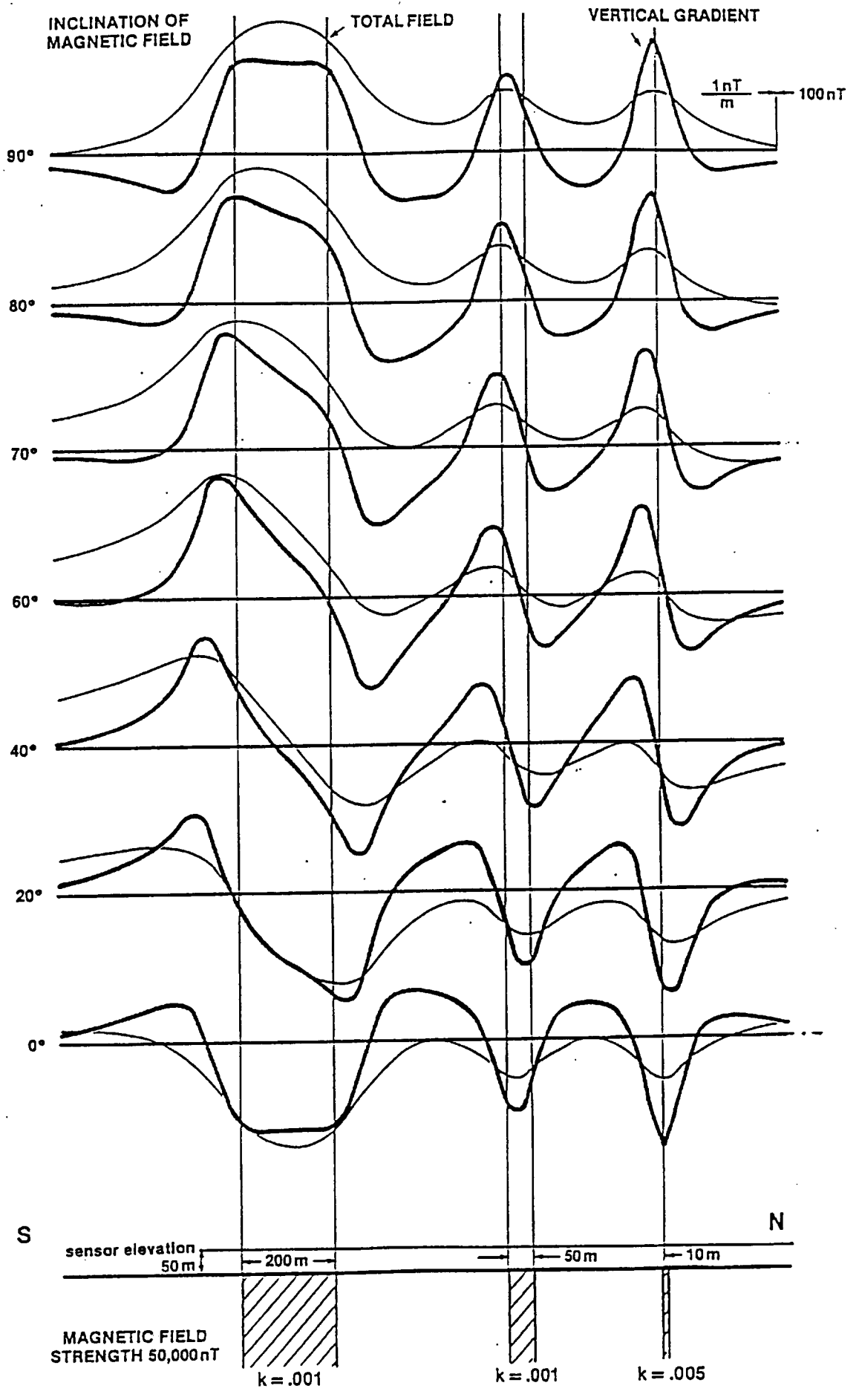
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$\frac{1nT}{m}$ —— 100nT

90°

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70°

60°

40°

20°

0°

S   N

sensor elevation
50 m ↓   ├── 200 m ──┤   ├──→ ├── 50 m ──┤   ├─ 10 m ─┤

MAGNETIC FIELD
STRENGTH 50,000 nT

k = .001   k = .001   k = .005

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A symmetrical vertical gradient response is produced by a body dipping to magnetic north. An asymmetrical response is produced by a body which is vertical or dipping to the south. For southern dips, the southern most zero contour line may be several hundred meters south of the source.

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The source-sensor separation is about equal to half of the distance between the zero contour lines for thin near-vertical sources. The estimated depth of burial for such sources is this separation minus 50 m. If a variety of VG anomaly widths are seen in an area, use the narrowest width seen to estimate local depths.

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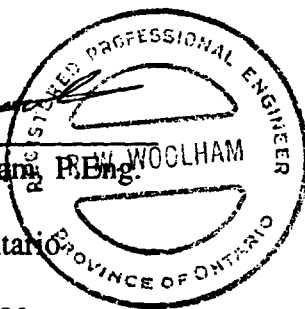
AERODAT LIMITED
June, 1991.

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I, Roderick W. Woolham of the town of Pickering, Province of Ontario, do hereby certify that:-

1. I am a geophysicist and reside at 1463 Fieldlight Blvd., Pickering, Ontario, L1V 2S3

2. I graduated from the University of Toronto in 1961 with a degree of Bachelor of Applied Science, Engineering Physics, Geophysics Option. I have been practising my profession since graduation.

3. I am a member in good standing of the following organizations: The Association of Professional Engineers of the Province of Ontario (Mining Branch); Society of Exploration Geophysicists; South African Geophysical Association.

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5. The statements contained in this report and the conclusions reached are based upon evaluation and review of maps and information supplied by Aerodat.

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R. W. Woolham, P.Eng.

Pickering, Ontario

March 18, 1993