



**PROJECT REPORT OF THE  
AIRBORNE GEOPHYSICAL SURVEY  
OF PART OF THE  
WESTERN FORTYMILE MINING DISTRICT  
EAST – CENTRAL ALASKA**

**STEVENS EXPLORATION MANAGEMENT CORP.  
DIGHEM SURVEY  
FOR THE  
STATE OF ALASKA  
DEPARTMENT OF NATURAL RESOURCES  
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS**

**Quadrangles: Eagle      A-4, A-5, B-4, B-5  
                                 Tanacross D-5**

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## SUMMARY

This report describes the logistics, data acquisition, processing and presentation of results of a DIGHEM airborne geophysical survey carried out under contract to Stevens Exploration Management Corp., Mining and Geological Consultants, for the State of Alaska, Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGs). The survey was flown from September 7<sup>th</sup> to September 24<sup>th</sup>, 2007 over part of the Western Fortymile mining district, east-central Alaska. Total coverage of the survey block amounted to 1134.5 line-miles (1825.9 line-km).

The U.S. Bureau of Land Management funded the survey. The information acquired is aimed at catalyzing new private sector exploration, discovery, and ultimate development and production. The purpose of the survey was to map the magnetic and conductive properties of the survey area, and to detect zones of conductive mineralization. This was accomplished by using a DIGHEM multi-coil, multi-frequency electromagnetic system, supplemented by a high sensitivity cesium magnetometer. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base map.

The survey data were processed and compiled in the Fugro Airborne Surveys Toronto office. Map products and digital data were provided in accordance with the scales and formats specified in the Survey Agreement.

Various maps depicting the survey results are provided at a scale of 1:63,360 (1" = 1 mile). Some of the maps are presented on a topographic base. The data sets are processed and presented using Zone 7 of the Universal Transverse Mercator projection coordinates using the NAD27 Alaska datum. The following geophysical parameters are presented on the maps and/or on the digital archive:

- Total Field Magnetism – IGRF Corrected
- Calculated First Vertical Derivative of the Magnetic Field
- Apparent Resistivity – 900 Hz
- Apparent Resistivity – 7,200 Hz
- Apparent Resistivity – 56,000 Hz
- Digital Elevation Model

The total field magnetic and apparent resistivity data sets have successfully mapped the magnetic and conductive characteristics of the lithologies in the survey area.

The survey property contains many anomalous features, some of which may be considered as exploration targets. Areas of interest may be assigned priorities on the basis of supporting geophysical, geochemical and/or geological information.

It is recommended that the survey results be reviewed in detail, in conjunction with all available geophysical, geological and geochemical information. Image processing of existing geophysical data should be considered, in order to extract the maximum amount of information from the survey results.

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## 1. INTRODUCTION

A DIGHEM electromagnetic/resistivity/magnetic survey was flown under contract to Stevens Exploration Management Corp., Mining and Geological Consultants for the State of Alaska, Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGs). The survey was flown from September 7<sup>th</sup> to September 24<sup>th</sup>, 2007, over a survey block located in part of the Western Fortymile mining district, east-central Alaska. The survey area is located in the Eagle quadrangle, map sheets A-4, A-5, B-4 and B-5, and in the Tanacross quadrangle, map sheet D-5, (Figure 2-1).

Survey coverage consisted of approximately 1134.5 line-miles (1825.9 line-km) including 128.0 line-miles (206.2 line-km) of tie lines. Flight lines were flown in an azimuthal direction of 170°/350° with a line separation of ¼-mile (approximately 400 metres). Tie lines were flown orthogonal to the traverse lines (80°/260°) with a line separation of 3 miles (5 kilometres). Several boundary lines were also flown around the edge of the survey area.

The survey employed the DIGHEM electromagnetic system. Ancillary equipment consisted of a magnetometer, radar altimeter, video camera, digital recorder, and an electronic navigation system. The instrumentation was installed in an AS350-B3 turbine helicopter (Registration C-GECL) that was provided by Questral Helicopters Ltd. The helicopter flew with an EM sensor height of approximately 100 feet (30 metres).

In some portions of the survey area, the steep 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 that permitted excessive bird swinging. This problem, combined with the severe stresses to which the bird was subjected, gave rise to aerodynamic noise levels that are slightly higher than normal on some lines. Where warranted, reflights were carried out to minimize these adverse effects.



**Figure 1-1:** Fugro Airborne Surveys DIGHEM EM Bird

## 2. SURVEY OPERATIONS

The base of operations for the survey was established at Tok, Alaska.

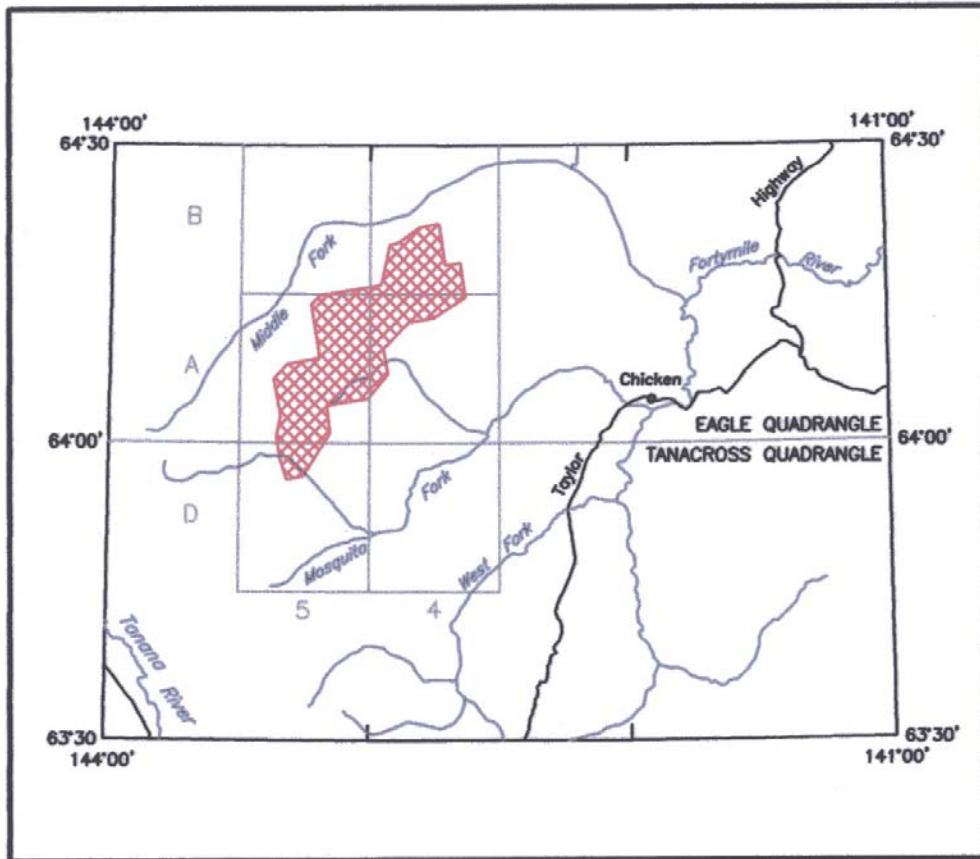
The survey area is located in the Eagle quadrangle, map sheets A-4, A-5, B-4 and B-5, and in the Tanacross quadrangle, map sheets D-5, (Figure 2-1).

Table 2-1 lists the corner coordinates of the survey area in NAD27 Alaska, UTM Zone 7, central meridian 141°W.

**Table 2-1 The Area Corners**

Block	Corners	X-UTM (E)	Y-UTM (N)
<b>07060-1</b>	1	384533	7110899
<b>Western</b>	2	387120	7113572
<b>Fortymile</b>	3	393146	7114511
	4	393058	7116128
	5	391964	7124641
	6	392019	7124849
	7	393613	7126258
	8	405024	7127876
	9	405456	7128833
	10	407031	7135308
	11	408667	7135644
	12	412535	7138284
	13	416283	7138948
	14	417301	7131269
	15	420067	7131621
	16	420867	7125143
	17	414765	7121392
	18	410062	7120748
	19	405229	7115894
	20	405992	7111164
	21	402122	7106626
	22	399122	7106281
	23	394281	7105582
	24	394778	7100472
	25	393774	7098834
	26	389445	7092551
	27	386433	7092113
	28	385296	7095898
	29	384769	7100163
	30	385594	7103958

### LOCATION INDEX



**Figure 2-1  
Location Map and Sheet Layout  
Part of the Western Fortymile Mining District  
East – Central Alaska  
Job # 07060**



The survey specifications are given below in table 2-2.

**Table 2-2 Survey Specifications**

Parameter	Specifications
Traverse line direction	170°/350°
Traverse line spacing	¼-mile (400 m)
Tie line direction	80°/260°
Tie line spacing	3 miles (5 km)
Sample interval	10 Hz, 3.3 m @ 120 km/h
Aircraft mean terrain clearance	58 m
EM sensor mean terrain clearance	30 m
Mag sensor mean terrain clearance	30 m
Navigation (guidance)	±5 m, Real-time GPS
Post-survey flight path	±2 m, Differential GPS

### 3. SURVEY EQUIPMENT

This section provides a brief description of the geophysical instruments used to acquire the survey data and the calibration procedures employed. The geophysical equipment was installed in an AS350-B3 turbine helicopter. This aircraft provides a safe and efficient platform for surveys of this type.

#### Electromagnetic System

Model: DIGHEM

Type: Towed bird, symmetric dipole configuration operated at a nominal survey altitude of 30 metres. Coil separation is 8 metres for 900 Hz, 1000 Hz, 5500 Hz and 7200 Hz, and 6.3 metres for the 56 000 Hz coil-pair.

Coil orientations, frequencies and dipole moments	Atm <sup>2</sup>	orientation	nominal	actual
	211	coaxial /	1000 Hz	1120 Hz
	211	coplanar /	900 Hz	870 Hz
	67	coaxial /	5500 Hz	5450 Hz
	56	coplanar /	7200 Hz	7150 Hz
	15	coplanar /	56 000 Hz	56 400 Hz

Channels recorded: 5 in-phase channels  
5 quadrature channels  
2 monitor channels

Sensitivity: 0.06 ppm at 1000 Hz Cx  
0.12 ppm at 900 Hz Cp  
0.12 ppm at 5500 Hz Cx  
0.24 ppm at 7200 Hz Cp  
0.60 ppm at 56 000 Hz Cp

Sample rate: 10 per second, equivalent to 1 sample every 3.3 m, at a survey speed of 120 km/h.

The electromagnetic system utilizes a multi-coil coaxial/coplanar technique to energize conductors in different directions. The coaxial coils are vertical with their axes in the flight direction. The coplanar coils are horizontal. The secondary fields are sensed simultaneously by means of receiver coils that are maximum coupled to their respective transmitter coils. The system yields an in-phase and a quadrature channel from each transmitter-receiver coil-pair.

## **In-Flight EM System Calibration**

Calibration of the system during the survey uses the Fugro AutoCal automatic, internal calibration process. At the beginning and end of each flight, and at intervals during the flight, the system is flown up to high altitude to remove it from any “ground effect” (response from the earth). Any remaining signal from the receiver coils (base level) is measured as the zero level, and is removed from the data collected until the time of the next calibration. Following the zero level setting, internal calibration coils, for which the response phase and amplitude have been determined at the factory, are automatically triggered – one for each frequency. The on-time of the coils is sufficient to determine an accurate response through any ambient noise. The receiver response to each calibration coil “event” is compared to the expected response (from the factory calibration) for both phase angle and amplitude, and any phase and gain corrections are automatically applied to bring the data to the correct value.

In addition, the outputs of the transmitter coils are continuously monitored during the survey, and the gains are adjusted to correct for any change in transmitter output.

Because the internal calibration coils are calibrated at the factory (on a resistive halfspace) ground calibrations using external calibration coils on-site are not necessary for system calibration. A check calibration may be carried out on-site to ensure all systems are working correctly. All system calibrations will be carried out in the air, at sufficient altitude that there will be no measurable response from the ground.

The internal calibration coils are rigidly positioned and mounted in the system relative to the transmitter and receiver coils. In addition, when the internal calibration coils are calibrated at the factory, a rigid jig is employed to ensure accurate response from the external coils.

Using real time Fast Fourier Transforms and the calibration procedures outlined above, the data are processed in real time, from measured total field at a high sampling rate, to in-phase and quadrature values at 10 samples per second.

## **Airborne Magnetometer**

Model:	Fugro D1344 processor with Scintrex CS3 sensor
Type:	Optically pumped cesium vapour
Sensitivity:	0.01 nT
Sample rate:	10 per second

The magnetometer sensor is housed in the EM bird, 28 m below the helicopter.

## Magnetic Base Station

Model: Fugro CF1 base station with timing provided by integrated GPS

Sensor type: Scintrex CS3

Counter specifications: Accuracy:  $\pm 0.1$  nT  
Resolution: 0.01 nT  
Sample rate 1 Hz

GPS specifications: Model: Marconi Allstar  
Type: Code and carrier tracking of L1 band, 12-channel, C/A code at 1575.42 MHz  
Sensitivity: -90 dBm, 1.0 second update  
Accuracy: Manufacturer's stated accuracy for differential corrected GPS is 2 metres

### Environmental

Monitor specifications: Temperature:

- Accuracy:  $\pm 1.5^{\circ}\text{C}$  max
- Resolution:  $0.0305^{\circ}\text{C}$
- Sample rate: 1 Hz
- Range:  $-40^{\circ}\text{C}$  to  $+75^{\circ}\text{C}$

Barometric pressure:

- Model: Motorola MPXA4115A
- Accuracy:  $\pm 3.0^{\circ}$  kPa max ( $-20^{\circ}\text{C}$  to  $105^{\circ}\text{C}$  temp. ranges)
- Resolution: 0.013 kPa
- Sample rate: 1 Hz
- Range: 55 kPa to 108 kPa

A digital recorder is operated in conjunction with the base station magnetometer to record the diurnal variations of the earth's magnetic field. The clock of the base station is synchronized with that of the airborne system, using GPS time, to permit subsequent removal of diurnal drift. The location of the base station is given below in table 3-1.

**Table 3-1 Magnetic Base Station Locations**

Location	WGS84 Latitude (decimal degrees)	WGS84 Longitude (decimal degrees)	Date Setup	Date Torn Down
Joseph airstrip	64.3734436°N	143.0537262°W	14-Sep-07	24-Sep-07

## **Navigation (Global Positioning System)**

### Airborne Receiver for Flight Path Recovery

Model: Novatel OEM4  
Type: Code and carrier tracking of L1-C/A code at 1575.42 MHz and L2-P code at 1227.0 MHz. Dual frequency, 24-channel  
Sample rate: 10 Hz update  
Accuracy: Better than 1 metre in differential mode  
Antenna: Antcom 42G1215A, mounted on the tail of the aircraft

### Primary Base Station for Post-Survey Differential Correction

Model: Novatel OEM4  
Type: Code and carrier tracking of L1-C/A code at 1575.42 MHz and L2-P code at 1227.0 MHz. Dual frequency, 24-channel.  
Antenna: Novatel GPS 600  
Sample rate: 0.5 second update  
Accuracy: Manufacturer's stated accuracy for differential corrected GPS is better than 1 metre

### Secondary GPS Base Station

Model: Marconi Allstar OEM, CMT-1200, part of CF1 base station  
Type: Code and carrier tracking of L1 band, 12-channel, C/A code at 1575.42 MHz  
Sensitivity: -90 dBm, 1.0 second update  
Accuracy: Manufacturer's stated accuracy for differential corrected GPS is 2 metres.

The Novatel OEM4 is a line of sight, satellite navigation system that utilizes time-coded signals from at least four of forty-eight available satellites. Both Russian GLONASS and American NAVSTAR satellite constellations are used to calculate the position and to provide real time guidance to the helicopter. A Novatel Millennium GPS unit was used as the primary base station. A Marconi Allstar GPS unit, part of the CF-1, was used as the secondary base station. The mobile and base station raw XYZ data were recorded, thereby permitting post-survey differential corrections for theoretical accuracies of better than 2 metres.

Each base station receiver is able to calculate its own latitude and longitude. The locations of both the primary and secondary base stations are given below in table 3-2.

**Table 3-2 GPS Base Station Locations**

Status	Location Name	WGS84 Latitude	WGS84 Longitude	WGS84 Elevation (m)	Date Setup	Date Torn Down
Primary	Tok	63° 20 0.93063N	142° 56 24.29039W	514.79	11-Sep-06	24-Sep-07
Secondary	Joseph airstrip	64.3734436°N	143.0537262°W		14-Sep-07	24-Sep-07

The GPS records data relative to the WGS84 ellipsoid, which is the basis of the revised North American Datum (NAD83). Conversion software is used to transform the WGS84 coordinates to the NAD27 Alaska UTM system displayed on the maps.

### **Radar Altimeter**

Manufacturer: Honeywell/Sperry  
Model: RT300/AT220  
Type: Short pulse modulation, 4.3 GHz  
Sensitivity: 0.3 m  
Sample rate: 2 per second

The radar altimeter measures the vertical distance between the helicopter and the ground. This information is used in the processing algorithm that determines conductor depth.

### **Barometric Pressure and Temperature Sensors**

Model: DIGHEM D 1300  
Type: Motorola MPX4115AP analog pressure sensor  
AD592AN high-impedance remote temperature sensors  
Sensitivity: Pressure: 150 mV/kPa  
Temperature: 100 mV/°C or 10 mV/°C (selectable)  
Sample rate: 10 per second

The D1300 circuit is used in conjunction with one barometric sensor and up to three temperature sensors. Two sensors (baro and temp) are installed in the EM console in the aircraft, to monitor pressure (1KPA) and internal operating temperatures (2TDC).

## **Digital Data Acquisition System**

Manufacturer: Fugro  
Model: HELIDAS  
Recorder: Compact Flash Card

The stored data are downloaded to the field workstation PC at the survey base, for verification, backup and preparation of in-field products.

## **Video Flight Path Recording System**

Camera: Panasonic WVCD/32 colour  
Recorder: Axis 241S Video Server and tablet computer

Fiducial numbers are recorded continuously and are displayed on the margin of each image. This procedure ensures accurate correlation of data with respect to visible features on the ground.

## **4. QUALITY CONTROL AND IN-FIELD PROCESSING**

Digital data for each flight were transferred to the field workstation, in order to verify data quality and completeness. A database was created and updated using Geosoft Oasis Montaj and proprietary Fugro Atlas software. This allowed the field personnel to calculate, display and verify both the positional (flight path) and geophysical data on a screen or printer. The initial database was examined as a preliminary assessment of the data acquired for each flight.

In-field processing of Fugro survey data consists of differential corrections to the airborne GPS data, verification of EM calibrations, drift correction of the raw airborne EM data, spike rejection and filtering of all geophysical and ancillary data, verification of the digital flight path recordings, calculation of preliminary resistivity data, diurnal correction, and preliminary levelling of magnetic data.

All data, including base station records, were checked on a daily basis, to ensure compliance with the survey contract specifications. Reflights were required if any of the following specifications were not met.

### **Navigation**

A specialized GPS system provided in-flight navigation control. The system determined the absolute position of the helicopter by monitoring the range information of twelve channels (satellites). Novatel's OEM4-G2L receiver was used for this application. The OEM4-G2L receiver is WAAS-enabled (Wide Area Augmentation System) providing better real-time positioning.

A Novatel OEM4 GPS base station was used that recorded pseudo-range, carrier phase, ephemeris, and timing information for up to 12 NAVSTAR GPS satellites at a one second interval. Recording was via flash disk.

### **Flight Path**

All flight lines, including infills, intersect at least two tie lines. For boundaries not parallel to the flight lines, a control line was flown parallel to the boundary. All traverse lines extend at least one-third mile beyond the area boundaries at survey altitude. All control lines were flown at the same mean terrain clearance as the traverse lines, particularly at the point where the two intersect. These flights were carried out during optimum diurnal conditions.

Flight path lines were rejected and reflight if deviations from specified flight path of more than 500 feet persisted over a distance of more than ½ mile, except for rugged areas, where flight path deviations did not exceed 650 feet over a distance of more than ½ mile.

At no point did the spacing between adjacent lines exceed 1,820 feet or be less than 820 feet over a distance of more than ½ mile, except for rugged areas, where the spacing between adjacent lines did not exceed 1,970 feet or be less than 670 feet over a



distance of more than ½ mile, unless the spacing was required for safety. Some deviation from this specification was permitted in areas of particularly steep topography for safety reasons.

If the spacing between survey lines exceeded the specifications in this section for more than ½ mile, a fill-in line was flown. However, if the flight line spacing deviation was caused by safety requirements, as solely determined by the helicopter pilot, aerodynamic limitations of the helicopter, or FAA regulations, a fill-in line was not required.

Parts of lines reflown to complete a flight line cross control lines at either end and cross the original survey line at a low angle at a point where the data is acceptable.

## **Clearance**

Lines were flown at a mean terrain clearance of 200 feet averaged over any one mile distance. It was preferred that deviations not exceed 100 feet.

In areas of rough terrain or near person-made obstacles or populated areas, safety considerations could have required deviation from the 300 feet maximum terrain clearances. The pilot was solely responsible for determining minimum safe terrain clearances.

Additionally, it was expected that some deviation from the 300 feet maximum terrain clearance would occur in rough terrain due to a combination of altimeter behaviour and aerodynamic limitations of the helicopter.

## **Airborne Magnetic System**

The inflight noise envelope did not exceed 0.1 nT in straight and level flight. In rugged areas, the noise level did not exceed 0.5 nT. The errors due to changes in heading were required. Heading error was verified before the survey began by flying over the same point on magnetic north, east, south, and west directions at least twice. A maximum of 2 nT peak-to-peak variation was tolerated in a single 360° test. Verification was repeated if mechanical parts of the aircraft were changed or if the magnetometer was repaired or modified.

## **Magnetic Base Station**

Airborne surveys were not conducted when non-linear variations of the earth's magnetic field exceeded 10 nT from a chord 1.0 minutes long, as determined from the digital record on the ground monitor.

## Electromagnetic Data

**Table 4-1 The EM System Noise Specifications**

Nominal Frequency (Hz)	Coil Orientation	Peak-to-Peak Noise Envelope (ppm)
1000	coaxial	10
900	coplanar	10
5500	coaxial	10
7200	coplanar	20
56,000	coplanar	40

### Spherics

If the frequency of spherics events affected the quality of the electromagnetic data as it was being processed by the acquisition system in real time, survey flying was suspended. Flying was not performed when spherics became sufficiently intense and frequent that digital data processing techniques could not recover useful data.

The Dighem EM system includes two spheric/powerline channels for noise monitoring. Most spheric activity is susceptible to reduction by post-survey filtering to less than 2.0 ppm.

### System Drift

The system drift due to both mechanical and electronic changes did not exceed 40 ppm per hour for the 900 Hz, 80 ppm per hour for the 5500 and 7200 Hz and 120 ppm per hour for the 56,000 Hz between consecutive zero level measurements for any of the electromagnetic channels.

To determine drift error, drift (at high altitude locations) was plotted for each channel as a function of time and linearly interpolated. The drift was deemed to exceed the noise levels above, if the difference of drift at that high altitude location with the linearly interpolated drift from the previous and following high altitude drift measurements exceeded the noise levels given above by a factor of two.

## **5. DATA PROCESSING**

Appendix D depicts the data processing flow for the electromagnetic and magnetic datasets.

### **Flight Path Recovery**

The raw range data from at least four satellites are simultaneously recorded by both the base and mobile GPS units. The geographic positions of both units, relative to the model ellipsoid, are calculated from this information. Differential corrections, which are obtained from the base station, are applied to the mobile unit data to provide a post-flight track of the aircraft, accurate to within 2 m. Speed checks of the flight path are also carried out to determine if there are any spikes or gaps in the data.

The corrected WGS84 latitude/longitude coordinates are transformed to the coordinate system used on the final maps. Images or plots are then created to provide a visual check of the flight path.

### **Electromagnetic Data**

EM data are processed at the recorded sample rate of 10 samples/second. Spheric rejection median and Hanning filters are then applied to reduce noise to acceptable levels.

Excellent resolution and discrimination of conductors was accomplished by using a fast sampling rate of 0.1 sec and by employing a “common” frequency (5500/7200 Hz) on two orthogonal coil-pairs (coaxial and coplanar). The resulting difference channel parameters often permit differentiation of bedrock and surficial conductors, even though they may exhibit similar conductance values. For any Fugro multi-component helicopter frequency domain EM system (HFEM), the difference channel is a calculated product to assist interpretation of discrete conductor targets. There is one each for the in-phase and quadrature components of the EM channels, called DIFI and DIFQ.

The difference channel is a parameter used to quantify the difference between the coaxial and coplanar response, to help distinguish which conductivity changes are caused by flat-lying conductors (like swamps) or changes in the layered earth (with a 1:4 ratio between CX and CP), and which anomalies are caused by discrete conductive bodies (ideally with a 1:1 CX to CP ratio). The difference between the CP and CX for both in-phase and quadrature EM data is calculated everywhere, weighted to adjust the response for the geometric difference as well as differences in coil separation. For a flat-lying or halfspace (thick, flat-lying) conductor, the difference channel (DIFI or DIFQ) will be near zero, as it will over background areas (a layered earth). For a discrete conductor like a vertical thin dike, the difference channel will have a positive value. In practice the value will be somewhat variable, dependent on the shape and thickness of the conductor and the conductivity of the host rock. Because it is a difference, not a ratio, the amplitude of the difference channel over a discrete conductor will depend on the strength of the anomaly, but it will remain near zero for the flat-lying targets.

Anomalies that occur near the ends of the survey lines (i.e., outside the survey area) should be viewed with caution. Some of the weaker anomalies could be due to aerodynamic noise, i.e., bird bending, which is created by abnormal stresses to which the bird is subjected during the climb and turn of the aircraft between lines. Such aerodynamic noise is usually manifested by an anomaly on the coaxial in-phase channel only, although severe stresses can affect the coplanar in-phase channels as well.

In areas where EM responses are evident primarily on the quadrature components, zones of poor conductivity are indicated. Where these responses are coincident with magnetic anomalies, it is possible that the in-phase component amplitudes have been suppressed by the effects of magnetite. Poorly-conductive magnetic features can give rise to resistivity anomalies that are only slightly below or slightly above background. If it is expected that poorly-conductive economic mineralization could be associated with magnetite-rich units, most of these weakly anomalous features will be of interest. Magnetite effects usually give rise to overstated (higher) resistivity values and understated (shallow) depth calculations.

## **Apparent Resistivity**

The apparent resistivities in ohm-m are generated from the in-phase and quadrature EM components for all of the coplanar frequencies, using a pseudo-layer half-space model. The inputs to the resistivity algorithm are the in-phase and quadrature amplitudes of the secondary field. The algorithm calculates the apparent resistivity in ohm-m, and the apparent height of the bird above the conductive source. Any difference between the apparent height and the true height, as measured by the radar altimeter, is called the pseudo-layer and reflects the difference between the real geology and a homogeneous halfspace. This difference is often attributed to the presence of a highly resistive upper layer. Any errors in the altimeter reading, caused by heavy tree cover, are included in the pseudo-layer and do not affect the resistivity calculation. The apparent depth estimates, however, will reflect the altimeter errors. Apparent resistivities calculated in this manner may differ from those calculated using other models.

In areas where the effects of magnetic permeability or dielectric permittivity have suppressed the in-phase responses, the calculated resistivities will be erroneously high. Various algorithms and inversion techniques can be used to partially correct for the effects of permeability and permittivity. No corrections for permeability and permittivity were made to the data for this survey.

Apparent resistivity maps portray all of the information for a given frequency over the entire survey area. This full coverage contrasts with the electromagnetic anomaly map, which provides information only over interpreted conductors. The large dynamic range afforded by the multiple frequencies makes the apparent resistivity parameter an excellent mapping tool.

The preliminary apparent resistivity maps and images are carefully inspected to identify any lines or line segments that might require base level adjustments. Subtle changes between in-flight calibrations of the system can result in line-to-line differences that are

more recognizable in resistive (low signal amplitude) areas. If required, manual level adjustments are carried out to eliminate or minimize resistivity differences that can be attributed, in part, to changes in operating temperatures. These levelling adjustments are usually very subtle, and do not result in the degradation of discrete anomalies.

After the manual levelling process is complete, revised resistivity grids are created. The resulting grids can be subjected to a microlevelling technique in order to smooth the data for contouring. The coplanar resistivity parameter has a broad 'footprint' that requires very little filtering.

Apparent resistivity maps, which display the conductive properties of the survey area, were produced from the 900 Hz, 7200 Hz and 56,000 Hz coplanar data. The maximum resistivity values, which are calculated for each frequency, are 1325, 10 750 and 30 000 ohm-m respectively. These cutoffs eliminate the erratic higher resistivities that would result from unstable ratios of very small EM amplitudes.

## **Total Magnetic Field**

A Fugro CF-1 cesium vapour magnetometer was operated at the survey base 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 permit subsequent removal of diurnal drift.

A fourth difference editing routine was applied to the magnetic data to remove any spikes.

The aeromagnetic data were corrected for measured system lag, and then corrected for diurnal variations by subtraction of the digitally recorded base station magnetic data. The data were then adjusted for regional variations (or IGRF gradient, 2005, updated to September 2007) using altimeter adjusted IGRF, and the results were then levelled using tie and traverse line intercepts. Manual adjustments were applied to any lines that required levelling, as indicated by shadowed images of the gridded magnetic data. The manually levelled data were then subjected to a microlevelling filter. The resulting data have been presented on the maps using a contour interval of 2 nT where gradients permit. The map shows the magnetic properties of the rock units underlying the survey area.

There is some evidence on the magnetic map that suggests that the survey area has been subjected to deformation and/or alteration. These structural complexities are evident on the map as variations in magnetic intensity, irregular patterns, and as offsets or changes in strike direction.

If a specific magnetic intensity can be assigned to the rock type that is believed to host the target mineralization, it may be possible to select areas of higher priority on the basis of the total field magnetic data. This is based on the assumption that the magnetite content of the host rocks will give rise to a limited range of contour values that will permit differentiation of various lithological units.

The magnetic results, in conjunction with the other geophysical parameters, have provided valuable information that can be used to effectively map the geology and structure in the survey area.

### **Calculated Vertical Magnetic Gradient (First Vertical Derivative)**

The diurnally-corrected, IGRF-corrected magnetic data were subjected to a processing algorithm that enhances the response of magnetic bodies in the upper 500 m and attenuates the response of deeper bodies. The resulting vertical gradient map provides better definition and resolution of near-surface magnetic units. It also identifies weak magnetic features that may not be evident on the total field map. However, regional magnetic variations and changes in lithology may be better defined on the total magnetic field map.

### **Digital Elevation**

The radar altimeter values (ALTR – aircraft to ground clearance) are subtracted from the differentially corrected and de-spiked GPS-Z values to produce profiles of the height above the ellipsoid along the survey lines. These values are gridded to produce contour maps showing approximate elevations within the survey area. The calculated digital terrain data are then tie-line levelled and adjusted to mean sea level. Any remaining subtle line-to-line discrepancies are manually removed. After the manual corrections are applied, the digital terrain data are filtered with a microlevelling algorithm.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, ALTR and GPS-Z. The ALTR value may be erroneous in areas of heavy tree cover, where the altimeter reflects the distance to the tree canopy rather than the ground. The GPS-Z value is primarily dependent on the number of available satellites. Although post-processing of GPS data will yield X and Y accuracies in the order of 1-2 metres, the accuracy of the Z value is usually much less, sometimes in the  $\pm 10$  metre range. Further inaccuracies may be introduced during the interpolation and gridding process.

Because of the inherent inaccuracies of this method, no guarantee is made or implied that the information displayed is a true representation of the height above sea level. Although this product may be of some use as a general reference, THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.

## **Contour, Colour and Shadow Map Displays**

The geophysical data are interpolated onto a regular grid using a modified Akima spline technique. The resulting grid is suitable for image processing and generation of contour maps. The grid cell size is 20% of the line interval.

Colour maps are produced by interpolating the grid down to the pixel size. The parameter is then incremented with respect to specific amplitude ranges to provide colour "contour" maps.

Monochromatic shadow maps or images are generated by employing an artificial sun to cast shadows on a surface defined by the geophysical grid. There are many variations in the shadowing technique. These techniques can be applied to total field or enhanced magnetic data, magnetic derivatives, resistivity, etc. The shadowing technique is also used as a quality control method to detect subtle changes between lines.

## 6. PRODUCTS

This section lists the final maps and products that have been provided under the terms of the survey agreement. Other products can be prepared from the existing dataset, if requested. These include magnetic enhancements or derivatives, percent magnetite, resistivities corrected for magnetic permeability and/or dielectric permittivity, digital terrain, resistivity-depth sections, inversions, and overburden thickness. Most parameters can be displayed as contours, profiles, or in colour.

### Base Maps

Base maps of the survey area were produced by scanning published topographic maps to a bitmap (.bmp) format. This process provides a relatively accurate, distortion-free base that facilitates correlation of the navigation data to the map coordinate system. The topographic files were combined with geophysical data for plotting some of the final maps. All maps were created using the following parameters:

#### Projection Description:

Datum:	NAD27 Alaska
Ellipsoid:	Clarke 1866
Projection:	UTM (Zone: 7)
Central Meridian:	141°W
False Northing:	0
False Easting:	500000
Scale Factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Datum Shifts:	DX: 5 DY: -135 DZ: -172

Maps depicting the survey results have been provided at a scale of 1:63,360 as listed in Table 6-1.



**Table 6-1 Survey Products**

<b>Product Description</b>	<b>Product Number</b>	<b>Map Scale</b>
<b>DVD containing line, gridded and vector data, and items listed below</b>	<b>2008-1</b>	-
Colour Total Magnetic Field with topography	2008-1-1a	1:63,360
Colour Total Magnetic Field with contours and sections lines	2008-1-1b	1:63,360
Colour First Vertical Derivative of the Magnetic Field with topography	2008-1-1c	1:63,360
Colour Resistivity (56 000 Hz coplanar) with topography	2008-1-2a	1:63,360
Colour Resistivity (56 000 Hz coplanar) with contours and section lines	2008-1-2b	1:63,360
Colour Resistivity (7200 Hz coplanar) with topography	2008-1-3a	1:63,360
Colour Resistivity (7200 Hz coplanar) with contours and section lines	2008-1-3b	1:63,360
Colour Resistivity (900 Hz coplanar) with topography	2008-1-4a	1:63,360
Colour Resistivity (900 Hz coplanar) with contours and section lines	2008-1-4b	1:63,360
Project Report (This document)	2008-1-5	-

The final digital archives are provided on DVD. Both line data and grid archives are provided in Geosoft format. Appendix C gives a detailed description of the contents of GPR2008-1 and of the archive format. For more information about the survey or the processing, see the metadata file associated with this publication (GPR2008-1).

All original materials, including the digital flight path recordings, are also provided to DGGS.

## **7. CONCLUSIONS AND RECOMMENDATIONS**

This report describes the equipment, data processing procedures and logistics of the survey.

The survey has been successful in mapping the magnetic and conductive properties of the survey area. It is recommended that a complete assessment and detailed evaluation of the survey results be carried out, in conjunction with all available geophysical, geological and geochemical information.

Anomalous targets defined by the survey should be subjected to further investigation, using appropriate surface exploration techniques. Anomalies that are currently considered to be of moderately low priority may require upgrading if follow-up results are favourable.

It is also recommended that image processing of existing geophysical data be considered, in order to extract the maximum amount of information from the survey results. Current software and imaging techniques often provide valuable information on structure and lithology, which may not be clearly evident on the contour and colour maps. These techniques can yield images that define subtle, but significant, structural details.

Respectfully submitted,

**FUGRO AIRBORNE SURVEYS CORP.**

R07060NOV.07

## APPENDIX A

### LIST OF PERSONNEL

The following personnel were involved in the acquisition, processing and presentation of data, relating to a DIGHEM airborne geophysical survey carried out for The State of Alaska, Department of Natural Resources, Division of Geological and Geophysical Surveys over part of the Western Fortymile mining district, east-central Alaska.

David Miles	Manager, Helicopter Operations
Emily Farquhar	Manager, Data Processing and Interpretation
Nick Gavican	Geophysical Operator
Darcy McGill	Field Geophysicist
Wally Zec	Pilot (Questral Helicopters Ltd.)
Stephen Harrison	Geophysical Data Processor
Ruth Pritchard	Interpretation Geophysicist
Lyn Vanderstarren	Drafting Supervisor
Susan Pothiah	Word Processing Operator
Albina Tonello	Secretary/Expeditor

The survey consisted of approximately 1134.5 line-miles (1825.9 line-km) flown from September 7<sup>th</sup> to September 24<sup>th</sup>, 2007.

All personnel are employees of Fugro Airborne Surveys, except where indicated.

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**APPENDIX B**

**BACKGROUND INFORMATION**

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## APPENDIX B

### BACKGROUND INFORMATION

#### Electromagnetics<sup>1</sup>

Fugro electromagnetic responses fall into two general classes, discrete and broad. The discrete class consists of sharp, well-defined anomalies from discrete conductors such as sulphide lenses and steeply dipping sheets of graphite and sulphides. The broad class consists of wide anomalies from conductors having a large horizontal surface such as flatly dipping graphite or sulphide sheets, saline water-saturated sedimentary formations, conductive overburden and rock, kimberlite pipes 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 geophysical maps 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 sulphide bodies.

#### Geometric Interpretation

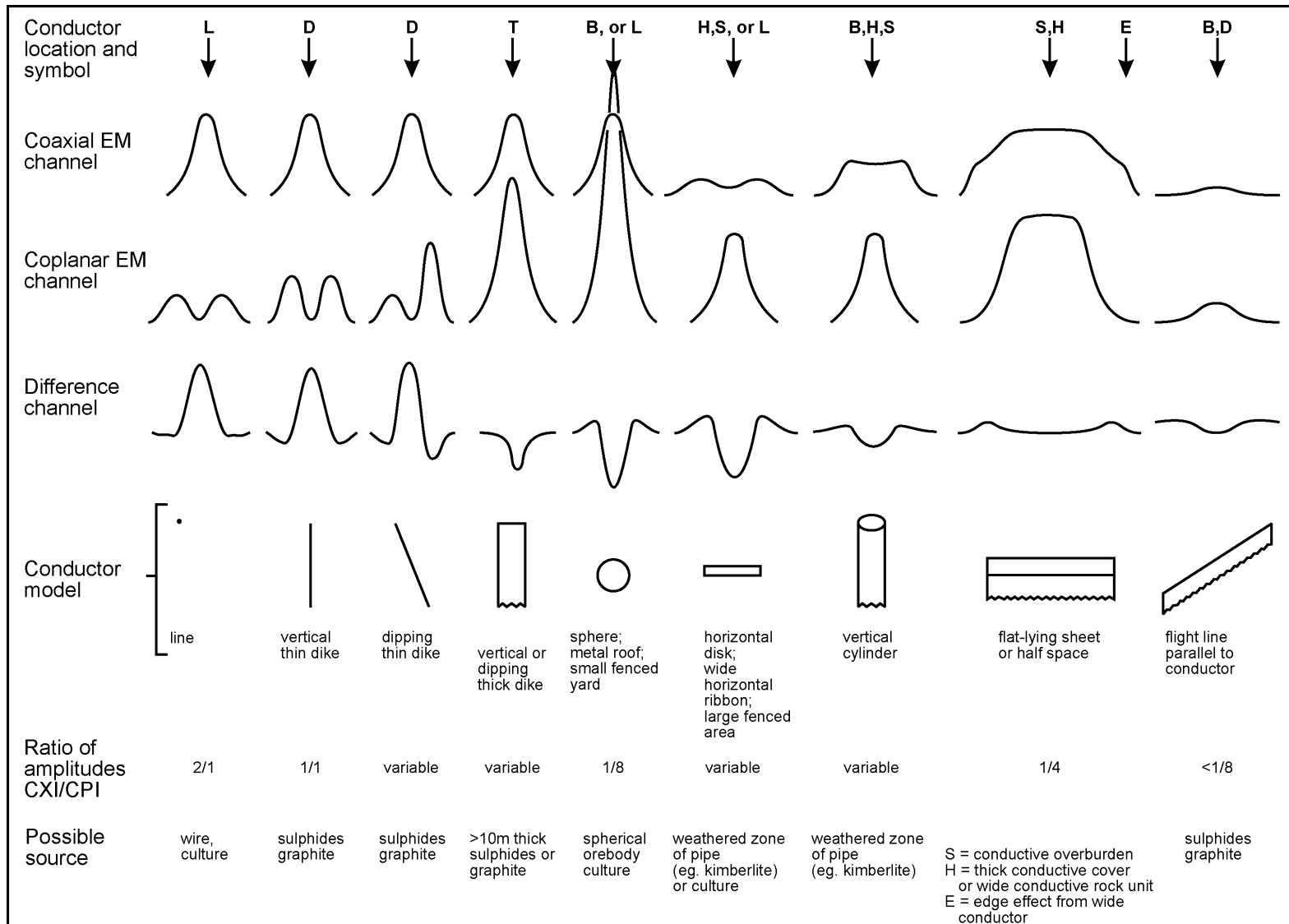
The geophysical interpreter attempts to determine the geometric shape and dip of the conductor. Figure B-1 shows typical HEM anomaly shapes which are used to guide the geometric interpretation.

#### 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 siemens (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 seven grades of conductance, as shown in Table B-1. The conductance in siemens (mhos) is the reciprocal of resistance in ohms.

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<sup>1</sup> Although a discrete conductor analysis was not a requirement for this survey, background information describing the process of identifying anomaly types was left in the project report as general information.



**Typical HEM anomaly shapes**  
**Figure B-1**

- Appendix B.3 -

The conductance value is a geological parameter because it is a characteristic of the conductor alone. It generally is independent of frequency, flying height or depth of burial, apart from the averaging over a greater portion of the conductor as height increases. 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.

**Table B-1. EM Anomaly Grades**

Anomaly Grade	Siemens
7	> 100
6	50 - 100
5	20 - 50
4	10 - 20
3	5 - 10
2	1 - 5
1	< 1

Conductive overburden generally produces broad EM responses which may not be shown as anomalies on the geophysical maps. However, patchy conductive overburden in otherwise resistive areas can yield discrete anomalies with a conductance grade (cf. Table B-1) of 1, 2 or even 3 for conducting clays which have resistivities as low as 50 ohm-m. In areas where ground resistivities are 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, and sometimes E on the geophysical maps (see EM legend on maps).

For bedrock conductors, the higher anomaly grades indicate increasingly higher conductances. Examples: the New Inco copper discovery (Noranda, Canada) yielded a grade 5 anomaly, as did the neighbouring copper-zinc Magusi River ore body; Mattabi (copper-zinc, Sturgeon Lake, Canada) and Whistle (nickel, Sudbury, Canada) gave grade 6; and the Montcalm nickel-copper discovery (Timmins, Canada) yielded a grade 7 anomaly. Graphite and sulphides 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 6 and 7) are characteristic of massive sulphides or graphite. Moderate conductors (grades 4 and 5) typically reflect graphite or sulphides of a less massive character, while weak bedrock conductors (grades 1 to 3) can signify poorly connected graphite or heavily disseminated sulphides. Grades 1 and 2 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 2 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

#### - Appendix B.4 -

produce anomalies that typically have low conductances (e.g., grades 1 to 3). 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.

For each interpreted electromagnetic anomaly on the geophysical maps, 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 in-phase 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.

The conductance measurement is considered more reliable than the depth estimate. There are a number of factors that 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 bedrock anomalies, which is based on a comparison of anomaly shapes on adjacent lines. This provides conductor axes that 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.

The electromagnetic anomalies 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



## - Appendix B.5 -

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. The accuracy is comparable to an interpretation from a high quality ground EM survey having the same line spacing.

The appended EM anomaly list provides a tabulation of anomalies in ppm, conductance, and depth for the vertical sheet model. No conductance or depth estimates are shown for weak anomalous responses that are not of sufficient amplitude to yield reliable calculations.

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.

### **Questionable Anomalies**

The EM maps may contain anomalous responses that are displayed as asterisks (\*). These responses denote weak anomalies of indeterminate conductance, which may reflect 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 legend on maps). The others probably do not warrant further investigation unless their locations are of considerable geological interest.

### **The Thickness Parameter**

A comparison of coaxial and coplanar shapes can provide an indication of the thickness of a steeply dipping conductor. The amplitude of the coplanar anomaly (e.g., CPI channel) 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. Thick conductors are indicated on the EM map by parentheses "( )". For base metal exploration in steeply dipping geology, thick conductors can be high priority targets because many massive sulphide ore bodies are thick. 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**

Resistivity mapping is useful in areas where broad or flat lying conductive units are of interest. One example of this is the clay alteration which is associated with Carlin-type

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deposits in the south west United States. The resistivity parameter was able to identify the clay alteration zone over the Cove deposit. The alteration zone appeared as a strong resistivity low on the 900 Hz resistivity parameter. The 7,200 Hz and 56,000 Hz resistivities showed more detail in the covering sediments, and delineated a range front fault. This is typical in many areas of the south west United States, where conductive near surface sediments, which may sometimes be alkalic, attenuate the higher frequencies.

Resistivity mapping has proven successful for locating diatremes in diamond exploration. Weathering products from relatively soft kimberlite pipes produce a resistivity contrast with the unaltered host rock. In many cases weathered kimberlite pipes were associated with thick conductive layers that contrasted with overlying or adjacent relatively thin layers of lake bottom sediments or overburden.

Areas of widespread conductivity are commonly encountered during surveys. These conductive zones may reflect alteration zones, shallow-dipping sulphide or graphite-rich units, saline ground water, or conductive overburden. In such areas, EM amplitude changes 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 in-phase and quadrature channels that 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 bedrock and 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 apparent resistivity is calculated using the pseudo-layer (or buried) half-space model defined by Fraser (1978)<sup>2</sup>. This model consists of a resistive layer overlying a conductive half-space. The depth channels give 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 that might 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 in-phase and quadrature components of the coplanar coil-pair. The outputs are the apparent resistivity of the conductive half-space (the

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

## - Appendix B.7 -

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 when the conductivity of the measured material is sufficient to yield significant in-phase as well as quadrature responses. 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. Depth information has been used for 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.

### **Interpretation in Conductive Environments**

Environments having low background resistivities (e.g., below 30 ohm-m for a 900 Hz system) yield very large responses from the conductive ground. This usually prohibits the recognition of discrete bedrock conductors. However, Fugro data processing techniques produce three parameters that contribute significantly to the recognition of bedrock conductors in conductive environments. These are the in-phase and quadrature difference channels (DIFI and DIFQ, which are available only on systems with “common” frequencies on orthogonal coil pairs), and the resistivity and depth channels (RES and DEP) for each coplanar frequency.

The EM difference channels (DIFI and DIFQ) eliminate most of the responses from conductive ground, leaving responses from bedrock conductors, cultural features (e.g., telephone lines, fences, etc.) and edge effects. Edge effects often occur near the perimeter of broad conductive zones. This can be 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 resistivity channels (RES). The most favourable situation is where anomalies coincide on all channels.

The DEP 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 depth profiles (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 the DEP 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 DEP channel is below the zero level and the high frequency DEP is above, this suggests that a bedrock conductor occurs beneath conductive cover.

## **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 previously that the EM difference channels (i.e., channel DIFI for in-phase and DIFQ for quadrature) tend to eliminate the response of conductive overburden.

Magnetite produces a form of geological noise on the in-phase channels. Rocks containing less than 1% magnetite can yield negative in-phase anomalies caused by magnetic permeability. When magnetite is widely distributed throughout a survey area, the in-phase 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 in-phase difference channel DIFI. This feature can be a significant aid in the recognition of conductors that occur in rocks containing accessory magnetite.

## **EM Magnetite Mapping**

The information content of HEM data consists of a combination of conductive eddy current responses and magnetic permeability responses. The secondary field resulting from conductive eddy current flow is frequency-dependent and consists of both in-phase 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 in-phase component which is negative in sign. When magnetic permeability manifests itself by decreasing the measured amount of positive in-phase, its presence may be difficult to recognize. However, when it manifests itself by yielding a negative in-phase 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, based on the low frequency coplanar data, 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 steep 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.

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 negative in-phase responses on the data profiles.

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.

## The Susceptibility Effect

When the host rock is conductive, the positive conductivity response will usually dominate the secondary field, and the susceptibility effect<sup>3</sup> will appear as a reduction in the in-phase, rather than as a negative value. The in-phase response will be lower than would be predicted by a model using zero susceptibility. At higher frequencies the in-phase conductivity response also gets larger, so a negative magnetite effect observed on the low frequency might not be observable on the higher frequencies, over the same body. The susceptibility effect is most obvious over discrete magnetite-rich zones, but also occurs over uniform geology such as a homogeneous half-space.

High magnetic susceptibility will affect the calculated apparent resistivity, if only conductivity is considered. Standard apparent resistivity algorithms use a homogeneous half-space model, with zero susceptibility. For these algorithms, the reduced in-phase response will, in most cases, make the apparent resistivity higher than it should be. It is important to note that there is nothing wrong with the data, nor is there anything wrong with the processing algorithms. The apparent difference results from the fact that the simple geological model used in processing does not match the complex geology.

## Measuring and Correcting the Magnetite Effect

Theoretically, it is possible to calculate (forward model) the combined effect of electrical conductivity and magnetic susceptibility on an EM response in all environments. The difficulty lies, however, in separating out the susceptibility effect from other geological effects when deriving resistivity and susceptibility from EM data.

Over a homogeneous half-space, there is a precise relationship between in-phase, quadrature, and altitude. These are often resolved as phase angle, amplitude, and altitude. Within a reasonable range, any two of these three parameters can be used to calculate the half space resistivity. If the rock has a positive magnetic susceptibility, the in-phase component will be reduced and this departure can be recognized by comparison to the other parameters.

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<sup>3</sup> Magnetic susceptibility and permeability are two measures of the same physical property. Permeability is generally given as relative permeability,  $\mu_r$ , which is the permeability of the substance divided by the permeability of free space ( $4 \pi \times 10^{-7}$ ). Magnetic susceptibility  $k$  is related to permeability by  $k = \mu_r - 1$ . Susceptibility is a unitless measurement, and is usually reported in units of  $10^{-6}$ . The typical range of susceptibilities is  $-1$  for quartz,  $130$  for pyrite, and up to  $5 \times 10^5$  for magnetite, in  $10^{-6}$  units (Telford et al, 1986).

The algorithm used to calculate apparent susceptibility and apparent resistivity from HEM data, uses a homogeneous half-space geological model. Non half-space geology, such as horizontal layers or dipping sources, can also distort the perfect half-space relationship of the three data parameters. While it may be possible to use more complex models to calculate both rock parameters, this procedure becomes very complex and time-consuming. For basic HEM data processing, it is most practical to stick to the simplest geological model.

Magnetite reversals (reversed in-phase anomalies) have been used for many years to calculate an “FeO” or magnetite response from HEM data (Fraser, 1981). However, this technique could only be applied to data where the in-phase was observed to be negative, which happens when susceptibility is high and conductivity is low.

## **Applying Susceptibility Corrections**

Resistivity calculations done with susceptibility correction may change the apparent resistivity. High-susceptibility conductors, that were previously masked by the susceptibility effect in standard resistivity algorithms, may become evident. In this case the susceptibility corrected apparent resistivity is a better measure of the actual resistivity of the earth. However, other geological variations, such as a deep resistive layer, can also reduce the in-phase by the same amount. In this case, susceptibility correction would not be the best method. Different geological models can apply in different areas of the same data set. The effects of susceptibility, and other effects that can create a similar response, must be considered when selecting the resistivity algorithm.

## **Susceptibility from EM vs. Magnetic Field Data**

The response of the EM system to magnetite may not match that from a magnetometer survey. First, HEM-derived susceptibility is a rock property measurement, like resistivity. Magnetic data show the total magnetic field, a measure of the potential field, not the rock property. Secondly, the shape of an anomaly depends on the shape and direction of the source magnetic field. The electromagnetic field of HEM is much different in shape from the earth's magnetic field. Total field magnetic anomalies are different at different magnetic latitudes; HEM susceptibility anomalies have the same shape regardless of their location on the earth.

In far northern latitudes, where the magnetic field is nearly vertical, the total magnetic field measurement over a thin vertical dike is very similar in shape to the anomaly from the HEM-derived susceptibility (a sharp peak over the body). The same vertical dike at the magnetic equator would yield a negative magnetic anomaly, but the HEM susceptibility anomaly would show a positive susceptibility peak.

## Effects of Permeability and Dielectric Permittivity

Resistivity algorithms that assume free-space magnetic permeability and dielectric permittivity, do not yield reliable values in highly magnetic or highly resistive areas. Both magnetic polarization and displacement currents cause a decrease in the in-phase component, often resulting in negative values that yield erroneously high apparent resistivities. The effects of magnetite occur at all frequencies, but are most evident at the lowest frequency. Conversely, the negative effects of dielectric permittivity are most evident at the higher frequencies, in resistive areas.

The table below shows the effects of varying permittivity over a resistive (10,000 ohm-m) half space, at frequencies of 56,000 Hz (DIGHEM<sup>V</sup>) and 102,000 Hz (RESOLVE).

### Apparent Resistivity Calculations

#### Effects of Permittivity on In-phase/Quadrature/Resistivity

Freq (Hz)	Coil	Sep (m)	Thres (ppm)	Alt (m)	In Phase	Quad Phase	App Res	App Depth (m)	Permittivity
56,000	CP	6.3	0.1	30	7.3	35.3	10118	-1.0	1 Air
56,000	CP	6.3	0.1	30	3.6	36.6	19838	-13.2	5 Quartz
56,000	CP	6.3	0.1	30	-1.1	38.3	81832	-25.7	10 Epidote
56,000	CP	6.3	0.1	30	-10.4	42.3	76620	-25.8	20 Granite
56,000	CP	6.3	0.1	30	-19.7	46.9	71550	-26.0	30 Diabase
56,000	CP	6.3	0.1	30	-28.7	52.0	66787	-26.1	40 Gabbro
102,000	CP	7.86	0.1	30	32.5	117.2	9409	-0.3	1 Air
102,000	CP	7.86	0.1	30	11.7	127.2	25956	-16.8	5 Quartz
102,000	CP	7.86	0.1	30	-14.0	141.6	97064	-26.5	10 Epidote
102,000	CP	7.86	0.1	30	-62.9	176.0	83995	-26.8	20 Granite
102,000	CP	7.86	0.1	30	-107.5	215.8	73320	-27.0	30 Diabase
102,000	CP	7.86	0.1	30	-147.1	259.2	64875	-27.2	40 Gabbro

Methods have been developed (Huang and Fraser, 2000, 2001) to correct apparent resistivities for the effects of permittivity and permeability. The corrected resistivities yield more credible values than if the effects of permittivity and permeability are disregarded.

### 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:

- Appendix B.12 -

1. Channels CXPL and CPPL monitor 60 Hz radiation. An anomaly on these channels shows that the conductor is radiating 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 that strikes across a power line, carrying leakage currents.
2. A flight that crosses a "line" (e.g., fence, telephone line, etc.) yields a centre-peaked coaxial anomaly and an m-shaped coplanar anomaly.<sup>4</sup> When the flight crosses the cultural line at a high angle of intersection, the amplitude ratio of coaxial/coplanar response is 2. Such an EM anomaly can only be caused by a line. The geologic body that yields anomalies most closely resembling a line is the vertically dipping thin dike. Such a body, however, yields an amplitude ratio of 1 rather than 2. Consequently, an m-shaped coplanar anomaly with a CXI/CPI amplitude ratio of 2 is virtually a guarantee that the source is a cultural line.
3. A flight that crosses a sphere or horizontal disk yields centre-peaked coaxial and coplanar anomalies with a CXI/CPI amplitude ratio (i.e., coaxial/coplanar) of 1/8. In the absence of geologic bodies of this geometry, the most likely conductor is a metal roof or small fenced yard.<sup>5</sup> Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.
4. A flight that crosses a horizontal rectangular body or wide ribbon yields an m-shaped coaxial anomaly and a centre-peaked coplanar anomaly. In the absence of geologic bodies of this geometry, the most likely conductor is a large fenced area.<sup>5</sup> Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.
5. EM anomalies that coincide with culture, as seen on the camera film or video display, 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 centre-peaked coplanar anomaly occurred, there would be concern that a thick geologic conductor coincided with the cultural line.
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

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<sup>4</sup> See Figure B-1 presented earlier.

<sup>5</sup> It is a characteristic of EM that geometrically similar 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.



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 and on the camera film or video records.

## **Magnetic Responses**

The measured total magnetic field provides information on the magnetic properties of the earth materials in the survey area. The information can be used to locate magnetic bodies of direct interest for exploration, and for structural and lithological mapping.

The total magnetic field response reflects the abundance of magnetic material in the source. Magnetite is the most common magnetic mineral. Other minerals such as ilmenite, pyrrhotite, franklinite, chromite, hematite, arsenopyrite, limonite and pyrite are also magnetic, but to a lesser extent than magnetite on average.

In some geological environments, an EM anomaly with magnetic correlation has a greater likelihood of being produced by sulphides than one which is non-magnetic. However, sulphide 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).

Iron ore deposits will be anomalously magnetic in comparison to surrounding rock due to the concentration of iron minerals such as magnetite, ilmenite and hematite.

Changes in magnetic susceptibility often allow rock units to be differentiated based on the total field magnetic response. Geophysical classifications may differ from geological classifications if various magnetite levels exist within one general geological classification. Geometric considerations of the source such as shape, dip and depth, inclination of the earth's field and remanent magnetization will complicate such an analysis.

In general, mafic lithologies contain more magnetite and are therefore more magnetic than many sediments which tend to be weakly magnetic. Metamorphism and alteration can also increase or decrease the magnetization of a rock unit.

Textural differences on a total field magnetic contour, colour or shadow map due to the frequency of activity of the magnetic parameter resulting from inhomogeneities in the distribution of magnetite within the rock, may define certain lithologies. For example, near surface volcanics may display highly complex contour patterns with little line-to-line correlation.

Rock units may be differentiated based on the plan shapes of their total field magnetic responses. Mafic intrusive plugs can appear as isolated "bulls-eye" anomalies. Granitic intrusives appear as sub-circular zones, and may have contrasting rings due to contact metamorphism. Generally, granitic terrain will lack a pronounced strike direction, although granite gneiss may display strike.

- Appendix B.14 -

Linear north-south units are theoretically not well-defined on total field magnetic maps in equatorial regions due to the low inclination of the earth's magnetic field. However, most stratigraphic units will have variations in composition along strike that will cause the units to appear as a series of alternating magnetic highs and lows.

Faults and shear zones may be characterized by alteration that causes destruction of magnetite (e.g., weathering) that produces a contrast with surrounding rock. Structural breaks may be filled by magnetite-rich, fracture filling material as is the case with diabase dikes, or by non-magnetic felsic material.

Faulting can also be identified by patterns in the magnetic total field contours or colours. Faults and dikes tend to appear as lineaments and often have strike lengths of several kilometres. Offsets in narrow, magnetic, stratigraphic trends also delineate structure. Sharp contrasts in magnetic lithologies may arise due to large displacements along strike-slip or dip-slip faults.

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**APPENDIX C**

**'README FILE FOR  
GPR2008-1**

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## APPENDIX C

### 'README' FILE FOR GPR2008-1

**Volume Label:** CDVD00251

**Archive Date:** 2007-December 7

**This publication consists of 1 DVD-ROM or other similar media.**



#### GPR 2008-1Readme.PDF for the publication

Burns, L.E., U.S. Bureau of Land Management, Fugro Airborne Surveys, and Stevens Management Corp., 2008, Line, grid, and vector data, plot files, and project report for the airborne geophysical survey data of part of the western Fortymile mining district, east-central Alaska: Alaska Division of Geological & Geophysical Surveys Geophysical Report 2008-1.

This 'readme' file contains

- basic and technical information about the airborne geophysical survey,
- DVD-ROM organization and contents (including file names),
- and projection information for the digital data.

More information is included in the metadata and project report included on this publication.



#### BASIC INFORMATION:

This DVD-ROM publication, GPR2008-1, contains final data for the airborne geophysical survey of part of the western Fortymile mining district, east-central Alaska, that was released in 2008 by the Alaska Division of Geological & Geophysical Surveys (DGGs), and funded by the U.S. Bureau of Land Management (BLM). Final processed linedata, gridded data and associated vector files, plot files of currently published maps, and a descriptive project report are included.

The project was completed under contract between the State of Alaska, Department of Natural Resources, Division of Geological & Geophysical Surveys (DGGs), and Stevens Exploration Management Corp. Airborne geophysical data for the area were acquired and processed in 2007 by Fugro Airborne Surveys. Additional products from this survey and the older surveys are available by mail order, or in person, from DGGs, 3354 College Road, Fairbanks, Alaska, 99709-3707. The map products are available at the DGGs website (<http://www.dggs.dnr.state.ak.us>). Some or all of the digital data should also be available for free download on the DGGs Web site (<http://www.dggs.dnr.state.ak.us/>) by December 2008 if not earlier.



## TECHNICAL NOTES:

The geophysical data were acquired with a DIGHEM V Electromagnetic (EM) system, and a Fugro D1344 cesium magnetometer. Both were flown at a height of 100 feet. In addition, the survey recorded data from a radar altimeter, GPS navigation system, 50/60 Hz monitors and video camera. Flights were performed with an AS350B-3 Squirrel helicopter at a mean terrain clearance of 200 feet along NW-SE (350°) flight lines with one-quarter mile line spacing. Tie lines were flown perpendicular to the flight lines at intervals of approximately 3 miles.

A Novatel OEM4 Global Positioning System was used for navigation. The helicopter position was derived every 0.5 seconds using post-flight differential positioning to a relative accuracy of better than 5 m. Flight path positions were projected onto the Clarke 1866 (UTM zone 7) spheroid, 1927 North American datum using a central meridian of 141°, a north constant of 0 and an east constant of 500,000. Positional accuracy of the presented data is better than 10 m with respect to the UTM grid.

The DIGHEM V EM system measured inphase and quadrature components at five frequencies. Two vertical coaxial-coil pairs operated at 1125 (1000) and 5454 (5500) Hz while three horizontal coplanar-coil pairs operated at 875 (900), 7153 (7200), and 55,400 (56,000) Hz. The EM data were sampled at 0.1 second intervals. The EM system responds to bedrock conductors, conductive overburden, and cultural sources. The power line monitors and the flight track video were examined to locate cultural sources.

The total magnetic field data were acquired with a sampling interval of 0.1 seconds, and were (1) corrected for measured system lag, (2) corrected for diurnal variations by subtraction of the digitally recorded base station magnetic data (saved as tfmag in Fortymile-Linedata.xyz), (3) adjusted for regional variations (or IGRF gradient, 2005, updated to September 2007) using altimeter adjusted IGRF, (4) leveled to the tie line data (saved as magigrf in Fortymile-Linedata.xyz), and (5) interpolated onto a regular 80m grid using a modified Akima (1970) technique.

Akima, H., 1970, A new method of interpolation and smooth curve fitting based on local procedures: Journal of the Association of Computing Machinery, v. 17, no. 4, p 589-602.



## PROJECTION INFORMATION:

The coordinate system for all grids and XYZ files is described as follows:

Datum	NAD27	Delta X shift	+5
Spheroid	Clarke 1866	Delta Y shift	-135
Projection	UTM Zone 7N	Delta Z shift	-172
Central meridian	-141		
False easting	500000		
False northing	0		
Scale factor	0.9996		
Northern parallel	N/A		
Base parallel	N/A		
WGS84 to local conversion method	Molodensky		



## DVD-ROM ORGANIZATION

There is one DVD-ROM in this set and 6 Main directories: LINEDATA, GRIDS, VECTORS, PROJECT REPORT, PLOTFILES, and METADATA. A few files are contained at the DVD level.



## FILES AT THE DVD LEVEL:

GPR2008-1ReadMe.pdf — this file; description for this publication  
GPR2008-1LocMap63360.jpg — Index map for the 63,360-scale map sheets on this publication



## LINEDATA\

Fortymile-Linedata.XYZ — ASCII line data archive in Geosoft XYZ format  
Fortymile-Linedata.TXT — text description file for the XYZ data archive



## GRIDS\ (in Geosoft binary float .grd and ER Mapper binary .ers format)


Fortymile-magigrf — Total Magnetic Field (TMF) — IGRF removed (nT)  
Fortymile-cvg — Calculated Vertical Gradient of TMF — IGRF removed (nT/m)  
(First vertical derivative)  
Fortymile-res56k — 56000 Hz Apparent Resistivity (ohm-m)  
Fortymile-res7200 — 7200 Hz Apparent Resistivity (ohm-m)  
Fortymile-res900 — 900 Hz Apparent Resistivity (ohm-m)  
Fortymile-dem — Digital Elevation Model (m)



## VECTORS\ (in AutoCAD 2000 DXF format)

The magnetic and resistivity files below contain the contour files produced from the gridded data. All of the dxf files are at a scale of 1:63360.


Fortymile-magigrf.dxf — Total Magnetic Field contours — IGRF removed (nT)  
Fortymile-res56k.dxf — 56000 Hz Apparent Resistivity (ohm-m) contours  
Fortymile-res7200.dxf — 7200 Hz Apparent Resistivity (ohm-m) contours  
Fortymile-res900.dxf — 900 Hz Apparent Resistivity (ohm-m) contours  
Fortymile-fp.dxf — Flight Path  
Fortymile-SecGrid.dxf — Alaska Section Grid



**PROJECT REPORT\** Contractors' project report for the airborne geophysical survey

Pritchard, Ruth, Fugro Airborne Surveys, and Stevens Management Corp., 2008, Project report of the airborne geophysical survey of part of the western Fortymile mining district, east-central Alaska: *in* Burns, L.E., U.S. Bureau of Land Management, Fugro Airborne Surveys, and Stevens Management Corp., 2008, Alaska Division of Geological & Geophysical Surveys Geophysical Report 2008-1, Section GPR 2008-1-5.

GPR2008-1-5.pdf — Adobe Acrobat format



**METADATA\** Metadata for this publication is in three formats

GPR2008-1.faq.html — Hypertext Markup Language format  
GPR2008-1.txt — ASCII text  
GPR2008-1.xml — Extensible Markup Language format



**PLOTFILES\** of published maps: [provided in HPGL2 (.prn) and Adobe Acrobat (.pdf) formats]

The HPGL2 files were created with HP Designjet 5000 printer driver v5.32 and will not work with all plotters, but do plot on the DGGG HP DesignJet 5000. The HPGL/2 files have brighter colors and sharper topography than the Adobe Acrobat files. The Adobe Acrobat format files were created with Adobe Acrobat Distiller v7.0 (PDF 1.3) from postscript files created from the HPGL/2 files.

All map files are provided in two subdirectories as below:

\HPGL2 — all files have a .prn extension  
\PDF — all files have a .pdf extension

## PLOT FILES

Publication Number	Type	With	Scale	File names	Sheet x of 1
GPR2008-1-1a	total magnetic field, IGRF removed	topography	1:63,360	GPR2008-1-1a	1
GPR2008-1-1b	total magnetic field, IGRF removed	magnetic contours	1:63,360	GPR2008-1-1b	1
GPR2008-1-1c	First vertical derivative of the total magnetic field, IGRF removed	topography	1:63,360	GPR2008-1-1c	1
GPR2008-1-2a	56K Hz apparent resistivity	topography	1:63,360	GPR2008-1-2a	1
GPR2008-1-2b	56K Hz apparent resistivity	56K contours	1:63,360	GPR2008-1-2b	1
GPR2008-1-3a	7200 Hz apparent resistivity	topography	1:63,360	GPR2008-1-3a	1
GPR2008-1-3b	7200 Hz apparent resistivity	7200 contours	1:63,360	GPR2008-1-3b	1
GPR2008-1-4a	900 Hz apparent resistivity	topography	1:63,360	GPR2008-1-4a	1
GPR2008-1-4b	900 Hz apparent resistivity	900 contours	1:63,360	GPR2008-1-4b	1



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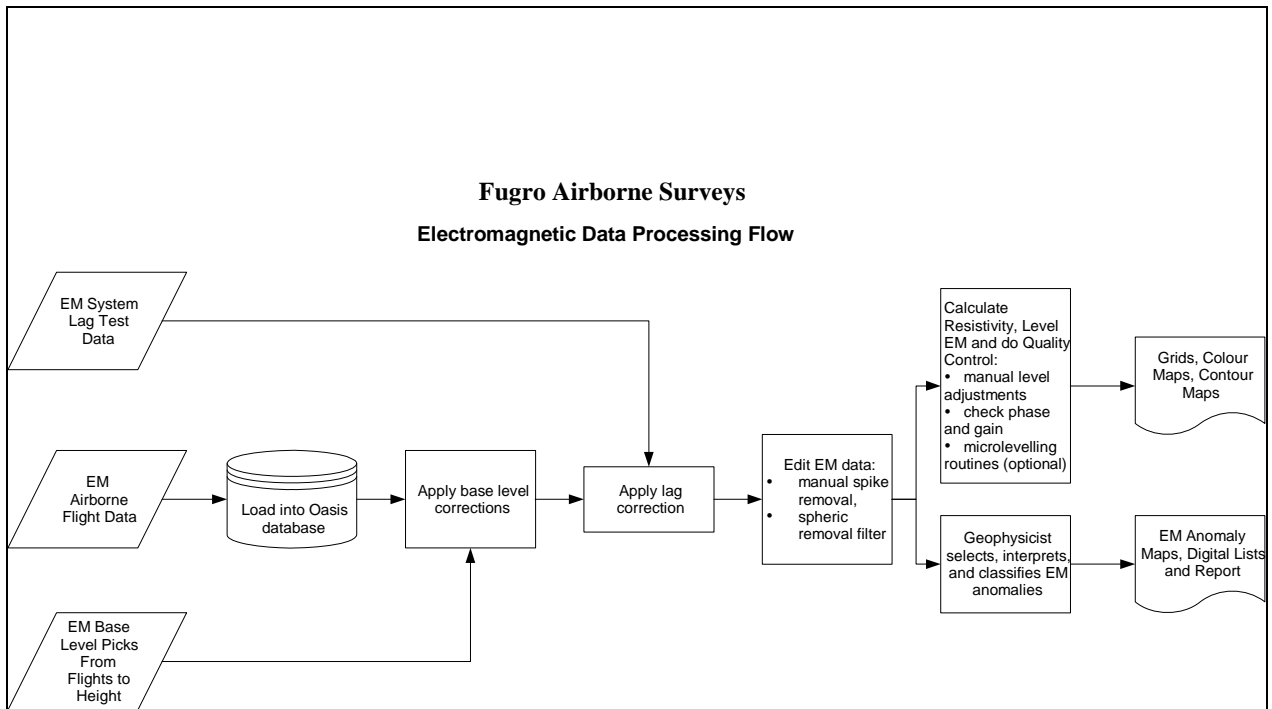
**APPENDIX D**

**DATA PROCESSING  
FLOWCHARTS**

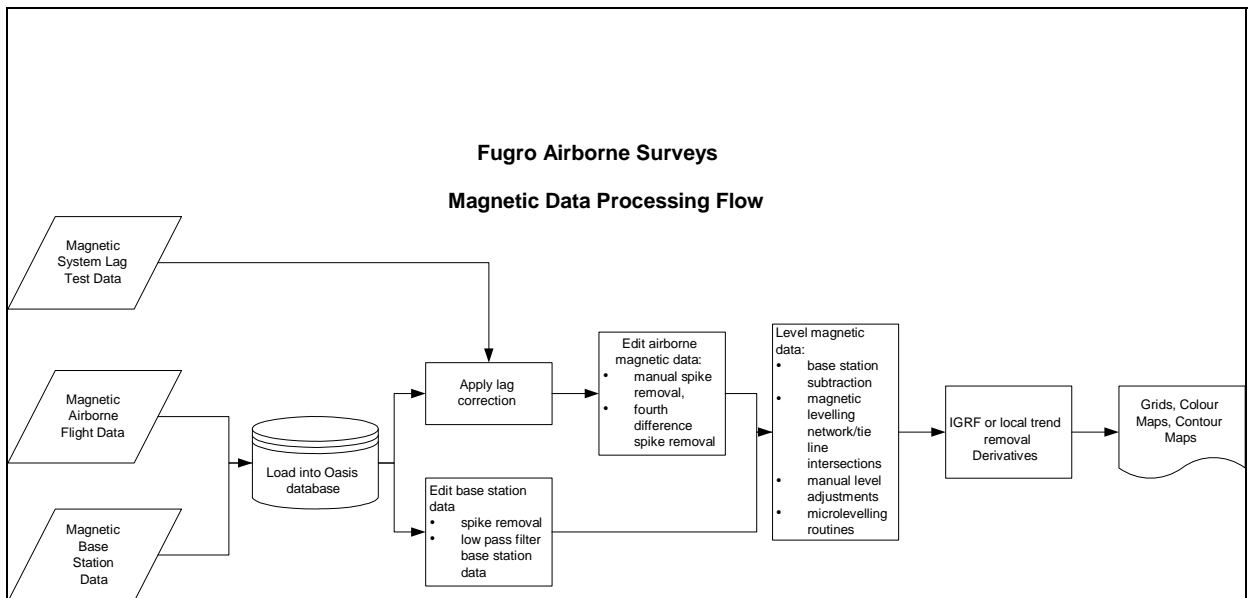
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# APPENDIX D

## Processing Flow Chart - Electromagnetic Data



## Processing Flow Chart - Magnetic Data



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**APPENDIX E**

**GLOSSARY**

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## APPENDIX E

### GLOSSARY OF AIRBORNE GEOPHYSICAL TERMS

Note: The definitions given in this glossary refer to the common terminology as used in airborne geophysics.

**altitude attenuation:** the absorption of gamma rays by the atmosphere between the earth and the detector. The number of gamma rays detected by a system decreases as the altitude increases.

**apparent- :** the *physical parameters* of the earth measured by a geophysical system are normally expressed as apparent, as in “apparent *resistivity*”. This means that the measurement is limited by assumptions made about the geology in calculating the response measured by the geophysical system. Apparent resistivity calculated with *HEM*, for example, generally assumes that the earth is a *homogeneous half-space* – not layered.

**amplitude:** The strength of the total electromagnetic field. In *frequency domain* it is most often the sum of the squares of *in-phase* and *quadrature* components. In multi-component electromagnetic surveys it is generally the sum of the squares of all three directional components.

**analytic signal:** The total amplitude of all the directions of magnetic *gradient*. Calculated as the sum of the squares.

**anisotropy:** Having different *physical parameters* in different directions. This can be caused by layering or fabric in the geology. Note that a unit can be anisotropic, but still **homogeneous**.

**anomaly:** A localized change in the geophysical data characteristic of a discrete source, such as a conductive or magnetic body. Something locally different from the **background**.

**B-field:** In time-domain **electromagnetic** surveys, the magnetic field component of the (electromagnetic) **field**. This can be measured directly, although more commonly it is calculated by integrating the time rate of change of the magnetic field **dB/dt**, as measured with a receiver coil.

**background:** The “normal” response in the geophysical data – that response observed over most of the survey area. **Anomalies** are usually measured relative to the background. In airborne gamma-ray spectrometric surveys the term defines the **cosmic**, radon, and aircraft responses in the absence of a signal from the ground.

**base-level:** The measured values in a geophysical system in the absence of any outside signal. All geophysical data are measured relative to the system base level.

**base frequency:** The frequency of the pulse repetition for a *time-domain electromagnetic* system. Measured between subsequent positive pulses.

**bird:** A common name for the pod towed beneath or behind an aircraft, carrying the geophysical sensor array.

**calibration coil:** A wire coil of known size and dipole moment, which is used to generate a field of known *amplitude* and *phase* in the receiver, for system calibration. Calibration coils can be external, or internal to the system. Internal coils may be called Q-coils.

**coaxial coils:** [CX] Coaxial coils are in the vertical plane, with their axes horizontal and collinear in the flight direction. These are most sensitive to vertical conductive objects in the ground, such as thin, steeply dipping conductors perpendicular to the flight direction. Coaxial coils generally give the sharpest anomalies over localized conductors. (See also *coplanar coils*)

**coil:** A multi-turn wire loop used to transmit or detect electromagnetic fields. Time varying *electromagnetic* fields through a coil induce a voltage proportional to the strength of the field and the rate of change over time.

**compensation:** Correction of airborne geophysical data for the changing effect of the aircraft. This process is generally used to correct data in *fixed-wing time-domain electromagnetic* surveys (where the transmitter is on the aircraft and the receiver is moving), and magnetic surveys (where the sensor is on the aircraft, turning in the earth's magnetic field).

**component:** In *frequency domain electromagnetic* surveys this is one of the two *phase* measurements – *in-phase or quadrature*. In “multi-component” electromagnetic surveys it is also used to define the measurement in one geometric direction (vertical, horizontal in-line and horizontal transverse – the Z, X and Y components).

**Compton scattering:** gamma ray photons will bounce off the nuclei of atoms they pass through (earth and atmosphere), reducing their energy and then being detected by *radiometric* sensors at lower energy levels. See also *stripping*.

**conductance:** See *conductivity thickness*

**conductivity:** [ $\sigma$ ] The facility with which the earth or a geological formation conducts electricity. Conductivity is usually measured in milli-Siemens per metre (mS/m). It is the reciprocal of *resistivity*.

**conductivity-depth imaging:** see *conductivity-depth transform*.

**conductivity-depth transform:** A process for converting electromagnetic measurements to an approximation of the conductivity distribution vertically in the earth, assuming a *layered earth*. (Macnae and Lamontagne, 1987; Wolfgram and Karlik, 1995)

**conductivity thickness:** [ $\sigma t$ ] The product of the *conductivity*, and thickness of a large, tabular body. (It is also called the “conductivity-thickness product”) In electromagnetic geophysics, the response of a thin plate-like conductor is proportional to the conductivity multiplied by thickness. For example a 10 metre thickness of 20 Siemens/m mineralization will be equivalent to 5 metres of 40 S/m; both have 200 S conductivity thickness. Sometimes referred to as conductance.

**conductor:** Used to describe anything in the ground more conductive than the surrounding geology. Conductors are most often clays or graphite, or hopefully some type of mineralization, but may also be man-made objects, such as fences or pipelines.

**coplanar coils:** [CP] The coplanar coils lie in the horizontal plane with their axes vertical, and parallel. These coils are most sensitive to massive conductive bodies, horizontal layers, and the *halfspace*.

**cosmic ray:** High energy sub-atomic particles from outer space that collide with the earth’s atmosphere to produce a shower of gamma rays (and other particles) at high energies.

**counts (per second):** The number of *gamma-rays* detected by a gamma-ray *spectrometer*. The rate depends on the geology, but also on the size and sensitivity of the detector.

**culture:** A term commonly used to denote any man-made object that creates a geophysical anomaly. Includes, but not limited to, power lines, pipelines, fences, and buildings.

**current gathering:** The tendency of electrical currents in the ground to channel into a conductive formation. This is particularly noticeable at higher frequencies or early time channels when the formation is long and parallel to the direction of current flow. This tends to enhance anomalies relative to inductive currents (see also *induction*). Also known as current channelling.

**current channelling:** See current gathering.

**daughter products:** The radioactive natural sources of gamma-rays decay from the original element (commonly potassium, uranium, and thorium) to one or more lower-energy elements. Some of these lower energy elements are also radioactive and decay

further. **Gamma-ray spectrometry** surveys may measure the gamma rays given off by the original element or by the decay of the daughter products.

**$dB/dt$ :** As the **secondary electromagnetic field** changes with time, the magnetic field [**B**] component induces a voltage in the receiving **coil**, which is proportional to the rate of change of the magnetic field over time.

**decay:** In **time-domain electromagnetic** theory, the weakening over time of the **eddy currents** in the ground, and hence the **secondary field** after the **primary field** electromagnetic pulse is turned off. In **gamma-ray spectrometry**, the radioactive breakdown of an element, generally potassium, uranium, thorium, or one of their **daughter** products.

**decay series:** In **gamma-ray spectrometry**, a series of progressively lower energy **daughter products** produced by the radioactive breakdown of uranium or thorium.

**decay constant:** see time constant.

**depth of exploration:** The maximum depth at which the geophysical system can detect the target. The depth of exploration depends very strongly on the type and size of the target, the contrast of the target with the surrounding geology, the homogeneity of the surrounding geology, and the type of geophysical system. One measure of the maximum depth of exploration for an electromagnetic system is the depth at which it can detect the strongest conductive target – generally a highly conductive horizontal layer.

**differential resistivity:** A process of transforming **apparent resistivity** to an approximation of layer resistivity at each depth. The method uses multi-frequency HEM data and approximates the effect of shallow layer **conductance** determined from higher frequencies to estimate the deeper conductivities (Huang and Fraser, 1996)

**dipole moment:** [NIA] For a transmitter, the product of the area of a **coil**, the number of turns of wire, and the current flowing in the coil. At a distance significantly larger than the size of the coil, the magnetic field from a coil will be the same if the dipole moment product is the same. For a receiver coil, this is the product of the area and the number of turns. The sensitivity to a magnetic field (assuming the source is far away) will be the same if the dipole moment is the same.

**diurnal:** The daily variation in a natural field, normally used to describe the natural fluctuations (over hours and days) of the earth's magnetic field.

**dielectric permittivity:** [ $\epsilon$ ] The capacity of a material to store electrical charge, this is most often measured as the relative permittivity [ $\epsilon_r$ ], or ratio of the material dielectric to that of free space. The effect of high permittivity may be seen in HEM data at high frequencies over highly resistive geology as a reduced or negative **in-phase**, and higher **quadrature** data.

**drift:** Long-time variations in the base-level or calibration of an instrument.

**eddy currents:** The electrical currents induced in the ground, or other conductors, by a time-varying **electromagnetic field** (usually the **primary field**). Eddy currents are also induced in the aircraft's metal frame and skin; a source of **noise** in EM surveys.

**electromagnetic: [EM]** Comprised of a time-varying electrical and magnetic field. Radio waves are common electromagnetic fields. In geophysics, an electromagnetic system is one which transmits a time-varying **primary field** to induce **eddy currents** in the ground, and then measures the **secondary field** emitted by those eddy currents.

**energy window:** A broad spectrum of **gamma-ray** energies measured by a spectrometric survey. The energy of each gamma-ray is measured and divided up into numerous discrete energy levels, called windows.

**equivalent** (thorium or uranium): The amount of radioelement calculated to be present, based on the gamma-rays measured from a **daughter** element. This assumes that the **decay series** is in equilibrium – progressing normally.

**fiducial, or fid:** Timing mark on a survey record. Originally these were timing marks on a profile or film; now the term is generally used to describe 1-second interval timing records in digital data, and on maps or profiles.

**fixed-wing:** Aircraft with wings, as opposed to “rotary wing” helicopters.

**footprint:** This is a measure of the area of sensitivity under the aircraft of an airborne geophysical system. The footprint of an **electromagnetic** system is dependent on the altitude of the system, the orientation of the transmitter and receiver and the separation between the receiver and transmitter, and the conductivity of the ground. The footprint of a **gamma-ray spectrometer** depends mostly on the altitude. For all geophysical systems, the footprint also depends on the strength of the contrasting **anomaly**.

**frequency domain:** An **electromagnetic** system which transmits a **primary field** that oscillates smoothly over time (sinusoidal), inducing a similarly varying electrical current in the ground. These systems generally measure the changes in the **amplitude** and **phase** of the **secondary field** from the ground at different frequencies by measuring the **in-phase** and **quadrature** phase components. See also **time-domain**.

**full-stream data:** Data collected and recorded continuously at the highest possible sampling rate. Normal data are stacked (see **stacking**) over some time interval before recording.

**gamma-ray:** A very high-energy photon, emitted from the nucleus of an atom as it undergoes a change in energy levels.



**gamma-ray spectrometry:** Measurement of the number and energy of natural (and sometimes man-made) gamma-rays across a range of photon energies.

**gradient:** In magnetic surveys, the gradient is the change of the magnetic field over a distance, either vertically or horizontally in either of two directions. Gradient data is often measured, or calculated from the total magnetic field data because it changes more quickly over distance than the **total magnetic field**, and so may provide a more precise measure of the location of a source. See also **analytic signal**.

**ground effect:** The response from the earth. A common calibration procedure in many geophysical surveys is to fly to altitude high enough to be beyond any measurable response from the ground, and there establish **base levels** or **backgrounds**.

**half-space:** A mathematical model used to describe the earth – as infinite in width, length, and depth below the surface. The most common halfspace models are **homogeneous** and **layered earth**.

**heading error:** A slight change in the magnetic field measured when flying in opposite directions.

**HEM:** Helicopter ElectroMagnetic, This designation is most commonly used to helicopter-borne, **frequency-domain** electromagnetic systems. At present, the transmitter and receivers are normally mounted in a **bird** carried on a sling line beneath the helicopter.

**herringbone pattern:** a pattern created in geophysical data by an asymmetric system, where the **anomaly** may be extended to either side of the source, in the direction of flight. Appears like fish bones, or like the teeth of a comb, extending either side of centre, each tooth an alternate flight line.

**homogeneous:** This is a geological unit that has the same **physical parameters** throughout its volume. This unit will create the same response to an HEM system anywhere, and the HEM system will measure the same apparent **resistivity** anywhere. The response may change with system direction (see **anisotropy**).

**in-phase:** the component of the measured **secondary field** that has the same phase as the transmitter and the **primary field**. The in-phase component is stronger than the **quadrature** phase over relatively higher **conductivity**.

**induction:** Any time-varying electromagnetic field will induce (cause) electrical currents to flow in any object with non-zero **conductivity**. (see **eddy currents**)

**infinite:** In geophysical terms, an “infinite” dimension is one much greater than the **footprint** of the system, so that the system does not detect changes at the edges of the object.

**International Geomagnetic Reference Field: [IGRF]** An approximation of the smooth magnetic field of the earth, in the absence of variations due to local geology. Once the IGRF is subtracted from the measured magnetic total field data, any remaining variations are assumed to be due to local geology. The IGRF also predicts the slow changes of the field up to five years in the future.

**inversion, or inverse modeling:** A process of converting geophysical data to an earth model, which compares theoretical models of the response of the earth to the data measured, and refines the model until the response closely fits the measured data (Huang and Palacky, 1991)

**layered earth:** A common geophysical model which assumes that the earth is horizontally layered – the **physical parameters** are constant to **infinite** distance horizontally, but change vertically.

**magnetic permeability: [ $\mu$ ]** This is defined as the ratio of magnetic induction to the inducing magnetic field. The relative magnetic permeability [ $\mu_r$ ] is often quoted, which is the ratio of the rock permeability to the permeability of free space. In geology and geophysics, the **magnetic susceptibility** is more commonly used to describe rocks.

**magnetic susceptibility: [k]** A measure of the degree to which a body is magnetized. In SI units this is related to relative **magnetic permeability** by  $k = \mu_r - 1$ , and is a dimensionless unit. For most geological material, susceptibility is influenced primarily by the percentage of magnetite. It is most often quoted in units of  $10^{-6}$ . In HEM data this is most often apparent as a negative **in-phase** component over high susceptibility, high **resistivity** geology such as diabase dikes.

**noise:** That part of a geophysical measurement that the user does not want. Typically this includes electronic interference from the system, the atmosphere (**sferics**), and man-made sources. This can be a subjective judgment, as it may include the response from geology other than the target of interest. Commonly the term is used to refer to high frequency (short period) interference. See also **drift**.

**Occam’s inversion:** an **inversion** process that matches the measured **electromagnetic** data to a theoretical model of many, thin layers with constant thickness and varying resistivity (Constable et al, 1987).

**off-time:** In a **time-domain electromagnetic** survey, the time after the end of the **primary field pulse**, and before the start of the next pulse.

**on-time:** In a *time-domain electromagnetic* survey, the time during the *primary field pulse*.

**phase:** The angular difference in time between a measured sinusoidal electromagnetic field and a reference – normally the primary field. The phase is calculated from  $\tan^{-1}(\text{in-phase} / \text{quadrature})$ .

**physical parameters:** These are the characteristics of a geological unit. For electromagnetic surveys, the important parameters for electromagnetic surveys are *conductivity*, *magnetic permeability* (or *susceptibility*) and *dielectric permittivity*; for magnetic surveys the parameter is magnetic susceptibility, and for gamma ray spectrometric surveys it is the concentration of the major radioactive elements: potassium, uranium, and thorium.

**permittivity:** see *dielectric permittivity*.

**permeability:** see *magnetic permeability*.

**primary field:** the EM field emitted by a transmitter. This field induces *eddy currents* in (energizes) the conductors in the ground, which then create their own *secondary fields*.

**pulse:** In time-domain EM surveys, the short period of intense *primary* field transmission. Most measurements (the *off-time*) are measured after the pulse.

**quadrature:** that component of the measured *secondary field* that is phase-shifted 90° from the *primary field*. The quadrature component tends to be stronger than the *in-phase* over relatively weaker *conductivity*.

**Q-coils:** see *calibration coil*.

**radiometric:** Commonly used to refer to *gamma ray* spectrometry.

**radon:** A radioactive daughter product of uranium and thorium, radon is a gas which can leak into the atmosphere, adding to the non-geological background of a gamma-ray spectrometric survey.

**resistivity:** [ $\rho$ ] The strength with which the earth or a geological formation resists the flow of electricity, typically the flow induced by the *primary field* of the electromagnetic transmitter. Normally expressed in ohm-metres, it is the reciprocal of *conductivity*.

**resistivity-depth transforms:** similar to *conductivity depth transforms*, but the calculated *conductivity* has been converted to *resistivity*.

**resistivity section:** an approximate vertical section of the resistivity of the layers in the earth. The resistivities can be derived from the **apparent resistivity**, the **differential resistivities**, **resistivity-depth transforms**, or **inversions**.

**secondary field:** The field created by conductors in the ground, as a result of electrical currents induced by the **primary field** from the **electromagnetic** transmitter. Airborne **electromagnetic** systems are designed to create, and measure a secondary field.

**Sengpiel section:** a **resistivity section** derived using the **apparent resistivity** and an approximation of the depth of maximum sensitivity for each frequency.

**sferic:** Lightning, or the **electromagnetic** signal from lightning, it is an abbreviation of “atmospheric discharge”. These appear to magnetic and electromagnetic sensors as sharp “spikes” in the data. Under some conditions lightning storms can be detected from hundreds of kilometres away. (see **noise**)

**signal:** That component of a measurement that the user wants to see – the response from the targets, from the earth, etc. (See also **noise**)

**skin depth:** A measure of the depth of penetration of an electromagnetic field into a material. It is defined as the depth at which the primary field decreases to 1/e of the field at the surface. It is calculated by approximately  $503 \times \sqrt{(\text{resistivity}/\text{frequency})}$ . Note that depth of penetration is greater at higher **resistivity** and/or lower **frequency**.

**spectrometry:** Measurement across a range of energies, where **amplitude** and energy are defined for each measurement. In gamma-ray spectrometry, the number of gamma rays are measured for each energy **window**, to define the **spectrum**.

**spectrum:** In **gamma ray spectrometry**, the continuous range of energy over which gamma rays are measured. In **time-domain electromagnetic** surveys, the spectrum is the energy of the **pulse** distributed across an equivalent, continuous range of frequencies.

**spheric:** see **sferic**.

**stacking:** Summing repeat measurements over time to enhance the repeating **signal**, and minimize the random **noise**.

**stripping:** Estimation and correction for the gamma ray photons of higher and lower energy that are observed in a particular **energy window**. See also **Compton scattering**.

**susceptibility:** See **magnetic susceptibility**.

**tau:** [ $\tau$ ] Often used as a name for the **time constant**.

**TDEM:** *time domain electromagnetic.*

**thin sheet:** A standard model for electromagnetic geophysical theory. It is usually defined as thin, flat-lying, and *infinite* in both horizontal directions. (see also *vertical plate*)

**tie-line:** A survey line flown across most of the *traverse lines*, generally perpendicular to them, to assist in measuring *drift* and *diurnal* variation. In the short time required to fly a tie-line it is assumed that the drift and/or diurnal will be minimal, or at least changing at a constant rate.

**time constant:** The time required for an *electromagnetic* field to decay to a value of 1/e of the original value. In *time-domain* electromagnetic data, the time constant is proportional to the size and *conductance* of a tabular conductive body. Also called the decay constant.

**Time channel:** In *time-domain electromagnetic* surveys the decaying *secondary field* is measured over a period of time, and the divided up into a series of consecutive discrete measurements over that time.

**time-domain:** *Electromagnetic* system which transmits a pulsed, or stepped *electromagnetic* field. These systems induce an electrical current (*eddy current*) in the ground that persists after the *primary field* is turned off, and measure the change over time of the *secondary field* created as the currents *decay*. See also *frequency-domain*.

**total energy envelope:** The sum of the squares of the three *components* of the *time-domain electromagnetic secondary field*. Equivalent to the *amplitude* of the secondary field.

**transient:** Time-varying. Usually used to describe a very short period pulse of *electromagnetic* field.

**traverse line:** A normal geophysical survey line. Normally parallel traverse lines are flown across the property in spacing of 50 m to 500 m, and generally perpendicular to the target geology.

**vertical plate:** A standard model for electromagnetic geophysical theory. It is usually defined as thin, and *infinite* in horizontal dimension and depth extent. (see also *thin sheet*)

**waveform:** The shape of the *electromagnetic pulse* from a *time-domain* electromagnetic transmitter.

**window:** A discrete portion of a *gamma-ray spectrum* or *time-domain electromagnetic decay*. The continuous energy spectrum or *full-stream* data are grouped into windows to reduce the number of samples, and reduce *noise*.

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### Common Symbols and Acronyms

<b>k</b>	Magnetic susceptibility
<b><math>\epsilon</math></b>	Dielectric permittivity
<b><math>\mu, \mu_r</math></b>	Magnetic permeability, apparent permeability
<b><math>\rho, \rho_a</math></b>	Resistivity, apparent resistivity
<b><math>\sigma, \sigma_a</math></b>	Conductivity, apparent conductivity
<b><math>\sigma t</math></b>	Conductivity thickness
<b><math>\tau</math></b>	Tau, or time constant
<b><math>\Omega.m</math></b>	Ohm-metres, units of resistivity
<b>AGS</b>	Airborne gamma ray spectrometry.
<b>CDT</b>	Conductivity-depth transform, conductivity-depth imaging (Macnae and Lamontagne, 1987; Wolfgram and Karlik, 1995)
<b>CPI, CPQ</b>	Coplanar in-phase, quadrature
<b>CPS</b>	Counts per second
<b>CTP</b>	Conductivity thickness product
<b>CXI, CXQ</b>	Coaxial, in-phase, quadrature
<b>fT</b>	femtoteslas, normal unit for measurement of B-Field
<b>EM</b>	Electromagnetic
<b>keV</b>	kilo electron volts – a measure of gamma-ray energy
<b>MeV</b>	mega electron volts – a measure of gamma-ray energy 1MeV = 1000keV
<b>NIA</b>	dipole moment: turns x current x Area
<b>nT</b>	nano-Tesla, a measure of the strength of a magnetic field
<b>ppm</b>	parts per million – a measure of secondary field or noise relative to the primary.
<b>pT/s</b>	picoTeslas per second: Units of decay of secondary field, dB/dt
<b>S</b>	Siemens – a unit of conductance
<b>x:</b>	the horizontal component of an EM field parallel to the direction of flight.
<b>y:</b>	the horizontal component of an EM field perpendicular to the direction of flight.
<b>z:</b>	the vertical component of an EM field.

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