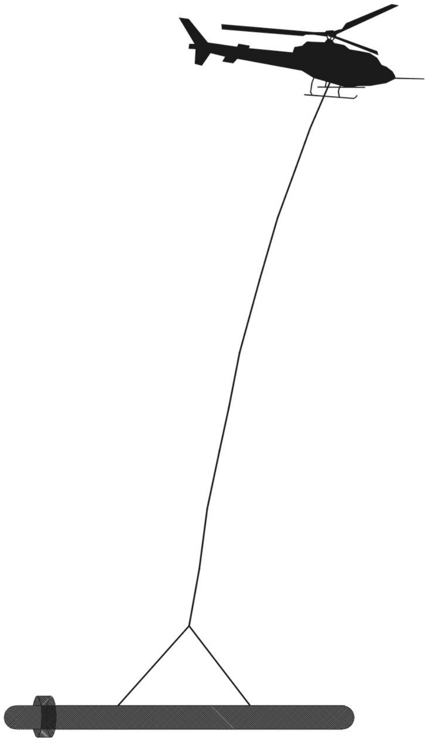
FUGRO AIRBORNE SURVEYS

Report # 09014

RESOLVE SURVEY
FOR
NORTH PLATTE NATURAL RESOURCES DISTRICT

NP, SP, AND CRESCENT LAKE AREAS

SCOTTSBLUFF, WESTERN NEBRASKA



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Mississauga, Ontario

July 22th, 2009

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SUMMARY

This report describes the logistics, data acquisition, processing and presentation of results of a RESOLVE airborne geophysical survey carried out for the North Platte Natural Resources District, over three grids and several test areas located near Scottsbluff, western Nebraska. Total coverage amounted to 937 km. The survey was flown from May 5th to May 17th, 2009.

The purpose of the survey was to define conductivity contrasts in the near-surface layers and to provide information that could be used to map the geology and structure of the survey areas, with the objective of mapping the subsurface features that control surface and subsurface ground-water distribution. This was accomplished by using a RESOLVE multi-coil, multi-frequency electromagnetic system, supplemented by a high sensitivity cesium magnetometer. The information from these sensors was processed to produce grids that display the magnetic and conductive properties of the survey areas. A GPS electronic navigation system ensured accurate positioning of the geophysical data.

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

CONTENTS

APPENDICES

1. INTRODUCTION

A RESOLVE electromagnetic/resistivity/magnetic survey was flown for North Platte Natural Resources District from May 5th to May 17th, 2009, over three main grids and several contiguous test line segments, near Scottsbluff, in western Nebraska. The survey areas are shown in Figure 2.

Survey coverage consisted of approximately 937 line-km, including 6.8 line-km of tie lines. The breakdown of kilometres flown per area and the line direction and line spacing (where applicable), are given below in table 1-1.

Table 1-1

Block	Area	Traverse azimuth	Tie line azimuth	Traverse line spacing	Tie line spacing (m)	Traverse line (km)	Tie line (km)	Total (km)
1	NP Area 1	360°	090°	400 m		247.2	5.7	252.9
2	NP F-lines	Variable				279.3		279.3
3	SP F-lines 3	Variable				105.9		105.9
4	SP F-lines 4	Variable						
5	SP Area 5	54°		1300 m		16.7		16.7
6	SP Area 6	64°		400 m		81.1		81.1
7	Crescent L.	341°	071°	200 m	15,895	48.9	1.1	50.0
8	Reflight of ’08 L40037	121°				3.8		3.8
TOTAL								937.1

The survey employed the RESOLVE electromagnetic system. Ancillary equipment consisted of a magnetometer, radar and laser altimeters, a video camera, a digital data recorder, and an electronic navigation system. The instrumentation was installed in an AS350-B3 turbine helicopter (Registration C-FYZF) that was provided by Great Slave Helicopters Ltd. The helicopter flew at an average airspeed of 120 km/h with an EM sensor height of approximately 35 metres.

Figure 1: Fugro Airborne Surveys RESOLVE EM bird with AS350-B3

2. SURVEY OPERATIONS

Operational bases were established at the Sydney Airport from May 4th to May 10th, and at the Scottsbluff Airport from May 10th to May 17th. The survey areas are shown in Figure 2-1.

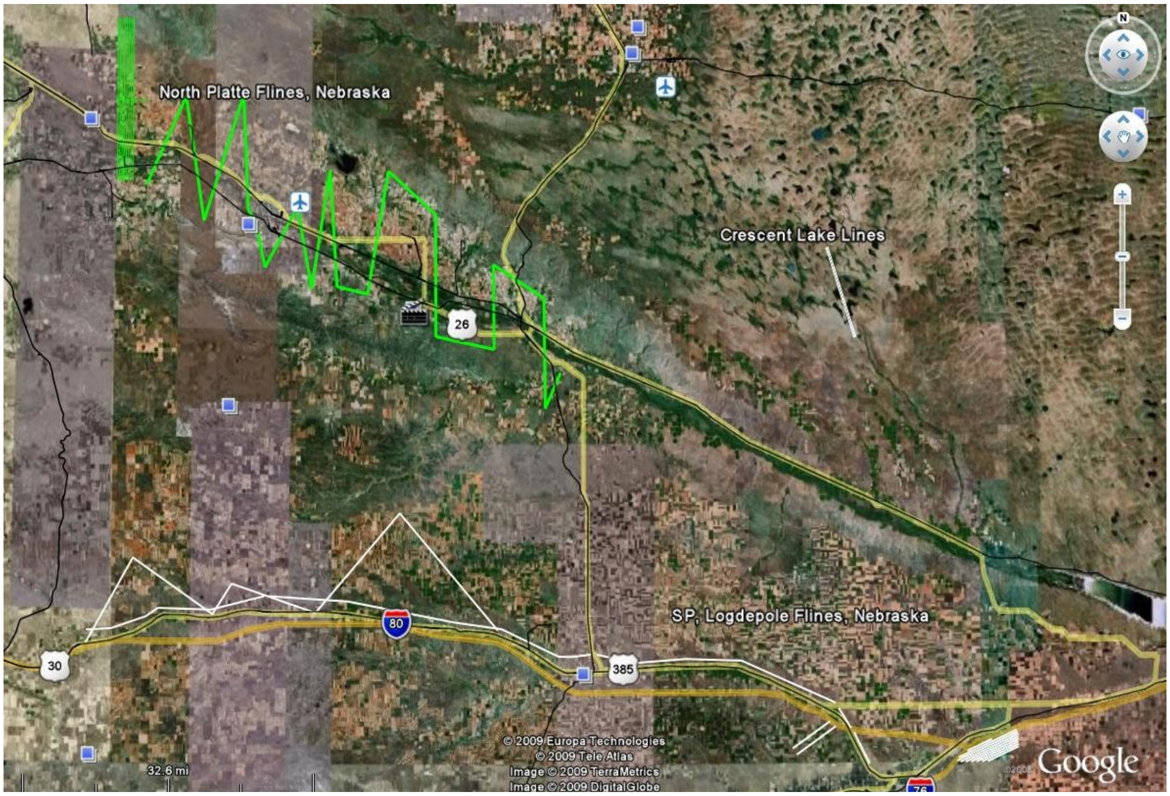


Figure 2-1
Location Map of the Survey Areas/Lines
Job # 09014

The survey specifications were as follows:

Table 2-1 Survey Specifications

Parameter	Specifications
Sample interval	10 Hz, 3.3 m @ 120 km/h
Aircraft mean terrain clearance	63 m
EM sensor mean terrain clearance	35 m
Mag sensor mean terrain clearance	35 m
Average speed	120 km/h
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 helicopter. This aircraft provides a safe and efficient platform for surveys of this type.

Electromagnetic System

Model: RESOLVE- BKS 55

Type: Towed bird, symmetric dipole configuration operated at a nominal survey altitude of 35 metres. Coil separation is 7.9 metres for 395 Hz, 1822 Hz, 8199 Hz, 38760 Hz and 128755 Hz, and 9.0 metres for the 3262 Hz coil-pair.

Coil orientations, frequencies and dipole moments

	orientation	nominal	actual
	coplanar	390 Hz	395 Hz
1	coplanar	1800 Hz	1822 Hz
	coaxial	3300 Hz	3262 Hz
	coplanar	8200 Hz	8199 Hz
	coplanar	40,000 Hz	38760 Hz
	coplanar	140,000 Hz	128755 Hz

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

Sensitivity:

0.12 ppm at	390 Hz Cp
0.12 ppm at	1800 Hz Cp
0.12 ppm at	3300 Hz Cx
0.24 ppm at	8200 Hz Cp
0.60 ppm at	40,000 Hz Cp
0.60 ppm at	140,000 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 half-space), ground calibrations using external calibration coils on-site are not necessary for system calibration. However, a ground check calibration is carried out on-site to ensure all systems are working correctly. All in-flight system calibrations are carried out 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 CS2 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 Stations

Primary

Model:	Fugro CF1 base station with timing provided by integrated GPS	
Sensor type:	Scintrex CS-3: Cesium vapour	
Counter specifications:	Accuracy:	±0.01 nT
	Resolution:	0.01 nT
	Sample rate	1 Hz

Secondary

Model:	Gem Systems GSM-19	
Sensor type:	Proton Precession	
Counter specifications:	Accuracy:	±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:	± 2 m for differentially corrected GPS

Environmental
Monitor specifications: Temperature:

- Accuracy: ±1.5°C max
- Resolution: 0.0305°C
- Sample rate: 1 Hz
- Range: -40°C to +75°C

Barometric pressure:

- Model: Motorola MPXA4115A
- Accuracy: ±3.0° kPa max (-20°C to 105°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 WGS 84 locations for the two base stations are given in Table 3-1. The base level values used for the in-field processing were 53871 nT for Sidney, and 53085 nT for Scottsbluff.

Table 3-1 Magnetic Base Station Locations

Status	Location Name	WGS84 Latitude (deg-min-sec)	WGS84 Longitude (deg-min-sec)	WGS84 Elevation (m)	Date Setup	Date Torn Down
Primary	Sidney Airport	41 06 11.557 N	102 58 48.818 W	1282.24	04-May-09	10-May-09
Secondary	Sidney Airport	41 06 11.557 N	102 58 48.818 W	1282.24	04-May-09	10-May-09
Primary	Scottsbluff Airport	41 52 19.726 N	103 35 54.513 W	1188.70	11-May-09	17-May-09
Secondary	Scottsbluff Airport	41 52 19.726 N	103 35 54.513 W	1188.70	11-May-09	17-May-09

Navigation (Global Positioning System)

Airborne Receiver for Guidance

Model:	NovAtel OEM4-G2L with PNAV 2100 interface
Type:	WAAS enabled. Code and carrier tracking of L1-C/A code at 1575.42MHz and L2-P code at 1227.0 MHz. Dual frequency, 24-channel. Real-time differential.
Sensitivity:	-132 dBm, 0.5 second update.
Accuracy:	Manufacturer’s stated accuracy is better than 2 metres real-time.
Antenna:	Mounted on tail of aircraft.

Airborne Receiver for Flight Path Recovery

Model:	NovAtel OEM4-G2L
Type:	WAAS enabled. 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. Real-time differential.
Sample rate:	10 Hz update.
Accuracy:	Better than 1 metre in differential mode.
Antenna:	Mounted on nose of EM bird.

Primary Base Station for Post-Survey Differential Correction

Model:	NovAtel OEM4
Type:	WAAS enabled. 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. Real-time differential.
Sample rate:	0.5 second update.
Accuracy:	Stated accuracy better than 1 m in differential mode.

Secondary GPS Base Station

Model:	Marconi Allstar, CMT-1200
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:	2 metres with differential corrections.

The NovAtel OEM4 is a line of sight, satellite navigation system that utilizes time-coded signals from at least four available satellites. Up to 24 satellite constellations are used to calculate the position and to provide real time guidance to the helicopter. For flight path processing, an identical NovAtel OEM4 was used as the mobile receiver. A similar system was used as the primary base station receiver. The mobile and base station raw XYZ data were recorded, thereby permitting post-survey differential corrections for theoretical accuracies of better than 2 metres. A Marconi Allstar GPS unit, part of the CF-1, was used as a secondary (back-up) base station.

Table 3-1 GPS Base Station Locations

Status	Make	Location Name	WGS84 Latitude	WGS84 Longitude	Elevation	Date Setup
Primary	NovAtel OEM4	Sidney Airport	41 06 11.557 N	102 58 48.818 W	1282.2m	04-May-09
Secondary	CF1 Marconi	Sidney Airport	41 06 11.557 N	102 58 48.818 W	1282.2m	04-May-09
Primary	NovAtel OEM4	Scottsbluff Airport	41 52 19.726 N	103 35 54.513 W	1188.7m	11-May-09
Secondary	CF1 Marconi	Scottsbluff Airport	41 52 19.726 N	103 35 54.513 W	1188.7m	11-May-09

The GPS units record data relative to the WGS84 ellipsoid, which is the basis of the revised North American Datum (NAD83). The elevations shown in Table 3-1 are heights above the ellipsoid, not above mean sea level. Conversion software is used to transform the WGS84 Lat/Lon coordinates to the local NAD 83 UTM (Zone 13N) system. Both coordinate systems are included in the final data archive.

Laser Altimeter

Manufacturer: Optech

Model: G150

Type: Fixed pulse repetition rate of 2 kHz

Sensitivity: ±5 cm from 10ºC to 30ºC
±10 cm from -20ºC to +50ºC

Sample rate: 2 per second

The laser altimeter is housed in the EM bird, and measures the distance from the EM bird to ground, except in areas of dense tree cover. This information is used in the processing algorithm that determines conductor depth. It is generally more accurate than the radar altimeter, as it tends to penetrate the tree canopy better. Because it is mounted in the bird, rather than in the helicopter, it is immune to errors in the calculated helicopter to bird (vertical) distance that can result from changes in aircraft speed, wind speed (bird lift), and helicopter attitude.

Radar Altimeter

Manufacturer:	Honeywell/Sperry
Model:	AA330
Type:	Short pulse modulation, 4.3 GHz
Sensitivity:	0.3 m
Sample rate:	10 per second

The radar altimeter measures the vertical distance between the helicopter and the ground, except in areas of dense tree cover.

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 (KPA) and internal (TEMP_INT). A third sensor is used to measure external (TEMP_EXT) operating temperatures.

Digital Data Acquisition System

Manufacturer: Fugro
Model: HeliIDAS
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

Type: Axis 2420 Digital Network Camera
Recorder: Axis 241S Video Server + 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. Records were 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 flight videos, 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	-	Positional (x,y) accuracy to be better than 5 m, with a CEP (circular error of probability) of 95%.

Flight Path - Deviations from the planned (pre-flight) path not to exceed 25 percent of the designated flight line spacing over a distance of more than 1 km. However, if the flight-line spacing deviation is caused by a safety requirement, FAA regulation, or military restriction, a fill-in line will not be required

Clearance - Mean terrain sensor clearance of 35 m, ±7 m, except where precluded by safety considerations, e.g., restricted or populated areas, severe topography, obstructions, tree canopy, aerodynamic limitations, etc.

Airborne Mag - Airborne survey data will be considered acceptable when gathered during magnetic storms or short-term disturbances of magnetic activity at the ground station, if they meet the following criteria:

- Monotonic changes in the magnetic field of less than 5 nT in any five-minute period.
- Pulsations having periods of 5 minutes or that do not exceed 2 nT.
- Pulsations having periods between 5 and 10 minutes that do not exceed 4 nT.
- Pulsations having periods between 10 and 20 minutes that do not exceed 8 nT.

The period of a pulsation is defined as the time between adjacent peaks or troughs. The amplitude of a pulsation is one-half the sum of the positive and negative excursions from trough to trough or peak to peak.

The non-normalized 4th difference will not exceed 1.6 nT over a continuous distance of 1 kilometre excluding areas where this specification is exceeded due to natural anomalies.

Base Mag - Diurnal variations not to exceed 10 nT over a straight line time chord of 1 minute.

EM - Spheric pulses may occur having strong peaks but narrow widths. The EM data area considered acceptable when their occurrence is less than 10 spheric events exceeding the stated noise specification for a given frequency per 100 samples continuously over a distance of 2,000 metres.

Frequency	**Coil Orientation**	**Peak to Peak Noise Envelope (ppm)**
390 Hz	horizontal coplanar	10.0
1800 Hz	horizontal coplanar	10.0
3300 Hz	vertical coaxial	10.0
8200 Hz	horizontal coplanar	20.0
40,000 Hz	horizontal coplanar	40.0
137,000 Hz	horizontal coplanar	50.0

5. DATA PROCESSING

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 UTM coordinate system used for the final presentation. 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 9 point median and 9 point Hanning filters are then applied to reduce noise to acceptable levels. The appropriate lag correction is then applied. For this survey, the EM lag based on the calibration check was determined to be 1.0 sec (10 scans).

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 filtered, lagged, flight-based levelled, 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 laser altimeter, is called the pseudo-layer and reflects the difference between the real geology and a homogeneous half space. 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.

Apparent resistivity grids were created using a USGS minimum curvature gridding algorithm, with a cell size of 50 m. The resistivity grids portray all of the information for a given frequency over the entire survey area. The preliminary apparent resistivity images were carefully inspected to identify any lines or line segments that might require base level adjustments.

For this survey, only Blocks 1, 6 and 7 had a sufficient line density (200 m to 400 m line spacing) to permit standard levelling procedures to be applied to the gridded data, using line-to-line comparisons. In other areas, where single lines of variable orientation were flown, the leveling procedure was based primarily on the results of the calculated differential sections, which tend to emphasize discrepancies between frequencies. Where indicated, phase adjustments and/or manual level adjustments were carried out to eliminate or minimize resistivity differences that could be attributed, in part, to non-linear changes in operating temperatures. These levelling adjustments are usually within the normal noise envelope of the system, and do not result in the degradation of discrete anomalies. A phase adjustment of –1° was applied to the Coaxial 3300 Hz data for all flights, although the coaxial data are not used in the Sengpiel or differential resistivity calculations.

In order to provide a direct comparison of the results of the current survey with those from a previous test survey flown in 2008, two test lines were reflown. The current (2009) lines 10090 and 80010 are reflights of (2008) line 30050 and a segment of 40031, respectively. The results indicated an apparent phase difference of about 7.5° on the 137,000 Hz frequency. It was concluded that the earlier results were probably erroneous, and that the near-surface (137kHz) resistivity calculations for that portion of the 2008 test survey were too high. See Figures 5-1 and 5-2. The current results are deemed to be more accurate.

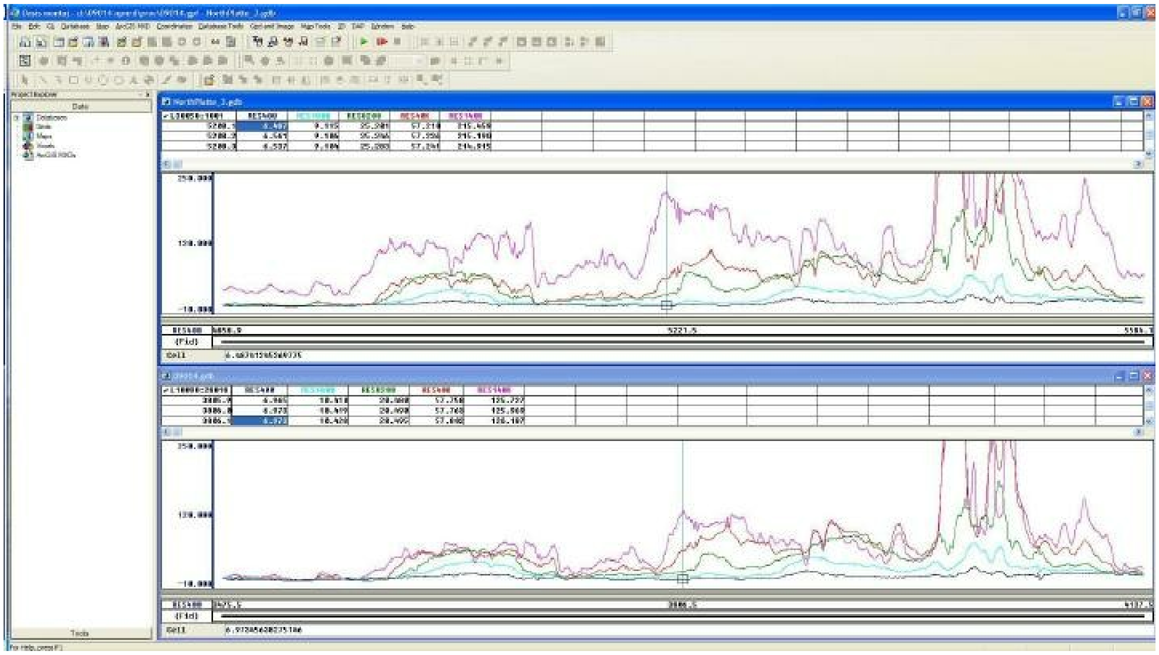
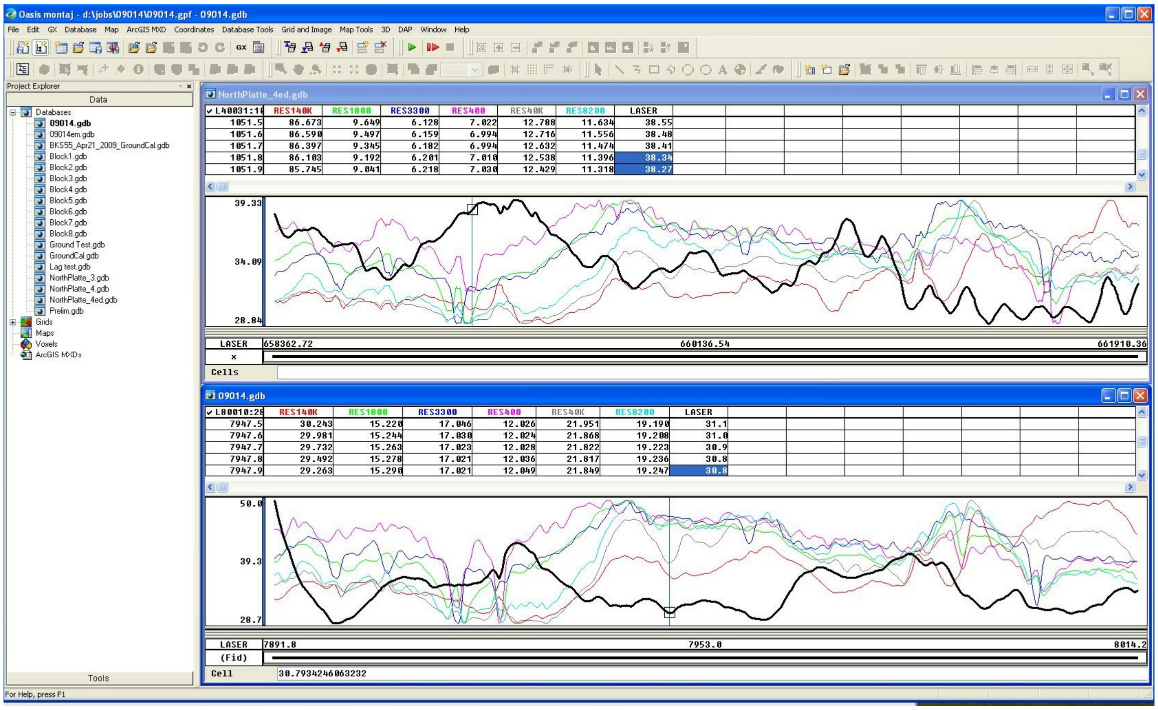


Figure 5-1 Comparison of previous 2008 survey line 30050 (top panel) and repeat 2009 line 10090 (bottom panel). Resistivity profiles are plotted at the same scale. Note the difference in the 137kHx resistivity (magenta) at the common point (curser).



✓ L40031:1	RES140K	RES1800	RES3300	RES400	RES40K	RES8200	LASER
1051.5	86.673	9.649	6.128	7.022	12.788	11.634	38.55
1051.6	86.590	9.497	6.159	6.994	12.716	11.556	38.48
1051.7	86.397	9.345	6.182	6.994	12.632	11.474	38.41
1051.8	86.103	9.192	6.201	7.010	12.538	11.396	38.34
1051.9	85.745	9.041	6.218	7.030	12.429	11.318	38.27

LASER 658362.72 660136.54 661910.36

x

Cells

✓ L80010:28	RES140K	RES1800	RES3300	RES400	RES40K	RES8200	LASER
7947.5	30.243	15.220	17.046	12.026	21.951	19.190	31.1
7947.6	29.981	15.244	17.030	12.024	21.868	19.208	31.0
7947.7	29.732	15.263	17.023	12.028	21.822	19.223	30.9
7947.8	29.492	15.278	17.021	12.036	21.817	19.236	30.8
7947.9	29.263	15.290	17.021	12.049	21.849	19.247	30.8

LASER 7891.8 7953.0 8014.2

(Fid)

Cell 30.7934246063232

Figure 5-2 Comparison of previous survey line 40031 (top panel) and repeat line 80010. Lines flown in opposite directions. Curser is approximately at the common point)

Resistivity-Depth Sections

The apparent resistivities for all frequencies can be displayed simultaneously as coloured resistivity-depth sections. Only the coplanar data are displayed as the close frequency separation between the coplanar and adjacent coaxial data tends to distort the section. Section images were created using both the Sengpiel and the Fugro differential resistivity methods. These images used the calculated digital elevation (topographic profile) as the surface. The digital terrain values, in metres above the WGS84 ellipsoid, were calculated from the bird GPS Z-value minus the laser altimeter.

Resistivity-depth sections can be generated in three formats:

(1) Sengpiel resistivity sections, where the apparent resistivity for each frequency is plotted at the centroid depth of of the in-phase current flow[1]; and,

(2) Differential resistivity sections, where the differential resistivity is plotted at the differential depth[2].

(3) Occam[3] or Multi-layer[4] inversion.

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[1] Sengpiel, K.P., 1988, Approximate Inversion of Airborne EM Data from Multilayered Ground: Geophysical Prospecting 36, 446-459.

[2] Huang, H. and Fraser, D.C., 1993, Differential Resistivity Method for Multi-frequency Airborne EM Sounding: presented at Intern. Airb. EM Workshop, Tucson, Ariz.

[3] Constable et al, 1987, Occam's inversion: a practical algorithm for generating smooth models from electromagnetic sounding data: Geophysics, 52, 289-300.

The apparent resistivity, centroid depth, differential resistivity and differential depth values are all included in the DVD archive that accompanies this report.

Both the Sengpiel and differential methods are derived from the pseudo-layer half-space model. Both yield a coloured resistivity-depth section that attempts to portray a smoothed approximation of the true resistivity distribution with depth. Resistivity-depth sections are most useful in conductive layered situations, but may be unreliable in areas of moderate to high resistivity where signal amplitudes are weak. In areas where in-phase responses have been suppressed by the effects of magnetite, or adversely affected by cultural features, the computed resistivities will be unreliable.

Both the Occam and multi-layer inversions (optional) compute the layered earth resistivity model that would best match the measured EM data. The Occam inversion uses a series of thin, fixed layers (usually 20 x 5m and 10 x 10m layers) and computes resistivities to fit the EM data. The multi-layer inversion computes the resistivity and thickness for each of a defined number of layers (typically 3-5 layers) to best fit the data.

Residual Magnetic Intensity

The residual magnetic intensity (RMI) is derived from the total magnetic field (TMF), the diurnal, and the regional magnetic field. The total magnetic intensity is measured in the

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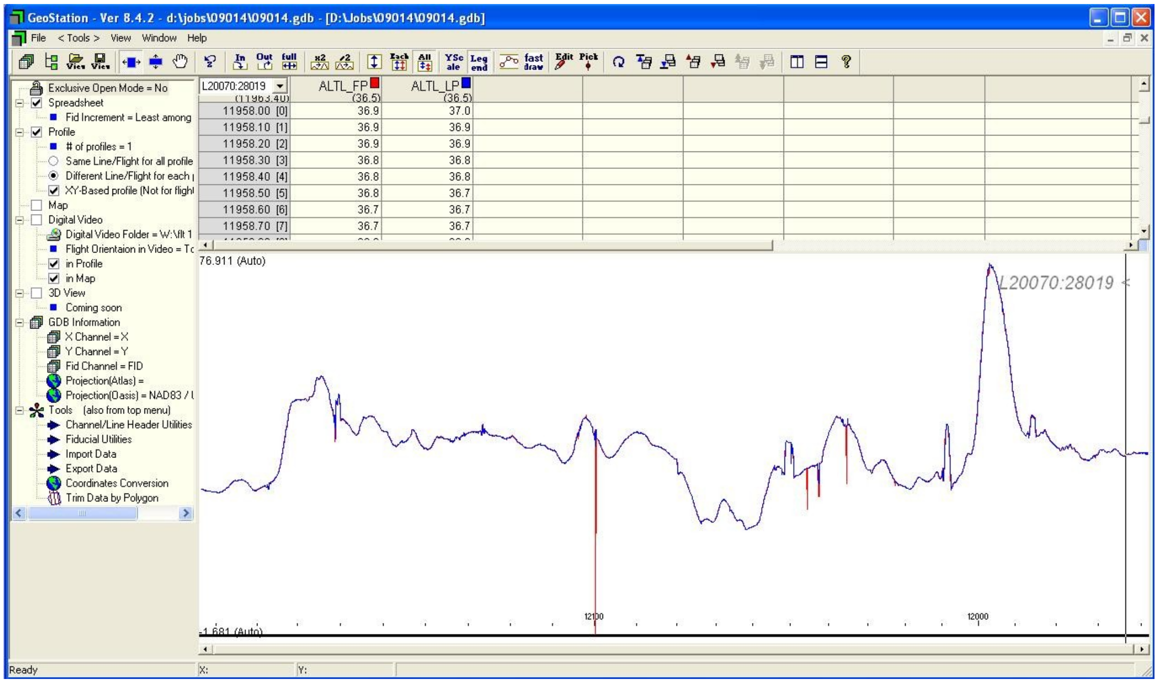
[4] Huang H., and Palacky, G.J., 1991, Damped least-squares inversion of time domain airborne EM data based on singular value decomposition: Geophysical Prospecting, 39, 827-844.

aircraft, the diurnal is measured from the ground station, and the regional magnetic field is calculated from the International Geomagnetic Reference Field (IGRF). First a fourth difference editing routine was applied to the magnetic data to remove any spikes. The low frequency component of the diurnal was then extracted from the filtered ground station data and removed from the TMF. The average of the diurnal was then added back to obtain the resultant total magnetic intensity. The regional magnetic field, calculated for the specific survey location and the time of the survey, was then removed from the resultant total magnetic intensity to yield the residual magnetic intensity.

Only blocks 1, 6 and 7 had lines that were close enough to allow useable grids to be generated for levelling. The line to line variations were within +/- 6nT; hence, micro-levelling was applied to remove these variations. A DC shift of 12nT was added to the residual magnetic intensity for the area to bring it in alignment with a previous survey over the area (project 08035).

Laser Altimeter

The laser altimeter works by emitting a pulse of light and measuring the amount of time it takes the photons to return to the sensor. The first photons that return are stored as the “first pulse” and have usually been reflected by foliage. The last photons that return are stored as the “last pulse” and usually have been reflected by the ground beneath the foliage. Both these data channels are compared for coherence. Whenever possible the last pulse data are processed to produce the best measurement from bird to ground. If the last pulse data are too noisy or have too many gaps the first pulse, if it is better quality is used.



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  ● Different Line/Flight for each
  ☑ XY-Based profile (Not for flight
☐ Map
☐ Digital Video
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  ☑ in Profile
  ☑ in Map
☐ 3D View
  Coming soon
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  Projection(Atlas) =
  Projection(Oasis) = NAD83 /
Tools (also from top menu)
  Channel/Line Header Utilities
  Fiducial Utilities
  Import Data
  Export Data
  Coordinates Conversion
  Trim Data by Polygon

L20070:28019 (11963.40)	ALTL_FP 🟥 (36.5)	ALTL_LP 🟦 (36.5)
11958.00 [0]	36.9	37.0
11958.10 [1]	36.9	36.9
11958.20 [2]	36.9	36.9
11958.30 [3]	36.8	36.8
11958.40 [4]	36.8	36.8
11958.50 [5]	36.8	36.7
11958.60 [6]	36.7	36.7
11958.70 [7]	36.7	36.7

Figure 5-1 A comparison of first pulse (red) vs. last pulse (blue) laser

The first step in producing a useable laser altimeter channel was to examine the raw data and determine the lowest altitude the bird was flown at. Values less than this were defaulted. The remaining data were despiked using an alfatrim filter specifically tuned to remove the most spikes from the dataset. The defaults were then interpolated if they were less than three seconds in width using an akima spline. A line by line inspection was then conducted comparing the pre splined and post splined data with the radar altimeter to ensure there were no areas where the laser had gaps too large to spline or where the spline was not believable when compared to the radar altimeter. The processed laser channel was then used in the em processing and to create the digital elevation model

Digital Elevation

The data archive contains the calculated digital elevations above the ellipsoid. The laser altimeter values (bird to ground clearance) were subtracted from the differentially corrected and de-spiked GPS-Z values to produce profiles of the sensor height above the ellipsoid along the survey lines. On the three blocks where the lines were close enough together, the data were gridded to produce contour images showing approximate ellipsoid elevations within the survey areas. The calculated digital terrain data were then tie-line levelled where appropriate. Any remaining subtle line-to-line discrepancies were manually removed.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, LASER and GPS-Z. The laser altimeter 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 ±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, <u>THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.</u>

6. PRODUCTS

This section lists the final products that have been provided under the terms of the survey agreement. Other products can be prepared from the existing dataset, if requested.

Digital Data

No map products were required for this survey. In addition to the quality control checks and calibrations carried out in the field, the original (raw) and processed data were provided for the video tracking and navigation systems, the airborne and ground magnetometers, the laser, radar, and barometric altimeters, and all EM data, in Geosoft ASCII xyz format.

Gridded data of the calculated apparent resistivity, centroid depth, differential resistivity and differential depth for each coplanar frequency were also provided in digital format. All gridded data have been created using the following coordinate system:

<u>Projection Description</u>:

Datum:	NAD83
Ellipsoid:	GRS 1980
Projection:	UTM (Zone: 13N)
Central Meridian:	105°W
False Northing:	0
False Easting:	500000
Scale Factor:	0.9996
WGS84 to Local Conversion:	Molodensky

Datum Shifts: DX:=0, DY:=0, DZ:=0

Additional Products

Digital Archive (see Archive Description)	2 copies on DVD-ROM
Survey Logistics Report	2 paper copies + Word .doc file
Flight Logs	

APPENDIX A

LIST OF PERSONNEL

The following personnel were involved in the acquisition, processing and presentation of data, relating to a RESOLVE airborne geophysical survey carried out for the North Platte Natural Resources District, over three grids and several test lines located near Scottsbluff, in western Nebraska.

Emily Farquhar	Manager, Geophysical Services
David Miles	Manager, Geophysical Projects
Graham Konieczny	Manager, Data Processing and Interpretation
Lesley Minty	Project Manager
Aaron Rampersad	Geophysical Operator
Amanda Heydorn	Field Geophysicist/Crew Leader
Chris Tucker	Pilot (Great Slave Helicopters Ltd.)
Jacques Fournier.	AME (Great Slave Helicopters Ltd.)
Richardo White	Geophysical Data Processor
Paul A Smith	Interpretation Supervisor
Lyn Vanderstarren	Drafting Supervisor
Susan Pothiah	Word Processing Operator
Albina Tonello	Secretary/Expeditor

The survey consisted of 937 km of coverage, flown from May 5th to May 17th, 2009.

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

APPENDIX B

BACKGROUND INFORMATION

- Appendix B.2 -

BACKGROUND INFORMATION

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 deposits in the southwest 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 southwest 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)[5]. 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

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

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 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[6] 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.

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[6] Magnetic susceptibility and permeability are two measures of the same physical property. Permeability is generally given as relative permeability, μ_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 5×10^5 for magnetite, in 10^{-6} units (Telford et al, 1986).

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.

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^{V}) 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:

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.[7] 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

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[7] See Figure B-1 presented earlier.

roof or small fenced yard.[8] 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.[5] 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 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,

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[8] 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.

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.

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.

APPENDIX C

DATA ARCHIVE DESCRIPTION

APPENDIX C

ARCHIVE DESCRIPTION

This archive contains data archive and grids of a RESOLVE EM airborne geophysical survey conducted by FUGRO AIRBORNE SURVEYS CORP. on behalf of North Platte Natural Resources District over Blocks 1-8 near Scottsbluff, Nebraska.

Job # 09014

\README.txt - This archive

\FASSurveyReplay.exe - Fugro Airborne Surveys flight video viewer installation program.
To install the viewer run the executable file and accept the default settings
To view the digital video copy the *.bin and *.bdx files to same directory.
Press the play tab to start video or stop to end video.
If you have any difficulty with this program contact the processing manager.

LINEDATA\

Block*.gdb - line data archive in Geosoft binary format Block*
Block*.xyz - line data archive in Geosoft ASCII format Block*

GRIDS\ Grids in Geosoft float (.grd) format with accompanying .GI files

Block*_ALTRADAR.GRD - Radar Altimeter Block*
Block*_DTM.GRD - Digital Terrain Model Block*
Block*_LASER.GRD - Laser Altimeter Block*
Block*_MAG.GRD - Residual Magnetic Field Block*
Block*_RES140K.GRD - Apparent Resistivity 129550 Hz coplanar Block*
Block*_RES1800.GRD - Apparent Resistivity 1792.6 Hz coplanar Block*
Block*_RES3300.GRD - Apparent Resistivity 3290 Hz coplanar Block*
Block*_RES400.GRD - Apparent Resistivity 380 Hz coplanar Block*
Block*_RES40K.GRD - Apparent Resistivity 41020 Hz coplanar Block*
Block*_RES8200.GRD - Apparent Resistivity 8171 Hz coplanar Block*

REPORT\ report in Adobe Acrobat (.pdf) format v1.3

R09014.doc - final report
R09014.pdf - final report

- Appendix C.2 -

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*****************************************************************************
Geosoft GDB ARCHIVE SUMMARY
*****************************************************************************

#    Channel          Time  Units      Description
 1    X                0.1  m          Final bird easting (NAD83) UTM Z13N
 2    Y                0.1  m          Final Bird Northing (NAD83) UTM Z13N
 3    FID              0.1             Fiducial counter
 4    Z                0.1  m          Leveled height of EM bird above WGS84 ellipsoid
 5    BALT             0.1  m          Leveled barometric altitude of helicopter
 6    LASER            0.1  m          Em Bird to Earth-Surface, Laser Altimeter
 7    ALTRADAR         0.1  m          Helicopter to Earth-Surface, Radar Altimeter
 8    DTM              0.1  m          Digital Terrain Model
 9    MAGSP            0.1  nT         Despiked total magnetic field
10    DIURNAL                 0.1  nT         Base level removed diurnal magnetic correction
11    MAGLD            0.1  nT         Lagged diurnal corrected total magnetic field
12    IGRF             0.1  nT         International Geomagnetic Reference Field 2005 based on date
13    MAG              0.1  nT         Leveled residual magnetic field
14    CPPL             0.1             Coplanar powerline monitor
15    CXSP             0.1             Coaxial powerline monitor
16    CPSP             0.1             Coplanar atmospheric monitor
17    CPI400_CAL       0.1  ppm        Raw Inphase-Coplanar 395 Hz
18    CPQ400_CAL       0.1  ppm        Raw Quadrature-Coplanar 395 Hz
19    CPI1800_CAL      0.1  ppm        Raw Inphase-Coplanar 1822 Hz
20    CPQ1800_CAL      0.1  ppm        Raw Quadrature-Coplanar 1822 Hz
21    CXI3300_CAL      0.1  ppm        Raw Inphase-Coaxial 3262 Hz
22    CXQ3300_CAL      0.1  ppm        Raw Quadrature-Coaxial 3262 Hz
23    CPI8200_CAL      0.1  ppm        Raw Inphase-Coplanar 8199 Hz
24    CPQ8200_CAL      0.1  ppm        Raw Quadrature-Coplanar 8199 Hz
25    CPI40K_CAL       0.1  ppm        Raw Inphase-Coplanar 38760 Hz
26    CPQ40K_CAL       0.1  ppm        Raw Quadrature-Coplanar 38760 Hz
27    CPI140K_CAL      0.1  ppm        Raw Inphase-Coplanar 128755 Hz
28    CPQ140K_CAL      0.1  ppm        Raw Quadrature-Coplanar 128755 Hz
29    CPI400_R         0.1  ppm        Background leveled, lagged Inphase-Coplanar 395 Hz
30    CPQ400_R         0.1  ppm        Background leveled, lagged Quadrature-Coplanar 395 Hz
31    CPI1800_R        0.1  ppm        Background leveled, lagged Inphase-Coplanar 1822 Hz
32    CPQ1800_R        0.1  ppm        Background leveled, lagged Quadrature-Coplanar 1822 Hz
33    CXI3300_R        0.1  ppm        Background leveled, lagged Inphase-Coaxial 3262 Hz
34    CXQ3300_R        0.1  ppm        Background leveled, lagged Quadrature-Coaxial 3262 Hz
35    CPI8200_R        0.1  ppm        Background leveled, lagged Inphase-Coplanar 8199 Hz
36    CPQ8200_R        0.1  ppm        Background leveled, lagged Quadrature-Coplanar 8199 Hz
37    CPI40K_R         0.1  ppm        Background leveled, lagged Inphase-Coplanar 38760 Hz
38    CPQ40K_R         0.1  ppm        Background leveled, lagged Quadrature-Coplanar 38760 Hz
39    CPI140K_R        0.1  ppm        Background leveled, lagged Inphase-Coplanar 128755 Hz
40    CPQ140K_R        0.1  ppm        Background leveled, lagged Quadrature-Coplanar 128755 Hz
41    CPI400           0.1  ppm        Final leveled Inphase-Coplanar 395 Hz
42    CPQ400           0.1  ppm        Final leveled Quadrature-Coplanar 395 Hz
43    CPI1800          0.1  ppm        Final leveled Inphase-Coplanar 1822 Hz
44    CPQ1800                 0.1  ppm        Final leveled Quadrature-Coplanar 1822 Hz
45    CXI3300          0.1  ppm        Final leveled Inphase-Coaxial 3262 Hz
46    CXQ3300                 0.1  ppm        Final leveled Quadrature-Coaxial 3262 Hz
```

- Appendix C.3 -

47	CPI8200	0.1	ppm	Final leveled Inphase-Coplanar 8199 Hz
48	CPQ8200	0.1	ppm	Final leveled Quadrature-Coplanar 8199 Hz
49	CPI40K	0.1	ppm	Final leveled Inphase-Coplanar 38760 Hz
50	CPQ40K	0.1	ppm	Final leveled Quadrature-Coplanar 38760 Hz
51	CPI140K	0.1	ppm	Final leveled Inphase-Coplanar 128755 Hz
52	CPQ140K	0.1	ppm	Final leveled Quadrature-Coplanar 128755 Hz
53	RES400	0.1	ohm.m	Apparent Resistivity 395 Hz
54	RES1800	0.1	ohm.m	Apparent Resistivity 1822 Hz
55	RES3300	0.1	ohm.m	Apparent Resistivity 3262 Hz Coaxial
56	RES8200	0.1	ohm.m	Apparent Resistivity 8199 Hz
57	RES40K	0.1	ohm.m	Apparent Resistivity 38760 Hz
58	RES140K	0.1	ohm.m	Apparent Resistivity 128755 Hz
59	DEP400	0.1	m	Apparent Depth 395 Hz
60	DEP1800	0.1	m	Apparent Depth 1822 Hz
61	DEP3300	0.1	m	Apparent Depth 3262 Hz Coaxial
62	DEP8200	0.1	m	Apparent Depth 8199 Hz
63	DEP40K	0.1	m	Apparent Depth 38760 Hz
64	DEP140K	0.1	m	Apparent Depth 128755 Hz
65	DRES400	0.1	ohm.m	Differential Resistivity 395 Hz
66	DRES1800	0.1	ohm.m	Differential Resistivity 1822 Hz
67	DRES8200	0.1	ohm.m	Differential Resistivity 8199 Hz
68	DRES40K	0.1	ohm.m	Differential Resistivity 38760 Hz
69	DRES140K	0.1	ohm.m	Differential Resistivity 128755 Hz
70	DDEP400	0.1	m	Differential Depth 395 Hz
71	DDEP1800	0.1	m	Differential Depth 1822 Hz
72	DDEP8200	0.1	m	Differential Depth 8199 Hz
73	DDEP40K	0.1	m	Differential Depth 38760 Hz
74	DDEP140K	0.1	m	Differential Depth 128755 Hz
75	CEN400	0.1	m	Centroid Depth 395 Hz
76	CEN1800	0.1	m	Centroid Depth 1822 Hz
77	CEN8200	0.1	m	Centroid Depth 8199 Hz
78	CEN40K	0.1	m	Centroid Depth 41020 Hz
79	CEN140K	0.1	m	Centroid Depth 129550 Hz
80	UTC	0.1	sec	Time
81	FLIGHT	0.1		Flight number
82	DATE	0.1	yyyy/mm/dd	Date
83	LATWGS84	0.1	deg	Bird latitude WGS 84 UTM Z13N
84	LONWGS84	0.1	deg	Bird longitude WGS 84 UTM Z13N
85	ALTL_FP	0.1	m	Raw bird laser altitude
86	ALTR	0.1	feet	Raw Helicopter radar altitude
87	KPA	0.1	kPa	Raw air pressure at helicopter
88	Z_BIRD	0.1	m	Raw GPS bird height above WGS84 ellipsoid
89	X_HELI	0.1	m	Helicopter GPS easting
90	Y_HELI	0.1	m	Helicopter GPS northing
91	Z_HELI	0.1	m	Helicopter GPS elevation

The coordinate system for all grids and the data archive is projected as follows

Datum	NAD83
Spheroid	WGS84
Projection	UTM Zone 13N

Central meridian	99° West
False easting	500000
False northing	0
Scale factor	0.9996
Northern parallel	N/A
Base parallel	N/A
WGS84 to local conversion method	Molodensky
Delta X shift	0
Delta Y shift	0
Delta Z shift	0

If you have any problems with this archive please contact

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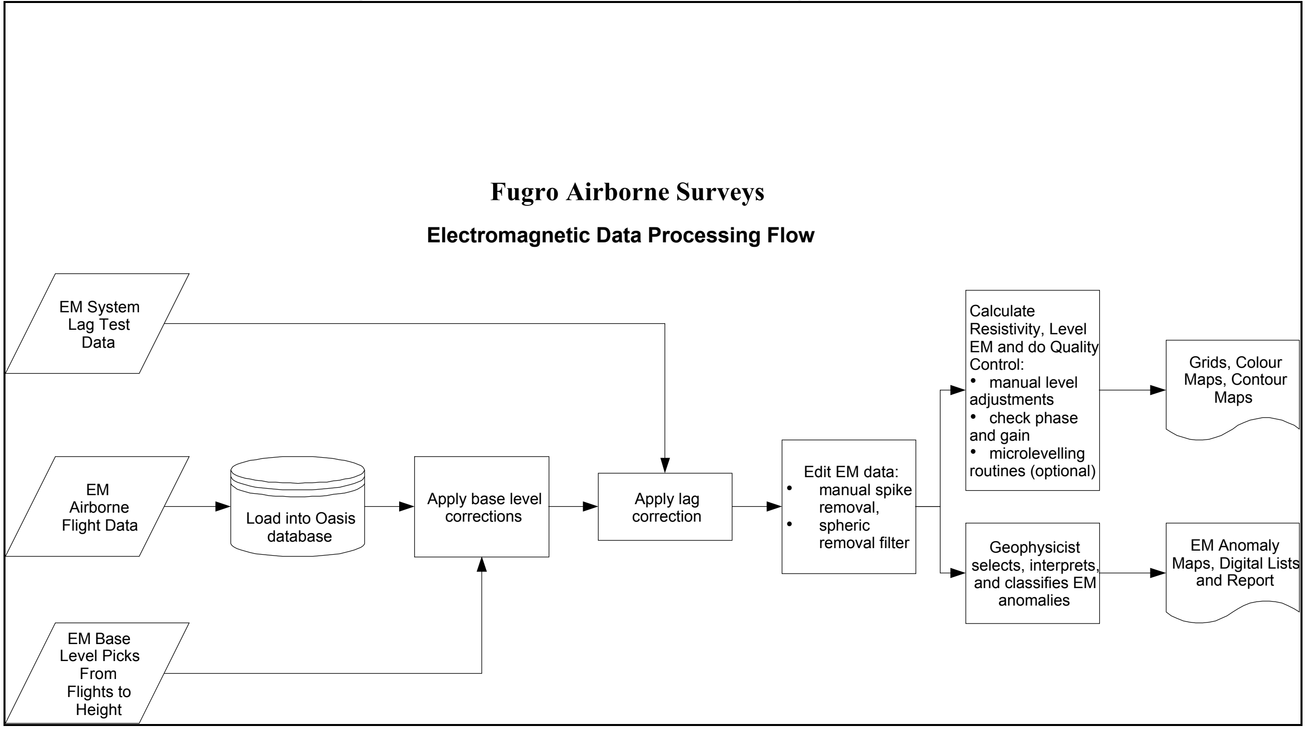
APPENDIX D

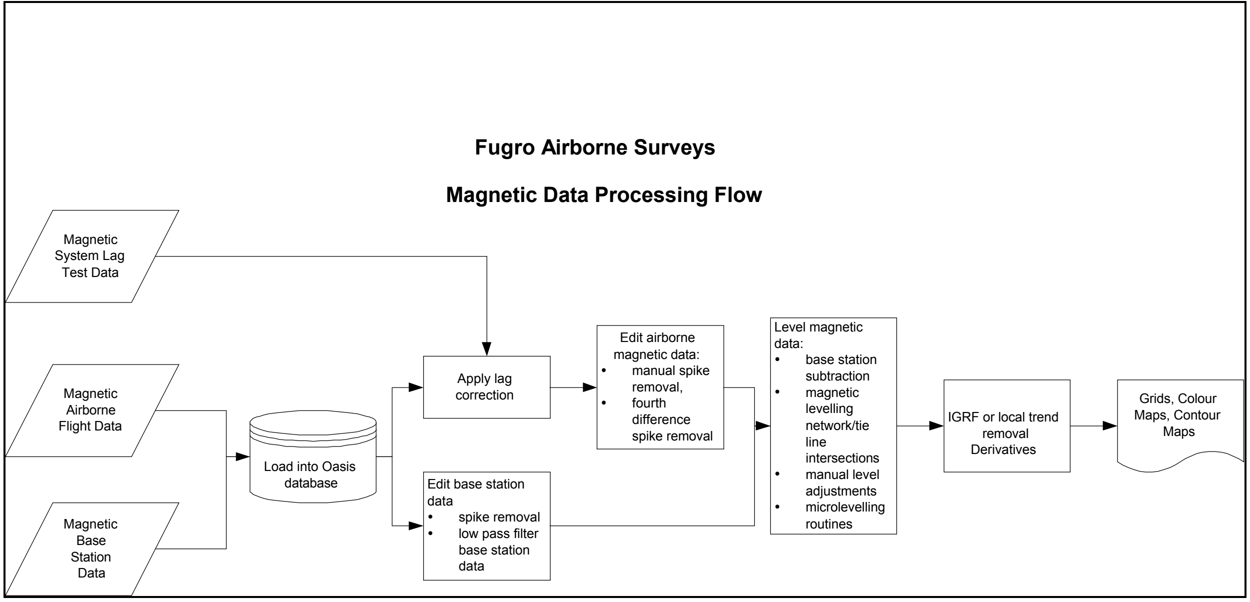
DATA PROCESSING FLOWCHARTS

APPENDIX D

Processing Flow Chart - Electromagnetic Data



Processing Flow Chart - Magnetic Data



APPENDIX E

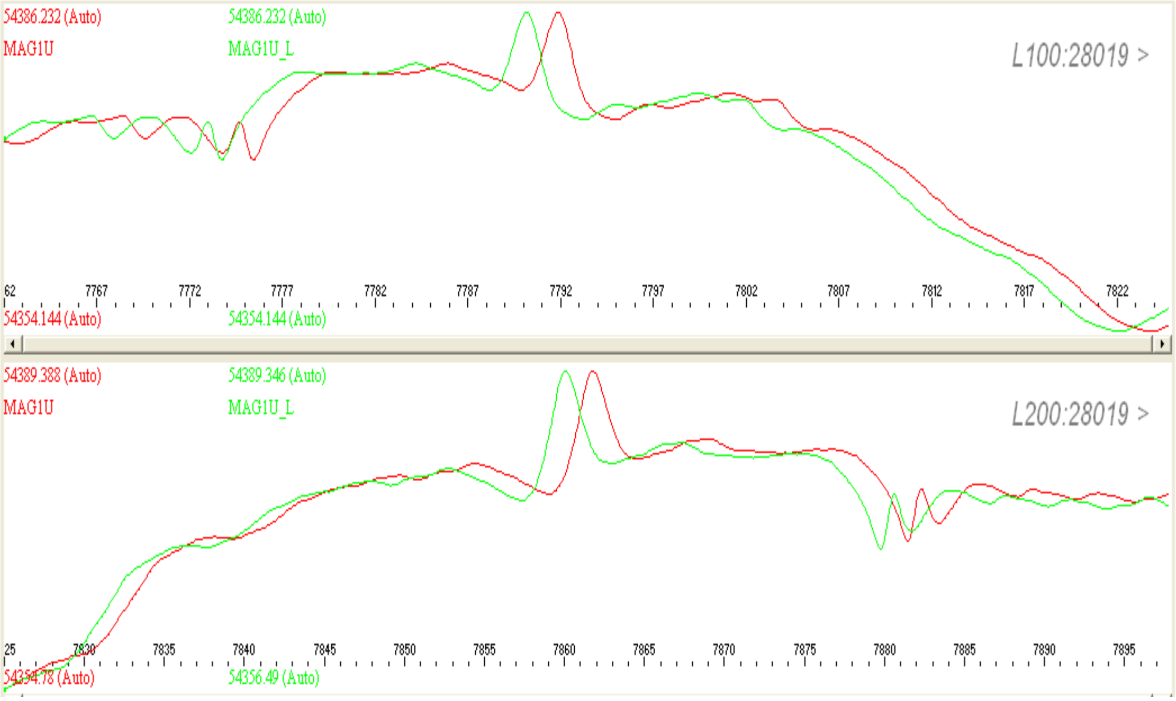
TESTS AND CALIBRATIONS

- Appendix E.1 -

LAG TEST

A magnetic lag test is flown to calculate the positional lag that develops between the time a reading is made and the time it is recorded in the data. A large metallic body such as a railway track, a bridge, a metal building, or a distinct magnetic anomaly is overflown along a single line, at survey altitude, in opposite directions. The time difference in the anomaly peaks allows a time constant to be determined. This time shift constant is then applied to the magnetic data collected during the survey.

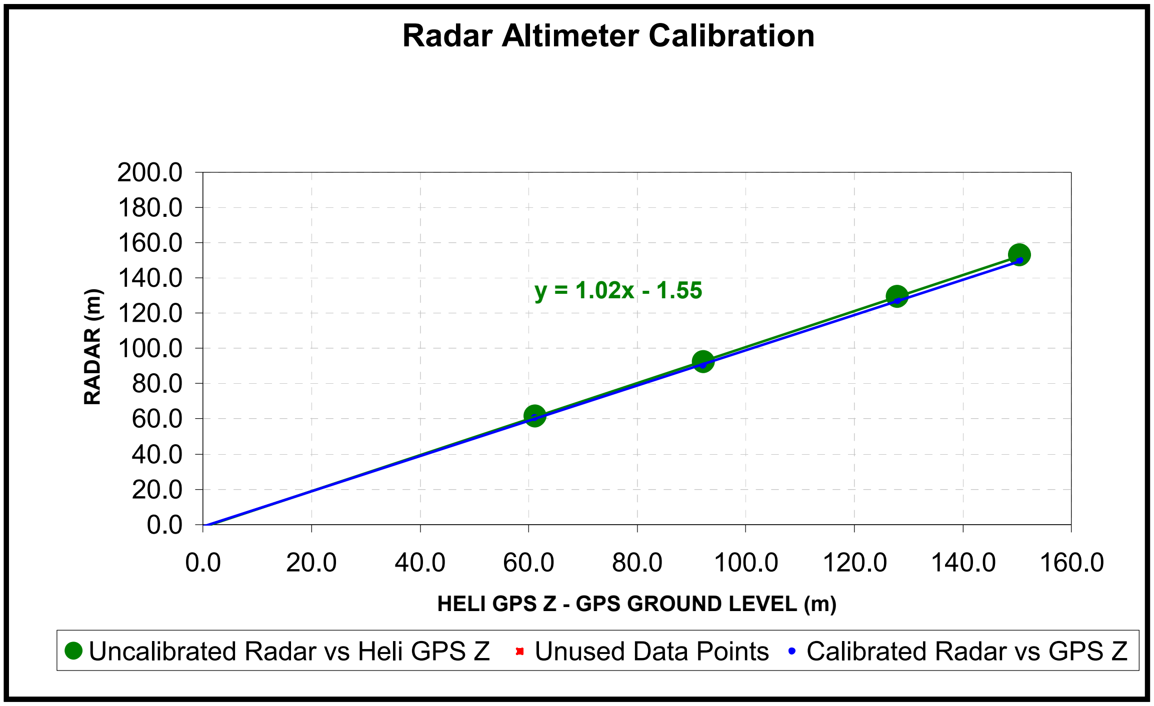
The lag test flown on May 17, 2009, for job 09014, showed a lag of 1.7 seconds. This lag correction was applied to the magnetic data.



A similar procedure was used to confirm the lag of the EM data, which was determined to be the standard 10 scans, or 1.0 second.

- Appendix E.2 -

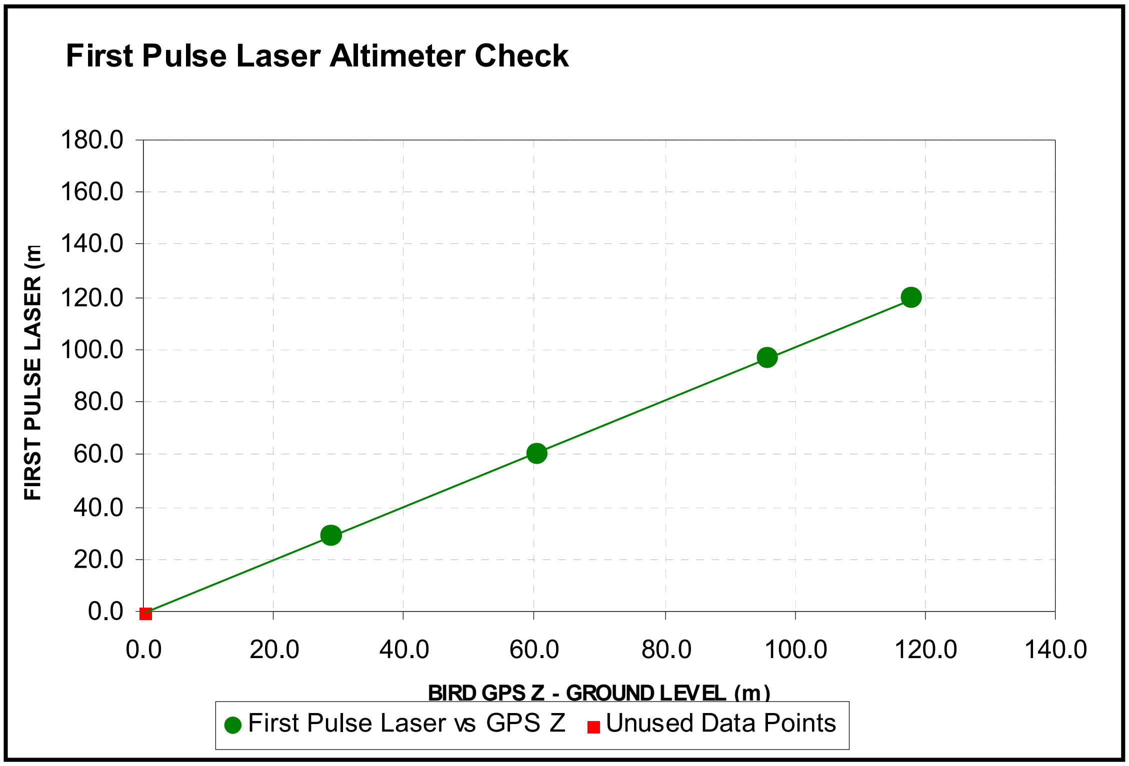
ALTIMETER CALIBRATIONS

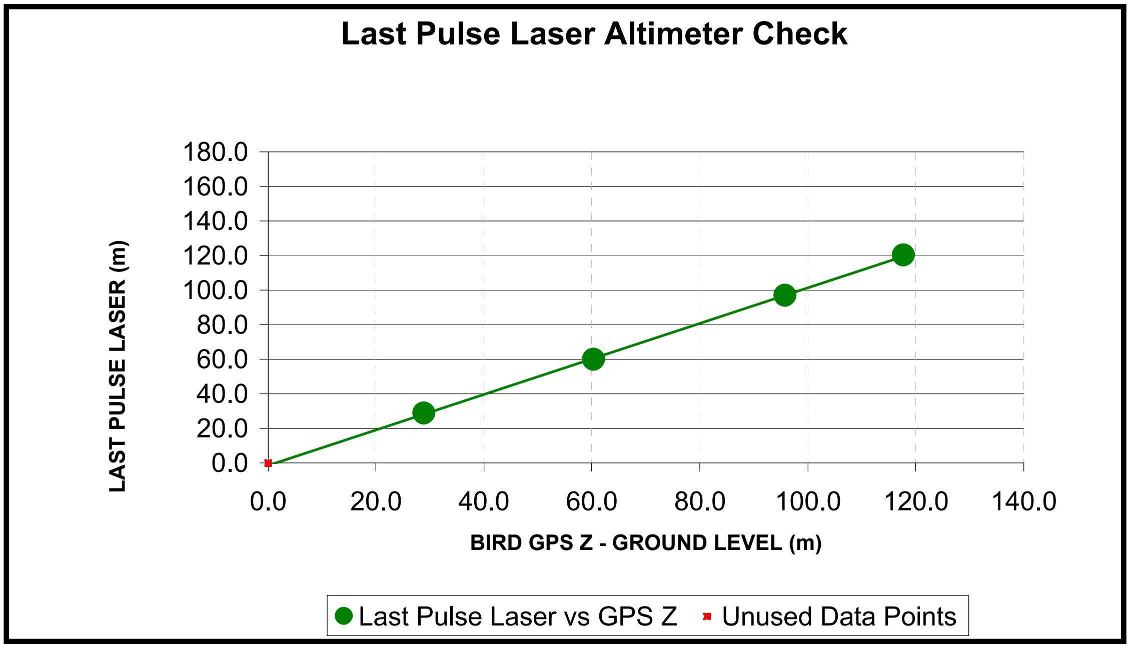


TARGET RADAR (ft)	ZHG_HELI	ZHG_BIRD	ALTRAD_U	Use Data Point	ALTLASFP_M	Use Data Point	ALTLASLP_M
0	342.6	342.6					
200	403.8	371.5	202.1		28.9	☑	28.9
300	434.8	403.0	302.2		60.0	☑	60.0
400	470.6	438.4	424.4		96.6	☑	96.9
500	493.1	460.4	501.5		119.7	☑	120.0
600			615.7		156.0		156.0

HELI GPS Z MINUS GROUND GPS LEVEL (m)	BIRD GPS Z MINUS GROUND GPS (m)	UNCALIBRATED RADAR (m)	CALIBRATED RADAR (m)
	0.0		
61.2	28.9	61.6	60.6
92.2	60.4	92.1	90.5
128.0	95.8	129.4	126.8
150.5	117.8	152.9	149.8
		187.7	183.8

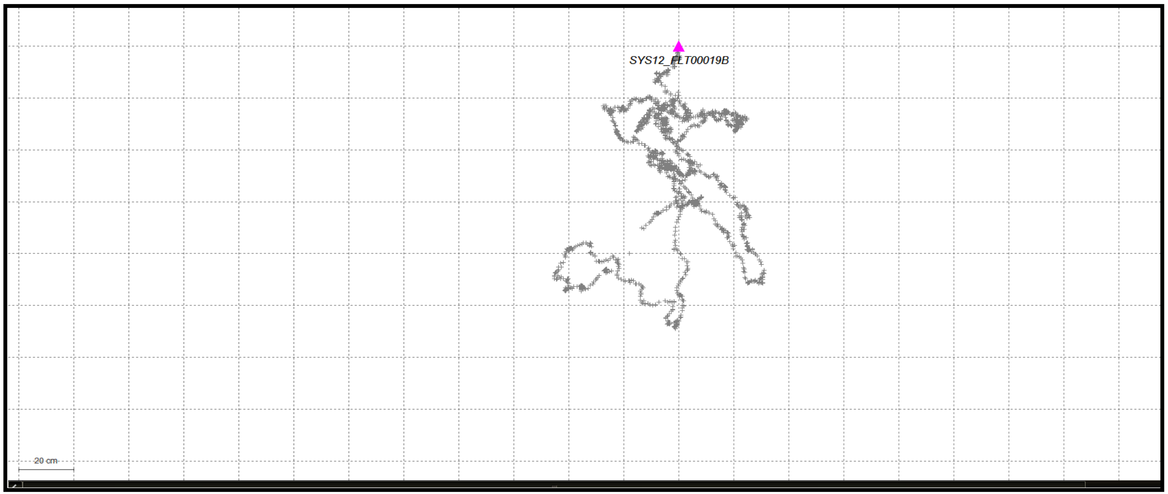
- Appendix E.3 -


First Pulse Laser Altimeter Check
FIRST PULSE LASER (m
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
BIRD GPS Z - GROUND LEVEL (m)
● First Pulse Laser vs GPS Z
■ Unused Data Points

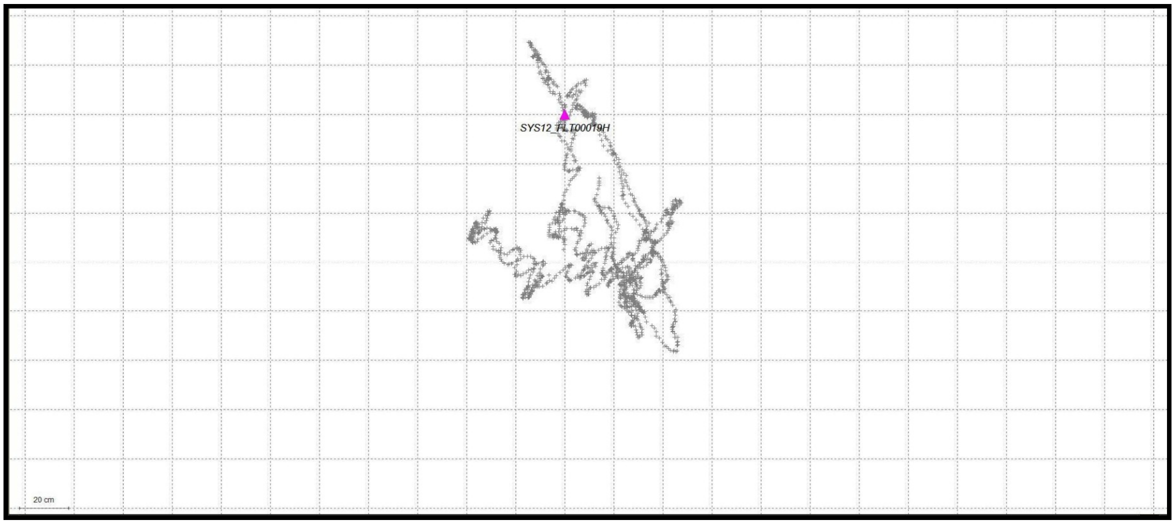

Last Pulse Laser Altimeter Check
LAST PULSE LASER (m)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
BIRD GPS Z - GROUND LEVEL (m)
● Last Pulse Laser vs GPS Z
■ Unused Data Points

NAVIGATION SYSTEM TEST

GPS positions were logged for approximately 3 hours to determine the accuracy of the GPS systems. The following scatter-plots indicate the distribution of the raw positions of the GPS in the bird, and on the Helicopter while on the ground. The GPS accuracy is estimated to be ± 1m, based on the 20 cm per square division scale shown on both scatter plots.



Distribution of bird position while on the ground



Distribution of the Helicopter position while on the ground.

- Appendix E.5 -

GROUND CALIBRATION

All HFEM sensors are calibrated before field service at Fugro Airborne Surveys' calibration site at Mountsberg Provincial Park, Ontario. The ground at Mountsberg is extremely resistive, which makes the site ideal for sensor calibration; no response from the ground affects the measured responses.

As part of Fugro's quality control procedures, a ground calibration check is performed at the beginning of every survey job, and monthly thereafter. The phase and gain settings are verified with the ferrite rod and external calibration coils. No changes are made to the system. The check is intended only to monitor system performance. A ground calibration was done at Lincoln Airport, NE, on April 21, 2009 for Bird # BKS 55, as indicated by the following record.

RESOLVE VI

FUGRO AIRBORNE SURVEYS

DATE **April 21, 2009**
LOCATION **Lincoln Airport**
PERFORMED BY **A. Rampersand, A. Heydorn**
TEMPERATURE **20**

BIRD NUMBER BKS55

TX-COILS	CP1		CP2		CP3		CP4		CP5		CX6		UNIT
NOM FREQ.	40000		8200		400		140000		1800		3300		Hz
ACT FREQ.	38760		8199		395		128755		1822		3262		Hz
Chart Scale	400		100		50		400		50		50		Units/Div
ICA	-682		-208		-251		-1168		-219		67		PPM
TX.VOLTS	20.8		20.1		25.8		20.0		21.2		19.1		VOLTS
RX.VOLTS	443		171		122		485		260		49		mVOLTS
Tx Coil Station	-4.50		9.50		23.75		38.25		52.75		2.00		INCH
Bx Coil Station	114.00		126.50		115.75		134.00		159.75		167.50		INCH
Rx Coil Station	306.75		321.00		335.25		349.00		364.00		357.38		INCH
Coil Separation	7.91		7.91		7.91		7.89		7.91		9.03		m
Exr Qcoil DistIS	70.6		70.6		70.6		70.6		70.6		93.5		INCH
	I	Q	I	Q	I	Q	I	Q	I	Q	I	Q	
Target Ext. Defl	228.9	228.9	201.2	201.1	222.2	222.2	209.7	209.7	221.5	221.5	101.7	101.7	PPM
Ext. Q-Coil Defl.	179.7	204.9	211.6	206.1	218.7	220.3	189.3	231.1	241.0	236.8	83.5	102.9	PPM
Int. Q-Coil Defl.	-600.3	-627.6	-198.5	-199.0	-251.1	-248.8	-1029	-1140	-218.8	-217.1	66.0	66.2	PPM
Phase Bar Defl.	-528.5	-31.3	-486.8	41.2	433.4	-4.0	-478.1	-23.0	569.1	-13.4	-488.8	-15.2	PPM
Phase Error	3.4		-4.8		-0.5		2.8		-1.3		1.8		
Ext Phase/Q Gain	48.7	0.895	44.2	1.025	45.2	0.991	50.7	1.102	44.5	1.069	50.9	1.012	
Int Phase/Q Gain	46.3	0.920	45.1	0.957	44.7	0.991	47.9	0.976	44.8	0.991	45.1	0.988	

APPENDIX F

GLOSSARY

APPENDIX F

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.

bucking: The process of removing the strong ***signal*** from the ***primary field*** at the ***receiver*** from the data, to measure the ***secondary field***. It can be done electronically or mathematically. This is done in ***frequency-domain EM***, and to measure ***on-time*** in ***time-domain EM***.

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 in an HEM system 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 electrons as they pass through the 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: [σ] 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: [**σt**] 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]** In HEM, 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 channelling: See current gathering.

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.

daughter products: The radioactive natural sources of gamma-rays decay from the original "parent" element (commonly potassium, uranium, and thorium) to one or more lower-energy "daughter" 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 constant: see time constant.

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

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: **[ε]** The capacity of a material to store electrical charge, this is most often measured as the relative permittivity [ε_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.

drape: To fly a survey following the terrain contours, maintaining a constant altitude above the local ground surface. Also applied to re-processing data collected at varying altitudes above ground to simulate a survey flown at constant altitude.

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.

exposure rate: in radiometric surveys, a calculation of the total exposure rate due to gamma rays at the ground surface. It is used as a measurement of the concentration of all the **radioelements** at the surface. See also: **natural exposure rate**.

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.

Figure of Merit: **(FOM)** A sum of the 12 distinct magnetic noise variations measured by each of four flight directions, and executing three aircraft attitude variations (yaw, pitch, and roll) for each direction. The flight directions are generally parallel and perpendicular to planned survey flight directions. The FOM is used as a measure of the **manoeuvre noise** before and after **compensation.**

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 for 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***).

HTEM: Helicopter Time-domain ElectroMagnetic, This designation is used for the new generation of helicopter-borne, ***time-domain*** electromagnetic systems.

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***)

induction number: also called the "response parameter", this number combines many of the most significant parameters affecting the ***EM*** response into one parameter against which to compare responses. For a ***layered earth*** the response parameter is $\mu\omega\sigma h^2$ and for a large, flat, ***conductor*** it is $\mu\omega\sigma th$, where μ is the ***magnetic permeability***, ω is the angular ***frequency***, σ is the **conductivity**, t is the thickness (for the flat conductor) and h is the height of the system above the conductor.

inductive limit: When the frequency of an EM system is very high, or the **conductivity** of the target is very high, the response measured will be entirely **in-phase** with no **quadrature** (**phase** angle =0). The in-phase response will remain constant with further increase in conductivity or frequency. The system can no longer detect changes in conductivity of the target.

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: **[μ]** This is defined as the ratio of magnetic induction to the inducing magnetic field. The relative magnetic permeability [μ_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.

manoeuvre noise: variations in the magnetic field measured caused by changes in the relative positions of the magnetic sensor and magnetic objects or electrical currents in the aircraft. This type of noise is generally corrected by magnetic **compensation**.

model: Geophysical theory and applications generally have to assume that the geology of the earth has a form that can be easily defined mathematically, called the model. For example steeply dipping **conductor**s are generally modeled as being **infinite** in horizontal and depth extent, and very thin. The earth is generally modeled as horizontally layered, each layer infinite in extent and uniform in characteristic. These models make the mathematics to describe the response of the (normally very complex) earth practical. As theory advances, and computers become more powerful, the useful models can become more complex.

natural exposure rate: in radiometric surveys, a calculation of the total exposure rate due to natural-source gamma rays at the ground surface. It is used as a measurement of the concentration of all the natural **radioelements** at the surface. See also: **exposure rate**.

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***.

overburden: In engineering and mineral exploration terms, this most often means the soil on top of the unweathered bedrock. It may be sand, glacial till, or weathered rock.

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

physical parameters: These are the characteristics of a geological unit. For electromagnetic surveys, the important parameters 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. **On-time** measurements may be made during 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***.

radioelements: This normally refers to the common, naturally-occurring radioactive elements: potassium (K), uranium (U), and thorium (Th). It can also refer to man-made radioelements, most often cobalt (Co) and cesium (Cs)

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.

receiver: the ***signal*** detector of a geophysical system. This term is most often used in active geophysical systems – systems that transmit some kind of signal. In airborne ***electromagnetic*** surveys it is most often a ***coil***. (see also, ***transmitter***)

resistivity: **[ρ]** 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***.

Response parameter: another name for the **induction number**.

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 x √(resistivity/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: [τ] 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 a thin, flat-lying conductive sheet, ***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.

transmitter: The source of the ***signa***l to be measured in a geophysical survey. In airborne ***EM*** it is most often a **coil** carrying a time-varying electrical current, transmitting the ***primary field***. (see also ***receiver***)

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 conductive sheet, ***infinite*** in horizontal dimension and depth extent. (see also ***thin shee***t)

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***.

Version 1.5, November 29, 2005
Greg Hodges,
Chief Geophysicist
Fugro Airborne Surveys, Toronto

-Appendix G.14 -

Common Symbols and Acronyms

k	Magnetic susceptibility
ε	Dielectric permittivity
μ, μ_r	Magnetic permeability, relative permeability
ρ, ρ_a	Resistivity, apparent resistivity
σ,σ_a	Conductivity, apparent conductivity
σ**t**	Conductivity thickness
τ	Tau, or time constant
Ωm	ohm-metres, units of resistivity
AGS	Airborne gamma ray spectrometry.
CDT	Conductivity-depth transform, conductivity-depth imaging (Macnae and Lamontagne, 1987; Wolfgram and Karlik, 1995)
CPI, CPQ	Coplanar in-phase, quadrature
CPS	Counts per second
CTP	Conductivity thickness product
CXI, CXQ	Coaxial, in-phase, quadrature
FOM	Figure of Merit
fT	femtoteslas, normal unit for measurement of B-Field
EM	Electromagnetic
keV	kilo electron volts – a measure of gamma-ray energy
MeV	mega electron volts – a measure of gamma-ray energy 1MeV = 1000keV
NIA	dipole moment: turns x current x Area
nT	nanotesla, a measure of the strength of a magnetic field
nG/h	nanoGreys/hour – gamma ray dose rate at ground level
ppm	parts per million – a measure of secondary field or noise relative to the primary or radioelement concentration.
pT/s	picoteslas per second: Units of decay of secondary field, dB/dt
S	siemens – a unit of conductance
x:	the horizontal component of an EM field parallel to the direction of flight.
y:	the horizontal component of an EM field perpendicular to the direction of flight.
z:	the vertical component of an EM field.

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Macnae, J. and Lamontagne, Y., 1987, Imaging quasi-layered conductive structures by simple processing of transient electromagnetic data: Geophysics, v52, 4, 545-554.

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APPENDIX G

FLIGHT LOGS

FUGRO

FLIGHT LOG

SYSTEM 55 JOB# 9014 FLT# 11

Aircraft Registration: YZF

DATE	May 5/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START:	END:	TOTAL (hrs):	WEATHER: Overcast 20kts , 18 °C	

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	[✓ YES] / NO	Are there any PLANNED Reflights for this flight?			YES / [✓ NO]
Has NEW NAV File been Created?	[✓ YES] / NO	Have new NAV files been verified on tablet?			[✓ YES] / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability*)

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8200	390	910	1820	3260
TX	13.9	13.4	18.3	14.3	14.9	13.4
RX	8	2	13	13	16	18
ICA						

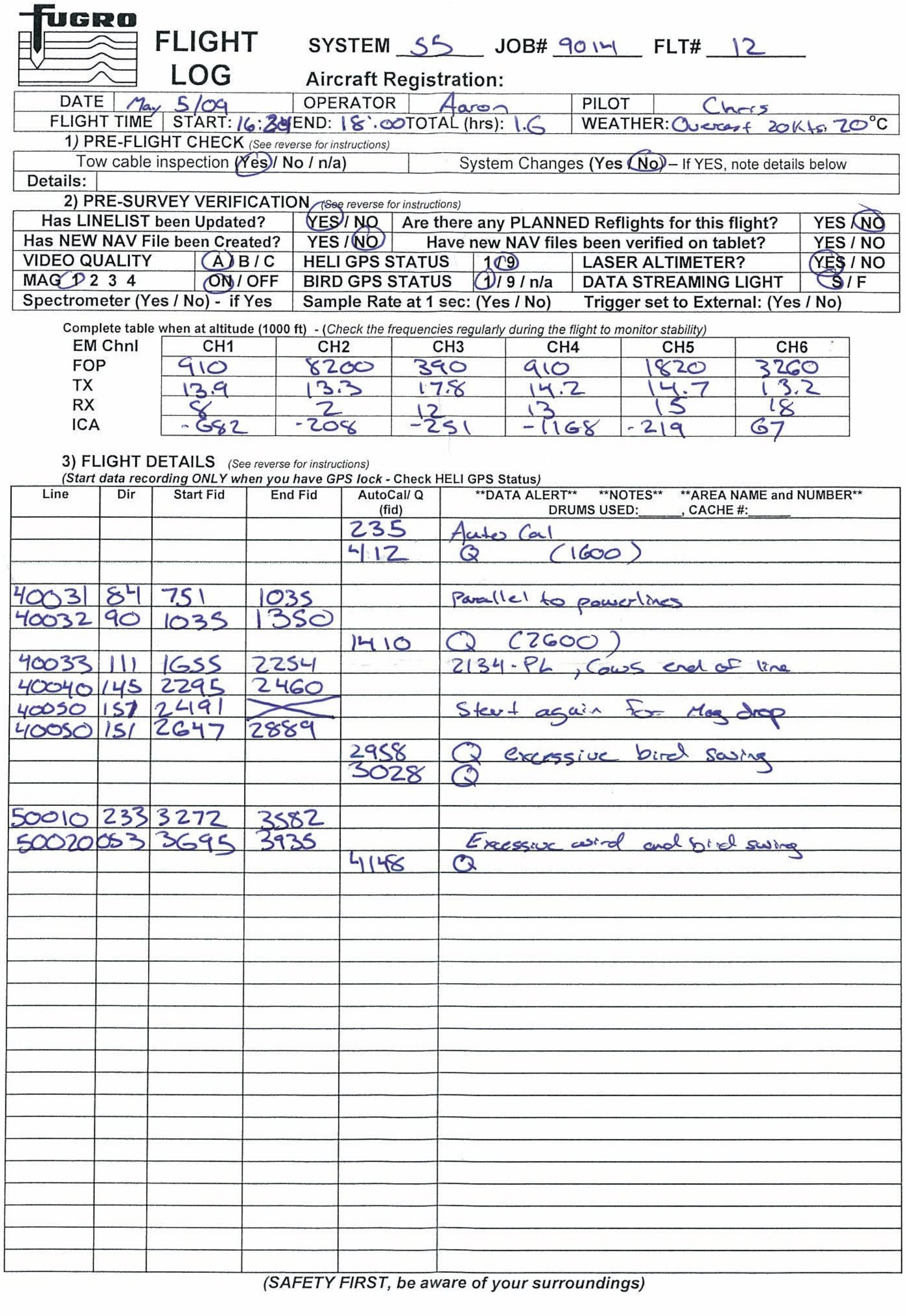
3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock **- Check HELI GPS Status*)***

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				397	Auto Cal
				583	Q
		685	720	~~685~~	Swing
		730	800		Swoop
		950	1010		50 Kts
		1015	1075		60 Kts
		1085	1145		70 Kts
		1160	1220		80 Kts
				1225	Q

(SAFETY FIRST, be aware of your surroundings)

-Appendix G.2 -



FUGRO **FLIGHT LOG** SYSTEM SS JOB# 9014 FLT# 12

Aircraft Registration:

DATE	May 5/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 16:34	END: 18:00	TOTAL (hrs): 1.6	WEATHER:	Overcast 20Kts, 20°C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?		[✓ YES] / NO	Are there any PLANNED Reflights for this flight?		YES / [✓ NO]
Has NEW NAV File been Created?		YES / [✓ NO]	Have new NAV files been verified on tablet?		YES / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability*)

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8200	390	910	1820	3260
TX	13.9	13.3	17.8	14.2	14.7	13.2
RX	8	2	12	13	15	18
ICA	-682	-208	-251	-1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock - Check HELI GPS Status*)*

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				235	Auto Cal
				412	Q (1600)
40031	84	751	1035		Parallel to powerlines
40032	90	1035	1350		
				1410	Q (2600)
40033	111	1655	2254		2134-PL, Cows end of line
40040	145	2295	2460		
40050	157	2491			Start again for Mag drop
40050	151	2647	2889		
				2958	Q excessive bird swing
				3028	Q
50010	233	3272	3582		
50020	053	3695	3935		Excessive wind and bird swing
				4148	Q

(SAFETY FIRST, be aware of your surroundings)

FUGRO

FLIGHT LOG

SYSTEM SS JOB# 904 FLT# 13

Aircraft Registration:

DATE	May 7/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 9:30	END: 18:15	TOTAL (hrs): 2.7	WEATHER:	Windy 15Kts 16°C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)

System Changes (Yes / [✓ No]) – If YES, note details below

Details:

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	[✓ YES] / NO	Are there any PLANNED Reflights for this flight?	YES / [✓ NO]
Has NEW NAV File been Created?	[✓ YES] / NO	Have new NAV files been verified on tablet?	[✓ YES] / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS 1 / [✓ 9]	LASER ALTIMETER? [✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS [✓ 1] / 9 / n/a	DATA STREAMING LIGHT [✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)	Trigger set to External: (Yes / No)

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability)*

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8210	390	910	1820	3260
TX	13.9	13.4	18.3	14.3	14.9	13.3
RX	8	2	12	13	15	18
ICA	-682	-208	-231	-1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock - Check HELI GPS Status*)*

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				555	AutoCal
				745	Q
				1475	Q
60010	64	1668	1840		
60020	244	1966	2390		2082 - 2095 - Houses
60030	64	2467	2930		2715 - brake line for other aircraft
60040	244			2992	Q
60040	244	3187	3540		
60050	64	3662	3978		
60060	244	4065	4350		
				4407	Q
60070	64	4620	4859		
60080	244	4929	5156		
60090	64	5228	5418		
				5544	Q
				7114	Q
40030	281	7337	7875		
40025	261	7602	7730		
40024	270	7806	7860		
40023	294	7820	8340		
40022	277	8340	8762		Too Windy 33Kts
				8979	Q

(SAFETY FIRST, be aware of your surroundings)

FUGRO

FLIGHT LOG

SYSTEM SS JOB# 9014 FLT# 14

Aircraft Registration: YZF

DATE	May 9/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 9:30 END:	TOTAL (hrs): 4.1		WEATHER:	Overcast , 6 °C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	**[✓ YES] / NO**	**Are there any PLANNED Reflights for this flight?**			**YES / [✓ NO]**
Has NEW NAV File been Created?	**[✓ YES] / NO**	**Have new NAV files been verified on tablet?**			**[✓ YES] / NO**
VIDEO QUALITY	**[✓ A] / B / C**	**HELI GPS STATUS**	**1 / [✓ 9]**	**LASER ALTIMETER?**	**[✓ YES] / NO**
MAG [✓ 1] 2 3 4	**[✓ ON] / OFF**	**BIRD GPS STATUS**	**[✓ 1] / 9 / n/a**	**DATA STREAMING LIGHT**	**[✓ S] / F**
Spectrometer (Yes / No) - if Yes		**Sample Rate at 1 sec: (Yes / No)**		**Trigger set to External: (Yes / No)**	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability*)

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8200	390	910	1820	3260
TX	14.1	13.6	19.2	14.5	15	13.5
RX	6	3	12	13	15	18
ICA	-682	-208	-~~1168~~ 251	1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock* - Check HELI GPS Status*)

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				262	Auto Cal
				460	Q
40021	279	804	1425		
40020	272	1430	1877		
				1993	Q
40014	255	2150	2470		
40013	270	2470	2752		
40012	235	2765	2836		
~~40010~~	~~255~~	~~2845~~			loop back 2900 Transmit
40011	255	3000	3161		~~Q~~
40010	265	3170	3295		~~Q~~
				3363	Q
30010	29	3536	4047		
30020	128	4152	4681		
				4760	Q
30030	32	4944	5144		
30040	107	5235	5721		
				5808	Q
30050	040	5935	6615		
				6680	Q
30060	138	6935	7700		
				7745	Q
80010	121	7691	8015		

(SAFETY FIRST, be aware of your surroundings)

FUGRO

FLIGHT LOG

SYSTEM 55 JOB# 9014 FLT# 17

Aircraft Registration: YZF

DATE	May 12/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 15:38	END: 18:39	TOTAL (hrs): 3.1	WEATHER: Clear	,23 °C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?		[✓ YES] / NO	Are there any PLANNED Reflights for this flight?		YES / [✓ NO]
Has NEW NAV File been Created?		YES / [✓ NO]	Have new NAV files been verified on tablet?		~~YES~~ / [✓ NO]
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability)*

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8200	390	910	1820	3260
TX	13.6	12.8	17.5	13.9	14.4	12.9
RX	8	2	13	14	16	17
ICA	682	208	~~244~~251	1168	219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock - Check HELI GPS Status*)*

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
					Block 1 178°
~~20010~~				437	AutoCal
				6221	Q
				2233	Q
70010	340	2520	2985		
70020	160	3058	3588		
79020	70	3685	3715		
				3776	Q
70030	340	3910	4382		
79010	250	4483	4513		
				4627	Q
				5520	Q
~~20200~~	~~202~~			5773	Q
20200	202	6060	6275		
20190	358	6380	6915		
				6979	Q
20180	301	7148	7484		
20170	178	7613	8047		
				8150	Q
20160	280	8375	8714		
~~20150~~	~~358~~	~~8850~~			~~Q~~
2050	358	8850	9400		
20140	340	9520	9865		~~Q~~
				9943	Q
~~20130~~	~~188~~	~~10198~~			
20130	188	10303			Too windy
				10465	Q

(SAFETY FIRST, be aware of your surroundings)

-Appendix G.6 -

FUGRO **FLIGHT LOG**

SYSTEM 55 JOB# 9014 FLT# 18

Aircraft Registration: YZF

DATE	May 16/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 10:05	END: 11:50	TOTAL (hrs): 1.7	WEATHER:	Cloudy 25Kts 0 °C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	[✓ YES] / NO	Are there any PLANNED Reflights for this flight?			YES / [✓ NO]
Has NEW NAV File been Created?	[✓ YES] / NO	Have new NAV files been verified on tablet?			[✓ YES] / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability)*

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8200	390	910	1820	3260
TX	14.0	13.4	18.1	14.3	14.9	13.4
RX	8	3	14	13	15	18
ICA	-682	-208	-251	-1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock - Check HELI GPS Status)

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				449	Autocal
				655	Q
				1045	Q
10080	358	1287	2110		1318-PL, 1361-RR
				2183	Q
10070	178	2352	3225		
				3290	Q
10090	~~178~~	3481	4133		17.5 - 18.5 Km
	358			4242	Q
Grawclpt	178	4600	4675		300ft
"	358	4720	4765		400 ft
"	178	4650	4900		500 ft
178°	~~358~~	5080			Lag over RR
	358	5160			" " "
				5278	Q

(SAFETY FIRST, be aware of your surroundings)

-Appendix G.7 -

FUGRO **FLIGHT LOG**

SYSTEM 55 **JOB#** 9014 **FLT#** 19

Aircraft Registration: C-FYZF

DATE	May 17/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 8:45	END: 12:30	TOTAL (hrs): 3.8	WEATHER:	Clear 10 Kts, 18 °C

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	[✓ YES] / NO	Are there any PLANNED Reflights for this flight?			[✓ YES] / NO
Has NEW NAV File been Created?	YES / [✓ NO]	Have new NAV files been verified on tablet?			YES / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability)*

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8210	390	910	1820	3260
TX	14.0	13.7	18.7	14.5	15.1	13.6
RX	8	3	14	13	16	18
ICA	-682	-208	-251	-1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

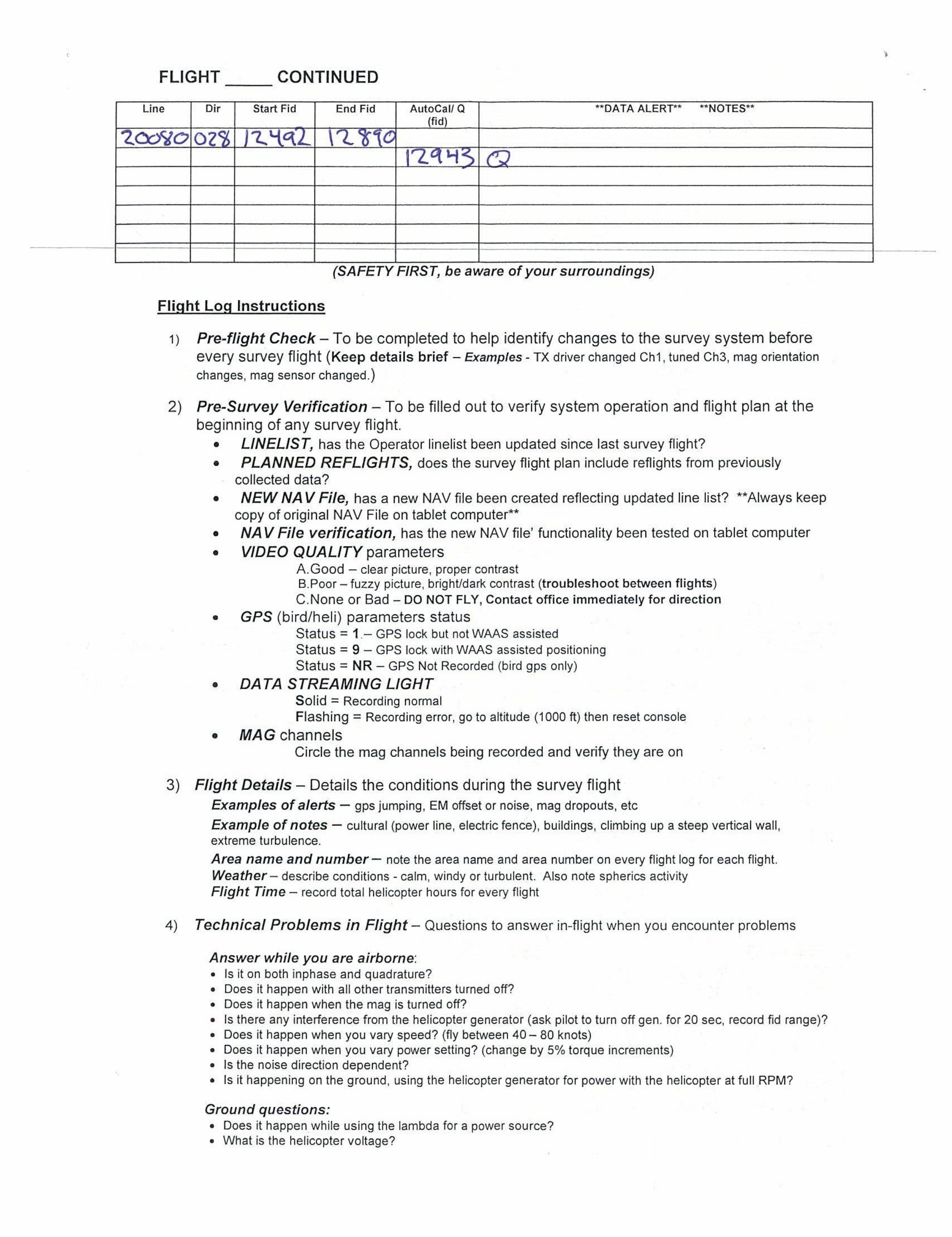
(Start data recording ONLY when you have GPS lock - ***Check HELI GPS Status)***

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				235	AutoCal
				417	AutoCal
				~~412~~	
				529	Autocal
				701	Q
	178				
10070	~~358~~	1010	1144		Harmonic anomaly at South end
10060	358	1197	2040		same harmonic observed. S end of block
				2084	Q
10050	178	2264	3120		Transformer Station ~~and~~ South end of block
				3178	Q
10040	358	3362	4210		3550-3160-Fence
10030	178	4268	5110		
				5155	Q
10020	358	5345	6180		
10010	178	6253	7066		
				7165	Q
19010	90	7600	7780		
				7995	Q
				8223	Q
			7773		Lag Test
			7880		Lag Test
		8410		~~8440~~	Autocal
~~20010~~	~~023~~			8586	Q
20010	023	8905	9416		
20020	169	9530	10162		
				10260	Q Tablet Restart
20030	017	10535	11195		
20040	176	11320	11829		
20050	177	11829	11888		~~Q~~
20060	148	11888	11960		
20070	166	11960	12196		~~Q~~
				12262	Q

20080

(SAFETY FIRST, be aware of your surroundings)

-Appendix G.8 -



FLIGHT _____ CONTINUED

Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES**
20080	028	12492	12890		
				12943	Q

(SAFETY FIRST, be aware of your surroundings)

Flight Log Instructions

1) ***Pre-flight Check*** – To be completed to help identify changes to the survey system before every survey flight (**Keep details brief** – ***Examples*** - TX driver changed Ch1, tuned Ch3, mag orientation changes, mag sensor changed.)

2) ***Pre-Survey Verification*** – To be filled out to verify system operation and flight plan at the beginning of any survey flight.
   - ***LINELIST,*** has the Operator linelist been updated since last survey flight?
   - ***PLANNED REFLIGHTS,*** does the survey flight plan include reflights from previously collected data?
   - ***NEW NAV File,*** has a new NAV file been created reflecting updated line list? **Always keep copy of original NAV File on tablet computer**
   - ***NAV File verification,*** has the new NAV file' functionality been tested on tablet computer
   - ***VIDEO QUALITY*** parameters
     - A.Good – clear picture, proper contrast
     - B.Poor – fuzzy picture, bright/dark contrast (**troubleshoot between flights**)
     - C.None or Bad – **DO NOT FLY, Contact office immediately for direction**
   - ***GPS*** (bird/heli) parameters status
     - Status = **1** – GPS lock but not WAAS assisted
     - Status = **9** – GPS lock with WAAS assisted positioning
     - Status = **NR** – GPS Not Recorded (bird gps only)
   - ***DATA STREAMING LIGHT***
     - **S**olid = Recording normal
     - **Flashing** = Recording error, go to altitude (1000 ft) then reset console
   - ***MAG*** channels
     - Circle the mag channels being recorded and verify they are on

3) ***Flight Details*** – Details the conditions during the survey flight

   Examples of alerts – gps jumping, EM offset or noise, mag dropouts, etc

   Example of notes – cultural (power line, electric fence), buildings, climbing up a steep vertical wall, extreme turbulence.

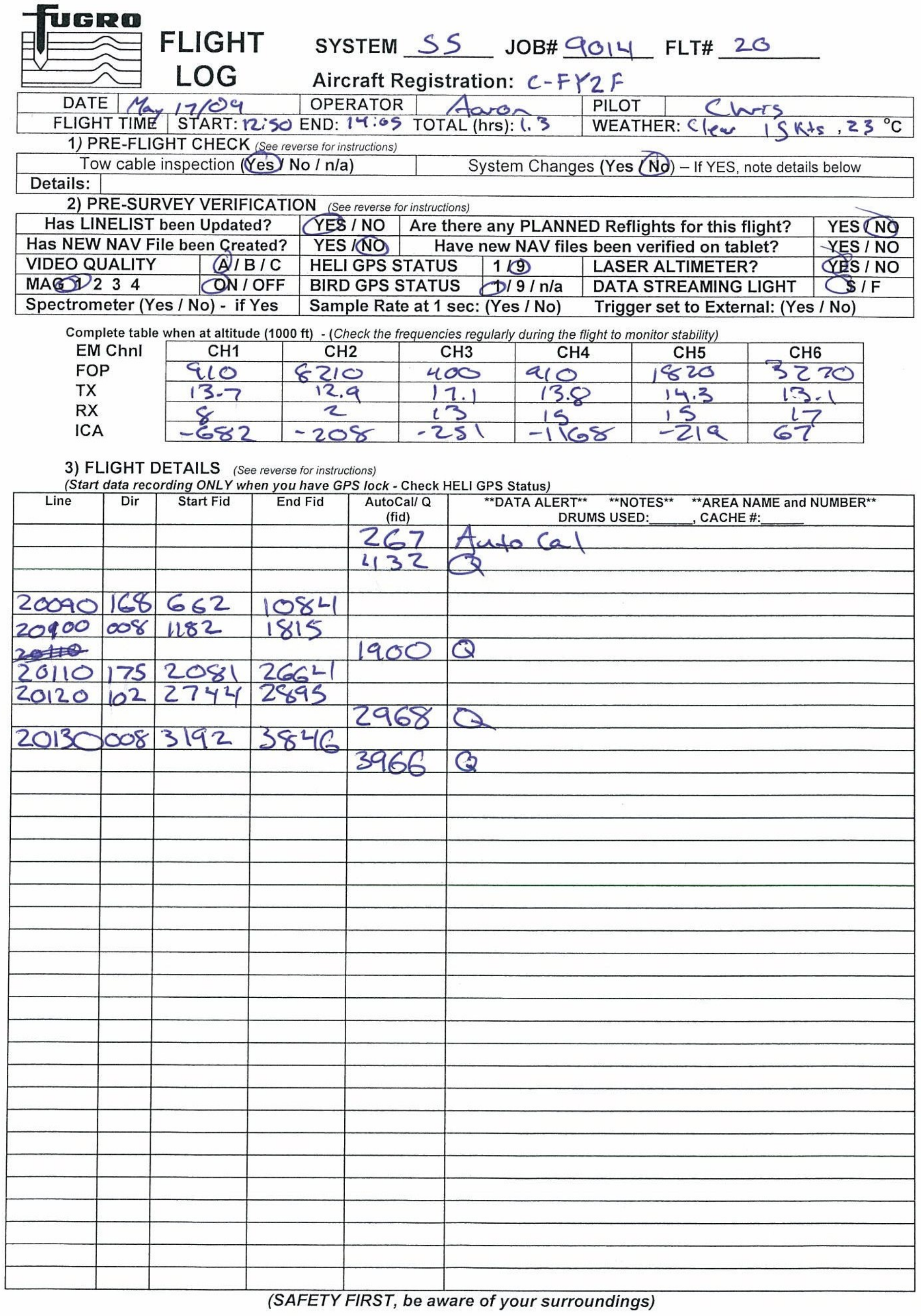
   Area name and number – note the area name and area number on every flight log for each flight.
   Weather – describe conditions - calm, windy or turbulent. Also note spherics activity
   Flight Time – record total helicopter hours for every flight

4) ***Technical Problems in Flight*** – Questions to answer in-flight when you encounter problems

   Answer while you are airborne:
   - Is it on both inphase and quadrature?
   - Does it happen with all other transmitters turned off?
   - Does it happen when the mag is turned off?
   - Is there any interference from the helicopter generator (ask pilot to turn off gen. for 20 sec, record fid range)?
   - Does it happen when you vary speed? (fly between 40 – 80 knots)
   - Does it happen when you vary power setting? (change by 5% torque increments)
   - Is the noise direction dependent?
   - Is it happening on the ground, using the helicopter generator for power with the helicopter at full RPM?

   Ground questions:
   - Does it happen while using the lambda for a power source?
   - What is the helicopter voltage?

-Appendix G.9 -



FUGRO FLIGHT LOG

SYSTEM SS JOB# 9014 FLT# 20

Aircraft Registration: C-FYZF

DATE	May 17/09	OPERATOR	Aaron	PILOT	Chris
FLIGHT TIME	START: 12:50 END: 14:05 TOTAL (hrs): 1.3			WEATHER: Clear 15Kts, 23 °C	

1) PRE-FLIGHT CHECK *(See reverse for instructions)*

Tow cable inspection ([✓ Yes] / No / n/a)	System Changes (Yes / [✓ No]) – If YES, note details below
Details:	

2) PRE-SURVEY VERIFICATION *(See reverse for instructions)*

Has LINELIST been Updated?	[✓ YES] / NO	Are there any PLANNED Reflights for this flight?			YES / [✓ NO]
Has NEW NAV File been Created?	YES / [✓ NO]	Have new NAV files been verified on tablet?			YES / NO
VIDEO QUALITY	[✓ A] / B / C	HELI GPS STATUS	1 / [✓ 9]	LASER ALTIMETER?	[✓ YES] / NO
MAG [✓ 1] 2 3 4	[✓ ON] / OFF	BIRD GPS STATUS	[✓ 1] / 9 / n/a	DATA STREAMING LIGHT	[✓ S] / F
Spectrometer (Yes / No) - if Yes		Sample Rate at 1 sec: (Yes / No)		Trigger set to External: (Yes / No)	

Complete table when at altitude (1000 ft) - (*Check the frequencies regularly during the flight to monitor stability)*

EM Chnl	CH1	CH2	CH3	CH4	CH5	CH6
FOP	910	8210	400	910	1820	3270
TX	13.7	12.9	17.1	13.8	14.3	13.1
RX	8	2	13	15	15	17
ICA	-682	-208	-251	-1168	-219	67

3) FLIGHT DETAILS *(See reverse for instructions)*

(Start data recording ONLY when you have GPS lock - Check HELI GPS Status*)*

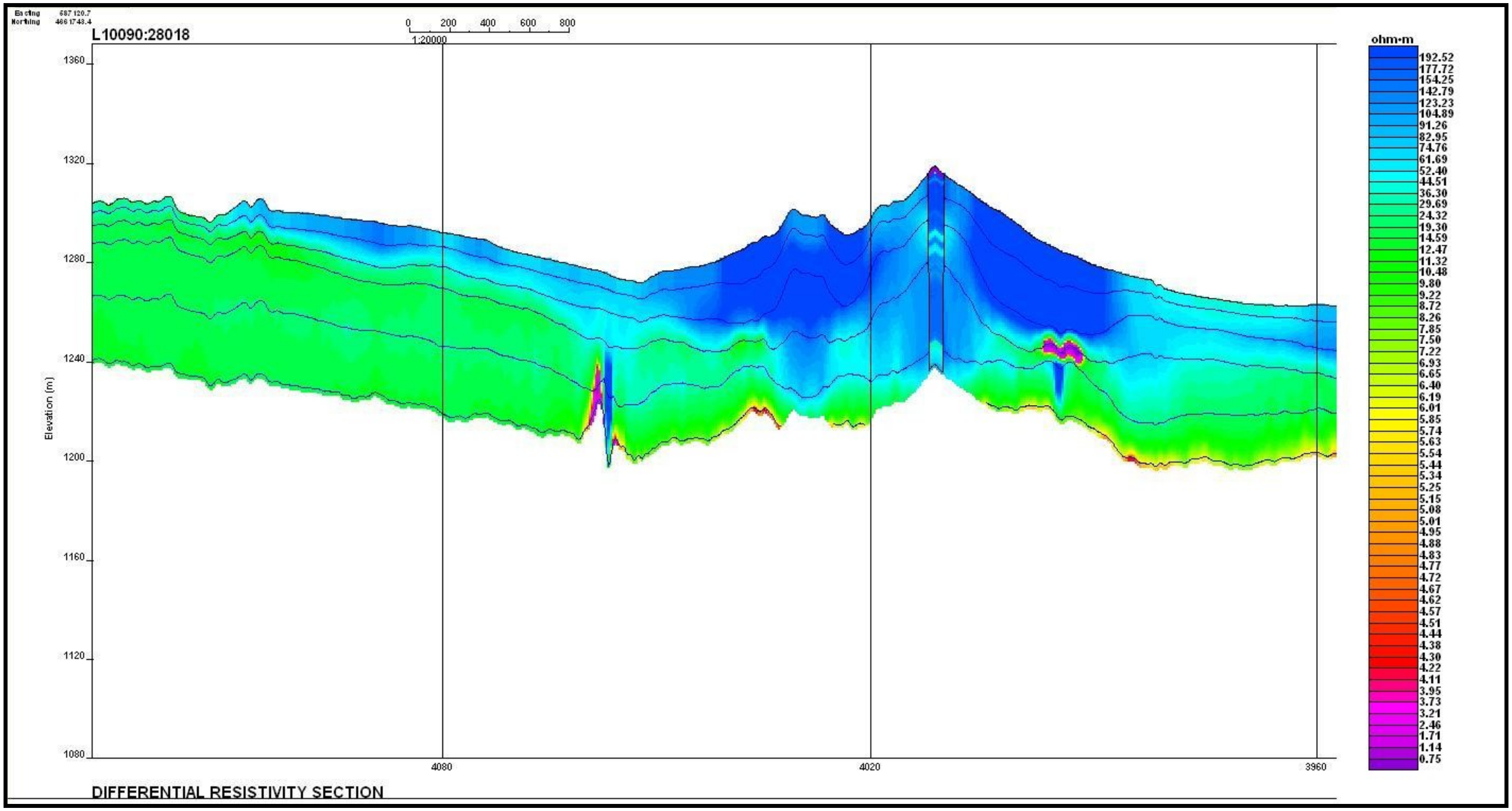
Line	Dir	Start Fid	End Fid	AutoCal/ Q (fid)	**DATA ALERT** **NOTES** **AREA NAME and NUMBER** DRUMS USED:______, CACHE #:______
				267	Auto Cal
				4132	Q
20090	168	662	10841		
20100	008	1182	1815		
~~20110~~				1900	Q
20110	175	2081	26641		
20120	102	2744	2895		
				2968	Q
20130	008	3192	3846		
				3966	Q

(SAFETY FIRST, be aware of your surroundings)

APPENDIX H

BOREHOLE RESISTIVITY AND DIFFERENTIAL RESISTIVITY COMPARISON

Borehole SI-1-09 Resistivity and test line L10090



The highest point on the profile shows the location of a borehole on repeat test line 10090. The resistivity log from the borehole (double vertical lines) is overlain on the calculated differential resistivity section from the airborne data, using the same color bar. The small, highly conductive zone at the collar surface has been attributed to casing. The horizontal and vertical scales are different, and the vertical values represent meters above the ellipsoid, not above mean sea level.