Fugro Airborne Surveys

LOGISTICS AND PROCESSING REPORT
Airborne Magnetic and HELITEM® Survey

WALABANBA AND MT HARDY AREAS
NORTHERN TERRITORY
AUSTRALIA

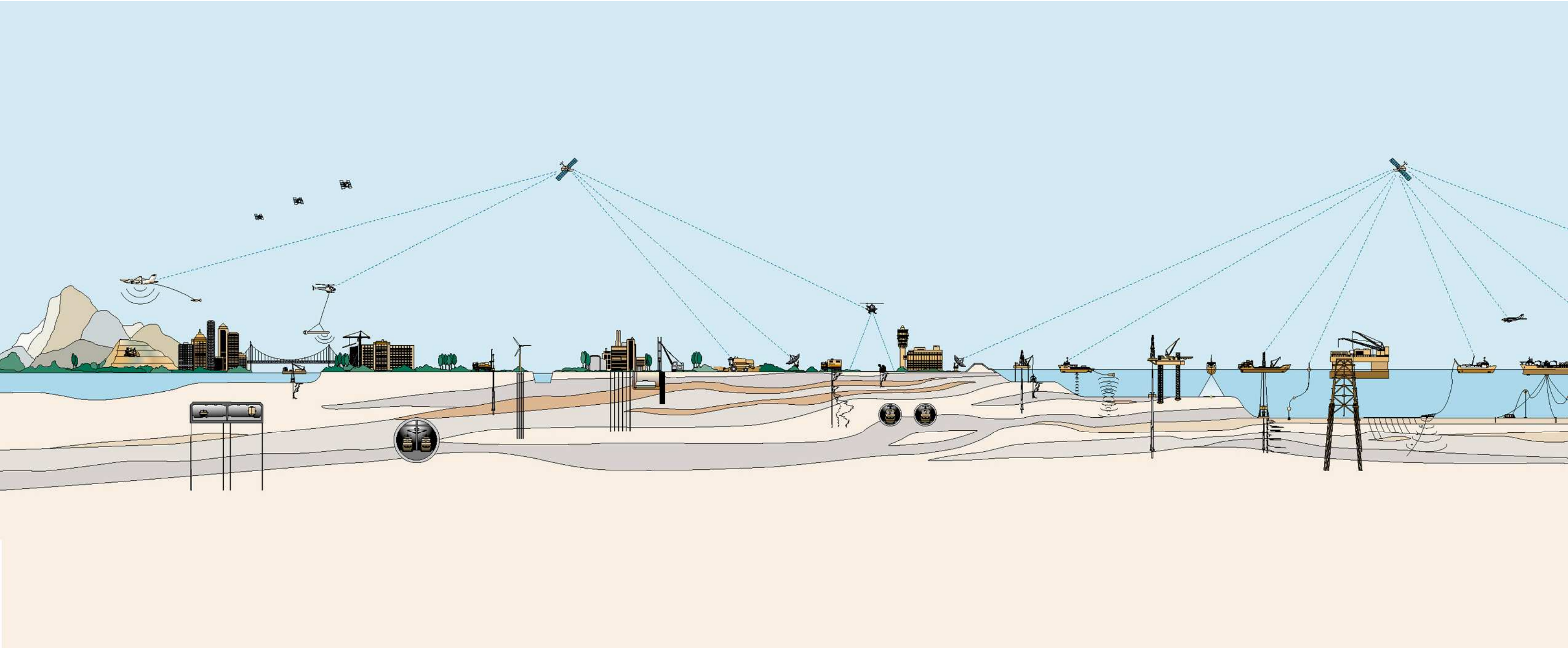
Job No. 2334

TNG Limited

Prepared by: S. Carter

Authorized for release by: M. Abubeker

Survey flown: July 2012



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APPENDICES

1. Survey Operations and Logistics

1.1 Introduction

This report describes the logistics, data acquisition, processing and presentation of results of a HELITEM® electromagnetic/magnetic survey flown from July 14 to July 27, 2012 for TNG Limited comprised of four (4) blocks, plus 131 km of traverses, in the Walabanba area, one (1) block in the Mt Hardy area, Northern Territory, Australia. Total coverage of the survey blocks amounted to 1779 km.

The purpose of the survey was to determine the existence and locations of bedrock conductors and for better understanding of the subsurface geology within the survey area. The EM data were processed to produce images and profiles that are indicative of the conductive properties of the survey area. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base maps.

The survey data were processed and compiled in the Fugro Airborne Surveys Perth office. Maps and data in digital format are provided with this report.

1.2 Location of the Survey Blocks

Figure 1 shows the location of the four (4) blocks in the Walabanba area. Total coverage of these blocks amounted to 718 line kilometres with flight lines flown in a North-South direction.

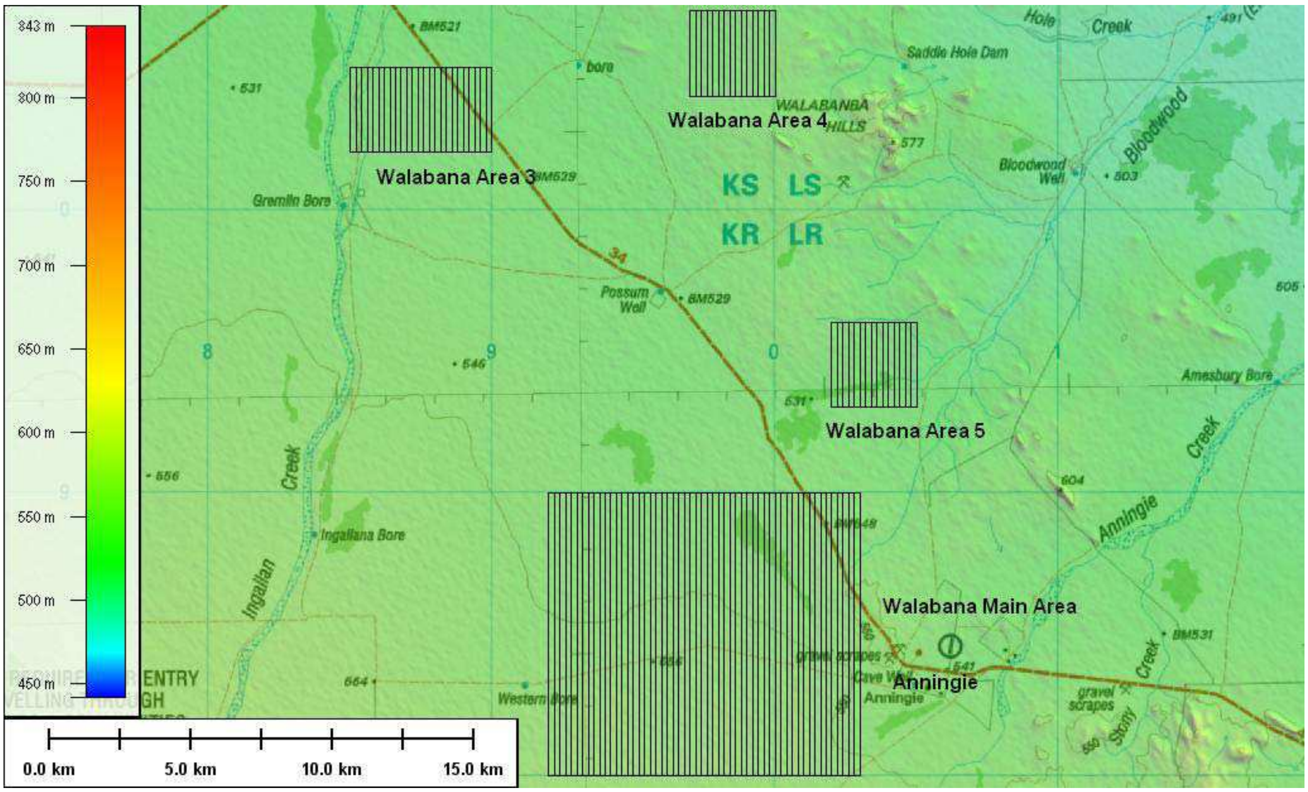

Figure 1. Blocks 3 to 5 and Main Block in the Walabanba Area.

Figure 2 shows the location of the transect lines in the Walabanba area. Total coverage of the transect lines amounted to 131 line kilometres with flight lines flown in both a North-South and East-West direction.

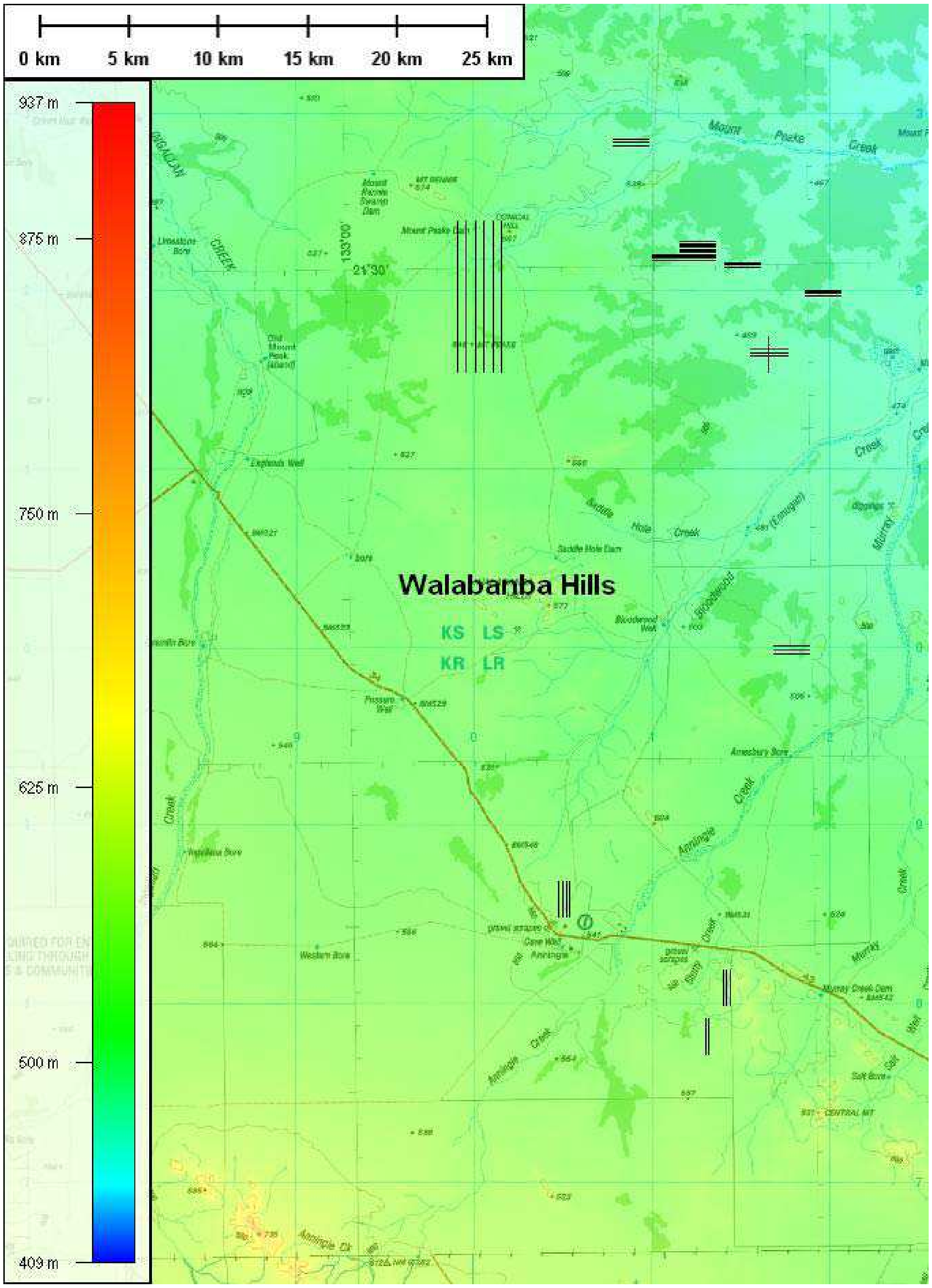

Figure 2. Transect Lines in the Walabanba Area.

Figure 3 shows the location of the one (1) block in the Mt Hardy area. Total coverage of the Mt Hardy block amounted to 930 line kilometres with flight lines flown in a North-South direction.

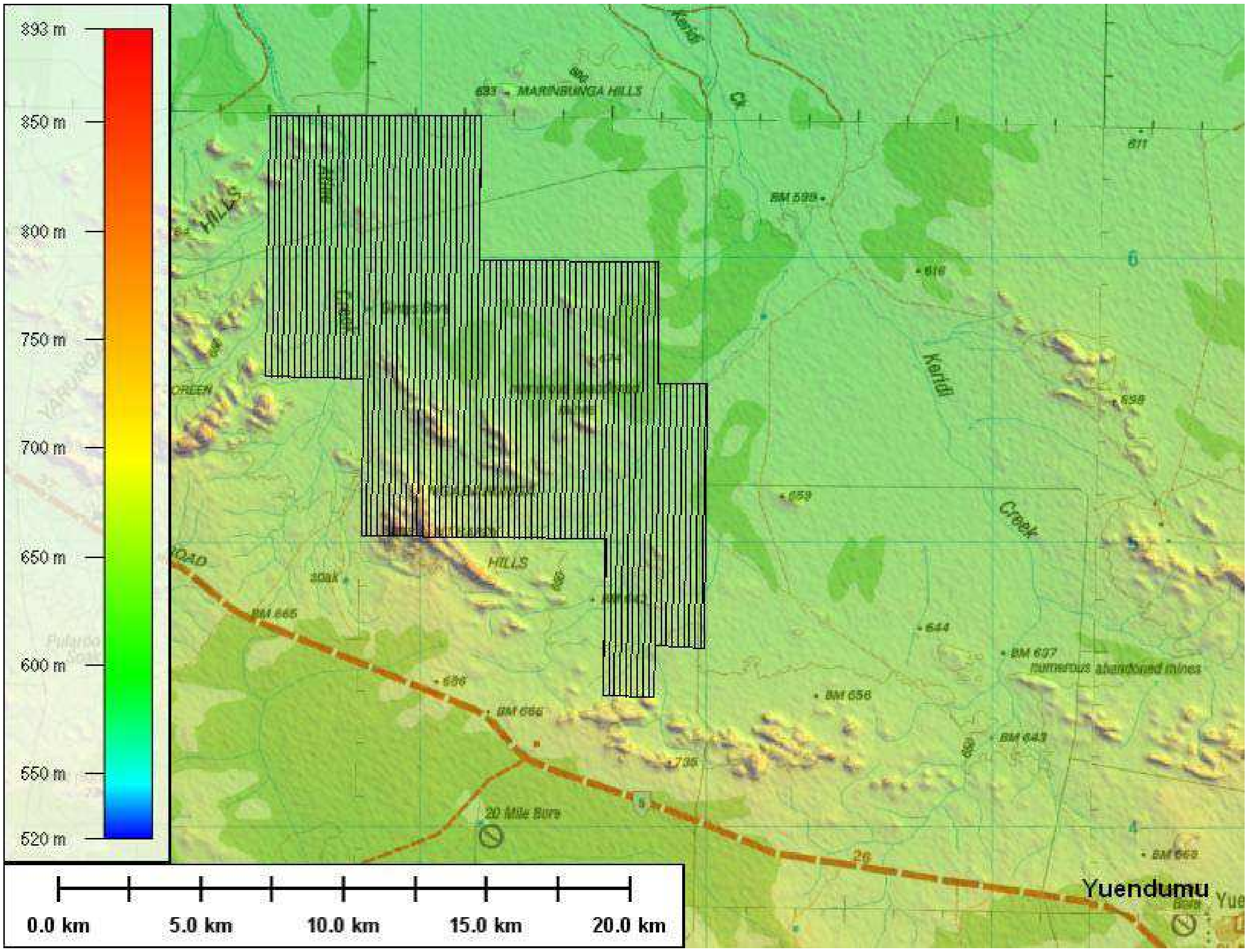

Figure 3. Mt Hardy Block.

1.3 Survey Personnel

The following personnel were involved in this project:

Project Manager:	John Black
Data Processors:	Stephen Carter, Chao Zhou
Pilot:	Steve Stanley
Electronics Operators:	John Stewart, Jorge Naranjor, James Levarre

1.4 General Disclaimer

It is Fugro Airborne Survey's understanding that the data and report provided to the client is to be used for the purpose agreed between the parties. That purpose was a significant factor in determining the scope and level of the Services being offered to the Client. Should the purpose for which the data and report is used change, the data and report may no longer be valid or appropriate and any further use of, or reliance upon, the data and report in those circumstances by the Client without Fugro Airborne Survey's review and advice shall be at the Client's own or sole risk.

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2. Survey Specifications and Parameters

2.1 Area Co-ordinates

Table 1 lists the area co-ordinates for Blocks 3 to 5, Main Block (Block 2) and the Transect Lines (Block 1) in the Walabanba Area. Co-ordinates are in WGS84 UTM Zone 53S.

Block	Corners	X-UTM (E)	Y-UTM (N)
Walabanba Transect Lines (Block 1)	1	295309	7571577
	2	295309	7632282
	3	325259	7632282
	4	325259	7571577
Walabanba Main Block (Block 2)	1	292000	7580000
	2	292000	7590000
	3	303000	7590000
	4	303000	7580000
Walabanba Block 3	1	285000	7602000
	2	285000	7605000
	3	290000	7605000
	4	290000	7602000
Walabanba Block 4	1	297000	7604000
	2	297000	7607000
	3	300000	7607000
	4	300000	7604000
Walabanba Block 5	1	302000	7593500
	2	302000	7595500
	3	305000	7595500
	4	305000	7593500

Table 1. Area Coordinates for Blocks 1 to 5 in the Walabanba Area in WGS84, UTM Zone 53S.

Table 2 lists the area co-ordinates for the Mt Hardy Block (Block 6) in the Mt Hardy Area. Co-ordinates are in WGS84 UTM Zone 52S.

Block	Corners	X-UTM (E)	Y-UTM (N)
Mt Hardy (Block 6)	1	754500	7565250
	2	762100	7565250
	3	762100	7560000
	4	768300	7560000
	5	768300	7555600
	6	770000	7555600
	7	770000	7546300
	8	768200	7546300
	9	768200	7544500
	10	766300	7544500
	11	766300	7550000
	12	757800	7550000
	13	757800	7555750
	14	754500	7555750

Table 2. Area Coordinates for Block 6 in the Mt Hardy Area in WGS84, UTM Zone 52S.

2.2 Survey Area Parameters

Job Number	-	2334
Survey Company	-	Fugro Airborne Surveys Pty Ltd
Date Flown	-	14th – 27th July 2012
Client	-	TNG Limited
EM System	-	HELITEM
Navigation	-	Real-time differential GPS
Datum	-	WGS84
Projection	-	UTM Zones 52S and 53S
Project Name	-	Walabanba and Mt Hardy, Northern Territory

Table 3 summarizes the survey specifications for each block, including the line spacing and flight directions.

Block	Lines From	Lines To	Flight Direction	Line Spacing m	Total Line Km
Walabanba Transects (Block 1)	10010	10060	N-S	500	51
	10070	10090	E-W	200	6
	10100	10270	E-W	100	42
	10280	10300	E-W	200	6
	10310	10310	N-S	-	2
	10320	10340	E-W	200	6
	10350	10430	N-S	200	18
Walabanba Main (Block 2)	20010	20560	N-S	200	560
Walabanba Block 3	30010	30260	N-S	200	78
Walabanba Block 4	40010	40160	N-S	200	48
Walabanba Block 5	50010	50160	N-S	200	32
Mt Hardy (Block 6)	60010	60780	N-S	200	930
				Total:	1779

Table 3. Summary of Survey Specifications.

Optimum survey elevations for the helicopter and instrumentation during normal survey flying are:

Helicopter: 83 m
HELITEM Receiver: 63 m
Magnetometer: 35 m
HELITEM Transmitter: 35 m

Survey elevations will not deviate by more than 20% over a distance of 2 km from the contracted elevation.

Survey elevation is defined as the measurement of the helicopter radar altimeter to the tallest obstacle in the helicopter path. An obstacle is any structure or object which will impede the path of the helicopter to the ground and is not limited to and includes tree canopy, towers and power lines.

Survey elevations may vary based on the pilot's judgement of safe flying conditions around man-made structures or in rugged terrain.

3. Aircraft and System Specifications

3.1 Aircraft

Aircraft:	AS 350 B3 Helicopter
Operator:	United Aero Helicopters
Registration:	VH-UAZ

3.2 HELITEM System Specifications

The HELITEM® system is composed of a 51.9 m cable to which is attached a receiver platform 22.4 m along the cable below the Helicopter, a magnetometer attached to the transmitter loop 47 m below the helicopter in flight. The top of the cable is attached to a helicopter and when in flight it drags to form a 25 degree angle from the vertical. The real time navigation GPS antenna is on the tail boom of the helicopter, the barometric altimeter, radar altimeter, video camera and data recorder are all installed in the helicopter. One GPS antenna is attached near the centre of transmitter loop to give positional information of the loop.

Survey Speed:	55 knots / 65 mph / 30 m/s
Magnetometer:	Scintrex CS-3 cesium vapour, attached to transmitter loop, sensitivity = 0.01 nT, sampling rate = 0.1 s, ambient range 20,000 to 100,000 nT. The general noise envelope was kept below 0.5 nT. The nominal sensor height was ~35 m above ground.
Electromagnetic system:	HELITEM® 30 channel multicoil system
Transmitter:	Vertical axis loop slung below helicopter Loop area 708 m^2 Number of turns 2 Nominal height above ground 35 m
Receiver:	Multicoil system (X, Y and Z) with a final recording rate of 10 samples/second, for 30 channels of X, Y and Z component data. The nominal height above ground was ~63 m.
Base frequency:	25 Hz
Pulse width:	4 ms
Pulse delay:	0.078 ms
Off-time:	15.977 ms
Point value:	9.77 µs
Transmitter Current:	1415 A
Dipole moment:	$2x10^6 Am^2$
Digital Acquisition:	Fugro Airborne Surveys HeliDAS system.
Barometric Altimeter:	Motorola MPX4115AP analog pressure sensor with a pressure sensitivity of 150mV/kPa and a 10 Hz sample interval, mounted in the helicopter.
Radar Altimeter:	Honeywell RT300 short pulse modulation 4.3 GHz, sensitivity 1 ft, range 0 to 2500 ft, 10 Hz recording interval mounted in the helicopter.
Camera:	Panasonic WVCD/32 Colour Video Camera
Electronic Navigation:	Novatel OEMV4/V, 0.5 sec recording interval. Antenna mounted on the tail of the helicopter.
Positional Data:	Novatel OEMV4/V, 0.5 sec recording interval. Antenna mounted on the tail of the helicopter.

Table 4 shows the HELITEM window information for a 25 Hz base frequency.

Times from start of cycle:						Times after Tx turnoff:				
Gate	Start time (ms)	End Time (ms)	Midpoint (ms)	Width (ms)			Start time (ms)	End Time (ms)	Midpoint (ms)	Width (ms)
0	0.078	0.234	0.156	0.156	Ontime					
1	0.234	1.494	0.864	1.260	Ontime					
2	1.494	2.764	2.129	1.270	Ontime					
3	2.764	4.023	3.394	1.260	Ontime					
4	4.160	4.180	4.170	0.020	Offtime	4	0.137	0.156	0.146	0.020
5	4.180	4.209	4.194	0.029	Offtime	5	0.156	0.186	0.171	0.029
6	4.209	4.248	4.229	0.039	Offtime	6	0.186	0.225	0.205	0.039
7	4.248	4.287	4.268	0.039	Offtime	7	0.225	0.264	0.244	0.039
8	4.287	4.336	4.312	0.049	Offtime	8	0.264	0.313	0.288	0.049
9	4.336	4.395	4.365	0.059	Offtime	9	0.313	0.371	0.342	0.059
10	4.395	4.473	4.434	0.078	Offtime	10	0.371	0.449	0.410	0.078
11	4.473	4.561	4.517	0.088	Offtime	11	0.449	0.537	0.493	0.088
12	4.561	4.658	4.609	0.098	Offtime	12	0.537	0.635	0.586	0.098
13	4.658	4.785	4.722	0.127	Offtime	13	0.635	0.762	0.698	0.127
14	4.785	4.941	4.863	0.156	Offtime	14	0.762	0.918	0.840	0.156
15	4.941	5.127	5.034	0.186	Offtime	15	0.918	1.104	1.011	0.186
16	5.127	5.352	5.239	0.225	Offtime	16	1.104	1.328	1.216	0.225
17	5.352	5.625	5.488	0.273	Offtime	17	1.328	1.602	1.465	0.273
18	5.625	5.947	5.786	0.322	Offtime	18	1.602	1.924	1.763	0.322
19	5.947	6.348	6.147	0.400	Offtime	19	1.924	2.324	2.124	0.400
20	6.348	6.816	6.582	0.469	Offtime	20	2.324	2.793	2.559	0.469
21	6.816	7.393	7.104	0.576	Offtime	21	2.793	3.369	3.081	0.576
22	7.393	8.086	7.739	0.693	Offtime	22	3.369	4.063	3.716	0.693
23	8.086	8.926	8.506	0.840	Offtime	23	4.063	4.902	4.482	0.840
24	8.926	9.932	9.429	1.006	Offtime	24	4.902	5.908	5.405	1.006
25	9.932	11.152	10.542	1.221	Offtime	25	5.908	7.129	6.519	1.221
26	11.152	12.627	11.890	1.475	Offtime	26	7.129	8.604	7.866	1.475
27	12.627	14.395	13.511	1.768	Offtime	27	8.604	10.371	9.487	1.768
28	14.395	16.543	15.469	2.148	Offtime	28	10.371	12.520	11.445	2.148
29	16.543	20.000	18.271	3.457	Offtime	29	12.520	15.977	14.248	3.457

Table 4. HELITEM® Gate positions.

Figure 5 shows the typical HELITEM Waveforms for the transmitter and X, Y and Z components.

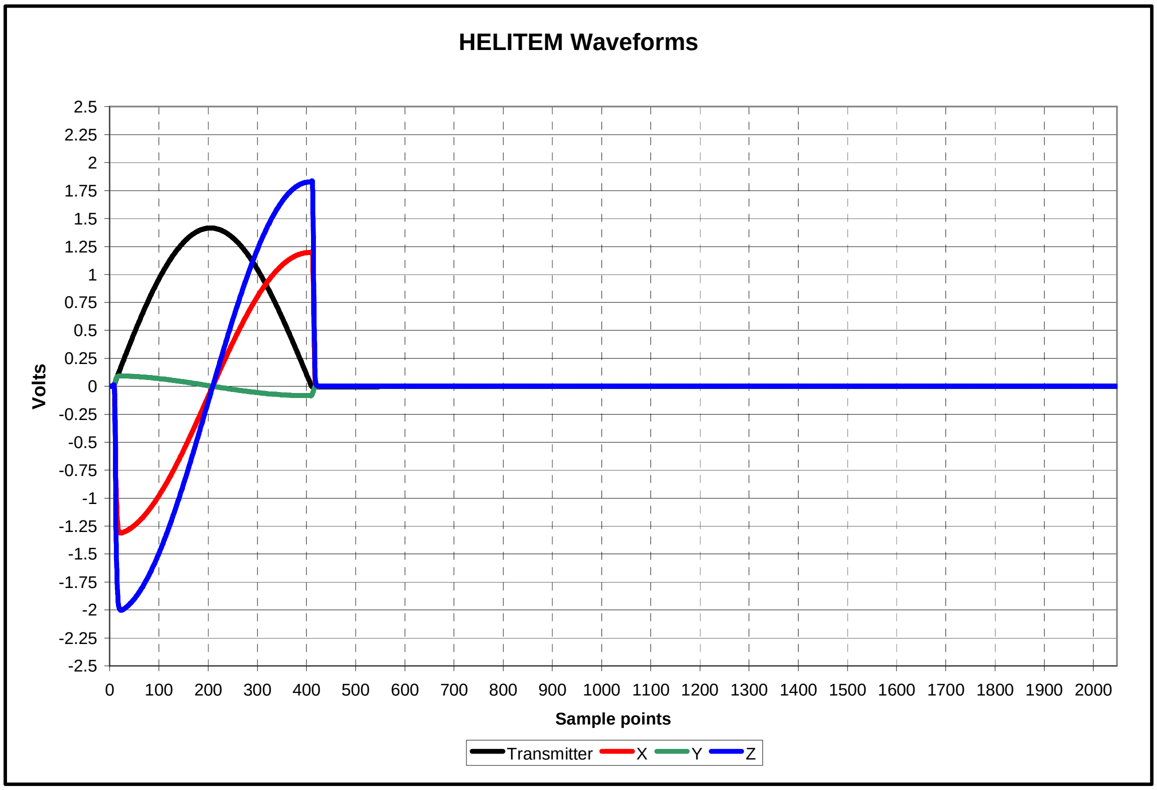

Figure 5. HELITEM® System Waveforms

3.3 Base Station Equipment

During the acquisition of the Mt Hardy Block 6 and Walabanba Blocks 1 to 5, a base station GPS was set up at Yuendumu and then Ti Tree Airports respectively to collect GPS data to allow post processing of the positional data for increased accuracy. The location of each GPS base station are recorded in Table 5.

Status	Location Name	WGS84 Latitude (deg-min-sec)	WGS84 Longitude (deg-min-sec)	Ellipsoidal Height (m)	Date Setup	Date Torn Down
Primary	Yuendumu Airport	22 15 28.72 S	131 47 25.91 E	693	11-Jul-12	18-Jul-12
Primary	Ti Tree Airport	22 07 51.84 S	133 25 18.88 E	578	19-Jul-12	25-Jul-12

Table 5. GPS Base Station Location.

Two magnetic base stations (Primary and Secondary) were setup near the GPS base station to record diurnal data. The magnetic base station locations and base values are listed in Table 6.

Status	Location Name	WGS84 Latitude (deg-min-sec)	WGS84 Longitude (deg-min-sec)	Base Level (nT)	Date Setup	Date Torn Down
Primary	Yuendumu Airport	22 15 28.76 S	131 47 25.73 E	52,300	11-Jul-12	18-Jul-12
Secondary	Yuendumu Airport	22 15 25.36 S	131 47 28.15 E	52,300	11-Jul-12	18-Jul-12
Primary	Ti Tree Airport	22 07 54.04 S	133 25 21.17 E	51,900	19-Jul-12	25-Jul-12
Secondary	Ti Tree Airport	22 07 56.92 S	133 25 18.70 E	51,900	19-Jul-12	25-Jul-12

Table 6. Magnetic Base Station Location.

GPS	Novatel OEM4/V receiver system
Magnetometer	Scintrex CS-3 cesium vapor sensor with timing provided by CFI Marconi GPS receiver

3.4 Noise Levels

3.4.1 Electromagnetic Data

The noise envelopes of the EM data, as indicated on the raw traces of dB/dt & B field channel 30 shall not exceed the following tolerances continuously over a horizontal distance of 1000 meters under normal survey conditions:

dB/dt X and Z < +/- 5 nT/s and B-Field X and Z < +/- 12.5 pT.

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

3.4.2 Airborne High Sensitivity Magnetometer

Magnetic total-field intensity data will be recorded on-board the aircraft as follows:

- Sample interval will be 0.1 second (10 samples/second)
- Magnetometer sensitivity will be 0.1 nT

Magnetometer noise level will not exceed ±1.0 nT for a distance of 1 km or more.

3.4.3 Ground Base Station Magnetometer

Base station magnetometer information will be recorded digitally at 1.0 second intervals.

For acceptance of the magnetic data, non-linear variations in the magnetic diurnal should not exceed 10 nT over a chord of 60 seconds.

4 Data Processing

4.1 Introduction

All digital data were verified for validity and continuity. The data from the aircraft and base station were transferred to the field PC. Basic statistics were generated for each parameter recorded, these included: the minimum, maximum, and mean values; the standard deviation; and any null values located. Data were checked in the field by the FUGRO AIRBORNE SURVEYS field geophysicist for adherence to the survey specifications as outlined in the survey specifications section. Any failure to meet the survey specifications resulted in a re-flight of the line or portion of the line unless aircraft safety was at risk or the client's on site representative approved the data.

4.2 Flight Path Recovery

The quality of the GPS navigation was controlled on a daily basis by recovering the flight path of the aircraft. The correction procedure used the raw ranges from the base station to create improved models of clock error, atmospheric error and satellite orbit. These models are used to improve the conversion of aircraft raw ranges to differentially corrected aircraft position.

To check the quality of the positional data the aircraft speed is calculated using the differentially corrected x, y and z data. Any sharp changes in the speed are used to flag possible problems with the positional data. Where speed jumps occur the data are inspected to determine the source of the error. The erroneous data are deleted and splined if less than two seconds in length. If the error is greater than two seconds the raw data are examined and if acceptable may be shifted and used to replace the bad data. The gps z component is the most common source of error. When it shows problems that cannot be corrected by recalculating the differential correction the barometric altimeter is used as a guide to assist in making the appropriate correction.

4.3 Altitude Data

Radar altimeter data is de-spiked by applying a one and a half second median and smoothed using a one and a half second Hanning filter. The data are then subtracted from the GPS elevation to create a digital terrain model that is gridded and consulted in conjunction with profiles of the radar altimeter and flight path video to detect any spurious points.

Barometric altimeter data is also smoothed with a 1.5 second Hanning filter.

4.4 Base Station Diurnal Magnetics

The raw diurnal data sampled at 1 Hz are imported into a database. The data are filtered with a 5 second median filter and then a 5 second Hanning filter to remove spikes and smooth short wavelength variations. A nonlinear variation is then calculated and a flag channel is created to indicate where the variation exceeds the survey tolerance. Acceptable diurnal data are interpolated to a 10 Hz sample rate and the local regional field value calculated from the average of the first day's diurnal data is removed to leave the diurnal variation. This diurnal variation is then ready to be used in the processing of the airborne magnetic data.

4.5 Airborne Magnetics

4.5.1 Residual Magnetic Intensity (RMI)

The RMI data collected in flight were profiled on screen along with a fourth difference channel calculated from the RMI. Spikes were removed manually where indicated by the fourth difference. The de-spiked data were then corrected for lag by 21 samples. The diurnal variation was extracted from the filtered ground station data was then removed from the de-spiked and lagged RMI. The RMI is then tie line levelled, manually corrected and micro-levelled if necessary.

4.5.2 Calculated Vertical Gradient (CVG)

The first vertical derivative was calculated in the frequency domain from the final gridded RMI values to enhance subtleties related to geological structures. A first vertical derivative was gridded back to the database for display in the multi-parameter profiles.

4.6 Electromagnetics

4.6.1 dB/dt Data

Lag correction:	0 sample
Data correction:	The X, Y and Z component data were re-processed from the raw stream to produce the 30 raw channels at 10 samples per second.

The following processing steps were applied to the dB/dt data from all coil sets:

a) The data from channels 1 to 4 (on-time) and 5 to 30 (off-time) were corrected for drift in flight form by passing a linear fitting along each channel between the base level points selected where the pre- and post- flight background checks were conducted when the system is out of ground effect, via a graphic screen display;

b) Both the on-time and off-time data were corrected for the noise caused by the receiver coil oscillation.

c) Spikes caused by spherics were corrected when necessary.

d) Noise filtering was done using an adaptive filter technique based on time domain triangular operators. Using a second difference value to identify changes in gradient along each channel, minimal filtering (21 points) is applied over the peaks of the anomalies, ranging in set increments up to a maximum amount of filtering in the resistive background areas (35 points for both the X and the Z component data);

e) The filtered X, Y and Z component data were then levelled in flight form for any residual and nonlinear drift that was not adequately corrected during the drift correction.

f) Line based levelling is rarely needed but is applied if necessary.

4.6.2 B-field Data

The processing steps for the B-field data are exactly the same as those for the dB/dt data.

4.6.3 Coil Oscillation Correction

The electromagnetic receiver sensor of the HELITEM® is housed in a platform container which is slung below the helicopter using a cable and attached to the transmitter loop through a network of cables. The platform design reduces the rotations of the receiver coils in flight as well as improves the stability of the receiver-transmitter geometry. However sudden changes in airspeed of the aircraft, strong variable crosswinds, or other turbulence can still result in sudden moves of the platform. This can cause the induction sensors inside the platform to rotate about their mean orientation. The rotation is most marked when the air is particularly turbulent. The changes in orientation result in variable coupling of the induction coils to the primary and secondary fields. For example, if the sensor that is normally aligned to measure the x-axis response pitches upward, it will be measuring a response that will include a mixture of the X and Z component responses. The effect of coil oscillation on the data increases as the signal from the ground (conductivity) increases and may not be noticeable when flying over areas which are generally resistive.

Using the changes in the coupling of the primary field, it is possible to estimate the pitch, roll and yaw of the receiver sensors. Only the pitch, which affects mainly the X and Z components, was considered for correction. The nominal pitch can be computed using the ideal system geometry. The pitch angles during flight are estimated and corrected to this nominal value, removing the effects caused by the deviation of the receiver sensor from its nominal position.

For the present datasets the data from all 30 channels of dB/dt and B-Field parameters have been corrected for coil oscillation.

Appendix A
Helicopter Airborne Electromagnetic Systems

HELICOPTER AIRBORNE ELECTROMAGNETIC SYSTEMS

General

The operation of a helicopter time-domain electromagnetic system (EM) involves the measurement of decaying secondary electromagnetic fields induced in the ground by a series of short current pulses generated from a towed transmitter. Variations in the decay characteristics of the secondary field (sampled and displayed as windows) are analyzed and interpreted to provide information about the subsurface geology.

A number of factors combine to give the helicopter platforms good signal-to-noise ratio, depth of penetration and excellent resolution: 1) the principle of sampling the induced secondary field in the absence of the primary field (during the “off-time”), 2) the large dipole moment 3) the low flying height of the system and spatial proximity of the transmitter and receiver. Such a system is also relatively insensitive to noise due to air turbulence. However, sampling in the “on-time” can also result in excellent sensitivity for mapping very resistive features and very conductive geologic features (Annan et al, 1991, Geophysics v.61, p. 93-99).

Methodology

The Fugro time-domain helicopter electromagnetic system (HELITEM®) uses a high-speed digital EM receiver. The primary electromagnetic pulses are created by a series of discontinuous sinusoidal current pulses fed into a two-turn transmitting loop towed below the helicopter. The base frequency rate is selectable, with 25, 30, 75 and 90 currently being available. The length of the pulse can be tailored to suit the targets. Standard pulse widths available are 2.0 and 4.0 ms. The available off-time can be selected to be as great as 16 ms. The dipole moment depends on the pulse width and base frequency used on the survey. The specific dipole moment, waveform and gate settings for this survey are given in the main body of the report.

The receiver sensor is a three-axis (x, y & z) induction coil set housed in a platform suspended on the tow cable below the helicopter and above the transmitter. The tow cable is non-magnetic to reduce noise levels. The tow cable is 51.9 m long. The receiver is 26.7 m above and 12.9 m ahead of the transmitter in flight.

For each primary pulse a secondary magnetic field is produced by decaying eddy currents in the ground. These in turn induce a voltage in the receiver coils, which is the electromagnetic response. Good conductors decay slowly, poorer conductors more rapidly.

Operations, which are carried out in the receiver, are:

1. *Primary-field removal:* In addition to measuring the secondary response from the ground, the receiver sensor coils also measure the primary response from the transmitter. During flight, the receiver sensor position and orientation changes slightly, and this has a very strong effect on the magnitude of the total response (primary plus secondary) measured at the receiver coils. The variable primary field response is distracting because it is unrelated to the ground response. The primary field can be measured by flying at an altitude such that no ground response is measurable. These calibration signals are used to define the shape of the primary waveform. By definition this primary field includes the response of the current in the transmitter loop plus the response of any slowly decaying eddy currents induced in the

helicopter. We assume that the shape of the primary will not change as the receiver sensor position changes, but that the amplitude will vary. The primary-field-removal procedure involves solving for the amplitude of the primary field in the measured response and removing this from the total response to leave a secondary response. Note that this procedure removes any (“in-phase”) response from the ground which has the same shape as the primary field.

2. *Digital Stacking:* Stacking is carried out to reduce the effect of broadband noise in the data.

3. *Windowing of data*: The digital receiver samples the secondary and primary electromagnetic field at 2048 points per EM pulse and windows the signal in up to 30 time gates whose centres and widths are software selectable and which may be placed anywhere within or outside the transmitter pulse. This flexibility offers the advantage of arranging the gates to suit the goals of a particular survey, ensuring that the signal is appropriately sampled through its entire dynamic range.

4. *Primary Field:* The primary field at the receiver sensor is measured for each stack and recorded as a separate data channel to assess the variation in coupling between the transmitter and the receiver sensor induced by changes in system geometry.

One of the major roles of the digital receiver is to provide diagnostic information on system functions and to allow for identification of noise events, such as sferics, which may be selectively removed from the EM signal. The high digital sampling rate yields maximum resolution of the secondary field.

System Hardware

The airborne EM system consists of the helicopter, the on-board hardware, and the software packages controlling the hardware.

Transmitter System

The transmitter system drives high-current pulses of an appropriate shape and duration through the coils towed below the helicopter.

System Timing Clock

This subsystem provides appropriate timing signals to the transmitter, and also to the analog-to-digital converter, in order to produce output pulses and capture the ground response. All systems are synchronized to GPS time.

Platform Systems

A three-axis induction coil sensor is mounted inside a platform on the tow cable. The platform is connected to the transmitter loop through a network of cables to ensure a more robust and better stability of the transmitter-receiver geometry. A magnetometer sensor is attached to the transmitter loop near its centre.

Appendix B
Airborne Transient EM Interpretation

Interpretation of transient electromagnetic data

Introduction

The basis of the transient electromagnetic (EM) geophysical surveying technique relies on the premise that changes in the primary EM field produced in the transmitting loop will result in eddy currents being generated in any conductors in the ground. The eddy currents then decay to produce a secondary EM field which may be sensed in the receiver coil.

The HELITEM® airborne transient (or time-domain) EM system incorporates a high-speed digital receiver which records the secondary field response with a high degree of accuracy. Most often the earth's total magnetic field is recorded concurrently.

Although the approach to interpretation varies from one survey to another depending on the type of data presentation, objectives and local conditions, the following generalizations may provide the reader with some helpful background information.

The main purpose of the interpretation is to determine the probable origin of the responses detected during the survey and to suggest recommendations for further exploration. This is possible through an objective analysis of all characteristics of the different types of responses and associated magnetic anomalies, if any. If possible the airborne results are compared to other available data. Certitude is seldom reached, but a high probability is achieved in identifying the causes in most cases. One of the most difficult problems is usually the differentiation between surface conductor responses and bedrock conductor responses.

Types of Conductors

Bedrock Conductors

The different types of bedrock conductors normally encountered are the following:

1. *Graphites*. Graphitic horizons (including a large variety of carbonaceous rocks) occur in sedimentary formations of the Precambrian as well as in volcanic tuffs, often concentrated in shear zones. They correspond generally to long, multiple conductors lying in parallel bands. They have no magnetic expression unless associated with pyrrhotite or magnetite. Their conductivity is variable but generally high.

2. *Massive sulphides*. Massive sulphide deposits usually manifest themselves as short conductors of high conductivity, often with a coincident magnetic anomaly. Some massive sulphides, however, are not magnetic, others are not very conductive (discontinuous mineralization or sphalerite), and some may be located among formational conductors so that one must not be too rigid in applying the selection criteria.

   In addition, there are syngenetic sulphides whose conductive pattern may be similar to that of graphitic horizons but these are generally not as prevalent as graphites.

3. *Magnetite and some serpentinized ultrabasics*. These rocks are conductive and very magnetic.

4. *Manganese oxides*. This mineralization may give rise to a weak EM response.

Surficial Conductors

1. Beds of clay and alluvium, some swamps, and brackish ground water are usually poorly conductive to moderately conductive.

2. Lateritic formations, residual soils and the weathered layer of the bedrock may cause surface anomalous zones, the conductivity of which is generally low to medium but can occasionally be high. Their presence is often related to the underlying bedrock.

Cultural Conductors (Man-Made)

3. *Power lines*. These frequently, but not always, produce a conductive type of response. In the case when the radiated field is not removed by the power line comb filter, the anomalous response can exhibit phase changes between different windows. In the case of current induced by the EM system in a grounded wire, or steel pylon, the anomaly may look very much like a bedrock conductor.

4. *Grounded fences or pipelines*. These will invariably produce responses much like a bedrock conductor. Whenever they cannot be identified positively, a ground check is recommended.

5. *General culture*. Other localized sources such as certain buildings, bridges, irrigation systems, tailings ponds etc., may produce EM anomalies. Their instances, however, are rare and often they can be identified on the visual path recovery system.

Analysis of the Conductors

The rate of decay of a conductor is generally indicative of the conductivity of the anomalous material. However, the decay rate alone is not generally a decisive criterion in the analysis of a conductor. In particular, one should note:

- its shape and size,
- all local variations of characteristics within a conductive zone,
- any associated geophysical parameter (e.g. magnetism),
- the geological environment,
- the structural context, and
- the pattern of surrounding conductors.

The first objective of the interpretation is to classify each conductive zone according to one of the three categories which best defines its probable origin. The categories are cultural, surficial and bedrock. A second objective is to assign to each zone a priority rating as to its potential as an economic prospect.

Bedrock Conductors

This category comprises those anomalies which cannot be classified according to the criteria established for cultural and surficial responses. It is difficult to assign a universal set of values which typify bedrock conductivity because any individual zone or anomaly might exhibit some, but not all, of these values and still be a bedrock conductor. The following criteria are considered indicative of a bedrock conductor:

1. An intermediate to high conductivity identified by a response with slow decay, with an anomalous response present in the later windows.

2. For vertical conductors, the anomaly should be narrow, relatively symmetrical, with two well-defined z-component peaks and a null between the peaks.

3. If the conductor is thin, the response characteristics varies as a function of depth and dips. If the conductor is wider, the responses might look more similar to the sphere responses.

4. A small to intermediate amplitude. Large amplitudes are normally associated with surficial conductors. The amplitude varies according to the depth of the source.

5. A degree of continuity of the EM characteristics across several lines.

6. An associated magnetic response of similar dimensions. One should note, however, that those magnetic rocks which weather to produce a conductive upper layer will possess this magnetic association. In the absence of one or more of the characteristics defined in 1, 2, 3, 4 and 5, the related magnetic response cannot be considered significant.

Most obvious bedrock conductors occur in long, relatively monotonous, sometimes multiple zones following formational strike. Graphitic material is usually the most probable source. Massive syngenetic sulphides extending for many kilometres are known in nature but, in general, they are not common. Long formational structures associated with a strong magnetic expression may be indicative of banded iron formations.

In summary, a bedrock conductor reflecting the presence of a massive sulphide would normally exhibit the following characteristics:

- a high conductivity,
- an appropriate anomaly shape,
- a small to intermediate amplitude,
- an isolated setting,
- a short strike length (in general, not exceeding one kilometre), and
- preferably, with a localized magnetic anomaly of matching dimensions.

Surficial Conductors

This term is used for geological conductors in the overburden, either glacial or residual in origin, and in the weathered layer of the bedrock. Most surficial conductors are probably caused by clay minerals. In some environments the presence of salts will contribute to the conductivity. Other possible electrolytic conductors are residual soils, swamps, brackish ground water and alluvium such as lake or river-bottom deposits, flood plains and estuaries.

Normally, most surficial materials have low to intermediate conductivity so they are not easily mistaken for highly conductive bedrock features. Also, many of them are wide and their anomaly shapes are typical of broad horizontal sheets.

When surficial conductivity is high it is usually still possible to distinguish between a horizontal plate (more likely to be surficial material) and a vertical body (more likely to be a bedrock source) thanks to the characteristic shapes of the two anomalies and the differences in the x-component responses.

One of the more ambiguous situations as to the true source of the response is when surface conductivity is related to bedrock lithology as for example, surface alteration of an underlying bedrock unit. At times, it is also difficult to distinguish between a weak conductor within the bedrock (e.g. near-massive sulphides) and a surficial source.

In the search for massive sulphides or other bedrock targets, surficial conductivity is generally considered as interference but there are situations where the interpretation of surficial-type conductors is the primary goal. When soils, weathered or altered products are conductive, and in-situ, the responses are a very useful aid to geologic mapping. Shears and faults are often identified by weak, usually narrow, anomalies.

Analysis of surficial conductivity can be used in the exploration for such features as lignite deposits, kimberlites, paleochannels and ground water. In coastal or arid areas, surficial responses may serve to define the limits of fresh, brackish and salty water.

Cultural Conductors

The majority of cultural anomalies occur along roads and are accompanied by a response on the power line monitor. This monitor is set to 50 or 60 Hz, depending on the local power grid. In some cases, the current induced in the power line results in anomalies which could be mistaken for bedrock responses. There are also some power lines which have no response whatsoever.

The power line monitor, of course, is of great assistance in identifying cultural anomalies of this type. It is important to note, however, that geological conductors in the vicinity of power lines may exhibit a weak response on the monitor because of current induction via the earth.

Fences, pipelines, communication lines, railways and other man-made conductors can give rise to responses, the strength of which will depend on the grounding of these objects.

Another facet of this analysis is the line-to-line comparison of anomaly character along suspected man-made conductors. In general, the amplitude, the rate of decay, and the anomaly width should not vary a great deal along any one conductor, except for the change in amplitude related to terrain clearance variation. A marked departure from the average response character along any given feature gives rise to the possibility of a second conductor.

In most cases a visual examination of the site will suffice to verify the presence of a man-made conductor. If a second conductor is suspected the ground check is more difficult to accomplish. The object would be to determine if there is (i) a change in the man-made construction, (ii) a difference in the grounding conditions, (iii) a second cultural source, or (iv) if there is, indeed, a geological conductor in addition to the known man-made source.

The selection of targets from within extensive (formational) belts is much more difficult than in the case of isolated conductors. Local variations in the EM characteristics, such as in the amplitude, decay, shape etc., can be used as evidence for a relatively localized occurrence. Changes in the character of the EM responses, however, may be simply reflecting differences in the conductive formations themselves rather than indicating the presence of massive sulphides and, for this reason, the degree of confidence is reduced.

Another useful guide for identifying localized variations within formational conductors is to examine the magnetic data in map or image form. Further study of the magnetic data can reveal the presence of faults, contacts, and other features which, in turn, help define areas of potential economic interest.

Finally, once ground investigations begin, it must be remembered that the continual comparison of ground knowledge to the airborne information is an essential step in maximizing the usefulness of the airborne EM data.

Appendix C
Multicomponent Modeling

Multicomponent helicopter airborne EM modelling

PLATE MODELING

The PLATE program has been used to generate synthetic responses over a number of plate models with 75 m of burial depth and varying dips (0, 45, 90 and 135 degrees). The geometry assumed for the HELITEM system is shown in Figure 6. In all cases the plate has a strike length of 200m, with a strike direction into the page. The width of the plate is 200m. As the flight path traverses the center of the plate, the Y component is zero and has not been plotted.

Figure 7 shows the model results as flying from left to right and Figure 8 shows the model results flying from right to left.

The plotting point is the transmitter receiver midpoint.

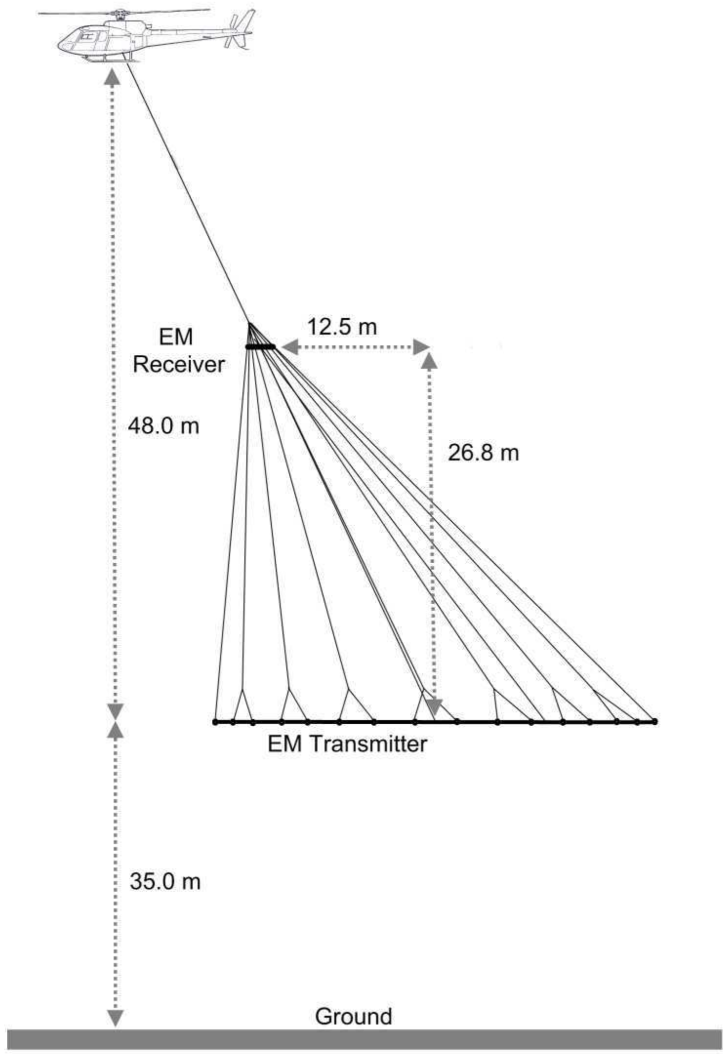

Figure 6. Geometry of the HELITEM System.

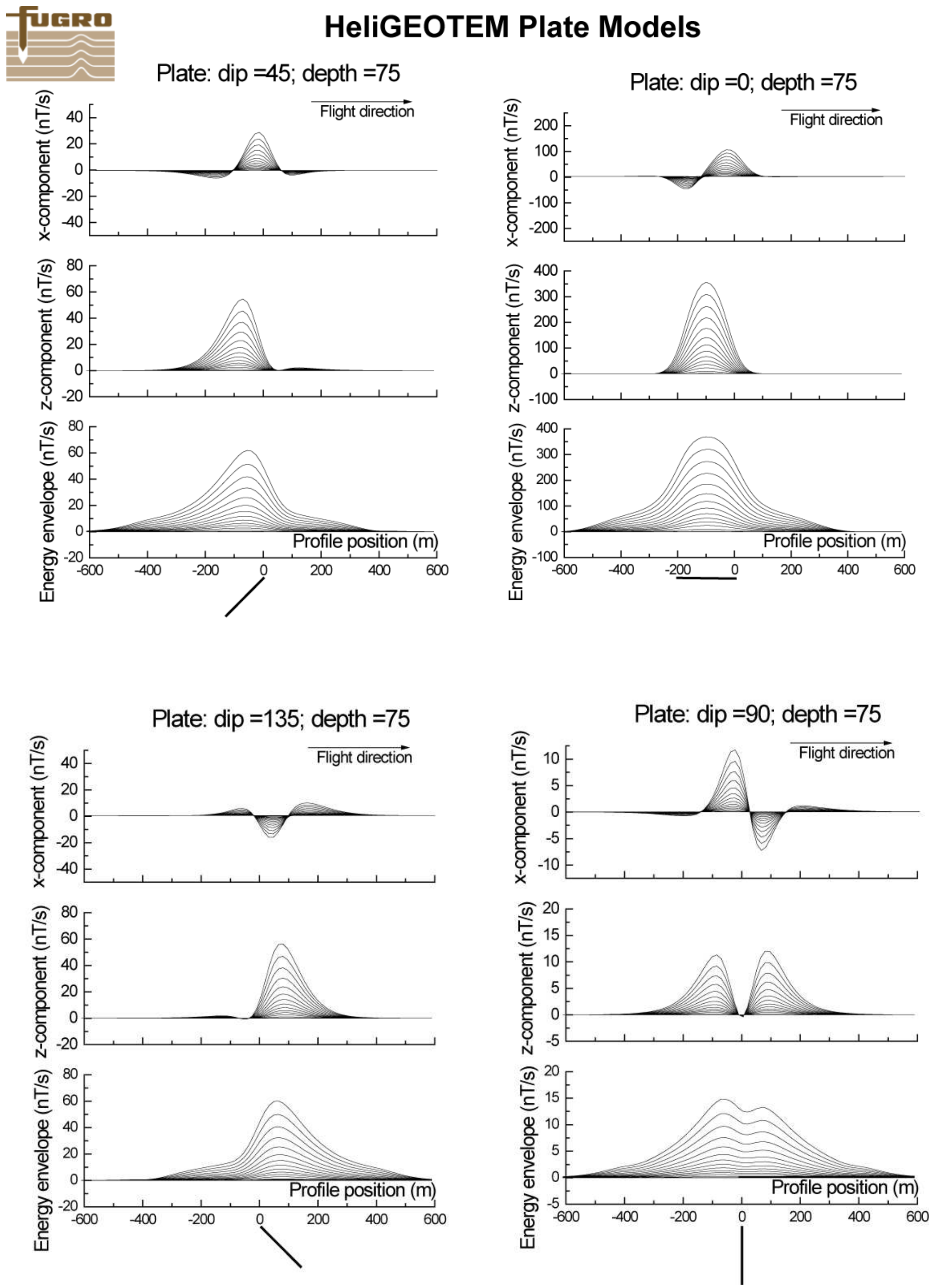

Figure 7. Model results as flying from left to right.

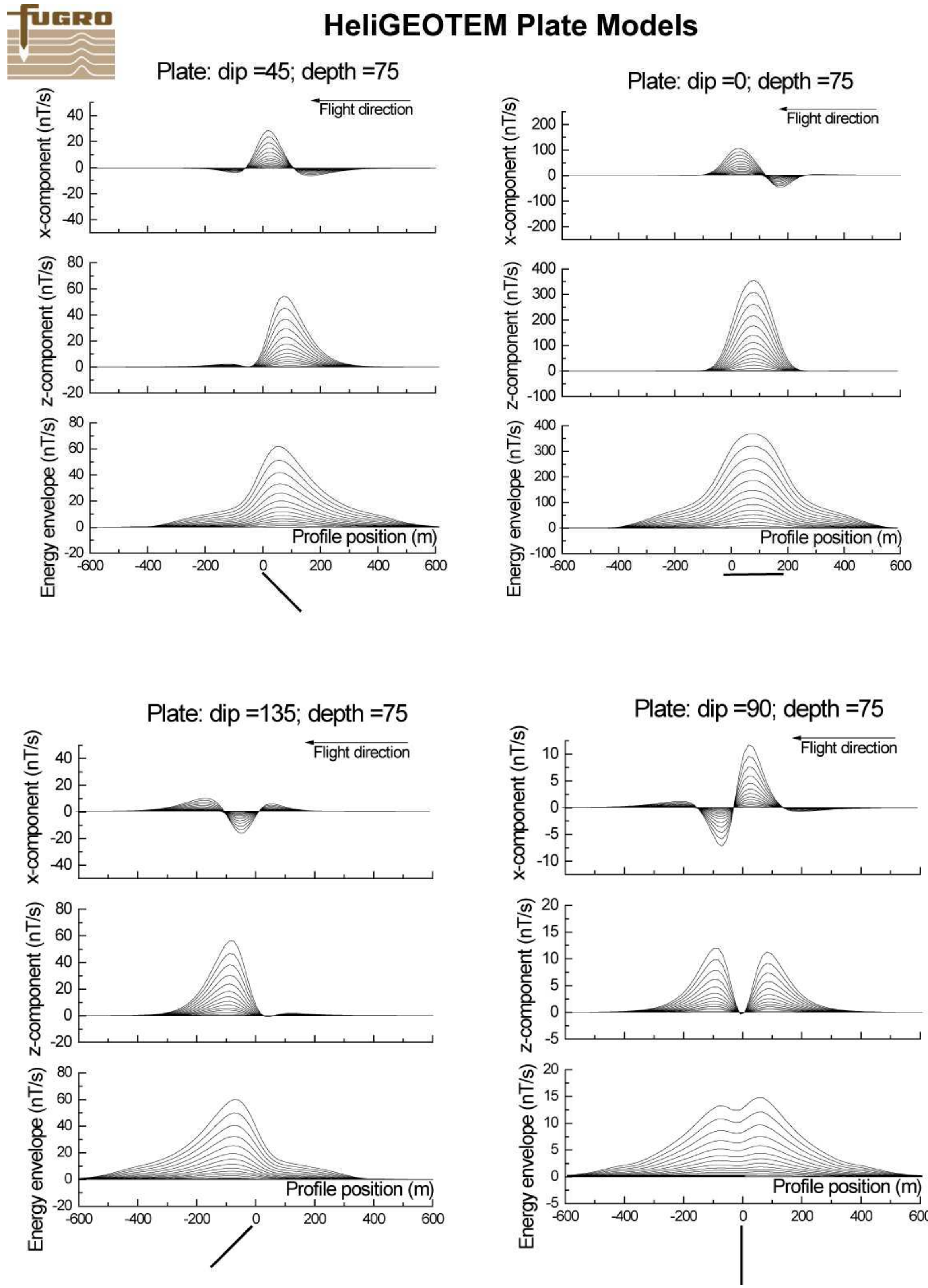

Figure 8. Model results as flying from right to left.

Appendix D
Data Archive Description

Data Archive Description:

Archive Date: September 2012

This archive contains data of an airborne geophysical survey conducted by FUGRO AIRBORNE SURVEYS CORP for TNG Limited from July 14, 2012 to July 27, 2012 near the towns of Yuendumu and Ti Tree in the Northern Territory, Australia.

The archive contains files in 7 directories on 1 DVD and 1 BR disc.

(1 x DVD)

<u>2334_Final_Data</u>

Block1_Walabanba_Transects
Block2_Walabanba_Main
Block3_Walabanba
Block4_Walabanba
Block5_Walabanba
Block6_Mt_Hardy

Each directory above contains the following sub-directories and associated files:

Database

2334_Block1_Walabanba_Transects.(***dfn/dat***)
2334_Block2_Walabanba_Main.(***dfn/dat***)
2334_Block3_Walabanba.(***dfn/dat***)
2334_Block4_Walabanba.(***dfn/dat***)
2334_Block5_Walabanba.(***dfn/dat***)
2334_Block6_Mt_Hardy.(***dfn/dat***)
**Data archives in ASEG-GDF format*

Database_CDT

2334_Block1_Walabanba_Transects_CDT_EWLines.(***dfn/dat***)
2334_Block1_Walabanba_Transects_CDT_NSLines.(***dfn/dat***)
2334_Block2_Walabanba_Main_CDT.(***dfn/dat***)
2334_Block3_Walabanba_CDT.(***dfn/dat***)
2334_Block4_Walabanba_CDT.(***dfn/dat***)
2334_Block5_Walabanba_CDT.(***dfn/dat***)
2334_Block6_Mt_Hardy_CDT.(***dfn/dat***)
**Data archives in ASEG-GDF format*

Flightpath\

Block1_Walabanba_Transects_Flightpath
Block2_Walabanba_Main_Flightpath
Block3_Walabanba_Flightpath
Block4_Walabanba_Flightpath
Block5_Walabanba_Flightpath
Block6_Mt_Hardy_Flightpath
**Map Images in GeoTIFF format*

Block1_Walabanba_Transects_Flightpath.map
Block2_Walabanba_Main_Flightpath.map
Block3_Walabanba_Flightpath.map
Block4_Walabanba_Flightpath.map
Block5_Walabanba_Flightpath.map
Block6_Mt_Hardy_Flightpath.map
*****_Maps in Geosoft format_

Grids\ERMapper\

TMI.ers	Total Magnetic Intensity (nT)
DTM.ers	Digital Terrain Model (m)
Tau1_emz_db_filt_6_to_11.ers	Decay Time Constant from channels 6 to 11 (us)
Tau2_emz_db_filt_11_to_16.ers	Decay Time Constant from channels 11 to 16 (us)
Tau3_emz_db_filt_16_to_20.ers	Decay Time Constant from channels 16 to 20 (us)
Tau4_emz_db_filt_20_to_26.ers	Decay Time Constant from channels 20 to 26 (us)
Tau5_emz_db_filt_22_to_30.ers	Decay Time Constant from channels 22 to 30 (us)
emx_db_filt_(***ch_No***).ers	dB/dt X amplitude response for channels 4 to 29 (nT/s)
emx_db_filt_(***ch_No***)_ff.ers	Fraser Filtered dB/dt X amplitude response for channels 4 to 29 (nT/s)
emx_bf_filt_(***ch_No***).ers	B-Field X amplitude response for channels 4 to 29 (pT)
emy_db_filt_(***ch_No***).ers	dB/dt Y amplitude response for channels 4 to 29 (nT/s)
emy_db_filt_(***ch_No***)_ff.ers	Fraser Filtered dB/dt Y amplitude response for channels 4 to 29 (nT/s)
emy_bf_filt_(***ch_No***).ers	B-Field Y amplitude response for channels 4 to 29 (pT)
emz_db_filt_(***ch_No***).ers	dB/dt Z amplitude response for channels 4 to 29 (nT/s)
emz_bf_filt_(***ch_No***).ers	B-Field Z amplitude response for channels 4 to 29 (pT)

Grids\Geosoft\

TMI.grd	Total Magnetic Intensity (nT)
DTM.grd	Digital Terrain Model (m)
Tau1_emz_db_filt_6_to_11.grd	Decay Time Constant from channels 6 to 11 (us)
Tau2_emz_db_filt_11_to_16.grd	Decay Time Constant from channels 11 to 16 (us)
Tau3_emz_db_filt_16_to_20.grd	Decay Time Constant from channels 16 to 20 (us)
Tau4_emz_db_filt_20_to_26.grd	Decay Time Constant from channels 20 to 26 (us)
Tau5_emz_db_filt_22_to_30.grd	Decay Time Constant from channels 22 to 30 (us)
emx_db_filt_(***ch_No***).grd	dB/dt X amplitude response for channels 4 to 29 (nT/s)
emx_db_filt_(***ch_No***)_ff.grd	Fraser Filtered dB/dt X amplitude response for channels 4 to 29 (nT/s)
emx_bf_filt_(***ch_No***).grd	B-Field X amplitude response for channels 4 to 29 (pT)
emy_db_filt_(***ch_No***).grd	dB/dt Y amplitude response for channels 4 to 29 (nT/s)
emy_db_filt_(***ch_No***)_ff.grd	Fraser Filtered dB/dt Y amplitude response for channels 4 to 29 (nT/s)
emy_bf_filt_(***ch_No***).grd	B-Field Y amplitude response for channels 4 to 29 (pT)
emz_db_filt_(***ch_No***).grd	dB/dt Z amplitude response for channels 4 to 29 (nT/s)
emz_bf_filt_(***ch_No***).grd	B-Field Z amplitude response for channels 4 to 29 (pT)

Multiplots

Prof_(***Line_No_Flt_No***).pdf
**Multi parameter plots in PDF format*

Report

R2334_TNG.pdf
**Final logistics report in PDF format*

Reference_Waveform

FLT_14_1_Ref.txt
**Waveform file in XYZ format*

(disclaimer.txt)

(1 x BD)

2334_Final Data

Video

FLT(*Flt_No*)

FLT(***Flt_No***).(***bdx/vlc***)
**Video files in binary format*

(disclaimer.txt)

****
Final Database Header Information

Project #:	2334
Type of Survey:	Fugro HELITEM Survey
Client:	TNG Limited
Areas:	Walabanba Blocks 1 to 5 and Mt Hardy Block 6, Northern Territory, Australia

****
Survey Data Format

# Channel	Time	Units	Description
1 Line	0.1		line number
2 FID	0.1		fiducial increment
3 Flight	0.1		flight number
4 Powerline	0.1	V	power line monitor channel
5 TX_Current	0.1	A	transmitter peak current
6 X_HELI	0.1	m	helicopter easting WGS84 (UTM Zone 52S or 53S)
7 Y_HELI	0.1	m	helicopter northing WGS84 (UTM Zone 52S or 53S)
8 LAT_HELI	0.1	deg	helicopter latitude WGS 84
9 LON_HELI	0.1	deg	helicopter longitude WGS 84
10 X_TX	0.1	m	transmitter loop easting WGS84 (UTM Zone 52S or 53S)
11 Y_TX	0.1	m	transmitter loop northing WGS84 (UTM Zone 52S or 53S)
12 LAT_TX	0.1	deg	transmitter loop latitude WGS 84
13 LON_TX	0.1	deg	transmitter loop longitude WGS 84
14 Radar	0.1	m	helicopter height above surface from radar altimeter
15 Z_Ell_HELI	0.1	m	helicopter height (above WGS84 ellipsoid)
16 Z_Ell_TX	0.1	m	transmitter height (above WGS84 ellipsoid)
17 DTM	0.1	m	digital terrain model
18 TX_Height	0.1	m	transmitter height above surface
19 TMI	0.1	nT	total magnetic intensity
20 emx_bf_filt	0.1	pT	B field X component channels 0 - 29 - filtered/levelled
21 emx_db_filt	0.1	nT/s	dB/dt X component channels 0 - 29 - filtered/levelled
22 emx_db_filt_ff	0.1	nT/s/m	dB/dt Fraser Filtered X component channels 0 – 29
23 emy_bf_filt	0.1	pT	B field Y component channels 0 - 29 - filtered/levelled
24 emy_db_filt	0.1	nT/s	dB/dt Y component channels 0 - 29 - filtered/levelled
25 emy_db_filt_ff	0.1	nT/s/m	dB/dt Fraser Filtered Y component channels 0 – 29
26 emz_bf_filt	0.1	pT	B field Z component channels 0 - 29 - filtered/levelled
27 emz_db_filt	0.1	nT/s	dB/dt Z component channels 0 - 29 - filtered/levelled

Datum	WGS84
Spheroid	WGS84
Projection	UTM Zones 52S and 53S
Central meridian	129 Deg East and 135 Deg East
False easting	500000
False northing	0
Scale factor	0.9996
Northern parallel	N/A
Base parallel	N/A

****

****
Final CDT Database Header Information

Project #:	2334
Type of Survey:	Fugro HELITEM Survey
Client:	TNG Limited
Areas:	Walabanba Blocks 1 to 5 and Mt Hardy Block 6, Northern Territory, Australia

****

Survey Data Format

# Channel	Time	Units	Description
1 Line	0.1		line number
2 FID	0.1		fiducial increment
3 Flight	0.1		flight number
4 Powerline	0.1	V	power line monitor channel
5 TX_Current	0.1	A	transmitter peak current
6 X_HELI	0.1	m	helicopter easting WGS84 (UTM Zone 52S or 53S)
7 Y_HELI	0.1	m	helicopter northing WGS84 (UTM Zone 52S or 53S)
8 LAT_HELI	0.1	deg	helicopter latitude WGS 84
9 LON_HELI	0.1	deg	helicopter longitude WGS 84
10 X_TX	0.1	m	transmitter loop easting WGS84 (UTM Zone 52S or 53S)
11 Y_TX	0.1	m	transmitter loop northing WGS84 (UTM Zone 52S or 53S)
12 LAT_TX	0.1	deg	transmitter loop latitude WGS 84
13 LON_TX	0.1	deg	transmitter loop longitude WGS 84
14 Radar	0.1	m	helicopter height above surface from radar altimeter
15 Z_Ell_HELI	0.1	m	helicopter height (above WGS84 ellipsoid)
16 Z_Ell_TX	0.1	m	transmitter height (above WGS84 ellipsoid)
17 DTM	0.1	m	digital terrain model
18 TX_Height	0.1	m	transmitter height above surface
19 TMI	0.1	nT	total magnetic intensity
20 emz_db_CDT	0.1	mS/m	Conductivity derived from dB/dt Z component channels 4 to 29

Datum	WGS84
Spheroid	WGS84
Projection	UTM Zones 52S and 53S
Central meridian	129 Deg East and 135 Deg East
False easting	500000
False northing	0
Scale factor	0.9996
Northern parallel	N/A
Base parallel	N/A

****

Reference Waveform Description

The information shown below is only an example.

/Calibration Data [FLT 3 Cal# 2 Start FID 80551 End Fid 80672]
/Base Frequency : 25 Hz
/Sample Interval: 9.7656250 µs

/--
/XYZ REF WAVEFORM EXPORT

/SAMPLE	T_Current[A]	dB/dt_X[nT/s]	dB/dt_Y[nT/s]	dB/dt_Z[nT/s]	BF_X[pT]	BF_Y[pT]	BF_Z[pT]
0	3.736	6.248	-2.922	-1.123	91.637	-16.882	125.727
1	3.736	13.597	-2.604	-6.418	91.576	-16.853	125.738
2	3.735	4.993	-0.009	-1.581	91.443	-16.828	125.801

The first column is the sample number. There are a total of 2048 samples representing a half-wave cycle or one pulse. The subsequent columns are: transmitter current, measured X primary field, measured Y primary field, and measured Z primary field for dB/dt and B-Field.

Data Archive Issue Date: 19 September 2012
By Whom: Fugro Airborne Surveys Pty Ltd.
Unit 3, 435 Scarborough Beach Road, Osborne Park, WA, 6017
Phone: +61 8 9273 6400
Fax: +61 8 9723 6466
Website www.fugroairborne.com.au

If you have any problems with this archive please contact

Processing Manager - FASP
Fugro Airborne Surveys Pty Ltd.
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Phone:+61 8 9273 6400
Fax: +61 8 9723 6466
Website www.fugroairborne.com.au

Appendix E
Glossary

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

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

coplanar coils: **[CP]** 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 timevarying ***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 $\mu\omega\sigma t h$, 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***, ***resistivitydepth-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***.

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
σt	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, 1 987;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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