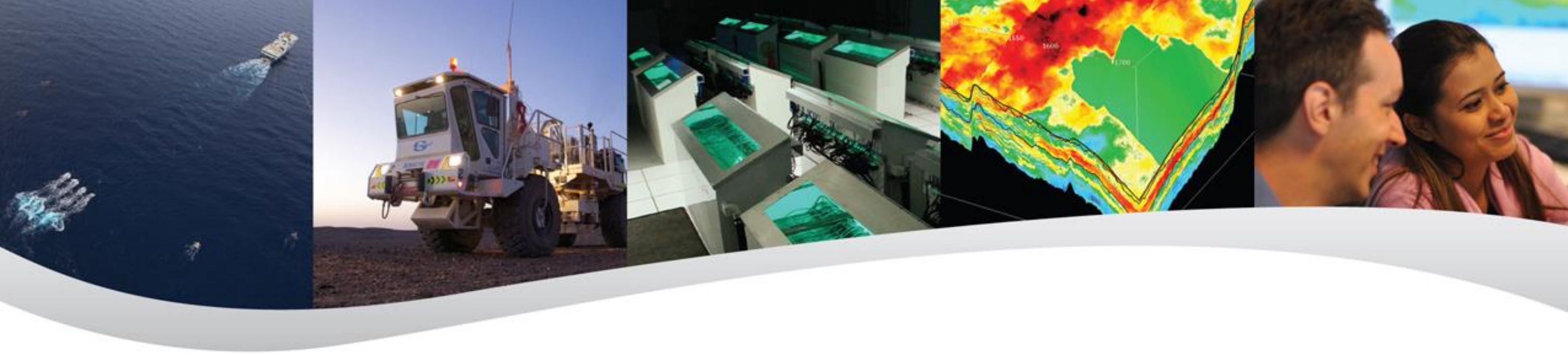

GEOPHYSICAL SURVEY REPORT

AIRBORNE MAGNETIC AND HELITEM$_{30C}$ WITH MULTIPULSE™ SURVEY

MOUNT LYELL MINE AREA, AUSTRALIA

PROJECT 602803

COPPER MINES OF TASMANIA PTY LTD.

February 2017

Passion for Geoscience
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Introduction

This report describes the logistics, data acquisition, processing and presentation of results of a $HELITEM_{30C}$ electromagnetic magnetic airborne geophysical survey carried out for Copper Mines of Tasmania PTY Ltd. over a block near the Mount Lyell Mine Area, Queenstown Tasmania. Total coverage of the survey block amounted to 582.6 km. The survey was flown between December 7 and December 15, 2016.

The purpose of the survey was to map the geology and structure of the area and detect possible base metal conductors in resistive sediments. Data were acquired using a $HELITEM_{30C}$ electromagnetic system, supplemented by a high-sensitivity cesium magnetometer. The information from these sensors was processed to produce images that display the magnetic and conductivity properties of the survey area. A GPS electronic navigation system ensured accurate positioning of the geophysical data.

The survey was performed by CGG Canada Services Ltd., Toronto office. Grids and digital data are provided with this report.

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Survey Area Description

Location of the Survey Area

The survey consisted of a single survey block located northwest of Queenstown Tasmania. The survey block corners are listed in Table 1 and the acquired line kilometres are listed in Table 2. The block was flown between December 7 and December 15, 2016, with Queenstown as the base of operations.

Figure 1 Mount Lyell Mine Area - Location Map

Block	Corners	X-UTM (E)	Y-UTM (N)
601676	1	381528	5350695
Mount Lyell Mine Area	2	382024	5350001
	3	385000	5350000
	4	384995	5349351
	5	385248	5349003
	6	386000	5349000
	7	386000	5346000
	8	384127	5344718
	9	383285	5343957
	10	383422	5343783
	11	383616	5343783
	12	383609	5342039
	13	384485	5340859
	14	383169	5339915
	15	382855	5339706
	16	381714	5341191
	17	380720	5342509
	18	380500	5344598
	19	380501	5345478
	20	384005	5347929
	21	383663	5348420
	22	382436	5347556
	23	381018	5349581
	24	380263	5349042
	25	379898	5349536

Table 1 Area Corners WGS84 UTM Zone 55S

Block	Line Numbers	Line direction	Line Spacing	Line km
1	10010 - 11300	55°/235°	75 m	567.4
	27030-27040	90°/270°	75 m	4.4
	19010 - 19020	270°	750 m	10.8

Table 2 Acquired line kilometre summary

System Information

Figure 2 HELITEM$_{30C}$ with MULTIPULSE™ System

The HELITEM$_{30C}$ with MULTIPULSE™ system configuration is shown in Figure 3. 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 putting the transmitter coil approximately 34.7 m below the helicopter. The receiver platform and the receiver coil is located at the centre of the 30m diameter transmitter loop approximately 0.1 m above the centre of the transmitter plane. The real time navigation GPS antenna is on the tail boom of the helicopter. The barometric altimeter, radar altimeter, helicopter laser altimeter, video camera and data recorder are installed in the helicopter. GPS antenna was attached to the front edge transmitter loop to give positional information. An IMU was mounted on the transmitter loop to give receiver pitch, roll and yaw.

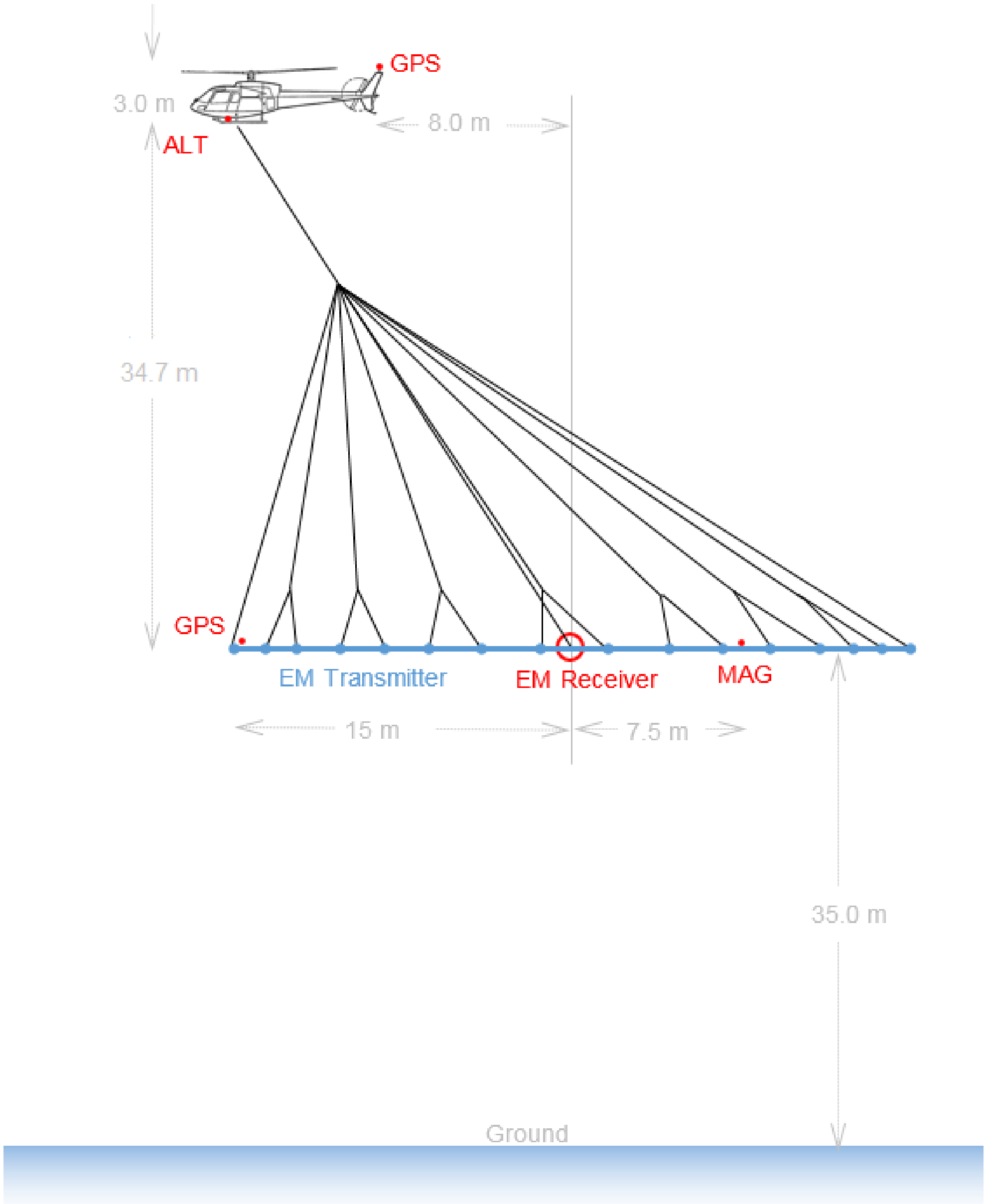


Figure 3 Geometry of the HELITEM$_{30C}$ with MULTIPULSE™ System

Aircraft and Geophysical On-Board Equipment

Helicopter:	AS350 B3
Operator:	United Aero Helicopters
Registration:	VH-7HS
EM system:	HELITEM$_{30C}$ 30 m diameter loop with MULTIPULSE™ 20 channel multicoil system add-on
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 per second of X, Y and Z component data; 30 channels of half sine pulse and 20 channels of square pulse.
Inflight Vertical Rx-Tx separation (m)	0.1m
Nominal height above ground:	35 m
Base frequency:	25 Hz
Transmitter Current:	Half sine pulse 300 A; Square pulse 35 A
Dipole moment:	Half sine pulse 424800 A·m^2; Square pulse 49560 A·m^2
Digital Acquisition:	CGG HeliDAS.
Video:	Panasonic WVCD/32 Camera with Axis 241S Video Server. Camera is mounted to the exterior bottom of the helicopter between the forward skid tubes
Magnetometer:	Scintrex Cesium Vapour (CS-2), mounted in the plane of the transmitter loop Operating Range: 15,000 to 100,000 nT Operating Limit: -40°C to 50°C Accuracy: ±0.002 nT Measurement Precision: 0.001 nT Sampling rate: 10.0 Hz
Radar Altimeter:	Honeywell Sperry Altimeter System. Radar antennas are mounted to the exterior bottom of the helicopter between the forward skid tubes

Operating Range: 0 – 2500ft
Operating Limit: -55°C to 70°C
0 to 55,000 ft
Accuracy:
± 3% (100 – 500ft above obstacle)
± 4% (500 – 2500ft above obstacle)
Measurement Precision: 1 ft
Sample Rate: 10.0 Hz

Laser Altimeter on helicopter: TruSense - S2 Laser Altimeter mounted to the exterior bottom of the helicopter between the forward skid tubes

Operating Range: 0 – 29000 m
Operating Limit: -30°C to 60°C

Accuracy: ± 3 cm at 750 m
Sample Rate: 10 Hz

Aircraft Navigation: NovAtel OEM4 Card with an Aero antenna mounted on the tail of the helicopter;

Operating Limit: -40°C to 85°C
Real-Time Accuracy:1.8m CEP (L1/L2);
Real-Time Measurement Precision: 6 cm RMS
Sample Rate: 2.0 Hz

Transmitter Loop Positional Data: NovAtel OEM4 with Aero Antenna mounted on the transmitter loop.

Operating Limit: -40°C to 85°C
Real-Time Accuracy: 1.8m CEP (L1/L2)
Real-Time Measurement Precision: 6 cm RMS
Sample Rate: 2.0 Hz

Barometric Altimeter: Motorola MPX4115AP analog pressure sensor mounted in the helicopter

Operating Range: 55 kPa to 108 kPa
Operating Limit: -40°C to 125°C
Accuracy:
± 1.5 kPa (0°C to 85°C)
± 3.0 kPa (-20°C to 0°C, 85°C to 105°C)
± 4.5 kPa (-40°C to -20°C, 105°C to 125°C)
Measurement Precision: 0.01 kPa
Sampling Rate = 10.0 Hz

Temperature: Analog Devices 592 sensor mounted on the camera box

Operating Range: -40°C to + 75°C
Operating Limit: -40°C to + 75°C
Accuracy: ± 1.5°C
Measurement Precision: 0.03°C
Sampling Rate = 10.0 Hz

Base Station Equipment

Primary Magnetometer: CGG CF1_V1 using Scintrex CS-3 cesium vapour sensor with Marconi GPS card and antenna for measurement synchronization to GPS. The base station also collects barometric pressure and outside temperature.

Magnetometer Operating Range: 15,000 to 100,000 nT
Barometric Operating Range: 55kPa to 108 kPa
Temperature Operating Range: -40°C to 75°C
Sample Rate: 1.0 Hz

GPS Receiver: NovAtel OEM4/VL1 Card with an Aero antenna

Real-Time Accuracy:1.8m CEP (L1)
Sample Rate: 1.0 Hz

Secondary Magnetometer: CGG CF1 using GEM GSM-19T sensor with Marconi GPS card and antenna for measurement synchronization to GPS. The base station also collects barometric pressure and outside temperature.

Magnetometer Operating Range: 15,000 to 100,000 nT
Barometric Operating Range: 55kPa to 108 kPa
Temperature Operating Range: -40°C to 75°C
Sample Rate: 1.0 Hz

Base Station Locations

During the survey GPS base stations were set up to collect data to allow post processing of the positional data for increased accuracy. The location of the GPS base stations are shown in
Table 3.

Status	Location Name	WGS84 Longitude (deg-min-sec)	WGS84 Latitude (deg-min-sec)	Orthometric Height (m)
Primary	Silver Hills Motel, Queenstown	145° 33’ 26.87547” E	42° 4’ 28.59877” S	145.195

Table 3 GPS Base Station Location

The location of the Magnetic base stations are listed in
Table 4.

Status	Location Name	WGS84 Longitude (deg-min-sec)	WGS84 Latitude (deg-min-sec)	Base Level (nT)
Primary	Queenstown Airport	145° 31’ 45.5074” E	42° 4’ 23.8280” S	61841.5
Secondary	Queenstown Airport	145° 31’ 42.7370” E	42° 4’ 21.9466” S	61839.2

Table 4 Magnetic Base Station Location

Pulse Configuration and Sampling windows

The HELITEM$_{30C}$ with MULTIPULSE™ system transmits two differently shaped pulses. As can be seen in Figure 4 from sample 0 to approximately sample 1790 is the half sine pulse and from approximately 1800 to 2047 is the square pulse portion. Together they comprise one half cycle of the system. Each of these pulses has an on-time when the pulse is transmitting and an off-time after the pulse has been turned off. The receiver coils measure during the entire half cycle and after acquisition the measured data from a range of samples are averaged into “gates”. The gates for the half sine data are documented in Table 5 and the gates for the square pulse data are documented in Table 6. The position of the first off-time gate is selected after examining several flights of data and is as close to the transmitter turn off as possible. The earliest data has had less time to penetrate the subsurface and so contains information from the near surface. Note that the half sine data have four gates during the on-time while the square pulse data have none. The power of the half sine pulse causes eddy currents in the system after the turn off and the first off-time gate cannot start until these have died away. The first on-time gate has occasionally been used on HELITEM$_{30C}$ only surveys to provide near surface data. The square pulse is less powerful than the half sine and this allows the first off-time gate to be positioned much closer to the turn off. This earlier gate position means that the earlier square pulse gates will contain data closer to the surface than the half sine data. In addition the square pulse is higher in frequency than the half sine pulse and this allows it to yield better resolution. Gate widths increase as time after turn off increases because as the energy from the transmitter decays a wider sample must be taken to get a valid average.

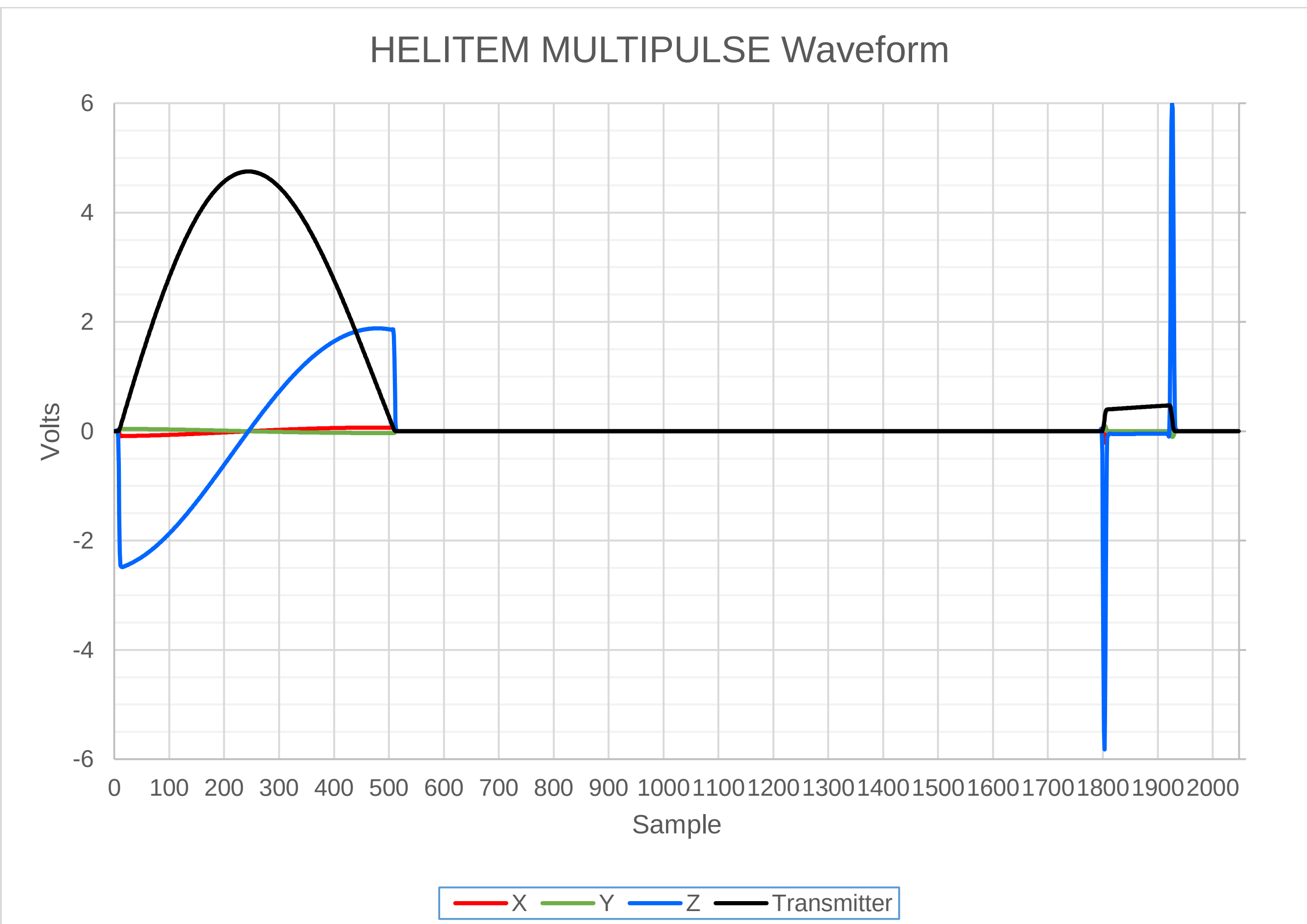


Figure 4 HELITEM$_{30C}$ with MULTIPULSE™ System receiver waveform for one half cycle

HELITEM$_{30C}$ with MULTIPULSE™ Gate positions 25 Hz / 4.3 ms pulse width for half sine									
Gate	**Start time (ms)**	**End Time (ms)**	**Midpoint (ms)**	**Width (ms)**			**Start time (ms)**	**End Time (ms)**	**Midpoint (ms)**
1	0.0391	0.1563	0.0977	0.1172	Ontime	Time after pulse shut-off			
2	1.0352	2.0215	1.5283	0.9863	Ontime				
3	2.0117	2.5098	2.2607	0.4980	Ontime				
4	3.9844	4.1113	4.0479	0.1270	Ontime				
5	4.3555	4.3750	4.3652	0.0195	Offtime	5	0.0977	0.1172	0.1074
6	4.3750	4.4043	4.3896	0.0293	Offtime	6	0.1172	0.1465	0.1318
7	4.4043	4.4336	4.4189	0.0293	Offtime	7	0.1465	0.1758	0.1611
8	4.4336	4.4727	4.4531	0.0391	Offtime	8	0.1758	0.2148	0.1953
9	4.4727	4.5215	4.4971	0.0488	Offtime	9	0.2148	0.2637	0.2393
10	4.5215	4.5801	4.5508	0.0586	Offtime	10	0.2637	0.3223	0.2930
11	4.5801	4.6484	4.6143	0.0684	Offtime	11	0.3223	0.3906	0.3564
12	4.6484	4.7266	4.6875	0.0781	Offtime	12	0.3906	0.4688	0.4297
13	4.7266	4.8242	4.7754	0.0977	Offtime	13	0.4688	0.5664	0.5176
14	4.8242	4.9414	4.8828	0.1172	Offtime	14	0.5664	0.6836	0.6250
15	4.9414	5.0781	5.0098	0.1367	Offtime	15	0.6836	0.8203	0.7520
16	5.0781	5.2441	5.1611	0.1660	Offtime	16	0.8203	0.9863	0.9033
17	5.2441	5.4492	5.3467	0.2051	Offtime	17	0.9863	1.1914	1.0889
18	5.4492	5.6934	5.5713	0.2441	Offtime	18	1.1914	1.4355	1.3135
19	5.6934	5.9863	5.8398	0.2930	Offtime	19	1.4355	1.7285	1.5820
20	5.9863	6.3379	6.1621	0.3516	Offtime	20	1.7285	2.0801	1.9043
21	6.3379	6.7578	6.5479	0.4199	Offtime	21	2.0801	2.5000	2.2900
22	6.7578	7.2656	7.0117	0.5078	Offtime	22	2.5000	3.0078	2.7539
23	7.2656	7.8711	7.5684	0.6055	Offtime	23	3.0078	3.6133	3.3105
24	7.8711	8.6035	8.2373	0.7324	Offtime	24	3.6133	4.3457	3.9795
25	8.6035	9.4824	9.0430	0.8789	Offtime	25	4.3457	5.2246	4.7852
26	9.4824	10.5371	10.0098	1.0547	Offtime	26	5.2246	6.2793	5.7520
27	10.5371	11.8066	11.1719	1.2695	Offtime	27	6.2793	7.5488	6.9141
28	11.8066	13.3301	12.5684	1.5234	Offtime	28	7.5488	9.0723	8.3105
29	13.3301	15.1660	14.2480	1.8359	Offtime	29	9.0723	10.9082	9.9902
30	15.1660	17.3535	16.2598	2.1875	Offtime	30	10.9082	13.0957	12.0020

Table 5 HELITEM$_{30C}$ with MULTIPULSE™ Gate Positions Half sine

HELITEM$_{30C}$ with MULTIPULSE™ Gate positions 25 Hz / 1.3 ms pulse width for square pulse									
Gate	Start time (ms)	End Time (ms)	Midpoint (ms)	Width (ms)			Start time (ms)	End Time (ms)	Midpoint (ms)
1	17.5098	17.6758	17.5928	0.1660	Ontime	1	Time after pulse shut-off		
2	18.7695	18.7891	18.7793	0.0195	Offtime	2	0.0684	0.0879	0.0781
3	18.7891	18.8086	18.7988	0.0195	Offtime	3	0.0879	0.1074	0.0977
4	18.8086	18.8281	18.8184	0.0195	Offtime	4	0.1074	0.1270	0.1172
5	18.8281	18.8477	18.8379	0.0195	Offtime	5	0.1270	0.1465	0.1367
6	18.8477	18.8672	18.8574	0.0195	Offtime	6	0.1465	0.1660	0.1563
7	18.8672	18.8965	18.8818	0.0293	Offtime	7	0.1660	0.1953	0.1807
8	18.8965	18.9258	18.9111	0.0293	Offtime	8	0.1953	0.2246	0.2100
9	18.9258	18.9648	18.9453	0.0391	Offtime	9	0.2246	0.2637	0.2441
10	18.9648	19.0039	18.9844	0.0391	Offtime	10	0.2637	0.3027	0.2832
11	19.0039	19.0527	19.0283	0.0488	Offtime	11	0.3027	0.3516	0.3271
12	19.0527	19.1113	19.0820	0.0586	Offtime	12	0.3516	0.4102	0.3809
13	19.1113	19.1797	19.1455	0.0684	Offtime	13	0.4102	0.4785	0.4443
14	19.1797	19.2578	19.2188	0.0781	Offtime	14	0.4785	0.5566	0.5176
15	19.2578	19.3457	19.3018	0.0879	Offtime	15	0.5566	0.6445	0.6006
16	19.3457	19.4434	19.3945	0.0977	Offtime	16	0.6445	0.7422	0.6934
17	19.4434	19.5508	19.4971	0.1074	Offtime	17	0.7422	0.8496	0.7959
18	19.5508	19.6777	19.6143	0.1270	Offtime	18	0.8496	0.9766	0.9131
19	19.6777	19.8242	19.7510	0.1465	Offtime	19	0.9766	1.1230	1.0498
20	19.8242	20.0000	19.9121	0.1758	Offtime	20	1.1230	1.2988	1.2109

Table 6 HELITEM$_{30C}$ with MULTIPULSE™ Gate Positions square wave

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 CGG Atlas software. This allowed the field personnel to calculate, display and verify both the positional (flight path) and geophysical data. The initial database was examined as a preliminary assessment of the data acquired for each flight.

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

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

Navigation

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

A Novatel OEM4 GPS base station was used to record pseudo-range, carrier phase, ephemeris, and timing information of all available GPS satellites in view at a one second interval. These data are used to improve the conversion of aircraft raw ranges to differentially corrected aircraft position. The GPS antenna was set-up in a location that allowed for clear sight of the satellites above. The set-up of the antenna also considered surfaces that could cause signal reflection around the antenna that could be a source of error to the received data measurements.

Flight Path

Flight lines did not deviate from the intended flight path by more than 25% of the planned flight path over a distance of more than 1 kilometre. Flight specifications were based on GPS positional data recorded at the helicopter.

Clearance

The 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 that will impede the path of the helicopter to the ground 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.

The ideal survey elevation for the helicopter and instrumentation during data collection was:

Helicopter	72 metres
Magnetometer	35 metres
HELITEM$_{30C}$ with MULTIPULSE™ Receiver	35 metres
HELITEM$_{30C}$ with MULTIPULSE™ Transmitter	35 metres

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

The achieved survey height average was impacted by some steep terrain in the northern part of the block and by built up infrastructure in the south.

Airborne High Sensitivity Magnetometer

To assess the noise quality of the collected airborne magnetic data, CGG monitors the 4^{th} difference results during flight which is verified post flight by the processor. The contracted specification for the collected airborne magnetic data was that the non-normalized 4^{th} difference would not exceed 1.0 nT over a continuous distance of 1 kilometre excluding areas where this specification was exceeded due to natural anomalies.

Magnetic Base Station

Ground magnetic base stations were set-up to measure the total intensity of the earth's magnetic field. The base stations were placed in a magnetically quiet area, away from power lines and moving metallic objects. The contracted specification for the collected ground magnetic data was the non-linear variations in the magnetic data were not to exceed 10 nT per minute. CGG's standard of setting up the base station within 50 km from the centre of the survey block allowed for successful removal of the active magnetic events on the collected airborne magnetic data.

Electromagnetic Data

The noise envelopes of the EM data, as calculated from the last off-time channel shall not exceed the following tolerances continuously over a horizontal distance of 1,000 metres under normal survey conditions:

- 25 Hz configuration: dB/dt Z < +/- 0.5 nT/s

Noise levels are measured in the raw profiles of the last off-time channel during the high altitude background. 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.

The $HELITEM_{30C}$ with MULTIPULSE™ EM system includes a power line channel for noise monitoring. Flying was not performed when spheric pulses became sufficiently intense and frequent that digital data processing techniques could not recover useful data. Several buildings and mines are visible on the video throughout the survey area and are evident as anomalous sources in the survey data. Caution is advised when interpreting data near any man made source.

In-Flight EM System Calibration

Calibration consists of measuring the system characteristics out of ground effect and compensation of the electromagnetic data for these measured effects. The reference waveforms recorded during the pre-flight calibration form an important part of the delivered data and are critical to accurate inversion of the data. During the pre-flight calibration, a minimum of 30 seconds of data is collected out-of-ground-effect to monitor the effectiveness of the calibration and the accuracy to the base levels. During any post-flight calibration, a minimum of 30 seconds of data is collected out-of-ground-effect; these data are compared with the pre-flight calibration data to quantify drift.

Data Processing

Flight Path Recovery

To check the quality of the positional data the speed of the helicopter 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. The corrected WGS84 longitude and latitude coordinates were transformed to GDA94 UTM coordinates using the following parameters:

Datum:	GDA94
Ellipsoid:	GDA 94
Projection:	UTM Zone 55S
Central meridian:	147°East
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

The GPS antenna mounted on the transmitter failed during the final flight 53027 after line 10351. Since the receiver position is taken from the heli gps this failure was not considered critical to the survey. There is however no transmitter height in channel gps_tx for this flight apart from line 10351. If transmitter height is required it can be estimated by subtracting the average gps_heli, gps_tx difference from earlier filghts from the flight 53027 gps_heli.

Recorded video flight path may also be linked to the data and used for verification of the flight path. Fiducial numbers are recorded continuously and are displayed on the margin of each digital image. This procedure ensures accurate correlation of data with respect to visible features on the ground. The fiducials appearing on the video frames and the corresponding fiducials in the digital profile database originate from the data acquisition system and are based on incremental time from start-up. Along with the acquisition system time, UTC time is also recorded in parallel and displayed see Figure 5. Several flights experienced a problem that interrupted video recording creating gaps of approximately 10-15 seconds. Discontinuous video coverage exists on several flights. There were no video files for flight 53014. The video for flight 53013 ends prematurely at fiducial 75635.

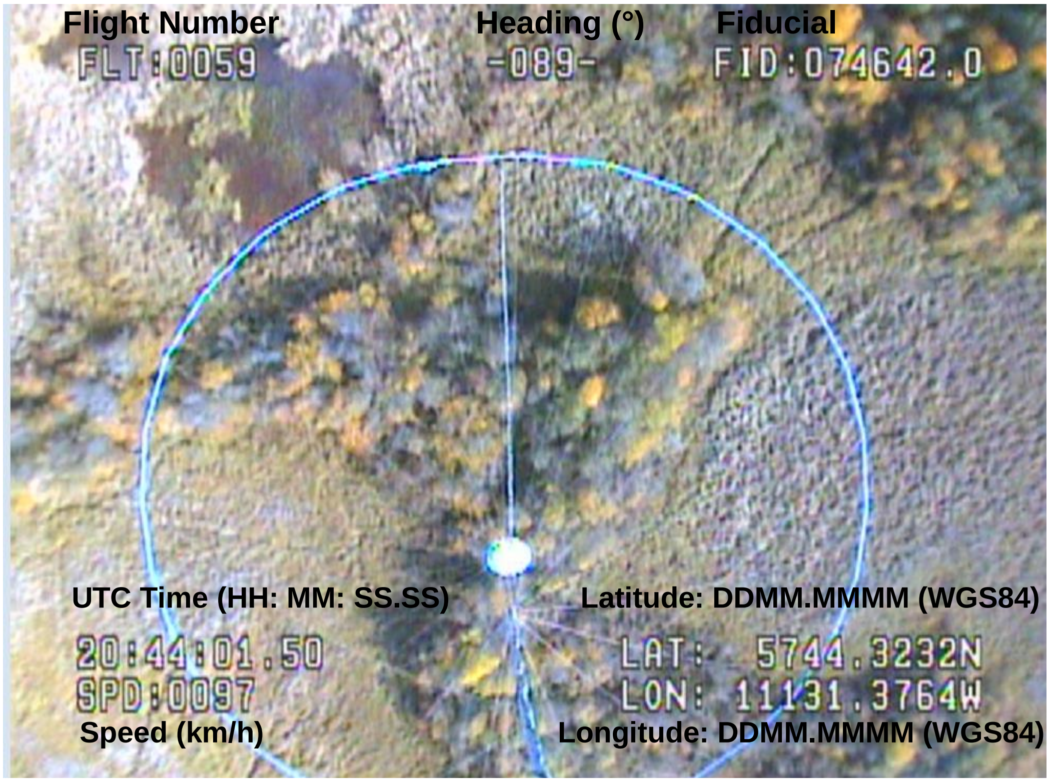


Figure 5 Flight path video

Altitude Data

The helicopter laser altimeter data are de-spiked and iteratively filtered and examined to ensure that false readings from tree canopy are excluded. The laser altimeter data are then subtracted from the helicopter GPS elevation to create a digital elevation model that is gridded and used in conjunction with profiles of the laser altimeter and flight path video to detect any spurious values.

Magnetics

Magnetic Base Station Diurnal

The raw diurnal data are sampled at 1 Hz and imported into a database. The data are filtered with a 51 second median filter and then a 51 second Hanning filter to remove spikes and smooth short wavelength variations. A non-linear variation is then calculated and a flag channel is created to indicate where the variation exceeds the survey tolerance. Acceptable diurnal data were interpolated to a 10 Hz sample rate before the international geomagnetic reference field (IGRF) for the base station location was removed. This diurnal variation was then ready to be used in the processing of the airborne magnetic data.

Total Magnetic Intensity

The Total Magnetic Intensity (TMI) data collected in flight were profiled on screen along with a fourth difference channel calculated from the TMI. Spikes were removed manually where indicated by the fourth difference. The de-spiked data were then corrected for lag by 3.1 seconds. The diurnal variation that was extracted from the filtered ground station data was then removed from the de-spiked and lagged total magnetic field. A low pass filter was applied to remove an oscillation caused by the Helitem transmitter. The IGRF was subtracted based on aircraft position and date then manual adjustments were applied to any lines that required levelling, as indicated by shadowed images of the gridded magnetic data. The manually levelled data were then subjected to a microlevelling filter and finally the International Geomagnetic Reference Field was calculated for the mean survey date and mean survey and this plane was added back to produce the archived TMI.

Calculated Vertical Magnetic Gradient

The levelled, total magnetic intensity grid was subjected to a processing algorithm that enhances the response of magnetic bodies in the upper 500 metres and attenuates the response of deeper bodies. The resulting calculated vertical gradient grid provides better definition and resolution of near-surface magnetic units. It also identifies weak magnetic features that may not be quite as evident in the TMI data. Regional magnetic variations and changes in lithology, however, may be better defined on the total magnetic intensity.

Electromagnetics

dB/dt Data

Data correction: The X, Y and Z component data are re-processed from the raw stream to produce the 30 raw channels at 10 samples per second from the half sine pulse and 20 raw channels at 10 samples per second for the square pulse.

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

- The raw stream data is re-processed post-flight using start-of-flight and end-of-flight calibrations to remove spheric spikes, coil oscillation, and system drift.
- Noise filtering was accomplished using a 61 point hanning filter on the db/dt x,y and z components;
- 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;
- Finally, line-based levelling was applied as required.

B-field Data

The data acquisition system produces 30 B-field channels each for X, Y and Z component for half sine and 20 B-field channels for square wave in real-time during flight, however these channels are only used for field QC. For delivery, mapping and generation of derived products, the final B-field channels are derived from the final levelled dB/dt data.

dB/dt Z Data

Except for extremely conductive areas, the amplitude of the dB/dt Z component increases with the conductivities of the earth. Due to the geometry of the $HELITEM_{30C}$ with MULTIPULSE™ system, the Z component response from a near vertical discrete conductor peaks at either side but nulls where the transmitter is on top of the conductor. This results an “M” shaped Z component anomaly over a vertical conductor. The amplitudes of, and the distance between the two peaks can be used to indicate the dip angle and dip direction of the conductor.

Apparent Resistivity from Z data

CGG has developed an algorithm that converts the response in any measurement window (on-time or off-time) into an apparent resistivity. This is performed using a look-up table that contains the response at a range of half-space resistivities and altimeter heights. The apparent resistivity is calculated by fitting all 50 channels (from half sine pulse and square pulse) of the Z-coil response of the dB/dt component to the homogeneous-halfspace model. The apparent resistivity provides the maximum information on the near-surface resistivity of the ground which, when combined with the magnetic signature, provides good geological mapping.

Differential Conductivity™

Differential Conductivity™ is a simple, relatively accurate conductivity section developed by CGG to be derived from airborne electromagnetic data (Huang and Fraser, 1996[1]). This type of conductivity section is fast and robust, and provides a good picture of conductivity conditions in the earth. It can be derived from both frequency[1] domain and time domain EM data.

Differential Conductivity™ is derived from a homogeneous halfspace model of the conductivity calculated for each time channel, each at an approximate depth of maximum induced current flow. The early time channel provides a measure of the shallow conductivity, and the deeper (later time) halfspace conductivities are modified using the shallow information to give a more accurate measure of the conductivity at depth. The depth of investigation for each time channel is adjusted as well.

It is very important to recognize that Differential Conductivity™ sections, like conductivity-depth images or layered-earth inversions, assume that the earth is made of uniform layers. Any feature in the earth which is not much wider than the footprint of the airborne EM system will not be properly represented (generally they are too deep) and the contrast will be reduced.

Differential Conductivity™ sections tend to smooth sharply defined layers (compared to layered-earth inversions) but provide an excellent model of the conductivity, quickly and without the complex processing necessary for inversions, and without the dependence on accurate starting models.
provide guidance and a starting model for more complex inversions.

Time Constant (TAU)

The time constant values are obtained by fitting the channel data from either the complete off-time signal of the decay transient or only a selected portion of it (as defined by specific channels) to a single exponential of the form:

$$Y = Ae^{-t/\tau}$$

where A is amplitude at time zero, t is time in microseconds and τ is the time constant, expressed in microseconds. A semi-log plot of this exponential function will be displayed as a straight line, the slope of which will reflect the rate of decay and therefore the strength of the conductivity. A slow rate of decay, reflecting a high conductivity, will be represented by a high time constant.

As a single parameter, the time constant provides more useful information than the amplitude data of any given single channel, as it indicates not only the peak position of the response but also the relative strength of the conductor. It also allows better discrimination of conductive axes within a broad formational group of conductors.

For the present dataset, three time constant channels and grids were generated for early, middle and late delay times to provide an approximation of conductor response strength and position at varying depth (where early time is the shallowest, late time the deepest). These time constant channels were calculated by fitting the response of the dB/dt Z-component to the exponential function over the following windows:

- Square Pulse Channels 2 - 4 (0.0781 – 0.1172 ms after turnoff)
- Half Sine Channels 11 - 13 (0.3564 – 0.5176 ms after turnoff)
- Half Sine Channels 14 - 19 (0.6250 – 1.5820 ms after turnoff)

Note that blank spaces in the grid products (and null values in the profile data) represent areas (generally of very high resistivity) where the algorithm is unable to fit an exponential function to the channels selected.

[1] Huang, Haoping and Fraser, Douglas, 1996, The differential parameter method for multifrequency airborne resistivity mapping, Geophysics Vol 61, No 1, January-February 1996, P 100-109.

Digital Elevation

The laser altimeter values are subtracted from the differentially corrected and de-spiked GPS-Z values to produce profiles of the height above mean sea level along the survey lines. These values are gridded to produce a surface showing approximate elevations within the survey area. Any subtle line-to-line discrepancies are manually removed.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, radar/laser altimeter and GPS-Z. 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 ±5 metre range. Further inaccuracies may be introduced during the interpolation and gridding process.

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

Appendix A Data Archive Description

Data Archive Description:

Survey Details:

Survey Area Name: Mount Lyell Mine Area
Project number: 602803
Client: Copper Mines of Tasmania PTY Ltd.
Survey Company Name: CGG
Flown Dates: December 7 to December 15, 2016
Archive Creation Date: February 2017

Geodetic Information:

Datum: WGS84
Ellipsoid: GDA 94
Projection: UTM Zone 55S
Central meridian: 147°East
False Easting: 500000 metres
False Northing: 0 metres
Scale factor: 0.9996
WGS84 to Local Conversion: Molodensky
Dx,Dy,Dz: 0, 0, 0

\Grids

Geosoft format grids and accompanying .GI files

File	Description	Units
TMI	Total Magnetic Intensity	nT
CVG	Calculated Vertical Magnetic Gradient from TMI	nT/m
DEM	Digital Elevation Model	m
Decay_Early	Decay constant square pulse Z dB/dt 0.0781-0.1172 ms after turn-off	µs
Decay_Mid	Decay constant half-sine pulse Z dB/dt 0.3564 - 0.5176 ms after turn-off	µs
Decay_Late	Decay constant half sine pulse Z dB/dt 0.6250 - 1.5820 ms after turn-off	µs
Each_Conductivity_hs_db_z[04-29]	Apparent conductivity from half-sine off-time channels	mS/m
Each_Conductivity_sq_db_z[01-20]	Apparent conductivity from square pulse off-time channels	mS/m

\Linedata

Geosoft Database Layout for file **CMT_MountLyell_archive.gdb**;

Variable	Description	Units
x	Heli/Rx Easting GDA94 Z55S	m
y	Heli/Rx Northing GDA94 Z55S	m
lon	Heli/Rx Longitude WGS84	degrees
lat	Heli/Rx Latitude WGS84	degrees
fid	fiducial	-
date	Flight date	ddmmyy
heli_alt	Height of helicopter above surface from laser and radar	m

	altimeter	
gpsz_heli	Height of heli tail above geoid	m
gpsz_tx	Tx/Rx height above geoid	m
dem	Digital elevation model (above geoid)	m
mag_raw	Total magnetic field – spike rejected	nT
mag_lag	Total magnetic field – lagged	nt
diurnal_cor	Diurnal correction – IGRF and base removed	nT
mag_lag_diu	Total magnetic intensity - corrected for lag,diurnal and heading	nT
mag_filt	Total magnetic intensity –filtered	nT
igrf	International geomagnetic reference field base corrected	nT
tmi	Total magnetic intensity – IGRF corrected and levelled	nT
emx_db_hs_post[0] – [29]	dB/dt X component half-sine channels 1 – 30 – compensated	nT/s
emy_db_hs_post[0] – [29]	dB/dt Y component half-sine channels 1 – 30 – compensated	nT/s
emz_db_hs_post[0] – [29]	dB/dt Z component half-sine channels 1 – 30 – compensated	nT/s
emx_db_hs_final[0] – [29]	dB/dt X component half-sine channels 1 – 30 - levelled	nT/s
emy_db_hs_final[0] – [29]	dB/dt Y component half-sine channels 1 – 30 - levelled	nT/s
emz_db_hs_final [0] – [29]	dB/dt Z component half-sine channels 1 – 30 - levelled	nT/s
emx_bf_hs_final [0] – [29]	B field X component half-sine channels 1 – 30 - levelled	pT
emy_bf_hs_final [0] – [29]	B field Y component half-sine channels 1 – 30 - levelled	pT
emz_bf_hs_final [0] – [29]	B field Z component half-sine channels 1 – 30 - levelled	pT
emx_db_sq_post[0] – [19]	dB/dt X component square channels 1 – 20 – compensated	nT/s
emy_db_sq_post[0] – [19]	dB/dt Y component square channels 1 – 20 – compensated	nT/s
emz_db_sq_post[0] – [19]	dB/dt Z component square channels 1 – 20 – compensated	nT/s
emx_db_sq_final[0] – [19]	dB/dt X component square channels 1 – 20 - levelled	nT/s
emy_db_sq_final[0] – [19]	dB/dt Y component square channels 1 – 20 - levelled	nT/s
emz_db_sq_final [0] – [19]	dB/dt Z component square channels 1 – 20 - levelled	nT/s
emx_bf_sq_final [0] – [19]	B field X component square channels 1 – 20 - levelled	pT
emy_bf_sq_final [0] – [19]	B field Y component square channels 1 – 20 - levelled	pT
emz_bf_sq_final [0] – [19]	B field Z component square channels 1 – 20 - levelled	pT
each_conductivity_hs_dbz	Apparent Conductivity_half-sine_dbz	mS/m
each_conductivity_sq_dbz	Apparent Conductivity_square_dbz	mS/m
dcon_hs_5mto600m	Differential Conductivity half-sine 5m slices from 0 to 600m depth	mS/m
dcon_sq_2mto300m	Differential Conductivity square 2m slices from 0 to 300m depth	mS/m
dcon_hs_5mto600m_surface	Differential Conductivity half-sine 5m slices from 0 to 600m depth extrapolated to surface assuming on-time conductivity at surface	mS/m
decay_early	Tau 0.0781-0.1172 ms after square pulse turn off	µs
decay_mid	Tau 0.3564 - 0.5176 ms after half-sine pulse turn off	µs
decay_late	Tau 0.6250 - 1.5820 ms after half-sine pulse turn off	µs
powerline	Power line monitor	µV
tx_current_hs	Transmitter peak current half sine	amp
tx_current_sq	Transmitter peak current square pulse	amp

Note – Null values are displayed as *

\Profiles\PDF

1:10,000 scale stacked multi-parameter profiles in PDF format for each survey line

\Waveform

Reference waveform files for the square and half-sine pulses. The information shown below is a sample.

```
/Calibration Data [FLT 53009 Cal# 0 Start FID 84807 End Fid 84918]
/Base Frequency : 25.00 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]
     0      -0.001     -553.810     -128.972       72.080
     1      -0.002    -1141.320     -272.953     3741.770
     2      -0.005     -858.424     -195.934    20492.264
     |               |               |               |               |
     |               |               |               |               |
     |               |               |               |               |
  2045       0.001       -3.893       -2.160        0.603
  2046       0.001       -3.893       -2.160        0.598
  2047       0.001       -3.890       -2.163        0.609
```

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.

\Report

A logistics and processing report in PDF format
R602803CMT.pdf

\Video

Digital video in BIN/BDX format for all survey flights including a viewer.

CGGSurveyReplay

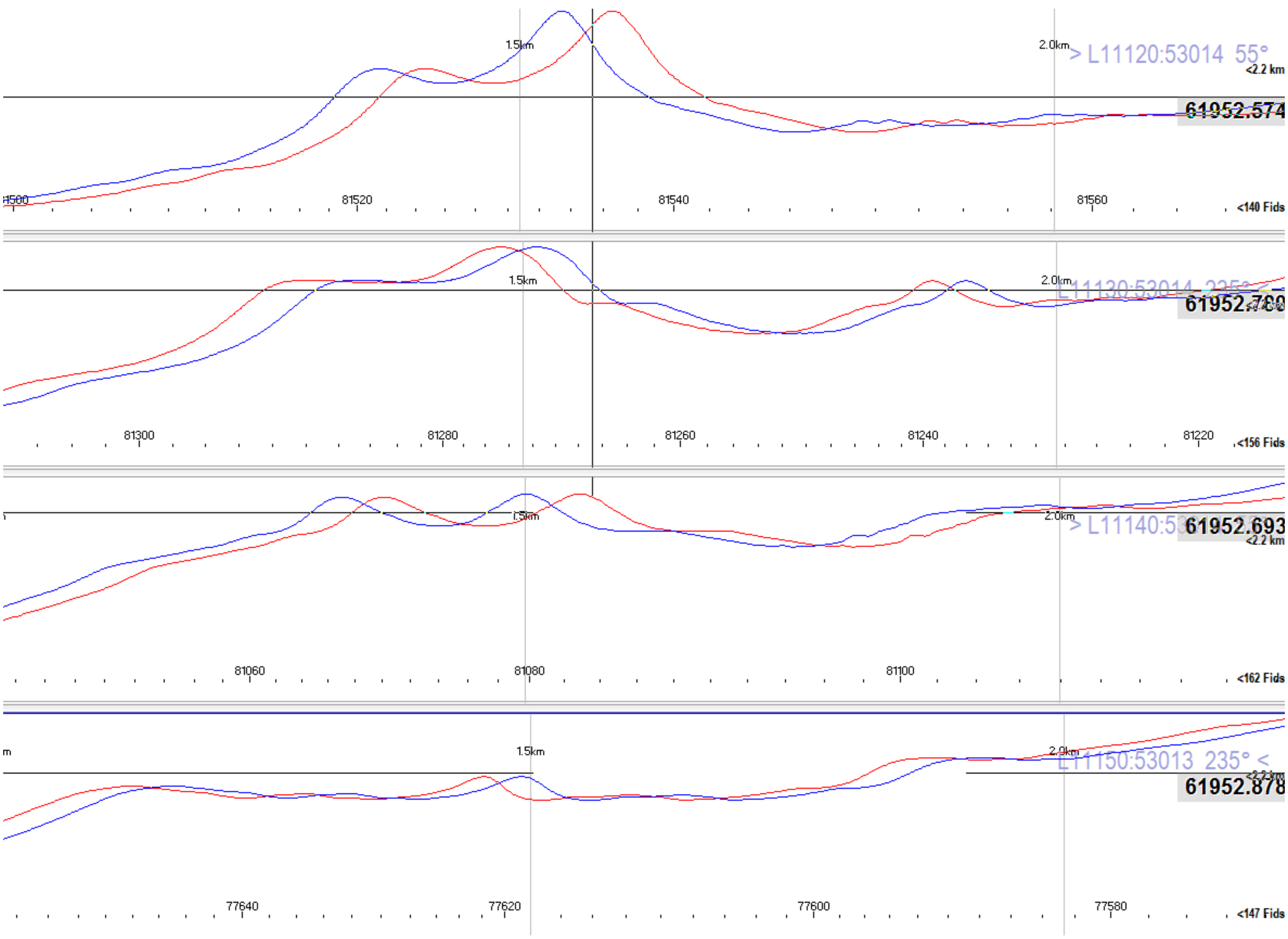
Appendix B Calibration and Tests

Magnetics Lag Test

Project Number: 602803
Date Flown:
Flight Number:

Survey Type: MULTIPULSE™ \ MAG
Aircraft Registration: VH-7HS
Location: Tasmania

Correction Lag Applied: 3.1 seconds

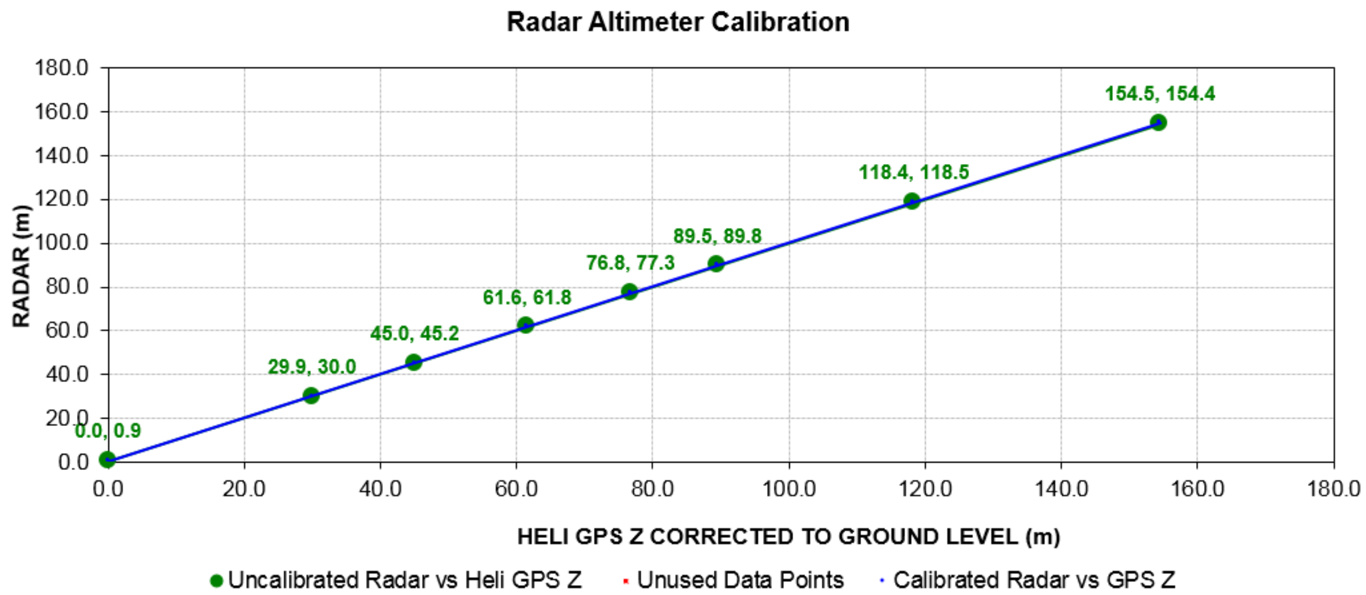


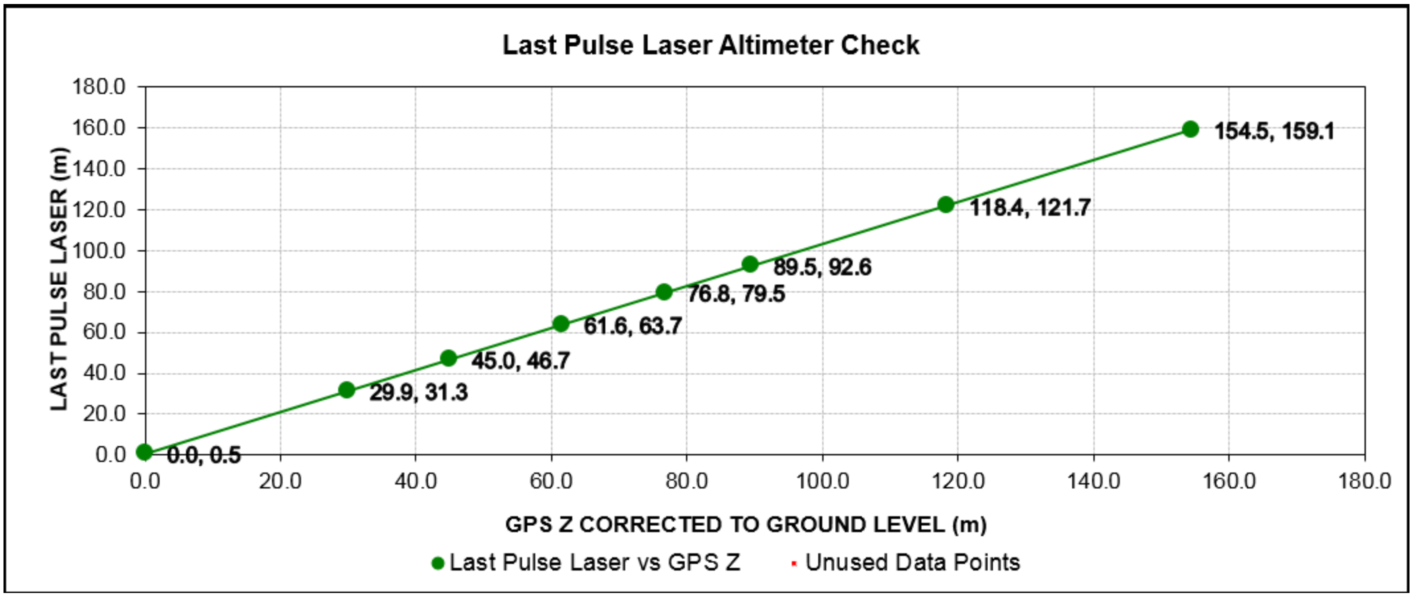
Adjacent flight lines 11120, 11130, 11140 and 11150 which were flown in alternating directions have a magnetic anomaly that crosses the lines at approximately right angles to the flight direction. The red trace shows the location of the unlagged magnetic data and the blue trace show the data after lagging has been applied. The red profiles show an offset in the location of the anomaly peak. After the 3.1 second lag is applied the resulting blue trace shows that the anomaly location is close to the same geographic location on each line.

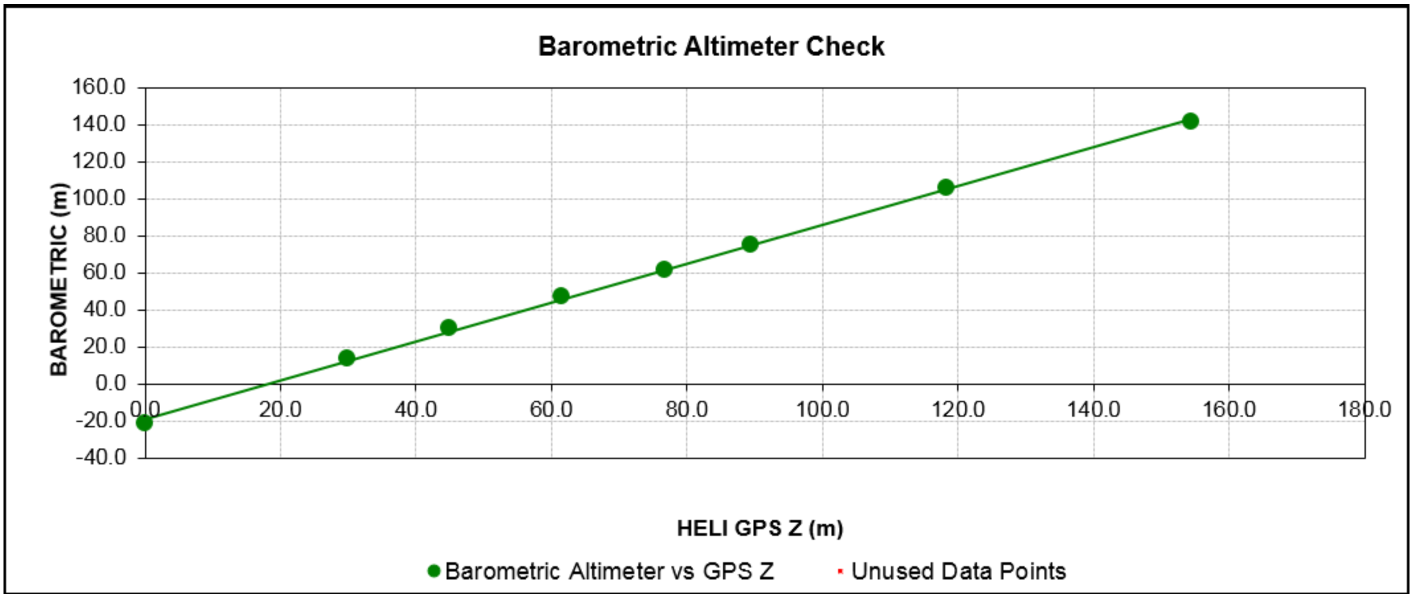
Project Number: 602803
Date:
Flight Number:

Survey Type: MULTIPULSE™ \ MAG
Aircraft Registration: VH-7HS
Location: Tasmania

LINE	TARGET RADAR (ft)	ZHG_HELI	ALTRAD_FT	ALTLASLP_M	ALTBAR_M
1	0	263.8	3.0	0.5	242.2
100	100	293.7	98.4	31.3	276.7
150	150	308.8	148.3	46.7	293.6
200	200	325.3	202.8	63.7	310.4
250	250	340.5	253.7	79.5	324.6
300	300	353.3	294.5	92.6	338.3
400	400	382.1	388.9	121.7	369.2
500	500	418.3	506.5	159.1	405.1




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
160.0
180.0
GPS Z CORRECTED TO GROUND LEVEL (m)
154.5, 159.1
118.4, 121.7
89.5, 92.6
76.8, 79.5
61.6, 63.7
45.0, 46.7
29.9, 31.3
0.0, 0.5
Last Pulse Laser vs GPS Z
Unused Data Points


Barometric Altimeter Check
BAROMETRIC (m)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
HELI GPS Z (m)
Barometric Altimeter vs GPS Z
Unused Data Points

Appendix C 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 CGG time-domain helicopter electromagnetic system (HELITEM$_{30C}$ with MULTIPULSE™) uses a high-speed digital EM receiver. The primary electromagnetic pulses are created by a series of discontinuous sinusoidal and trapezoidal current pulses fed into a transmitting loop towed below the helicopter. The base frequency rate is selectable, with 25 and 30 currently being available. The length of the pulse can be tailored to suit the targets. Standard pulse widths available are 4.0 and 6.0 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 in the centre of the transmitter loop approximately 10 cm above the plane of the transmitter loop. The tow cable is non-magnetic to reduce noise levels. Exact system specifications are documented in the system information section of this report.

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 is 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 for the half sine pulse and 20 gates for the square pulse. The gate centres and widths are software selectable and 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.

Power Line Monitor

The power line monitor gives the amplitude of the received signal at the power line frequency (50 or 60 Hz). Appropriate selection of the base frequency (such that the power line frequency is an even harmonic of the base frequency) and tapered stacking combine to strongly attenuate power line signals. When passing directly over a power line, the rapid lateral variations in the strength and direction of the magnetic fields associated with the power line can result in imperfect cancellation of the power line response during stacking. Some power line related interference can manifest itself in a form that is similar to the response of a discrete conductor. The exact form of the monitor profile over a power line depends on the flight line direction, power line direction, power line current, and receiver component, but the monitor will show a general increase in amplitude approaching the power line.

Grids (or images) of the power line monitor reveal the location of the transmission lines. Note that the X component (horizontal receiver coil axis parallel with the flight line direction) does not register any response from power lines parallel to the flight line direction since the magnetic fields associated with power lines only vary in a direction perpendicular to the power line. Note also that the Y component (horizontal receiver coil axis perpendicular to the flight line direction) is sensitive to power lines parallel to the flight direction.

Appendix D 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$_{30C}$ with MULTIPULSE™ 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 are often concentrated in shear zones and correspond generally to long, multiple conductors lying in parallel bands. They have no magnetic expression unless associated with pyrrhotite or magnetite. They are polarizable and 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 E Glossary

CGG GLOSSARY OF AIRBORNE GEOPHYSICAL TERMS

accelerometer: an instrument that measures both acceleration (due to motion) and acceleration due to ***gravity***.

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.

AGG: Airborne ***gravity gradiometer.***

AGS: Airborne ***gamma-ray spectrometry***.

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**.

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.

attitude: the orientation of a geophysical system relative to the earth. Some surveys assume the instrument attitudes are constant, and other surveys measure the attitude and correct the data for the changes in response because of attitude.

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.

base magnetometer: A stationary magnetometer used to record the ***diurnal*** variations in the earth's magnetic field; to be used to correct the survey magnetic data.

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: a procedure to ensure a geophysical instrument is measuring accurately and repeatably. Most often applied in ***EM*** and ***gamma-ray spectrometry***.

calibration coil: A wire coil of known size and dipole moment, which is used to generate a field of known ***amplitude*** and ***phase*** or ***decay constant*** 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.

continuation: mathematical procedure applied to ***potential field*** geophysical data to approximate data collected at a different altitude. Data can be continued upward to a higher altitude or downward to a lower altitude.

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, into 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.

dose rate: see **exposure rate**.

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. Sometimes called "dose rate".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.

flight: a continuous interval of survey data collection, generally between stops at base to refuel.

flight-line: a single line of data across the survey area. Surveys are generally comprised of many parallel flight lines to cover the survey area, with wider-spaced ***tie lines*** perpendicular. Flight lines are generally separated by ***turn-arounds*** when the aircraft is outside the survey area.

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 harmonic ***primary field*** that oscillates over time (e.g. 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.

GGI: gravity gradiometer instrument. An airborne gravity gradiometer (AGG) consists of a GGI mounted in an inertial platform together with a temperature control system.

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 can be 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***.

gradiometer, gradiometry: instrument and measurement of the gradient, or change in a field with location usually for ***gravity*** or ***magnetic*** surveys. Used to provide higher resolution of ***targets***, better ***interpretation*** of ***target*** geometry, independence from drift and absolute field and, for ***gravity***, accelerations of the aircraft.

gravity: Survey collecting measurements of the earth's gravitational field strength. Denser objects in the earth create stronger gravitational pull above them.

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***).

HFEM: Helicopter Frequency-domain ElectroMagnetic, This designation is used for helicopter-borne, **frequency-*domain*** electromagnetic systems. Formerly most often called HEM.

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.

lead-in: approach to a ***flight line*** outside of survey area to establish proper track and stabilize instrumentations. The lead-in for a helicopter survey is generally shorter than required for fixed-wing.

line source, or line current: a long narrow object that creates an ***anomaly*** on an ***EM*** survey. Generally man-made objects like fences, power lines, and pipelines (***culture***).

mag: common abbreviation for ***magnetic.***

magnetic: ("**mag**") a survey measuring the strength of the earth's magnetic field, to identify geology and targets by their effect on the field.

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**.

natural source: any geophysical technique for which the source of the energy is from nature, not from a man-made object. Most commonly applied to natural source ***electromagnetic*** surveys.

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***.

potential field: A field that obeys Laplace's Equation. Most commonly used to describe ***gravity*** and ***magnetic*** measurements.

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****.*

spec: common abbreviation for *gamma-ray spectrometry*.

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***.

stinger: A boom mounted on an aircraft to carry a geophysical sensor (usually ***magnetic***). The boom moves the sensor farther from the aircraft, which might otherwise be a source of ***noise*** in the survey data.

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 ***decay 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. Also called a **flight line**.

turn-arounds: The time the aircraft is turning between one ***traverse*** or ***tie line*** and the next. Turn-arounds are generally outside the survey area, and the data collected during this time generally are not useable, because of aircraft ***manoeuvre noise***.

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***.

zero, or zero level: The ***base level*** of an instrument, with no ***ground effect*** or ***drift***. Also, the act of measuring and setting the zero level.
can detect the strongest conductive target – generally a highly conductive horizontal layer.

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
Ω·m 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, common unit for measurement of B-Field in time-domain EM
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
nT/s nanoteslas/second; standard unit of measurement of secondary field dB/dt in time domain EM.
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 picoteslas: standard unit of measurement of B-Field in time-domain EM
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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