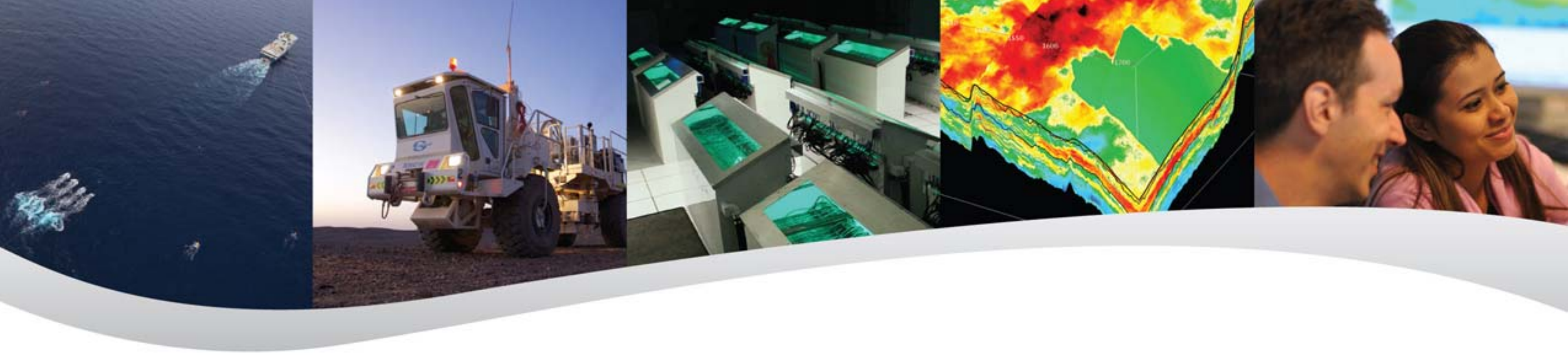


GEOPHYSICAL SURVEY REPORT

MIDAS HIGH RESOLUTION MAGNETIC AND RADIOMETRIC SURVEY

SEARCH PROJECT PHASE III

PROJECT 701503

GEOSCIENCE BC SOCIETY

January 12, 2018

Geoscience BC Report 2018-02

Disclaimer

1. The Survey that is described in this report was undertaken in accordance with current internationally accepted practices of the geophysical survey industry, and the terms and specifications of a Survey Agreement signed between the CLIENT and CGG. Under no circumstances does CGG make any warranties either expressed or implied relating to the accuracy or fitness for purpose or otherwise in relation to information and data provided in this report. The CLIENT is solely responsible for the use, interpretation, and application of all such data and information in this report and for any costs incurred and expenditures made in relation thereto. The CLIENT agrees that any use, reuse, modification, or extension of CGG's data or information in this report by the CLIENT is at the CLIENT's sole risk and without liability to CGG. Should the data and report be made available in whole or part to any third party, and such party relies thereon, that party does so wholly at its own and sole risk and CGG disclaims any liability to such party.

2. Furthermore, the Survey was performed by CGG after considering the limits of the scope of work and the time scale for the Survey.

3. The results that are presented and the interpretation of these results by CGG represent only the distribution of ground conditions and geology that are measurable with the airborne geophysical instrumentation and survey design that was used. CGG endeavours to ensure that the results and interpretation are as accurate as can be reasonably achieved through a geophysical survey and interpretation by a qualified geophysical interpreter. CGG did not perform any observations, investigations, studies or testing not specifically defined in the Agreement between the CLIENT and CGG. The CLIENT accepts that there are limitations to the accuracy of information that can be derived from a geophysical survey, including, but not limited to, similar geophysical responses from different geological conditions, variable responses from apparently similar geology, and limitations on the signal which can be detected in a background of natural and electronic noise, and geological variation. The data presented relates only to the conditions as revealed by the measurements at the sampling points, and conditions between such locations and survey lines may differ considerably. CGG is not liable for the existence of any condition, the discovery of which would require the performance of services that are not otherwise defined in the Agreement.

4. The passage of time may result in changes (whether man-made or natural) in site conditions. The results provided in this report only represent the site conditions and geology for the period that the survey was flown.

5. Where the processing and interpretation have involved CGG's interpretation or other use of any information (including, but not limited to, topographic maps, geological maps, and drill information; analysis, recommendations and conclusions) provided by the CLIENT or by third parties on behalf of the CLIENT and upon which CGG was reasonably entitled or expected to rely upon, then the Survey is limited by the accuracy of such information. Unless otherwise stated, CGG was not authorized and did not attempt to independently verify the accuracy or completeness of such information that was received from the CLIENT or third parties during the performance of the Survey. CGG is not liable for any inaccuracies (including any incompleteness) in the said information.

Introduction

This report describes the logistics, data acquisition, processing and presentation of results of a MIDAS magnetic and radiometric airborne geophysical survey carried out for Geoscience BC Society over one property near Northcentral and Northeastern British Columbia. Total coverage of the survey block amounted to 42337 km. The survey was flown between June 28 and November 5, 2017.

The purpose of the survey was to map the geology and structure of the area. Data were acquired using a MIDAS magnetic system with two high-sensitivity cesium magnetometers. The information from these sensors was processed to produce maps and images that display the magnetic properties of the survey area. A GPS electronic navigation system ensured accurate positioning of the geophysical data with respect to the base map coordinates.

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

TABLE OF CONTENTS

APPENDICES

TABLE OF TABLES

TABLE OF FIGURES

Survey Area Description

Location of the Survey Area

One block in Northcentral and Northeastern British Columbia (Figure 1) was flown between June 28 and November 5, 2017, with Kemess Camp and Osilinka Camp as the bases of operations. Survey coverage consisted of 38452 km of traverse lines flown with a spacing of 250 m and 3886 km of tie lines with a spacing of 2500 m for a total of 42707 km.

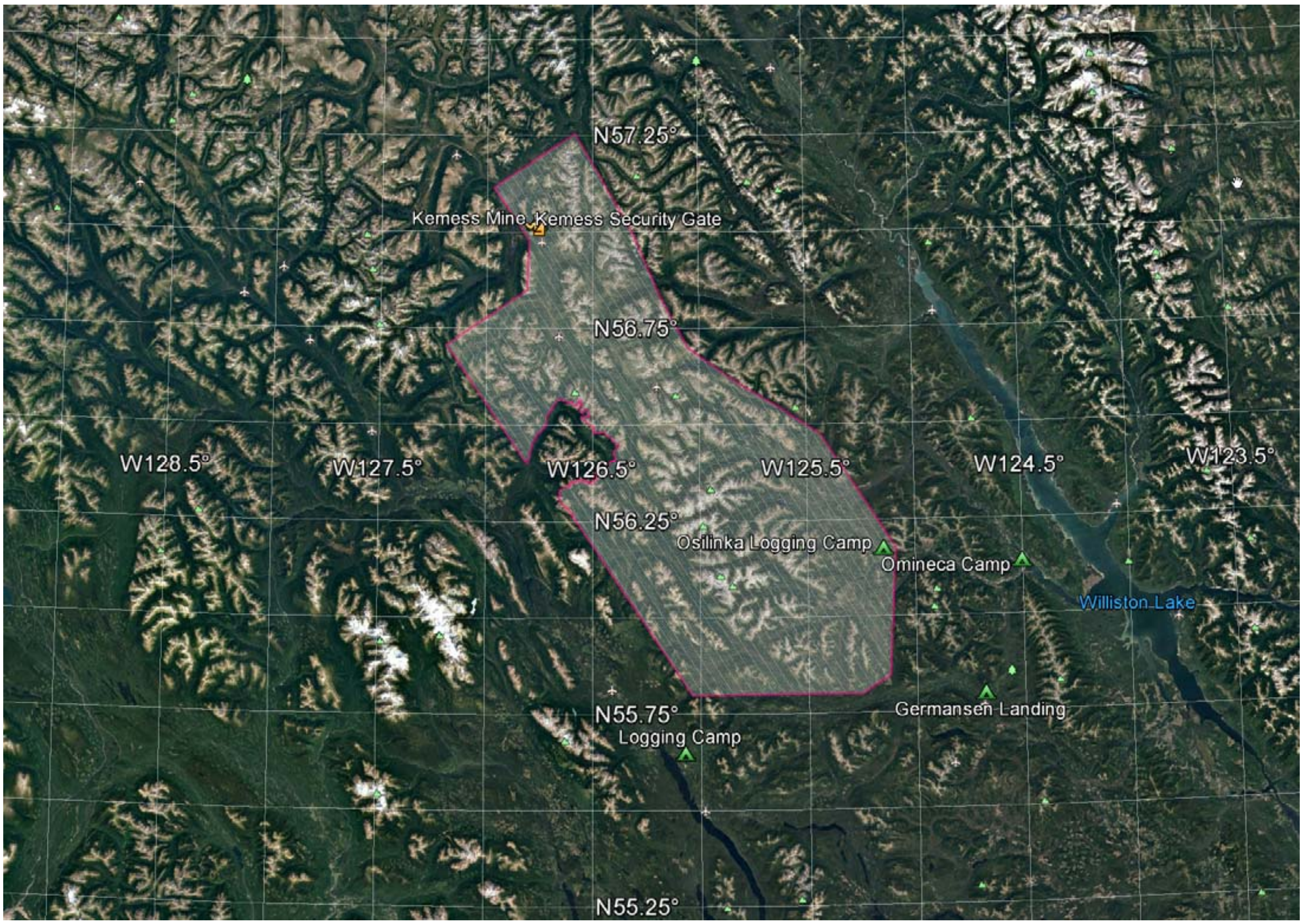


Figure 1 Search Project Phase III - Location Map

Block	Line Numbers	Line direction	Line Spacing	Line km
1	10010 - 17220	55°/235°	250 m	38452 km
Search Project Phase III	19005 - 19300	145°/325°	2500 m	3886 km

Table 1 Planned line kilometre summary

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 2.

Status	Location Name	WGS84 Longitude (deg-min-sec)	WGS84 Latitude (deg-min-sec)	Ellipsoidal Height (m)	Dates
Primary	Kemess Camp	126° 46' 35.9820" W	56° 59' 17.0203" N	1226.851	July 3 – August 14
Primary	Osilinka Camp	125° 08' 58.1838" W	56° 08' 42.2844" N	849.390	August 15 – October 14
Primary	Osilinka Camp	125° 08' 58.2262" W	56° 08' 42.2751" N	849.426	October 15 – November 5

Table 2 GPS Base Station Location

The location of the Magnetic base stations are shown in Table 3.

Status	Location Name	WGS84 Longitude (deg-min-sec)	WGS84 Latitude (deg-min-sec)	Dates
Primary	Kemess Camp	126° 46' 36.60" W	56° 59' 19.03" N	July 4 – August 3
Secondary	Kemess Camp	126° 46' 40.05" W	56° 59' 15.35" N	July 4 – August 3
Primary	Osilinka Camp	125° 09' 02.06" W	56° 08' 44.05" N	August 4 – October 14
Secondary	Johanson	126° 11' 20.15" W	56° 35' 54.29" N	August 4 – October 14
Primary	Osilinka Camp	125° 08' 58.93" W	56° 08' 43.07" N	October 15 – November 5
Secondary	Osilinka Camp	125° 08' 58.92" W	56° 08' 58.92" N	October 15 – November 5

Table 3 Magnetic Base Station Location

System Information

Figure 2 MIDAS System

The MIDAS system is composed of a horizontal boom fixed to the belly of a helicopter containing two magnetometers, a fluxgate magnetometer and a GPS antenna for flight path recovery. The helicopter has a tail boom mounted GPS antenna for in-flight navigation, radar, laser and barometric altimeters, video camera and data acquisition system.

Aircraft and Geophysical On-Board Equipment

Helicopter:	AS350 B2 and AS350 B3
Operator:	Questral Helicopters
Registration:	C-FZTA, C-FKMX and C-GJIX
Average Survey Speed:	93 km/h (26 m/s)
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:	2-Scintrex Cesium Vapour (CS-3), mounted on a transverse boom (13.3 m separation); 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
Spectrometer:	Radiation Solutions RS-500 with 16.8 L downward-looking crystals and 4.2 L upward-looking crystal Operating Range: 0 to 100,000 counts/sec Operating Limit: -20°C to 50°C Average Dead-Time: 5 µsec/pulse Sampling rate = 1.0 Hz
Fluxgate:	Billingsley TMF100 Triaxial fluxgate, mounted on one of the booms; Axial alignment: < ±1 degree Sensitivity: 100 µV per nT Sampling rate10.0 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: Optech G-150 mounted on the belly of the helicopter;

Operating Range: 0.2 to 250 m
Operating Limit: -10°C to 45°C
Accuracy:
±5 cm (10°C to 30°C)
±10 cm (-10°C to 45°C)
Measurement Precision: 1 cm
Sample Rate: 10.0 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:
1.2m CEP (L1 WAAS)
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 using Scintrex 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 Card with an Aero antenna
	Real-Time Accuracy: 1.8m CEP (L1) Sample Rate: 1.0 Hz
Secondary Magnetometer:	GEM Systems GSM-19
	Operating Range: 20,000 to 120,000 nT Operating Limit: -40°C to 60°C Accuracy: ± 0.2 nT Measurement Precision: 0.01 nT Sample Rate: 0.33 Hz

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, filtering of all geophysical and ancillary data, verification of the digital video, 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 50 m from the planned flight path over a distance of more than 1.5 kilometres. 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 which will impede the path of the helicopter to the ground and is not limited to and includes tree canopy, towers and power lines.

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

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

Helicopter	95 metres
Magnetometer	95 metres

Survey elevations did not deviate by more than ±40 m over a distance of 1 km from the contracted elevation (80m).

The achieved survey height average was impacted by steep terrain in the survey area.

Flying Speed

The average calculated ground speed was 93 km/h with a standard deviation of 36 km/h. This resulted in a ground sample interval averaging 2.6 metres at a 10 Hz sampling rate. Variance in the survey speed was due to climbing and descending over steep terrain.

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 normalized 4^{th} difference would not exceed 0.05 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 over a 3 minute linear chord, or over a 5 minute chord if the base station is more than 50 km from helicopter operations. Throughout the period of the survey the earth's magnetic activity was calm with an average non-linear variation less than 2.0 nT. 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.

Compensation System

The presence of the helicopter in close proximity to the sensors causes considerable interference on the readings. The orientation of the aircraft with respect to the sensors and the motion of the aircraft through the earth's magnetic field are contributing factors. A special calibration flight is flown to record the information necessary to remove these effects.

The manoeuvre consists of flying a series of calibration lines at high altitude to gain information in each of the required line directions. During this procedure, the pitch, roll and yaw of the aircraft are varied. Each variation is conducted in succession (first vary pitch, then roll, then yaw).

A three-axis fluxgate magnetometer measures the orientation and rates of change of the aircraft's magnetic field with respect to the earth's magnetic field. A compensation algorithm is applied to generate a set of coefficients for each line direction and for each magnetometer sensor to compensate for permanent, induced and eddy current magnetic noise generated by the aircraft.

Radiometric Data

To test the validity of the radiometric system, 5 km test lines were established near the survey area. Several lines were chosen, as the block was large and more than one base of operation was used. Data along the line was acquired at the start and end of each day at survey altitude. The data were then corrected for live time, aircraft background and cosmic radiation. The average altitude, effective height and radio-element values are calculated and tracked against the running average for the project. Deviations greater than 15% for thorium are examined for altitude deviations, atmospheric changes, and variations in moisture content.

Data Processing

Flight Path Recovery

To check the quality of the positional data the speed of the bird 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 five seconds in length. If the error is greater than five 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 NAD83 using the following parameters.

Datum:	NAD83
Ellipsoid:	GRS80
Projection:	UTM Zone 9N and 10N
Central meridian:	123°/129° West
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

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 (Figure 3).

Altitude Data

Radar altimeter data are despiked by applying a 1.5 second median and smoothed using a 1.5 second Hanning filter. The radar altimeter data are then subtracted from the GPS elevation to create a digital elevation model that is gridded and used in conjunction with profiles of the radar altimeter and flight path video to detect any spurious values.

Laser altimeter data are despiked and filtered using an alpha-trim filter. The laser altimeter data are then subtracted from the GPS elevation to create a digital elevation model that is examined in grid format for spurious values. The laser does a better job of piercing the tree canopy than the radar altimeter.

Figure 3 Flight path video

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 are interpolated to a 10 Hz sample rate and the local regional field value calculated from the average of the first day's diurnal data for each station, was removed to leave the diurnal variation. This diurnal variation is then ready to be used in the processing of the airborne magnetic data.

Total Magnetic Field

The Total Magnetic Field (TMF) data collected in flight were profiled on screen along with a fourth difference channel calculated from the TMF. Spikes were removed manually where indicated by the fourth difference. The despiked data were then corrected for lag by 1.3 seconds. The diurnal variation that was extracted from the filtered ground station data was then removed from the despiked and lagged TMF. Once, the diurnal was removed, a magnetic value for the centre of the measurement platform was calculated by taking the average of the lagged and diurnally corrected, port and starboard magnetic sensors.

Residual Magnetic Intensity

The residual magnetic intensity (RMI) was calculated from the total magnetic field, the diurnal, and the regional magnetic field. The total magnetic field was measured in the aircraft, the diurnal was measured from the ground station and the regional magnetic field was calculated from the International Geomagnetic Reference Field (IGRF 2015). The low frequency component of the diurnal was extracted from the filtered ground station data and removed from the Total magnetic filed. The RMI data were then tie line levelled and micro-levelled. The regional magnetic field, calculated for the specific survey height and time using the IGRF model, was added back to the levelled RMI to obtain the TMI.

Transverse Magnetic Gradient

Transverse magnetic gradient data was calculated from the lag corrected port and starboard sensors of the MIDAS system. The gradient was calculated with respect to the flight line direction with the median removed on a line-by-line basis. The results were then subjected to a microlevelling filter to remove any short wavelength residual line-to-line discrepancies.

Enhanced Total Magnetic Field

Bidirectional gridding with the transverse gradient should produce a surface that correctly renders both the measured data and the measured horizontal gradient at each survey line. This can be an advantage when gridding data that include features approaching the line-separation in size and also for rendering features that are not perpendicular to the line direction, particularly those which are sub-parallel to the line direction

Final transverse magnetic gradient data were used in conjunction with the Total Magnetic Field to create a Horizontal Gradient Enhanced grid of the Total Magnetic Field. This grid was created using the enhanced bi-directional gridding tool in proprietary CGG Atlas software.

Calculated Vertical Magnetic Gradient

The Enhanced Total Magnetic Field 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 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 TMF data. Regional magnetic variations and changes in lithology, however, may be better defined on the Total Magnetic Field.

Reduction to the Pole

The residual magnetic intensity was reduced to the pole using a 2-D frequency domain operator, working from the gridded values of the levelled magnetic data. The calculation was based on a magnetic declination of 18° E and a magnetic field inclination of 75° N, assuming all induced magnetization.

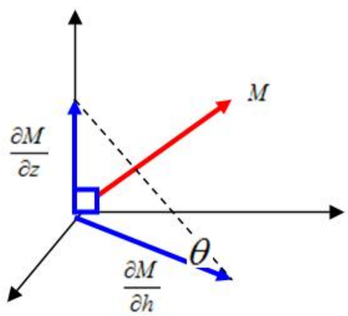
Analytic signal

Analytic signal is the total amplitude of all directions of magnetic gradient calculated from the sum of the squares of the three orthogonal gradients. Mapped highs in the calculated analytic signal of the magnetic parameter locate the anomalous source body edges and corners (e.g. contacts, fault/shear zones, etc.). Analytic signal maxima are located directly over faults and contacts, regardless of structural dip, and independently of the direction of the induced and/or remanent magnetizations.

Magnetic Tilt Derivative

The tilt derivative is calculated as the angle between the horizontal gradient and the vertical gradient, which is used in identifying the depth and type of magnetic source. The tilt angle is positive over the source, crosses through zero at, or near, the edge of a vertical sided source, and is negative outside the source zone. It responds equally well to shallow and deep sources and is able to resolve deeper sources that may be masked by larger responses from shallower sources.

- $\theta = \tan^{-1}\left[\frac{\partial M}{\partial z} / \frac{\partial M}{\partial h}\right]$; where $\frac{\partial M}{\partial h} = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2}$



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 contour maps showing approximate elevations within the survey area. Any subtle line-to-line discrepancies are manually removed. After the manual corrections are applied, the digital terrain data are filtered with a microlevelling algorithm.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, 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, <u>THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.</u>

Contour, Colour and Shadow Map Displays

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

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

Radiometrics

All radiometric data reductions performed by CGG rigorously follow the procedures described in the IAEA Technical Report[1].

All processing of radiometric data was undertaken at the natural sampling rate of the spectrometer, i.e., one second. The data were not interpolated to match the fundamental 0.1 second interval of the EM and magnetic data.

NASVD

CGG utilizes a multi-channel technique developed by Hovgaard and Gratsy to reduce statistical noise in AGS data. This method (described as *noise adjusted single valve decomposition* or “NASVD”), analyses the 256-channel survey data to identify all statistically significant spectral shapes. These “spectral components” are used to reconstruct new potassium, uranium, thorium, and total count window values, which then have significantly less noise than the original raw windows. This is particularly effective for the uranium window because of the low count rates. The spectral component method results in a more accurate measure of the ground concentration, which improves considerably the discrimination between background and anomalous ground concentrations.

Pre-filtering

Four parameters were filtered, but not returned to the database:

- Radar altimeter, pressure and temperature were smoothed with a 3-point Hanning filter
- Cosmic was smoothed with a 35-point Hanning filter

Live Time Correction

The spectrometer, an Radiation Solutions RS-500, uses the notion of "live time" to express the relative period of time the instrument was able to register new pulses per sample interval. This is the opposite of the traditional "dead time", which is an expression of the relative period of time the system was unable to register new pulses per sample interval.

The RS-500 measures the live time electronically, and outputs the value in milliseconds. The live time correction is applied to the total count, potassium, uranium, thorium, upward uranium and cosmic channels. The formula used to apply the correction is as follows:

$$C_{lt} = C_{raw} * \frac{1000.0}{L}$$

where: C_{lt} is the live time corrected channel in counts per second
C_{raw} is the raw channel data in counts per second

[1] Exploranium, I.A.E.A. Report, Airborne Gamma-Ray Spectrometer Surveying, Technical Report No. 323, 1991

L is the live time in milliseconds

Aircraft and Cosmic Background

Aircraft background and cosmic stripping corrections were applied to the total count, potassium, uranium, thorium and upward uranium channels using the following formula:

$$C_{ac} = C_{lt} - (a_c + b_c * \mathrm{Cos}_f)$$

where: C_{ac} is the background and cosmic corrected channel
C_{lt} is the live time corrected channel
a_c is the aircraft background for this channel
b_c is the cosmic stripping coefficient for this channel
Cos_f is the filtered Cosmic channel

Radon Background

The determination of calibration constants that enable the stripping of the effects of atmospheric radon from the downward-looking detectors through the use of an upward-looking detector is divided into two parts:

1. Determine the relationship between the upward- and downward-looking detector count rates for radiation originating from the ground.
2. Determine the relationship between the upward- and downward-looking detector count rates for radiation due to atmospheric radon.

The procedures to determine these calibration factors are documented in IAEA Report #323 on airborne gamma-ray surveying. The calibrations for the first part were determined as outlined in the report.

The latter case normally requires many over-water measurements where there is no contribution from the ground. Where this is not possible, it is standard procedure to establish a test line over which a series of repeat measurements are acquired. From these repeat flights, any change in the downward uranium window due to variations in radon background would be directly related to variations in the upward window and the other downward windows. In the case of this survey several locations were used due to the large survey block size and utilizing several bases of operations.

The validity of this technique rests on the assumption that the radiation from the ground is essentially constant from flight to flight. Inhomogeneities in the ground, coupled with deviations in the flight path between test runs, add to the inaccuracy of the accumulated results. Variations in flying heights and other environmental factors also contribute to the uncertainty.

The use of test lines is a common solution for a fixed-wing acquisition platform. The ability of rotary wing platforms to hover at a constant height over a fixed position eliminates a number of the variations that degrade the accuracy of the results required for this calibration.

A test site was established in or near the survey area. The tests were carried out at the start and end of each day. Data were acquired over a four-minute period at the nominal survey altitude (80 m). The data were then corrected for live time, aircraft background and cosmic activity.

Once the survey was completed, the relationships between the counts in the downward uranium window and in the other four windows due to atmospheric radon were determined using linear regression for each of the hover sites. The following equations were used:

$$u_r = a_u Ur + b_u$$
$$K_r = a_K U_r + b_K$$

$$T_r = a_T U_r + b_T$$
$$I_r = a_I U_r + b_I$$

where: u_r is the radon component in the upward uranium window
K_r, U_r, T_r and I_r are the radon components in the various windows of the downward detectors
the various "a" and "b" coefficients are the required calibration constants

In practice, only the "a" constants were used in the final processing. The "b" constants, which are normally near zero for over-water calibrations, were of no value as they reflected the local distribution of the ground concentrations measured in the five windows.

The upward uranium data for each line were copied into temporary arrays, then smoothed with a 51-point Hanning filter to produce u_f. The radon component in the downward uranium window was then determined using the following formula:

$$U_r = \frac{u_f - a_1 * U_f - a_2 * Th_f + a_2 * b_{Th} - b_u}{a_u - a_1 - a_2 * a_{Th}}$$

where: U_r is the radon component in the downward uranium window
u_f is the filtered upward uranium
U_f is the filtered uranium
Th_f is the filtered thorium
a_1, a_2, a_u and a_{Th} are proportionality factors and
b_u and b_{Th} are constants determined experimentally

The effects of radon in the downward uranium are removed by simply subtracting U_r from U_{ac}. The effects of radon in the total count, potassium, thorium and upward uranium are then removed based upon previously established relationships with U_r. The corrections are applied using the following formula:

$$C_{rc} = C_{ac} - (a_c * U_r + b_c)$$

where: C_{rc} is the radon corrected channel
C_{ac} is the background and cosmic corrected channel
U_r is the radon component in the downward uranium window
a_c is the proportionality factor and
b_c is the constant determined experimentally for this channel

Compton Stripping

Following the radon correction, the potassium, uranium and thorium are corrected for spectral overlap. First, α,β and γ the stripping ratios, are modified according to altitude. Then an adjustment factor based on a, the reversed stripping ratio, uranium into thorium, is calculated. (Note: the stripping ratio altitude correction constants are expressed in change per metre. A constant of 0.3048 is required to conform to the internal usage of height in feet):

$$\alpha_h = \alpha + h_{ef} * 0.00049$$

$$\alpha_r = \frac{1.0}{1.0 - a * \alpha_h}$$

$$\beta_h = \beta + h_{ef} * 0.00065$$

$$\gamma_h = \gamma + h_{ef} * 0.00069$$

where: α, β, γ are the Compton stripping coefficients
α_h, β_h, γ_h are the height corrected Compton stripping coefficients
h_{ef} is the height above ground in metres
α_r is the scaling factor correcting for back scatter
a is the reverse stripping ratio

The stripping corrections are then carried out using the following formulas:

$$Th_c = (Th_{rc} - a * U_{rc}) * \alpha_r$$
$$K_c = K_{rc} - \gamma_h * U_c - \beta_h * Th_c$$
$$U_c = (U_{rc} - \alpha_h * Th_{\gamma c}) * \alpha_\gamma$$

where: U_c, Th_c and K_c are corrected uranium, thorium and potassium
α_h,β_h,γ_h are the height corrected Compton stripping coefficients
U_{rc}, Th_{rc} and K_{rc} are radon-corrected uranium, thorium and potassium
α_r is the backscatter correction

Attenuation Corrections

The total count, potassium, uranium and thorium data are then corrected to a nominal survey altitude, in this case 80 m. This is done according to the equation:

$$C_a = C * e^{\mu(h_{ef} - ho)}$$

where: C_a is the output altitude corrected channel
C is the input channel
e^μ is the attenuation correction for that channel
h_{ef} is the effective altitude
h_0 is the nominal survey altitude to correct to

Conversion of Counts to Concentrations

At this point the corrections are complete. The final step is to convert the corrected total count, potassium, uranium and thorium to apparent radioelement concentrations using the following formula:

$$C = N/S$$

where: C is the concentration of element (Dose Rate nGy/h, K%, eU ppm or eTh ppm)
S is the broad source sensitivity for the window
N is the count rate for each window, after corrections

Finally, the natural air absorbed dose rate from geological sources may be calculated from the ground concentrations using the expression:

$$E = 13.10 * K + 5.67 * eU + 2.49 * eTh$$

where: E is the absorption dose rate in nGy/Hr
K is the concentration of potassium (%)
eU is the equivalent concentration of uranium (ppm)
eTh is the equivalent concentration of thorium (ppm)

Radiometric Ratios

The procedure to calculate the radiometric ratios follows the guidelines in the IAEA report. Due to statistical uncertainties in the individual radioelement measurements, some care was taken in the calculation of the ratio in order to obtain statistically significant values. Following IAEA guidelines, the method of determining ratios of the eU/eTh, eU/K and eTh/K was as follows:

1. Neglect any data points where the potassium concentration is less than 0.25%.
2. The element concentrations of adjacent points on either side of each data point, up to a maximum of 20 points, were summed until they exceeded a certain threshold value. This threshold was set to be approximately equivalent to 100 counts of each element. This ensures that noise in low concentration areas does not produce unreal and undesirable ratio results. The thresholds used were 1.2% for Potassium, 14 ppm for thorium, and 20 ppm for uranium.
3. Calculate the ratios using the accumulated sums.

With this method, the errors associated with the calculated ratios will be similar for all data points.

Radioelement Ternary Maps

The radioelement ternary map was produced by creating separate grids for each of the three radioelements and assigning a specific colour to each radioelement. Red represents potassium, green represents thorium, and blue represents uranium. The relative concentrations of the three radioelements are represented by the mixing of the three colours. For example, equal concentrations of potassium and uranium would yield a red, grading through orange, towards yellow as the relative concentration of uranium increases.

Each of the normalized radioelement concentrations and the exposure rate are then non-linearly quantized using histogram equalization. The radioelement concentrations are quantized into 49 levels, and the exposure rate into five levels. The three quantized radioelement concentrations were normalized once more by the sum of their components and assigned red (K), blue (Th) and green (U) values according to their relative amounts. The final colour intensities were then modulated by the quantized exposure rate, with five representing high intensity and one being low intensity.

The triangular icon which appears on the ternary radioelement maps shows the colours associated with each radioelement and their combinations at full intensity exposure rate. This scale is not linear, and accounts for approximately 90% of the data in the survey area. This facilitates the recognition of colours that would otherwise fall within a very small range on a linear scale diagram.

The radiometric correction parameters used for this survey are shown in Table 4.

Aircraft	C-GJIX		C-FKMX		C-FZTA	
Cosmic/Aircraft Background: TC	1.3200	16.17	1.2800	9.64	1.2654	-16.13
Cosmic/Aircraft Background : K	0.0750	6.52	0.0752	6.09	0.0800	-0.45
Cosmic/Aircraft Background : U	0.0594	-0.12	0.0578	-0.17	0.0594	-1.61
Cosmic/Aircraft Background : Th	0.0753	0.50	0.0731	-1.80	0.0643	0.23
Cosmic/Aircraft Background : UpU	0.0168	-0.13	0.0150	0.24	0.0149	-0.27
Radon Correction Parameter: TC	19.7097					
Radon Correction Parameter: K	1.3237					
Radon Correction Parameter: Th	0.1697					
Radon Correction Parameter: UpU	0.2125					
Radon Correction Skyshine Parameter: A1	0.03755					
Radon Correction Skyshine Parameter: A2	0.01306					
Compton Stripping: Alpha	0.277		0.277		0.285	
Compton Stripping: Beta	0.420		0.420		0.432	
Compton Stripping: Gamma	0.773		0.773		0.765	
Compton Stripping: AlphaPerMetre	0.00049		0.00049		0.00049	
Compton Stripping: BetaPerMetre	0.00065		0.00065		0.00065	
Compton Stripping: GammaPerMetre	0.00069		0.00069		0.00069	
Compton Stripping: GrastyBackscatter_a	0.045		0.045		0.041	
Compton Stripping: GrastyBackscatter_b	0.000		0.000		0.001	
Compton Stripping: GrastyBackscatter_g	0.000		0.000		0.002	
Altitude Attenuation: TC	-0.00801		-0.00482		-0.00579	
Altitude Attenuation: K	-0.01034		-0.00633		-0.00598	
Altitude Attenuation: U	-0.00664		-0.00202		-0.00447	
Altitude Attenuation: Th	-0.00680		-0.00662		-0.01061	
Concentration: K	81.1					
Concentration: U	8.0					
Concentration: Th	4.9					
Air Absorbed Dose Rate	25.42					

Table 4 Radiometric parameters

Final Products

This section lists the final maps and products that have been provided under the terms of the survey agreement. Other products can be prepared from the existing dataset, if requested. Most parameters can be displayed as contours, profiles, or in colour.

Maps

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

Projection Description:

Datum:	NAD83
Ellipsoid:	GRS80
Projection:	UTM Zone 9N and 10N
Central meridian:	123°/129° West
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

Maps depicting the survey results have been plotted and provided as a PDF at a scale of 1:250,000 and 1:100 000 as listed in Table 5. Each parameter is plotted on one map sheet.

Final Map Products	No. of Map Sets Plotted
Geoscience BC Map 2018-02-1#_rmi	2
Geoscience BC Map 2018-02-2#_1VD_rmi	2
Geoscience BC Map 2018-02-3#_dem	2
Geoscience BC Map 2018-02-4#_doseRate	2
Geoscience BC Map 2018-02-5#_ternary	2

Table 5 Final Map Products

Note – The # values are 0 for 1:250 000 scale maps and 1, 2, 3, 4 and 5 are respectively for the five map sheets for the 1:100 000 scale maps.

Digital Archives

Line and grid data in the form of a Geosoft database (*.gdb), XYZ files, Geosoft grids (*.grd), PDF maps and PNG/GeoTIFF's have been written to DVD. The formats and layouts of these archives are further described in Appendix B (Data Archive Description).

Report

Two paper copies of this Geophysical Survey Report plus a digital copy in PDF format.

Flight Path Videos

All survey flights in BIN/BDX format with a viewer.

CONCLUSIONS AND RECOMMENDATIONS

This report provides a very brief description of the survey results and describes the equipment, data processing procedures and logistics of the airborne survey over the Search Project Phase III, near Northcentral and Northeastern British Columbia. The various maps included with this report display the magnetic and radiometric properties of the survey area.

Since the project was flown late in the season, the contract specified to continue flying if conditions were not ideal for radiometric data collections. As a result some of the later flights were carried out with significant snowfall accumulation on the ground. This has impacted the quality of the radiometric products and is seen as striping on grids.

It is recommended that the survey results be assessed and fully evaluated in conjunction with all other available geophysical, geological and geochemical information. In particular, structural analysis of the data should be undertaken and areas of interest should be selected. An attempt should be made to determine the geophysical "signatures" over any known zones of mineralization in the survey areas or their vicinity.

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

Respectfully submitted,

CGG

R701503

Appendix A List of Personnel

List of Personnel:

The following personnel were involved in the acquisition, processing, interpretation and presentation of data, relating to a MIDAS magnetic airborne geophysical survey carried out for Geoscience BC Society over the Search Project Phase III block in Northcentral and Northeastern British Columbia.

David Grenier	Project Manager
Chris Sawyer	Flight Planner
Al Sweet	Electronics Technician
Lucas Charbonneau	Electronics Technician/Crew Leader
Jeff Macarthur	Pilot (Questral Helicopters)
Mike Thornton	Pilot (Questral Helicopters)
Greg Charbonneau	Pilot (Questral Helicopters)
Shawn Corman	Pilot (Questral Helicopters)
Yuri Mironenko	Data Processor/Crew Leader
Amir Soltanzadeh	Data Processor
Mihai Szentesy	Data Processor
Ron Wiseman	Data Processor

All personnel were employees of CGG, except where indicated.

Appendix B Data Archive Description

Data Archive Description:

Survey Details:

Survey Area Name:	Search Project Phase III
Project number:	701503
Client:	Geoscience BC Society
Survey Company Name:	CGG
Flown Dates:	June 28 to November 5, 2017
Archive Creation Date:	December 12, 2017

Geodetic Information for map products:

Datum:	NAD83
Ellipsoid:	GRS80
Projection:	UTM Zone 9N and 10N
Central meridian:	123°/129° West
False Easting:	500000 metres
False Northing:	0 metres
Scale factor:	0.9996
WGS84 to Local Conversion:	Molodensky
Dx,Dy,Dz:	0, 0, 0

Grid Archive:

Geosoft Grids:

File	Description	Units
dem	Digital elevation model	m
mag_tmi	Total Magnetic Field	nT
mag_tmi_1VD	Calculated Vertical Magnetic Gradient	nT/m
mag_rmi	Residual Magnetic Field	nT
mag_rmi_1vd	Calculated Vertical Magnetic Gradient	nT/m
mag_tmi_hg_xl	Measured Transverse Magnetic Gradient	nT/m
magge_tmi_hg	Transverse Horizontal Magnetic Gradient based on Horizontal Gradient Enhanced TMI	nT/m
magge_tmi	Horizontal Gradient Enhanced Total Magnetic Field	nT
magge_tmi_1vd	Calculated Vertical Gradient of Horizontal Gradient Enhanced Total Magnetic Field	nT/m
magge_rmi	Horizontal Gradient Enhanced Residual Magnetic Field	nT
magge_rmi_1vd	Calculated Vertical Gradient of Horizontal Gradient Enhanced Residual Magnetic Field	nT/m
magge_rmi_gsc	Horizontal Gradient Enhanced Residual Magnetic Field, Leveled to GSC data	nT
magge_rmi_asig	Analytic signal of Horizontal Gradient Enhanced Residual Magnetic Field	nT
magge_rmi_rtp	Horizontal Gradient Enhanced Residual Magnetic Field, Reduced to Pole	nT
magge_rmi_rtp_tilt	Tilt Derivative of Horizontal Gradient Enhanced Residual Magnetic Field, Reduced to Pole	-
doserate	Air absorbed dose rate	nGy/h
k_concentration	Potassium concentration	%
u_concentration	Equivalent uranium concentration	ppm
th_concentration	Equivalent thorium concentration	ppm

th_over_k	Ratio of eTh/K	ppm/%
u_over_k	Ratio of eU/K	ppm/%
u_over_th	Ratio of eU/eTh	-

GEOTIFF/PNG:

File	Description	Units
dem	Digital elevation model	m
mag_tmi	Total Magnetic Field	nT
mag_tmi_1VD	Calculated Vertical Magnetic Gradient	nT/m
mag_rmi	Residual Magnetic Field	nT
mag_rmi_1vd	Calculated Vertical Magnetic Gradient	nT/m
mag_tmi_hg_xl	Measured Transverse Magnetic Gradient	nT/m
magge_tmi_hg	Transverse Horizontal Magnetic Gradient based on Horizontal Gradient Enhanced TMI	nT/m
magge_tmi	Horizontal Gradient Enhanced Total Magnetic Field	nT
magge_tmi_1vd	Calculated Vertical Gradient of Horizontal Gradient Enhanced Total Magnetic Field	nT/m
magge_rmi	Horizontal Gradient Enhanced Residual Magnetic Field	nT
magge_rmi_1vd	Calculated Vertical Gradient of Horizontal Gradient Enhanced Residual Magnetic Field	nT/m
magge_rmi_gsc	Horizontal Gradient Enhanced Residual Magnetic Field, Leveled to GSC data	nT
magge_rmi_asig	Analytic signal of Horizontal Gradient Enhanced Residual Magnetic Field	nT
magge_rmi_rtp	Horizontal Gradient Enhanced Residual Magnetic Field, Reduced to Pole	nT
magge_rmi_rtp_tilt	Tilt Derivative of Horizontal Gradient Enhanced Residual Magnetic Field, Reduced to Pole	-
doserate	Air absorbed dose rate	nGy/h
k_concentration	Potassium concentration	%
u_concentration	Equivalent uranium concentration	ppm
th_concentration	Equivalent thorium concentration	ppm
th_over_k	Ratio of eTh/K	ppm/%
u_over_k	Ratio of eU/K	ppm/%
u_over_th	Ratio of eU/eTh	-
ternary	Radiometric ternary image	-

SHAPE FILES:

Flight path was delivered as shape files projected in NAD83 zones UTM 9 and UTM 10.

Linedata Archive:

Geosoft Magnetic Database Layout:

Variable	Description	Units
line	Line Number	-
flight	Flight Number	-
date	Date of Survey Flight	yyyymmdd
fiducial	HELIDAS Fiducial Counter	sec
time	Universal Time (Seconds Since Midnight)	sec
lat_wgs84	Latitude WGS84	degrees
long_wgs84	Longitude WGS84	degrees
x_wgs84_9n	Easting WGS84 UTM Zone 9N	m
y_wgs84_9n	Northing WGS84 UTM Zone 9N	m
x_nad83_9n	Easting NAD83 UTM Zone 9N	m
y_nad83_9n	Northing NAD83 UTM Zone 9N	m
x_nad83_10n	Easting NAD83 UTM Zone 10N	m
y_nad83_10n	Northing NAD83 UTM Zone 10N	m
gpsz	GPS Elevation (Referenced to Mean Sea Level)	m
altrad_heli	Helicopter height above surface from radar altimeter	m
altlas_heli	Helicopter height above surface from laser altimeter	m
dem	Terrain (Referenced to Mean Sea Level)	m
diurnal	Magnetic Ground Base Station	m
diurnal_cor	Magnetic Ground Base Station (Base Removed)	nT
fx	Fluxgate X Component	nT
fy	Fluxgate Y Component	nT
fz	Fluxgate Z Component	nT
mag_ave_diu	Total Magnetic Field (Average of Port and Starboard, Diurnal Removed)	nT
mag_tie	Residual Magnetic Intensity (IGRF Removed and Tie Line Levelled)	nT
mag_tmi	Total Magnetic Intensity (Levelled)	nT
igrf	International Geomagnetic Reference Field	nT
mag_rmi	Residual Magnetic Intensity (Levelled)	nT
magport_raw	Total Magnetic Intensity (Uncompensated) from Port Sensor	nT
magport_comp	Total Magnetic Intensity (Compensated) from Port Sensor	nT
magport_lag	Total Magnetic Intensity (Lagged) from Port Sensor	nT
magport_diu	Total Magnetic Intensity (Diurnal Removed) from Port Sensor	nT
magport_diu_4th	Normalized Fourth Difference of Total Magnetic Intensity (Diurnal Removed) from Port Sensor	nT
magstar_raw	Total Magnetic Intensity (Uncompensated) from Starboard Sensor	nT
magstar_comp	Total Magnetic Intensity (Compensated) from Starboard Sensor	nT
magstar_lag	Total Magnetic Intensity (Lagged) from Starboard Sensor	nT
magstar_diu	Total Magnetic Intensity (Diurnal Removed) from Starboard Sensor	nT
magstar_diu_4th	Normalized Fourth Difference of Total Magnetic Intensity (Diurnal Removed) from Starboard Sensor	nT
transgrad	Measured Lateral Horizontal Magnetic Gradient (Levelled)	nT/m

Geosoft Radiometric Database Layout:

Variable	Description	Units
line	Line Number	-
flight	Flight Number	-
date	Date of Survey Flight	yyyymmdd
fiducial	HELIDAS Fiducial Counter	sec
time	Universal Time (Seconds Since Midnight)	sec
lat_wgs84	Latitude WGS84	degrees
long_wgs84	Longitude WGS84	degrees
x_nad83_9n	Easting NAD83 UTM Zone 9N	m
y_nad83_9n	Northing NAD83 UTM Zone 9N	m
x_nad83_10n	Easting NAD83 UTM Zone 10N	m
y_nad83_10n	Northing NAD83 UTM Zone 10N	m
gpsz	GPS Elevation (Referenced to Mean Sea Level)	m
altrad_heli	Helicopter height above surface from radar altimeter	m
altlas_heli	Helicopter height above surface from laser altimeter	m
dem	Terrain (Referenced to Mean Sea Level)	m
effectiveheight	Effective Height	m
tc_raw	Total Count Raw	cps
k_raw	Potassium Count Raw	cps
u_raw	Uranium Count Raw	cps
th_raw	Thorium Count Raw	cps
u_up_raw	Upward Uranium Count Raw	cps
cosmic	Cosmic Count Raw	cps
livetime	Spectrometer Live Time	ms
radon	Radon Contribution in the Uranium Window	cps
altbaro_heli	Helicopter Barometric Altitude	m
temp	Air Temperature	degrees Celsius
u_concentration	Equivalent Uranium Concentration	ppm
th_concentration	Equivalent Thorium Concentration	ppm
k_concentration	Percent Potassium	%
doserate	Total Count Air Absorbed Dose Rate	nGy/h
ratio_u_th	Equivalent Uranium over Equivalent Thorium	
ratio_u_k	Equivalent Uranium over Percent Potassium	ppm/%
ratio_th_k	Equivalent Thorium over Percent Potassium	ppm/%

Note – The null values in the GDB and XYZ archives are displayed as *.

Maps:

PDF files of final maps at a scale of 1:250 000 and 1:100 000. The 1:250 000 maps cover the entire survey block, while the 1:100 000 splits the survey into five sheets.

File	Description	Units
Geoscience BC Map 2018-02-1#_rmi	Residual Magnetic Field	nT
Geoscience BC Map 2018-02-2#_1VD_rmi	Calculated Magnetic Vertical Gradient	nT/m
Geoscience BC Map 2018-02-3#_dem	Terrain (Referenced to Mean Sea Level)	m
Geoscience BC Map 2018-02-4#_doseRate	Air absorbed dose rate	nGy/h
Geoscience BC Map 2018-02-5#_ternary	Ternary image of K-eTh-eU radioelements	-

Note – The # values are 0 for 1:250 000 scale maps and 1, 2, 3, 4 and 5 are respectively for the five map sheets for the 1:100 000 scale maps.

Report:

A logistics and processing report for Project #701503 in PDF format:

R701503.pdf

Video:

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

CGGSurveyReplay

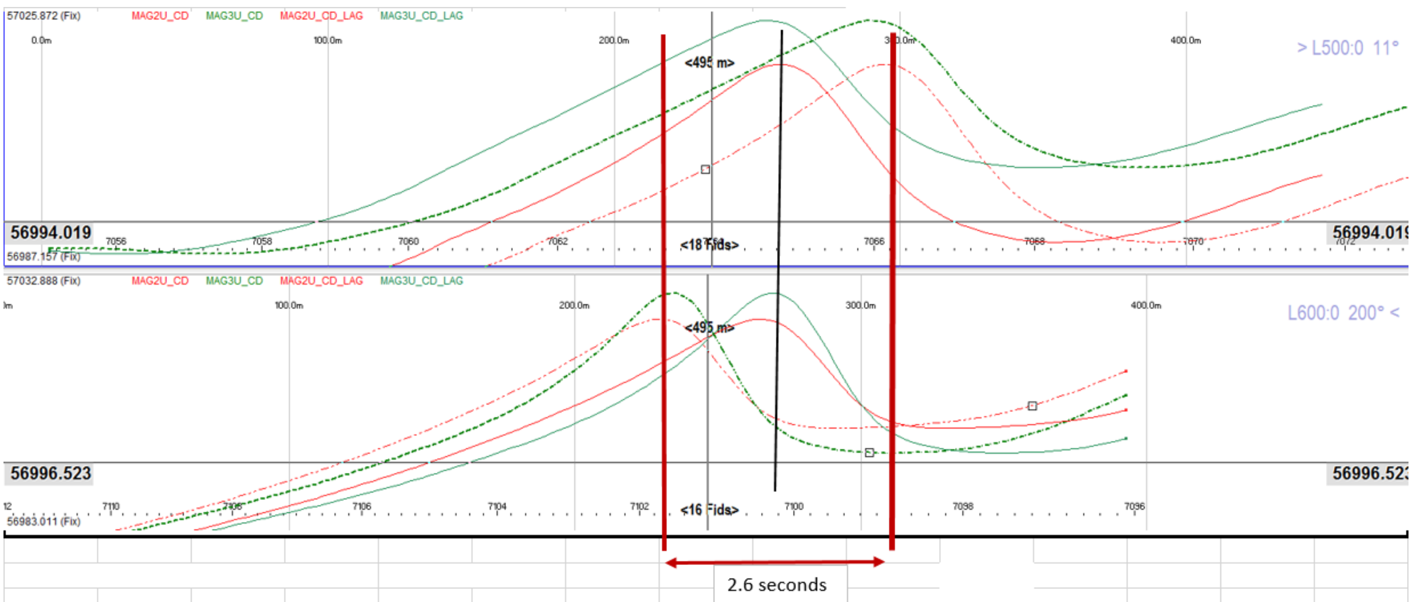
Appendix C Calibration and Tests

Magnetics Lag Test

Project Number: 701503
Date Flown: July 6
Flight Number: 55030

Survey Type: MIDAS
Aircraft: C-FZTA
Location: BC

Correction Lag Applied: 1.3 seconds

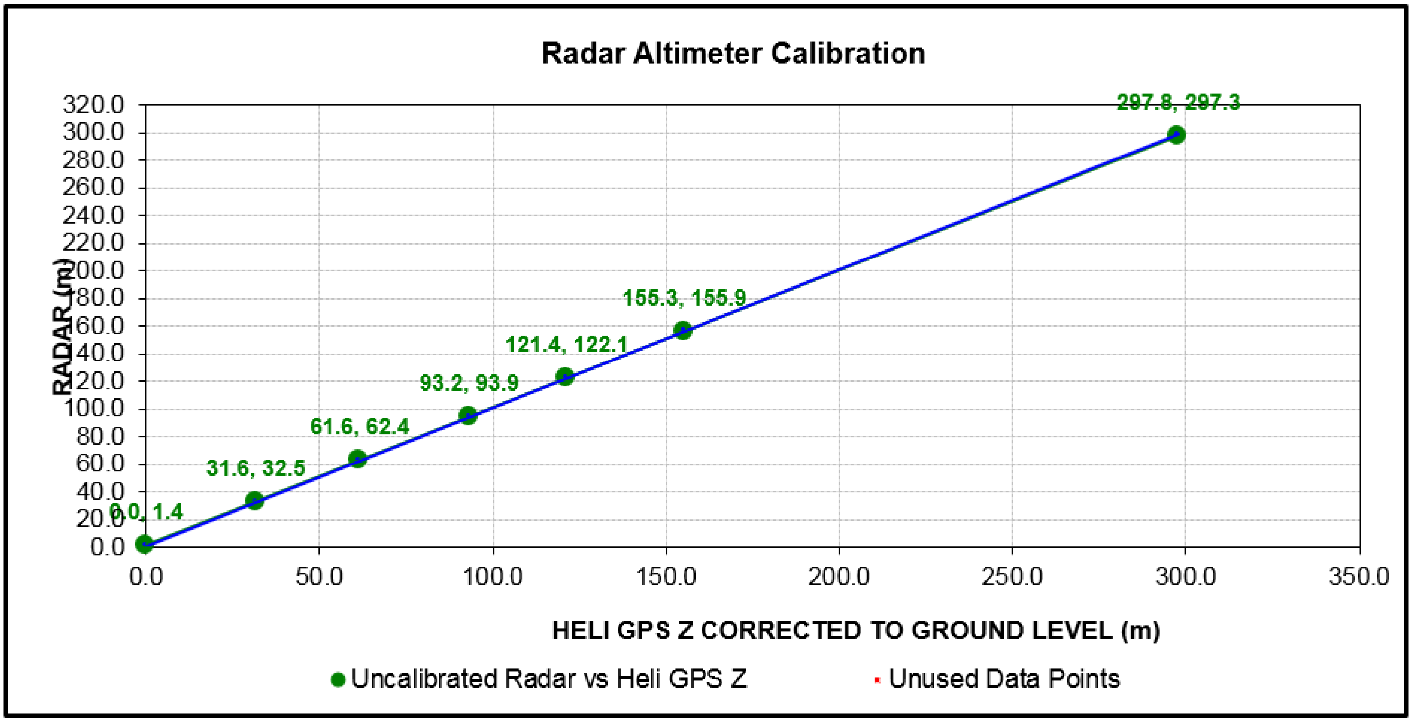


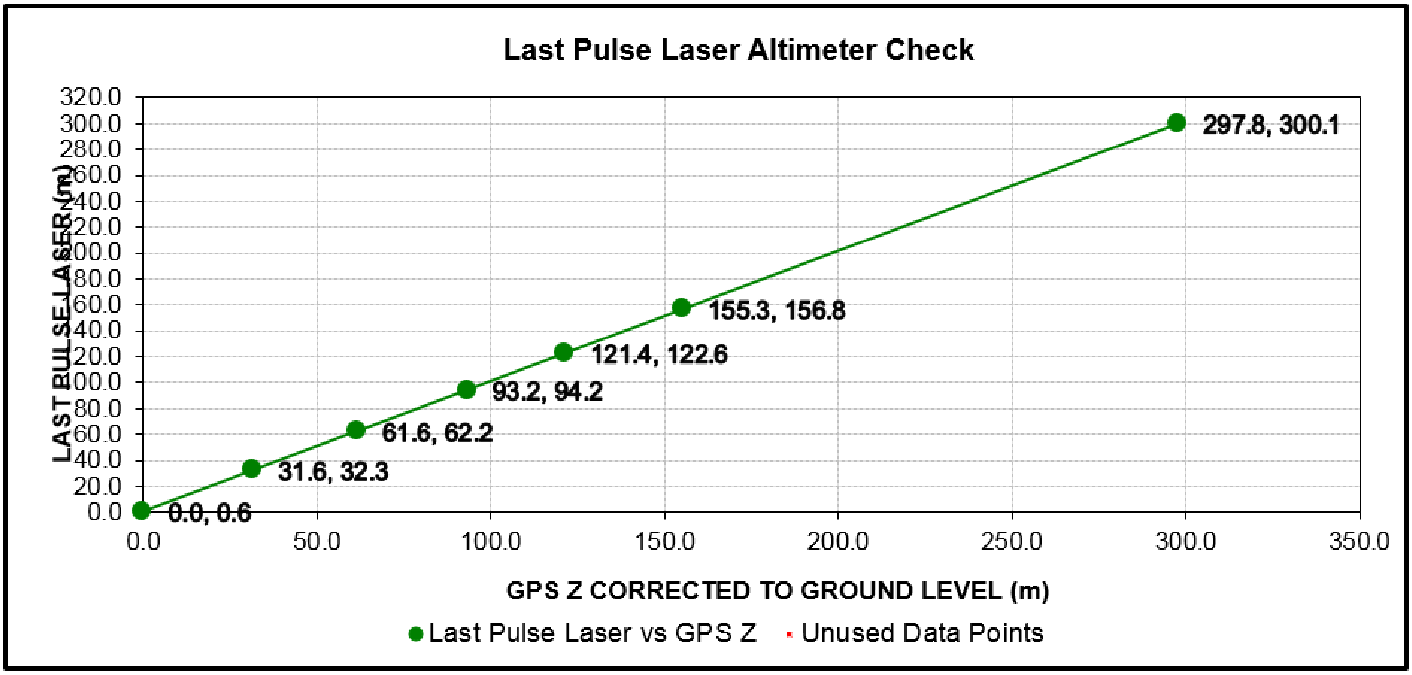
ALTIMETER CALIBRATION

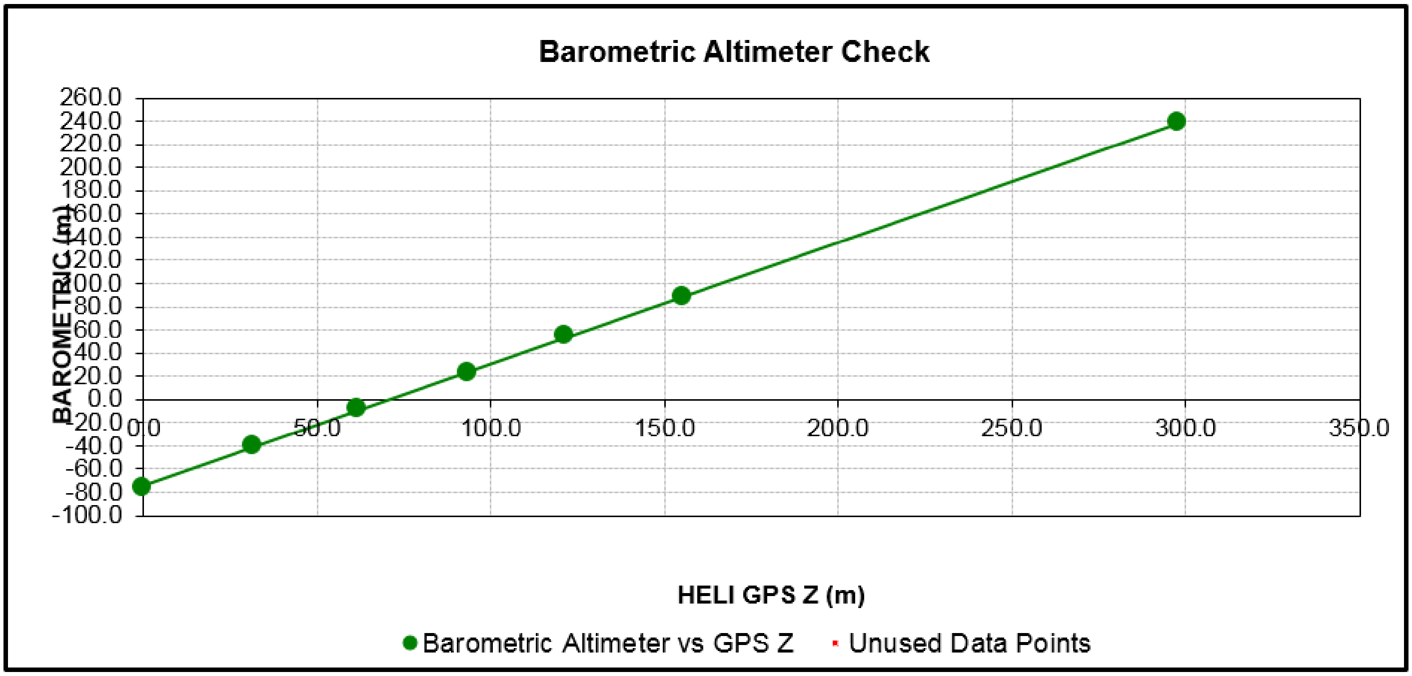
Project Number: 701503
Date Flown: July 19
Flight Number: 0007

Survey Type: Midas
Aircraft: C-GJIX
Location: BC

LINE	TARGET RADAR (ft)	ZHG_HELI	ZHG_BIRD	ALTRAD_F	ALTLASLP_M	ALTBAR_M
L1:0	0	1289.8	N/A	4.7	0.6	1213.3
L100:0	100	1321.4	N/A	106.7	32.3	1249.0
L200:0	200	1351.4	N/A	204.6	62.2	1281.4
L300:0	300	1383.0	N/A	308.0	94.2	1311.9
L400:0	400	1411.2	N/A	400.5	122.6	1344.7
L500:0	500	1445.0	N/A	511.4	156.8	1377.6
L1000:0	1000	1587.6	N/A	975.2	300.1	1528.0




Last Pulse Laser Altimeter Check
LAST PULSE LASER (m)
GPS Z CORRECTED TO GROUND LEVEL (m)
0.0, 0.6
31.6, 32.3
61.6, 62.2
93.2, 94.2
121.4, 122.6
155.3, 156.8
297.8, 300.1
Last Pulse Laser vs GPS Z
Unused Data Points

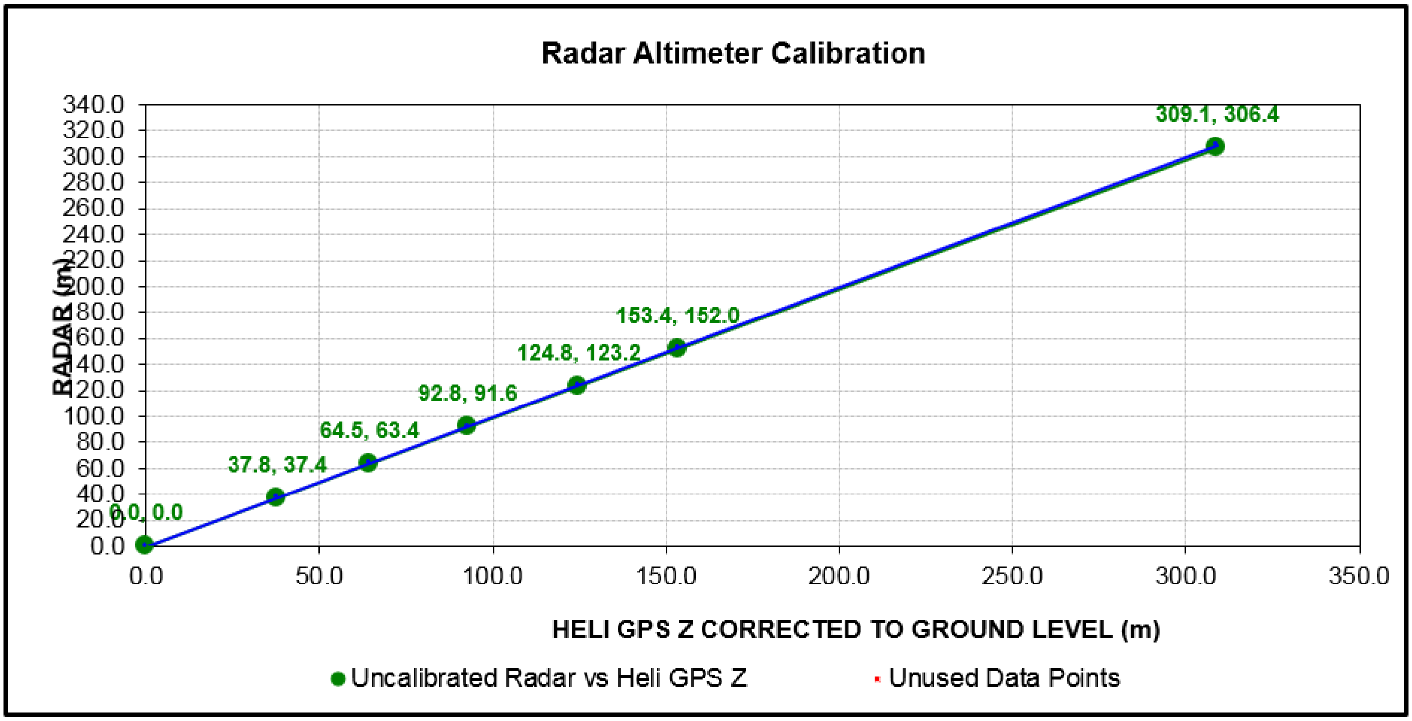

Barometric Altimeter Check
BAROMETRIC (m)
HELI GPS Z (m)
Barometric Altimeter vs GPS Z
Unused Data Points

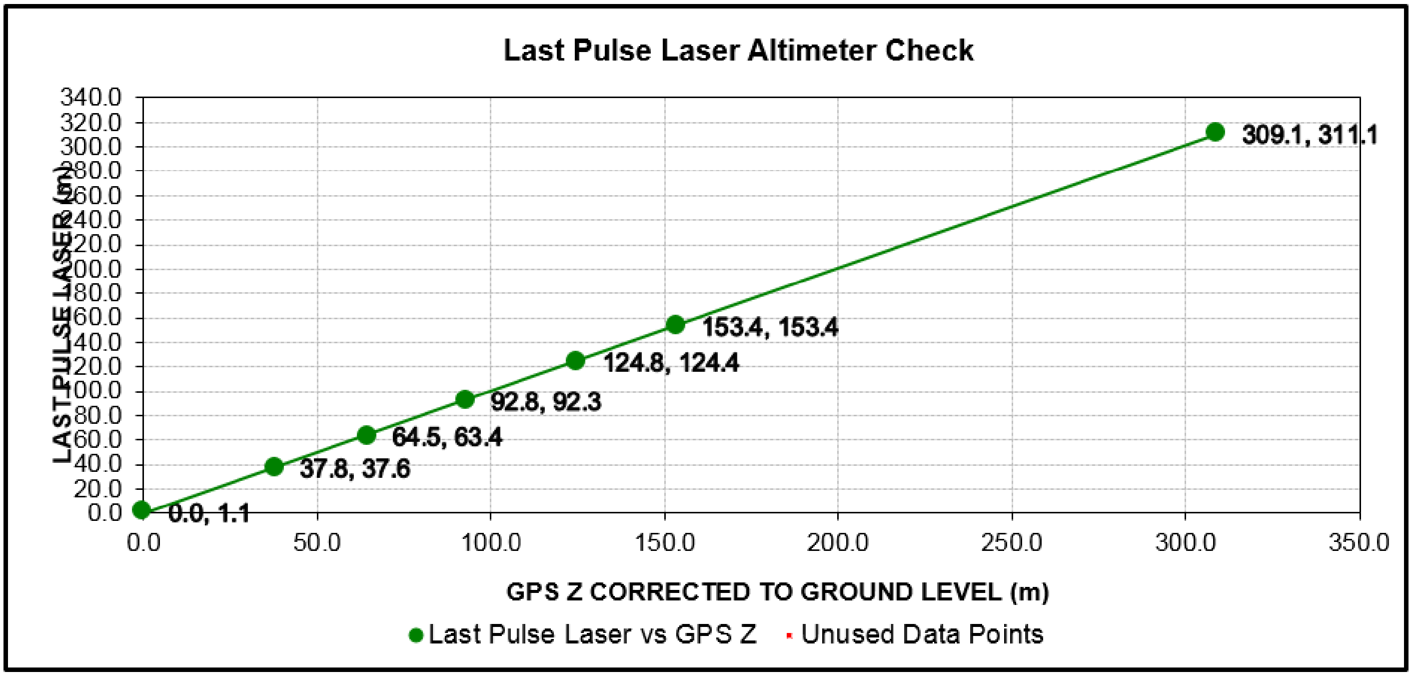
ALTIMETER CALIBRATION

Project Number: 701503
Date Flown: July 6
Flight Number: 0025

Survey Type: Midas
Aircraft: C-FZTA
Location: BC

LINE	TARGET RADAR (ft)	ZHG_HELI	ZHG_BIRD	ALTRAD_F	ALTLASLP_M	ALTBAR_M
L1:0	0	1288.0	N/A	0.0	1.1	1206.2
L100:0	100	1325.8	N/A	122.8	37.6	1247.9
L200:0	200	1352.4	N/A	207.9	63.4	1278.5
L300:0	300	1380.8	N/A	300.5	92.3	1303.6
L400:0	400	1412.8	N/A	404.3	124.4	1339.5
L500:0	500	1441.4	N/A	498.6	153.4	1364.3
L1000:0	1000	1597.0	N/A	1005.2	311.1	1525.5




Last Pulse Laser Altimeter Check
LAST PULSE LASER (m)
GPS Z CORRECTED TO GROUND LEVEL (m)
0.0, 1.1
37.8, 37.6
64.5, 63.4
92.8, 92.3
124.8, 124.4
153.4, 153.4
309.1, 311.1
Last Pulse Laser vs GPS Z
Unused Data Points

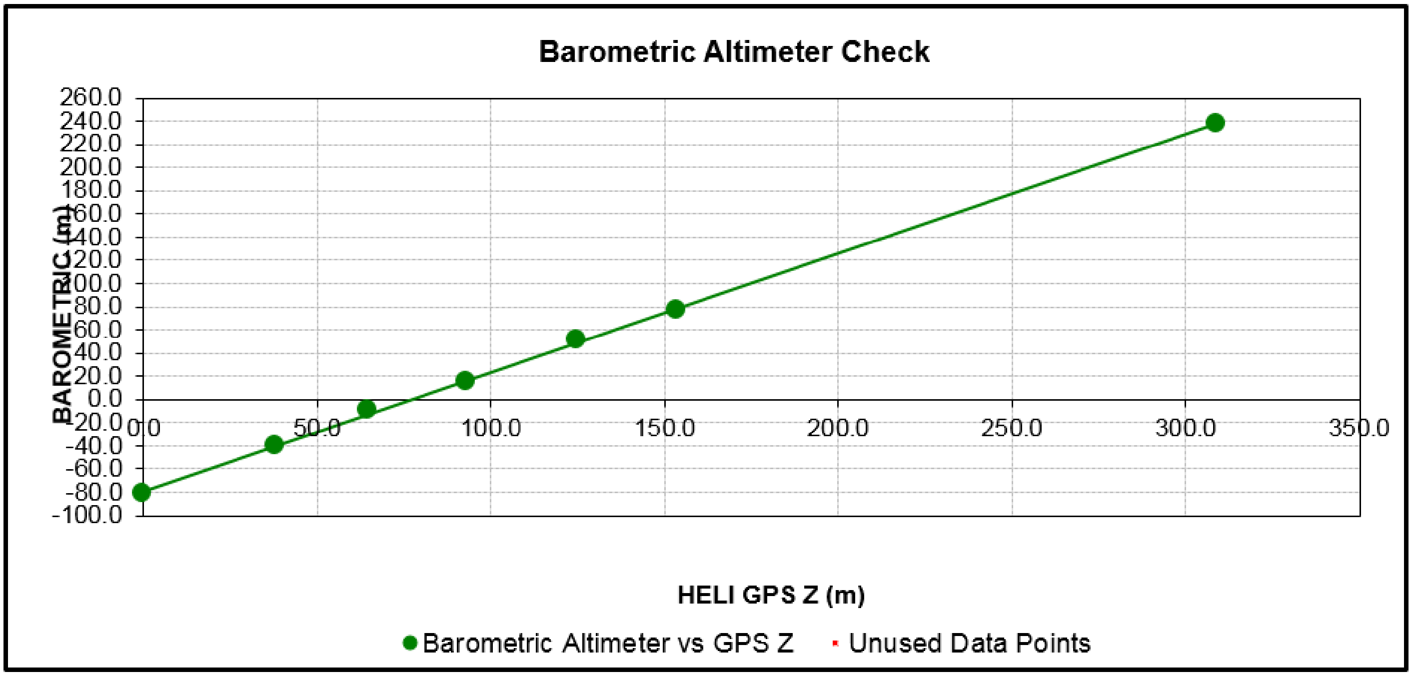

Barometric Altimeter Check
BAROMETRIC (m)
HELI GPS Z (m)
Barometric Altimeter vs GPS Z
Unused Data Points

Figure of Merit

Project Number:	**701503**	**Survey Type:**	**Midas**
Date Flown:	**July 1**	**Aircraft Registration:**	**C-FZTA**
Flight Number:	**55018**	**Location:**	BC

FOM BOX	Sensor Position: Port		Pitch	Roll	Yaw	Total	Figure of Merit
	Raw Mag Channel: MAG2		Residual Peak to Peak	Residual Peak to Peak	Residual Peak to Peak		
	Line Number	Heading					
Direction 1:	L2100	350	0.044	0.055	0.035	0.133	**0.517**
Direction 2:	L2200	62	0.046	0.059	0.030	0.135	
Direction 3:	L2300	150	0.045	0.037	0.040	0.123	
Direction 4:	L2400	240	0.038	0.041	0.047	0.126	

FOM BOX	Sensor Position: Starboard		Pitch	Roll	Yaw	Total	Figure of Merit
	Raw Mag Channel: MAG3		Residual Peak to Peak	Residual Peak to Peak	Residual Peak to Peak		
	Line Number	Heading					
Direction 1:	L2100	350	0.044	0.113	0.032	0.190	**0.653**
Direction 2:	L2200	62	0.046	0.059	0.028	0.133	
Direction 3:	L2300	150	0.045	0.042	0.040	0.127	
Direction 4:	L2400	240	0.038	0.120	0.046	0.203	

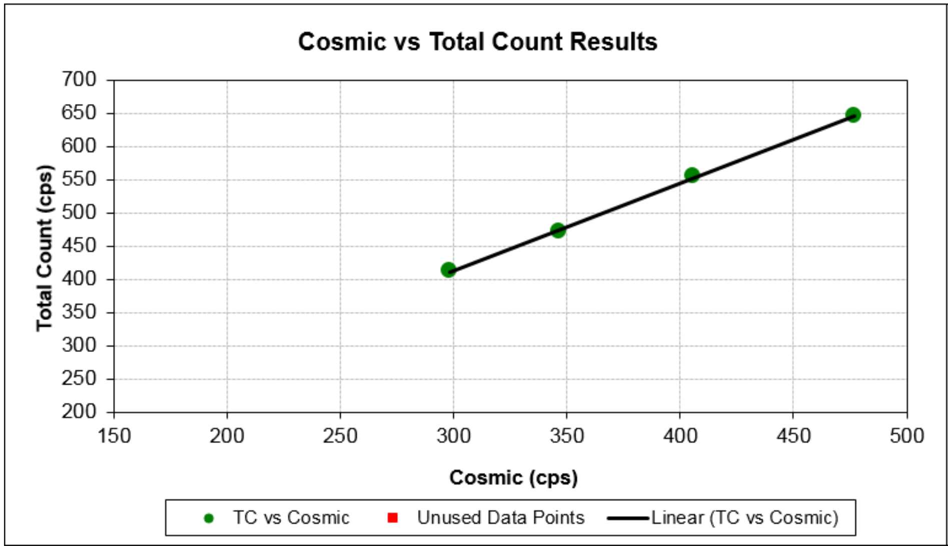
COSMIC CORRECTION COEFFICENTS

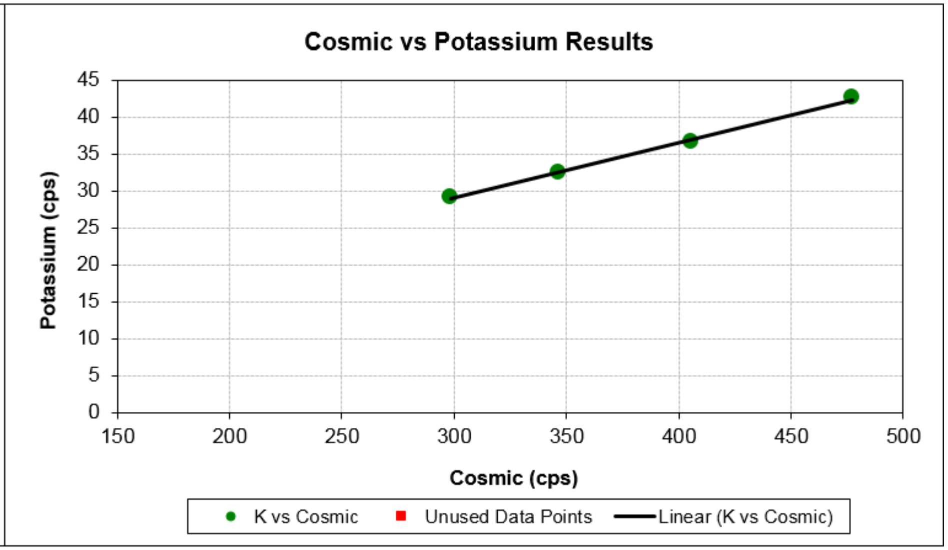
Project Number: 701503
Date Flown: July 19
Flight Number: 51036

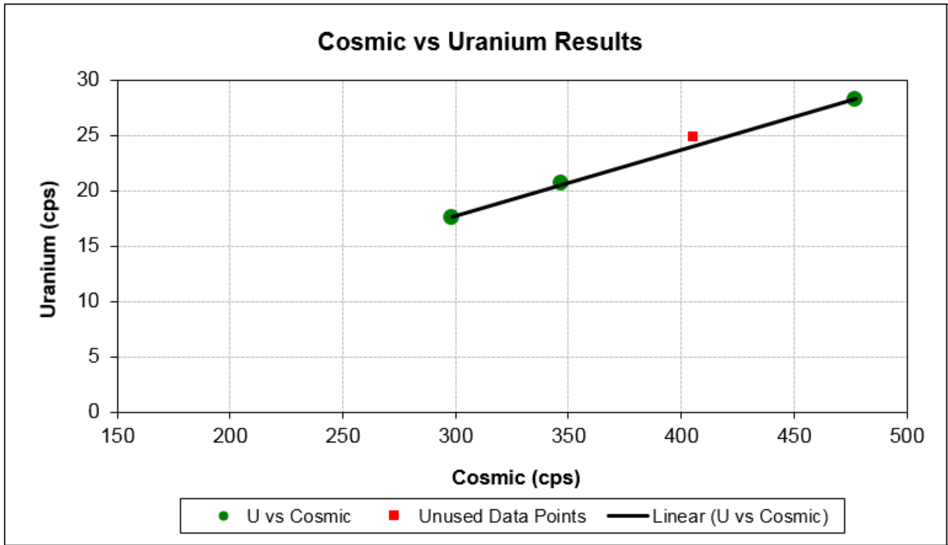
Spec Pack(s) Serial Number: 5501
Spec Console Type: RS500
Spec Console Serial Number: N/A

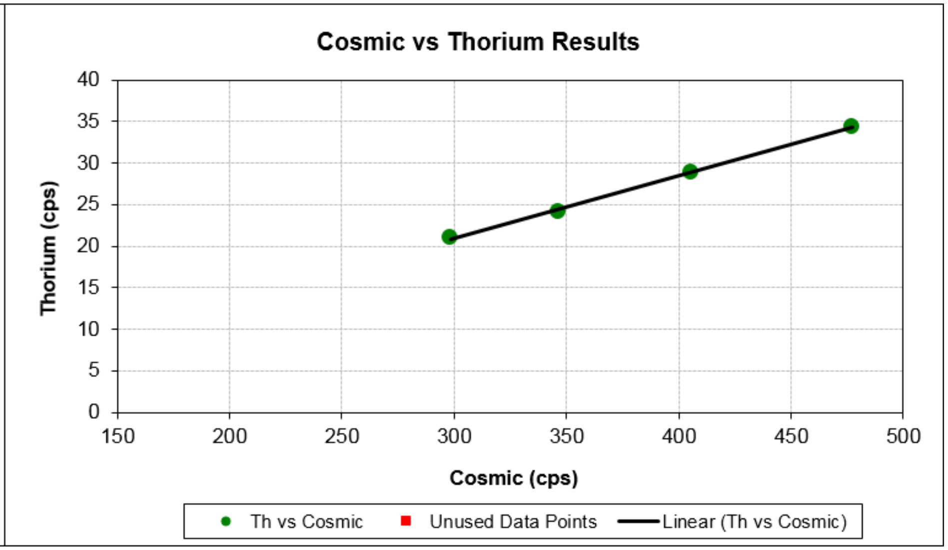
LINE	AVERAGE TC_DOWN	AVERAGE K_DOWN	AVERAGE U_DOWN	AVERAGE TH_DOWN	AVERAGE U_UP	AVERAGE COSMIC
11000	411.129	29.125	17.539	20.983	4.867	298.409
12000	471.271	32.374	20.598	24.124	5.809	346.822
13000	553.790	36.603	24.857	28.790	6.687	405.583
14000	645.392	42.524	28.210	34.327	7.861	477.161

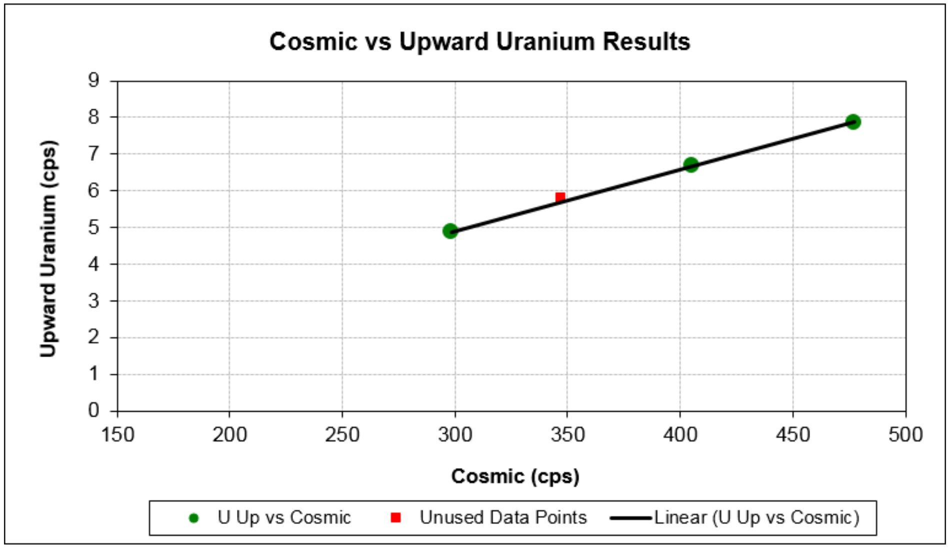
Cosmic Correction Coefficents		
	Cosmic Stripping (Slope)	Aircraft Background (Intercept)
TC	1.320	16.17
K	0.075	6.52
U	0.059	-0.12
Th	0.075	-1.72
U Up	0.017	-0.13


Cosmic vs Total Count Results
Total Count (cps)
Cosmic (cps)
TC vs Cosmic
Unused Data Points
Linear (TC vs Cosmic)


Cosmic vs Potassium Results
Potassium (cps)
Cosmic (cps)
K vs Cosmic
Unused Data Points
Linear (K vs Cosmic)


Cosmic vs Uranium Results
Uranium (cps)
Cosmic (cps)
U vs Cosmic
Unused Data Points
Linear (U vs Cosmic)


Cosmic vs Thorium Results
Thorium (cps)
Cosmic (cps)
Th vs Cosmic
Unused Data Points
Linear (Th vs Cosmic)


Cosmic vs Upward Uranium Results
Upward Uranium (cps)
0
1
2
3
4
5
6
7
8
9
150
200
250
300
350
400
450
500
Cosmic (cps)
U Up vs Cosmic
Unused Data Points
Linear (U Up vs Cosmic)

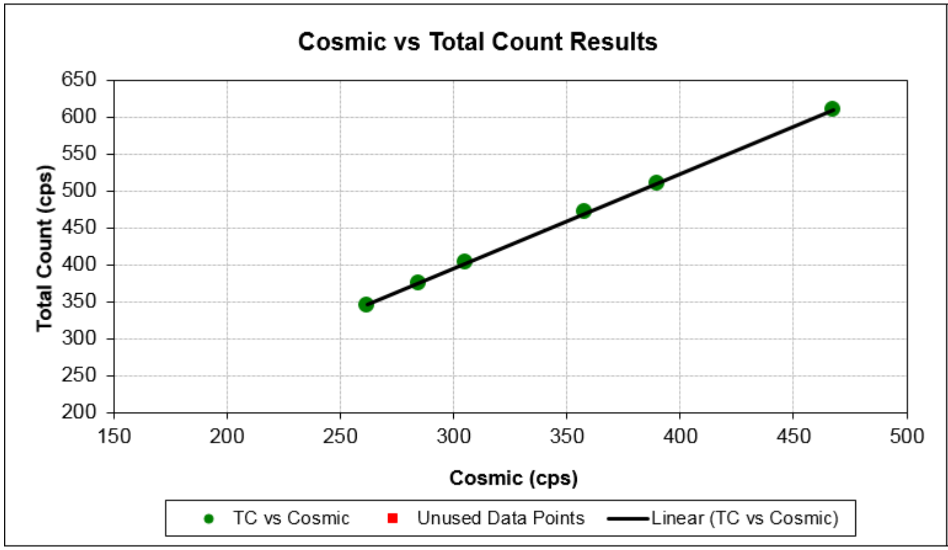
COSMIC CORRECTION COEFFICENTS

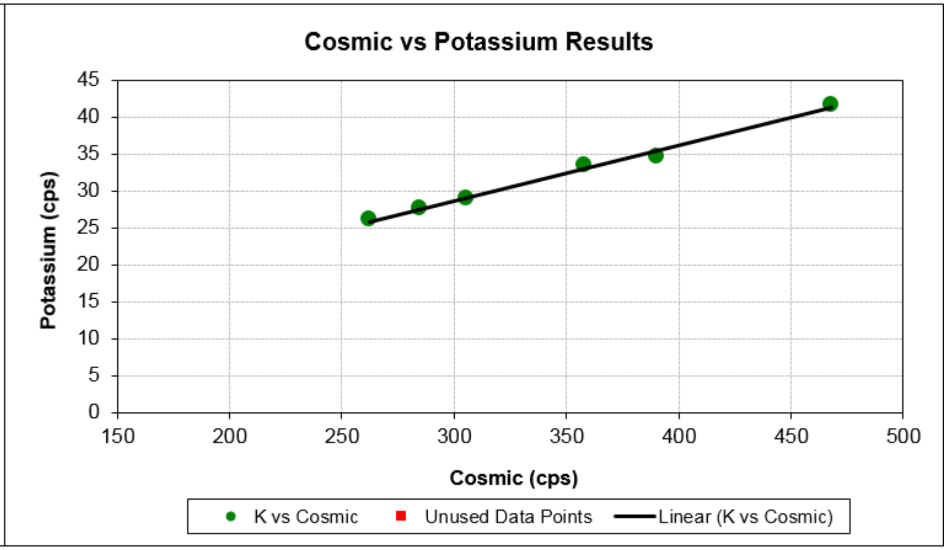
Project Number: 701503
Date Flown: Nov 3
Flight Number: 28193

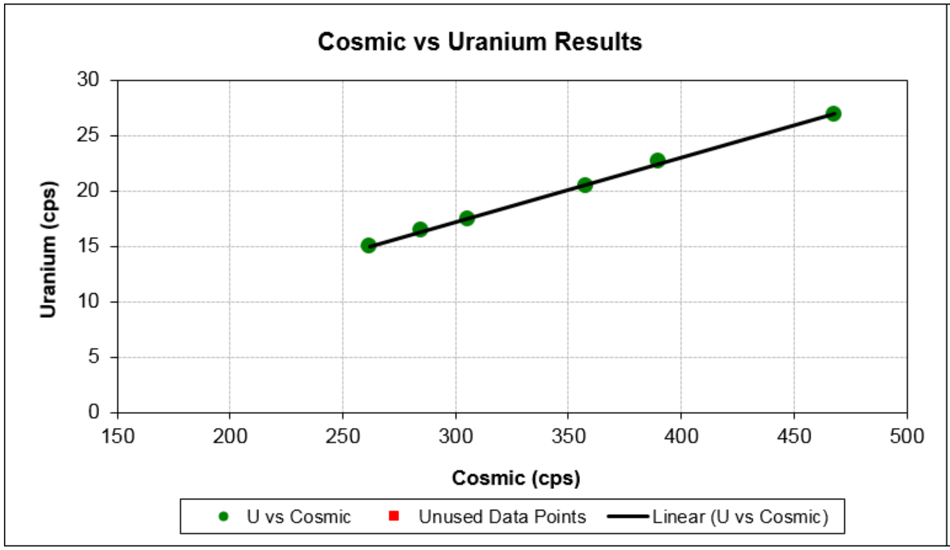
Spec Pack(s) Serial Number: 5501
Spec Console Type: RS500
Spec Console Serial Number: N/A

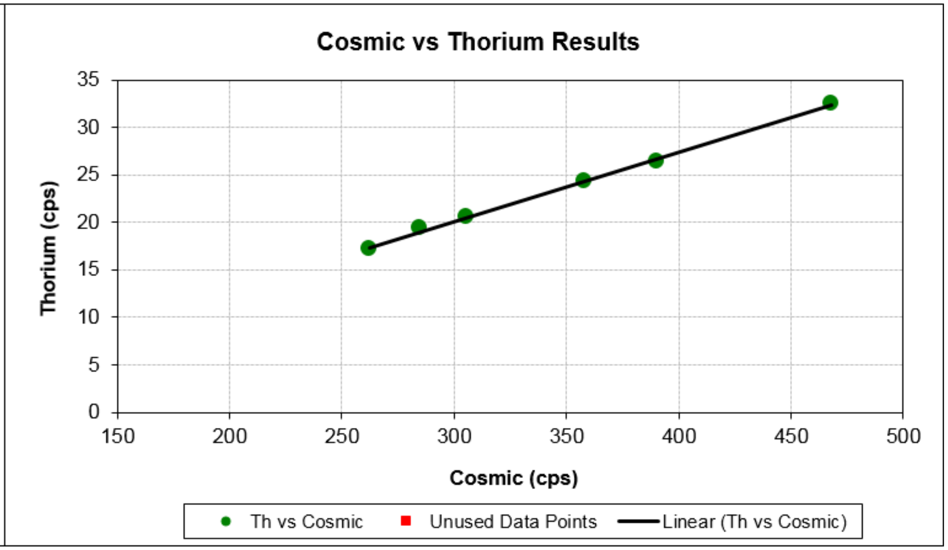
LINE	AVERAGE TC_DOWN	AVERAGE K_DOWN	AVERAGE U_DOWN	AVERAGE TH_DOWN	AVERAGE U_UP	AVERAGE COSMIC
10500	344.136	26.022	14.957	17.118	4.134	262.103
11200	374.997	27.503	16.441	19.424	4.580	284.932
11500	401.915	28.981	17.372	20.517	4.591	305.435
13000	471.367	33.378	20.437	24.318	5.830	357.893
13300	509.083	34.632	22.568	26.437	6.016	390.166
15000	608.726	41.652	26.838	32.530	7.184	467.860

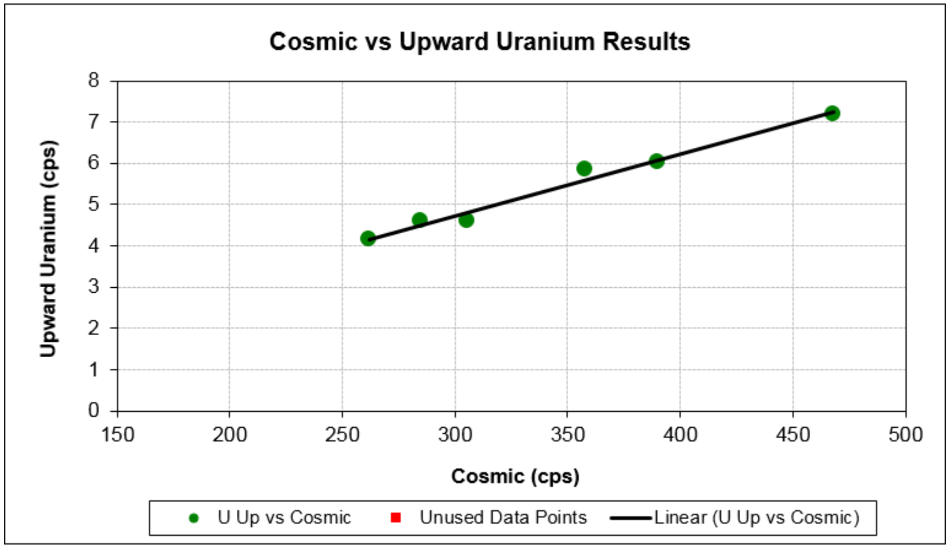
Cosmic Correction Coefficents		
	Cosmic Stripping (Slope)	Aircraft Background (Intercept)
TC	1.282	9.64
K	0.075	6.09
U	0.058	-0.17
Th	0.073	-1.80
U Up	0.015	0.24


Cosmic vs Total Count Results
Total Count (cps)
650
600
550
500
450
400
350
300
250
200
150
200
250
300
350
400
450
500
Cosmic (cps)
TC vs Cosmic
Unused Data Points
Linear (TC vs Cosmic)


Cosmic vs Potassium Results
Potassium (cps)
45
40
35
30
25
20
15
10
5
0
150
200
250
300
350
400
450
500
Cosmic (cps)
K vs Cosmic
Unused Data Points
Linear (K vs Cosmic)


Cosmic vs Uranium Results
Uranium (cps)
Cosmic (cps)
U vs Cosmic
Unused Data Points
Linear (U vs Cosmic)


Cosmic vs Thorium Results
Thorium (cps)
Cosmic (cps)
Th vs Cosmic
Unused Data Points
Linear (Th vs Cosmic)


Cosmic vs Upward Uranium Results
Upward Uranium (cps)
Cosmic (cps)
U Up vs Cosmic
Unused Data Points
Linear (U Up vs Cosmic)

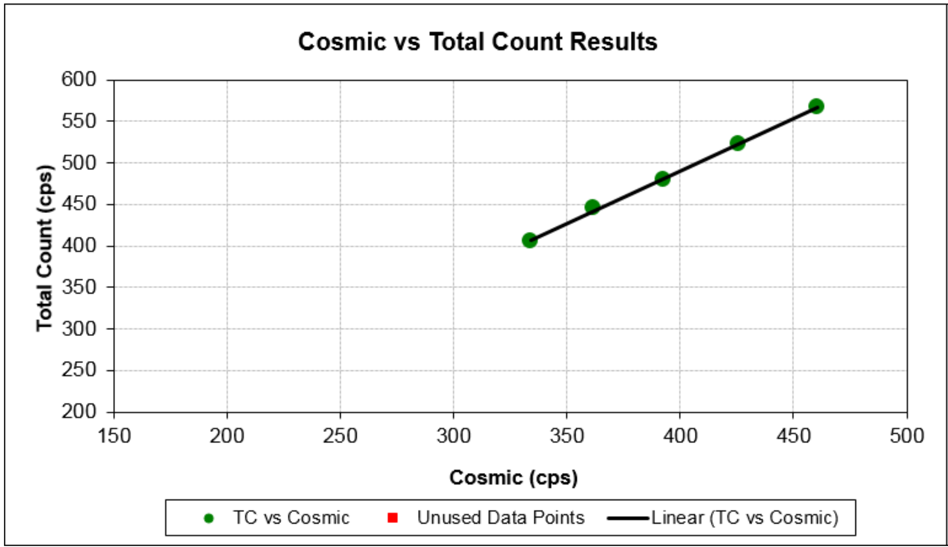
COSMIC CORRECTION COEFFICENTS

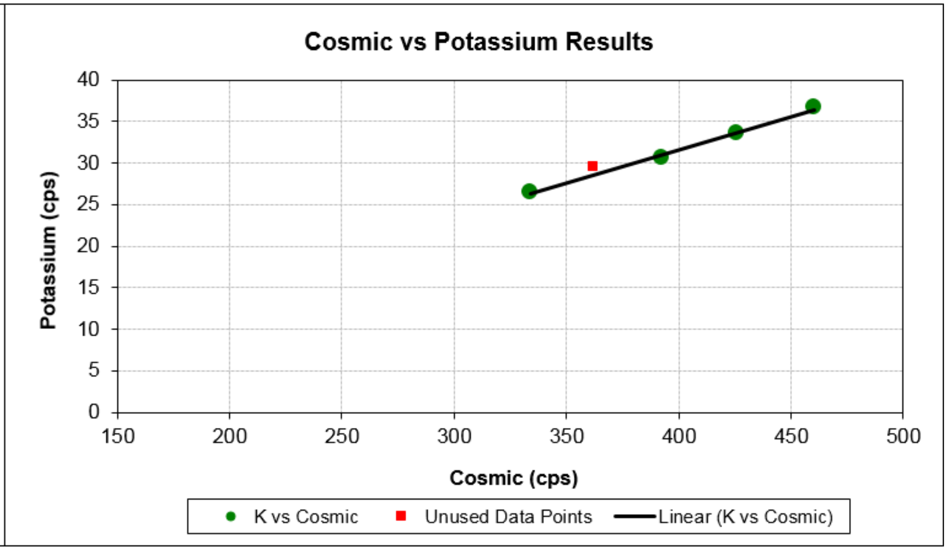
Project Number: 701503
Date Flown: Jul 19
Flight Number: 55035

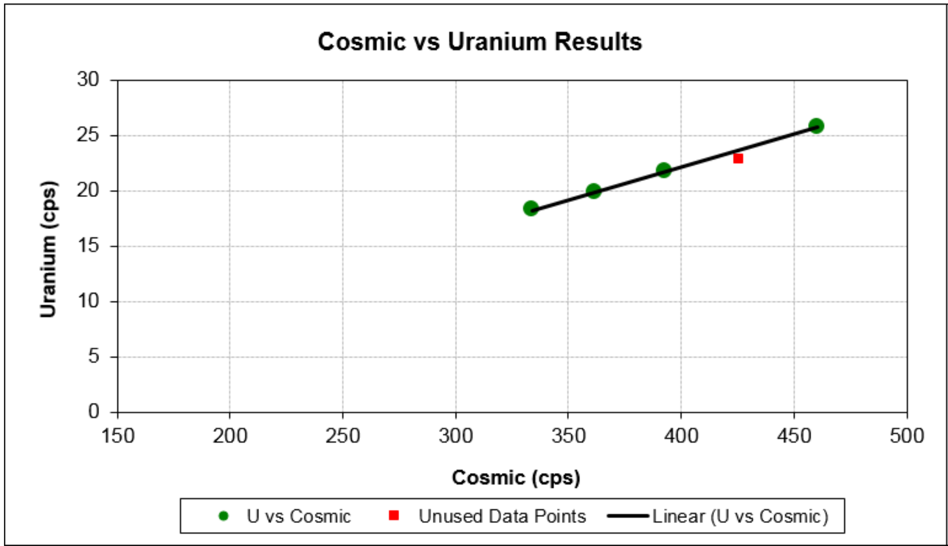
Spec Pack(s) Serial Number: 5522
Spec Console Type: RS500
Spec Console Serial Number: N/A

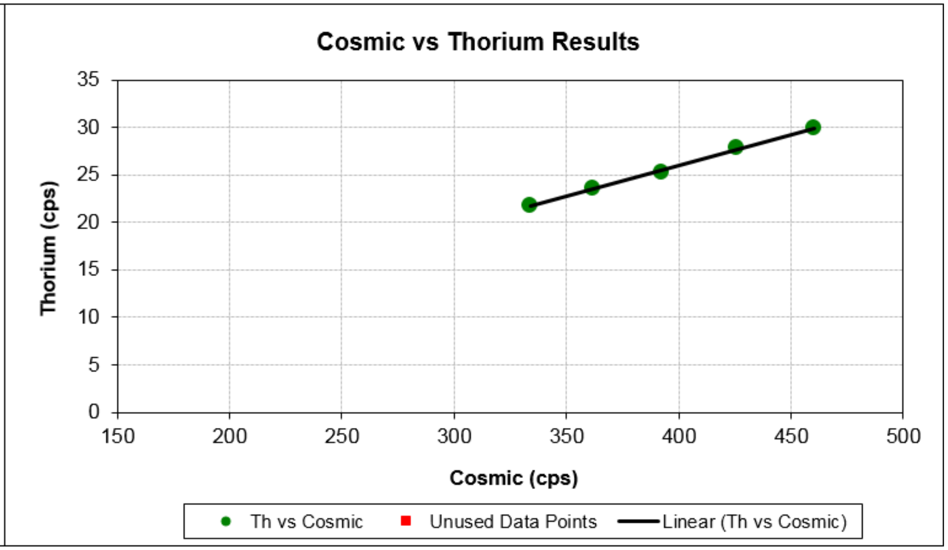
LINE	AVERAGE TC_DOWN	AVERAGE K_DOWN	AVERAGE U_DOWN	AVERAGE TH_DOWN	AVERAGE U_UP	AVERAGE COSMIC
11700	405.418	26.482	18.234	21.721	4.574	334.003
12200	444.600	29.485	19.845	23.592	5.289	362.056
12700	479.559	30.638	21.726	25.269	5.542	392.768
13300	521.673	33.498	22.833	27.745	6.396	425.673
13800	567.178	36.624	25.724	29.820	6.552	460.477
11700	405.418	26.482	18.234	21.721	4.574	334.003

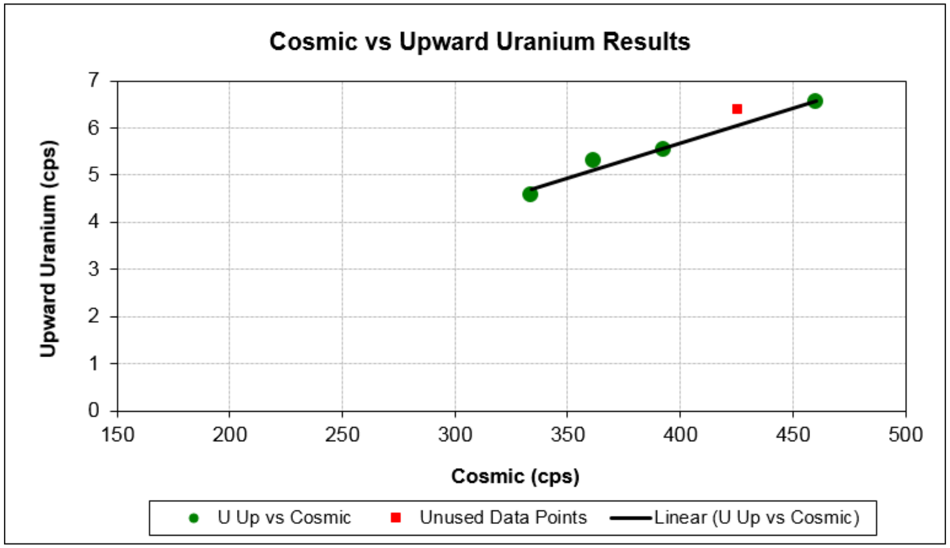
Cosmic Correction Coefficents		
	Cosmic Stripping (Slope)	Aircraft Background (Intercept)
TC	1.265	-16.1
K	0.080	-0.45
U	0.059	-1.61
Th	0.064	0.23
U Up	0.015	-0.27


Cosmic vs Total Count Results
Total Count (cps)
Cosmic (cps)
TC vs Cosmic
Unused Data Points
Linear (TC vs Cosmic)


Cosmic vs Potassium Results
Potassium (cps)
Cosmic (cps)
K vs Cosmic
Unused Data Points
Linear (K vs Cosmic)


Cosmic vs Uranium Results
Uranium (cps)
Cosmic (cps)
U vs Cosmic
Unused Data Points
Linear (U vs Cosmic)


Cosmic vs Thorium Results
Thorium (cps)
Cosmic (cps)
Th vs Cosmic
Unused Data Points
Linear (Th vs Cosmic)


Cosmic vs Upward Uranium Results
Upward Uranium (cps)
0
1
2
3
4
5
6
7
150
200
250
300
350
400
450
500
Cosmic (cps)
U Up vs Cosmic
Unused Data Points
Linear (U Up vs Cosmic)

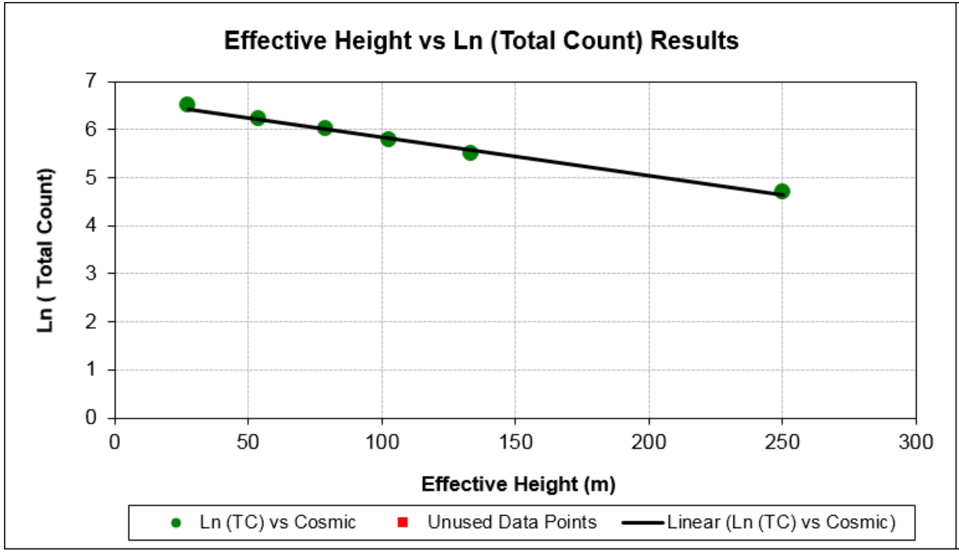
ALTITUDE ATTENUATION COEFFICENTS

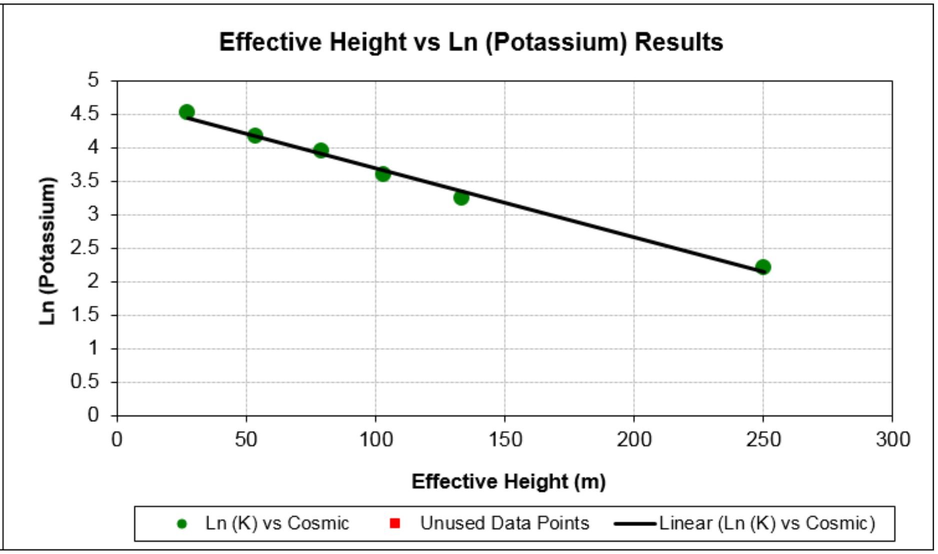
Project Number: 701503
Date Flown: Jul 11
Flight Number: 51007

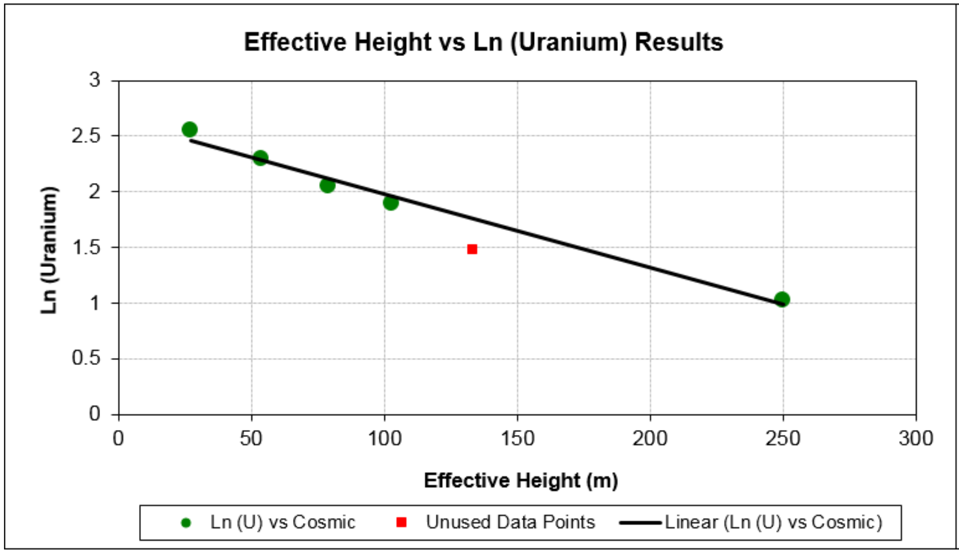
Spec Pack(s) Serial Number: 5501
Spec Console Type: RS500
Spec Console Serial Number: N/A

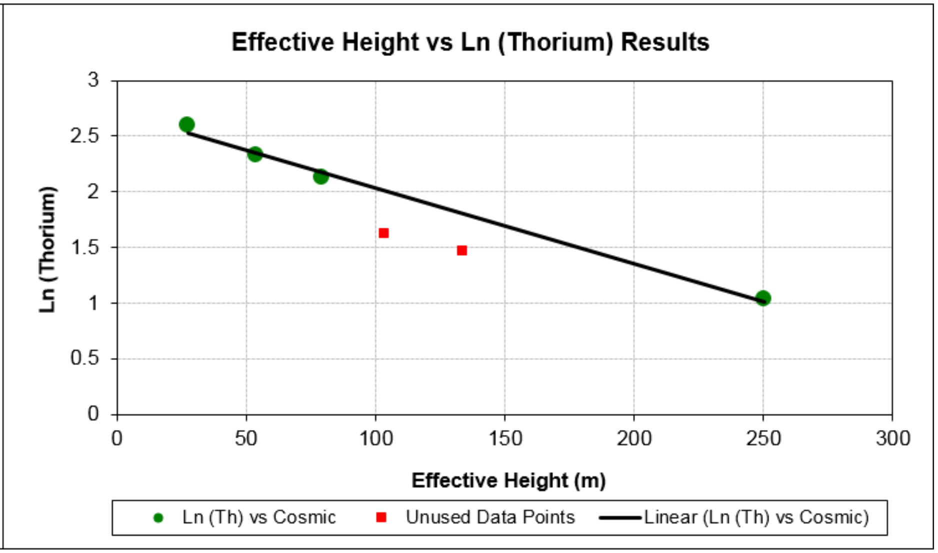
LINE	AVERAGE TC_DOWN_ ATTENCOR	AVERAGE K_DOWN_ ATTENCOR	AVERAGE U_DOWN_ ATTENCOR	AVERAGE TH_DOWN_ ATTENCOR	AVERAGE EFFECTIVE HEIGHT
100	657.17900	91.31800	12.82400	13.31000	27.55600
200	498.56700	64.31800	9.94800	10.22600	54.05800
300	400.92100	50.84100	7.76200	8.32800	79.40000
400	319.85500	36.30400	6.63400	5.07100	103.22400
500	243.98500	25.22300	4.37500	4.32400	133.50900
1000	108.24400	9.04400	2.77700	2.79600	250.29300

Summary of Altitude Attenuation Coefficents (Must Be Negative)	
TC	-0.00801
K	-0.01034
U	-0.00664
Th	-0.00680


Effective Height vs Ln (Total Count) Results
Ln (Total Count)
Effective Height (m)
Ln (TC) vs Cosmic
Unused Data Points
Linear (Ln (TC) vs Cosmic)


Effective Height vs Ln (Potassium) Results
Ln (Potassium)
Effective Height (m)
Ln (K) vs Cosmic
Unused Data Points
Linear (Ln (K) vs Cosmic)


Effective Height vs Ln (Uranium) Results
Ln (Uranium)
Effective Height (m)
Ln (U) vs Cosmic
Unused Data Points
Linear (Ln (U) vs Cosmic)


Effective Height vs Ln (Thorium) Results
Ln (Thorium)
Effective Height (m)
Ln (Th) vs Cosmic
Unused Data Points
Linear (Ln (Th) vs Cosmic)

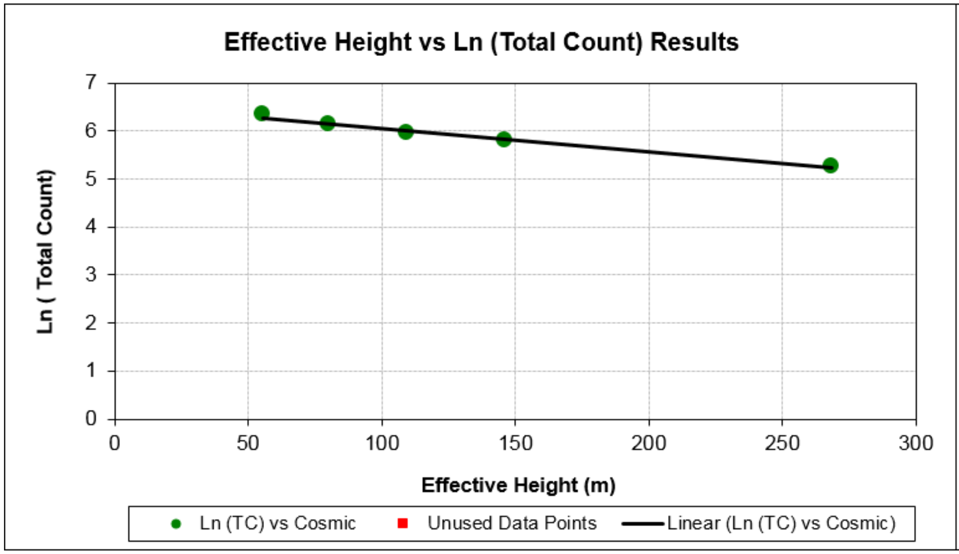
ALTITUDE ATTENUATION COEFFICENTS

Project Number: 701503
Date Flown: Nov 3
Flight Number: 28193

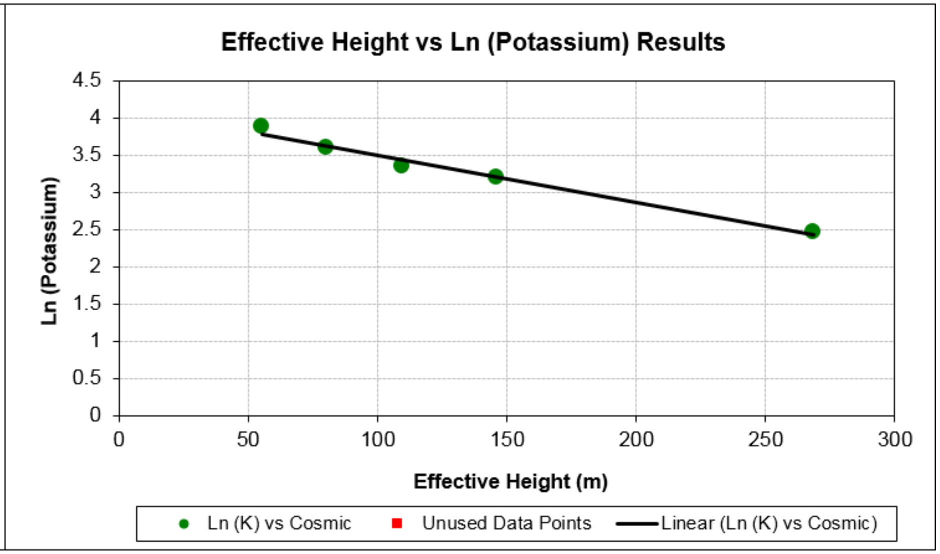
Spec Pack(s) Serial Number: 5501
Spec Console Type: RS500
Spec Console Serial Number: N/A

LINE	AVERAGE TC_DOWN_ ATTENCOR	AVERAGE K_DOWN_ ATTENCOR	AVERAGE U_DOWN_ ATTENCOR	AVERAGE TH_DOWN_ ATTENCOR	AVERAGE EFFECTIVE HEIGHT
100	657.17900	91.31800	12.82400	13.31000	27.55600
200	498.56700	64.31800	9.94800	10.22600	54.05800
300	400.92100	50.84100	7.76200	8.32800	79.40000
400	319.85500	36.30400	6.63400	5.07100	103.22400
500	243.98500	25.22300	4.37500	4.32400	133.50900

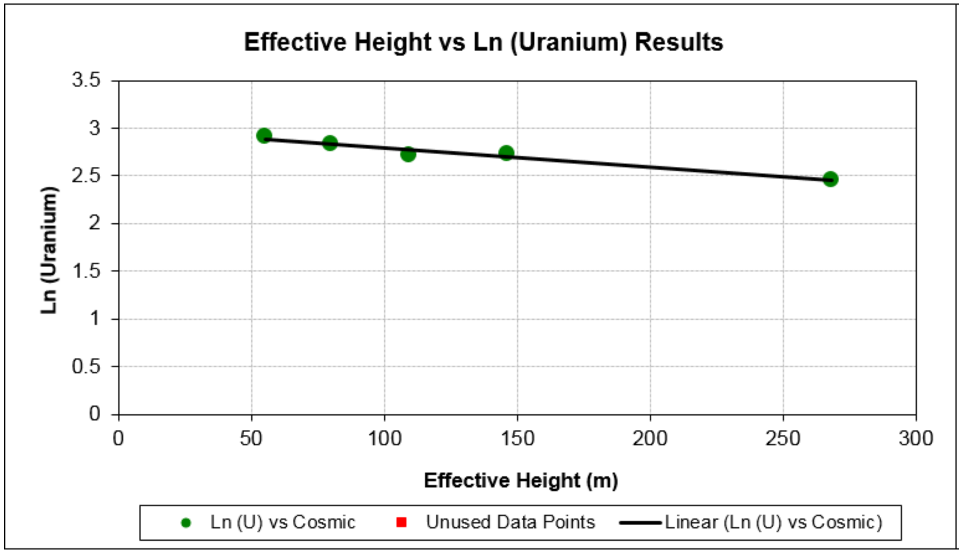
Summary of Altitude Attenuation Coefficents (Must Be Negative)	
TC	-0.00482
K	-0.00633
U	-0.00202
Th	-0.00662



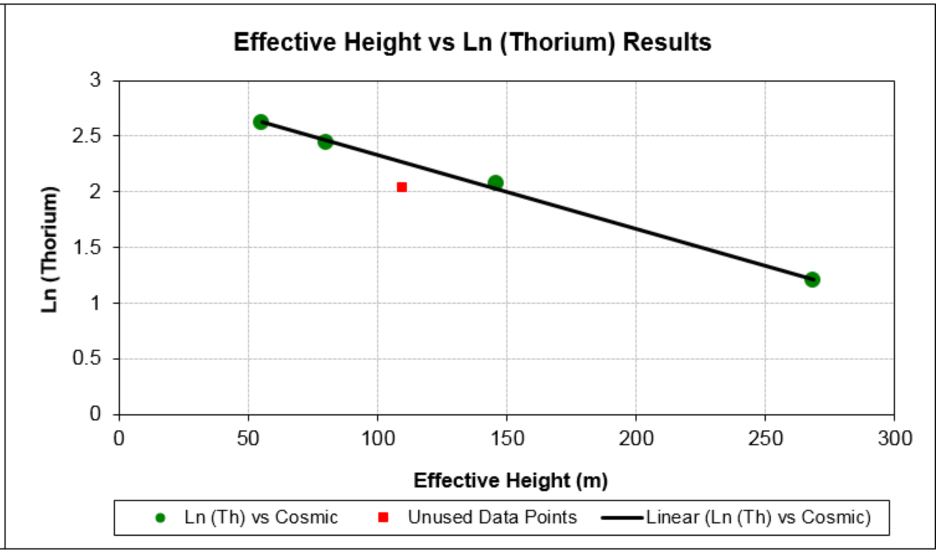
Effective Height vs Ln (Total Count) Results
Ln (Total Count)
Effective Height (m)
Ln (TC) vs Cosmic
Unused Data Points
Linear (Ln (TC) vs Cosmic)



Effective Height vs Ln (Potassium) Results
Ln (Potassium)
Effective Height (m)
Ln (K) vs Cosmic
Unused Data Points
Linear (Ln (K) vs Cosmic)



Effective Height vs Ln (Uranium) Results
Ln (Uranium)
Effective Height (m)
Ln (U) vs Cosmic
Unused Data Points
Linear (Ln (U) vs Cosmic)



Effective Height vs Ln (Thorium) Results
Ln (Thorium)
Effective Height (m)
Ln (Th) vs Cosmic
Unused Data Points
Linear (Ln (Th) vs Cosmic)

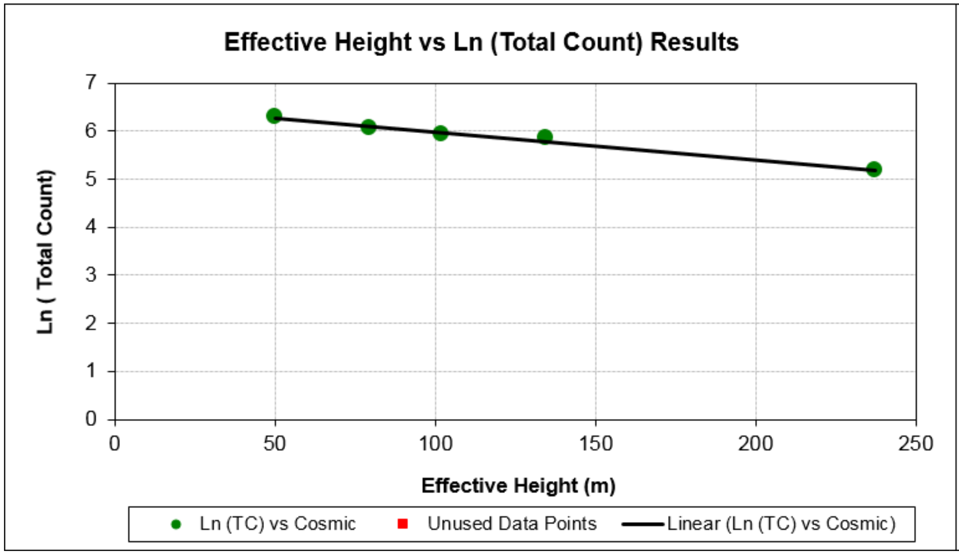
ALTITUDE ATTENUATION COEFFICENTS

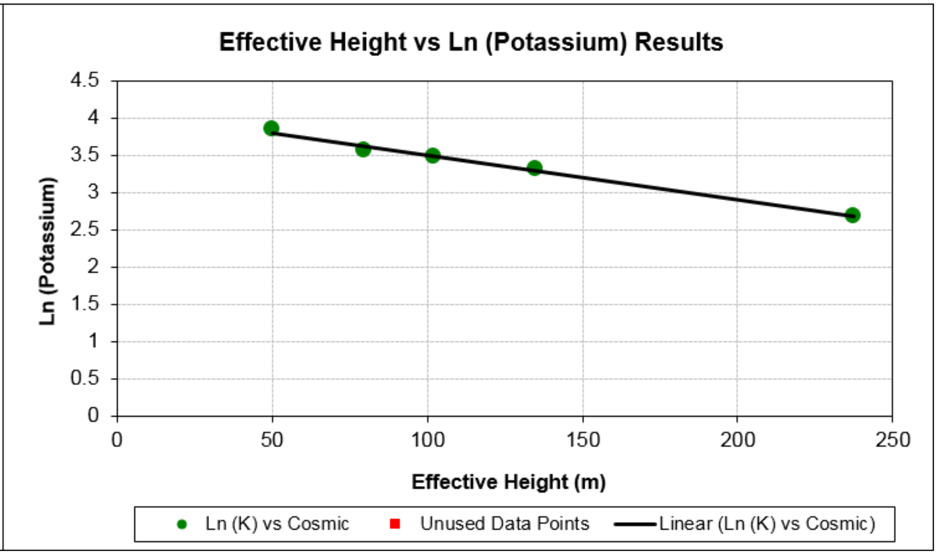
Project Number: 701503
Date Flown: Nov 3
Flight Number: 32034

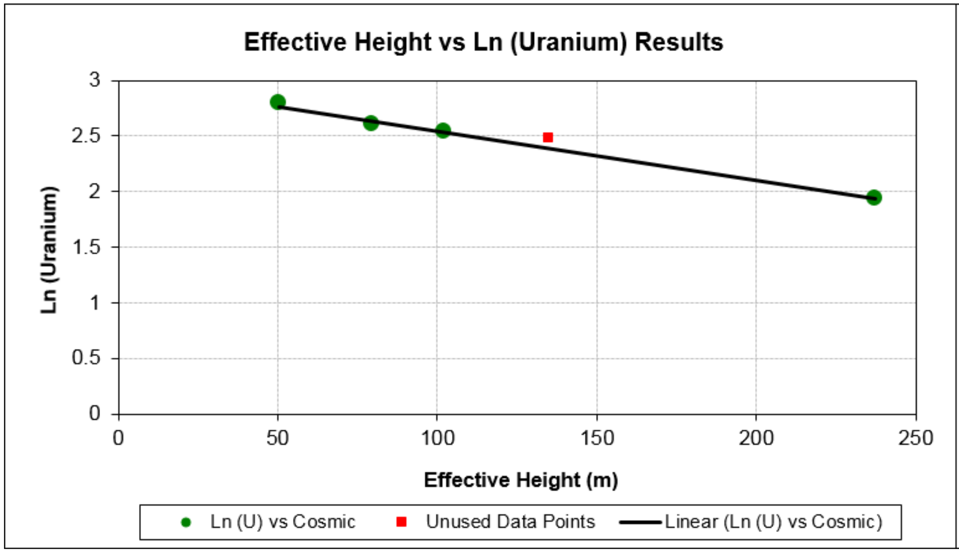
Spec Pack(s) Serial Number: 5522
Spec Console Type: RS500
Spec Console Serial Number: N/A

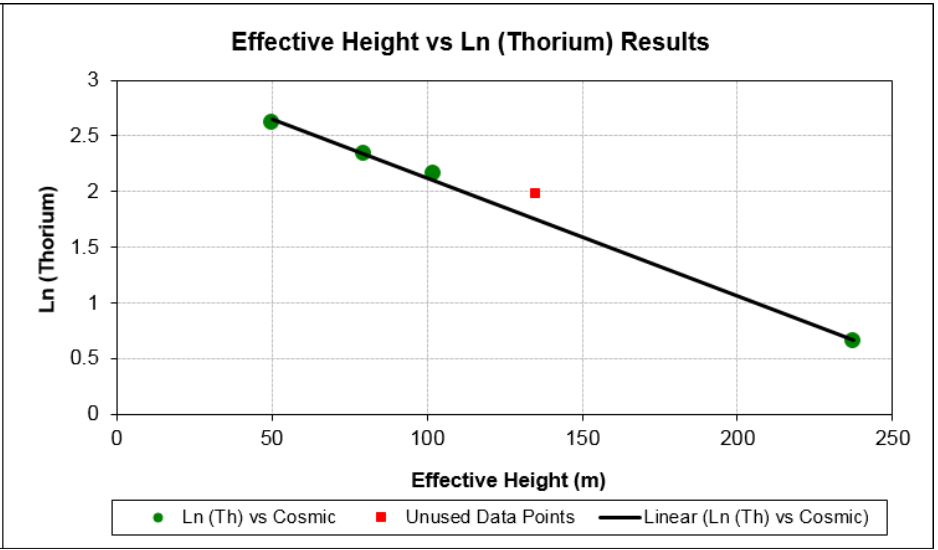
LINE	AVERAGE TC_DOWN_ ATTENCOR	AVERAGE K_DOWN_ ATTENCOR	AVERAGE U_DOWN_ ATTENCOR	AVERAGE TH_DOWN_ ATTENCOR	AVERAGE EFFECTIVE HEIGHT
100	534.12400	46.62900	16.30800	13.63100	50.28400
200	430.81900	34.89400	13.50800	10.33300	79.69000
300	379.60100	32.43400	12.59500	8.62800	102.11000
400	343.35800	27.56000	11.97200	7.23600	134.85100
500	175.94200	14.55300	6.92200	1.91600	237.30800

Summary of Altitude Attenuation Coefficents (Must Be Negative)	
TC	-0.00579
K	-0.00598
U	-0.00447
Th	-0.01061


Effective Height vs Ln (Total Count) Results
Ln (Total Count)
Effective Height (m)
0
1
2
3
4
5
6
7
0
50
100
150
200
250
Ln (TC) vs Cosmic
Unused Data Points
Linear (Ln (TC) vs Cosmic)


Effective Height vs Ln (Potassium) Results
Ln (Potassium)
Effective Height (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
50
100
150
200
250
Ln (K) vs Cosmic
Unused Data Points
Linear (Ln (K) vs Cosmic)


Effective Height vs Ln (Uranium) Results
Ln (Uranium)
Effective Height (m)
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250
Ln (U) vs Cosmic
Unused Data Points
Linear (Ln (U) vs Cosmic)


Effective Height vs Ln (Thorium) Results
Ln (Thorium)
Effective Height (m)
0
0.5
1
1.5
2
2.5
3
0
50
100
150
200
250
Ln (Th) vs Cosmic
Unused Data Points
Linear (Ln (Th) vs Cosmic)

Appendix D Background Information

Magnetic Responses

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

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

In some geological environments, an EM anomaly with magnetic correlation has a greater likelihood of being produced by sulphides than one which is non-magnetic. However, sulphide ore bodies may be non-magnetic (e.g., the Kidd Creek deposit near Timmins, Canada) as well as magnetic (e.g., the Mattabi deposit near Sturgeon Lake, Canada).

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

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

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

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

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

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

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

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

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

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

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 $\mu\omega\sigma \mathbf{h^2}$ and for a large, flat, ***conductor*** it is $\mu\omega\sigma\mathbf{th}$, 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.

Common Symbols and Acronyms

k	Magnetic susceptibility
ε	Dielectric permittivity
μ, μ_r	Magnetic permeability, relative permeability
ρ, ρ_a	Resistivity, apparent resistivity
σ,σ_a	Conductivity, apparent conductivity
σ**t**	Conductivity thickness
τ	Tau, or time constant
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.

References:

Constable, S.C., Parker, R.L., And Constable, C.G., 1987, Occam's inversion: a practical algorithm for generating smooth models from electromagnetic sounding data: Geophysics, 52, 289-300

Huang, H. and Fraser, D.C, 1996. The differential parameter method for muiltifrequency airborne resistivity mapping. Geophysics, 55, 1327-1337

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

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

Sengpiel, K-P. 1988, Approximate inversion of airborne EM data from a multi-layered ground. Geophysical Prospecting, 36, 446-459

Wolfgram, P. and Karlik, G., 1995, Conductivity-depth transform of GEOTEM data: Exploration Geophysics, 26, 179-185.

Yin, C. and Fraser, D.C. (2002), The effect of the electrical anisotropy on the responses of helicopter-borne frequency domain electromagnetic systems, Submitted to *Geophysical Prospecting*