Airborne Geophysical Survey

Ben Lomond, Tasmania

January 2008

Survey Operations and Logistics Report

For

MINEMAKERS LIMITED

Survey Flown by:

GPX Airborne

Job 2310

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1 GENERAL SURVEY INFORMATION

1.1 INTRODUCTION

On 23rd August 2007, GPX Airborne commenced a helicopter aeromagnetic and radiometric survey for Minemakers Limited in Tasmania. The helicopter was a Eurocopter AS-350D “Squirrel” owned and operated by Heli Aust located in Bankstown NSW. This report summarizes the procedures, details and equipment used by GPX Airborne in the acquisition, verification and processing of the airborne geophysical data.

Client:	Minemakers Limited
GPX Job Number:	2310
Survey Area:	Ben Lomond
Data Processing Base:	Launceston
Production:	23rd August – 7th September 2007
Line km surveyed:	111.835 km (in-fill)
	233.550km (in-fill & GA combined)

1.2 SURVEY BRIEF

The crew mobilised to Tasmania in early March to commence a survey for Geoscience Australia. This survey for Minemakers was flown as in-fill whilst conducting the survey for Geoscience Australia. Flying for Minemakers commenced on 23rd August 2007 and was completed on 7th September 2007. Throughout the survey system stability and continuity was monitored.

1.3 SURVEY PERSONNEL

The following personnel were involved on this project:

Operations and Safety Manager:	Bob Blizzard
Project Leader:	Daniel Ting
	Terry McCambridge
Technical Support:	Mike Barrett
Operators:	Liam Parry
	Anthony Jenkinson
Pilot:	Leon Garry
	Mark Watson
Data Processing:	Cathy Car

1.4 SURVEY EQUIPMENT

Survey Platform	Eurocopter AS-350D Squirrel (VH-JWD)
Data Acquisition System	Pico Envirotec AGIS PC104 Console
Magnetometer Processor	Pico Envirotec MMS4 Magnetometer Processor
Magnetometer	Scintrex CS3 Cesium Vapour
Spectrometer	Exploranium GR820 (16 Litre Crystal)
Fluxgate Magnetometer	Billingsley TFM100-G2
GPS / DGPS Receiver	CSI DGPSMax
Radar Altimeter	Collins ALT-50A
Magnetic Base Stations	Gem Systems GSM-19W
In-field Computer	Toshiba Notebook
In-field Software	Pico Envirotec PEIView, ChrisDBF

Figure 1: VH-JWD in Launceston

1.5 SURVEY PARAMETERS

Line spacing:	200 metres
Line direction:	090° and 270°
Tie line spacing:	2000 metres
Tie line direction:	000° and 180°
Sensor height:	90 metres
Magnetometer sample rate:	10 Hz
Spectrometer sample rate:	1 Hz recording 256 channels
Altimeter sample rate:	10 Hz
Base magnetometer sample rate:	1 Hz

1.6 SURVEY AREA

The following coordinates are in GDA94 / Map Grid of Australia zone 55 and defines the survey area.

557100mE	5385100mN
560100mE	5385100mN
560100mE	5379100mN
557100mE	5379100mN

1.7 FLIGHT PATH IMAGE

Figure 2: Actual flight path of the Ben Lomond survey.

2 SURVEY EQUIPMENT SPECIFICATIONS

2.1 DATA ACQUISITION CONSOLE

The Data Acquisition console is a Pico Envirotec AGIS PC104. This is a versatile multi-function system that is capable of operation in many different configurations, depending on platform type, navigation and system requirements. The AGIS PC104 provides the following functions:

- Navigation / flight control
- Data recording
- Display of real-time collected data and status monitoring
- Data retrieval access

Figure 3: Real time monitor and navigation console.

2.1.1 Navigation / Flight Control

The AGIS PC104 is used to guide the aircraft on a pre-defined flight plan that can be generated in UTM or Latitude/Longitude coordinates. The pre-defined flight plan can be designed to file prior to the start of the project, entered or altered in the AGIS system or delineated ‘on-the-fly’ e.g. while in the air flying the boundary and entering corner coordinates. Co-ordinates can only be entered in the WGS84 datum system, this has been implemented to avoid confusion and eliminate possible conversion errors. Normal survey altitude and ground speed, with pre-set tolerances are also entered.

The pilot display consisted of a 2-line strip display or more comprehensive Pilot Guidance Unit (PGU). The strip display is driven directly from the AGIS PC104 console; whereas the PGU is a self-contained computer system that is capable of more demanding navigation functions such as “drape” flying using a pre-programmed altitude grid.

The desired flight line is selected from the operator interface, which will either be a keyboard or touch-screen.

2.1.2 Data Recording

The AGIS PC104 relates all acquired data to the instant position from the GPS receiver and records the collected data to three separate data files. The data is recorded in compressed binary format, to a commercial solid-state hard disk.

The flight path file is recorded from AGIS program start-up to shutdown and cannot be turned off by the operator. It contains position, timing, altitude and basic data.

The data file is recorded whenever the acquisition system is “On-line”. It contains all navigation data plus “enabled” data.

The raw data file, when enabled and supported by the GPS receiver in use, contains raw GPS data necessary for post-flight position correction. It is recorded from AGIS program start-up to shutdown.

2.1.3 Display of real-time collected Data and status monitoring

The AGIS displays flight path and geophysical data as it is acquired aiding the data quality control and real time navigation guidance. The user is presented with graphical representations of the survey area, flight lines, navigation status, and sensor data. The spectra data was also displayed.

Several other status indications are also provided which will either change state indicating a major system malfunction, such as a magnetometer or spectrometer failure, or will change state during normal operation, indicating data being written to a file etc

2.1.4 Data Retrieval

The AGIS PC104 provides facility to transfer the recorded data from the internal solid-state disk to compact flash media immediately following the completion of the survey flight. Recorded data is not deleted from the main disk until this “retrieved” data has been verified “error free”.

2.2 MAGNETOMETER PROCESSOR

The Magnetometer Processor is a Pico Envirotec MMS4 Magnetometer Processor. This is an advanced frequency-measuring device that can support several continuous signal magnetometers (Cs, He, K). It is a hardware-software designed system, exhibiting simplicity, easy interfacing and substantial versatility. Magnetometer readings are synchronized with the PPS (Pulse Per Second) signal derived from the GPS for accurate timing.

The MMS4 contains 8 channels of analog differential inputs. The first 4 analog channels are sampled synchronously with MMS4 magnetometer at up to 50 samples per second. The remaining 4 analog channels are sampled at 10 samples per second. Analog data is integrated into the magnetometer data stream.

Specifications:

Input:	Coaxial - Larmour signal over DC Power Supply
Resolution:	0.0002 nT (Gamma) = 0.2 picoTesla
Sampling rates:	10, 20, 50 samples per second
Dynamic range:	15000 to 100000nT
Synchronization:	GPS – PPS (Pulse Per Second)
Data Storage:	Removable Compact Flash Memory

2.3 MAGNETOMETER SENSOR

The Magnetometer Sensor is a Scintrex CS3, which employs an optically pumped cesium-vapour atomic magnetic resonance system that functions as the frequency control element in an oscillator circuit.

Specifications:

Model:	Scintrex CS3
Type:	Cesium Vapour Magnetometer
Operating Range:	15,000 – 105,000 nT
Sensitivity:	0.002nT P-P in 0.1-1Hz bandwidth
Heading Error:	± 0.25nT inside the optical axis to the field direction angle range 20º to70º and 110º to 160º
Output:	Larmour frequency, 3.498577 Hz/nT

2.4 FLUXGATE MAGNETOMETER

The Fluxgate Magnetometer is a Billingsley Ultra Miniature TFM 100G2. This unit is a low noise, high sensitivity unit, packaged into a compact housing. An analog DC output voltage is produced for each of the measured X, Y and Z orthogonal components of the current magnetic field.

Specifications:

Model:	Billingsley TFM 100G2
Axial Alignment:	Orthogonality better than ±1º
Sensitivity:	100uV / nT
Noise:	20pT RMS / Hz @ 1Hz
Output:	± 100uT = ± 10V

2.5 SPECTROMETER

The Spectrometer is an Exploranium GR820 system. The survey used a single pack crystal which had a volume of detection of 16 litres. The spectrometer employs automatic gain stabilisation control to eliminate the need to heat the detectors. Signal processing automatically perform digital gain control to the individual crystal spectra, ensuring the summed spectrum is stable.

Model:	Exploranium GR820
Sensitivity:	0 – 3.0 MeV
Maximum count rate:	100,000 counts/sec
Detector volume:	16.7 Litres
Detector weight:	83.9 kgs

2.6 TEMPERATURE AND HUMIDITY SENSORS

The Temperature and Humidity transmitter is a Vaisala HMP233. The unit provides both a digital RS232 output and Analogue voltage or current output directly proportional to the measured Temperature and Humidity. The unit is a commercial grade device housed in a rugged aluminium enclosure.

Specifications:

Model:	HMP233
Humidity Range:	0 – 100% RH
Humidity Accuracy:	±1 %RH (0...90 %RH)
	±2 %RH (90...100 %RH)
Temperature Range:	-40 to +80°C
Temperature Accuracy:	± 0.1°C
Analog Output Accuracy:	±0.05 % full scale

2.7 BAROMETRIC PRESSURE SENSOR

The Barometric Pressure transmitter is a Vaisala PTB220. The unit provides both a digital RS232 output and Analogue voltage or current output directly proportional to the measured Barometric Pressure. The unit is a Class "A" commercial grade device housed in a rugged aluminium enclosure.

Specifications:

Model:	PTB220
Range:	500 – 1100 hPa
Resolution:	0.01 hPa
Accuracy at +20ºC:	± 0.1 hPa

2.8 RADAR ALTIMETER

The Radar Altimeter is a Rockwell Collins ALT-50 two-antenna unit operating at a centre frequency of 4300MHz. The voltage output to the data system is directly proportional to the aircraft flying height with an output characteristic of 20mV/ft up to 500ft, then 10.4V + 3mV/ft above 500ft.

Specifications:

Model:	Collins ALT-50A Radio Altimeter System
Accuracy:	± 3ft - 0 to 150ft range ± 2% of indicated altitude – 150 to 500ft range ± 3.5% of indicated altitude – 500 to 200ft range
Measurement Rate:	Same rate as magnetometer, 10Hz minimum.

2.9 GPS/DGPS RECEIVER

The DGPS receiver is a CSI DGPS MAX, which is a 12-channel combined GPS/DGPS unit. The DGPS MAX is able to use differential corrections received through an internal WAAS demodulator, VLF beacon receiver, or the OmniSTAR DGPS Service.

Specifications:

Receiver:	CSI DGPS MAX
GPS Position update rate:	5Hz
GPS Input frequency:	L1
Antenna:	Fugro Wideband – Stinger Mounted
DGPS Update rate:	Typically every 6 seconds
DGPS Solution Used:	OmniSTAR VBS

2.10 GEM GSM-19W OVERHAUSER MAGNETOMETER

The Earth's diurnal activity was monitored using a GEM GSM-19W Overhauser Magnetometer and sampled at 1 Hz. The portable unit has a built-in GPS receiver.

Specifications:

Model:	GEM GSM-19W Overhauser
Type:	Overhauser Magnetometer
Resolution:	0.01 nT
Sensitivity:	0.02 nT
Absolute Accuracy:	+/- 0.1nT
Dynamic Range:	10,000 to 120,000 nT
Sampling Rate:	1 hour to 5 Hz
Data Storage:	Internal memory
Data Retrieval:	Up to 115,200bps serial transfer

2.10.1 Base Station Locations

The magnetic base station at Launceston was located at

Longitude: 147° 11' 32.8" E
Latitude: 41° 32' 36.5" S

Figure 4: Sketch of the base station's location at Launceston (image courtesy of Google Earth).

3 EQUIPMENT CALIBRATIONS AND DATA ACQUISITION CHECKS

3.1 DYNAMIC MAGNETOMETER COMPENSATION

Aircraft compensation tests were flown at high altitude on the 4 survey line headings and also at +/-15° to the line headings (to accommodate for cross wind flying conditions). The data for each heading consists of a series of aircraft manoeuvres with large angular excursions: specifically pitches, rolls and yaws. This is done to artificially create the worst possible attitudes and rates of attitudinal change likely to be encountered while on line and compensate for any magnetic noise created by the aircraft's motion within the earth's magnetic field. This data is processed to obtain the REAL TIME COMPENSATION terms of which the aircraft used the standard 17-term model. These terms include permanent, induced and eddy values. These coefficients may be applied in real time or during post processing. Note that this form of compensation will only remove those noise effects modelled in the manoeuvres test flight. External noise sources and random motions of the stinger with respect to the aircraft airframe generally establish the noise floor for this type of installation. The surveyor's goal is to achieve a 4th difference noise level on the order of 0.01nT RMS during normal surveying conditions. In general, this noise level was routinely achieved or bettered as a matter of course.

3.2 HEADING ERROR CHECK

Historically, heading error checks have been an essential part of the aeromagnetic data acquisition procedure but their importance now has diminished. GPX Airborne now corrects for these effects using the dynamic aircraft magnetic compensation system and specially developed software. In the past, repeatable heading errors of less than one nanotesla (1.0 nT) were considered good. Dynamic compensation typically yields heading errors in the order of 0.1 to 0.3 nT, which are effectively eliminated by modern data levelling techniques.

3.3 SYSTEM PARALLAX TESTS

One of the processing parameters required to process digital data was the parallax or offset time, between the time the digital reading was taken by the instrument and the time the position fix for the fiducial of the reading was obtained. Each instrument - magnetometer, altimeter - may have a different parallax, so the parallax must be computed for each instrument.

The parallax correction derived is the correction to be applied to each survey line. A positive parallax indicates the instrument reading is ahead of the position of the fiducial. Each integer fiducial represents one second so the parallax can be expressed in either fiducial or seconds.

The correct fiducial is computed by:

Parallax corrected fid = Fid for recorded reading – Instrument parallax

The following table summarises the parallax test.

Data	**Parallax applied (seconds)**
GPS Position	2.5
Magnetic data	1.5
Radiometric data	0.0

Table 1: Summary of parallax test.

3.4 ALTIMETER CALIBRATIONS

The height of the aircraft above ground is recorded by a radar altimeter as a voltage every 0.1 second. The voltage data is converted to height via a lookup table determined by calibration with the GPS altitude.

3.5 RADIOMETRIC PRE SURVEY CALIBRATIONS

Pre-survey gamma-ray spectrometer calibration results are summarised below.

The calibration methods are as generally described by Grasty and Minty (1995).

VH-JWD	**Window**	**Value**
Aircraft Background	TC	81.67
	K	23.35
	U	0.59
	Th	0.67
Cosmic Background	TC	0.811201
	K	0.044663
	U	0.038646
	Th	0.043791
Stripping	Alpha	0.2540
	Beta	0.5145
	Gamma	0.7997
	a	0.0692
Height Attenuation	TC	0.009414
	K	0.012094
	U	0.009558
	Th	0.009178

Table 2: Gamma-ray spectrometer calibration summary

3.6 TIME SYNCHRONIZATION

The magnetic base station is synchronised to GPS time so there is no time drift in the system.

3.7 SURVEY LINE NUMBERING SYSTEM

The first digit in any line number represents the area number, i.e. 100050 is area no. 1.

The next four numbers are the line number it self, i.e. 101030 is line number 103.

All Tie lines begin with the digit 7, i.e. 170020.

The sixth digits of any line number represent the attempt number, i.e. 100010 is the first attempt.

4 DATA VERIFICATION AND FINAL PROCESSING

4.1 IN FIELD DATA PROCESSING

All data verification and preliminary processing and map production was conducted at the field office using a Toshiba Notebook computer. ChrisDBF was the primary field quality control software.

At the conclusion of each days survey all magnetic, radiometric, altimeter, flight path and diurnal data was transferred via compact flash memory onto the office computer for preliminary data verification.

4.1.1 Altimeter Data

Radar Altimeter Data

The radar altimeter is verified to check that a reasonably constant height above the terrain specified in section 1.5 was flown; readings during the course of the survey did not exceed the specified tolerances. The radar altimeter data is used in the production of digital terrain maps.

GPS Height Data

The aircraft's height above mean sea level each second was determined by data from the post-processed GPS. The GPS height of the aircraft is verified to check for data masking and for equipment reliability. The GPS height data is used in the production of digital terrain maps.

Digital Terrain Data

After verification the radar altimeter height was subtracted from the GPS height to give the elevation of the terrain above mean sea level.

Gridding and Inspection

The digital terrain data was gridded and grid image enhancements were computed and displayed on screen. These were viewed also with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.1.2 Flight Path Data

The flight path is plotted daily to ensure it was within survey specifications. Any data not within specification was re-flown. The aircraft GPS recorded the data in the WGS84 datum.

4.1.3 Magnetic Data

The raw un-edited magnetic data was checked to identify noise and spikes. Single reading spikes were manually edited and if the noise exceeded the contract specifications, the line was re-flown.

Magnetic Diurnal Data

Diurnal data recorded once a second from the primary base station was down loaded from the magnetometer's memory onto the field processing computer via compact flash. The diurnal data was then checked and corrected for spikes. Single reading spikes were manually edited and multiple erroneous readings flagged as invalid. If invalid diurnal data occurred whilst survey data was being acquired the affected section was re-flown. The diurnal data was also checked to see that the change in diurnal readings during the course of the survey did not exceed the specified tolerances. When this occurred the affected survey lines were re-flown. The diurnal data was merged with the aircraft data and used in the verification of the magnetic data.

Diurnal Correction

The synchronized digital diurnal data collected by the base station was first subtracted from the corresponding airborne magnetic readings to calculate a difference. The resultant difference was then subtracted from the base value to produce diurnally corrected magnetic data.

Parallax Correction

The aircraft system parallax is also checked prior to project commencement. A parallax error correction of 0.0 second was used for in field verification.

Gridding and Inspection

The magnetic data was gridded and grid image enhancements were computed and displayed on screen. These were also viewed with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.1.4 Radiometric Data

Spectra Verification

The 256-channel radiometric data is viewed to confirm that the spectra peaks are correctly calibrated. The following peak locations are checked daily.

- Potassium 1460 keV
- Uranium 1760 keV
- Thorium 2614 keV

Parallax Correction

The aircraft system parallax is also checked prior to project commencement. A parallax error correction of 0.0 second was used for in field verification.

Gridding and Inspection

The radiometric data was gridded and grid image enhancements were computed and displayed on screen. These were also viewed with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.1.5 Digital Archives

All raw aircraft, and diurnal base data were backed up on CD-ROM disk at the end of each day's survey. A further backup of all raw and edited data remained on the field-processing computer for the entire duration of the project. A copy of each days flying was transferred to the company's ftp site for further verification.

4.2 FINAL PROCESSING

All final data processing of the data was performed in the offices of GPX Airborne. Raw field data was transferred to the offices and processed to produce the final data. No field-processed data was used in the making of the final data. The final processing of the data follows the same quality control checks that are made in the field, however the final data has additional processes performed.

4.2.1 Altimeter Data

Radar Altimeter Data

The radar altimeter is verified to check that a reasonably constant height above the terrain specified in section 1.5 was flown; readings during the course of the survey did not exceed the specified tolerances. The radar altimeter data is used in the production of digital terrain maps.

GPS Height Data

The aircraft's height above mean sea level each second was determined by data from the post-processed GPS. The GPS height of the aircraft is verified to check for data masking and for equipment reliability. The GPS height data is used in the production of digital terrain maps.

Parallax Correction

A parallax error correction as described in section 3.3 was applied to the coordinate data.

Tie Line Levelling

A crossover program was used to compute the height difference between each tie line and the traverse line intersection. These differences were then applied to level the traverse lines to the tie lines.

Micro Levelling

Micro levelling was used to remove residual differences with a long wavelength along line and short wavelength across line. Application of the micro levelling process removed the streaks that were sometimes visible when using various grid enhancements.

Digital Terrain Data

After verification the radar altimeter height was subtracted from the GPS height and the Geoid – Ellipsoid separation correction applied to give the elevation of the terrain above mean sea level.

Gridding and Inspection

The digital terrain data was gridded and grid image enhancements were computed and displayed on screen. These were viewed also with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.2.2 Magnetic Data

The raw un-edited magnetic data was checked to identify noise and spikes. Single reading spikes were manually edited.

Magnetic Diurnal Data

The diurnal data was then checked and corrected for spikes. Single reading spikes were manually edited and multiple erroneous readings flagged as invalid.

Diurnal Correction

The synchronized digital diurnal data collected by the base station was first subtracted from the corresponding airborne magnetic readings to calculate a difference. The resultant difference was then subtracted from the base value to produce diurnally corrected magnetic data.

Parallax Correction

A parallax error correction as described in section 3.3 was applied to the coordinate data.

IGRF correction

The magnetics data has been corrected for the regional gradient by subtracting the calculated IGRF (2005 model) computed continuously over the whole area. The calculation of these corrections used the GPS flying height.

Tie Line Levelling

A crossover program was used to compute the magnetic difference between each tie line and the traverse line intersection. These differences were then applied to level the traverse lines to the tie lines.

Micro Levelling

Micro levelling was used to remove residual differences with a long wavelength along line and short wavelength across line. Application of the micro levelling process removed the streaks that were sometimes visible when using various grid enhancements.

Gridding and Inspection

The magnetic data was gridded and grid image enhancements were computed and displayed on screen. These were also viewed with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.2.3 Radiometric Data

IAEA Processing
The processing of the radiometric data is summarised below.

1. Apply the deadtime correction.
2. Energy recalibrate the 256 channel spectra and re-window the data.
3. Noise Adjusted Singular Value Decomposition (NASVD).
4. Remove spikes from the altimeter, temperature and pressure values.
5. Correct radiometric data to standard temperature and pressure.
6. Remove the aircraft background, apply the cosmic correction, remove radon, apply the stripping values and finally apply the height correction.

Deadtime correction
The GR-820 spectrometer requires a finite time to process each pulse from the detectors. The deadtime of the GR-820 is less than 5 microseconds per detector and this correction was applied.

Energy Recalibration
Spectra analysis was performed on each line of data and the position of the thorium and potassium peak positions determined and compared to their theoretical positions. The original spectra data was then mapped to the correct peak positions and new windowed data created for each of the standard IAEA windows as follows.

Window	Peak Energy (KeV)	Energy Window (KeV)
Total Count		410 - 2810
Potassium	1460	1370 - 1570
Uranium	1760	1660 - 1860
Thorium	2615	2410 - 2810
Cosmic		3000

256 Channel Noise Reduction
The two most common processing methods are:

1. Noise adjusted Singular Value Decomposition (NASVD). This was developed specifically for radiometric processing.
2. Maximum Noise Fraction (MNF). This was developed for removing noise from satellite images and subsequently used in radiometric processing.

Both methods use Principal Component Analysis (PCA) with the only difference being in the estimation of noise in the raw spectra and subsequent scaling before PCA.

We have implemented and extensively used both methods but prefer NASVD because it is simpler, requires one less pass of the data and less observations for a good join when adjacent data sets are merged. However the 2 methods give almost the same result and both work well.

Careful analysis of the eigenvalues and eigenvectors of the PCA is required to ensure the process has worked correctly. We use the 7 most significant principal components to reduce the data with the remainder considered to be noise. If this is not the case, as seen from eigenvalue and eigenvector plots, then there is a problem with the data. So this is an excellent quality control tool as well as a noise reduction method. There are strong theoretical reasons for this approach and if less than 7 components are used some signal is likely to be removed. On large surveys we have found it is best to use 7 components globally rather than having to make difficult decisions for different segments of the survey as this provides a globally consistent result.

As final proof the method has worked correctly, residual line profiles and images of potassium, uranium and thorium must confirm that no signal is present. Also the ternary potassium, uranium and thorium image must be sharp. If signal has been removed this image will be blurred.

Standard Temperature and Pressure correction
The data was converted to effective altitude at standard temperature and pressure (STP) using the expression:

$$Alt(STP) = BA \times (\frac{P}{1013}) \times \frac{273}{(T + 273)}$$

Alt(STP) = Effective altitude at STP
BA = Barometric Altitude
P = Pressure
T = Temperature in °C

Cosmic Correction
The aircraft background radiation was removed by subtracting the aircraft background values from the Total Count, Potassium, Uranium and Thorium windows. The effect of cosmic radiation was removed from each window by multiplying the cosmic channel by the cosmic stripping factor for each window and subtracting the result from the window data.

Radon Background Removal
Although in the past upward looking crystals have often been used as an acceptable method of correcting for the effects of atmospheric radon in airborne radiometric surveys, we now consider this method to be inadequate to provide the data quality required by modern processing techniques for the following reasons.

The crystal volume of the upward looking detectors is usually small relative to that of the primary downward looking detectors (typically 1 or 2 upward detectors for 4 downward detectors). For this reason, noise dominates signal in the spectra obtained from the upward looking detectors. Consequently the ability of these detectors to accurately reflect coincident (i.e. non geological) responses in the primary detectors is severely compromised. The low signal to noise ratio has the added affect of compromising spectral calibration of the upward looking detectors, further eroding their ability as indicators of coincident events.

More importantly, the very nature of airborne radon distribution renders this method inherently inaccurate, as atmospheric radon does not exist in uniform distributions but rather in radon clouds that have a distinctly non uniform density distribution. Sensors receiving signal from different directions will therefore detect different radon responses.

Another problem with upward looking crystals is preventing contamination effects from ground signal. This is especially a problem for low level surveys or for areas with significant terrain variation where aircraft attitude movements will allow ground signal to be recorded by the upward looking crystals.

It is clearly evident that any effective radon correction method should use the downward looking crystals only.

For this reason we prefer to use the spectral ratio method for radon removal. This method uses the 352 keV uranium peak as a substitute for upward crystals. The only time upward crystals may be needed is where cesium contamination affects the use of the 352 keV uranium peak. The use of the low energy uranium peak at 352 keV instead of the 609 keV uranium peak should make even this use of upward crystals redundant. The 352 keV uranium peak is an extremely good detector of radon gas because very little radiation from the ground will reach the aircraft at this low energy. Also the thorium peak close to the 352 keV peak has much less intensity than the thorium peak close to the 609 keV uranium peak.

Stripping
The radiometric spectra of potassium (K), uranium (U) and thorium (Th) series overlap. To evaluate of any one spectral window, which is designed to detect one radioelement, requires removal of the spectral overlap. This process of removal of the spectral overlap is known as stripping. The stripping procedure uses spectral stripping ratios determined experimentally using concrete calibration pads of known K, U and Th concentration.

Parallax Correction
A parallax error correction of 0.0 seconds was applied to the radiometric data.

Tie Line Levelling
A crossover program was used to compute the radiometric difference between each tie line and the traverse line intersection. These differences were then applied to level the traverse lines to the tie lines.

Micro Levelling
Micro levelling was used to remove residual differences with a long wavelength along line and short wavelength across line. Application of the

micro levelling process removed the streaks that were sometimes visible when using various grid enhancements.

Gridding and Inspection

The radiometric data was gridded and grid image enhancements were computed and displayed on screen. These were also viewed with the aid of crossline sun angles and inspected for inconsistencies and errors and appropriate corrections were made if required.

4.2.4 Digital Archives

The final digital data was written out as a flat ASCII located data file. The format and channel description can be found in Appendix A. Grids of the final data were created in ERMapper format.

5 IMAGES

5.1 TOTAL MAGNETIC INTENSITY IMAGE

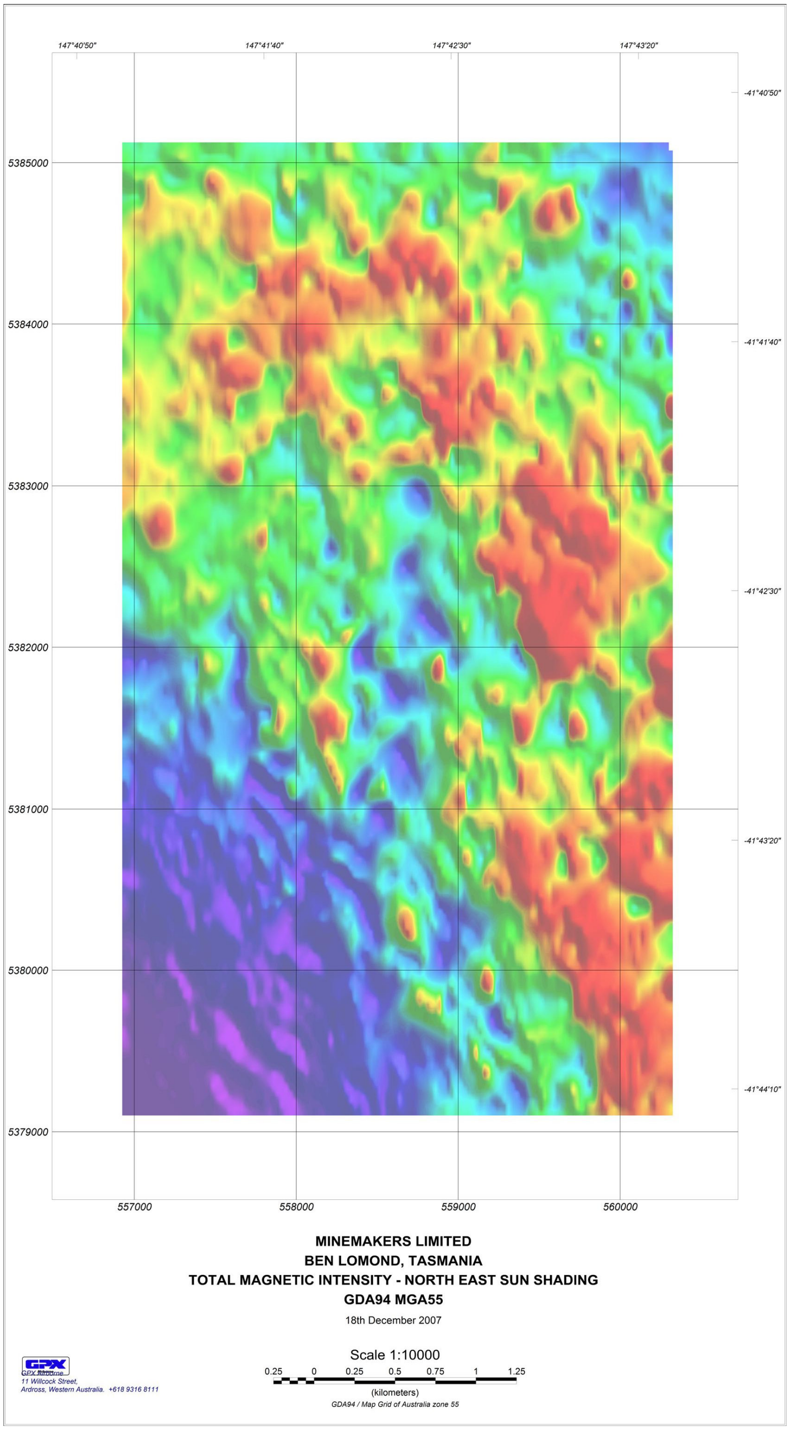

Figure 5: Total Magnetic Intensity Image - NE Sunshading

5.2 REDUCED TO POLE FIRST VERTICAL DERIVATIVE IMAGE

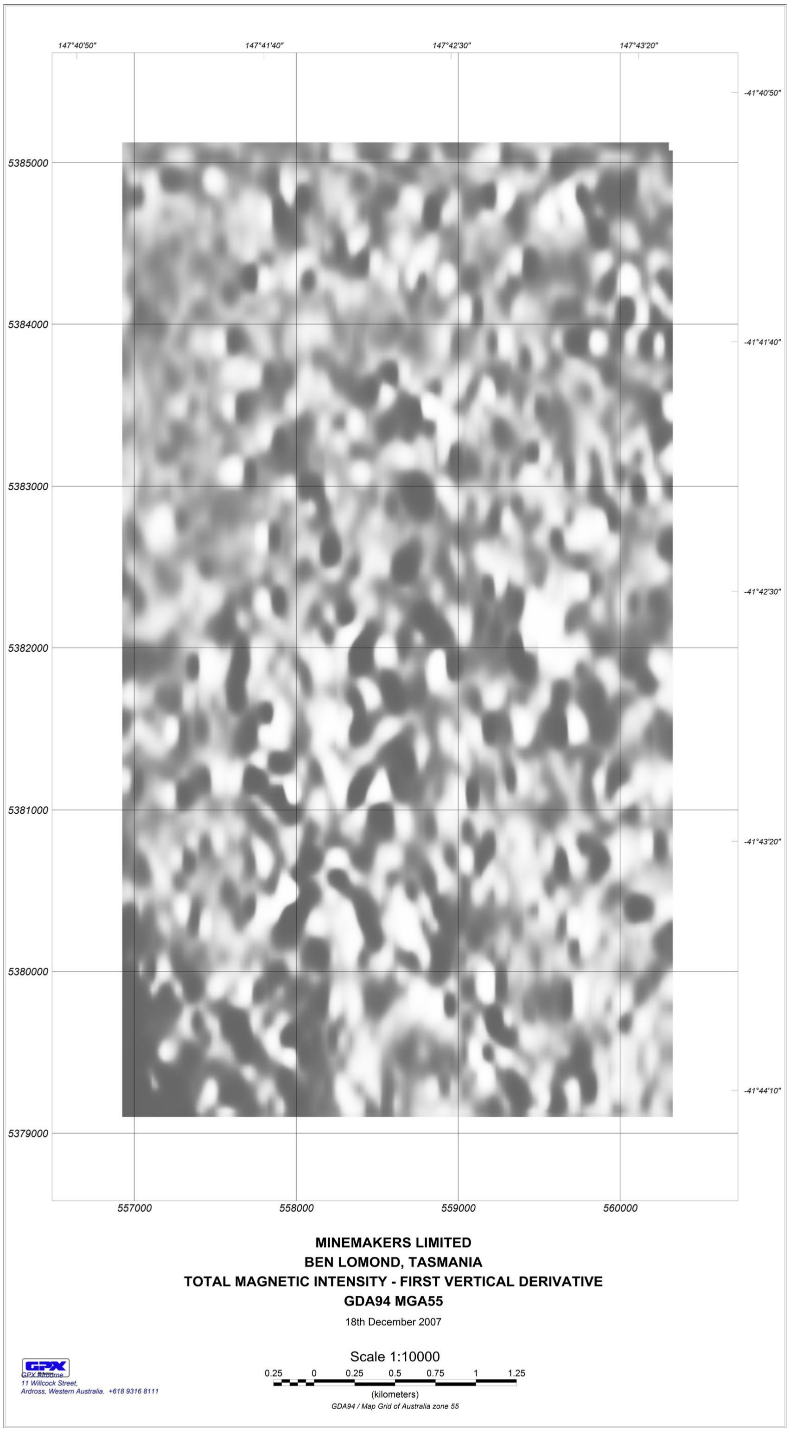

Figure 6: Total magnetic Intensity - First Vertical Derivative

5.3 TOTAL COUNT IMAGE

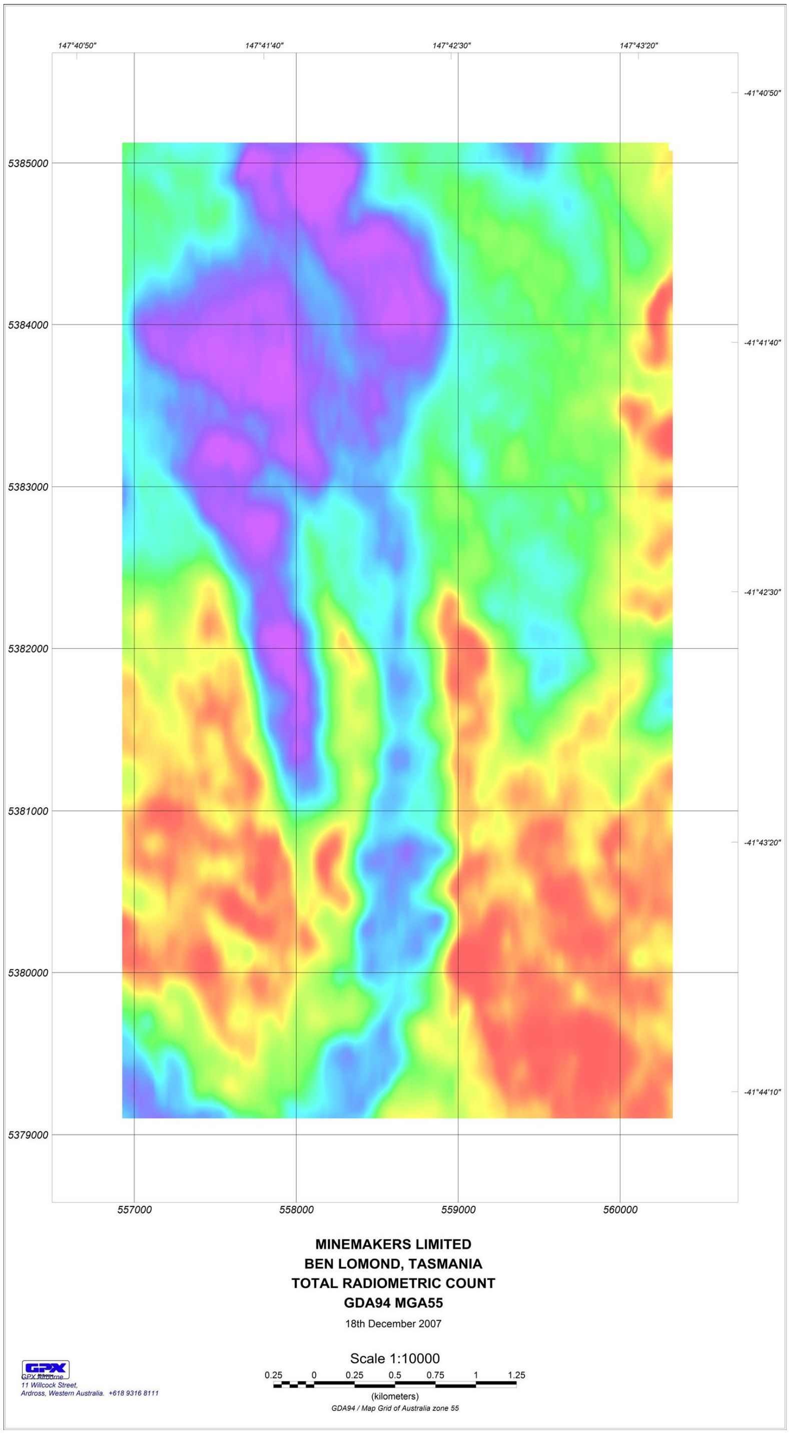

Figure 7: Total Radiometric Count

6 CONTRACTOR INFORMATION

GPX Airborne

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Western Australia. 6153

Telephone: +618 9316 8111
Fax: +618 9316 8033

Web: http://www.gpxair.com.au/

7 APPENDIX A: FINAL LOCATED DATA FORMAT

7.1 MAGNETIC DATA

GENERAL

Project	Ben Lomond
Survey area	Ben Lomond
Located data type	0.1 Second Final Data
Surveyed by	GPX AIRBORNE PTY LTD.
Job number	2310
Processed by	GPX AIRBORNE PTY LTD.
Creation date	November 2007

SURVEY SPECIFICATIONS

Survey flown	March - September 2007
Traverse line spacing	200 metres
Traverse line direction	090-270 degrees
Tie line spacing	2000 metres
Tie line direction	000-180 degrees
Survey height	90 metres

LOCATED DATA FORMAT

Variable	Units	Undefined	From	To	Format
Line number		9999999	1	8	I8
Easting (MGA55)	metres	9999999.99	9	19	F11.2
Northing (MGA55)	metres	9999999.99	20	30	F11.2
Fiducial		99999.99	31	39	F9.2
Flight number		999	40	43	I4
Direction (1=E, 2=N, 3=W, 4=S)		9	44	45	I2
Date (YYYYMMDD)		99999999	46	54	I9
Time (GPS)	seconds	99999.99	55	63	F9.2
Longitude (GDA94)	degrees	999.999999	64	74	F11.6
Latitude (GDA94)	degrees	999.999999	75	85	F11.6
Radar altimeter	metres	9999.9	86	92	F7.1
GPS altitude	metres	9999.9	93	99	F7.1
Raw magnetics	nT	99999.999	100	109	F10.3
Post compensated magnetics	nT	99999.999	110	119	F10.3
Diurnal	nT	99999.999	120	129	F10.3
Final magnetics	nT	99999.999	130	139	F10.3
Pressure	millibars	9999.9	140	146	F7.1
Temperature	degrees C	99.9	147	151	F5.1
Raw total count	cps	999999	152	158	F7.0
Raw potassium	cps	9999	159	163	F5.0
Raw uranium	cps	9999	164	168	F5.0
Raw thorium	cps	9999	169	173	F5.0
Raw cosmic	cps	99999.9	174	178	F5.0
Final dose rate	nGy/h	99999.99999	179	190	F12.5
Final potassium	percent	99999.99999	191	202	F12.5
Final uranium	eppm	99999.99999	203	214	F12.5
Final thorium	eppm	99999.99999	215	226	F12.5
Final DTM	metres	99999.9	227	234	F8.1

DATA PROCESSING

COORDINATE DATA
All lines are scissored to the following rules:
1) A 'smooth' edge outside the area boundary.
2) Maximum line overlap of 0 fiducials within the area boundary.

The local projection is a UTM projection based on the GDA94 spheroid with a central meridian of 147 East degrees.
System parallax of 2.5 fiducial has been removed.

MAGNETIC DATA
The magnetic data has been corrected for regional gradient by subtraction of IGRF model 2005 computed continuously over the whole area based on the GPS height.
Diurnal magnetic variations have been removed.
System parallax of 1.5 fiducial has been removed.
Tie-line levelling has been applied.
Microlevelling has been applied.
A base value of 61320 nT has been added to the data.

RADIOMETRIC DATA

Raw channel data provided has been energy calibrated
NASVD has been applied to channel data prior to windowing
System parallax of 0.0 fiducial has been removed.
Height attenuated to 90m AGL
Airborne radon has been removed

AIRCRAFT BACKGROUND		UNITS	
Total Count	68.07	cps	
Potassium	8.74	cps	
Uranium	2.32	cps	
Thorium	1.43	cps	
COSMIC STRIPPING RATIOS			
Total Count	0.809713		
Potassium	0.066459		
Uranium	0.033387		
Thorium	0.046899		
COMPTON STRIPPING RATIOS			
alpha	0.2540		
beta	0.5145		
gamma	0.7997		
a	0.0692		
HEIGHT ATTENUATION COEFFICIENT			
Total Count	0.009414	per metre	
Potassium	0.012094	per metre	
Uranium	0.009558	per metre	
Thorium	0.009178	per metre	
SENSITIVITY CONSTANTS			
Total Count - nGy/h	18.95	cps	
Potassium - 1%	57.26	cps	
Uranium - 1ppm	5.43	cps	
Thorium - 1ppm	3.97	cps	
WINDOW ENERGY LEVELS	Low Energy	High Energy	
Total Count	410.0	2810.0	keV
Potassium	1370.0	1570.0	keV
Uranium	1660.0	1860.0	keV
Thorium	2410.0	2810.0	keV

DIGITAL TERRAIN MODEL DATA

DIGITAL TERRAIN MODEL CALCULATION
The radar altimeter data was subtracted from the GPS heights to provide a digital elevation model which is height above the WGS84 spheroid. Using interpolation on the 120 second DMA Geoid model, a correction was computed and subtracted from the WGS84 data to convert to height above the geoid.

DATA RELIABILITY
This Digital Terrain Model (DTM) has been computed from data generated during the course of an airborne geophysical survey flown at a nominal spacing of 200m and data has been interpolated between such lines. Every effort has been made to make this model a useful general reference. No guarantee can be made that this model is a true representation of height above sea level as it can contain radar altimeter responses from buildings and in some instances dense timber. Users of the product should be aware of the topographic limitations mapped herewithin. Do not use this DTM for navigation purposes.

7.2 RADIOMETRIC DATA

GENERAL

Project	Ben Lomond
Survey area	Ben Lomond
Located data type	1 Second Radiometric Data
Surveyed by	GPX AIRBORNE PTY LTD.
Job number	2310
Processed by	GPX AIRBORNE PTY LTD.
Creation date	November 2007

SURVEY SPECIFICATIONS

Survey flown	March - September 2007
Traverse line spacing	200 metres
Traverse line direction	090-270 degrees
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Survey height	90 metres

LOCATED DATA FORMAT

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Pressure	millibars	9999.9	93	99	F7.1
Temperature	degrees C	99.9	100	104	F5.1
Raw total count	cps	999999	105	111	F7.0

Raw potassium	cps	9999	112	116	F5.0
Raw uranium	cps	9999	117	121	F5.0
Raw thorium	cps	9999	122	126	F5.0
Raw cosmic	cps	99999.9	127	131	F5.0
Final dose rate	nGy/h	99999.99999	132	143	F12.5
Final potassium	percent	99999.99999	144	155	F12.5
Final uranium	eppm	99999.99999	156	167	F12.5
Final thorium	eppm	99999.99999	168	179	F12.5
Raw 256 channel data	cps	999	180	1203	I4
Energy calibrated 256 channel	cps	9999.9	1204	2995	F7.1

DATA PROCESSING

COORDINATE DATA

All lines are scissored to the following rules:
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