GEORGETOWN, QLD
AIRBORNE GEOPHYSICAL SURVEY, 1998
OPERATIONS REPORT

by

L. M. Richardson

Australian Geological Survey Organisation
Record 1999/13

DEPARTMENT OF INDUSTRY, SCIENCE AND RESOURCES

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SUMMARY

The Australian Geological Survey Organisation (AGSO) flew an airborne geophysical survey of 66 000 line km covering the Forest Home, Georgetown, North Head and Forsayth 1:100 000 map Sheet areas on the Georgetown 1:250 000 map Sheet area in north Queensland. The area covered the highly prospective mineralised fields of the Georgetown Block.

This survey, which formed part of the National Geoscience Mapping Accord, was flown along north–south flight lines 200 metres apart at an altitude of 80 metres above ground level. The survey was flown from September to November 1998.

The total magnetic intensity, gamma-ray spectrometric and digital elevation model data collected during the survey, have been processed and are available for purchase. These data are sold as digital point located data, grids and hardcopy maps by the Australian Geological Survey Organisation.

1. SURVEY AREA AND PARAMETERS

(i) Area Description

The Georgetown airborne survey covered the Forest Home, Georgetown, North Head and Forsayth 1:100 000 map Sheet areas on the Georgetown 1:250 000 topographic map Sheet area in Queensland. See Appendix A for a diagram of the exact survey area.

(ii) Survey Parameters

Altitude:	80 m nominal terrain clearance
Flight line direction:	North – South
Tie line direction:	East – West
Survey line spacing	
Flight line spacing:	200 metres
Tie line spacing:	2000 metres
Survey distance flown	
Lines:	59 835 km
Ties:	6 134 km
Total distance:	65 969 km
Sampling interval	
Magnetics (compensated, uncompensated and vector):	0.1 seconds (approx 7 metres)
Gamma–ray spectrometrics 4 – channel data:	1.0 seconds (approx 70 metres)
Accumulated 256 channel spectra:	1.0 seconds (approx 70 metres)
GPS:	0.5 seconds (approx 35 metres)
Altimeter:	1.0 seconds (approx 70 metres)
Barometric pressure:	1.0 seconds (approx 70 metres)
Temperature:	1.0 seconds (approx 70 metres)
Humidity:	1.0 seconds (approx 70 metres)

2. LOGISTICS

(i) Operating Base and Dates of Flying

(a) Operating Base

Aircraft and crew were based in Georgetown, Queensland for the duration of the survey from 9 September to 4 November 1998.

(b) Flying Dates

Calibration flights for the Automatic Aeromagnetic Digital Compensator (used to compensate for the magnetic field of the aircraft) were flown at the start of the survey, after aircraft services and installation of any new equipment. Production flying commenced on 11 September and continued through to 2 November. Appendix B summarises flying days and distances flown.

(ii) Survey Aircraft and Field Crew

(a) Aircraft

Aero Commander 500 S "Shrike", VH-BGE

(b) Field Crew

Party Leader:	Murray Richardson	9 September to 4 November
Technicians:	Jim Whatman	9 September to 1 October
	Steve Thomas	24 September to 4 November
Operator:	Craig Smith	9 September to 4 November
Pilots (Pearl Aviation):	Capt. Lee Geraghty	9 September to 1 October
	Capt. Shane Lawrey	9 September to 4 November
	Capt. Mike Waters	25 September to 22 October
	Capt. Anthony Whitten	12 October to 4 November

3. SURVEY EQUIPMENT

(i) Major Equipment

Magnetometer:	Geometrics G822A caesium magnetometer
Compensator:	RMS Instruments Automatic Aeromagnetic Digital Compensator
Gamma–ray spectrometer:	Exploranium gamma–ray spectrometer consisting of a GR820 spectrum processor and two DET1024 spectrometer crystal detectors (33.56 litres total)
Altimeter:	Collins ALT–50 radar altimeter
Barometer:	AGSO digital – Setra sensor
Thermometer/Humidity:	AGSO digital – RS combined temperature and humidity sensor
Navigation:	Ashtech XII "Ranger"/"ZSurveyor" GPS receivers and Ashtech "Ranger"/"PNAV" differential processing software. Fugro Omnistar Plus real time differential GPS base station system.
Video:	National colour video camera (WV CL 302E) National VCR (NV 180) National LCD TV (TCL 3A)
Acquisition hardware:	Axiom–Ax6150A industrial computer, 3.5 inch floppy disc drive, 504 Mb removable SCSI hard disc, IOMEGA SCSI zip drive and Planar VGA monitor.
Acquisition software:	AGSO-developed QNX C language program

(ii) Navigation

(a) GPS Navigation System

Navigation in the survey aircraft was by the real-time differential GPS method. The aircraft navigation system used an Ashtech XII global positioning system (GPS) receiver which manipulated range data received from satellites every 0.5 seconds and calculated the current latitude and longitude coordinates of the aircraft in the World Geodetic System 1984 (WGS84). The range data were recorded internally in the "Ranger" GPS receiver every 1.0 seconds. Differential GPS corrections to the range data, supplied by Fugro Starfix Pty Ltd, were transmitted in real time via an Optus satellite link to a Fugro OmniStar Plus base station system. The real time method employed is described more fully in Appendix C. The "ZSurveyor" GPS receiver recorded satellite range data onto PCMCIA flash disks every 1.0 second.

The real time differentially corrected position of the aircraft was recorded on the aircraft acquisition system every 0.5 second and was used to provide the pilot with aircraft guidance information on an LCD display.

To enable differential GPS post flight processing, a second "ZSurveyor" GPS receiver was set up at AGSO's field office as a GPS base station and recorded range data onto PCMCIA flash disks every 1.0 second. The AGSO field office was located in a small room in the Etheridge Shire Council offices. The data were post processed using Ashtech 'PNAV' software at the end of each flight. The error in position of the post processed flight path data is approximately 1-2 metres.

The position of the base station GPS receiver was accurately determined by differential GPS surveying using as a fixed reference point the “Sullivan” survey mark located 11 km south of Georgetown on the Forsayth road.

The coordinates in WGS 84 for the reference point Sullivan are:

Longitude	: 143°	29'	58.6132" E	
Latitude	: 18°	22'	45.2822" S	
Ellipsoidal height	:		479.835 metres	

The determined base station GPS coordinates (WGS 84) were:

Longitude	: 143°	32'	59.85288" E	
Latitude	: 18°	17'	31.48628" S	
Ellipsoidal height	:		405.049 metres	

The horizontal positions of the geophysical data from the survey are reported with respect to the WGS84 datum which is almost identical to the Geocentric Datum of Australia (GDA). It is intended that the GDA will be fully adopted in Australia by the year 2000. In the survey area there is an apparent translation in geographical position of 214 metres to the north–east from AGD66 to WGS84.

(b) Video Flight Path Recording

The aircraft's flight path was recorded on a VHS video system consisting of a National colour video camera with a wide angle lens, a National VCR and a National LCD TV.

(iii) Magnetometer

A Geometrics G822A caesium magnetometer, with the sensor mounted in a boom attached to the rear of the aircraft, was used for the survey. The specifications of the magnetometer are summarised in Appendix D.

The recorded total magnetic field data were compensated in real time using an RMS Instruments automatic aeromagnetic digital compensator (AADC). The AADC compensates for the effects of aircraft motion and heading. The specifications of the AADC are summarised in Appendix E. Compensation procedures are described in Chapter 4.

The AADC applies a low pass filter to the total magnetic field intensity data using a second order 0.9 Hz recursive Butterworth filter. The uncompensated, the filtered compensated total magnetic field intensity data and the XYZT components of the fluxgate sensor mounted in the aircraft starboard wingtip, were all recorded on the aircraft acquisition system.

(iv) Gamma-ray Spectrometer

An Exploranium gamma-ray spectrometer, incorporating two DET1024 crystal detectors with a total volume of 33.56 litres, was used. The crystal gains were controlled by an Exploranium GR820 spectrum processor. Appendix F summarises the specifications of the gamma-ray spectrometer components.

Two hundred and fifty six channels of data between 0.0 MeV and 3.00 MeV were recorded every second.

Additionally five channels of data were recorded once a second using the following window limits:

Total Count	0.41-2.81 MeV
Potassium	1.37-1.57 MeV
Uranium	1.66-1.86 MeV
Thorium	2.41-2.81 MeV
Cosmic	3.00 MeV and above

The total count, potassium, uranium and thorium data were used for data quality control and the cosmic counts were used for background estimation and later data processing.

System live time (sample time - total dead time) was output with the data for later data processing.

(v) Altimeter

A Collins ALT-50 radar altimeter was used to measure ground clearance. The radar altimeter display indicates ground clearance from 0-2000 feet. The manufacturer's specifications claim a +/-2% accuracy for the ALT-50 system.

(vi) Barometer, Thermometer and Humidity

Atmospheric temperature, pressure and humidity were measured using a digital barometer (Setra sensor) and combined digital thermometer/humidity sensor (RS sensor). Although both of these units were built by AGSO, the sensors were factory calibrated and no AGSO calibrations were performed.

(vii) Base Station Magnetometer

Daily variations of the Earth's magnetic field were monitored using a Geometrics G–823B base station caesium magnetometer, the specifications of which are given in Appendix G. The base station was set up approximately 690 metres east of the AGSO office in an area of shallow magnetic gradient, away from cultural influences and within telemetry range of AGSO's office. Data from the base station were telemetered back to the AGSO's field office caravan for display and recording on a Toshiba Pentium 110 CS lap–top computer. The telemetry system used Proxim Proxlink MSP–500 modems. The software program, "DIURNAL", developed in–house by AGSO, was used to display and log diurnal data.

Base station diurnal data were recorded at an interval of 0.1 seconds for every production and compensation flight.

(viii) Aircraft Data Acquisition

The aircraft acquisition program and system were run using an Axiom–Ax6150A industrial 486 computer with data recorded via an IOMEGA SCSI zip drive onto 100 Mb zip discs.

The acquisition program written in the QNX C language was developed in-house at AGSO. A schematic diagram of the aircraft's acquisition system is shown in Appendix H.

4. CALIBRATION

(i) Compensation for the Magnetic Field of the Aircraft

Compensation flights were flown prior to the start of the survey and after each aircraft service. These flights were conducted over a magnetically quiet zone 60 km southwest of Georgetown at an altitude of 2800 metres above ground level, between 142º 42' E to 143º 5' E and -18º 36' to -18º 18'.

The compensation comprises a series of rolls(+/-10°), pitches(+/-5°) and yaws(+/-5°) in the four cardinal headings to enable the AADC to calculate correction coefficients needed to remove aircraft manoeuvre noise. Each manoeuvre component was of 30 seconds duration.

The compensation manoeuvres were repeated after calculation of the coefficients to check the compensation quality. Peak-to-peak noise during repeat manoeuvres and after the final compensation was 0.15 nT or less. On normal survey flights, noise levels from all sources were generally less than 0.15 nT peak-to-peak.

The AADC calculates basic statistics which reflect the degree of merit of the compensation. These include the standard deviation of the recorded data without corrections applied, the standard deviation with the corrections applied, the improvement ratio (the ratio of the standard deviation of the recorded data without and with the corrections applied) and the vector norm (the degree of difficulty in calculating the corrections). Examples of these statistics are given for all of the compensations in Appendix I.

(ii) Gamma-ray Spectrometer Calibration

The GR820 spectrum processor uses a sophisticated automatic control method to maintain crystal alignment while stabilising on naturally occurring isotopes (typically potassium). During operation the system continuously monitors each of the eight crystal signals and accumulates a separate spectra for each configured signal. When the confidence level for the selected stabilisation peak (potassium) is exceeded, the peak channel of this isotope is computed, compared to the correct peak location, and the gain is then corrected. The gain for each crystal was corrected at least every 30 minutes.

Gamma-ray spectrometric test lines were flown at the beginning and end of each production flight. The survey area was flown from the eastern to the western boundary. To reduce ferry times at the start of each survey flight, two test lines were used for this survey. One in the eastern half and one in the western half of the survey area. Test line A was used from the start of the survey until 13 October, test line B was used from 14 October until the end of the survey. These lines were flown at survey altitude with data recorded for 100 seconds or approximately 6.5 km. The location of the test lines used for the Georgetown survey is shown in Appendix J.

Before any test line statistics were calculated the multichannel spectra were deadtime corrected, energy calibrated and background corrected using a full spectrum method (Minty, 1992). The spectra were then integrated over the conventional 4-channel windows prior to stripping and height correction.

After each flight, statistics were calculated from data recorded between fixed reference points along the test line. These statistics were recorded in spreadsheet form and compared with the preceding flights in order to detect any irregularities. In particular, the difference between the average in the total count channel for the most recently flown test line and the running average of all the previously flown test lines was analysed. This value only rarely varied by greater than 10% for the test line, well inside a 15% variation which would be considered acceptable.

5. DATA PROCESSING

Flight path recovery, data checking and editing, and preliminary processing, gridding and imaging were performed at the survey base using the Geophysical Mapping Section's INTREPID airborne geophysical data processing and visualisation system. Final magnetic, gamma-ray spectrometric and digital elevation model data processing were carried out in Canberra using INTREPID.

(i) Data Checking and Editing

Data recorded on the aircraft acquisition system were transferred on a flight by flight basis to a hard disk on a Scorpion 10/20 Sparcstation to be edited for missing values, noise, spikes or steps using INTREPID. All the recorded data were displayed for each survey line and any errors were interactively corrected. Anomalies arising from cultural influences, such as sheds, houses, fences and pipelines were usually not edited out. They were only edited out if they caused severe noise or caused the magnetometer to lose lock.

(ii) Flight Path Recovery

Range data which were recorded internally every one second on both “ZSurveyor” GPS receivers were post-processed daily in the field using "PNAV" - an Ashtech proprietary program. "PNAV" calculates the corrected flight path (longitude, latitude and height) relative to the WGS84 reference ellipsoid.

At the end of each flying day the corrected longitude and latitude data calculated at one second intervals by "PNAV" were used to correct the GPS data recorded every half second on the aircraft acquisition system. As well as the standard "PNAV" corrections, other acquisition system specific corrections were applied. Position data were retained in the WGS84 coordinate system. The World Geodetic System 1984 (WGS84) coordinate system is defined in Appendix K. The full correction procedure is described in Appendix L and is outlined below:

(a) Position calculation delay correction.

(b) Fiducial synchronisation correction.

(c) "PNAV" corrections.

(d) Low pass filter.

(e) Reference navigation data to position of magnetometer sensor.

(f) Linear infill of gaps.

The fully corrected flight path was plotted each day to check the position of survey lines and their spacing. For the survey line spacing of 200 metres navigation reflies were determined by the following criteria:

Across Track Deviation	Distance along line	GPS Data Gap
20 metres	greater than 1 km	greater than 3 km

Whenever the across track deviation and along line distance or the GPS data gap were exceeded, the survey line was reflown or an infill line flown to rectify the problem. This occurred very infrequently.

(iii) Magnetic Data Processing

Raw magnetic data were merged with the navigation data, and diurnal variation corrections were removed. The IGRF 1990 geomagnetic reference field, updated to 1998.83 at an altitude of 680 metres above sea level, which was estimated to be the mean survey altitude, was then subtracted from the data.

The IGRF was calculated from the coefficients defined by the IAGA (1991). All magnetic values were adjusted by a constant so that the average residual magnetic field value was approximately 5000 nT.

The data were levelled using standard tie line levelling procedures. Luyendyk (1997) describes the procedure involved in the tie line levelling method in more detail. The steps involved in the tie line levelling were as follows:

(a) Tie line 380 was chosen as a reference tie.

(b) All other ties were levelled to tie line 380 using degree three polynomial adjustments.

(c) Lines were adjusted on a flight by flight basis using degree three polynomial adjustments to minimise the differences at line/tie crossover points.

(d) Finally the lines were individually adjusted using degree three polynomial adjustments to minimise crossover differences.

The data were micro-levelled using the technique described by Minty (1991). Filter characteristics are described below.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 5000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 600 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1000 metres before being applied to the line data and were constrained to fall within the range ±10 nT. Statistics on the applied corrections indicated that 99.9% of the corrections were between ±2 nT.

At the end of the first pass of tie–line levelling and microlevelling an image of the magnetic data with artificial illumination perpendicular to the flight line direction was made. In this image several areas displayed levelling errors which required further processing.

Eight areas required further microlevelling. The vertices of each survey area and the filter characteristics applied are listed in the table below.

Area	Longitude	Latitude	(a)Filter width (m)	(b)Filter length (m)	(c)Bounds ±x nT
1	143.008333	-18.012500	250	650	2
	143.058333	-18.012500			

	143.058333	-18.045833			
	143.008333	-18.045833			
2	143.273333	-18.097222	300	700	5
	143.311255	-18.097222			
	143.311255	-18.116666			
	143.273333	-18.116666			
3	142.991666	-18.077777	250	500	5
	143.116666	-18.077777			
	143.116666	-18.183333			
	142.991666	-18.183333			
4	143.919444	-18.486111	300	700	5
	143.972089	-18.486111			
	143.972089	-18.523611			
	143.919444	-18.523611			
5	143.333333	-18.688611	300	750	5
	143.377500	-18.688611			
	143.377500	-18.708888			
	143.333333	-18.708888			
6	142.983333	-18.566666	300	450	5
	143.316666	-18.566666			
	143.316666	-18.991666			
	142.983333	-18.991666			
7	143.858333	-18.033333	300	450	2
	143.936111	-18.033333			
	143.936111	-18.216666			
	143.878694	-18.288531			
8	142.983333	-18.012500	300	450	5
	143.079167	-18.012500			
	143.137500	-18.093056			
	142.983333	-18.220833			

where

(a) Filter width denotes the cut-off wavelength in metres for a high pass filter in the tie line direction.

(b) Filter length denotes the cut-off wavelength in metres for a low pass filter in the flight line direction.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1000 metres before being applied to the line data and were constrained to fall within the range as indicated. Statistics on the applied corrections indicated that 99.00% of the corrections were between ±0.1 nT.

The micro-levelled data were gridded using the minimum curvature technique described by Briggs (1974), with a 1.5 second (40 metre) grid cell size.

(iv) Gamma-ray Spectrometer Data Processing.

A combination of full-spectrum and 3-channel processing methods were used to correct the gamma-ray spectrometric data. The raw spectra were first smoothed using the Noise Adjusted Singular Value Decomposition spectral smoothing technique, described by Hovgaard and Grasty (1997), applied to spectral clusters according to the methodology described by Minty and McFadden (1998). This method transforms observed spectra into orthogonal spectral components. The higher-order components represent the signal in the observed spectra, and the lower-order components represent uncorrelated noise. Noise is removed from the observed spectra by rejecting noise components and reconstructing smooth spectra from the higher-order components. For this survey, 8 higher-order components were used to reconstruct the smooth spectra. The smoothed spectra were livetime corrected, energy calibrated and background corrected. The spectra were then summed over the conventional 4-channel windows (IAEA, 1991), for subsequent stripping and height correction as described below.

The energy calibration was effected by using the positions of prominent photopeaks in the sum spectrum for each line to obtain an estimate of the energy at channel one and the gain (keV per channel). These parameters were then used to correct each spectrum in the line by resampling each channel to its correct energy range.

The three components of background were removed as follows.

(a) Aircraft and Cosmic Background.

Aircraft and cosmic spectra for the AGSO aircraft were determined from high altitude calibration flights using the procedure described by Minty and Richardson (1989).

(b) Atmospheric Radon Background.

A full spectrum method (Minty, 1996) was used to remove radon background. The method is based on the assumption that the observed spectrum (after correcting for aircraft and cosmic background) is the linear sum of the spectra due to K, U and Th in the ground and atmospheric radon. Since the shapes of these spectra can be determined through suitable calibrations, the atmospheric radon contribution to the observed spectrum can be estimated.

The energy-calibrated and background-corrected spectra were then summed over the conventional 4-channel windows recommended by the IAEA (IAEA, 1991). Stripping (channel interaction correction) to correct for Compton scattering was applied to the K, U and Th window count rates as follows.

$$N_{TH(corrected)} = N_{TH}$$
$$N_{U(corrected)} = N_U - A \times N_{TH(corrected)}$$
$$N_{K(corrected)} = N_K - B \times N_{TH} - C \times N_{U(corrected)}$$

where

N_{TH} = counts in the thorium channel

N_U = counts in the uranium channel

N_K = counts in the potassium channel

A = 0.2588 + 0.00049 * height

B = 0.4300 + 0.00065 * height

C = 0.7518 + 0.00069 * height

The TC, K, U and Th window count rates were height corrected to a nominal survey flying height of 80 m. Where the aircraft attained a height of 250 m or higher above the ground, 250 m was used to height correct the potassium and thorium elemental count rates. For uranium, the maximum aircraft height used in the height correction was 160 m.

The height corrections were applied as follows.

$$N_{corrected} = N_{uncorrected}\, e^{-\mu\,(H-h)}$$

where

$N_{corrected}$ = corrected counts (cps)

$N_{uncorrected}$ = uncorrected counts (cps)

H = nominal flying height (m)

h = measured flying height (m)

μ = attenuation coefficient (m^{-1})

Attenuation coefficients for each channel are given below.

μ total count = 0.00785 (m^{-1})

μ potassium = 0.00943 (m^{-1})

μ uranium = 0.01150 (m^{-1})

μ thorium = 0.00748 (m^{-1})

The corrected window count rates were converted to ground concentrations of K, U and Th using the expression:

$$C = \frac{N}{S}$$

where

C = concentration of the radioelement (K%, U ppm or Th ppm);
S = broad source sensitivity for the elemental count rate; and
N = the fully processed elemental count rate (cps).

The broad source sensitivities were obtained from flights over a calibration range. The following sensitivities were used:

Potassium:	110.42	cps/%K
Uranium:	8.33	cps/ppm eU
Thorium:	5.79	cps/ppm eTh.

The total count was converted to the equivalent air-absorbed dose rate at ground level using the expression:

$$D = \frac{N}{F}$$

where

D = the air absorbed dose rate (nGh^{-1});
F = the conversion factor determined experimentally from flights over a calibration range (29.70 cps/nGh^{-1}); and
N = the total count rate (cps).

The data were not levelled using standard tie line levelling procedures. Instead, the data were micro-levelled using the technique described by Minty (1991). Filter characteristics are described in the following table.

Channel	[a]Filter width	[b]Filter length	[c]Bounds ±x units	Statistics ±x units
Dose Rate (nG/hr)	300	1500	30	97.3 % ±5
Potassium (%)	300	1500	10	92.6 % ±0.1
Uranium (ppm)	300	1500	0.8	92.8 % ±0.25
Thorium (ppm)	300	1500	1.2	96.1 % ±1

where

[a] Filter width denotes the cut-off wavelength in metres for a high pass filter in the tie line direction.

[b] Filter length denotes the cut-off wavelength in metres for a low pass filter in the flight line direction.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1000 metres before being applied to the line data and were constrained to fall within the range as indicated. Statistics on the applied corrections are indicated in the last column and indicate the percentage of corrections falling between the bounds indicated.

The uranium channel data were micro–levelled a second time to remove broad bands in the image using the following parameters.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 10 000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 2000 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1 000 metres before being applied to the position located data. Adjustments were limited to a maximum of 0.5 ppmU. Statistics on the applied corrections indicated that 93.6% of the corrections were between ±0.25 ppmU.

The four channels of micro-levelled data were gridded using the minimum curvature technique described by Briggs (1974), with a 1.5 second (40 metre) grid cell size.

(v) Digital Elevation Model Data Processing

As described in Chapter 5, Section (ii), range data recorded internally every one second on the Ashtech Z Surveyor GPS receiver were post—processed on a daily basis using "PNAV" — an Ashtech proprietary program. "PNAV" calculates the position of the aircraft GPS receiver's antenna, including longitude, latitude and height relative to the WGS84 reference ellipsoid for each set of range data (every one second).

As in the case of the longitude and latitude data, the following acquisition system specific corrections, which are described in Appendix L, are applied to the height data.

(a) Position calculation delay correction.

(b) Fiducial synchronisation correction.

The corrected height data, which are relative to the WGS84 reference ellipsoid, are then linearly interpolated to one half of one second samples (35 m) and merged with the longitude and latitude data.

A radar altimeter provided the aircraft's ground clearance, the altimeter data being sampled every one second.

The raw ground elevation data were then calculated as the difference between the height of the aircraft above the ellipsoid and the height of the aircraft above the ground. These raw elevation data calculated every one second (70 m along the ground) are relative to the WGS84 reference ellipsoid - the ellipsoid being a horizontal datum.

The next step was to convert the heights relative to the WGS84 ellipsoid to heights relative to the geoid. The geoid, which is defined as "the equipotential surface of the gravity field which best approximates mean sea level", is usually chosen as the datum to which heights plotted on maps are referred. The height of the geoid above the WGS84 ellipsoid is called the geoid-ellipsoid separation or N value.

Geoid-ellipsoid separation information for the Georgetown Sheet areas was supplied by the Australian Surveying and Land Information Group (AUSLIG) in December 1998. The set of N values were supplied as a 10 minute of arc (approximately 18 km) grid. AUSLIG also provides a program "DINTER" which uses bilinear interpolation to calculate N values on a one minute of arc (approximately 1 600 metre) grid. These values were then regridded. to a cell size of 12 seconds of arc (approximately 320 metres). This grid of N values was then used to calculate correction strings to be subtracted from the elevation data. The correction strings were low pass filtered with a cut-off wavelength of 1 000 metres before being applied to the point-located elevation data.

The elevation data were then corrected to account for the vertical separation between the antenna of the aircraft's GPS receiver, on the roof of the aircraft, and the radar altimeter antenna on the belly of the aircraft. This antenna separation distance of 1.675 metres was also subtracted from the elevation data.

The elevation data were levelled using tie line information and then micro-levelled.

The steps involved in the tie line levelling were as follows:

(a) Tie line 380 was chosen as a reference tie.

(b) All other ties were levelled to the reference tie using degree one polynomial adjustments.

(c) Lines were adjusted on a flight by flight basis to minimise the differences at line/tie crossover points, using degree one polynomial adjustments.

(d) Finally the lines were adjusted individually to minimise crossover differences, using degree one polynomial adjustments.

The data were micro–levelled using the technique described by Minty (1991). Filter characteristics are described below.

(a) Low pass filter in the flight line direction with a cut-off wavelength of 3 000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 800 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1 000 metres before being applied to the position located data. Adjustments were limited to a maximum of 30 metres. Statistics on the applied corrections indicated that 96.8% of the corrections were between ±10 metres.

The accuracy of the position located height data is expected to be better than +/- 2 metres. Relative precision from point to point along a flight line is expected to be better than +/- 1 metres.

A comparison between several ground elevations from the airborne DEM profile data and terrain elevations from third order gravity traverses across the survey area are listed in the following table:

Longitude (DMS)	**Latitude (DMS)**	**Terrain Height (m)**		**Difference (m)**
		Airborne DEM	**3rd order gravity**	
143-09 24.8	-18-02-09.0	213.23	204.59	+8.64
143-40-21.2	-18-20-26.1	335.55	327.25	+8.30
143-22-58.6	-18-10-55.8	254.29	255.48	-1.19
143-53-03.8	-18-07-31.7	348.24	354..64	-6.40
143-31-41.5	-18-18-07.4	301.78	300.05	+1.73
143-33-47.2	-18-55-20.8	400.60	392.62	+7.98
143-43-32.9	-18-53-20.2	495.22	496.11	-0.89
143-53-50.5	-18-27-14.5	737.08	730.99	+6.09
143-56-44.9	-18-37-03.0	670.30	667.56	+2.74

The offset between the flight line profiles and the gravity traverses was at most 100 metres. In most cases terrain heights from the airborne DEM profiles were higher than terrain heights from the gravity traverses. The average difference in elevations between the airborne DEM profiles and the gravity traverses is 6.0 metres with a standard deviation of 15.0 metres.

The micro-levelled data were gridded using ANUDEM46 (Hutchinson, 1988, 1989) with a 1.5 second (40 metre) grid cell size.

(vi) Final Products

(a) Standard AGSO geophysical maps

An AGSO standard set of geophysical maps have been produced at scales of 1:100 000 for the entire survey area. Flight path and contour maps were produced using the INTREPID processing system. The standard set of maps produced are shown in Appendix M.

(b) Digital Data

Final processed point-located data and grids were archived in the standard AGSO ARGUS format, on exabyte magnetic tape cartridges and compact discs, in ASCII format (Appendix N).

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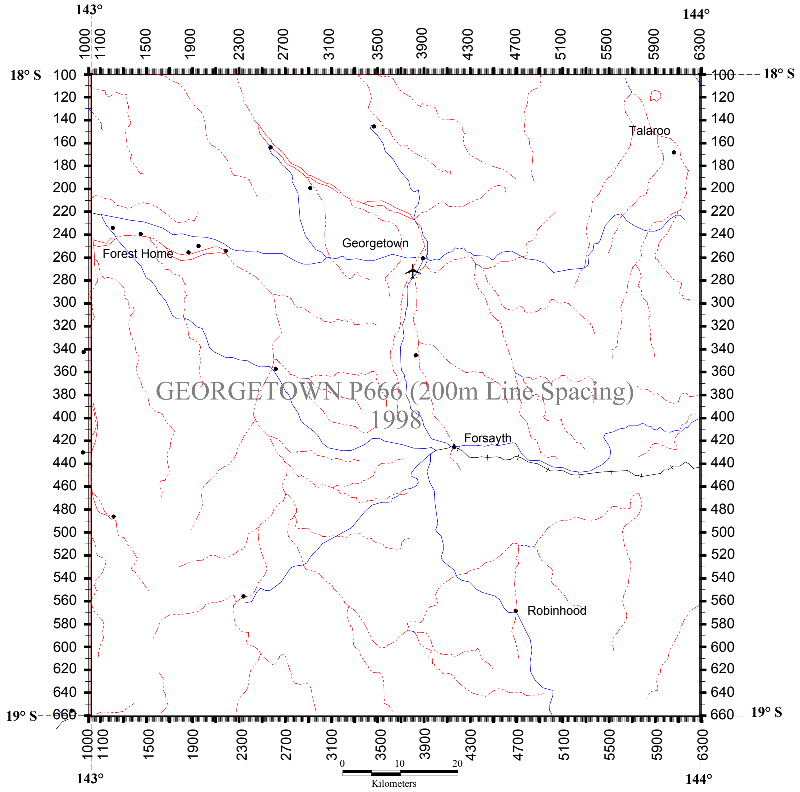
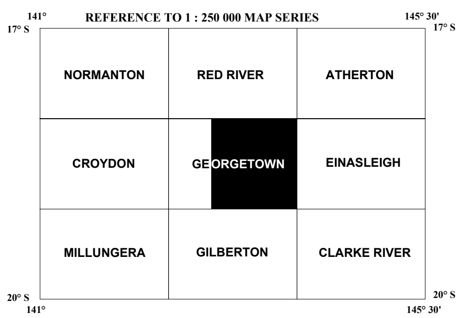
APPENDIX A

Survey Area



GEORGETOWN QLD 1998 P666



Appendix B1

FLYING DATES AND LINE KILOMETRES ACCEPTED

DATE	FLIGHT No.	COMMENTS	LINE KM
10-9-98	300	Compensation Flight	0
11-9-98	301	Operations Normal	1045
11-9-98	302	Operations Normal	1155
12-9-98	303	Operations Normal	1100
12-9-98	304	Operations Normal	1100
13-9-98	305	Flight aborted Port engine tachometer failed	0
16-9-98	306	Compensation flight	0
17-9-98	307	Operations Normal	1100
17-9-98	308	Operations Normal	1100
18-9-98	309	Operations Normal	1100
18-9-98	310	Operations Normal	1100
19-9-98	311	Operations Normal	1100
19-9-98	312	Operations Normal	880
20-9-98	313	Operations Normal	1100
20-9-98	314	Operations Normal	1100
21-9-98	315	Flight aborted - too windy	220
24-9-98	316	Operations Normal	1100
24-9-98	317	Operations Normal	1155
25-9-98	318	Operations Normal	660
26-9-98	319	Operations Normal	990
27-9-98	320	Operations Normal	880
27-9-98	321	Operations Normal	990
28-9-98	322	Operations Normal	1320
28-9-98	323	Flight aborted - data disk failure	550
29-9-98	324	Operations Normal	770
29-9-98	325	Operations Normal	770
30-9-98	326/7	Operations Normal	1045
30-9-98	328	Operations Normal	880
1-10-98	329	Operations Normal	990
3-10-98	330	Compensation flight/Operations Normal	220
4-10-98	331	Operations Normal	880
5-10-98	332	Operations Normal	1320
5-10-98	333	Flight aborted - severe turbulence	110
6-10-98	334	Operations Normal	935
6-10-98	335	Operations Normal	770
7-10-98	336	Operations Normal	990
8-10-98	337	Operations Normal	1320
8-10-98	338	Operations Normal	880
9-10-98	339	Flight aborted - alternator failure	0
10-10-98	340	Operations Normal	1045
10-10-98	341	Operations Normal	825
11-10-98	342	Operations Normal	770

Appendix B2

FLYING DATES AND LINE KILOMETRES ACCEPTED

DATE	FLIGHT No.	COMMENTS	LINE KM
12-10-98	343	Operations Normal	1100
12-10-98	344	Operations Normal	880
13-10-98	345	Operations Normal	990
14-10-98	346	Operations Normal	880
15-10-98	347	Operations Normal	440
16-10-98	348	Operations Normal	1320
17-10-98	349	Operations Normal	660
17-10-98	350	Operations Normal	990
18-10-98	351	Operations Normal	770
19-10-98	352	Operations Normal	935
19-10-98	353	Operations Normal	770
20-10-98	354	Operations Normal	770
20-10-98	355	Operations Normal	990
21-10-98	356	Operations Normal	1265
21-10-98	357	Operations Normal	880
22-10-98	358	Operations Normal	1210
22-10-98	359	Operations Normal	550
25-10-98	360	Compensation Flight	0
25-10-98	361	Operations Normal	550
26-10-98	362	Operations Normal	990
26-10-98	363	Operations Normal	990
27-10-98	364	Operations Normal	1320
27-10-98	365	Operations Normal	880
28-10-98	366	Operations Normal	1210
28-10-98	367	Operations Normal	990
29-10-98	368	Operations Normal	1320
29-10-98	369	Operations Normal	880
30-10-98	370	Operations Normal	1100
30-10-98	371	Operations Normal	880
1-11-98	372	Operations Normal	1265
1-11-98	373	Operations Normal	910
2-11-98	374	Operations Normal	600

Total line/tie kilometres flown		66000
Total flights in survey	75	
Productive survey flights	67	
Compensation flights only	3	
Abandoned flights	5	
Abandoned survey flights consisted of:		
Equipment malfunction	3	
Weather	2	

APPENDIX C
REAL TIME DIFFERENTIAL GPS

Real time differential GPS navigation is a method used to improve navigation accuracy. Line tracking using this method is more precise than by the single GPS receiver method thus allowing a pilot to fly an aircraft to an accuracy of better than 5 m.

The navigation equipment used for this survey consisted of two Ashtech GPS receivers in the aircraft - (Ashtech XII, Ashtech Z-Surveyor) - and one Ashtech Z-Surveyor GPS receiver located at a known position on the roof of the Etheridge Shire Council offices at Georgetown. The ground based GPS receiver operated in non-differential mode while the aircraft Ashtech XII GPS receiver was configured to run in differential mode.

Fugro Starfix Pty Ltd supplied the satellite range corrections to the aircraft. The range corrections were calculated using Fugro's OmniSTAR Wide Area Differential GPS (WADGPS) service. OmniSTAR is a differential GPS service over Australia which is supported by a network of reference stations located throughout the continent to provide differential GPS corrections back to Fugro's Network Control Centre (NCC) in Perth. The WADGPS service allows monitoring of data from more than one reference station, quality control parameters, weighted least squares solution and improved accuracy over a single reference station

The range corrections from all the available reference stations are transmitted to the NCC in Perth, then to an OmniSTAR Plus - Enhanced Differential System (EDS) receiver in the aircraft via the Optus satellite. The EDS receiver contains a demodulator board, an eight channel GPS engine, a computing engine and an interface and power supply board. The OmniSTAR Plus demodulator receives the Fugro compressed data from the satellite and using the aircraft's position and the "least squares method" computes an optimum set of RTCM (Radio Technical Commission for Maritime Services) corrections for output to the aircraft GPS receiver. The EDS receiver calculates the aircraft position from the internal GPS engine and then provides corrections for output to the aircraft GPS receiver in RTCM 104 format.

The EDS receiver gets satellite range data and range correction data through an OPTUS plate antenna on the roof of the aircraft. Both Ashtech GPS receivers in the aircraft uses an Ashtech plate antenna for receiving satellite range data. The EDS receiver outputs corrections to the aircraft Ashtech XII GPS receiver at 4800 baud.

APPENDIX D

SPECIFICATIONS - G822A CAESIUM MAGNETOMETER

Operating principle:	Self-oscillating cesium vapour magnetometer
Operating range:	20,000 to 95,000 nT
Active Zones:	Sensor equator ±10° H_o field sensor axis ±10°, switchable or auto switch
Noise level:	<= 0.01 nT peak-to-peak
Heading error:	<= ± 0.25 nT, <= 0.5 nT envelope
Power required:	26 to 32 VDC, 500 mA continuous, 750 mA while starting
Output:	2V p-p, f (Hz) = 3.498 H_o (nT)
Interface:	Larmor signal AC coupled to power input
Environmental:	-35 °C to +50 °C, humidity 95% non-condensing
Dimensions:	Sensor: 5 cm diameter, 18 cm long, 140 grams Electronics module: 5 cm wide, 5 cm high, 23 cm long 170 grams Sensor electronics cable: 135 cm to 270 cm long
Qualification:	MIL-I-45208, MIL-M-19595

APPENDIX E-1

Specifications - RMS Instruments
Automatic Aeromagnetic Digital Compensator

INPUTS:	one or two high sensitivity magnetometers of optical absorption type.
INPUT FREQUENCY RANGE:	70 KHz - 350 KHz - Cs sensor 140 KHz - 700 KHz - K sensor 560 KHz - 2800 KHz - He sensor 850 Hz - 4260 Hz - Overhauser
MAGNETIC FIELD RANGE:	20,000 - 100,000 nT (gamma)
RESOLUTION:	1 pT (picotesla)
COMPENSATION PROCEDURE:	improvement ratio 10 - 20 typical for total field improvement ratio 20 - 100 typical for gradient
ACCURACY OF COMPENSATION:	0.035 nT (gamma) standard deviation for the entire aircraft flight envelope in the bandwidth 0 - 1 Hz typical
DATA OUTPUT RATE:	10 Hz
SYSTEM FREQUENCY RESPONSE:	0 - 0.9 Hz
INTERNAL SYSTEM NOISE:	less than 2 pT (standard deviation in the bandwidth 0 - 1 Hz)
DURATION OF CALIBRATION: FLIGHT MANOUEVRES	5 - 8 minutes typical
VECTOR MAGNETOMETER:	Develco Model 9202-02 (3-axis fluxgate)
MICROCOMPUTER:	SBC-11/21 Plus (DEC) Front End LSI-11/73 (DEC) Main CPU
KEYBOARD:	limited alphanumeric
DISPLAY:	green fluorescent, 80 character self scan panel
OUTPUTS:	serial data communication port: RS232C - max. rate 19.2 K Baud parallel output port: 16 bit with full handshaking (DRV11-J) (optional)

APPENDIX E-2

Specifications - RMS Instruments
Automatic Aeromagnetic Digital Compensator

POWER:	28 +/- 4 VDC, 5A, 150 W (for single magnetometer) 7A, 196 W (for gradiometer system)
ENVIRONMENTAL:	
OPERATING TEMPERATURE:	0 to 50 degrees C
STORAGE TEMPERATURE:	-20 to 55 degrees C
RELATIVE HUMIDITY:	0 - 99%, non-condensing
ALTITUDE:	0 - 6000 m (0 - 20,000 ft)
PHYSICAL DATA:	console dimensions: 483 x 178 x 440 mm console weight: 12.5 kg power supply dimensions: 225 x 180 x 220 mm power supply weight: 5.5 kg

APPENDIX F-1
SPECIFICATIONS - GR820 SPECTROMETER SYSTEM

A. Detector Controller

- Maximum number of crystals - 16. Each crystal has individual pole-zero cancellation, semi-gaussian shaping and advanced base line restoration circuitry.
- Continuous, individual-crystal spectrum analysis ensures that optimum system stabilization is achieved. Resolution is calculated by a sophisticated gaussian curve fitting algorithm to perform an accurate centroid analysis of the selected stabilization peak.
- High energy cosmic pulses are accumulated in a separate channel.
- Accurate pile-up rejection for simultaneous pulses allows qualitative gamma-ray spectrum analysis almost independent of the system count rate. Special circuitry analyzes for pulse pile-up and permits only detector signals from single events to be analyzed. Simultaneous events in adjacent crystals are added to reduce the Compton effect.
- Residual pulse pile-up at 100,000 counts/sec are less than 2%.

B. Analog to digital converter (ADC)

- 50 Mhz Wilkinson ramp ADC.
- Linearity - integral - less than 0.2% ; - differential - less than 1%.
- Average system dead-time is less than 5 microsec/pulse.
- Live-time channel records the actual system live-time. This data is output with the digital data which allows post correction for system dead-time to an accuracy of 0.1%.
- Number of channels - selection of 256 channels or 512 channel operation.
- Maximum number of counts/channel - 65,535 (16 bits).
- The lower threshold - manually selectable from channel 2 to channel 50 (20-500 keV).
- The upper threshold is set to 3 MeV. All pulses above 3 MeV are accumulated in the cosmic channel as a direct measure of cosmic ray activity.
- ADC offset set from the keyboard.
- The maximum input count rate is 100,000 counts/second.

C. System outputs

- Visual display - the front panel display is a 640x200 electroluminescent (EL) high contrast graphics display which allows full spectrum display, system set-up and various parameter monitoring functions. In the spectrum display

  mode, the region of interest and cursor may be viewed by channel number or directly in keV.

- The internal channel number to energy level (keV) conversion table compensates for non-linearity of the detector's light output.
- The front panel has a 21 button keyboard for easy operator control.
- The system's operation is fully menu driven.
- Digital outputs
  - RS-232 port (1200 to 19200 baud).
  - IEEE-488 bus output - talk listen/talk only.
  - Geometrics GR-800 output format.
  - Some system functions can be controlled remotely by an external computer via the RS-232 and the IEEE-488 digital ports.
- Anolog output
  - 4 channels of roi data can be selected for output on the analog port. The outputs have 10 bit resolution (0-10V). Scaling can be set from the keyboard (100-50K counts/sec FSD) and output data may be raw or stripped using internally stored calibration constants. Analog output wraps at fsd limits and is dead-time corrected.

D. Miscellaneous

- Regions of interest (ROI) 8ROIs can be selected. The upper and lower thresholds can be individually set over the entire spectrum range.
- The first 4 ROIs are available for digital and analog output. The second 4 rois are available only for digital output on the RS-232 or the IEEE-488 ports.
- System resolution. Detector resolution is automatically computed for each (and summed crystals) during peak analysis and is displayed for operator monitoring when required. The summed down resolution is also output on the data stream.

  System test. At power on, a full system test of all internal pcb handshaking is performed. Included in the testing is the lithium back-up battery, the system ram memory, display handshaking, the systems configuration (options installed), the selected detectors (checked via ADC analysis) and peripheral handshaking response.
- Configuration menus. The configuration menus allow the selection of the number of detectors in use, confidence levels for gain analysis, maximum crystal resolution levels for each detector (with operator warning if levels exceeded), output configurations for analog and digital data and various special display/monitoring functions.

  Maintenance. A set of special menus allows the user to test and calibrate many system functions including system test, ADC offset, low level discriminator etc.
- Power : 28V - 1.25 amps

E. Detectors

APPENDIX F-3
SPECIFICATIONS - GR820 SPECTROMETER SYSTEM

The crystals are housed in specially designed hi-impact polystyrene cases using low background materials for minimum signal attenuation. Full thermal and internal shock protection allows the units to be directly mounted to the floor. A very low noise, high voltage power supply is housed in each pack so high voltage is not present in the connecting cables. A unique preamplifier with special processing for signal optimization is used. The GPX-1024 has 4 crystals with a total volume of 16.78 litres

- Outputs : Individual BNC connectors output each crystal's signal separately.
- Size : GPX-1024 : 73x51x30 cms
- Weight : GPX-1024 : 84 kg
- Power : 28 V @ 0.5 A/crystal pack
- Temperature limitations

  Closed pack : storage -40° C to +60° C, operation -40° C to +60° C

  Open pack : not recommended

  Temperature gradient

  Closed pack : -40° C to +50° C (instantaneous)

  Open pack : a change of 1° C/hr.

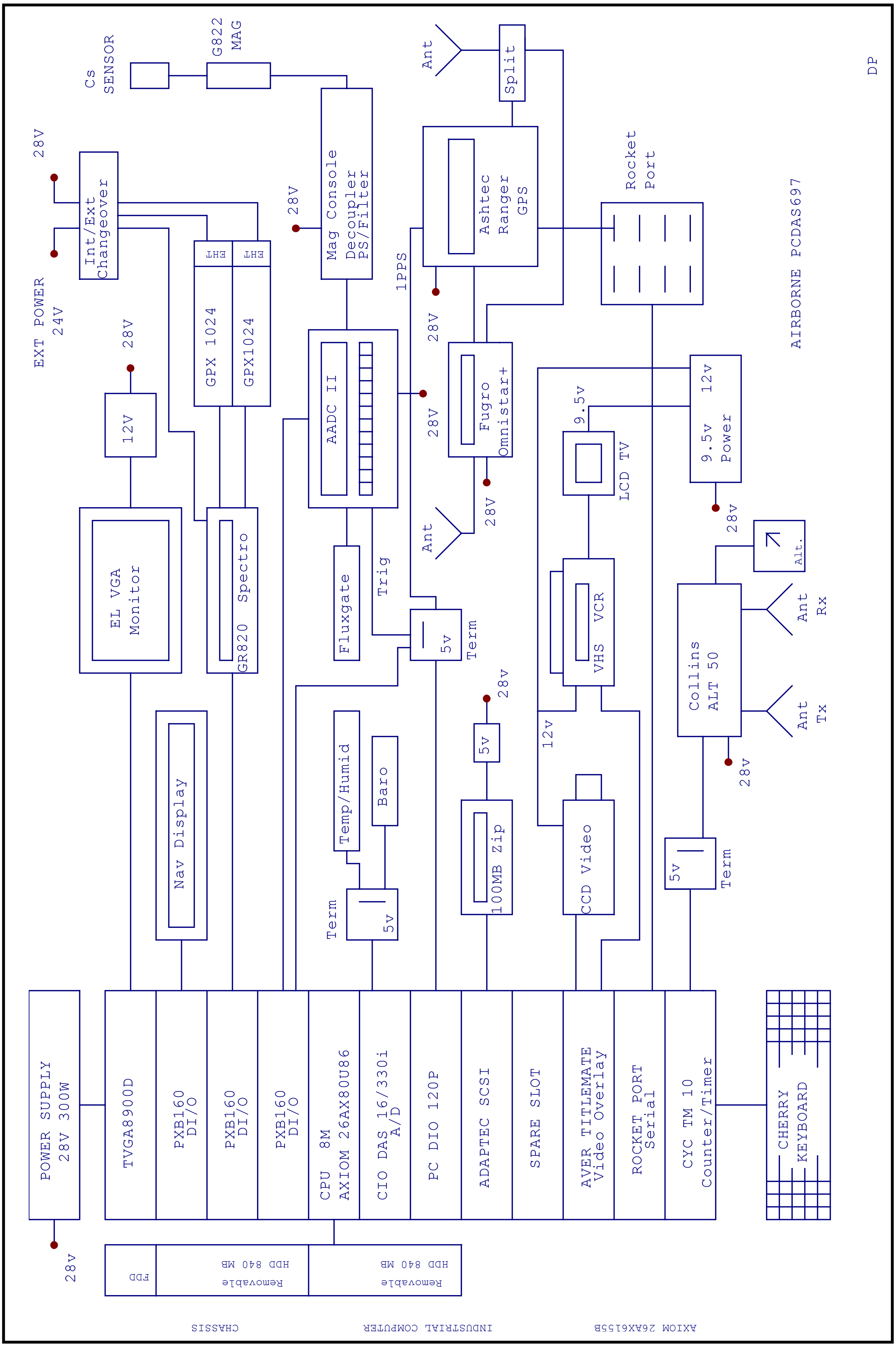
APPENDIX G-1

SPECIFICATIONS - G823B CAESIUM BASE STATION MAGNETOMETER

Operating principle:	Self-oscillating caesium vapour magnetometer
Operating range:	20,000 to 95,000 nT
Active Zones:	Sensor equator ±10° H_o field sensor axis ±10°, switchable or auto switch
Noise level:	<= 0.01 nT peak-to-peak
Heading error:	<= ± 0.25 nT, <= 0.5 nT envelope
Power required:	26 to 32 VDC, 500 mA continuous, 750 mA while starting
Output:	2V p-p, f (Hz) = 3.498 H_o (nT)
Interface:	Larmor signal AC coupled to power input
Environmental:	-35 °C to +50 °C, humidity 95% non-condensing
Dimensions:	Sensor: 5 cm diameter, 18 cm long, 140 grams Electronics module: 5 cm wide, 5 cm high, 23 cm long 170 grams Sensor electronics cable: 135 cm to 270 cm long
Qualification:	MIL-I-45208, MIL-M-19595

APPENDIX H-1

Aircraft Data Acquisition System



APPENDIX I-1

Compensation Results

COMPENSATION 1. Date flown: 10 September 1998
Dates used: 10 September 1998 - 16 September 1998

Air conditioner off	SDU	=	0.2215
	SDC	=	0.01484
	IR	=	14.9
	VN	=	27.3
Air conditioner on	SDU	=	0.2549
	SDC	=	0.01234
	IR	=	20.7
	VN	=	28.9

COMPENSATION 2. Date flown: 16 September 1998
Dates used: 16 September 1998 - 3 October 1998

Air conditioner off	SDU	=	0.2083
	SDC	=	0.01404
	IR	=	14.8
	VN	=	23.6
Air conditioner on	SDU	=	0.2404
	SDC	=	0.01519
	IR	=	15.8
	VN	=	25.1

COMPENSATION 3. Date flown: 3 October 1998
Dates used: 3 October 1998 - 10 October 1998

Air conditioner off	SDU	=	0.4028
	SDC	=	0.04212
	IR	=	9.6
	VN	=	26.3
Air conditioner on	SDU	=	0.5014
	SDC	=	0.03318
	IR	=	15.1
	VN	=	28.2

COMPENSATION 4. Date flown: 10 October 1998
Dates used: 10 October 1998 - 25 October 1998

Air conditioner off	SDU	=	0.3468
	SDC	=	0.01608
	IR	=	21.6
	VN	=	24.4

APPENDIX I-2

Compensation Results

Air conditioner on	SDU	=	0.4673
	SDC	=	0.01471
	IR	=	31.8
	VN	=	26.7

COMPENSATION 5. Date flown: 25 October 1998
Dates used: 25 October 1998 - 2 November 1998

Air conditioner off	SDU	=	0.4239
	SDC	=	0.02086
	IR	=	20.3
	VN	=	24.7
Air conditioner on	SDU	=	0.4399
	SDC	=	0.01467
	IR	=	30.0
	VN	=	26.9

SDU = Standard deviation of the data recorded during manoeuvres.

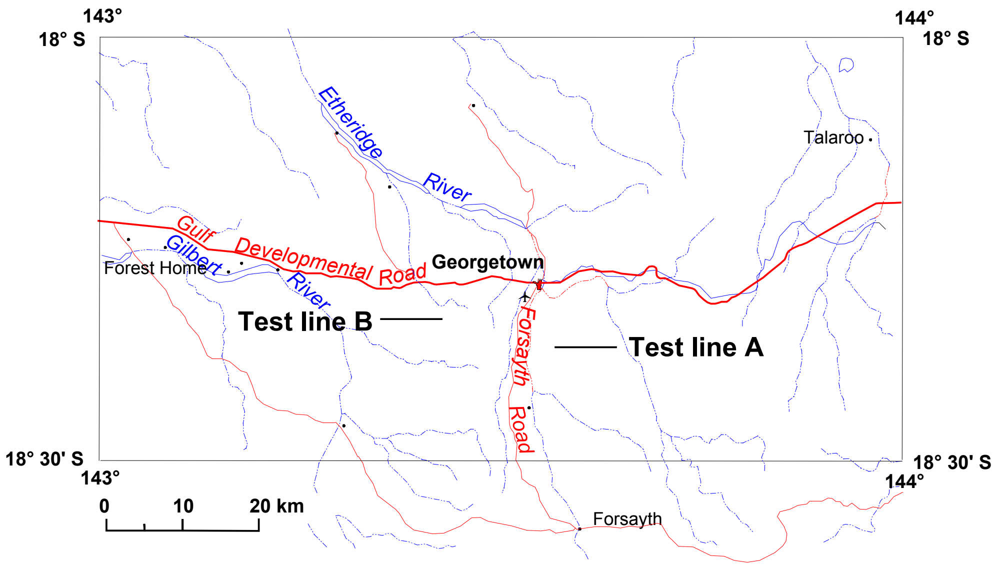
SDC = Standard deviation of the data recorded during manoeuvres after compensation corrections have been applied.

IR = Improvement ratio = SDU / SDC

VN = Vector Norm, a measure of the degree of difficulty in calculating the coefficients.

APPENDIX J

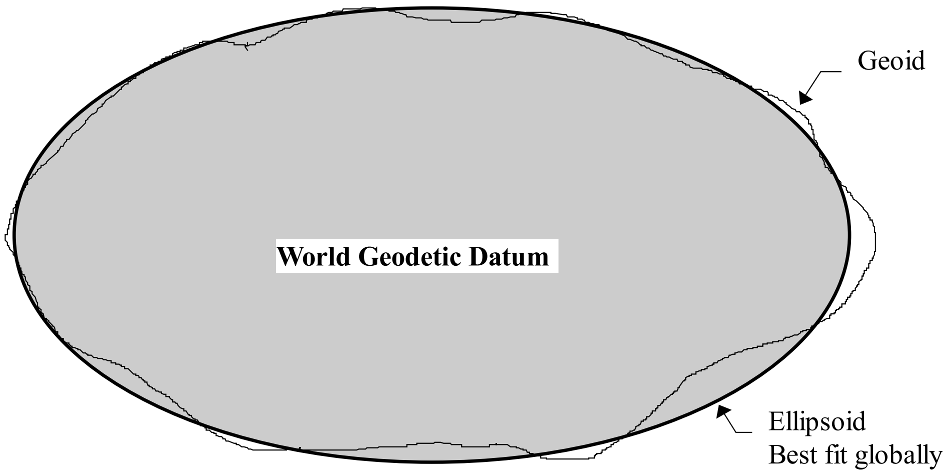
Gamma-ray Spectrometer Test Line Location



APPENDIX K

The World Geodetic System 1984 Datum

For geophysical surveys the real shape of the earth has to be considered. An ellipsoid of revolution around the earth's north-south axis approximates the earth's shape. This figure is called the spheroid. The mean sea level equipotential surface describing the shape of the earth is known as the geoid.



Calculated positions from the GPS are in the World Geodetic System 1984 (WGS84). The WGS84 datum is a global geocentric reference datum that has as its origin the Earth's centre of mass.

This geocentric datum comprises a spheroid (also known as an ellipsoid) oriented and located in such a manner as to "best-fit" the geoid over the entire earth.

The WGS84 datum is defined by a semi-major axis (a) and flattening (f) of the selected ellipsoid.

a	=	6378137 m
f	=	1/298.2572

APPENDIX L

Corrections to Differential GPS Navigation Data

(a) Position calculation delay correction

A correction due to the finite time taken for the GPS system to calculate a position and transfer the information to the acquisition system. A delay of 0.6 seconds has been determined for calculations using up to eight satellites by flying clover leaf patterns over a reference point. This value is considered to be representative and was used for all delay corrections.

(b) Fiducial synchronisation correction

A correction due to the time lag between when a GPS position is available to the acquisition system and when the next fiducial is available to pair the position with.

(c) "Ranger"/"PNAV" corrections

For this survey the primary source of GPS corrections was the dual frequency range data received by Ashtech Z Surveyor GPS receivers recorded onto PCMCIA flash disks every one second. For flights where the flash disk data was un-readable or recorded incorrectly the range data internally recorded every five seconds on the Ashtech XII single frequency GPS receivers was used. "Ranger" calculates the correct positions at five second intervals along the flight path for single frequency range data. "PNAV" calculates the correct positions at one second intervals along the flight path for dual frequency data. These corrected positions are utilised when correcting the aircraft raw position data which are recorded every second.

Discontinuities (steps) sometimes occur in raw GPS data. These are also manifested as steps in the correction set.

When such steps in the raw GPS data occur between successive correction values, the corrections are linearly interpolated to the step boundary using corrections from the appropriate side of the step.

If multiple steps in the raw GPS data occur between successive correction values it is impossible to interpolate corrections over this interval, in which case the intervening GPS data are set to undefined.

(d) Low pass filter

The problem described in (c) can lead to small steps in the data where the original steps were too small to detect so were not corrected. A low pass 11 point convolution filter with a cut-off wavelength of 300 m was passed over the data.

(e) Reference navigation data to position of magnetometer sensor

The calculated GPS positions refer to the position of the GPS receiver's antenna. Since the magnetometer is the most position sensitive instrument, all position data is shifted 11.4 metres toward the rear of the aircraft to correspond with the position of the magnetometer's sensor.

(f) Doppler infill of gaps

Whenever gaps (<3 km) in the GPS data occurred they were linearly interpolated with data across the gap extent. Gaps in the GPS data greater than three kilometres were reflown.

APPENDIX M-1

Geophysical Maps

Name	Type	Contour Interval	Reference Number
1:100 000 scale			
Forest Home	TMI Contours	5 nT	22-2/E54_12/1-2
"	DOSE RATE Contours	5 nG/hr	22-2/E54_12/18-2
"	Flight Line System		22-2/E54_12/3-2
Georgetown	TMI Contours	5 nT	22-2/E54_12/1-3
"	DOSE RATE Contours	5 nG/hr	22-2/E54_12/18-3
"	Flight Line System		22-2/E54_12/3-3
North Head	TMI Contours	5 nT	22-2/E54_12/1-5
"	DOSE RATE Contours	5 nG/hr	22-2/E54_12/18-5
"	Flight Line System		22-2/E54_12/3-5
Forsayth	TMI Contours	5 nT	22-2/E54_12/1-6
"	DOSE RATE Contours	5 nG/hr	22-2/E54_12/18-6
"	Flight Line System		22-2/E54_12/3-6

APPENDIX N-1

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

CONTENTS

APPENDIX N-2

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

1. THE AGSO SEQUENTIAL FILE STRUCTURE

1.1 INTRODUCTION

This appendix describes the general sequential file structure used by AGSO to store airborne geophysical data. For the purpose of this survey nine data chains are involved for each line and tie. They are:

channel 4 edition 1 (processed navigation)
channel 4 edition 2 (processed magnetics)
channel 4 edition 3 (processed spectrometrics)
channel 4 edition 4 (processed digital elevation model)
channel 6 edition 1 (raw spectrometrics)
channel 8 edition 1 (raw magnetics)
channel 9 edition 1 (uncompensated raw magnetics)
channel 14 edition 1 (pressure, temperature, cosmic data)
channel 16 edition 1 (raw navigation)
channel 17 edition 1 (raw 1 second gamma-ray spectra)

1.2 GENERAL FILE STRUCTURE

The information pertaining to each traverse (line or tie) is held on the file as a separate entity called a segment. Segments are separated from each other by industry standard EOF records. The end of the file is indicated by two or more consecutive EOF records. Each segment consists of two types of records. Both types are 5120 characters long.

1. Segment Directory Record (SDR) : the first record on each segment. It defines the data content of the segment.
2. Data Records (DAR's) : hold the measured data values. The general structure is shown in Figure 1.

1.3 CHANNELS AND SAMPLES

Data are recorded at regular intervals in time along a traverse. The data recorded at one instant of time are held as any ordered set or sub-set. Each set is held logically distinct and referred to as a channel. The data records in a segment hold all the information for one channel in the form of a data chain, then all the data for the next channel and so on for as many channels as the segment holds.

Each channel is uniquely defined by a channel number and an edition number. The measurement(s) taken for a channel at a given time is called a sample. Samples are held within each channel in increasing order of fiducial (time).

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In defining channels the channel number can be used to define the sample format and the edition type of the data. For example, within AGSO, samples with format (longitude, latitude, value, value....) have a channel number of 4 with edition 2 for magnetics and edition 3 for radiometrics.

1.4 SEGMENT DIRECTORY RECORD (SDR)

Lines and ties are uniquely identified as follows :

1. Project number: a unique number to identify the survey.

2. Group number : a unique number within a survey for each flight made. That is, several lines may be recorded on one flight (group). AGSO convention is for group numbers to lie between 001 and 999 inclusive.

3. Segment numbers : a unique number within a survey for a line or tie. AGSO convention is for ordinary line numbers to lie between 1000 and 9999 inclusive and tie line numbers between 100 and 999 inclusive.

The segment directory record identifies the data segment at Project, Group and Segment level and defines the data channels, their structure and the location of their data chains in the segment. Each SDR consists of one or more 10 word blocks. The first , the Segment Identification Block (SIB), identifies the segment and gives the number of data channels held in the segment.

For this survey the number of data channels is nine as mentioned in the introduction. Subsequent blocks, one for each data channel, define the data channels and their location within the segment. These are called Channel Identification Blocks (CIB's). The exact format of a typical SDR is given in Table 1. All unused words in the SDR are set to zero.

The last word in the record in the past has been used as check sum and represents the sum of all the other words in the record. The check sum word is no longer used and is set to zero.

The overall record format is 2I9, 509I10, I12.

1.5 DATA RECORD (DAR)

These each contain 512 values. The first two are fiducials giving the fiducial range of the samples contained in the record. The next 508 represent data values, the second last is always zero (to maintain compatibility with our random access file format) and the last is a record check sum representing the sum of all other values in the record.

If a record is the last one in a data chain for a given channel all unused values are set to zero, with the next channel commencing at the start of the next data record. The N data records in a segment are numbered from 2 to N+1, the SDR being regarded as record one in a segment, with records for a given channel following each other sequentially. The data record addresses in the channel identification block of the SDR refer to this sequential numbering of the data records. The exact format of a data record is given in Table 2.

The overall format of each data record is : 2I9, 509I10, I12.

1.6 NO DATA VALUE

For a variety of reasons it is sometimes necessary to flag a data value to indicate it is to be ignored. This is achieved by replacing the data word in question by the value 536870912. If a gap exists in a data chain each word of every sample involved must be replaced by 536870912, the so-called missing value. Thus a 1:1 correspondence is maintained between the fiducials encompassed by a data chain and its samples.

1.7 STANDARD DATA CHANNELS

The standard AGSO data channels are :

channel 4 edition 1 (processed navigation)
channel 4 edition 2 (processed magnetics)
channel 4 edition 3 (processed spectrometrics)
channel 4 edition 4 (processed digital elevation model)
channel 6 edition 1 (raw spectrometrics)
channel 6 edition 3 (magnetometer base station diurnal data)
channel 8 edition 1 (raw magnetics)
channel 9 edition 1 (uncompensated raw magnetics)
channel 14 edition 1 (pressure, temperature, cosmic data)
channel 16 edition 1 (raw navigation)
channel 17 edition 1 (raw 1 second gamma-ray spectra)

C4 E1 - Navigation
Channel number = 4
Edition number = 1
Sample size = 2 words
word 1 = Longitude in degrees * 1 000 000
word 2 = Latitude in degrees * 1 000 000

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C4 E2 - Corrected Total Magnetic Intensity
Channel number = 4
Edition number = 2
Sample size = 4 words
word 1 = Longitude in degrees * 1 000 000
word 2 = Latitude in degrees * 1 000 000
word 3 = final (non micro-levelled) TMI (nT) * 1000
word 4 = final micro-levelled TMI (nT) *1000

C4 E3 - Corrected Gamma-ray Spectrometer Data
Channel number = 4
Edition number = 3
Sample size = 7 words
word 1 = Longitude in degrees * 1 000 000 (parallax corrected)
word 2 = Latitude in degrees * 1 000 000 (parallax corrected)
word 3 = final Total Count (nG/hr) * 1000
word 4 = final Potassium (% K) * 1000
word 5 = final Uranium (ppm U) * 1000
word 6 = final Thorium (ppm TH) * 1000
word 7 = Altitude in metres above ground level

C4 E4 - Corrected Digital Elevation Model Data
Channel number = 4
Edition number = 2
Sample size = 4 words
word 1 = Longitude in degrees * 1 000 000 (parallax corrected)
word 2 = Latitude in degrees * 1 000 000 (parallax corrected)
word 3 = final Aircraft Elevation (metres above sea level) * 100
word 4 = final Terrain Elevation (metres above sea level) * 100

C6 E1 - Raw spectrometer data.
Channel number = 6
Edition number = 1
Sample size = 5 words
word 1 = Total count (counts/sec) * 1000
word 2 = Potassium (counts/sec) * 1000
word 3 = Uranium (counts/sec) * 1000
word 4 = Thorium (counts/sec) * 1000
word 5 = Altitude in metres above ground level

C6 E3 - Raw Data - Base Station Magnetometer Diurnal
Channel number = 6
Edition number = 3
Sample size = 2 words
word1 = Raw Diurnal TMI (nT) * 1 000
word2 = Filtered Diurnal TMI (nT)* 1 000 (if applicable)

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C8 E1 - Raw Magnetics
Channel number = 8
Edition number = 1
Sample size = 1 word
word 1 = TMI * 1000

C9 E1 - Uncompensated Raw Data - Magnetics
Channel number = 9
Edition number = 1
Sample size = 4 word
word 1 = Uncompensated TMI * 1000
word 2 = 3 Axis Fluxgate X Component * 1000
word 3 = 3 Axis Fluxgate Y Component * 1000
word 4 = 3 Axis Fluxgate Z Component * 1000

C14 E1 - Pressure and Temperature
Channel number = 14
Edition number = 1
Sample size = 7 words
word 1 = pressure in millibars * 10
word 2 = temperature in degrees celsius * 10
word 3 - 6 = no longer used
word 7 = cosmic channel (counts) * 1000

C16 E1 - Raw GPS data
Channel number = 16
Edition number = 1
Sample size = 4 words
word 1 = Longitude in degrees * 1 000 000
word 2 = Latitude in degrees * 1 000 000
word 3 = GPS time in seconds * 1000.
GPS time is recorded in seconds from midnight the previous Sunday
word 4 = Lag time. Time difference between time when a position is calculated and time until the next fiducial is generated by the data acquisition system. (hundredths of a second)

C17 E1 - Raw 1 second Spectra
Channel number = 17
Edition number = 1
Sample size = 290 words
word 1 = Fiducial at start of acquisition of spectrum
word 2 = Cosmic count (3-6 MeV) * 1000
word 3 = Sample interval - integration time (seconds) * 1000
word 4 = Low energy bound of spectrum (MeV) * 1000
word 5 = High energy bound of spectrum (MeV) * 1000
word 6 = Spectrum dead time corrected? (0 -No, 1 -Yes)
word 7 = Spectrum energy calibrated? (0 -No, 1 -Yes)
word 8 = Aircraft background spectrum subtracted? (0 -No, 1 -Yes)
word 9 = Cosmic background spectrum subtracted? (0 -No, 1 -Yes)
word 10 = Radon background spectrum subtracted? (0 -No, 1 -Yes)
word 11 = Maximum possible live time (seconds) * 1000
word 12 = Live time for this spectrum (seconds) * 1000
word 13 = Spectrometer resolution
word 14-34 = Unused
word 35 = Channel 1 (counts) * 1000
word 36 = Channel 2 (counts) * 1000
word 37 = Channel 3 (counts) * 1000

word 290 = Channel 256 (counts) * 1000

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

2. PHYSICAL FORMAT FOR MEDIA

2.1 General

The digital data is archived on Exabyte or Compact Disc. Each Exabyte or CD consists of a sequence of segments each segment consisting of one or more physical records. Segments are to be separated by one EOF markers. The end of all information on a tape/CD must be flagged by two or more consecutive EOF markers. Industry standard EOF records apply. Records are to be fixed length and each block is to contain one record.

2.2 Physical Parameters of Tapes

(a) Exabyte tapes are 8mm, Exabyte.
(b) Compact Discs are standard IBM compatible PC, readable Compact Discs.
(c) Each Exabyte or Compact Disc has an external label to identify the airborne survey, date written, the number in a set and the lines/ties it contains.

2.3 Media Structure

(a) Compact Disc or 5.0 Gigabyte Exabyte
(b) Data in the format described in Section 1 are transferred to Exabyte via the INTREPID EXPORT utility in 5.0 Gigabyte Exabyte structure.
(c) Data in the format described in Section 1 are transferred to Compact Disc via the ISO 9660 Logical File Format.
(d) Written in ASCII
(e) International Standards Organisation end-of-block markers (EOB)
(f) International Standards Organisation end-of-file markers (EOF)
(g) No multi-tape files
(h) Multi-file tapes can be expected. Files will not span tapes.
(i) Last file on each tape shall end with at least two EOF's.

2.4 Physical Records And Blocks

a. Fixed length records of 5120 characters
b. One record per block

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3. GRID FILE FORMAT

3.1 HEADER RECORD

The first record on the file defines the content of the grid, including:

a. Origin in latitude and longitude.
b. Grid cell size.
c. Number of rows and columns in the grid.
d. Storage mode, i.e. whether the data is stored row by row or column by column. In general the data is stored by row.
e. The exact header record format is in Table 3.

3.2 DATA RECORDS

Each data record contains 320 values in E16.10 format. No location data is held in the data records - the location of a grid point is determined by its sequence within the file. The data for the grid may be sequenced in row or column order (i.e. row by row or column by column respectively). Each row or column is written on consecutive records and begins at the start of a new record. If the rows/columns do not contain a multiple of 320 values the last record for each row/column is padded with zeros. Any point in the grid which is undefined is set to -9999.0.

In ROW mode , rows are sequenced from north to south and within each row values are ordered from west to east.

In COLUMN mode, columns are sequenced from west to east and within each column values are ordered from north to south.

APPENDIX N-10

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

TABLE 1

SEGMENT DIRECTORY RECORD FORMAT

1. SEGMENT IDENTIFICATION BLOCK

WORD	CONTENT AND USE	FORMAT
1	PROJECT IDENTIFICATION	I9
2	GROUP IDENTIFIACTION	I9
3	SEGMENT IDENTIFICATION	I10
4	NUMBER OF CHANNELS ON SEGMENT	I10
5	DATE CODE - YYMMDD	I10
6	FIDUCIAL FACTOR - (fiducial size in seconds)	I10
7	TIME OF DAY AT FIDUCIAL ZERO IN SECONDS	I10
8	BEARING IN DEGREES (0-359) MEASURED EAST OF NORTH	I10
9	ALTITUDE IN METRES ABOVE SEA LEVEL	I10
10	GROUND CLEARANCE IN METRES	I10

2. CHANNEL IDENTIFICATION BLOCK (for the Nth channel)

WORD	CONTENT AND USE	FORMAT
1	CHANNEL CODE	I10
2	EDITION NUMBERS	I10
3	FIDUCIAL INTERVAL BETWEEN SAMPLES	I10
4	NUMBER OF DATA VALUES (WORDS) PER SAMPLE	I10
5	ADDRESS OF FIRST DATA RECORD FOR CHANNEL	I10
6	ADDRESS OF LAST SAMPLE IN DATA CHAIN	I10
7	FIDUCIAL OF FIRST SAMPLE IN DATA CHAIN	I10
8	FIDUCIAL OF LAST SAMPLE IN DATA CHAIN	I10
9	UNUSED - SET TO ZERO	I10
10	UNUSED - SET TO ZERO	I10

APPENDIX N-11

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

TABLE 2

DATA RECORD FORMAT

WORD	CONTENT AND USE	FORMAT
1	FIDUCIAL AT FIRST DATA SAMPLE IN RECORD	I9
2	FIDUCIAL AT LAST DATA SAMPLE IN RECORD	I9
3	FIRST WORD OF FIRST SAMPLE	I10
4	SECOND WORD OF FIRST SAMPLE	I10
	•	
	•	
	•	
	•	
	•	
	•	
	FIRST WORD OF SECOND SAMPLE	I10
	SECOND WORD OF SECOND SAMPLE	I10
	•	
	•	
	ETC	
511	ALWAYS UNUSED - SET TO ZERO	I10
512	ALWAYS UNUSED - SET TO ZERO	I12

NOTE:

1. A data sample can be of any length greater than zero.
2. Each record contains an integral number of samples. This may lead to several unused words at the end of the record which are set to zero.

   i.e. If a sample is 7 words long 72 samples will fit in a data record and words 507-510 will be set to zero.

APPENDIX N-12

AGSO ARCHIVE DATA, GRID AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

TABLE 3

GRID HEADER RECORD FORMAT

CHARACTER POSITION	FIELD LENGTH	FORTRAN FORMAT	CONTENT
1-60	60	6A10	Grid Identification
61-170	10	11A10	Facts defining data acquisition/processing
171-180	10	A10	x,y units defining grid, Usually degrees.
181-192	12	E12.6	x origin of surface. Bottom left hand corner.
193-204	12	E12.6	y origin of surface. Bottom left hand corner.
205-214	10	A10	Type of z data in grid (e.g. TMI).
215-216	2	A2	Blanks.
217-228	12	I12	Number of data records per column or row.
229-240	12	E12.6	Grid increment in the x direction
241-252	12	E12.6	Grid increment in the y direction
253-262	10	A10	Time when original surface created (hh.mm.ss).
263-286	24	2A10,A4	Filter used on original z data.
287-310	12	2E12.6	x,y co-ordinate of the bottom left hand corner of the grid. Same as x,y origin.
311-320	10	A10	Date of creation of surface (dd/mm/yy).
321-344	24	2A10,A4	Blanks.
345-368	12	2E12.6	x,y co-ordinate of top right hand corner of grid. NOTE: these values are too large by one grid increment for tapes created prior to 01/06/85.
369-373	5	I5	Number of rows in the grid.
374-378	5	I5	Number of columns in the grid.
379-382	4	A4	Blanks.
383-388	6	A6	Defines if the grid is stored in column mode (COLUMN) or row mode (ROW).
389-5120			Blank filled.