BOULIA AND SPRINGVALE, QLD, AIRBORNE GEOPHYSICAL SURVEY, 1997, OPERATIONS REPORT

by

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Australian Geological Survey Organisation
Record 1999/28

DEPARTMENT OF INDUSTRY, SCIENCE & RESOURCES

Minister for Industry, Science and Resources: Senator the Hon. Nick Minchin
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Russell Higgins

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Dr Neil Williams

ISSN: 1039 – 0073

ISBN: 0 642 397 88 0

Bibliographic reference: Brodie, R.C., 1999. Title – Boulia and Springvale, Qld, Airborne Geophysical Survey, 1997, Operations Report. Australian Geological Survey Organisation, Record 1999/28.

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SUMMARY

The Australian Geological Survey Organisation (AGSO) flew an airborne geophysical survey of 97,020 line kilometres over the Boulia and Springvale 1:250 000 map Sheet areas in northwest Queensland. The survey area covers the southern continuation of various units of the Proterozoic Mount Isa Inlier beneath younger sediments.

The survey was flown along east-west flight lines spaced 400 m apart at a nominal altitude of 80 m above ground level. AGSO flew the survey from May to August 1997.

The total magnetic intensity, gamma-ray spectrometric and digital elevation model data which were collected during the survey, have been processed and are available for purchase, in both digital (point located data and gridded) and map form, from the Australian Geological Survey Organisation.

1. SURVEY AREA AND PARAMETERS

(i) Area Description

The airborne geophysical survey covers the entire Boulia and Springvale 1:250 000 map Sheet areas in northwest Queensland. The survey area is shown in Appendix A.

(ii) Survey Parameters

Altitude:	80 m above ground level
Flight line direction:	East – West
Tie line direction:	North – South
Survey line spacing	
Flight line spacing:	400 m
Tie line spacing:	4000 m
Survey distance flown	
Lines:	88,040 km
Ties:	8,980 km
Total distance:	97,020 km
Sampling interval	
Magnetics:	0.1 s (approx 7 m)
Gamma–ray spectrometrics:	1.0 s (approx 70 m)
GPS:	0.5 s (approx 35 m)
Altimeter:	1.0 s (approx 70 m)
Barometric pressure:	1.0 s (approx 700 m)
Temperature:	1.0 s (approx 700 m)
Humidity:	1.0 s (approx 700 m)

2. LOGISTICS

(i) Operating Base and Dates of Flying

(a) Operating Base

Aircraft and crew were based at Boulia, Queensland for the duration of the survey from 13 May to 13 August 1997.

(b) Flying Dates

The first calibration flight to compensate for the magnetic field of the aircraft, using an automatic aeromagnetic digital compensator was flown on 14 May. Further calibration flights were flown on 19 May, 30 May, 22 June, 15 July and 7 August. Production flying commenced on 16 May and was completed on 12 August. Appendix B summarises flying days and production kilometres flown. Production flying was only significantly interrupted for aircraft services on 25 to 29 May, 18 to 21 June, 10 to 14 July, 27 to 29 July and 4 to 7 August.

(ii) Survey Aircraft and Field Crew

(a) Aircraft

Aero Commander 500 S "Shrike", VH-BGE

(b) Field Crew

Party Leaders:	Ross Brodie	13 May to 14 August 1997
	Tony Meixner	13 May to 26 May 1997
Technicians:	Anthony Veness	13 May to 13 June 1997 25 July to 14 August 1997
	Trevor Dalziell	11 June to 25 July 1997
Operators:	Lars Rickardsson	13 May to 14 August 1997
Pilots:	Capt. John Biffin	13 May to 9 July 1997
(Pearl Aviation)	Capt. Neil McGreevey	13 May to 14 August 1997
	Capt. Lee Geraghty	1 July to 14 August 1997

3. SURVEY EQUIPMENT

(i) Major Equipment

Magnetometer:	Geometrics G822A Caesium magnetometer
Compensator:	RMS Instruments Automatic Aeromagnetic Digital Compensator
Gamma–ray spectrometer:	Geometrics 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/Hygrometer:	AGSO digital – RS combined humidity and temperature sensor
Navigation:	Ashtech XII "Ranger" GPS receivers Ashtech "Ranger" 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

Real time differential global positioning system (RT-DGPS) aircraft navigation was accomplished using Ashtech XII GPS receivers and a Fugro OmniSTAR Plus base station system.

The receiver in the aircraft received range data from the GPS satellites and differential corrections every second and calculated the aircraft's current latitude and longitude coordinates in the World Geodetic System 1984 (WGS84). The range data were recorded internally in the GPS receiver every second.

A Fugro OmniSTAR Plus base station system was utilised for real time differential GPS corrections. This system uses differential corrections, supplied by Fugro Starfix Pty. Ltd., which are transmitted via an Optus satellite link.

The real time differential corrections were applied by the aircraft receiver. The receiver then calculated the aircraft's corrected latitude and longitude coordinates in the World Geodetic System 1984 (WGS84). The position was recorded on the aircraft acquisition system every half second and was also used to provide the pilot with aircraft guidance information on an LCD display. The RT-DGPS method employed is more fully described in Appendix C.

The internally recorded range data were post processed using Ashtech "Ranger" software at the end of each flying day. The error in position of the post processed flight path data is approximately five metres or less.

The position of the base station GPS receiver was accurately determined by differential GPS surveying using the "NMB189" trig site, approximately 2 km northwest of Boulia, as a fixed reference point.

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

Longitude :139° 53' 26.5022" E
Latitude : 22° 53' 33.5431" S
Ellipsoidal height : 221.897 m

The horizontal positions of the geophysical data from the survey are reported with respect to the WGS84 Datum. Taking the accuracy of the navigation data into account, the WGS84 system can be considered to be the same as the Geocentric Datum of Australia (GDA) for the survey data. It is intended that the GDA will be fully adopted in Australia by the year 2000. For a given position in the survey area, the GDA coordinate will appear to lie approximately 205 m northeast of the corresponding Australian Geodetic Datum (AGD) coordinate. That is to convert from GDA to AGD, coordinates must be moved 121.5 m west and 165.3 m south.

(c) 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 X, Y, Z components and calculated total field of the fluxgate sensor were 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 windows of data were recorded once a second using the following window limits:

Total count	0.410 – 3.00 MeV
Potassium	1.370 – 1.570 MeV
Uranium	1.660 – 1.860 MeV
Thorium	2.410 – 2.810 MeV
Cosmic	3.00 MeV and above

Total count, potassium, uranium and thorium window counts were used for data checking during acquisition and the cosmic counts were used for cosmic background estimation and 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 ±2% accuracy for the ALT-50 system.

(vi) Barometer, Thermometer and Hygrometer

Atmospheric pressure, temperature and humidity were measured using a digital barometer (Setra sensor) and combined digital thermometer/hygrometer (RS sensor). The analogue output sensors were integrated into the data acquisition system via an analogue to digital converter. 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 G823B caesium base station magnetometer. The specifications of the base station magnetometer are given in Appendix G. The base station was set up in an area of shallow magnetic gradient, away from cultural influences and within telemetry range of AGSO's office caravan.

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 notebook computer. The telemetry system used Proxim Proxlink MSP500 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 Megabyte zip discs.

The acquisition program, which was written in the C language and developed in-house at AGSO, was run under the QNX operating system. See Appendix H for a schematic diagram of the aircraft's acquisition system.

4. CALIBRATION

(i) Compensation for the Magnetic Field of the Aircraft

Compensation flights were flown in an area of low magnetic gradient prior to the start of the survey and after each aircraft service or change of aircraft alternators. The flights were flown at an altitude of 2800 m above sea level, approximately 18 km northeast of Boulia over an area between 139° 58' to 140° 06' E and 22° 46' to 22° 51' S.

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 s duration.

The compensation manoeuvres were repeated after calculation of the coefficients to check the compensation quality. Prior to compensation the peak-to peak manoeuvre noise was generally 1 nT. Peak-to-peak noise during repeat manoeuvres after the compensation was 0.20 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). Appendix I lists these statistics, the dates the compensations were performed and the period over which each compensation was used.

(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 or thorium). During operation, the system continuously monitors and accumulates separate spectra for each crystal detector. When the confidence level for the selected stabilisation peak (potassium or thorium) is exceeded, the peak channel of this isotope is computed, compared to the correct peak location, and the gain is then corrected.

Crystal alignment checks were performed (using a small thorium source) at the start of each day prior to production flying. Adjustments were made to ensure the spectrometer stabilised on the thorium 2.62 MeV photopeak at channel 206. The resolution of the gamma-ray spectrometer system was measured using the full width at half maximum method (IAEA, 1991). The resolution of the thorium peak was between 5.1% and 5.9% and averaged 5.58% over the duration of the survey.

Gamma-ray spectrometric test lines were flown at the beginning and end of each production flight. These lines were flown at survey altitude along a line located 15 km due west of Boulia. The 7 km long test line was flown using real time differential GPS navigation and lasted 100 s. The location of the test line is shown in Appendix J. Background estimates for the low level test lines were obtained using a full spectrum method (Minty 1992).

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 to the preceding flights in order to detect any irregularities. In particular, the percentage difference between the average background corrected thorium channel counts for each test line and the running average of all previously flown test lines was analysed. This value did not exceed 5.0% for any test line, well inside a 15% variation, which was considered acceptable.

5. DATA PROCESSING

Flight path recovery, data checking and editing, diurnal variation and preliminary IGRF corrections applied to the magnetic data, gridding and imaging were performed at the survey base using the INTREPID data processing system. Final magnetic, gamma-ray spectrometric and digital elevation model data processing were carried out in Canberra using the INTREPID data processing system.

(i) Data Checking and Editing

Data recorded on the aircraft acquisition zip drive were transferred on a flight by flight basis from the zip disc to a Graphics Computer Systems Scorpion 10 Workstation (SUN Clone). All data transferred to this workstation was edited for missing values, noise, spikes or steps using INTREPID software. 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 and fences, were usually not edited out. They were edited out if they caused severe noise or caused the magnetometer to lose lock.

(ii) Flight Path Recovery

The range data, which were recorded internally every second on both GPS receivers, were post-processed daily in the field using "Ranger" – an Ashtech proprietary program. "Ranger" calculates the corrected flight path (longitude, latitude and height) relative to the World Geodetic System 1984 (WGS84) reference ellipsoid.

At the end of each flying day the corrected longitude and latitude data calculated at one second intervals by "Ranger" were used to correct the GPS data which were recorded every half second on the aircraft acquisition system. As well as the standard "Ranger" corrections, other acquisition system specific corrections were applied. Position data were retained in the WGS84 coordinate system. The WGS84 is defined in Appendix K.

Taking the accuracy of the navigation data into account, the WGS84 system can be considered to be the same as the Geocentric Datum of Australia (GDA) for the survey data. For a given position in the survey area, the GDA coordinate will appear to lie approximately 205 m northeast of the corresponding Australian Geodetic Datum (AGD) coordinate. That is to convert from GDA to AGD, coordinates must be moved 121.5 m west and 165.3 m south.

The full post-processing correction procedure applied to the position data is described in Appendix L and is outlined below;

(a) "Ranger" corrections.

(b) Infilling of “Ranger” data.

(c) Infilling of final navigation data.

(d) Low pass filter.

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

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

Line Spacing	Across Track Deviation	Distance along line
400 m	40 m	greater than 3 km

Where both the across track deviation and along line distance were exceeded that portion of the survey line was reflown. This occurred on one survey line.

(iii) Magnetic Data Processing

Compensated checked and edited magnetic data were read into an INTREPID database which included the navigation data. Diurnal variation corrections were applied. The 0.1 s data recorded from the G823B base station magnetometer were used for the diurnal variation correction. These 0.1 s data were low pass filtered prior to the correction being applied. The filter used removed high frequency variations with periods less than 20 seconds.

The IGRF 1995 geomagnetic reference field, updated to 1 July 1997 and for an altitude of 250 m above sea level (estimated to be the mean survey altitude) was then subtracted from the data. The IGRF was calculated from the coefficients defined by the International Association of Geomagnetism and Aeronomy, Barton (1997). 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 290 was chosen as the reference tie.

(b) All other ties were levelled to tie line 290 using degree three piecewise polynomial adjustments.

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

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

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

Pass 1:

(a) Low pass filter in the flight line direction with a cut-off wavelength of 7000 m.

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

(c) Correction strings were low pass filtered with a cut-off wavelength of 200 m before being applied to the line data and were constrained to lie within the range ±5 nT (95% of these corrections fell in the range ±2.5 nT).

Pass 2:

(a) Low pass filter in the flight line direction with a cut-off wavelength of 3500 m.

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

(c) Correction strings were low pass filtered with a cut-off wavelength of 100 m before being applied to the line data and were constrained to lie within the range ±3 nT (95% of these corrections fell in the range ±1.5 nT).

The micro-levelled data were gridded using the minimum curvature technique described by Briggs (1974), employing a 80 metre (3.0″) 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 (NASVD) spectral smoothing technique described by Hovgaard and Grasty (1997). This procedure 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 performed by using the positions of prominent photopeaks in the accumulated line spectrum (the sum of all individual spectra for the line) to obtain an estimate of the base energy (energy at channel one in keV) and the gain (channel width in keV). These parameters were then used to correct each spectrum in the line by resampling each channel over its correct energy range.

The three components of background were determined 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, 1998) 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 were then applied to the K, U, and Th window count rates. Stripping ratios for the AGSO system were determined using the procedure recommended by the International Atomic Energy Agency (IAEA, 1991). The corrections were applied 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 data were then corrected for height attenuation and reduced to a nominal flying height of 80 m. Where the aircraft attained a height of 250 m or higher above the ground gamma-ray spectrometric data have been set to undefined. Height attenuation corrections were made using the following formula:

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

where

$N_{corrected}$ = Corrected counts

$N_{uncorrected}$ = uncorrected counts

H = nominal flying height

h = measured flying height

u = attenuation coefficient

Attenuation coefficients for each channel are given below:

$U_{total\ count}$ = 0.00785

$U_{potassium}$ = 0.00943

$U_{uranium}$ = 0.01150

$U_{thorium}$ = 0.00747

The corrected window count rates were then 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 = Fully processed elemental count rate (cps).

The broad source sensitivities were obtained from flights over the Lake Hume 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 = Air absorbed dose rate (nanoGrays per hour, (nGh^{-1}));

F = The conversion factor determined experimentally from flights over a calibration range (29.70 cps/nGh^{-1}); and

N = Fully processed total count rate (cps).

Before any further processing of the gamma–ray spectrometric, data the associated position data were corrected for a parallax error of -9.03 m (ie. shifted toward the front of the aircraft by 9.03 m) to account for the difference between the position of the spectrometer crystals and the position data reference point (at the magnetometer sensor).

All four windows of gamma–ray spectrometric data were levelled in much the same way as the magnetic data. However prior to sampling the crossover points, a 5 point convolution filter with a cut-off wavelength of 350 m was passed over the data. Note that these filtered data were only used for the crossover analysis and the final point located data have not been filtered.

The steps involved in tie line levelling were as follows:

(a) Tie line 290 was chosen as a reference tie.

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

(c) Lines were adjusted on a flight by flight basis using degree two piecewise polynomial adjustments for total count and uranium and degree zero adjustments for potassium and thorium, to minimise the differences at line/tie crossover points.

(d) The lines were then individually adjusted to minimise crossover differences using degree two piecewise polynomial adjustments for total count and uranium. Lines were not individually adjusted for potassium or thorium.

All gamma-ray spectrometric 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 7000 m .

(b) High pass filter in the tie line direction with a cut-off wavelength of 800 m (1600 m for total count and uranium).

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 m before being applied to the line data and were constrained to lie within the following ranges;

  - ±6 nGh^{-1} for total count (95% of adjustments were less than ±2.15 nGh^{-1})
  - ±0.1 % for potassium (90% of adjustments were less than ±0.026 %)
  - ±1.5 ppm for uranium (90% of adjustments were less than ±0.489 ppm)
  - ±1.0 ppm for thorium (90% of adjustments were less than ±0.26 ppm)

A second pass of micro–levelling was applied to the total count and uranium data. Filter characteristics are described below:

(a) Low pass filter in the flight line direction with a cut-off wavelength of 3500 m.

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

(c) Correction strings were low pass filtered with a cut-off wavelength of 250 m before being applied to the line data and were constrained to lie within the following ranges;

  - ±8 nGh^{-1} for total count (95% of adjustments were less than ±1.27 nGh^{-1})
  - ±2.0 ppm for uranium (90% of adjustments were less than ±0.19 ppm)

All channels were gridded to a 80 metre (3.0″) cell size using Brigg's minimum curvature technique.

(v) Digital Elevation Model Data Processing.

As described in Chapter 5 – Section (ii), range data recorded internally every second on both GPS receivers were post-processed on a daily basis using "Ranger" - an Ashtech proprietary program. "Ranger" calculates the position of aircraft GPS receiver's antenna, including longitude, latitude and height relative to the WGS84 reference ellipsoid for each set of range data (every 1 s).

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) “Ranger” corrections.

(b) Barometric infill of height gaps.

The corrected height data, which are relative to the WGS84 reference ellipsoid, are then linearly interpolated to half second samples (35 m) and are 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 half second (35 m along the ground) are relative to the WGS84 reference ellipsoid - the ellipsoid being a horizontal datum.

Before any further processing of the digital elevation model data the associated position data were corrected for a parallax error of -11.4 m (ie. shifted toward the front of the aircraft by 11.4 m) to account for the difference between the position of the GPS and radar altimeter antennae and the position data reference point (at the magnetometer sensor).

Elevation data were tie line levelled in much the same way as the magnetic data. The steps involved in tie line levelling were as follows:

(a) Tie line 290 was chosen as a reference tie.

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

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

(d) The lines were then individually adjusted to minimise crossover differences using degree two piecewise polynomial adjustments.

Elevation data were then micro-levelled in two passes using the technique described by Minty (1991). Filter characteristics are described below:

Pass 1:

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

(b) High pass filter in the tie line direction with a cut-off wavelength of 1000 m.

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 m before being applied to the line data and were constrained to lie within the range ±3 m (95% of these corrections fell in the range ±1.24 m).

Pass 2:

(a) Low pass filter in the flight line direction with a cut-off wavelength of 8000 m.

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

(c) Correction strings were low pass filtered with a cut-off wavelength of 500 m before being applied to the line data and were constrained to lie within the range ±2 m (95% of these corrections fell in the range ±0.79 m).

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 survey area were supplied by the Australian Surveying and Land Information Group (AUSLIG) in September 1997. 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 1600 metre) grid.

These values were then imported into an INTREPID database and gridded using the INTREPID software package to a cell size of 15 seconds of arc (approximately 400 m). This grid of N values was 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 500 m 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 radar altimeter on the belly of the aircraft. This antenna separation distance of 1.675 m was subtracted from the elevation data.

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 metre.

A comparison was made between third order gravity station heights and the elevation data. There were 169 gravity stations within 20 m of airborne sample points. For these 169 stations the elevation data were on average 0.17 m larger than the gravity station heights. The standard deviation of the differences between the elevation data and gravity station heights was 0.70 m.

The fully corrected elevation data were gridded using ANUDEM46 (Hutchinson, 1988, 1989) employing a 80 metre (3.0″) grid cell size.

(vi) Final Products

(a) Standard AGSO geophysical maps

An AGSO standard set of geophysical maps have been produced at scales of 1:250 000 and 1:100 000 for the entire survey area. Profile, flight path and contour maps were produced using the INTREPID software. 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).

(c) Pixel image maps

Additional to the standard AGSO geophysical maps listed in Appendix M, pixel image maps have been compiled using the method described by Milligan and others (1992). The following pixel image maps have been released at 1:250 000 scale for both the Boulia and Springvale 1:250 000 map sheets;

(i) Colour gradient enhanced total magnetic intensity reduced to the pole.
(ii) Greyscale vertical derivative of total magnetic intensity reduced to the pole.
(iii) Gamma-ray spectrometric colour composite.
(iv) Colour gradient enhanced digital elevation model.

Digital versions of the pixel image data are available on CR-ROM in BIL format suitable for import into and use in many standard geographic information system (GIS) applications,

(d) Interpretation

AGSO has interpreted the geophysical data acquired from the survey. The results of the interpretation are available as hardcopy "Interpreted Geology Maps" at 1:250 000 scale for both the Boulia and Springvale 1:250 000 map sheets. The results are also available in digital form on CD-ROM in a format suitable for import into and use in many standard geographic information system (GIS) applications,

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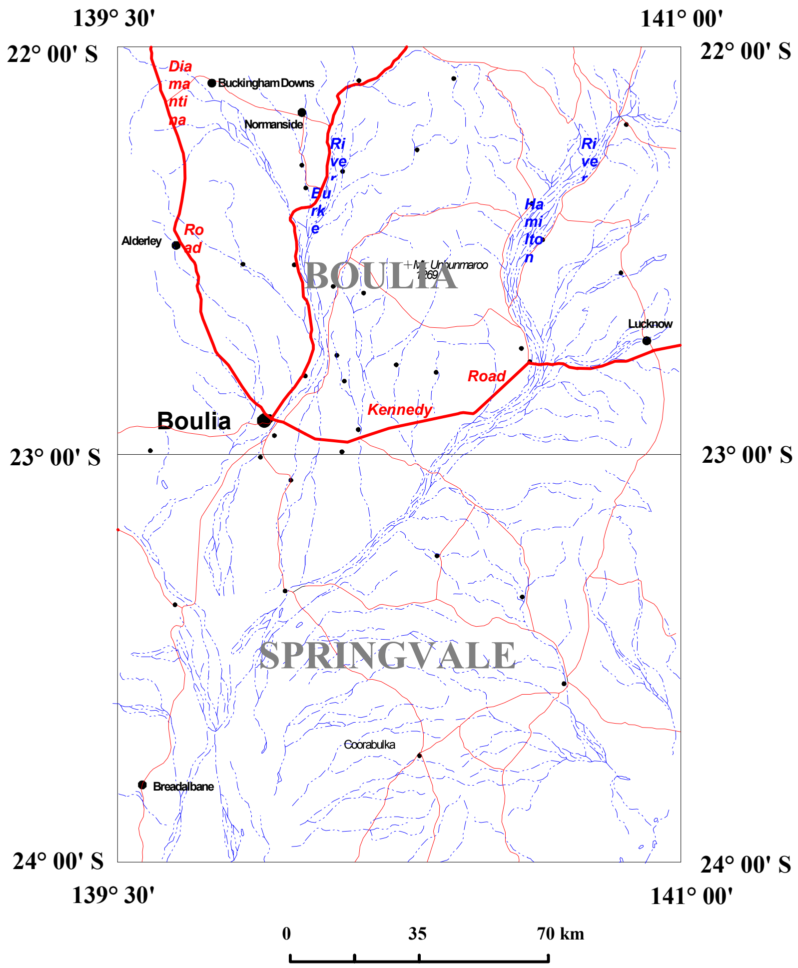
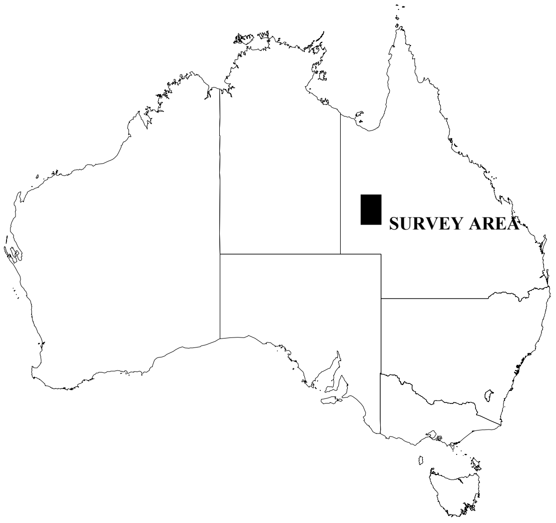
Appendix A-1





REFERENCE TO 1 : 250 000 MAP INDEX

138° 21° S — 142° 30' 21° S

URANDANGI	DUCHESS	MCKINLAY
GLENORMISTON	**BOULIA**	MACKUNDA
MOUNT WHELAN	**SPRINGVALE**	BRIGHTON DOWNS

24° S 138° — 24° S 142° 30'

Survey Area

Appendix B-1

Flying Dates and Production Kilometres Flown

Date	Flight Number	Comments	Line / Tie Kilometres
13-May-97		Ferry Canberra to Cunnamulla en-route Boulia	0
13-May-97		Ferry Cunnamulla to Boulia	0
14-May-97	231	Compensation	0
16-May-97	232	First production flight	1124
16-May-97	233	Operations normal	900
17-May-97	234	Reflown due to faulty AADC	0
17-May-97		Test flight for AADC	0
18-May-97		Ferry to Mt Isa to pick up spare AADC	0
19-May-97		Return ferry from Mt Isa	0
19-May-97	235	Compensation after installation of new AADC	0
19-May-97	236	Operations normal	900
19-May-97	237	Operations normal	900
20-May-97	238	Operations normal	987
21-May-97	239	Operations normal	987
21-May-97	240	Operations normal	851
22-May-97	241	Operations normal	847
22-May-97	242	Operations normal	938
23-May-97	243	Operations normal	938
23-May-97	244	Operations normal	938
24-May-97	245	Operations normal	900
24-May-97		Ferry to Cairns for service and LHS engine change	0
29-May-97		Test flight after service	0
29-May-97		Return ferry from Cairns	0
30-May-97	246	Compensation after service	0
30-May-97	247	Operations normal	626
30-May-97	248	Operations normal	938
31-May-97	249	Operations normal	938
31-May-97	250	Operations normal	938
01-Jun-97	251	Operations normal	938
01-Jun-97	252	Operations normal	938
02-Jun-97	253	Operations normal	938
02-Jun-97	254	Operations normal	938
03-Jun-97	255	Operations normal	938
03-Jun-97	256	Operations normal	938
04-Jun-97	257	Spectrometer failed after four lines	626
05-Jun-97		Ferry to Mt Isa – wing spar inspection & collect spare spectrometer	0
05-Jun-97		Return ferry from Mt Isa	0
06-Jun-97	258	Operations normal	626
07-Jun-97	259	Operations normal	754
07-Jun-97	260	Operations normal	938
08-Jun-97	261	Operations normal	626
08-Jun-97	262	Operations normal	626
09-Jun-97	263	Operations normal	938
09-Jun-97	264	Operations normal	938
10-Jun-97	265	Operations normal	938
10-Jun-97	266	Operations normal	938
11-Jun-97	267	Operations normal	938

11-Jun-97	268	Operations normal	938
12-Jun-97	269	Operations normal	938
13-Jun-97	270	Operations normal	938
14-Jun-97	271	Operations normal	938
14-Jun-97	272	Operations normal	938
15-Jun-97	273	Operations normal	938
15-Jun-97	274	Operations normal	938
16-Jun-97	275	Operations normal	938
16-Jun-97	276	Operations normal	938
17-Jun-97	277	Operations normal	938
17-Jun-97	278	Operations normal	938
18-Jun-97		Ferry to Charters Towers en-route Cairns for service	0
18-Jun-97		Ferry to Cairns from Charters Towers	0
21-Jun-97		Ferry from Cairns to Charters Towers en-route Boulia	0
21-Jun-97		Ferry to Boulia from Charters Towers	0
22-Jun-97	279	Compensation and radar altimeter check	0
22-Jun-97	280	Operations normal	938
23-Jun-97	281	Operations normal	938
23-Jun-97	282	Operations normal	938
24-Jun-97	283	Operations normal	938
24-Jun-97	284	Operations normal	938
25-Jun-97	285	Operations normal	938
25-Jun-97	286	Operations normal	938
26-Jun-97	287	Operations normal	938
26-Jun-97	288	Operations normal	938
27-Jun-97	289	Operations normal	938
28-Jun-97	290	Operations normal	938
29-Jun-97	291	Operations normal	938
29-Jun-97	292	Operations normal	938
30-Jun-97	293	Operations normal	938
30-Jun-97	294	Operations normal	938
01-Jul-97		Ferry to Mt Isa for wing spar inspection	0
01-Jul-97		Return ferry from Mt Isa	0
01-Jul-97	295	Reflown due to data synchronisation errors	0
02-Jul-97		Ferry to Mt Isa for check and training and to remove oil filter	0
02-Jul-97		Return ferry from Mt Isa and check and training flying	0
02-Jul-97	296	Operations normal	754
03-Jul-97	297	Operations normal	938
03-Jul-97	298	Operations normal	938
04-Jul-97	299	Operations normal	938
04-Jul-97	300	Operations normal	900
05-Jul-97	301	Operations normal	626
05-Jul-97	302	Operations normal	938
05-Jul-97		Check and Training	0
06-Jul-97	303	Operations normal	626
06-Jul-97	304	Operations normal	938
06-Jul-97		Check and Training	0
07-Jul-97	305	Operations normal	938
07-Jul-97	306	Operations normal	938
08-Jul-97	307	Operations normal	851
08-Jul-97	308	Operations normal	938
09-Jul-97	309	Operations normal	938

Appendix B-3

09-Jul-97		Ferry to Cairns for service	0
14-Jul-97		Return ferry from Cairns	0
15-Jul-97	310	Compensation after service	0
15-Jul-97	311	Operations normal	626
15-Jul-97	312	Operations normal	938
16-Jul-97	313	Test flight for radar altimeter problems	0
16-Jul-97	314	Operations normal	938
17-Jul-97	315	Operations normal	938
17-Jul-97	316	Operations normal	938
18-Jul-97	317	Operations normal	938
18-Jul-97	318	Operations normal	938
18-Jul-97		Night circuits	0
19-Jul-97	319/320	Two flight numbers - reboot in flight due engine problems	626
21-Jul-97	321	Operations normal	938
21-Jul-97	322	Operations normal	938
22-Jul-97	323	Operations normal	938
22-Jul-97	324	Operations normal	938
23-Jul-97	325	Operations normal	938
23-Jul-97	326	Operations normal	938
24-Jul-97	327	Operations normal	938
24-Jul-97		Ferry to Mt Isa for wing spar inspection	0
24-Jul-97		Return ferry from Mt Isa	0
25-Jul-97	328	Operations normal	938
25-Jul-97	329	Radar altimeter failed in flight - flight abandoned	158
25-Jul-97	330	Radar altimeter test flight	0
26-Jul-97	331	Radar altimeter test flight	0
26-Jul-97	332	Radar altimeter failed in flight - flight abandoned	0
27-Jul-97		Ferry to Broken Hill en-route Melbourne for altimeter maintenance	0
27-Jul-97		Ferry Broken Hill to Melbourne	0
29-Jul-97	333	Radar altimeter test flight in Melbourne	0
29-Jul-97		Ferry Melbourne to Broken Hill en-route Boulia	0
29-Jul-97		Ferry Broken Hill to Boulia	0
30-Jul-97	334	Operations normal	938
30-Jul-97	335	Operations normal	938
31-Jul-97	336	Operations normal	938
31-Jul-97	337	Operations normal	938
01-Aug-97	338	Operations normal	938
02-Aug-97	339	Operations normal	938
03-Aug-97	340	Operations normal	938
03-Aug-97	341	Operations normal	938
04-Aug-97	342	Operations normal	938
04-Aug-97		Ferry to Cairns for service	0
05-Aug-97		Test flight in Cairns	0
07-Aug-97		Return ferry from Cairns	0
07-Aug-97	343	Compensation after service	0
08-Aug-97	344	Operations normal	938
08-Aug-97	345	Operations normal	938
09-Aug-97	346	Operations normal	938
09-Aug-97	347	Operations normal	938
10-Aug-97	348	Operations normal	938
10-Aug-97	349	Operations normal	938

11-Aug-97	350	Operations normal	938
11-Aug-97	351	Operations normal	938
12-Aug-97	352	Operations normal	782

SUMMARY

Total line kilometres flown	97,020

Productive flights	108
Unproductive flights	45
Abandoned flights (productive or not)	2
Total flights in survey	153

Unproductive flights consisted of:

Aircraft ferries	24
Compensation flights	6
Check and training flights	5
Aircraft and equipment test flights	8
Abandoned flights	2

Abandoned flights due to:

Equipment failure	2

Appendix C-1

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 metres.

The primary navigation equipment used for this survey consisted of two Ashtech XII GPS receivers; one at a known position on the Boulia airport next to the office caravan, and the other in the aircraft. The ground based GPS receiver operated in non–differential mode and was not used as part of the real–time navigation system but it was used to record base station data for post flight differential processing. The aircraft GPS receiver was set up to run in differential mode.

Fugro Starfix Pty Ltd supplied 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. The EDS receiver calculates a non–differentially corrected aircraft position from its internal GPS engine and using this position computes a "least squares method" optimum set of RTCM (Radio Technical Commission for Maritime Services) corrections for output to the Ashtech GPS receiver in RTCM 104 format.

The EDS receiver obtains satellite range data through an Ashtech plate antenna and range correction data through an OPTUS plate antenna, both mounted on the upper fuselage of the aircraft. The Ashtech GPS receiver in the aircraft uses the Ashtech plate antenna for receiving satellite range data. The EDS receiver outputs corrections to the aircraft GPS receiver at 4800 baud.

Appendix D-1

Specifications – G822A Caesium Magnetometer

Operating principle:	Self-oscillating caesium vapour magnetometer
Operating range:	20,000 nT 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 peak to peak, frequency (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 g 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 nT – 100,000 nT
Resolution:	1 pT (picotesla)
Compensation procedure:	improvement ratio 10 – 20 (typical for total field) improvement ratio 20 – 100 (typical for gradient)
Accuracy of compensation:	0.35 nT 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:	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)
Power:	28 ± 4 VDC 5A, 150 W (for single magnetometer) 7A, 196 W (for gradiometer system)
Environmental:	Operating temperature: 0°C to 50°C Storage temperature -20°C to 55°C Relative humidity 0–99%, non-condensing Altitude 0–6000 m
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 stabilisation is achieved. Resolution is calculated by a sophisticated gaussian curve fitting algorithm to perform an accurate centroid analysis of the selected stabilisation 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 analyses for pulse pile–up and permits only detector signals from single events to be analysed. 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. Analogue 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 msec/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 cps.

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.
- Analogue output:
  - 4 channels of ROI data can be selected for output on the analogue 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. Analogue output wraps at FSD limits and is dead-time corrected.

D. Miscellaneous

- Regions of interest (ROI): 8 ROIs 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 analogue 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 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 analogue 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

The crystals are housed in a 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 optimisation is used. The GPX–1024 has 4 crystals with a total volume of 16.78 litres

Appendix F-3

- Outputs: Individual BNC connectors output each crystal's signal separately
- Size: GPX−1024 : (73x51x30 cm)
- Weight: GPX−1024 : 84 kg
- Power: 28V @ 0.5A/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

Sensor Module:

Operating principle: Self-oscillating caesium vapour magnetometer

Operating range: 20,000 nT 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 peak to peak, frequency (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 g
Sensor electronics cable: 135 cm to 270 cm long

Qualification: MIL–I–45208, MIL–M–19595

Counter Module:

Operating frequency range: 70 kHz to 350 kHz

Operating field range: 20,000 nT to 100,000 nT

Cycle rate: variable from 20 s to 0.01 s in 0.005 s increments

Sensitivity (nT) (Counter LSB)	Noise (RMS) (nT)	Earth's Field (nT)	Sample Rate (Hz)
0.001	0.003	30,000	1
0.002	0.004	50,000	
0.003	0.005	70,000	
0.013	0.015	30,000	10
0.023	0.020	50,000	
0.032	0.025	70,000	

Julian clock: Resolution: 0.01 seconds
Drift: < 1 second/day

A/D channels: Internal: one channel for Larmor signal amplitude
External: five, 12 bit channels

Data output: RS–232 standard serial port

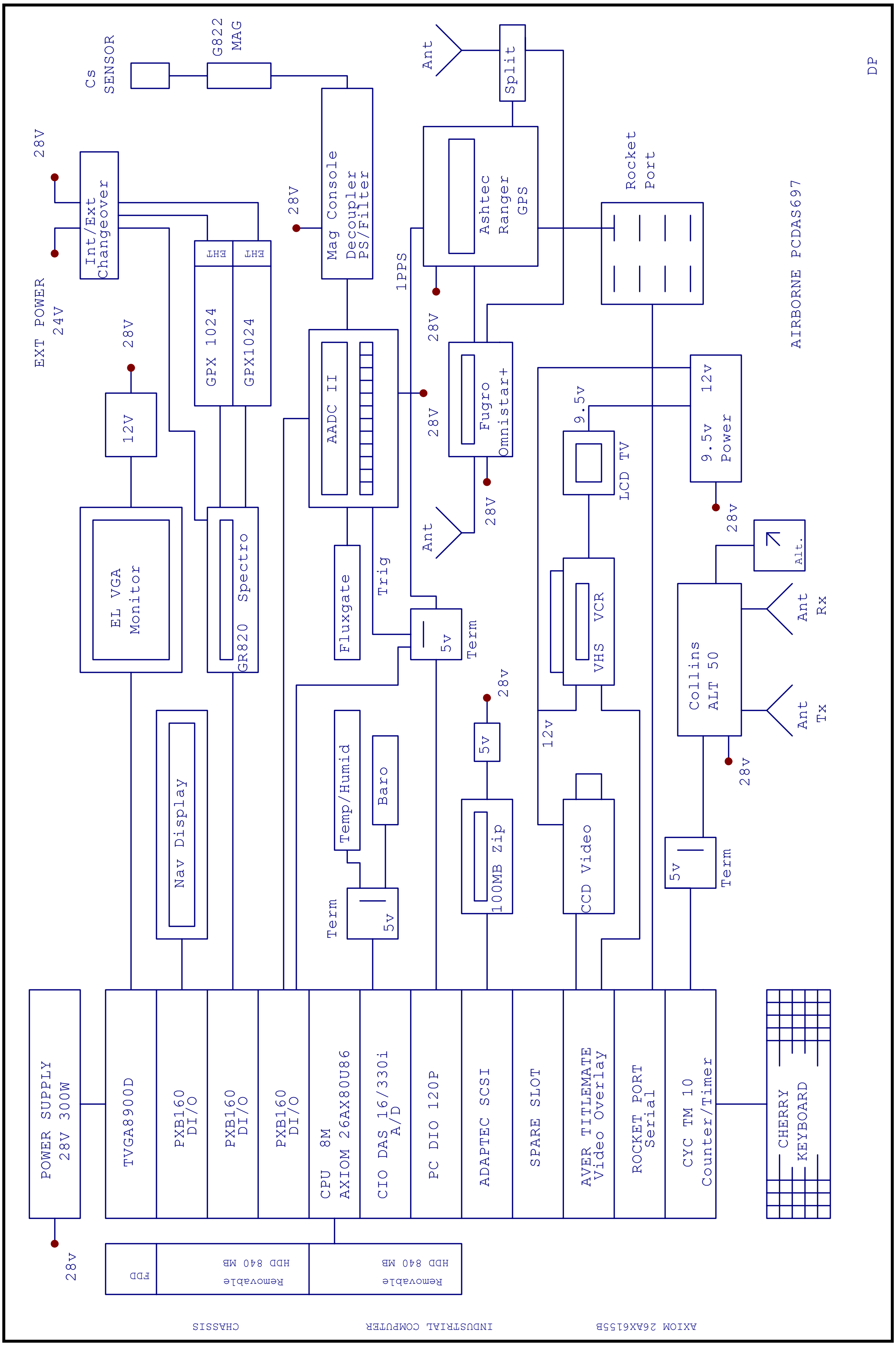
Operating temperature: -25°C to +50°C

Power: CM–201 alone runs on 5 V @ 0.30 A

Compatibility: PC based systems

APPENDIX H-1

Aircraft Data Acquisition System



Appendix I-1

Compensation Results

Compensation 1

Date flown	14 May 1997
Date used	16 May

Air conditioner off

σ_u = 0.2120
σ_c = 0.009387
λ = 22.4
ν = 20.5

Air conditioner on

σ_u = 0.2167
σ_c = 0.07965
λ = 2.7
ν = 26.5

Compensation 2

Date flown	19 May 1997
Dates used	19 to 24 May

Air conditioner off

σ_u = 0.2009
σ_c = 0.02697
λ = 7.4
ν = 8.0

Air conditioner on

σ_u = 0.2308
σ_c = 0.09561
λ = 2.4
ν = 9.0

Compensation 3

Date flown	30 May 1997
Dates used	30 May to 17 June

Air conditioner off

σ_u = 0.1858
σ_c = 0.01191
λ = 15.6
ν = 7.7

Air conditioner on

σ_u = 0.1607
σ_c = 0.03686
λ = 4.4
ν = 6.2

Appendix I-2

Compensation 4

Date flown 22 June 1997
Dates used 22 June to 9 July

Air conditioner off
$\sigma_u = 0.1459$
$\sigma_c = 0.01223$
$\lambda = 13.6$
$\nu = 6.5$

Air conditioner on
$\sigma_u = 0.2153$
$\sigma_c = 0.09890$
$\lambda = 2.2$
$\nu = 7.5$

Compensation 5

Date flown 15 July 1997
Dates used 15 July to 4 August

Air conditioner off
$\sigma_u = 0.1740$
$\sigma_c = 0.01040$
$\lambda = 16.7$
$\nu = 6.2$

Air conditioner on
$\sigma_u = 0.1479$
$\sigma_c = 0.09055$
$\lambda = 1.4$
$\nu = 8.1$

Compensation 6

Date flown 7 August 1997
Dates used 7 to 12 August

Air conditioner off
$\sigma_u = 0.1353$
$\sigma_c = 0.01375$
$\lambda = 9.8$
$\nu = 9.2$

Air conditioner on
$\sigma_u = 0.1689$
$\sigma_c = 0.08962$
$\lambda = 1.9$
$\nu = 6.5$

σ_u = standard deviation of data recorded during manoeuvres

σ_c = standard deviation of data recorded during manoeuvres after compensation corrections have been applied

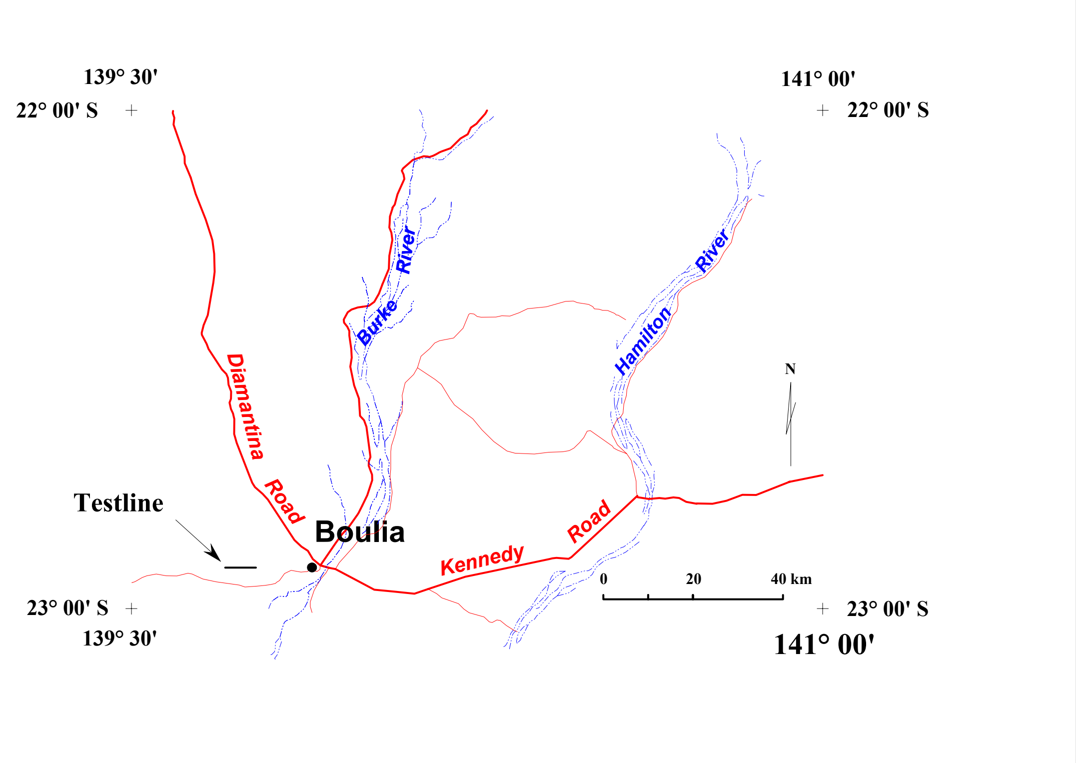
λ = improvement ratio = σ_u / σ_c

ν = vector norm, a measure of the degree of difficulty in calculating the coefficients

Appendix J-1

Gamma-ray Spectrometer Test Line Location

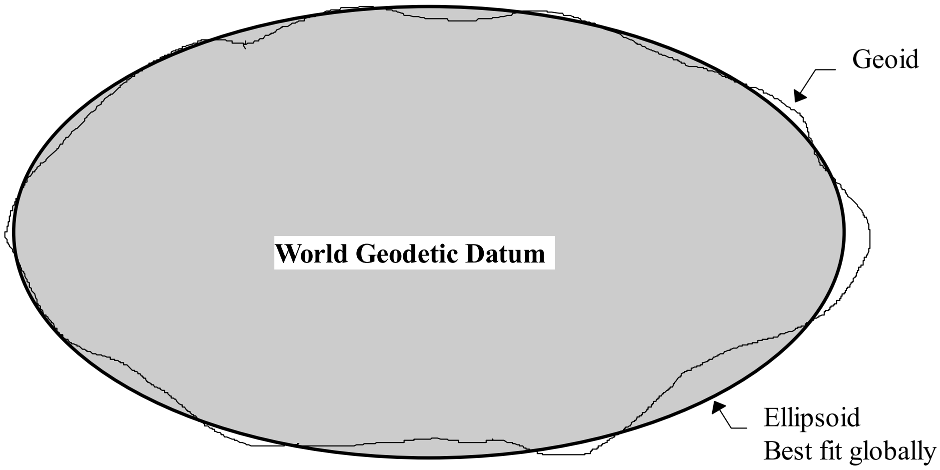
Coordinates 139° 42′ 09.22″E 22° 55′ 03.22″S to 139° 46′ 09.22″E 22° 55′ 03.22″S



Appendix K-1

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 at 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-1

Corrections to Differential GPS Navigation Data

(a) "Ranger" corrections

Using the range data which are recorded internally on the aircraft and base GPS receivers every second, "Ranger" calculates the correct positions at one second intervals along the flight path. These corrected positions are utilised to correct the raw aircraft position data recorded every half second.

Discontinuities (steps) and spikes sometimes occur in the raw aircraft GPS data. These may also be manifested as steps in the correction set. When such steps in the raw aircraft 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.

(b) Infilling "Ranger" data

Data gaps can appear in the "Ranger" data and not in the raw aircraft data. To infill these gaps the difference between the raw aircraft data and the "Ranger" data are calculated at each point for which both exist. It is these differences that are actually infilled, therefore preserving the shape of the aircraft's flight path over the gap in the "Ranger" data whilst still moving the navigation data to the absolute locations defined by the "Ranger" data. The maximum gap that will be infilled by this method is 10 s (700 m).

(c) Infilling final navigation data

For a variety of reasons, data gaps may appear in the final navigation data. Common causes are the multiple steps as in (a) above and gaps in the "Ranger" data. These gaps in the final navigation data are linearly infilled. The maximum gap size is 10 seconds.

(d) Generation of terrain data

The terrain data is generated by subtracting radar altimeter clearance data from the "Ranger" ellipsoidal height data. The terrain data are linearly interpolated to match the half second sampling interval of the "Ranger" corrected navigation data.

(e) 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 5 point Fuller filter with a cut-off wavelength of 175 m was passed over the navigation data. The terrain data are not filtered.

(f) 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 are shifted 11.4 m towards the rear of the aircraft to correspond with the position of the magnetometer sensor. In the processing of the gamma-ray and digital elevation model data parallax corrections are made to account for this shift.

(g) Barometric infill of height data gaps

Whenever gaps less than 5 km in the GPS height data occur, these gaps are infilled with height data calculated using the recorded barometric and temperature data. Gaps greater than 5 km require the line to be reflown or an infill line flown.

Appendix M-1

Geophysical Maps

Name	Type	Interval or Scale	Reference Number

1:250 000 scale

Boulia	TMI Contours	10 nT	22-1/F54-10/1
	Dose Rate Contours	2 nG/hr	22-1/F54-10/18
	DEM Contours	2 m	22-1/F54-10/19
Springvale	TMI Contours	10 nT	22-1/F54-14/1
	Dose Rate Contours	2 nG/hr	22-1/F54-14/18
	DEM Contours	2 m	22-1/F54-14/19

1:100 000 scale (Boulia 1:250 000 sheet)

Buckingham Downs	TMI Contours	5 nT	22-2/F54-10/1-1
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-1
	TMI Profiles (AGC)		22-2/F54-10/4-1
	Flight line System		22-2/F54-10/3-1
Digby Peaks	TMI Contours	5 nT	22-2/F54-10/1-2
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-2
	TMI Profiles (AGC)		22-2/F54-10/4-2
	Flight line System		22-2/F54-10/3-2
Toolebuc	TMI Contours	5 nT	22-2/F54-10/1-3
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-3
	TMI Profiles (AGC)		22-2/F54-10/4-3
	Flight line System		22-2/F54-10/3-3
Boulia	TMI Contours	2 nT	22-2/F54-10/1-4
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-4
	TMI Profiles (AGC)		22-2/F54-10/4-4
	Flight line System		22-2/F54-10/3-4
Goodwood	TMI Contours	2 nT	22-2/F54-10/1-5
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-5
	TMI Profiles (AGC)		22-2/F54-10/4-5
	Flight line System		22-2/F54-10/3-5
Lucknow	TMI Contours	5 nT	22-2/F54-10/1-6
	Dose Rate Contours	1 nG/hr	22-2/F54-10/18-6
	TMI Profiles (AGC)		22-2/F54-10/4-6
	Flight line System		22-2/F54-10/3-6

Appendix M-2

Name	Type	Interval or Scale	Reference Number

1:100 000 scale (Springvale 1:250 000 sheet)

Marion Downs	TMI Contours	5 nT	22-2/F54-14/1-1
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-1
	TMI Profiles (AGC)		22-2/F54-14/4-1
	Flight line System		22-2/F54-14/3-1
Canary	TMI Contours	2 nT	22-2/F54-14/1-2
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-2
	TMI Profiles (AGC)		22-2/F54-14/4-2
	Flight line System		22-2/F54-14/3-2
Elizabeth Springs	TMI Contours	5 nT	22-2/F54-14/1-3
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-3
	TMI Profiles (AGC)		22-2/F54-14/4-3
	Flight line System		22-2/F54-14/3-3
Breadalbane	TMI Contours	2 nT	22-2/F54-14/1-4
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-4
	TMI Profiles (AGC)		22-2/F54-14/4-4
	Flight line System		22-2/F54-14/3-4
Corrabulka	TMI Contours	2 nT	22-2/F54-14/1-5
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-5
	TMI Profiles (AGC)		22-2/F54-14/4-5
	Flight line System		22-2/F54-14/3-5
Springvale	TMI Contours	5 nT	22-2/F54-14/1-6
	Dose Rate Contours	1 nG/hr	22-2/F54-14/18-6
	TMI Profiles (AGC)		22-2/F54-14/4-6
	Flight line System		22-2/F54-14/3-6

Appendix N-1

AGSO Archive Data, Grid and Magnetic Tape Format for Airborne Geophysical Data

CONTENTS

TABLES

Appendix N-2

1. THE AGSO SEQUENTIAL FILE STRUCTURE

(i) Introduction

This appendix describes the general sequential file structure used by AGSO to store airborne geophysical data. For the purpose of this survey 14 data chains are involved for each line and tie. They are:

channel 4 edition 1 (processed navigation data)
channel 4 edition 2 (processed magnetic data)
channel 4 edition 3 (processed spectrometric data)
channel 4 edition 4 (processed digital elevation model data)
channel 6 edition 2 (terrain and altimeter data)
channel 6 edition 3 (diurnal data)
channel 8 edition 1 (raw compensated magnetic data)
channel 8 edition 2 (fluxgate data and uncompensated magnetic data)
channel 14 edition 2 (pressure, temperature, humidity, cosmic data)
channel 16 edition 2 (raw navigation data)
channel 17 edition 1 (raw 256 channel spectrometer data)
channel 18 edition 1 (gridding flag for magnetics data)
channel 18 edition 1 (gridding flag for gamma-ray spectrometer data)
channel 18 edition 1 (gridding flag for digital elevation model data)

(ii) 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.

Segment Directory Record (SDR):	the first record on each segment; defines the data content of the segment.
Data Records (DAR's):	hold the measured data values.

(iii) 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).

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 magnetic data and edition 3 for gamma–ray spectrometric data.

(iv) Segment Directory Record (SDR)

Lines and ties are uniquely identified as follows:

Project number:	a unique number to identify the survey
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.
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). A typical SDR is shown in Figure 1 and its exact format 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.

(v) 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. A typical segment is shown in Figure 1 and the exact format of a data record given in Table 2.

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

(vi) 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.

(vii) Standard Data Channels

The standard AGSO data channels are:

channel 4 edition 1 (processed navigation data)
channel 4 edition 2 (processed magnetic data)
channel 4 edition 3 (processed spectrometric data)
channel 4 edition 4 (processed digital elevation model data)
channel 6 edition 2 (terrain and altimeter data)
channel 6 edition 3 (diurnal data)
channel 8 edition 1 (raw compensated magnetic data)
channel 8 edition 2 (fluxgate data and uncompensated magnetic data)
channel 14 edition 2 (pressure, temperature, humidity, cosmic data)
channel 16 edition 2 (raw navigation data)
channel 17 edition 1 (raw 256 channel spectrometer data)
channel 18 edition 1 (gridding flag for magnetics data)
channel 18 edition 1 (gridding flag for gamma-ray spectrometer data)
channel 18 edition 1 (gridding flag for digital elevation model data)

C4 E1 - Corrected GPS Navigation Data

channel number = 4
edition number = 1
sample size = 2 words
word 1 = longitude (degrees) * 1 000 000
word 2 = latitude (degrees) * 1 000 000

C4 E2 - Corrected Total Magnetic Intensity Data

channel number = 4
edition number = 2
sample size = 4 words
word 1 and word 2 as for C4 E1
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 = parallax corrected longitude (degrees) * 1 000 000
word 2 = parallax corrected latitude (degrees) * 1 000 000
word 3 = final total count (nG/hr) * 1000
word 4 = final potassium (%) * 1000
word 5 = final uranium (ppm) * 1000
word 6 = final thorium (ppm) * 1000
word 7 = radar altimeter (m above ground level) * 1000

C4 E4 - Corrected Digital Elevation Model Data

channel number = 4
edition number = 4

sample size = 4 words
word 1 = parallax corrected longitude (degrees) * 1 000 000
word 2 = parallax corrected latitude (degrees) * 1 000 000
word 3 = final aircraft elevation (m above WGS84 ellipsoid) * 1000
word 4 = final terrain elevation (m above sea level) * 1000

C6 E2 – Terrain and Altimeter Data

channel number = 6
edition number = 2
sample size = 2 words
word 1 = raw terrain elevation (m above sea level) * 1000
word 2 = radar altimeter (m above ground level) * 1000

C6 E3 - Diurnal Data

channel number = 6
edition number = 3
sample size = 2 words
word 1 = diurnal (nT) * 1000
word 2 = filtered diurnal (nT) * 1000

C8 E1 - Raw Magnetic Data

channel number = 8
edition number = 1
sample size = 1 word
word 1 = compensated TMI (nT)* 1000

C8 E2 - Fluxgate and Uncompensated Magnetic Data

channel number = 8
edition number = 2
sample size = 5 words
word 1 = fluxgate X (nT) * 1000
word 2 = fluxgate Y (nT) * 1000
word 3 = fluxgate Z (nT) * 1000
word 4 = fluxgate T (nT) * 1000
word 5 = uncompensated magnetic data (nT) * 1000

C14 E2 - Pressure, Temperature, Humidity and Cosmic Data

Channel number = 14
Edition number = 2
Sample size = 4 words
word 1 = pressure (millibars) * 1000
word 2 = temperature (degrees Celsius) * 1000
word 3 = humidity (%) * 1000
word 4 = cosmic channel (counts) * 1000

C16 E2 - Raw Navigation Data

channel number = 16
edition number = 2
sample size = 5 words
word 1 = longitude (degrees) * 1 000 000
word 2 = latitude (degrees) * 1 000 000
word 3 = raw aircraft elevation (m above WGS84 ellipsoid) * 1000
word 4 = GPS time (seconds) * 1000 (GPS time is recorded in seconds
from midnight the previous Sunday)
word 5 = GPS Quality * 1000 (flag indicates whether data are real time corrected)

C17 E1 - Raw 256 Channel Gamma–Ray Spectrometric Data

channel number = 17
edition number = 1
sample size = 290 words
word 1 - 34 = various control information words
word 35 - 290 = individual 256 channels from channel 1 to 256
(counts per second * 1000)

C18 E1 – Gridding Flag – Magnetic Data

channel number = 18
edition number = 1
sample size = 1 word
word 1 = magnetics gridding flag (0 = USE and 1=IGNORE)

C18 E2 – Gridding Flag – Gamma-ray Spectrometric Data

channel number = 18
edition number = 2
sample size = 1 word
word 1 = gamma-ray spectrometrics gridding flag (0 = USE and 1=IGNORE)

C18 E3 – Gridding Flag – Digital Elevation Model Data

channel number = 18
edition number = 3
sample size = 1 word
word 1 = digital elevation model gridding flag (0 = USE and 1=IGNORE)

2. PHYSICAL FORMAT OF STORAGE MEDIA

(i) General

Each exabyte magnetic tape or CD–ROM consists of a sequence of segments, each segment consisting of one or more physical records. Segments are to be separated by one EOF marker. The end of all information on the media 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.

(ii) Physical Parameters of Media

(a) Exabyte Tapes are 8 mm wide, computer grade standard data cartridge.

(b) CD–ROM are 74 minute (640 Mb) standard media.

(c) Each media have an external label identifying the airborne survey, character code, recording density, date data written.

(iii) Tape Structure

(a) Written in ASCII.

(b) No multi-tape files.

(iv) Physical Records and Blocks

(a) Fixed length records of 5120 characters.

(b) One record per block.

3. GRID FILE FORMAT

(i) 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, ie. 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.

(ii) 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 (ie. 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.

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

Appendix N-9

Table 1

Segment Directory Record Format

1. Segment Identification Block

Word	Content And Use	Format
1	Project identification	I9
2	Group identification	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 m	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

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

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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.