AGSO

CLARENCE RICHMOND, MACLEAN, TWEED HEADS AND EASTERN GRAFTON 1 : 250 000 SHEET AREAS AIRBORNE GEOPHYSICAL SURVEY, 1997 – OPERATIONS REPORT

by

J. N. Mitchell & B. R. S. Minty

AGSO Record 1998/27

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

CLARENCE RICHMOND
MACLEAN, TWEED HEADS, AND EASTERN GRAFTON
1:250 000 SHEET AREAS
AIRBORNE GEOPHYSICAL SURVEY, 1997 -
OPERATIONS REPORT

by

J. N. Mitchell & B. R. S. Minty

Australian Geological Survey Organisation
Record 1998/27

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Primary Industries and Energy: Hon. J. Anderson, M.P.
Minister for Resources and Energy: Senator the Hon. W.R. Parer
Secretary: Ken Matthews

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Dr Neil Williams

ISSN: 1039-0073
ISBN: 0 642 27363 4

SUMMARY

The Australian Geological Survey Organisation flew an airborne geophysical survey of 84 200 line km over the Maclean, southern Tweed Heads, eastern Grafton 1 : 250 000 map Sheet areas from the 5 March to 13 March and from 11 August to 28 September 1996. The Clarence Richmond survey was flown along east-west flight lines. Onshore the lines were 200 metres apart at an altitude of 80m above ground level. The survey altitude was 130 m above sea level over offshore areas and flight lines were spaced at 400m west of longitude 153.94 degrees E and 1600m east of this longitude.

The purpose of this survey was three fold;
- to demonstrate how airborne geophysical data can be used to discriminate coastal environments,
- to develop enhancements that target areas of coastal land degradation, and
- to examine the underlying structure of the continental shelf and the extension of large coastal rivers across the shelf during low sea level periods

The total magnetic intensity, 256 channel spectrometric and digital elevation model data 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.

CONTENTS

1. SURVEY AREA AND PARAMETERS

(i) Area Description

The Clarence Richmond airborne survey covers approximately the northern two thirds of the Maclean 1:250 000 map Sheet area, the southern quarter of the Tweed Heads 1:250 000 map Sheet area, a very small portion of the Grafton 1:250 000 map Sheet area and also a small portion of the completely offshore sheet 1:250 000 area known as SH56-07. The exact survey area is shown in Appendix A.

(ii) Survey Parameters

Altitude	80 m agl onshore 130m asl offshore
Flight line direction	East-West
Tie line direction:	North-South
<u>Line spacing</u>	
Flight lines:	200/400/1600 m
Tie lines:	2000/3000/15000 m

Survey distance accepted:

Lines:	43 237km
Ties:	5127 km
Total distance:	48 401 km

Sampling interval

Magnetics:	0.1 seconds (approx 7m)
Gamma-ray spectrometrics:	1.0 seconds (approx 67m)
GPS/Doppler/Radar Altimeter:	1.0 seconds (approx 67m)
Barometric pressure/Temperature:	10.0 seconds (approx 670m)

2. LOGISTICS

(i) Operating Base and Dates of Flying

(a) Operating Base

Aircraft and crew were based at Lismore in NSW for the duration of the survey, initially from 5 to 13 March and for the most part of the survey from 11 August to 28 September 1996.

(b) Flying Dates

The survey was flown in two parts, the first between the 5 and 13 March, and the second over 11 August to 28 September 1996. For the first part of the survey, a compensation for the magnetic field of the aircraft was flown on the 4 March and production flying began on 5 March and proceeded until 13 March . It was determined that the ground conditions were too wet for accurate gamma-ray spectrometric readings to comply with the aims of the survey and production was consequently aborted on 13 March. Once the ground had dried out considerably and ground checks made, a compensation flight for the magnetic field of the aircraft was flown on the 11 August and production began on 12 August and continued through to 28 September. Due to the majority of flight lines being flown during August and September, all onshore lines flown during March were re-flown, owing to different elemental counts being evident in the radiometric data channels. 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 Leaders:	Mario Bacchin Ross Brodie Jane Mitchell	
Technicians:	Trevor Dalziell Dave Pownall	
Operators:	Lars Rickardsson "Curly" Wilcox	
Pilots:	Capt. John Biffin Capt. Marc Bourguignon	(Skywest Aviation) (" ")

3. SURVEY EQUIPMENT

(i) Major Equipment

Magnetometer:	Geometrics G833 helium magnetometer (March) Geometrics G822A caesium magnetometer (August - September)
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 l total)
Altimeter:	Collins ALT-50 radar altimeter
Barometer:	AGSO digital-Setra sensor
Thermometer:	AGSO digital-RS sensor
Navigation:	Ashtech XII "Ranger" GPS receivers and Ashtech "Ranger" differential processing software Fugro Omnistar Plus real-time differential GPS base station system
Doppler	Racal (Decca) doppler antenna (80561 CAD) Sperry C 14 D compass
Video:	National colour video camera (WV CL 302E) National VCR (NV 180) National LCD TV (TCL 3A) National Time Date Generator (WJ 810)
Acquisition hardware:	HP-A400 computer, HP9122 720 Kb 3.5 inch dual floppy disc drive and HP Thinkjet printer Compaq Notebook and 120 Mb portable hard disc drive
Acquisition software:	AGSO-developed HP assembler language program

(ii) Navigation

(a) GPS Navigation System

Navigation in the survey aircraft was by the real-time differential global positioning system (GPS) method. The aircraft navigation system used an Ashtech XII (GPS) receiver which received range data from satellites every 0.5 second and calculated the current latitude and longitude coordinates of the aircraft in the datum, World Geodetic System 1984 (WGS84). The range data were recorded internally in the GPS receiver every five seconds for post flight differential GPS processing against the base station set up at the Lismore base. Differential GPS corrections to the range data, supplied by Fugro Starfix GPS base station network, were transmitted in real time via an Optus satellite link to a Fugro OmniStar Plus receiver in the aircraft. The real time method employed is described more fully in Appendix C.

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

To enable differential GPS post flight processing, and as a quality control against the real-time system, a second GPS receiver was set up as a GPS base station. The base station was located at the airfield, east of the Lismore Aero Club. The base station internally recorded range data every five seconds. The data from the aircraft were post processed using these range data employing Ashtech 'Ranger' software at the end of each flying day. The error in position of the post processed flight path data was checked by flying a cloverleaf over the windsock at the airport and was within approximately 5-10 metres.

The position of the base station GPS receiver was accurately determined by differential GPS surveying using the aerodrome reference point (ARP), PM 83106, located at Lismore aerodrome, (near the windsock), as a fixed reference. The position of the ARP is known to better than 5 metres.

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

Longitude	: -28°	49'	32.749325" E	
Latitude	:153°	15'	29.248995" S	
Ellipsoidal height	:		51.289 m	

(b) Doppler Navigation System

Doppler navigation data were used as a secondary navigation system for the aircraft. The doppler data were used as a back-up for the main navigation system (GPS) and to infill gaps (< 5 km) in the GPS data.

(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. This system was also used for locating start and end positions for the gamma-ray spectrometer test lines.

(iii) Magnetometer

A Geometrics G833 helium magnetometer, with the sensor mounted in a boom attached to the rear of the aircraft, was used during the March flights. During August and September a caesium sensor was used, (this was installed into VH-BGE on June 5). The specifications of both magnetometers 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 low pass filters the total magnetic field intensity data using a second order 0.9 Hz recursive Butterworth filter. The filtered compensated total magnetic field intensity data 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 3.2 MeV were recorded every second. These data were recorded on a portable hard disk via a communications link between the HP-A400 computer acquisition system and a Compaq Notebook computer.

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

Total Count	0.40-3.00 MeV
Potassium	1.35-1.57 MeV
Uranium	1.63-1.89 MeV
Thorium	2.42-2.82 MeV
Cosmic	3.00-6.00 MeV

The Total Count, Potassium, Uranium and Thorium counts were used for data checking during acquisition and the Cosmic counts were used for background estimation and later data processing. A cumulative 256 channel spectrum between 0.0 MeV and 3.2 MeV was also recorded every 300 seconds for each survey line. These spectra were also used for data checking during acquisition. 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.

Prior to commencement of production flying the radar altimeter system was checked. This involved flying the aircraft at 30 metre height intervals, up to a height of 180 metres over the ocean using the aircraft's barometric altimeter as the height reference. Radar altimeter and GPS height data were recorded for each height interval flown. A comparison of these data with the aircraft's barometric altimeter verified that the system was operating satisfactorily.

(vi) Barometer and Thermometer

Atmospheric temperature and pressure were measured using a digital barometer (Setra sensor) and digital thermometer (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 G833 helium magnetometer, the specifications of which 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 recorded at the base station every five seconds onto a Chicony 486 SLC laptop computer incorporating a GT100 universal counter card to calculate the magnetic field values and a Magellan OEM GPS module to time synchronise the diurnal data with aircraft data. In addition the data were telemetered to AGSO's field office caravan for display and recording every five seconds on a Acer 466 DP desktop computer. The telemetry system used AGSO-built modems incorporating Phillips 828 UHF mobile radiotelephone transmit boards at a frequency of 471.8 MHz.

The acquisition program and hardware were developed in-house at AGSO.

(viii) Data Acquisition

The acquisition program and system were run using a HP-A400 computer with data recorded on 3.5 inch floppy discs using a HP9122 720 Kb disc drive. The one second multichannel spectra were recorded on a portable hard disk linked to the acquisition system through a Compaq notebook computer. The acquisition program was developed in-house at AGSO.

The data are displayed in real time in the aircraft in analogue form on a HP Thinkjet printer.

A schematic diagram of the aircraft's acquisition system is shown in Appendix H.

The data are displayed in real time in the aircraft in analogue form on a HP Thinkjet printer.

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 in an area of low magnetic gradient prior to the start of the survey and after each aircraft service. The compensation flights were flown approximately 50 kilometres south of Lismore over an area between 153° 3' to 153° 30' E and 28° 56' to 29°21' S. All compensation flights were flown at an altitude of 2500 m above sea level.

The compensation flight procedure 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. Prior to compensation the peak–to–peak noise was approximately 1 nT. Peak-to-peak noise during repeat manoeuvres and after the final compensation was 0.20 nT or less. On normal survey flights, noise levels from all sources were generally less than 0.10 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). These statistics are given for all 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 Thorium). 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 (Thorium) is reached, 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. These lines were flown at survey altitude along a dirt road and lasted 150 seconds or approximately 10 kilometres. The location of the test lines used for the 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, observed on video, 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. Only one flight, flight no. 371, varied greater than 15% and once incorporated with the other gamma ray data there were significant differences in neighbouring lines, making it evident that equipment problems had occurred with the spectrometer, and the flight was re-flown.

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 in a Compaq SLT386s/20 desktop computer. This computer was networked to a Scorpion 10/20 Sparcstation and all aircraft data were transferred to the Scorpion hard drive to be edited, using INTREPID, for missing values, noise, spikes or steps. 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 only edited out if they caused severe noise or caused the magnetometer to lose lock.

(ii) Flight Path Recovery

GPS range data which were recorded internally every five seconds 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 'The World Geodetic System 1984, WGS84 reference ellipsoid'.

At the end of each flying day the corrected longitude and latitude data calculated at five second intervals by "Ranger" were used to correct the GPS data which were recorded every one 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 which 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) "Ranger" corrections.

(d) Low pass filter.

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

(f) Doppler infill of gaps.

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
200 m	30 m	greater than 3 km
400 m	60 m	greater than 5 km
1600 m	80 m	greater than 5 km

When both the across track deviation and along line distance were exceeded that portion of the survey line was reflown. 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 1996.64 and for an altitude of 130 m 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 (60,000 nT) so that the average residual magnetic field value was approximately 5000 nT.

Tie-line levelling - Part 1 - All flight lines

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

(a) Tie line 1310 was chosen as a reference tie.

(b) All other ties were levelled to this tie line using degree one or two polynomial adjustments.

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

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

Micro-levelling - Part 1 - 200m lines

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 2000 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 500 metres before being applied to the line data. Adjustments were limited to a maximum of 20 nT. Statistics on the applied corrections indicated that 93.5% of the corrections were between ±10 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.

Micro-levelling - Part 2 - 400m lines

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 2400 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1000 metres before being applied to the line data. Adjustments were limited to a maximum of 20 nT. Statistics on the applied corrections indicated that 95 % of the corrections were between ±10 nT.

Micro-levelling - Part 3 - 1600m lines

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

(a) Low pass filter in the flight line direction with a cut-off wavelength of 10000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 6400 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 2000 metres before being applied to the line data. Adjustments were limited to a maximum of 20 nT. Statistics on the applied corrections indicated that 95.5% of the corrections were between ±10 nT.

The micro-levelled data were gridded using the minimum curvature technique described by Briggs (1974), employing a 200 m (7.5") grid cell size for the entire area, and a 40m (1.5”) grid cell size for the 200 and 400m data only.

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

(c) Correction strings were low-pass filtered with a cut-off wavelength of 1000 m. Adjustments were limited to a maximum of 120 cps for TC and 50 cps for Th. Ninety-five percent of the corrections were within ±2.1 and ±1.2 cps for TC and Th respectively.

The corrected elemental 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 located in Albury, NSW, during 1995 (Minty 1996). The following sensitivities were used:

Potassium:	377.74 cps/%K
Uranium:	108.07 cps/ppm eU
Thorium:	56.63 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 (23.14 cps/nGh^{-1}); and
N = the total count rate (cps).

A subsection of the U data was then micro-levelled a second time. The area is bounded by a polygon with the following vertices:

152.7936°	-29.6929°
153.8785°	-29.6908°
153.8793°	-29.7466°
153.7936°	-29.7474°

A 4 km streak in the U data on the western end of line 7680 within this subsectioned area may be an atmospheric radon effect. This section of line is situated over a topographic low and abuts mountainous terrain to the west. The line was flown early morning and the anomalous streak may be the effect of atmospheric radon trapped locally under still-air conditions. The streak was removed (after converting from cps to ppm) by microlevelling the U data within the polygon using the following parameters.

(a) High-pass filter in the tie-line direction with a cut-off wavelength of 400 m.

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

(c) Correction strings were low-pass filtered with a cut-off wavelength of 1000 m. Adjustments were limited to a maximum of 0.6 ppm. Ninety-five percent of the corrections were within ±0.022 ppm.

The microlevelled data were gridded with a 40 m (1.5") 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 five seconds on both GPS receivers were post-processed on a daily basis using "Ranger" - an Ashtech proprietary program. "Ranger" 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 five seconds).

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 second samples (70 metres) 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 one second (70 metres) are relative to the WGS84 reference ellipsoid - the ellipsoid being a horizontal datum.

The next step is 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 area covered by the Clarence Richmond Airborne Survey was supplied by the Australian Surveying and Land Information Group (AUSLIG) in May 1996. 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 metres) grid. These values were then regridded using the INTREPID imaging and data processing system to a cell size of 12.0 seconds of arc (approximately 320 metres). This grid of N values was then used to calculate correction strings to be subtracted from the elevation point located 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 metres was subtracted from the elevation data.

Tie-line levelling

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

(a) Tie line 1310 was chosen as the 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 4000 metres.

(b) High pass filter in the tie line direction with a cut-off wavelength of 400 metres.

(c) Correction strings were low pass filtered with a cut-off wavelength of 1000 metres before being applied to the line data. Adjustments were limited to a maximum of 50 m. Statistics on the applied corrections indicated that 98% of the corrections were between ±2.6 m.

The micro-levelled data were gridded using Brigg's minimum curvature technique, employing a 40 m (1.5") 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 and 1:250 000 for the entire survey area. Flight path, TMI profiles 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).

(c) Pixel Image Maps

In addition to the standard AGSO geophysical maps listed in Appendix M, pixel image maps will be produced using the method described by Milligan and others (1992).

References

Briggs, I. C., 1974 - Machine contouring using minimum-curvature. *Geophysics*, **39**, 39-48.

Green, A. A., 1983 - A comparison of adjustment procedures for levelling aeromagnetic survey data. *Geophysics*, **48**, 745-753.

Grasty, R. L., 1975 - Uranium measurements by airborne gamma-ray spectrometry. *Geophysics*, **40**, 503-519.

International Association of Geomagnetism and Aeronomy, 1991 - Division V Working Group 8. International Geomagnetic Reference Field, 1991 Revision. *Journal of Geomagnetism and Geoelectricity*, **43**, 1007-1012.

International Atomic Energy Agency, 1991 - Airborne Gamma Ray Spectrometer Surveying. *International Atomic Energy Agency Technical Reports Series Number 323*, IAEA Vienna.

Luyendyk, A. P. J., 1997 – Processing of airborne magnetic data. *AGSO Journal of Australian Geology and Geophysics,* **17** (2), 31-38.

Milligan, P. R., Morse, M. P., and Rajagopalan, S., 1992 - Pixel map preparation using the HSV colour model. *Exploration Geophysics*, **23**, 219-224.

Minty, B. R. S., Morse, M. P., and Richardson, L. M., 1990 - Portable calibration sources for airborne gamma-ray spectrometers. *Exploration Geophysics*, **21**, 187-195.

Minty, B. R. S., 1991 - Simple micro-levelling for aeromagnetic data. *Exploration Geophysics*, **22**, 591-592.

Minty, B. R. S., 1992 - Airborne gamma-ray spectrometric background estimation using full spectrum analysis. *Geophysics*, **57**, 279-287.

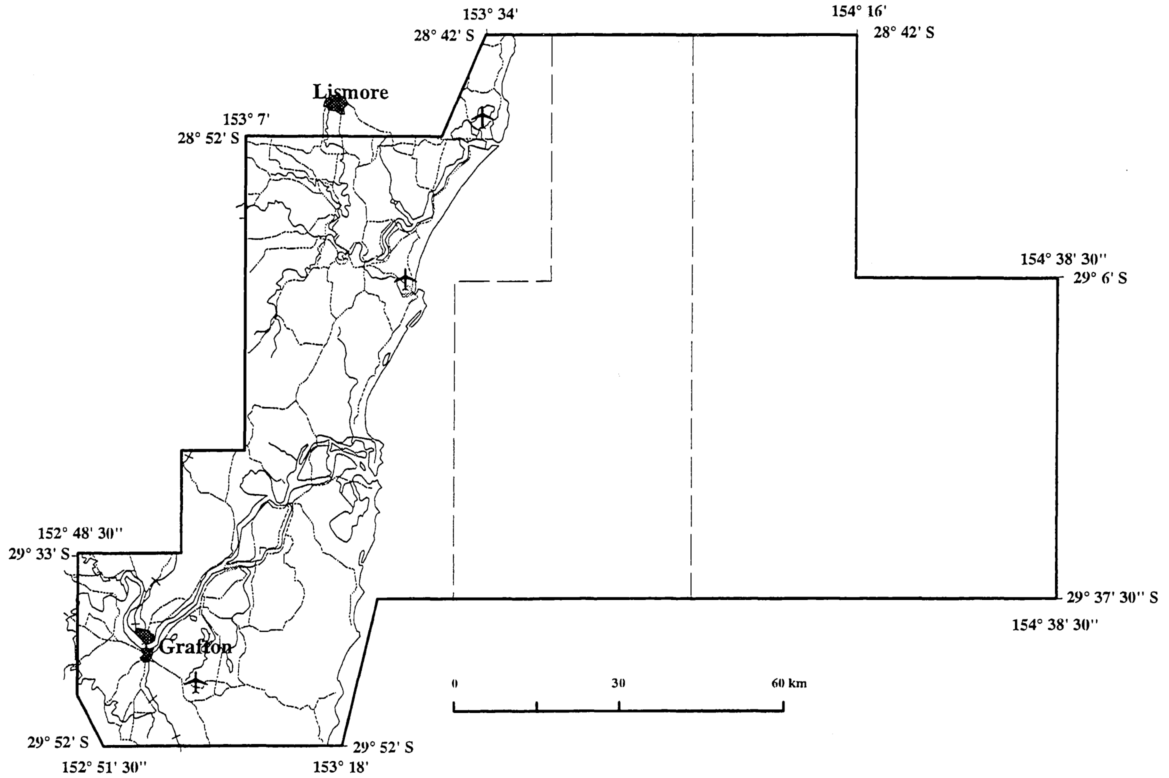
Minty, B. R. S., 1996 - The analysis of multichannel airborne gamma-ray spectra. *PhD thesis, Australian National University, September 1996.*

Minty, B. R. S., and Richardson, L. M., 1989 - Calibration of the BMR airborne gamma-ray spectrometer upward-looking detector, February 1989. *Bureau of Mineral Resources, Australia, Record 1989/8.*

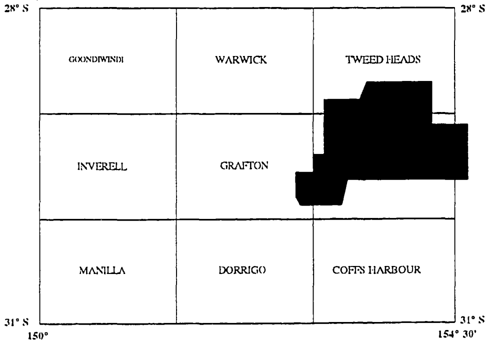
APPENDICES

APPENDIX A

Survey Area



LISMORE NSW 1996 SURVEY P643



19-06-1997

Appendix B1

FLYING DATES AND LINE KILOMETRES ACCEPTED

DATE	FLIGHT No.	COMMENTS	LINE KM
04-3-96	115	Compensation flight	0
05-3-96	116	Operations Normal	466
06-3-96	117	Operations Normal	776
06-3-96	118	Operations Normal - onshore re-flown	561
07-3-96	119	Operations Normal - onshore re-flown	766
07-3-96	120	Re-Flown	0
08-3-96	121	Flight aborted - GPS problems	0
08-3-96	122	Re-flown	0
09-3-96	123	Flight aborted - Mag problems	0
09-3-96	124	Flight aborted - Rain	0
11-3-96	125	Flight aborted - AADC problems	0
11-3-96	126	Testing system	0
12-3-96	127	Operations Normal - onshore re-flown	816
12-3-96	128	Re-flown	0
13-3-96	129	Operations Normal	606
13-3-96	130	Operations Normal - onshore re-flown	616
11-8-96	313	Compensation flight	0
12-8-96	314	Operations Normal	651
13-8-96	315	Flight aborted - AADC failure Replaced AADC	0
13-8-96	316	Compensation flight	0
14-8-96	317	Operations Normal	744
14-8-96	318	Operations Normal	686
15-8-96	319	Operations Normal	942
15-8-96	320	Operations Normal	702
16-8-96	321	Operations Normal	906
18-8-96	322	Operations Normal	892
18-8-96	323	Operations Normal	954
19-8-96	324	Operations Normal	680
19-8-96	325	Operations Normal	679
20-8-96	326/327	Restarted computer Operations Normal	844
20-8-96	328	Operations Normal	864
21-8-96	329	Operations Normal	921
21-8-96	330	Operations Normal	856
22-8-96	331	Operations Normal	928
24-8-96	332	Operations Normal	662
25-8-96	333	Operations Normal	816
26-8-96	334	Compensation flight after alternator change	0
26-8-96	335	Operations Normal	798
27-8-96	336	Operations Normal	686
27-8-96	337	Operations Normal	675
28-8-96	338	Operations Normal	235
28-8-96	339	Operations Normal	532

Appendix B2

FLYING DATES AND LINE KILOMETRES ACCEPTED

DATE	FLIGHT No.	COMMENTS	LINE KM
28-8-96	340	Operations Normal	754
29-8-96	341	Operations Normal	858
29-8-96	342	Operations Normal	322
31-8-96	343	Equipment check of spare spectrometer board	0
01-9-96	344	Operations Normal	1000
01-9-96	345	Operations Normal	828
02-9-96	346	Operations Normal	830
02-9-96	347	Operations Normal	704
03-9-96	348	Operations Normal	700
04-9-96		Aircraft in for service	0
06-9-96		New regulator and balance alternators	0
07-9-96	349	Compensation flight	0
07-9-96	350	Operations Normal	515
07-9-96	351	Operations Normal	761
08-9-96	352	Operations Normal	707
08-9-96	353	Operations Normal	896
09-9-96	354	Operations Normal	225
09-9-96	355	Operations Normal	628
09-9-96	356	Operations Normal	700
10-9-96	357	Operations Normal	664
11-9-96	358	Operations Normal	793
11-9-96	359	Operations Normal	669
12-9-96	360	Operations Normal	509
13-9-96	361	Operations Normal	803
14-9-96	362	Operations Normal	592
14-9-96	363	Operations Normal	696
15-9-96	364	Operations Normal	636
15-9-96	365	Operations Normal	730
16-9-96	366	Operations Normal	532
17-9-96	367	Operations Normal	694
17-9-96	368	Operations Normal	707
18-9-96	369	Operations Normal	187
18-9-96	370	Operations Normal	524
19-9-96	371	Flight re-flown due to testline specs out	0
19-9-96	372	Operations Normal	248
21-9-96	373	Operations Normal	745
21-9-96	374	Operations Normal	609
22-9-96	375	Compensation flight due to alternator replaced	0
23-9-96	376	Operations Normal	460
23-9-96	377	Altitude Radon Test for B. Minty	0
24-9-96	378	Operations Normal	433
24-9-96	379	Operations Normal	775

Appendix B3

FLYING DATES AND LINE KILOMETRES ACCEPTED

DATE	FLIGHT No.	COMMENTS	LINE KM
25-9-96	380	Operations Normal	177
25-9-96	381	Operations Normal	766
26-9-96	382	Operations Normal	808
26-9-96	383	Operations Normal	777
27-9-96	384	Operations Normal	691
27-9-96	385	Operations Normal	698
28-9-96	386	Operations Normal	790

Total line/tie kilometres flown 48401

Total number of flights in survey 89

- Productive survey flights 68
- Compensation flights only 6
- Abandoned flights 5

Abandoned survey flights consisted of:

- In flight bad weather 4
- Equipment malfunction 6

NOTE : On shore areas of this survey were reflown during the second phase of the survey to ensure compatibility in gamma-spectrometry data.

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 XII GPS receivers; one at a known position on the Lismore airfield near where the office caravan was located, and the other in the aircraft. The ground based GPS receiver operated in base mode while the aircraft GPS receiver was configured 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 uses a network of reference stations located throughout the continent to provide differential GPS corrections to Fugro's Network Control Centre (NCC) in Perth. The WADGPS service provides data from more than one reference station, quality control parameters, weighted least squares solution and improved accuracy over a single reference station system

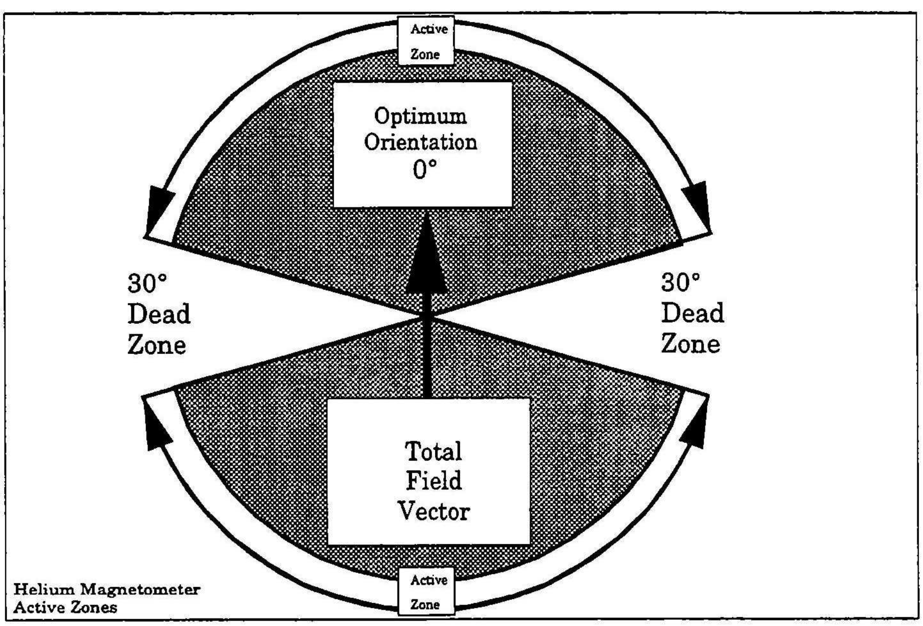
The range corrections from all the available reference stations are transmitted to the NCC in Perth, then to an OmniSTAR Plus - Enhanced Differential System (EDS) receiver in the aircraft via the Optus satellite. The EDS receiver contains a demodulator board, an eight channel GPS engine, a computing 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 acquires satellite range data through an Ashtech plate antenna and range correction data through an OPTUS plate antenna, both on the roof 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

SPECIFICATIONS - G833 HELIUM MAGNETOMETER

Operating Range:	20,000 to 95,000 nT
Temperature:	-20 to +50°C
Sensitivity:	0.0032 nT/root Hz RMS
Bandwidth:	350 Hz (-3dB point)
Loop scan rate:	1000 cycles/second
Input power:	28 V DC, 6 A max.
Output signal:	At He gyromagnetic frequency, approximately 28.02468 Hz/nT. Three volts peak to peak
Dimensions:	Sensor cell - 80 mm diameter x 145 mm length Scan processor - 270 x 120 x 85 mm Control panel - 19 inch rack mount
Weight:	approximately 6 kg.



APPENDIX D-2

SPECIFICATIONS - G822A CESIUM 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)
Inerface:	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.

APPENDIX F-2
SPECIFICATIONS - GR820 SPECTROMETER SYSTEM

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 curser 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

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 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

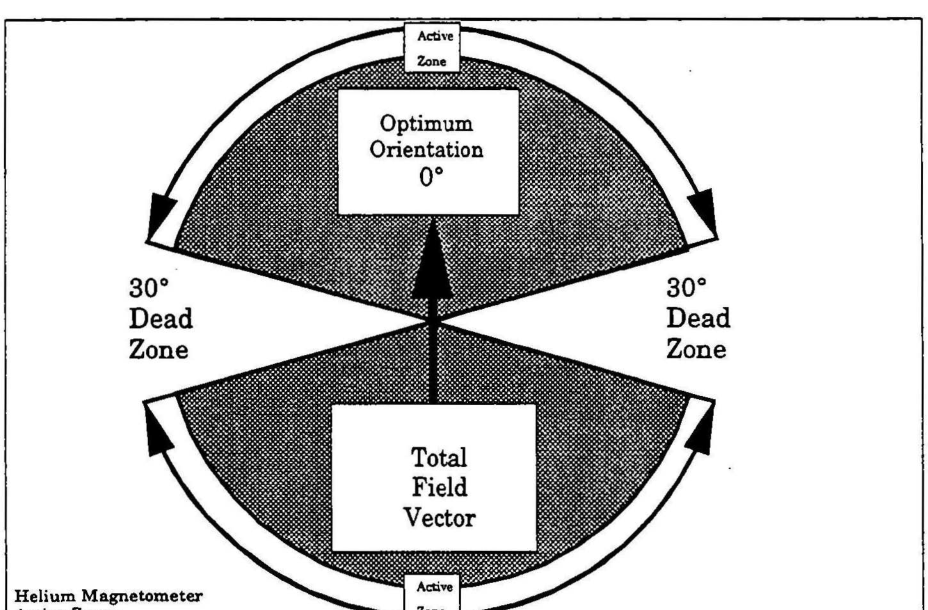
  Closed pack : -40° C to +50° C (instantaneous)

  Open pack : a change of 1° C/hr.

APPENDIX G

SPECIFICATIONS - G833 BASE STATION HELIUM MAGNETOMETER

Operating Range:	20,000 to 95,000 nT
Temperature:	-20 to +50°C
Sensitivity:	0.0032 nT/root Hz RMS
Bandwidth:	350 Hz (-3dB point)
Loop scan rate:	1000 cycles/second
Input power:	28 V DC, 6 A max.
Output signal:	At He gyromagnetic frequency, approximately 28.02468 Hz/nT. Three volts peak to peak
Dimensions:	Sensor cell - 80 mm diameter x 145 mm length Scan processor - 270 x 120 x 85 mm Control panel - 19 inch rack mount
Weight:	approximately 6 kg.



Helium Magnetometer Active Zones

APPENDIX G-2

SPECIFICATIONS - MAGELLAN OEM GPS MODULE

Operational Characteristics	
Position Update Rate:	1 second continuous (approximate)
Time to First Fix	
Warm Start: (with almanac/date/time/ initial position and ephemeris < 2 hours old)	30 seconds (approximate)
Cold Start: (with almanac/date/time/initial position)	75 seconds 2D/3D 9 approximate)
Autonomous start: (no almanac/ephemeris/date/ time/initial position)	5 - 12 minutes typical
Position Accuracy * (HDOP < 2, C no > 47 db-Hz, 2D)	
Horizontal Position:	25 metres RMS in 2D 30 metres RMS in 3D
Vertical Position:	50 metres RMS

* with Selective Availability disabled

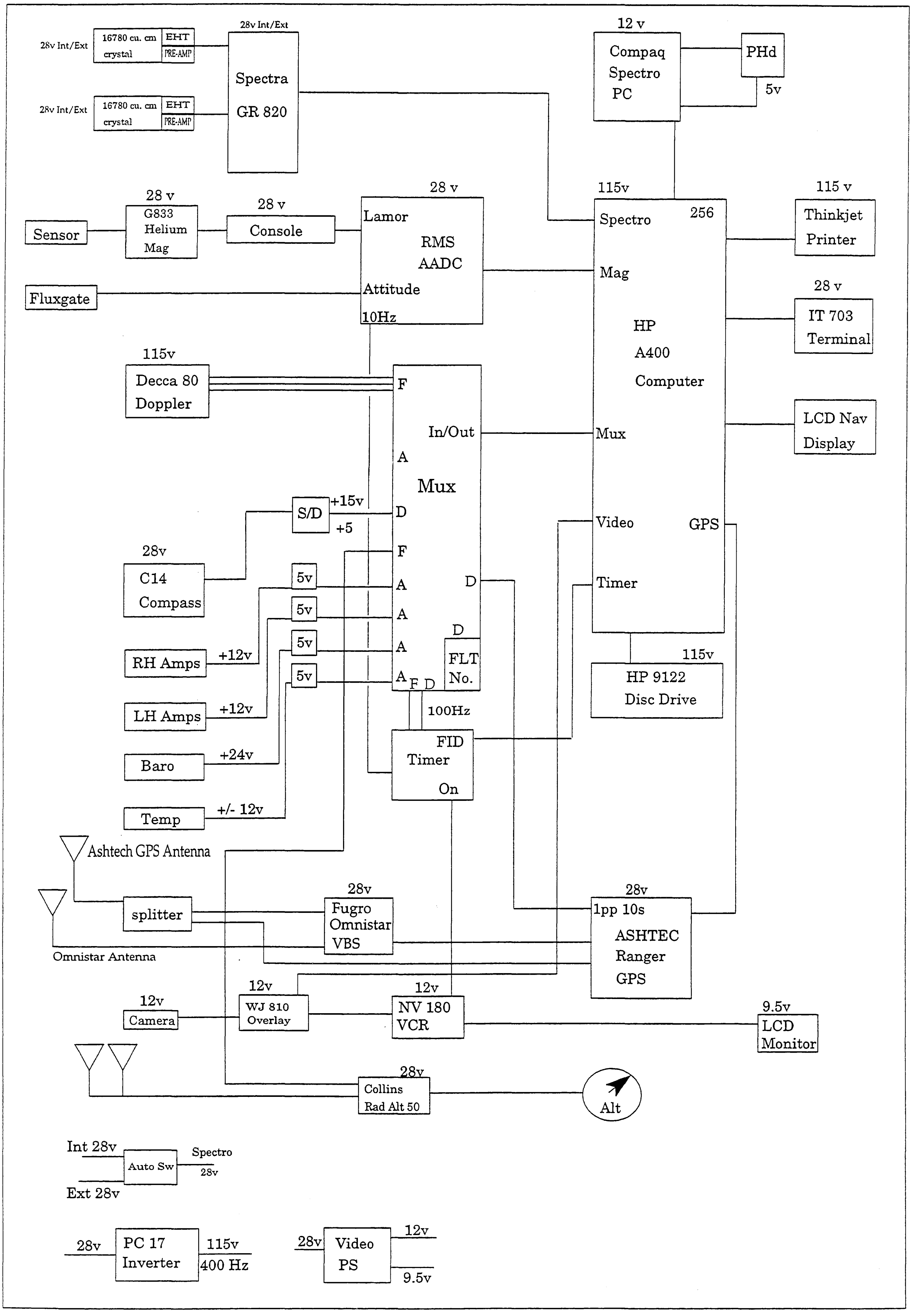
Electrical Characteristics	
Power:	
OEM/PS:	9 - 16 VDC 235 mA at 12 VDC typical, 250 mA max
OEM/5V:	5 VDC +/- 0.2 VDC 170 mA
Interfaces:	RS232
Baud Rates:	Jumper - selectable 1200,2400,4800,9600
Receiver Type:	4 channels dedicated to tracking satellites 1 channel dedicated to tracking all other satellites in the sky
Firmware Functions	
Timing:	Timing pulse ON/OFF UTC or GMT reference Time only mode Single satellite timing default all modes Hour,minute,second,day,month,year Status indicator Satellites in solution Signal Quality
OEM Antenna	Active Quadrifilar Helix

APPENDIX G-3

SPECIFICATIONS - GT100 UNIVERSAL COUNTER

Input Characteristics		
Channels A and B		
Frequency Range:	DC to 100 Mhz	
Signal Operating Range:	+5 V to -5 V	
Sensitivity:	Sinewave	25 mV RMS Dc to 20 Mhz
		50 mV RMS 20 Mhz to 50 Mhz
		160 mV RMS 50 Mhz to 100 Mhz
	Pulse	450 mV pk-pk at 5 ns pulse width
Measurement Functions		
Resolution: (in Hz)	+/- LSD +/- Freq *1.4 *Trigger Error/Gate time	
Accuracy: (in Hz)	+/-Resolution +/- Time Base Error	
General		
Compatibility:	1 full size slot in any PC/XT, PC/AT or compatible, using DOS 3.0 or higher. Compatible with any programming language.	
Time Base:	Standard 10 Mhz Crystal Oscillator Accuracy +/- 100 ppm (0.01 %)	

APPENDIX H AIRCRAFT ACQUISITION SYSTEM



APPENDIX I-1

Compensation Results

COMPENSATION 1. Date flown: 4 March 1996
Dates used: 5 March 1996 - 13 March 1996

Air conditioner on	SDU	=	0.4405
	SDC	=	0.06179
	IR	=	7.1
	VN	=	24.6
Air conditioner off	SDU	=	0.4117
	SDC	=	0.03599
	IR	=	11.4
	VN	=	21.2

COMPENSATION 2. Using new AADC and caesium magnetometer
Date flown: 11 August 1996
Dates used: 12 August 1996 - 13 August 1996

Air conditioner on	SDU	=	0.3533
	SDC	=	0.02681
	IR	=	13.2
	VN	=	19.8
Air conditioner off	SDU	=	0.3047
	SDC	=	0.02698
	IR	=	11.3
	VN	=	20.4

COMPENSATION 3. Date flown: 13 August 1996
Dates used: 14 August 1996 - 25 August 1996

Air conditioner on	SDU	=	0.1708
	SDC	=	0.03459
	IR	=	4.9
	VN	=	4.1
Air conditioner off	SDU	=	0.1957
	SDC	=	0.01749
	IR	=	11.2
	VN	=	2.8

COMPENSATION 4. Date flown: 26 August 1996
Dates used: 26 August 1996 - 3 September 1996

Air conditioner on	SDU	=	0.1620
	SDC	=	0.07276
	IR	=	2.2
	VN	=	8.4

APPENDIX I-2

Compensation Results

COMPENSATION 4. Continued
Date flown: 26 August 1996
Dates used: 26 August 1996 - 3 September 1996

Air conditioner off

SDU	=	0.1265
SDC	=	0.02468
IR	=	5.1
VN	=	1.2

COMPENSATION 5. Date flown: 7 September 1996
Dates used: 7 September 1996 - 21 September 1996

Air conditioner on

SDU	=	0.736
SDC	=	0.07597
IR	=	2.3
VN	=	5.5

Air conditioner off

SDU	=	0.1315
SDC	=	0.02190
IR	=	6.0
VN	=	1.8

COMPENSATION 6. Date flown: 22 September 1996
Dates used: 23 September 1996 - 28 September 1996

Air conditioner on

SDU	=	0.2197
SDC	=	0.06138
IR	=	3.6
VN	=	3.0

Air conditioner off

SDU	=	0.1906
SDC	=	0.01812
IR	=	10.5
VN	=	6.1

SDU = Standard deviation of the data recorded during manoeuvres.

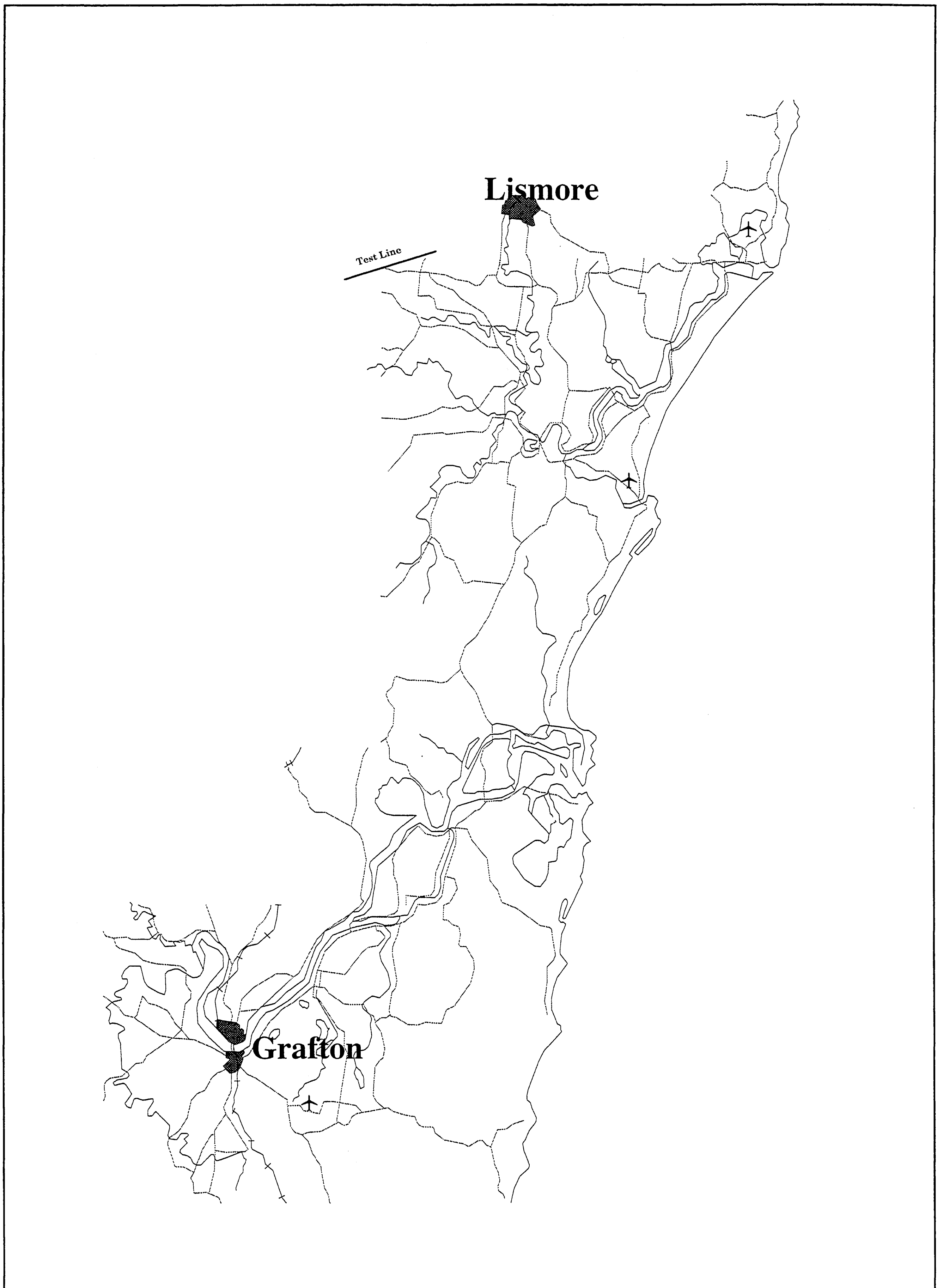
SDC = Standard deviation of the data recorded during manoeuvres after compensation corrections have been applied.

IR = Improvement ratio = SDU / SDC

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

APPENDIX J

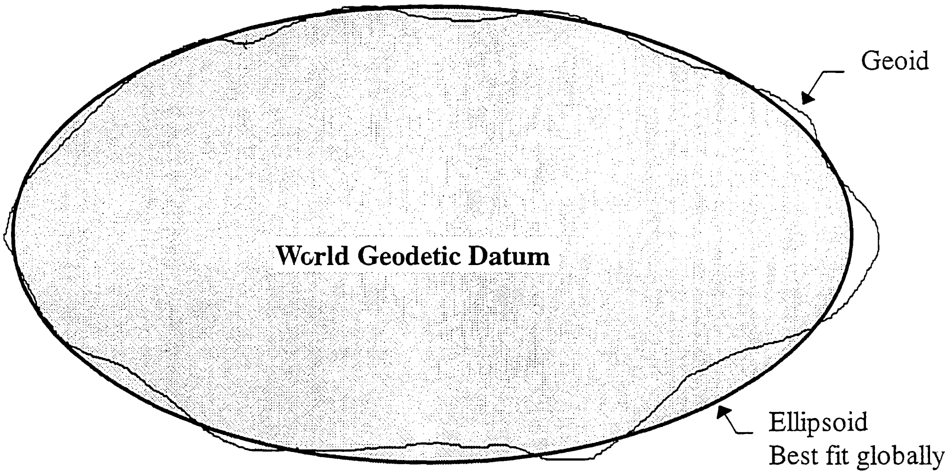
Gamma-ray Spectrometer Test Line Location



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" corrections

Using the range data which are recorded internally on both GPS receivers every five seconds, "Ranger" calculates the correct positions at five second intervals along the flight path. 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 (<5 km) in the GPS data occurred they were infilled with data generated from the doppler navigation system. Gaps in the GPS data greater than ten kilometres were reflown.

APPENDIX M-1

Geophysical Maps

Name	Type	Contour Interval / Vertical Scale	Reference Number
1:250 000 scale			
Maclean	TMI Contours	5 nT	22-1/F56-07/1
"	DOSE RATE Contours	2 nG/h	22-1/F56-07/2
"	DEM Contours	5 m	22-1/F56-07/19
1:100 000 scale			
Woodburn	TMI Contours	2 nT	22-2/F56-07/1-1
"	DOSE RATE Contours	2 nG/h	22-2/F56-07/2-1
"	Flight Line System		22-2/F56-07/3-1
"	TMI Profiles	AGC applied	22-2/F56-07/4-1
Barepoint	TMI Contours	2 nT	22-2/F56-07/1-4
"	DOSE RATE Contours	2 nG/h	22-2/F56-07/2-4
"	Flight Line System		22-2/F56-07/3-4
"	TMI Profiles	AGC applied	22-2/F56-07/4-4
Lismore	TMI Contours	2 nT	22-2/F56-03/1-4
"	DOSE RATE Contours	2 nG/h	22-2/F56-03/2-4
"	Flight Line System		22-2/F56-03/3-4
"	TMI Profiles	AGC applied	22-2/F56-03/4-4

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 5 edition 1 (doppler)
channel 6 edition 1 (raw spectrometrics)
channel 8 edition 1 (raw magnetics)
channel 10 edition 1 (multi-channel spectra)
channel 14 edition 1 (pressure,temperature,cosmic data)
channel 16 edition 1 (raw navigation)

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).

APPENDIX N-3

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

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 wihtin the segment. These are called Channel Identification Blocks (CIB's). A typical SDR is shown in Figure 1 and its extact 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.

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 compatability with our random access file format) and the last is a record check sum representing the sum of all other values in the record.

APPENDIX N-4

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

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.

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 maintaind 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 5 edition 1 (doppler)
channel 6 edition 1 (raw spectrometrics)
channel 8 edition 1 (raw magnetics)
channel 10 edition 1 (multi-channel spectra)
channel 14 edition 1 (pressure,temperature,cosmic data)
channel 16 edition 1 (raw navigation)

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

APPENDIX N-5

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

C4 E2 - Corrected Total Magnetic Intensity
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 and word 2 as for C4 E1
word 3 = final Total Count (counts/sec) * 1000
word 4 = final Potassium (counts/sec) * 1000
word 5 = final Uranium (counts/sec) * 1000
word 6 = final Thorium (counts/sec) * 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 and word 2 as for C4 E1
word 3 = final Aircraft Elevation (metres above sea level) * 100
word 4 = final Terrain Elevation (metres above sea level) * 100

C5 E1 - Doppler navigation data
Channel number = 5
Edition number = 1
Sample size = 2 words
word 1 = doppler along track (km)
word 2 = doppler across track (m)

C6 E1 - Raw spectrometer data, Raw VLF data.
Channel number = 6
Edition number = 1
Sample size = 7 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
word 6 = VLF Total Field (% of primary field)
word 7 = VLF Vertical Quadrature (% of primary field)

APPENDIX N-6

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

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

C10 E1 - Multi-channel spectra
Channel number = 10
Edition number = 1
Sample size = 290 words
word 1 = start fiducial for spectra
word 2 = integration time for spectra (seconds)
word 3 - 34 = define energy range of spectra, fiducials etc.
Some control words yet to be defined.
word 35 = counts in channel 0 (* 1000)
word 36 = counts in channel 1 (* 1000)
word 290 = counts in channel 255 (* 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 berween time when a position is calculated and time until the next fiducial is generated by the data acquisition system. (hundredths of a second)

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

2. PHYSICAL FORMAT FOR MAGNETIC TAPES

2.1 GENERAL

Each magnetic tape (MT) 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 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. Tapes are 12.7 mm (0.5 inch) wide, 9 track industry standard magnetic tapes.
b. Each tape has an external label identifying the airborne survey, character code, recording density, date tape written and the reel number in the set.

2.3 TAPE STRUCTURE

a. 9 track
b. Written in ASCII
c. Recording density of 6250 bpi
d. International Standards Organisation end-of-block markers (EOB)
e. International Standards Organisation end-of-file markers (EOF)
f. No multi-tape files
g. Multi-file tapes can be expected. Files will not span tapes.
h. 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

APPENDIX N-8

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

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-9

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-10

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-11

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.