AGSO

RECORD NO 1993/16

PENOLA (WESTERN OTWAY BASIN) AIRBORNE GEOPHYSICAL SURVEY, 1992 - OPERATIONS REPORT

by

R. C. Brodie

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

PENOLA (WESTERN OTWAY BASIN) AIRBORNE GEOPHYSICAL SURVEY, 1992 - OPERATIONS REPORT

by

R. C. Brodie

Australian Geological Survey Organisation
Record 1993/16

Australian Geological Survey Organisation

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: The Hon. Michael Lee
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Executive Director: Roye Rutland

ISSN: 1039-0073

ISBN: 0 642 19292 8

CONTENTS

APPENDICES

1. SURVEY AREA AND PARAMETERS

(i) Area Description

The Penola airborne survey covers most of the Penola 1:250 000 topographic map sheet area. The survey area extends to longitude 139°10"00' E in the west and to latitude 38°10"00' S in the south. However survey lines do not cover all of the south western corner of this area. The exact survey area is shown in Appendix A.

(ii) Survey Parameters

Altitude:	80 m nominal terrain/sea clearance
Flight line direction:	North - South
Tie line direction:	East - West
Flight line spacing:	1500 m (+/- 400m)
Tie line spacing:	13000 m (+/- 400m)
Survey distance	
Lines:	12626 km.
Ties:	1534 km.
Total distance:	14160 km.
Sampling interval	
Magnetics:	0.1 seconds (approx 7m)
Gamma-ray spectrometrics/GPS/Doppler/VLF:	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 Mt Gambier in South Australia for the duration of the survey from 23/11/92 to 15/12/92.

(b) Flying Dates

Compensation flights, of magnetic field of the aircraft, were flown on 27 and 28 November. Production flying commenced on 28 November and continued through to 14 December. Appendix B summarises flying days and distance flown.

(ii) Survey Aircraft and Field Crew

(a) Aircraft
Aero Commander 500 S "Shrike", VH-BGE

(b) Field Crew

Party Leader:	Mario Bacchin
Geophysicists:	Murray Richardson (part time)
	Ross Brodie (part time)
Technician:	Phillip Doolan
Operator:	"Curly" Wilcox
Pilots:	Capt. Robert Tonkin
	Capt. John Biffin
	(Skywest Aviation)

3. SURVEY EQUIPMENT

(i) Major Equipment

Magnetometer:	Geometrics G833 helium magnetometer
Compensator:	RMS Instruments Automatic Aeromagnetic Digital Compensator
Gamma-ray spectrometer:	Geometrics gamma-ray spectrometer consisting of GR900 interface, two DET1024 spectrometer crystal detectors (33.56 l total) and Norland IT-5410 Analog-To-Digital converter
VLF:	Totem-1A VLF receiver
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
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
Acquisition software:	AGSO-developed assembly language program

(ii) Navigation

(a) GPS Navigation System

Aircraft navigation was carried out by an Ashtech XII global positioning system (GPS). A receiver in the aircraft received range data from satellites every second and calculated the current latitude and longitude coordinates (WGS84) of the aircraft. The range data were recorded internally in the GPS receiver every five seconds.

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

To enable differential GPS post flight processing, a second GPS receiver was set up in AGSO's field office caravan as a GPS base station and internally recorded range data every five seconds.

The position of the base station GPS receiver was accurately determined by differential GPS surveying using a permanent survey marker (PSM#41) at the airport as a fixed reference.

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

Longitude	: 140°46"55.73' E
Latitude	: 37°44"41.88' S
Ellipsoidal height	: 40.003 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 (<10 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 (WV CL 302E) with wide angle lens, a National VCR (NV180) and a National LCD TV (TCL3A). 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 which was 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 K. Compensation procedures are described in Chapter 4.

Unfiltered compensated total magnetic field intensity data were recorded on the aircraft acquisition system.

(iv) Gamma-ray Spectrometer

A Geometrics gamma-ray spectrometer, comprising two DET1024 crystal detectors with a total volume of 33.56 litres, was used. The crystal gains and temperatures were controlled by a Geometrics GR900 Detector Interface console. Analog to digital conversion was achieved through a Norland IT-5410 Analog-To-Digital converter. Appendix E summarises the specifications of the gamma-ray spectrometer components.

Five channels of data were recorded once a second 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

A cumulative 256 channel spectrum between 0.0 MeV and 0.35 MeV was recorded every 100 seconds. Total system dead-time was reduced by electronically suppressing counts in the 0.0 MeV - 0.35 MeV energy range before these signals reached the analogue to digital converter. Gamma-rays in this energy range are not very diagnostic in airborne geophysical surveying.

(v) VLF

A Totem 1A electromagnetometer measured the total field and vertical quadrature components of VLF transmissions from the North West Cape (NWC) submarine communication facility. The NWC transmitter transmits at a frequency of 22.3 khz. Transmissions were intermittent over the period of the survey.

The recording interval was one second. Output from the receiver is +/- 1 Volt DC for +/- 100% signal change, with one channel each for total field and quadrature.

(vi) 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.

(vii) Barometer and Thermometer

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

(viii) Base Station Magnetometer

Daily variations of the Earth's magnetic field were monitored using a Geometrics G866 proton precession base station magnetometer, the specifications of which are given in Appendix L. Data from the base station were telemetered back to the AGSO's field office caravan for display and recording on a Zenith 286 lap-top computer. The telemetry system used AGSO-built modems incorporating Phillips 828 UHF mobile radiotelephone transmit boards at a frequency of 471.8 Mhz.

The base station was set up in an area of shallow magnetic gradient area, away from cultural influences and within telemetry range of AGSO's office caravan at the Mt Gambier airport. Throughout the survey, base station data were recorded every twenty seconds during production flights.

(ix) Data Acquisition

The acquisition program and system are run using a HP-A400 computer with data recorded on a HP9122 720 Kb disc drive using 3.5 inch floppy discs. The acquisition program was written 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 F.

4. CALIBRATION

(i) Compensation

Two compensation flights were flown prior to the start of the survey. On each of these flights two attempts at compensation were made. The first three attempts were made in the far south of the survey area, south-southeast of Mt Gambier. The best compensation, the results of which were used for the entire survey, was flown approximately 10 kilometres due south of the township of Carpenter Rocks at 38°00"0' S, 140°23"0' E.

On these flights the aircraft flew at an altitude of 2200 m above sea level and the magnetic field was monitored to find an area of low magnetic gradient suitable to conduct a compensation. When such an area was found, a series of rolls(+/-10°), pitches(+/-5°) and yaws(+/-5°) were performed in the four cardinal headings to enable the AADC to calculate correction coefficients needed to remove aircraft manoeuvre noise. Each manoeuvre component was of 20 seconds duration

The manoeuvre procedure was repeated after calculation of the coefficients to check the quality of the compensation. Peak-to-peak noise during repeat manoeuvres, after the final compensation, was at worst 0.30 nT. On normal survey flights, noise levels from all sources were generally less than 0.2 nT peak-to-peak.

The AADC calculates some 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 the four compensations in Appendix G.

(ii) Gamma-ray Spectrometer Calibration

Crystal alignment checks were performed using a small thorium source on 27 November and 5 December. The resolution of the gamma-ray spectrometer system was measured using the full width at half maximum method (IAEA, 1991). Adjustments were made such that the resolution of the thorium (2.62 MeV) photopeak was 6% or less. Gamma-ray spectrometer channels were positioned such that the thorium photopeak was centred within one channel (+/-12 keV) of channel 223.

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 100 seconds or approximately 6.5 kilometres. Two test lines were used for Penola (Appendix H). The first line, approximately 20 kilometres west of the Mt Gambier airport was used until 1 December. This test line was then abandoned as it was considered to be too turbulent to fly along due to a forest plantation along the road. A second line was then chosen away from forest plantations approximately 25 kilometres south-west of the airport. This line was used for the remainder of the survey.

Although background corrections for gamma-ray spectrometrics are calculated using full spectrum analysis (Minty, 1992) at AGSO, background estimation lines were flown as a means of data checking. Background lines, of 300 seconds duration, were flown off-shore at survey altitude at the start and end of each flight.

After each flight statistics were calculated for data recorded between fixed reference points, observed on video, along the test line and for background lines. These statistics were recorded in spreadsheet form. Statistics for each flight were compared with the preceding flight in order to detect any irregularities. In particular, the difference between the average in the total count channel for the test line and the background line was analysed. This value never varied by greater then 4.4% for the first test line or 12% for the second test line, well inside a 15% variation which would be considered acceptable.

5. DATA PROCESSING

Flight path recovery, and data checking and editing were conducted at the survey base. Merging of geophysical and navigation data, and magnetic and gamma-ray spectrometric data processing were carried out in Canberra using Geophysical Mapping Section's airborne data processing system, ARGUS.

(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 386 personal computer, and edited using AGSO-developed software 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

Range data recorded internally on both GPS receivers were post-processed daily using "Ranger" - an Ashtech propriety program.

The correction data calculated by "Ranger" were later applied to the GPS data recorded on the aircraft acquisition system. As well as the standard "Ranger" corrections, other acquisition system specific corrections were applied. The full correction procedure is described in Appendix J and is outlined below.

(a) Position calculation delay correction.

(b) Fiducial synchronisataion correction.

(c) "Ranger" corrections.

(d) Low pass filter.

(e) Coordinate system conversion.

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

(g) Doppler infill of gaps.

The fully corrected flight path was plotted each day to check the position of survey lines and their spacing.

(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 1992.9 and for an altitude of 160 m above sea level, which was estimated to be the mean on-shore survey altitude, was then subtracted from the data. The IGRF was calculated from the coefficients defined by the IAGA (1991). All 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. The steps involved in tie line levelling were as follows.

(a) Tie line 130 was chosen as a reference tie.

(b) A low pass 11 point convolution filter with a cut-off wavelength of 60 m was passed over the data prior to sampling crossover points. Note that these filtered data were only used for the crossover analysis and the final data have not been filtered.

(c) All other ties were levelled to tie line 130 using degree three polynomial adjustments.

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

(e) Ties were then adjusted to minimise crossover differences, using degree three polynomial adjustments.

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

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

(a) Low pass filter in the flight line direction with a cut-off wavelength of 20 km

(b) High pass filter in the tie line direction with a cut-off wavelength of 6 km.

(c) Correction strings were low pass filtered with a cut-off wavelength of 200m before being applied to the line data.

The micro-levelled data were gridded using Brigg's minimum curvature technique, employing a 400 m (15') grid cell size.

(iv) Gamma-ray Spectrometric Data Processing.

Raw gamma-ray spectrometric and altimeter data were merged with the navigation data. Background estimates for each of the four recording windows were removed. These estimates were determined as follows

(a) Aircraft and Cosmic Background
Minty and Richardson (1989) derived aircraft and cosmic spectra for the AGSO aircraft from high altitude calibration flights.

(b) Atmospheric Radon Background
Full spectrum analysis (Minty, 1992) was used to calculate the radon contribution to the background in the uranium window.

(c) Total Background
The total background in the uranium window is the sum of the aircraft, cosmic and radon background. In the total count and potassium windows the total background was estimated directly from the total uranium background since they are linearly dependent (Grasty, 1975). The thorium window was considered to be not affected by atmospheric radon, so total thorium background was estimated from the aircraft and cosmic backgrounds.

Data were corrected for height attenuation to the nominal flying height of 80 m. Where the aircraft attained a height of 300 m or higher above the ground gamma-ray spectrometric data have been set to undefined. Height attenuation corrections were made using the following formula

$$NC = N \exp(-u(H-h))$$

where

NC = corrected counts
N = uncorrected counts
H = nominal flying height
h = measured flying height
u = attenuation coefficient
for total count u = 0.00656
for potassium u = 0.00755
for uranium u = 0.00557
for thorium u = 0.00557

Channel interaction corrections (stripping) were then applied to the data. Stripping ratios for the AGSO system were determined by Minty and others (1990) using portable calibration sources. The Compton Scattering equations were as follows

NTH(corrected) = NTH
NU(corrected) = NU - A x NTH
NK(corrected) = NK - B x NTH - C x NU(corrected)

where

NTH = counts in thorium channel
NU = counts in uranium channel
NK = counts in potassium channel
A = 0.49644
B = 0.50532
C = 0.88308

Total count data were levelled in exactly the same way as the magnetic data. However prior to sampling crossover points a 11 point convolution filter with a cut-off wavelength of 600 m was passed over the data.

The potassium and thorium channels did not require levelling.

The uranium channel was levelled using a technique utilising cross channel correlation information between the uranium channel and the potassium and thorium channels (Green, 1987). This technique determines a constant correction for each line.

All channels were gridded to a 400 m (15') cell size using Brigg's minimum curvature technique. Prior to sampling total count data for gridding, the data were filtered with a seven point low pass convolution filter with a cut-off wavelength of 400 m. As in the case of filtering prior to crossover sampling, the data were only filtered for the purpose of gridding and the final data were not filtered. Potassium, thorium and uranium data were not filtered prior to gridding.

(v) Final Products

(a) Standard AGSO geophysical products

A standard AGSO set of geophysical maps have been produced at a scale of 1:250 000 for the entire survey area. Profiles and flight path maps were produced using ARGUS programs. Contour maps were produced using the GIPSI processing system. The standard set of maps include

MAP TYPE	CONTOUR INTERVAL /VERTICAL SCALE	REFERENCE NUMBER
TMI CONTOURS	10 nT	22-1/J54-6/1
TOTAL COUNT CONTOURS	40 counts/s	22-1/J54-6/2
FLIGHT PATH		22-1/J54-6/3
TMI PROFILES	500 nT/cm	22-1/J54-6/4a
TMI PROFILES	100 nT/cm	22-1/J54-6/4b
RADIO ALTIMETER PROFILES	100 m/cm	22-1/J54-6/5
TOTAL COUNT PROFILES	1000 counts/s/cm	22-1/J54-6/6
POTASSIUM PROFILES	150 counts/s/cm	22-1/J54-6/7
URANIUM PROFILES	50 counts/s/cm	22-1/J54-6/8
THORIUM PROFILES	100 counts/s/cm	22-1/J54-6/9

Final processed line data and grids were archived in the normal AGSO ARGUS format - 6250 bpi on nine track magnetic tape in ASCII format (Appendix J). Both micro-levelled and non micro-levelled versions of the magnetic line data have been archived.

Standard AGSO gravity maps and digital data are available for the Penola 1:250 000 sheet area.

(b) Interpretation Report and Map and Image Folio

In addition to the standard AGSO geophysical maps and digital data, Reeves and others (1993) are producing a package containing an interpretation report and a map and image folio.

The interpretation report incorporates a tectonic overview of the western Otway Basin, description of image preparation, interpretation of aeromagnetic and gravity data, and description of the significance of the geophysical data to hydrocarbon exploration.

The map and image folio is envisaged to contain the following products

(a) Gravity image (colour) of the Otway Basin and surrounding areas derived from the Gravity Map of Australia (1:5 000 000 scale).

(b) Gravity image (greyscale) of the Otway Basin and surrounding areas derived from the Gravity Map of Australia (1:5 000 000 scale).

(c) Geosat image of the Southern Ocean.

(d) Bathymetry of the Southern Ocean.

(e) Gravity contour map of the Otway Basin (1:1 000 000 scale).

(f) Palaeozoic trends and the gravity field of the Otway Basin (1:1 000 000 scale).

(g) TMI represented by rainbow pseudocolour, with the intensity and saturation modulated by the south-west illumination of high band-pass filtered TMI (750 m to 2,250 m).

(h) South-west illumination of high band-pass filtered TMI (750 m to 2,250 m).

(i) South-east illumination of high band-pass filtered TMI (750 m to 2,250 m).

(j) High band-pass filtered TMI (750 m to 2,250 m) pseudocoloured.

(k) Reduction to the pole of TMI.

(l) Low pass filtered and downward continued to 4,000 m TMI.

(m) Band-pass filtered TMI (6,000 m to 12,000 m).

(n) Band-pass filtered TMI (12,000 m to 24,000 m).

(o) First vertical derivative of TMI (pseudocoloured).

(q) First vertical derivative of TMI (greyscale).

(p) Second vertical derivative of TMI (pseudocoloured).

(r) Second vertical derivative of TMI (greyscale).

(s) Gamma-ray spectrometry - Potassium (red), Thorium (green), Uranium (blue).

(t) Interpretational overlay for western Otway Basin images (1:250 000 scale).

References

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

Green, A. A., 1987 - Levelling airborne gamma-radiation data using between-channel correlation information. *Geophysics*, **52**, 1557-1562.

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.

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. *Geophysics*, **22**, 591-592.

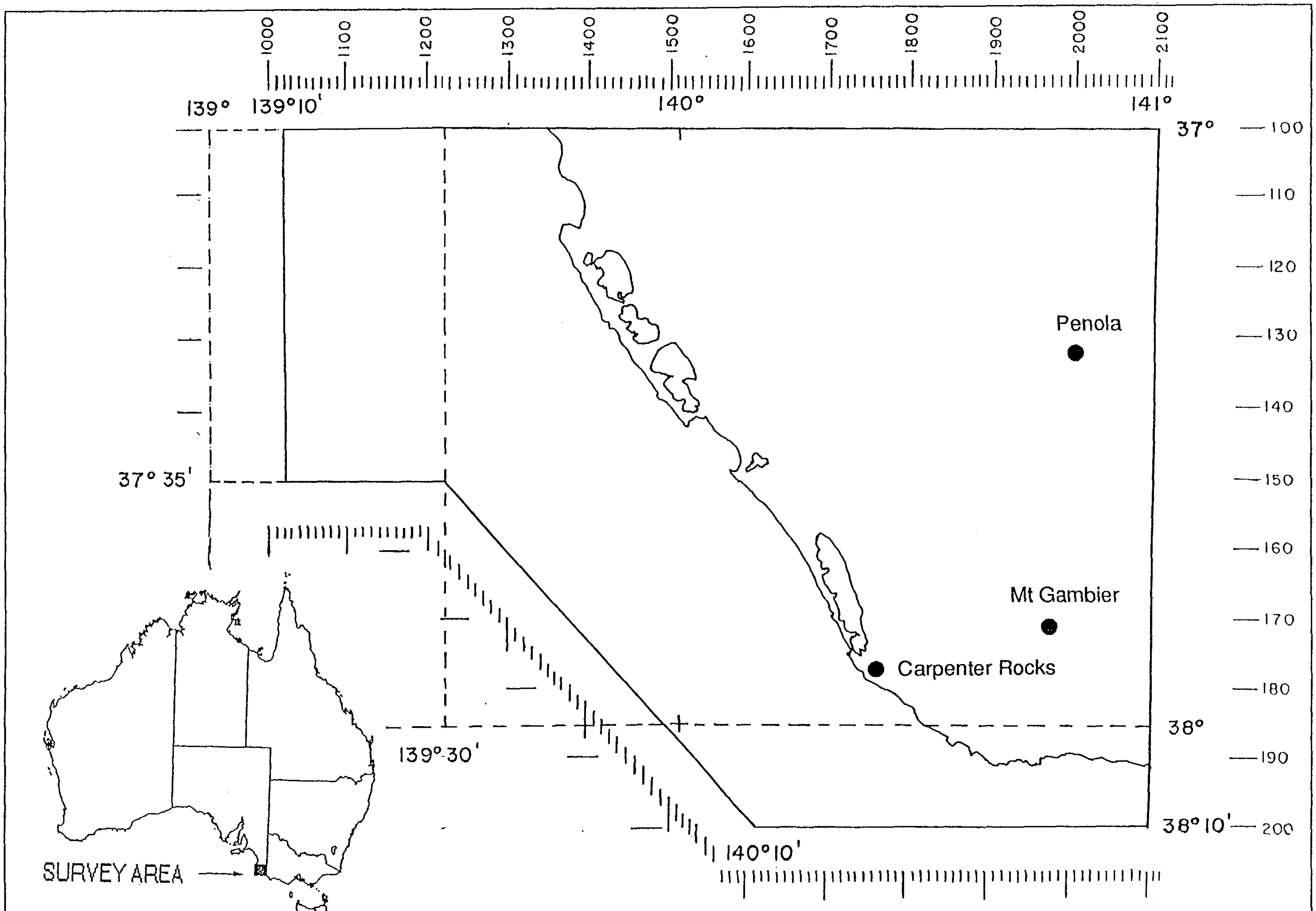
Minty, B. R. S., 1992 - Airborne gamma-ray spectrometric background estimation using full spectrum analysis. *Geophysics*, **57**, 279-287.

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

Reeves C. V., Finlayson D. M., O'Brien G. W., Milligan P. R., and Brodie R. C., 1993 - Western Otway Basin: 1992 Aeromagnetic dataset - Images and Interpretation. *Australian Geological Survey Organisation, Record 1993/14.*

APPENDIX A

SURVEY AREA



AIRBORNE SURVEY - PENOLA 1992

Australian Geological Survey Organisation

APPENDIX B

FLYING DATES AND LINE KILOMETRES FLOWN

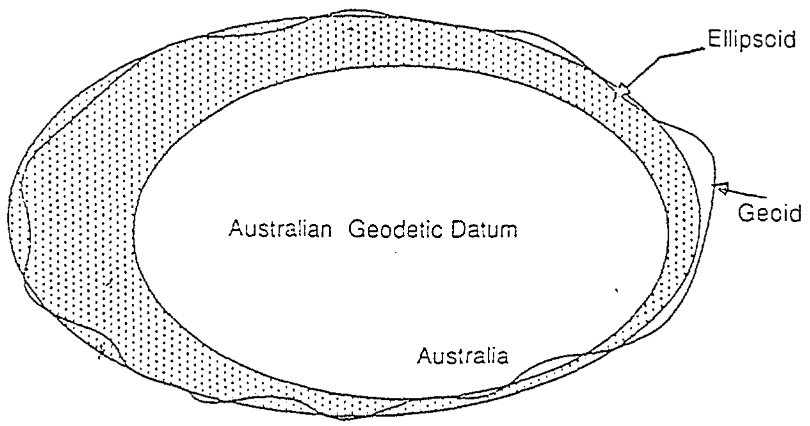
DATE	FLIGHT No.	COMMENTS	LINE KM
27/11/92	293	Compensation flight	0
28/11/92	294	Compensation flight	0
28/11/92	295	First survey flight	456
29/11/92	296	Southern 50 Km of line 1510 reflown -data recording error	1008
30/11/92	NA	Test flight - Oil leak	0
30/11/92	297	Operations Normal	822
1/12/92	298	Test flight - Oil leak Find new test line	0
1/12/92	NA	Test flight - Oil leak	0
2/12/92	NA	Test flight - Oil leak	0
2/12/92	299	New test line in use Line abandoned - Rain	200
3/12/92	300	Operations normal	1100
4/12/92	301	Operations normal	1080
4/12/92	302	Operations normal	606
5/12/92	303a	Flight abandoned - Rain	0
5/12/92	303b	Flight abandoned - Rain	0
6/12/92	304	Flight abandoned - Low cloud	0
7/12/92	305	Operations normal	960
7/12/92	306	Operations normal	1100
8/12/92	307	Flight abandoned - Active diurnal	145
10/12/92	308	Operations normal	1080
10/12/92	309	Operations normal	1080
11/12/92	310	Operations normal	810
11/12/92	311	Operations normal	1080
12/12/92	312	Operations normal	1015
12/12/92	313	Flight abandoned - rain	0
13/12/92	314	Flight abandoned - rain	0
14/12/92	315	No test lines - all lines off-shore	865
14/12/92	316	Operations normal	890

Total flights in survey	28		14297 line km.
Aircraft test flights	4		
Compensation flights	2		
Problem free flights	14		12944 line km.
Problem flights	2		1208 line km.
Abandoned flights	6		145 line km.
-Reason flight abandoned		weather	5 flights
		active diurnal	1 flight

APPENDIX C

THE AUSTRALIAN GEODETIC 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 WGS84 geodetic system. During processing these positions are converted to the local reference datum, AGD66 or Australian Geodetic Datum 1966.

This non-geocentric datum comprises the Australian National Spheroid (ANS) oriented and located in such a manner as to "best-fit" the geoid over the Australian continent.

The Australian geodetic datum is defined by a semi-major axis (a) and flattening (f) of the selected ellipsoid and the geodetic coordinates of the origin or fundamental station. The origin is referred to as the Johnston Origin. For AGD66:

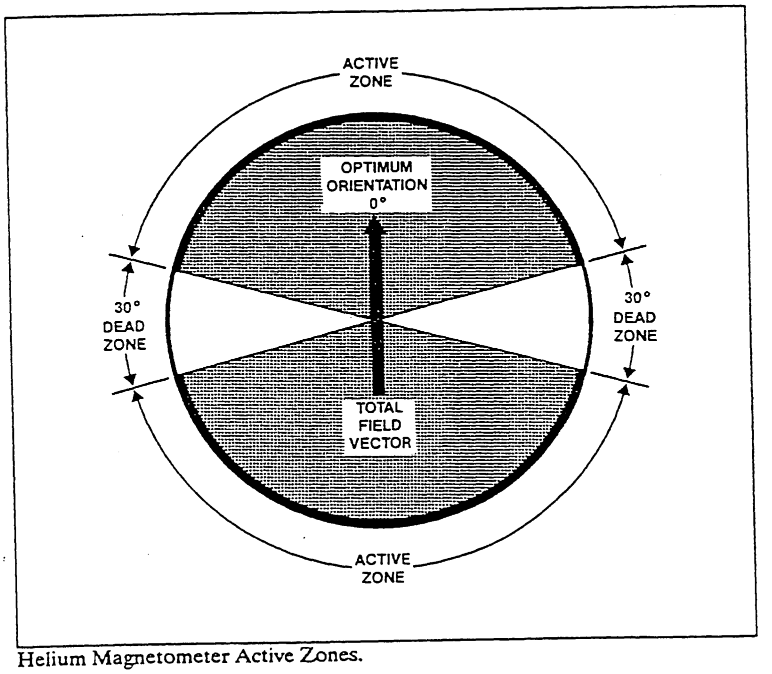
a	= 6378160 m
f	= 1/298.25
latitude	= 25°56'54.5515" S
longitude	= 133°12'30.0771" E
Height	= 571.2 m above ellipsoid

For an ideal local datum the geoid-spheroid separation over a region should be small and uniform. At the time of the AGD66 adjustment it was assumed that the geoid and the spheroid coincided at Johnston.

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 3 V 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 E-1

SPECIFICATIONS - GR900 DETECTOR INTERFACE CONSOLE

PMT Capacity:	A maximum of 12 downward-looking and 3 upward-looking photomultiplier tubes (PMT) may be accommodated.
H. V. Power Supply:	Common supply of 1400 V for all PMT anodes with an individual PMT cathode adjustment range from 0 to +400 volts.
Gain Range:	Adjustable over 16/1 range by varying PMT cathode voltage.
Resolution:	The PMT gain can be adjusted and reset to within $\pm$ 0.2%, i.e. the resolution of the gain control is $\pm$ 0.2 volts.
Output Current:	250 μamps @ 1400 volts max. available for each PMT.
PMT Regulation:	Each PMT voltage is stable to $\pm$ 0.01%.
Operating Temperature:	0° C to + 50° C ambient.
Mixer Amplifiers:	Input capability up to 12 PMT's, or 3,072 cu. in. (50.4 l) downward-looking and 3 PMT's or 768 cu. in. (12.6 l) upward-looking.
Mixer Gain:	Input equals output (gain = 1). With a 95 Ω load. 0.5 volt = 1 MeV. 5.0 volt max. output into 95 Ω load.
Temperature Control:	+20° C to + 60° C internal DET package temperature in 10° C steps.
Temperature Regulation:	$\pm$ 1° C for ambient temperature range from -20° C to +45° C.
Power Requirements:	Console: $\pm$ 15 V, 100 ma Xtal Heater: 28 V, 0.75 amp/Xtal Note: Additional $\pm$ 20 ma required for each PMT
Console Size and Weight:	3.5" high x 19" wide x 15" deep (8.9 x 48.3 x 38 cm) 17.5 lbs. (7.9 kg)

APPENDIX E-2

SPECIFICATIONS - DET1024 SPECTROMETER CRYSTAL DETECTOR

Crystal Type:	NaI - slab form - 4" thick x 16" wide x 16" long
Volume:	1024 cu. in. (16,780 cm^3)
System Resolution:	Equal to or less than 10% FWHM at 662 KeV. Held within 0.5% of starting value over 12 hours of continuous operation.
Peak Shift:	Held within $\pm$ 1% over 12 hours of continuous operation. Split window peak setting by front panel meter.
Gain Controls:	Individual controls for each PMT on Detector Interface (see GR-900 Detector Interface specification)
High Voltage Power Supply:	1200V DC held within $\pm$1V over 24 hours of continuous operation. (Supplied by GR-900)
Temperature:	Operating: Internal temperature automatically regulated to $\pm$1°C over the range +10°C to +50°C by the GR-900. Storage: -20°C to +65°C.
Power:	22 to 32V DC. 20 watts average, 150 watts peak (Supplied by GR-900) Provision for separate stand-by overnight power supply.
Dimensions and Weight:	Crystal Detector package - 7-1/8 × 21-1/8 × 25 $\frac{1}{4}$ inches - 170 lbs.

APPENDIX E-3

SPECIFICATIONS - NORLAND IT-5410 ANALOG-TO-DIGITAL CONVERTER

A. ADC INPUT

Polarity:	0-10V unipolar or positive first bipolar
Full scale input:	8 volts
Rise time:	0.1 to 10 uSec
Fall time:	0.1 to 10 uSec
Impedance:	1 K ohm
Duration:	.5 uSec minimum
Coupling:	DC (BLR OFF) or AC (BLR ON)

B. PERFORMANCE

Conversion Clock Rate:

50 MHz (IT-5410/50), 8192 channel resolution
100 MHz (IT-5410/100), 8192 channel resolution
200 MHz (IT-5410/200), 8192 channel resolution

Conversion Time per event

Signal rise time + 1.2 uSec + Logic + (Y • N) nSec
where Y = 20 for 50 MHz
10 for 100 MHz
5 for 200 MHz
and N = Channel Number

ADC Linearity

1. Integral: ±.075 over upper 99% of full scale range
2. Differential: ±.75% over upper 99% of full scale range

ADC Stability

Long Term: Less than .01% zero level and conversion gain shift for 24-hour period at constant temperature and line voltage

Temperature: Less than .005% of full scale/°C

Peak Shift: Less than 0.04% of full scale for count rates up to 20 KHz

Channel Profile: Typically better than 90%

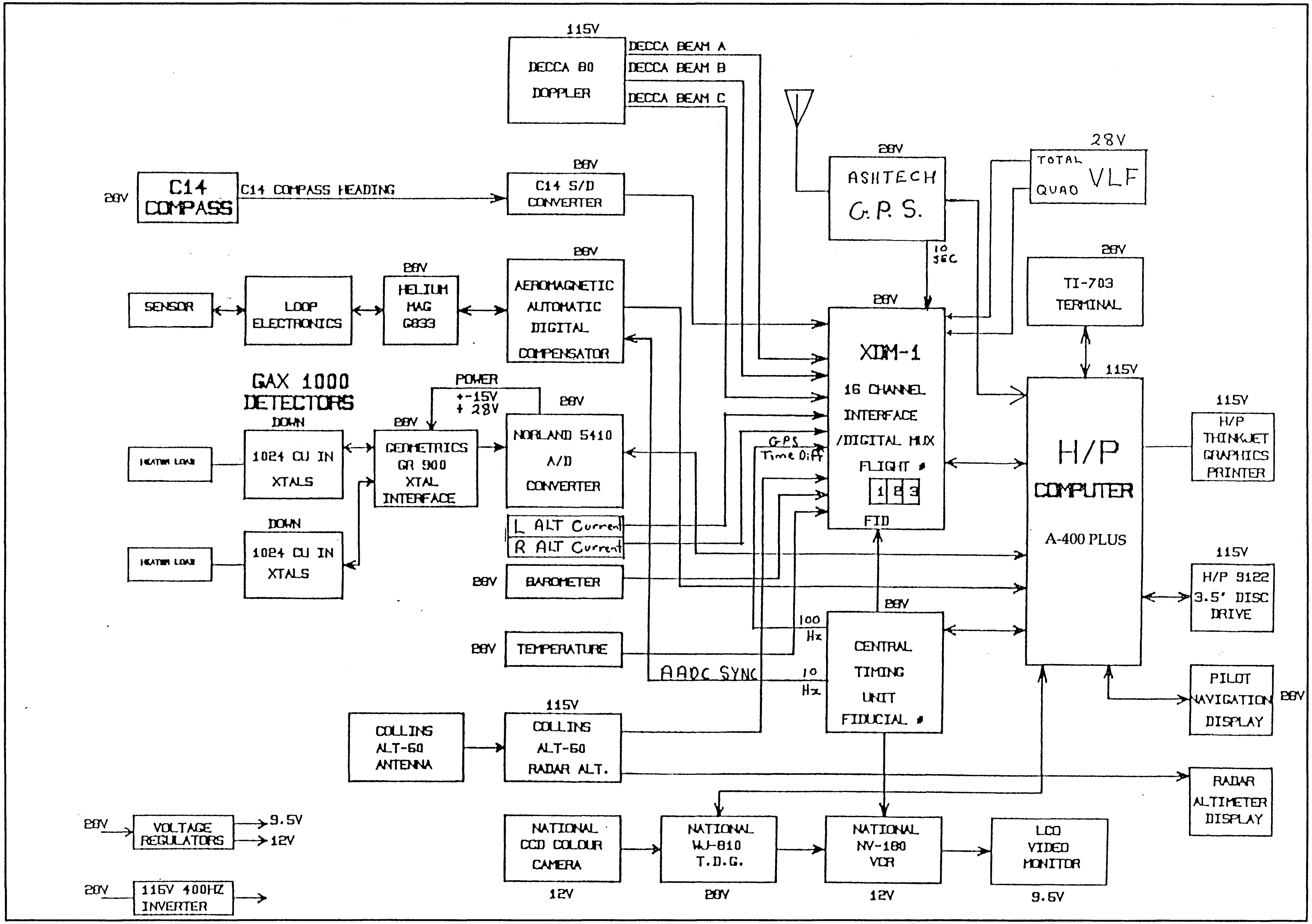
C. CONTROLS

Baseline Restorer (BLR):	Switchable AC passive
Coincidence (COINC):	Prompt (delayed jumper selectable)
ZERO:	0-100% range control For selecting zero energy intercept level by 22-turn potentiometer
Lower Level Discriminator (LLD):	10-turn potentiometer control for 0-100% discrimination of lower level input signal
Upper Level Discriminator (ULD):	22-turn potentiometer control for 5-125% discrimination of upper level input signal
GAIN:	Miniature LED indicators activated by momentary toggle switch selects conversion gain setting. Ranges available for 8-volt input signal are: 256, 512, 1024, 2048, 4096, 8192 channels.
OFFSET:	Function: Offsets spectrum digitally by value indicated on miniature LED. Offsets are toggle selectable in 256 channel increments throughout the 8192 channel range.
Dead Time Meter:	Indicates % of dead time of ADC for converting an input pulse. Range is 0-100%.
SCA:	Single channel analyzer output available on ADC rear panel. 50-pin connector and BNC connector and BNC connector on rear panel of IT-5400 mainframe.

D. MECHANICAL

1) Single width NIM—standard configuration.
2) 50-pin connector on rear panel provides all significant I/O signals.
3) Compatible with all NIM standard bins and power supplies per TID-20893 (Rev. 3) which provide ±6V DC output.

APPENDIX F
AIRCRAFT DATA ACQUISITION SYSTEM - VH-BGE



APPENDIX G

COMPENSATION RESULTS

COMPENSATION 1.	SDU	=	0.4063
	SDC	=	0.0594
	IR	=	6.8
	VN	=	11.8
COMPENSATION 2.	SDU	=	0.4437
	SDC	=	0.0597
	IR	=	7.4
	VN	=	13.9
COMPENSATION 3.	SDU	=	0.3322
	SDC	=	0.0572
	IR	=	5.8
	VN	=	12.4
COMPENSATION 4.	SDU	=	0.4336
	SDC	=	0.0540
	IR	=	8.0
	VN	=	12.2

SDU = Standard deviation of the data recorded during manoeuvres.

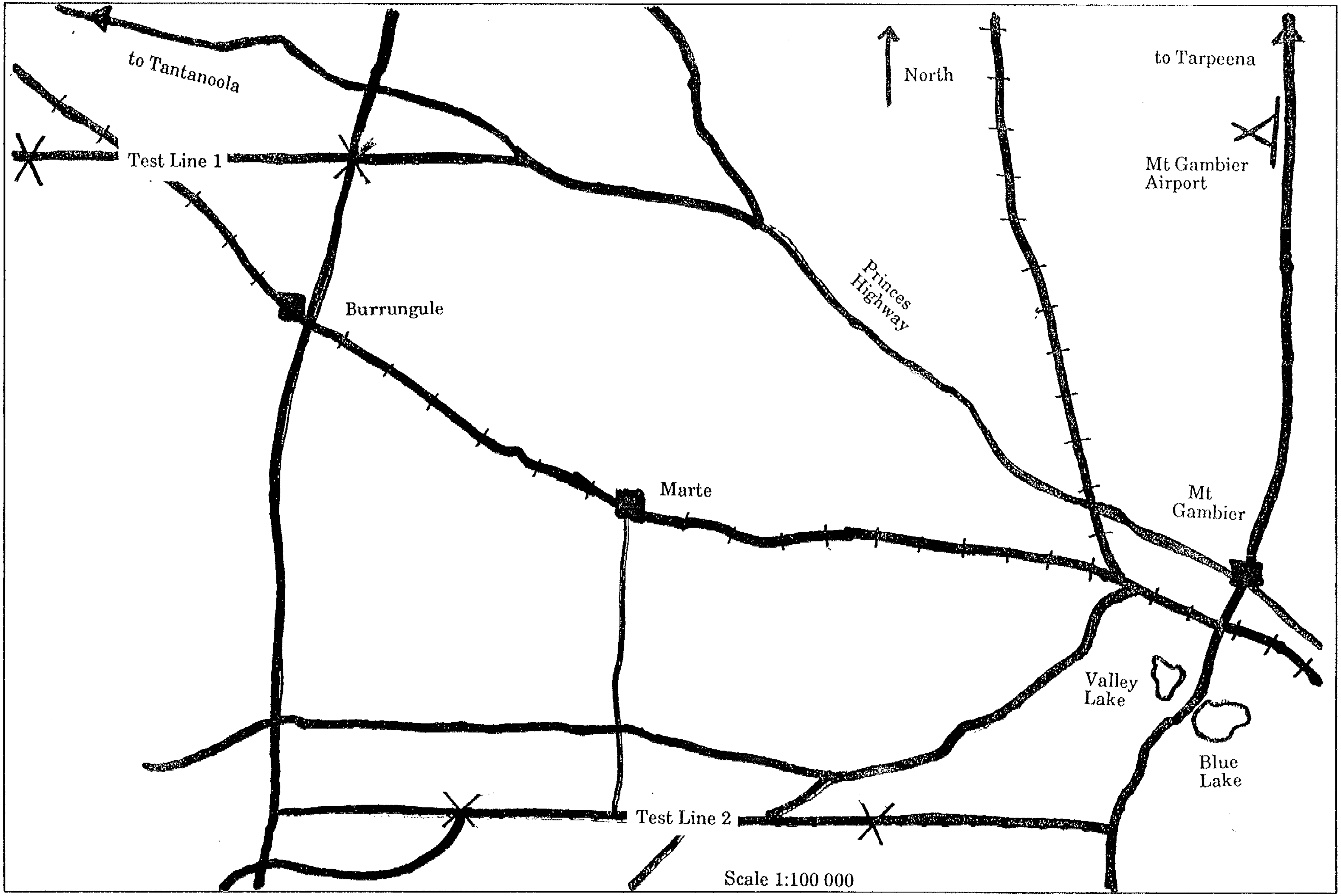
SDC = Standard deviation of the data recorded during manoeuvres after compensation corrections have been applied.

IR = Improvement ratio = SDU/SDC

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

APPENDIX H

LOCATION OF GAMMA-RAY SPECTROMETRIC TEST LINES



APPENDIX I

CORRECTIONS TO NAVIGATION DATA

(a) A correction due to the finite time taken for the GPS system to calculate a position and transfer the information to the acquisition system. This delay time is dependent on the number of satellites used to calculate the position. A delay of 0.6 seconds has been determined for a calculation using five 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) 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) GPS base station data are used to calculate "Ranger" position corrections at five second intervals. These corrections are applied to 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) 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) GPS data were converted from the WGS 84 geodetic coordinate system to the AGD 66 geodetic coordinate system.

(f) 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 meters toward the rear of the aircraft to correspond with the position of the magnetometer's sensor.

(g) Whenever gaps (<10 km) in the GPS data occurred they were infilled with data generated from the doppler navigation system.

APPENDIX J-1

AGSO ARCHIVE DATA AND MAGNETIC TAPE FORMAT FOR AIRBORNE GEOPHYSICAL DATA

CONTENTS

APPENDIX J-2

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 5 edition 1 (doppler)
channel 6 edition 1 (raw spectrometrics, raw VLF)
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).

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 bewteen 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.

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 5 edition 1 (doppler)
channel 6 edition 1 (raw spectrometrics, raw VLF)
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

C4 E2 - 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 (not micro-levelled) TMI (nT) * 1000
word 4 = final micro-levelled TMI (nT) *1000

C4 E3 - Corrected 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

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)

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)

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 J-7

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 J-8

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:

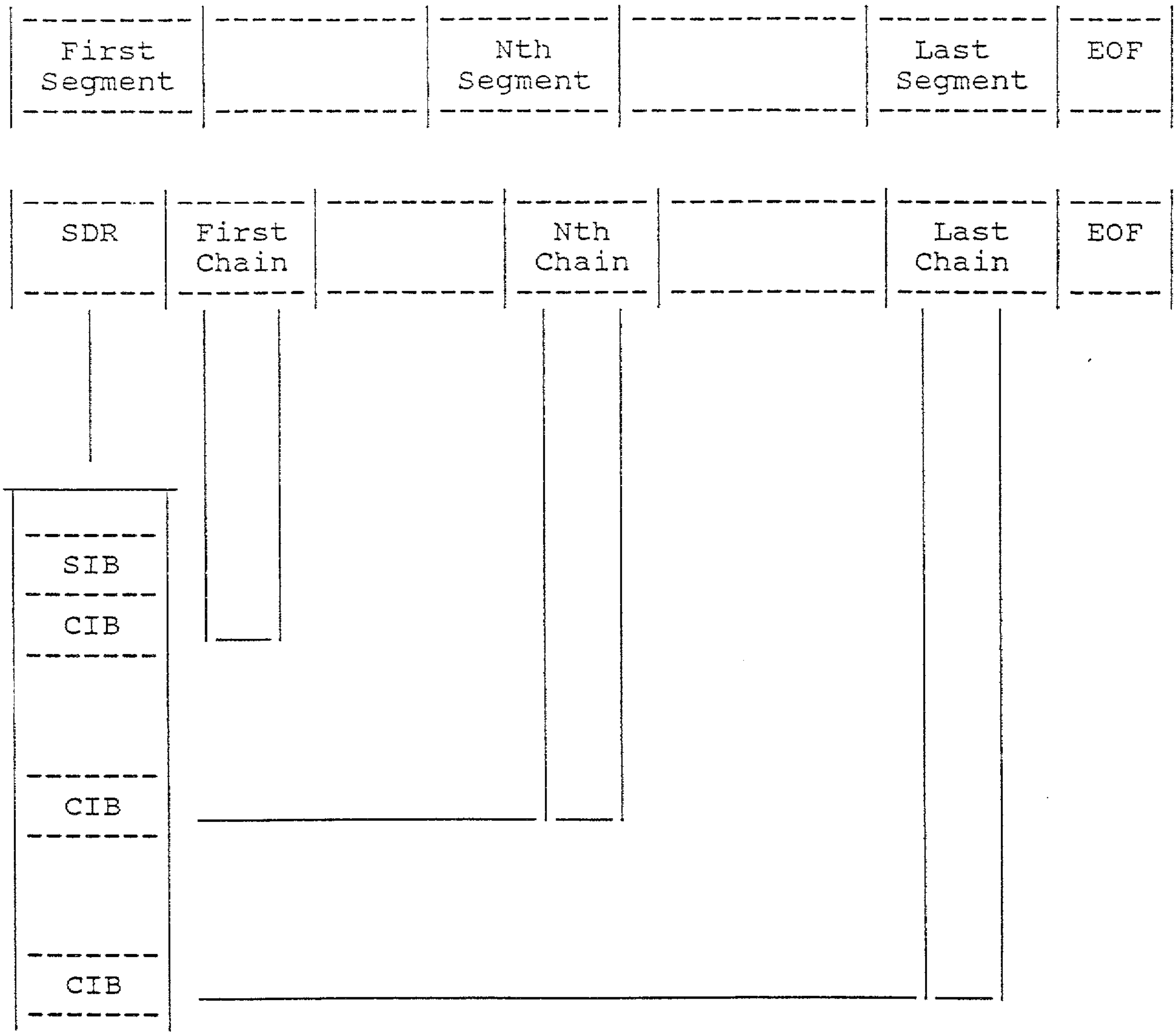
1. A data sample can be of any length greater than zero.
2. Each record contains an integral number of samples. This may lead to several unused words at the end of the record which are set to zero.

   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 J-9

FIGURE 1

SEQUENTIAL DATA FILE STRUCTURE



APPENDIX K-1

SPECIFICATIONS - RMS INSTRUMENTS AADC

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 PERFORMANCE:	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 MANOEUVRES	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

APPENDIX K-2

SPECIFICATIONS - RMS INSTRUMENTS AADC (CONTINUED)

KEYBOARD:	limited alphanumeric
DISPLAY:	green fluorescent, 80 character self scan panel
OUTPUTS:	serial data communication port: RS232C - max. rate 19.2 KBaud parallel output port: 16 bit with full handshaking (DRV11-J) (optional) 4 analog outputs of 12 bit resolution, 10V full scale (optional)
POWER:	28 ± 4 VDC, 5 A, 150 W (for single magnetometer) 7 A, 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 (19 x 7 x 17.3 in) console weight: 12.5 kg (28 lbs) power supply dimensions: 225 x 180 x 220 mm (8.9x7.25x8.7 in) power supply weight: 5.5 kg (12 lbs)

APPENDIX L

SPECIFICATIONS - G866 BASE STATION MAGNETOMETER

Display: Six-digit, seven-segment, numeric display of magnetic field with 0.1 gamma resolution. Same display used to set or view time-of-day and date, signal strength, battery voltage, and variables.

Resolution: Varies from 0.1 to 1 gamma depending on sample interval. 1 gamma for 0.5 to 0.9 second, 0.5 gamma for 1.0 to 1.7 seconds, 0.2 gamma for 1.4 to 2.9 seconds, and 0.1 gamma for 3.0 or more seconds.

Accuracy: One-half gamma.

Controls: Pressure-sensitive keyboard to control operation and to select variables. All control clock settings are stored in non-volatile memory, powered by a lithium battery.

Clock: Julian clock with stability of 5 seconds per month at room temperature and 5 seconds per day over a temperature range of -20 to +50 degrees Celsius.

Tuning: Push-button tuning from keyboard. Current tuning value displayed on request. Tuning range is 20 to 90 kilogammas.

Gradient Tolerance: Tolerates gradients to 5000 gammas/meter. When high gradients reduce signal quality, a partial reading is maintained at a resolution consistent with implied accuracy.