Simpson Extension Part 2
Northern Territory
Airborne Magnetic and Radiometric Geophysical Survey

for

NT Department of Business, Industry & Resource Development

Acquisition and Processing Report

Prepared by : D.Gay ……………………….....

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Authorised for release by : ……………………….....

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Survey flown: May 2004 - July 2004

by

FUGRO

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FAS JOB# 1660

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1 SURVEY OPERATIONS AND LOGISTICS

1.1 Introduction

Between the 26th of May 2004 and the 19th of July 2004 Fugro Airborne Surveys Pty. Ltd. (Fugro) undertook an airborne magnetic and radiometric survey for the NT Department of Business, Industry & Resource Development (NTDBIRD) over the Simpson Extension Part 2 area in the south east of the Northern Territory, Australia. The Simpson Extension Part 2 survey consists of one area of new flying. The survey was flown using a Cessna 210R aircraft owned and operated by Fugro. This report summarises the procedures, details and equipment used by Fugro in the acquisition, verification and processing of the airborne geophysical data.

1.2 Survey Base

The survey was based out of New Crown Station in the Northern Territory. The aircraft was operated from the New Crown Station airstrip with the aircraft fuel available on site. A temporary office was set up at the base site where all survey operations were run from and the post-flight data verification and processing was performed.

1.3 Flying Summary

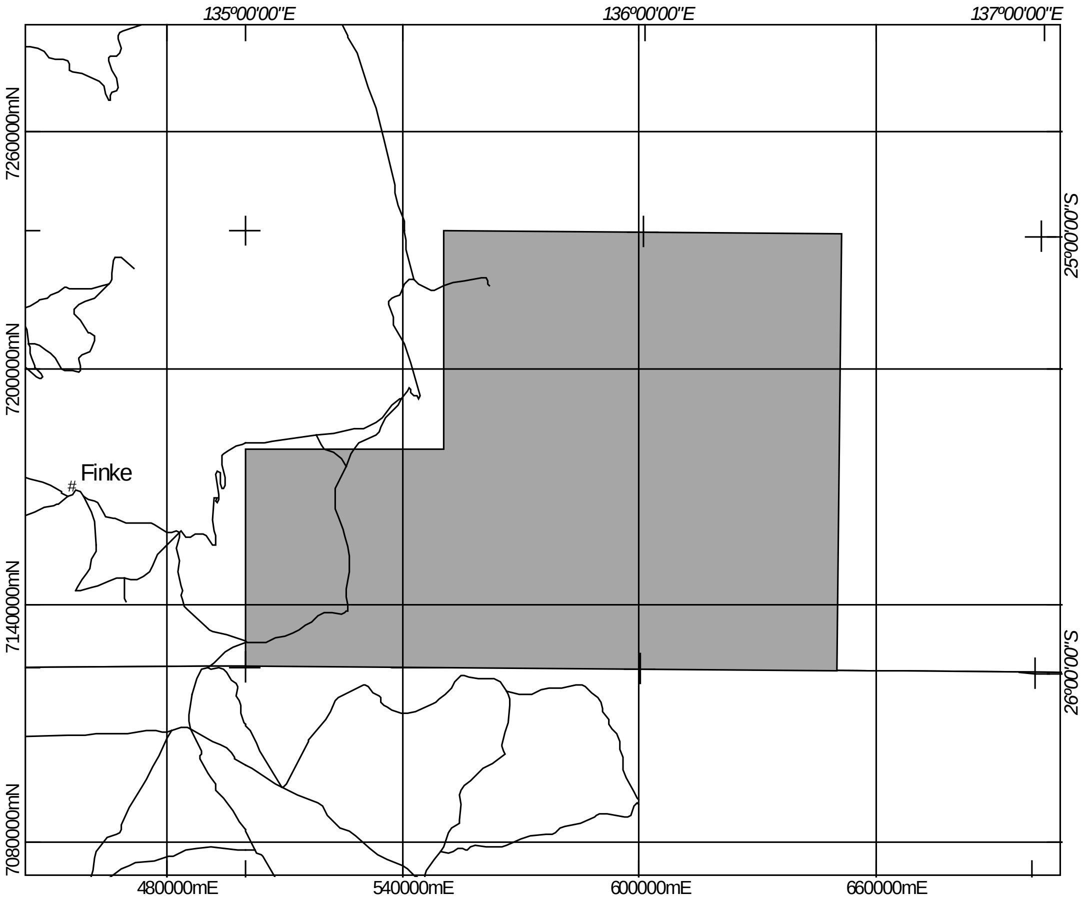
The terrain over the survey area was mainly sanddunes with scrubby to sparse vegetation. The weather pattern was generally the same with clear weather every day. One day was lost due weather. Some production was lost due active diurnal.

1.4 Survey Personnel

The following personnel were involved on this project:

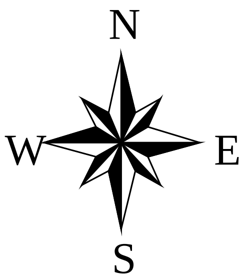
Project Manager/s (Perth)	Katherine McKenna
Data Processing Manager (Perth)	Andrea Tovey
On-site Crew Leader	Justin Bombardieri
Pilots	James Gibbs
	Kyron Florisson
	Til Ribarich
System Operators	Justin Bombardieri
Electronics Technician	Bart Anderson
Data Processing (Perth)	Mark Baigent (Contractor)

1.5 Area Map



Client: Northern Territory Geological Survey
Area: Simpson Extension Part 2
Survey: Magnetic and Radiometric Survey

Datum: GDA94
Projection: MGA
Zone: 53



1.6 Survey Equipment

Survey Platform

Aircraft	-	Cessna 210R
Registration	-	VH-MOK

Data Acquisition System

Model	-	FUGRO DAS (in-house developed)

Compensator

Model	-	RMS Instruments Automatic Aeromagnetic Digital Compensator

Magnetometer Sensor

Model	-	Scintrex CS-2 caesium vapour magnetometer
Mounting	-	Tail stinger

Vector Magnetometer

Model	-	Billingsley TFM100-IE (3-axis fluxgate)

Gamma-Ray Spectrometer

Model	-	Exploranium GR820 self-calibrating spectrometer
Detectors	-	8 all viewing NaI (Tl activated) crystals
Total Crystal Volume	-	33.56 litres

Aircraft GPS Navigation

Model	-	Marconi Allstar GPS Receiver

Radar Altimeter

Model	-	Collins ALT-55

Temperature/Humidity

Model	-	Vaisala HMY133

Pressure

Model	-	Vaisala PTB 200A

Base Station Magnetometers

Model	-	Scintrex Envi-Mag (primary)

Base GPS

Model	-	Marconi OEM Allstar

2 SURVEY SPECIFICATIONS AND PARAMETERS

2.1 Area Co-ordinates

For the purpose of flight planning the survey area was planned and flown in the WGS84 datum using a UTM projection, zone 53. The data was processed in GDA94 using the MGA projection, zone 53.

The Simpson Extension Part 2 survey is located on the following 1:250,000 map sheet:

SG53-7 McDills

and is bounded by the following map boundary:

Corner 1	-25º 00’ 00.000”	135º 30’ 00.000”
Corner 2	-25º 00’ 00.000”	136º 30’ 00.000”
Corner 3	-26º 00’ 00.000”	136º 30’ 00.000”
Corner 4	-26º 00’ 00.000”	135º 00’ 00.000”
Corner 5	-25º 30’ 00.000”	135º 00’ 00.000”
Corner 6	-25º 30’ 00.000”	135º 30’ 00.000”

2.2 Line Spacing

Traverse line spacing	-	400 m
Tie line spacing	-	4000 m

2.3 Line Heading

Traverse line heading	-	000º/180º
Tie line heading	-	090º/270º

2.4 Line Kilometres Planned

(Note – distances include overfly)

Traverse line distance	36467 km
Tie line distance	3750 km
Total distance	40217 km

2.5 Survey Height

Mean survey height	-	Nominal 80 m AGL

2.6 Data Sample Intervals

Data sample intervals calculated on a nominal aircraft speed of 252 km/h.

Magnetometer	-	7 m (@10 Hz)
Radar altimeter	-	7 m (@10 Hz)
Temperature	-	70 m (@1 Hz)
Pressure	-	70 m (@1 Hz)
GPS	-	70 m (@1 Hz)
Spectrometer	-	70 m (@1 Hz)
Magnetic base station Envi-mag	-	2 s
Magnetic base station CS2	-	1 s

2.7 Survey Tolerances

As specified in the contract the following tolerances were used:

Traverse line deviation	-	5 % of nominated line spacing over 2 km or more
Tie line deviation	-	0.5 % of nominated tie line spacing over 2 km or more
Terrain clearance deviation	-	+/-10 m of nominal terrain clearance over 2 km or more

Total magnetometer system noise	-	More than 0.1 nT continuously over 1 km or more
Traverse line diurnal variation	-	More than 5 nT in 5 minutes
Tie line diurnal variation	-	More than 5 nT in 5 minutes
Diurnal noise	-	More than 0.5 nT for 5 minutes or more

3 SURVEY EQUIPMENT AND SPECIFICATIONS

3.1 Aircraft

Manufacturer	-	Cessna
Model	-	210 R
Registration	-	VH-MOK (Australia)
Ownership	-	Fugro Airborne Surveys

3.2 Magnetometer and Compensator

A Scintrex CS-2 magnetometer sensor, mounted in a stinger secured to the rear of the aircraft was used for this survey.
The magnetometer sensor was coupled to an RMS Instruments Automatic Aeromagnetic Digital Compensator (AADC). The AADC compensates the total magnetic field data in real time for the magnetic effect of the aircraft manoeuvring with respect to the earth's magnetic field. This effect comprises permanent magnetism, induced magnetism and eddy current effects.
The correction coefficients used by the AADC during compensation were calculated from a compensation flight conducted prior to the survey commencing, or at any other time deemed necessary.

3.3 Gamma Ray Spectrometer

An Exploranium GR-820 multi-channel gamma-ray spectrometer, coupled to two GPX crystal detectors, was used for this survey. The crystal detectors were secured to a rack on the floor of the aircraft.
The GR-820 uses a sophisticated automatic control method to ensure crystal alignment is maintained, while stabilising on naturally occurring isotopes. The system continuously monitors each of the eight crystal signals and accumulates an individual spectrum for each configured crystal. The peak channel of the selected stabilisation isotope is computed when a specified number of counts have been accumulated. This peak channel is then compared to the correct peak location and the gain is subsequently adjusted.
Two hundred and fifty six channels of data between 0.3 MeV and 3.0 MeV were recorded once per second. Additionally, 4 ROIs and a cosmic channel were recorded using the following window limits:

Total Count		:	0.41 - 2.80 MeV
Potassium	(K_{40} peak at 1.460 MeV)	:	1.37 - 1.57 MeV
Uranium	(Bi_{214} peak at 1.765 MeV)	:	1.66 - 1.86 MeV
Thorium	(Tl_{208} peak at 2.614 MeV)	:	2.41 - 2.80 MeV
Cosmic		:	4.00 - 6.00 MeV

The calibration procedures for the gamma-ray spectrometer are described in Section 5.

3.4 Data Acquisition System

The FUGRO digital acquisition system runs on a personal computer. The data were recorded to hard disk and dumped to disk at the completion of each flight. The system was synchronised to GPS time. The data were viewed in real time, enabling the operator to confirm that quality specifications were being met. The following parameters were recorded digitally.

a) Time in seconds (to 0.1 seconds)
b) Fiducial number, incrementing by smallest data sample interval
c) Navigation data including GPS height
d) Terrain clearance (radar altimeter)
e) Barometric pressure
f) Relative humidity
g) Ambient temperature outside the aircraft in degrees Celsius
h) Uncompensated Total Magnetic Intensity (TMI) reading
i) Fluxgate axes X, Y & Z
j) Compensated TMI reading
k) Full 256-channel gamma-ray spectrum
l) Total count reading in counts per second (uncorrected)
m) Potassium window reading in counts per second (uncorrected)
n) Uranium window reading in counts per second (uncorrected)
o) Thorium window reading in counts per second (uncorrected)

p) Cosmic window reading in counts per second (uncorrected)
q) Spectrometer live time
r) Number of satellites
s) Position dilution of precision

3.5 GPS Navigation System

The GPS position referencing WGS84 is read by the FUGRO digital acquisition system. The navigational errors, with reference to the planned survey line, are then calculated and displayed for the pilot and operator. This completes the cycle. Two navigation cycles are performed each second.
Real time differential correction was achieved via Fugro Surveys OmniSTAR System.

3.6 Radar Altimeter

A Collins ALT-55 Radar Altimeter was used to measure the aircraft height above ground level (AGL). The radar altimeter system is of high resolution designed for automatic continuous operation over a wide variation of terrain, target reflectivity, weather and aircraft altitude.
The radar altimeter data were recorded 10 times per second with an accuracy of ± 1 m (at 80 m AGL).

3.7 Temperature and Humidity Sensor

A Vaisala HMY133 Sensor was used to measure outside air temperature and relative humidity. The data were recorded once per second.

3.8 Barometer

Atmospheric pressure was measured using a Vaisala PTB 200A Digital Barometer that was tapped into the aircraft static system. The barometric data were recorded once per second.

3.9 Flight Following

An integral part of the Safety Management System provides for the installation of a flight following system that transmits a position via satellite at pre determined intervals. The Thrane & Thrane Inmarsat C Tracking System was fitted to the aircraft and for the Simpson Extension Part 2 survey, position information was transmitted to FUGRO's premises in Perth. This information can be monitored by accessing the FUGRO web page where the updated flight path is displayed. In the event that positional information from the aircraft is lost for a period exceeding 12 minutes or three consecutive transmissions, an alarm is raised and a SMS text message sent to nominated contacts and the emergency response plan implemented.

4 GROUND DATA ACQUISITION EQUIPMENT AND SPECIFICATIONS

4.1 Magnetic Base Station

Scintrex CS-2 and Scintrex Envi-Mag cesium vapour magnetic base stations were used to measure the daily variations of the Earth's magnetic field. The base stations were established in an area of low gradient, away from cultural influences. The base stations were run continuously throughout the survey flying period with a sampling interval of 1 second and 2 seconds, respectively, and a sensitivity of 0.01 nT. The base station data were closely examined after each days production flying to determine in any data had been acquired during periods of out-of-specification diurnal variation. The magnetic base stations were set up at the New Crown Station airstrip approximately 200 metres apart. The Scintrex CS-2 mag was used as the primary base station and the Envi-mag as the backup station. The base station value for the primary base station was calculated and used in the diurnal correction of the magnetic data.

4.1.1 Magnetic Base Station Specifications

Scintrex CS-2

Model	-	Scintrex CS-2 Caesium vapour magnetometer
Operating range	-	20,000 – 100,000 nT
Sensitivity	-	0.002 nT @ 1 Hz
Sample rate	-	1 sec

Envi-Mag

Model	-	Scintrex Envi-Mag Caesium vapour magnetometer
Operating range	-	20,000 – 90,000 nT
Sensitivity	-	0.002 nT @ 1 Hz
Sample rate	-	2 sec

4.1.2 Magnetic Base Station Locations

The Scintrex CS-2 base station was located approximately 100 m SE from the SE end of the New Crown Station airstrip. The Envi-mag base station was located 200 m to the NW of the CS-2 base station on the southern edge of the airstrip approximately.

4.2 GPS Base Station System

A GPS base logging station was set up at the survey base office. The GPS antenna was set up on the caravan (office) roof near the C-150 aircraft hangar.

The GPS base system comprises a GPS receiver, a logging computer, an antenna and a UPS system to avoid down time if power fails or fluctuates. The GPS receiver is connected to the PC via a serial COM connector. Data is logged and displayed in real time on the screen. Logged base data is processed in conjunction with the airborne GPS data to calculate the post-processed differential position of the aircraft. The aircraft flight path and altitude clearance can then be displayed.

Specifications

Model	-	Marconi All Star
Receiver	-	12 Channel GPS code and carrier
Position Accuracy	-	Differential mode <40 cm

The GPS base station position was calibrated by obtaining trig. station data for 'ALIC' trig. from AUSLIG, and collecting data over a 24 hour period.

The calculated GPS base position was (in WGS84):

New Crown Station base: 25° 40' 35.13519" S, 134° 49' 59.86985" E, 236.726 m.

5 EQUIPMENT CALIBRATIONS AND DATA ACQUISITION CHECKS

5.1 Survey Calibrations

A series of calibrations were performed as follows:

5.1.1 Dynamic Magnetometer Compensation

The compensation sequences were flown in a region of low magnetic relief. The aircraft's altitude was 10,000 feet (above mean sea level). Each sequence consisted of a series of manoeuvres performed on each of the cardinal headings. The manoeuvres comprised ± 10 degree rolls, ± 5 degree pitches and ± 5 degree yaws. The coefficients are used in compensating for the effects of permanent magnetism, induced magnetism, eddy currents and heading error were calculated automatically by the AADC upon completion of a sequence. The calculated coefficients were then applied to the uncompensated total field readings (collected during the sequence) in order to assess the quality of the "solution". The (now compensated) data were then statistically analysed. The resultant statistics, revealing the quality of the compensation solution, are displayed by the AADC. The statistics include: standard deviation of the high-passed uncompensated TMI (UNC), standard deviation of the high-passed compensated TMI (CMP), improvement ratio (IR) and "vector norm of the interference set" (NRM). The IR is the result of dividing UNC by CMP.
A three-axes fluxgate magnetometer mounted in the stinger, enables derivation of motion information by the AADC during a sequence.
Compensation sequences were flown on the following dates:

Date flown	Flights covered
14/06/04	1 to 36
07/07/04	37 to 53
16/07/04	54 to 59

5.1.2 Parallax

Parallax error is caused by the physical difference in distance between the various sensors, the electronic delay and software timing in the acquisition system. Hence all variables are subjected to a displacement from the GPS co-ordinates. If these variables are processed without a position offset a parallax error will usually occur. The most suitable way to treat this problem is to use the 1 second radiometric data as a base with a zero correction. This will prevent interpolation of important variables (a filtering process). The co-ordinates were moved by linear interpolation and other data variables were displaced onto the radiometric data, without change.

5.1.2.1 Spectrometer

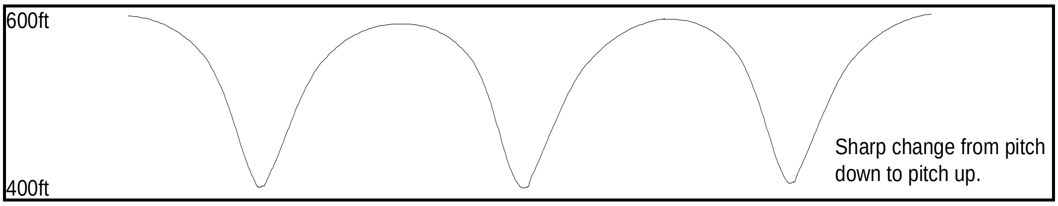
The spectrometer data were not parallaxed but a correction was made by applying a parallax to the co-ordinate data. This parallax was computed using a section of lines from a previous job with a spacing of 100 metres and regridding the data until the appropriate amount of parallax was applied. The parallax correction was checked on the current job to verify it was being correctly applied.

5.1.2.2 Magnetometer

The magnetometer parallax was computed using a section of lines from a previous job with a spacing of 100 metres and regridding the data until the appropriate amount of parallax was applied. The parallax correction was checked on the current job to verify it was being correctly applied.

5.1.2.3 Barometric and Radar Altimeter Parallax

In order for processing to accurately determine the parallax error associated with the barometric and radar altimeter data a parallax test line was flown. This line consisted of five sharp swoops between 600 ft and 400 ft. Starting at an altitude of 600 ft the aircraft sharply descended to 400 ft, then ascended upward to 600 ft, levelling off for a few seconds before repeating this a further four times.



5.1.2.4 Data parallaxes

Data	Parallax
Radiometrics	0 second
GPS easting	-0.5 second
GPS northing	-0.5 second
GPS height	-0.5 second
Magnetics	0 second
Radar altitude	-0.3 second
Pressure	2.25 seconds
Temperature	-0.5 second

5.1.3 Radar Altimeter Calibration Line

Height above the terrain is measured using a radar altimeter. The output voltage from the radar altimeter unit is recorded along with the survey data in the digital acquisition system binary files. A look-up table is used to convert this output voltage into an altitude in metres. The lookup table is computed by recording the output voltage at various heights above the ground as indicated on the radar altimeter display.

5.1.4 Background and Cosmic Calibration Stacks

Radiometric data recorded by the GR-820 is contaminated by various non-terrestrial sources. In order to provide an accurate representation of terrestrial (or natural) radiometric content these other sources must be identified and removed. This was done by flying a series of high level test lines over the ocean. Fixed barometric altitudes were flown for 5 minutes from 1000 ft above sea level (ASL) ascending at 2000 ft intervals up to and including 9000 ft ASL. then descending in the same manner.

5.1.5 Height Attenuation Calibrations

Gamma -rays are attenuated by air at approximately an exponential rate. It is therefore essential that corrections for aircraft altitude are incorporated into processing procedures. In order to correct for varying aircraft altitude and to accurately convert airborne counts into ground concentrations of potassium, uranium and thorium a series of height attenuation, or low level stacks, were flown. Over a calibration test line the stacks were flown starting at 150 ft and incrementing at 50 ft intervals to 450 ft, then 1000 ft, 1500 ft and 2000 ft with data recorded for 300 seconds at each level.

5.1.6 Daily Calibrations

A set of daily calibrations were performed each survey day as follows:

5.1.6.1 Magnetic Base Station Time Check

Prior to each days survey all magnetic base stations were time checked and synchronised with the time on the aircraft survey system GPS receiver. The temporal drift over a typical survey day of approximately 12 hours, was determined to be on the order of 1 second or less for all mag base stations.

5.1.6.2 Spectrometer Resolution Tests

Internal Quality Control of the Gamma-Ray Spectrometer relies on continually monitoring the resolution and peak positions of individual crystals. After a 20 minute warm-up, a Thorium source check was carried out by placing the source in a cradle specially designed to ensure precisely repeatable locations. A background count was also recorded. Once the aircraft completed the daily flight the source check was repeated.

5.1.6.3 Spectrometer Button Tests

Hand sample checks were performed on the spectrometer before and after each days survey acquisition. Each sample was placed in a predetermined location and data recorded for 60 sec. Relative Thorium channel count rates above background were within +/- 5% of the average sample checks for the duration of the survey.

5.1.6.4 Low Level Test line

To monitor the effects of soil moisture and radon and to verify the system was functioning correctly a low level test line was flown in a constant direction at survey altitude for 5 km prior to and after each days production. The collected data was checked by the operator to ensure the total count and Th. for the low level test line was within +/- 10% of the initial average.
The low level test line for the Simpson Extension Part 2 survey was located SE of New Crown Station along a NS running fenceline, and continued South where the fence turns to the SE. The co-ordinates are in the GDA94 datum.

Base	Mean start		Mean end	
	Longitude	Latitude	Longitude	Latitude
New Crown Station	134° 50’ 48.10”	-24° 41’ 56.02”	134° 51’ 04.84”	-25° 46’ 06.55”

6 SURVEY LINE NUMBERING SYSTEM

The following line numbering formula was employed for this survey, only the first 4 digits of the cal line numbers and the first 5 survey line numbers are shown, see sections 6.1 and 6.2 for additional explanation:

Line No./Range	Type	Duration	Frequency	Comments
1501	Thorium source	180 seconds	Daily	A.M. spec. cals
1504	Background	180 seconds	Daily	A.M. spec. cals
1508	Low level test line	~5 km	Daily	A.M. spec. cals
1601	Thorium source	180 seconds	Daily	P.M. spec. cals
1604	Background	180 seconds	Daily	P.M. spec. cals
1608	Low level test line	~5 km	Daily	P.M. spec. cals
1800-1810	Heading checks	As required	Survey commencement	
1811-1820	Comp box	~260 seconds	As required	
1826-1830	Parallax checks	As required	Survey commencement	
1831-1845	High level spec	300 seconds	Annually	Over water
1850-1865	Low level spec	5 km	Annually	Carnamah test range
1870-1874	Pad cals pack #1	300 seconds	Annually	Bg, K, U, Th
1875-1879	Pad cals pack #2	300 seconds	Annually	Bg, K, U, Th
1881-1890	Altimeter checks	As required	Survey commencement	
10001-10385	Traverse line	As required		MGA zone 53
17001-17029	Tie line	As required		MGA zone 53

6.1 Survey line numbering

6.1.1 Digital data

All survey lines are stored as 6 digit integers in the digital data and take the form ANNNNP where:

- A - Area number: for this survey a 1 indicates the line was flown as part of area 1
- NNNN- Line number: if the 1st digit is a 7 then the line is a tie line. e.g. 1**0140**0 is traverse line 140 from area 1, 1**7013**0 is tie line 13 from area 1.
- P - Attempt number: if a line is scrubbed and reflown or flown in multiple parts the attempt number will be increment by 1. e.g. 10031**2** indicated the 3rd attempt for line 0031 from area 1.

6.1.2 Flight logs

Survey lines written in the flight logs are written in the form SANNNN.PD where:

- S - Alphabetic descriptor: “ “ indicates a traverse line, “T” indicates a tie line, “S” indicates a scrubbed line.
- A - Area number
- NNNN- Line number
- . - Decimal point
- P - Attempt number
- D - Direction: **N**orth, **S**outh, **E**ast or **W**est.

6.2 Calibration line numbering

6.2.1 Digital data

All calibration lines are stored as 8 digit integers in the digital data and take the form ANNNPFFF where:

A - Area number: this is not important for a calibration line and is generally 1 for most calibration lines regardless of which block was being flown.
NNN - Line number: as per the line number description table.
P - Attempt number: unlike survey lines there are no part calibration lines
FFF - Flight number: the flight number is appended to the line number as calibration lines are repeated during the survey.

6.2.2 Flight logs

Calibration lines written in the flight logs are written in the form SANNNN.PD where:

S - Alphabetic descriptor: “C” indicates a calibration line, “S” indicates a scrubbed line.
A - Area number
NNNN- Line number
. - Decimal point
P - Attempt number
D - Direction: **N**orth, **S**outh, **E**ast or **W**est.

7 DATA VERIFICATION AND FIELD PROCESSING

All data verification and processing was conducted at the field office, which was established on site at New Crown Station for the duration of the survey. At the conclusion of each days survey all magnetic, spectrometer, altimeter, flight path and diurnal data was down-loaded onto the field office computer for preliminary verification.

7.1 Field Processing Equipment

IBM compatible Pentium computer with CD-ROM drive.
HP Pentium notebook.
Canon bubble jet printer.

7.2 Magnetic Diurnal Data

Diurnal data recorded every 1 second from the primary base station was down-loaded from the magnetometer's base logging computer onto the field processing computer. The data was then checked for spikes and erroneous readings. If invalid diurnal data occurred whilst survey data was being acquired the affected section was re-flown. The diurnal data was also checked to see that the change in diurnal readings during the course of the survey did not exceed the specified tolerances described in section 2.7. When this occurred the affected part of the survey line was re-flown. The diurnal data was merged with the aircraft data and used in the verification of the magnetic data. Diurnal data recorded by the backup base station was also down-loaded onto the field processing computer.

7.3 Altimeter Data

Radar altimeter, barometric altimeter and GPS height data from the aircraft was transferred onto the field processing computer.

7.3.1 Radar Altimeter Data

The radar altimeter is verified to check that a reasonably constant height above the terrain was flown and that readings during the course of the survey did not exceed the specified tolerances described in section 2.7 and for equipment reliability. The radar altimeter data is used in the production of topographic maps.

7.3.2 GPS Height Data

The aircraft's height above the WGS84 ellipsoid each second was determined by differentially post-processing the synchronised GPS data from the aircraft and the GPS base station. The GPS height of the aircraft is verified to check for data masking and for equipment reliability. The GPS height data is used in the production of topographical maps.

7.3.3 Barometric Altimeter Data

As a backup to the aircraft's GPS height barometric data was also recorded. The barometric height of the aircraft is verified to check for equipment reliability. The barometric data is also used in the processing of the spectrometer data.

7.3.4 Topographical Data

After verification parallax corrections as specified in section 5.1.2.4 were applied and the radar altimeter height was subtracted from the GPS height to give the elevation of the terrain above the WGS84 ellipsoid. It was not considered necessary to make any further corrections as this data is for verification purposes only.

7.3.5 Gridding and Inspection

The topographical data was gridded and grid image enhancements were computed and displayed on screen. These were inspected for inconsistencies and errors and appropriate corrections were made if required.

7.4 Flight Path Data

The flight path data from the aircraft and the GPS base station were transferred onto the field-processing computer. The aircraft's precise location each second was determined by differentially post-processing the synchronised GPS data from the aircraft and GPS base station. The flight path was recovered and plotted daily to ensure it was within specifications described in section 2.7. Any data not within specification was re-flown. The flight path data was then merged with the rest of the aircraft and diurnal data. Both the aircraft and GPS base station recorded the data in the WGS84 datum.

7.5 Magnetic Data

The real-time compensated and uncompensated magnetic data from the aircraft recorded every 0.1 second were transferred onto the field-processing computer. The raw, unedited magnetic data was checked to identify noise and spikes. Single reading spikes were manually edited and if the noise exceeded the specified tolerances described in section 2.7 the part of the line affected was re-flown. After the edited magnetic data was merged with the digital flight path the following sequence of processing operations were carried out to allow inspection and verification of the data:

7.5.1 Diurnal Correction

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

7.5.2 Parallax Correction

The magnetic data was corrected for system parallax as per section 5.1.2.4.

7.5.3 Preliminary Gridding and Inspection

The magnetic data was gridded and grid image enhancements were computed and displayed on screen. These were inspected for inconsistencies and errors and appropriate corrections were made if required.

7.6 Spectrometer Data

Spectrometer data from the aircraft was transferred onto the field-processing computer. The data is verified to check that readings during the course of the survey did not exceed the specified tolerances described in section 2.7 and for equipment reliability.

7.6.1 Preliminary Corrections

Standard radiometric data reduction corrections were then applied to the Total Count, Potassium, Uranium and Thorium window data.

7.6.2 Preliminary Gridding and Inspection

The spectrometer data was gridded and grid image enhancements were computed and displayed on screen. These were inspected for inconsistencies and errors and appropriate corrections were made if required.

7.7 Quality Control Products

Every 100 engine-hours of survey flying and/or whenever the aircraft departed the survey area, Hundred-Hourly Reports on the data the aircraft acquired during the preceding period was delivered.

Each QC Hundred-Hourly Report comprised the following:

- A map of the fourth difference in the magnetic signal with threshold 0.05 nT.
- A diurnal map showing every one minute period of flying during which the range of the diurnal exceeds 1 nT.
- A flight path map clearly showing separations greater than:

    1.05 x nominal flight line separation

    1.005 x nominal tie line separation

- A height deviation map highlighting flight segments where the nominal survey height has been exceeded by 10 metres (above or below the nominal height) and must precede any smoothing of the height data.
- A report of the thorium averages flown along the test line is required to show radon, moisture and stability.
- A report of the tests using the hand samples, taken before and after each day's flying, shall be presented to demonstrate the stability of sensitivity.

Grids of the following parameters, were also provided as ERMapper ERS files:

TMI (compensated, tie line levelled, corrected for diurnal and IGRF)

Digital Terrain Model (tie line levelled)

Potassium (fully corrected)

Thorium (fully corrected)

Uranium (fully corrected)

Total Count (fully corrected)

7.8 Digital Archives

All raw aircraft data was backed up at the end of each day's survey. Two copies of all verified and edited data were made at the end of each day's survey. One copy was sent by courier to the Fugro office in Perth with the other copy remaining at the field processing office.

8 FINAL DATA PROCESSING

8.1 Aircraft Location

The aircraft's location each second was determined by differentially post-processing the synchronised GPS data recorded on both the aircraft and GPS base station. Where small gaps occurred in the differential data, positions were interpolated. This data is recorded in the WGS84 datum. Prior to being merged with the magnetic, radiometric and topographic processing stream data, system parallax as specified in section 5.1.2.4 was applied. No datum transformation shift from WGS84 to GDA94 was applied as the difference between the two data is not considered large enough to have any meaningful effect on the positional accuracy of the survey. For all practical purposes WGS84 and GDA94 positions can be considered identical for this type of survey.

8.2 Magnetic Data Processing

Data collected by each of the raw data sources is checked for spikes and noise by complex procedures. These procedures are summarised below:

a) Apply any spike corrections (including Inmarsat transmissions) to the raw magnetic variables.
b) Interpolate undefined magnetic values.
c) Apply fluxgate corrections and compensate the data with post-processed compensation files.
d) Co-ordinate the data with post-processed GPS data.
e) Filter diurnal values and subtract them from individual compensated magnetic readings. The diurnal base values were then added.
f) Apply parallax correction (see section 5.1.2.4).
g) Correct for regional effects of the earth's magnetic field by calculating the IGRF value at each fiducial using following IGRF parameters.

Model	Secular variation	Elevation (metres)
2000	2004.5	238

h) Using the tie lines (flown at 90 degrees to the traverse lines) a set of miss-tie values were determined. These miss-tie values reflected the differences in the magnetic value between the tie lines and the traverse lines over the same geographical point. Using a least squares fit algorithm, which also takes into account the statistical variation inherent in DGPS positioning, a series of corrections were applied to the traverse line data. These allowed the data to be levelled to the same base value.
i) Following this, a micro-levelling process was applied in order to more subtly level the data. This process removes sub-gamma pulls evident only under image enhancement algorithms.
j) Compute along line Total Magnetic Intensity 1st Vertical Derivative (1VD) from the final levelled TMI data.

8.3 Radiometric Data Processing

The radiometric data was processed using the standard IAEA window processing technique as summarised below.

a) Apply NASVD filtering to the 256 channel data.
b) Window the NASVD filtered 256 channel data using the IAEA standard energy windows.
c) Co-ordinate the data with post-processed GPS data as per section 8.1.
d) Apply spike corrections to the radar altimeter, temperature and pressure values.
e) Apply parallax corrections to altimeter, temperature and pressure data (see section 5.1.2.4).
f) Calculate the equivalent terrain clearance at STP (standard temperature and pressure).
g) Remove aircraft background.
h) Remove cosmic background.
i) Remove radon background.
j) Apply stripping ratios.
k) Apply height corrections.
l) Convert to ground concentrations.

8.3.1 Energy Calibration

The spectral drift was checked by monitoring the position of Potassium, Uranium and Thorium peaks on average spectra along flight lines. The peak positions were determined by removing the Compton continuum and applying a gradient search technique on the residual spectrum.
No energy calibration was required for this survey.

8.3.2 NASVD Filtering

The radiometrics were produced with NASVD smoothing. Using the NASVD technique, the raw spectra were first smoothed using 5 principal components. Eigenvectors and statistics on the NASVD processing results were used for analysis. Raw count rates used for final processing were extracted by summing the 256 channel data over the IAEA windows centred on the peak locations, to the nearest channel.

8.3.3 Windowing and Dead-Time Correction

The NASVD smoothed 256 channel data were summed into the standard IAEA windows.

Window	Peak Energy (keV)	Energy Window (keV)			GR-820 Channel Window		
Total Count	-	414	-	2799	34	-	234
Potassium	1460	1374	-	1566	115	-	131
Uranium	1765	1662	-	1854	139	-	155
Thorium	2615	2416	-	2799	201	-	234
Cosmic	-	4000	-	6000		-	

Gamma-ray spectrometers require a finite time to process each pulse from the detectors. While one pulse is being processed, any other pulse that arrives will be rejected. Consequently the 'live' time of a spectrometer is reduced by the time taken to process all pulses reaching the multi-channel analyser. The window data is then normalised to counts per second by dividing by the livetime. The cosmic channel does not undergo the normalising process at it is output by the GR-820 in counts per second.

8.3.4 Cosmic Aircraft Background Removal

The cosmic and aircraft backgrounds for each channel are of the form:

$N = a + b*C$
where

N =	combined cosmic & aircraft background in each spectral window
a =	aircraft background in the window
C =	cosmic channel count
b =	cosmic stripping factor

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

Aircraft Background and Cosmic Stripping Ratio for VH-MOK

Window	Aircraft Background	Cosmic Stripping Ratio
Total Count	68.0	0.8400
Potassium	17.8	0.0480
Uranium	2.0	0.0370
Thorium	1.0	0.0475

8.3.5 Atmospheric Radon

The 256 channel data were then pre-processed to obtain data for Radon gas background removal. Radon corrections are performed using the spectral ratio technique, involving detailed curve-fitting techniques to determine the final count values for various peaks of filtered spectral data (using long filters). Corrections are made for the interference to the 0.609 MeV and 1.76 MeV peaks from adjacent thorium peaks, in an iterative way, before the final peak values are accepted, then the spectral ratios are established. This method is calibrated using the test range data, before the corrections are applied to the data.

8.3.6 STP Altitude

The radar altimeter data was converted to effective height at standard temperature and pressure using the expression:

STPAlt = RAlt * (P/103) * (273 / (T+273))
where:

RAlt =	the observed radar altitude in metres
T =	the measured air temperature in degrees C
P =	the barometric pressure in hectopascals

8.3.7 Spectral Stripping

Spectral stripping was applied to the Potassium, Uranium and Thorium windows. The stripping co-efficients were corrected for STP altitude.

Stripping Ratios for VH-MOK

Stripping	Value	STP adjustment (/m)
Alpha	0.246	0.00049
Beta	0.434	0.00065
Gamma	0.792	0.00069
A	0.061	0
B	0	0
G	0	0

8.3.8 Height Correction

The background corrected and stripped window data were then corrected for variations in the density altitude of the detector.

STP Altitude Coefficients for Aircraft VH-MOK

Window	Attenuation coefficient (m^{-1})
Total Count	-0.0075
Potassium	-0.0101
Uranium	-0.0079
Thorium	-0.0074

8.3.9 Ground Concentrations

The Total Count window data were then converted to dose rate and the Potassium, Uranium and Thorium windows were converted to ground concentrations using the expression:

C = N/S
where

C =	concentration of the radioelement in (nGy/h, % K, ppm U, ppm Th)
N =	count rate for each STP height corrected window
S =	sensitivity factor

Sensitivity factors for VH-MOK

Window	Factor

Total Count	23.56 nGy/h
Potassium	86.38 %
Uranium	6.14 ppm
Thorium	5.17 ppm

8.4 Digital Elevation Model

Data collected by each of the raw data sources is checked for spikes and then processed as follows:

a) Apply any spike corrections to the raw radar altimeter data.
b) Interpolate undefined values.
c) Co-ordinate the data with post-processed GPS data.
d) Apply parallax correction (see section 5.1.2.4).
e) Subtract the aircraft's height above ground from the aircraft's height above the GRS80 ellipsoid and correct for radar altimeter/GPS sensor separation.
f) Using the tie lines (flown at 90 degrees to the traverse lines) a set of miss-tie values were determined. These miss-tie values reflected the differences in the computed topographic height between the tie lines and the traverse lines over the same geographical point. Using a least squares fit algorithm, which also takes into account the statistical variation inherent in DGPS positioning, a series of corrections were applied to the traverse line data.
g) Following this, a Fugro proprietary micro-levelling process was applied in order to more subtly level the data.
h) The data were then corrected to Australian Height Datum using AUSLIG 1998 N-values.

The accuracy of the elevation calculation is directly dependent on the accuracy of the two input parameters, radar altitude and GPS altitude. The radar altitude value may be erroneous in areas of heavy tree cover, where the altimeter reflects the distance to the tree canopy rather than the ground. The GPS altitude value is primarily dependent on the number of available satellites. Although post-processing of GPS data will yield X and Y accuracies in the order of 1-2 metres, the accuracy of the altitude value is usually much less, sometimes in the ±5 metre range. Further inaccuracies may be introduced during the interpolation and gridding process.

Because of the inherent inaccuracies of this method, no guarantee is made or implied that the information displayed is a true representation of the height above sea level. Although this product may be of some use as a general reference, THIS PRODUCT MUST NOT BE USED FOR NAVIGATION PURPOSES.

8.5 Gridding

The final levelled magnetic, radiometric and elevation data were gridded using the minimum curvature method. A grid cell size of 100 metres, ¼ line spacing, was used. A list of the grids produced can be found in Appendix 3.

APPENDIX 1.: LINE LISTING

A line number summary has been included on the accompanying CD-ROM.
Directory: Simpson_ext2/appendix_docs
Format: MS-WORD 97
File: line_summary.doc

APPENDIX 2.: LINE DATA

Three copies of line data were provided on CD-ROM. The line data format conformed to the ASEG-GDF (II) format. Three sets of line data were provided:

a) Magnetic and elevation data at 0.1 second intervals.
b) Windowed radiometric data at 1.0 second intervals.
c) Raw radiometric 256 channel data at 1.0 second intervals.

Example .DAT, .DES and .DFN files covering the three types of line data have been included on the accompanying CD-ROM.
Directory: Simpson_ext2/appendix_docs/digital
Format: ASCII
Files:

File name	Description
README_located.txt	Located data README file
McDills_MAG_1.dat	Mag and elevation data file
McDills_MAG_1.des	Mag and elevation description file
McDills_MAG_1.dfn	Mag and elevation definition file
McDills_MAG_2.dat	Mag and elevation data file
McDills_MAG_2.des	Mag and elevation description file
McDills_MAG_2.dfn	Mag and elevation definition file
McDills_RAD.dat	Radiometric window data data file
McDills_RAD.des	Radiometric window data description file
MsDills_RAD.dfn	Radiometric window data definition file
McDills_RAD256_1.dat	Raw radiometric 256 channel data file
McDills_RAD256_1.des	Raw radiometric 256 channel description file
McDills_RAD256_1.dfn	Raw radiometric 256 channel definition file
McDills_RAD256_2.dat	Raw radiometric 256 channel data file
McDills_RAD256_2.des	Raw radiometric 256 channel description file
McDills_RAD256_2.dfn	Raw radiometric 256 channel definition file

APPENDIX 3.: GRIDDED DATA

Three copies of gridded data were provided on CD-ROM. All grids were in ERMapper .ERS format.

Grid names are of the form:
McDills_<gridded_parameter>_<datum>_<projection> for the final grid
where
datum = gda94
projection = mga53
gridded parameters are:
TMI = Total magnetic intensity
1VD = TMI 1st vertical derivative (2D Fourier)
AGC_1VD = 1VD with automatic gain control applied
RTP = TMI reduced to the pole
1VD_RTP = 1VD of RTP (2D Fourier)
DTM = Digital terrain model
TC = Total count
K = Potassium
U = Uranium
Th = Thorium
KThU_RGB = Potassium-Thorium-Uranium (Red-Green-Blue) composite

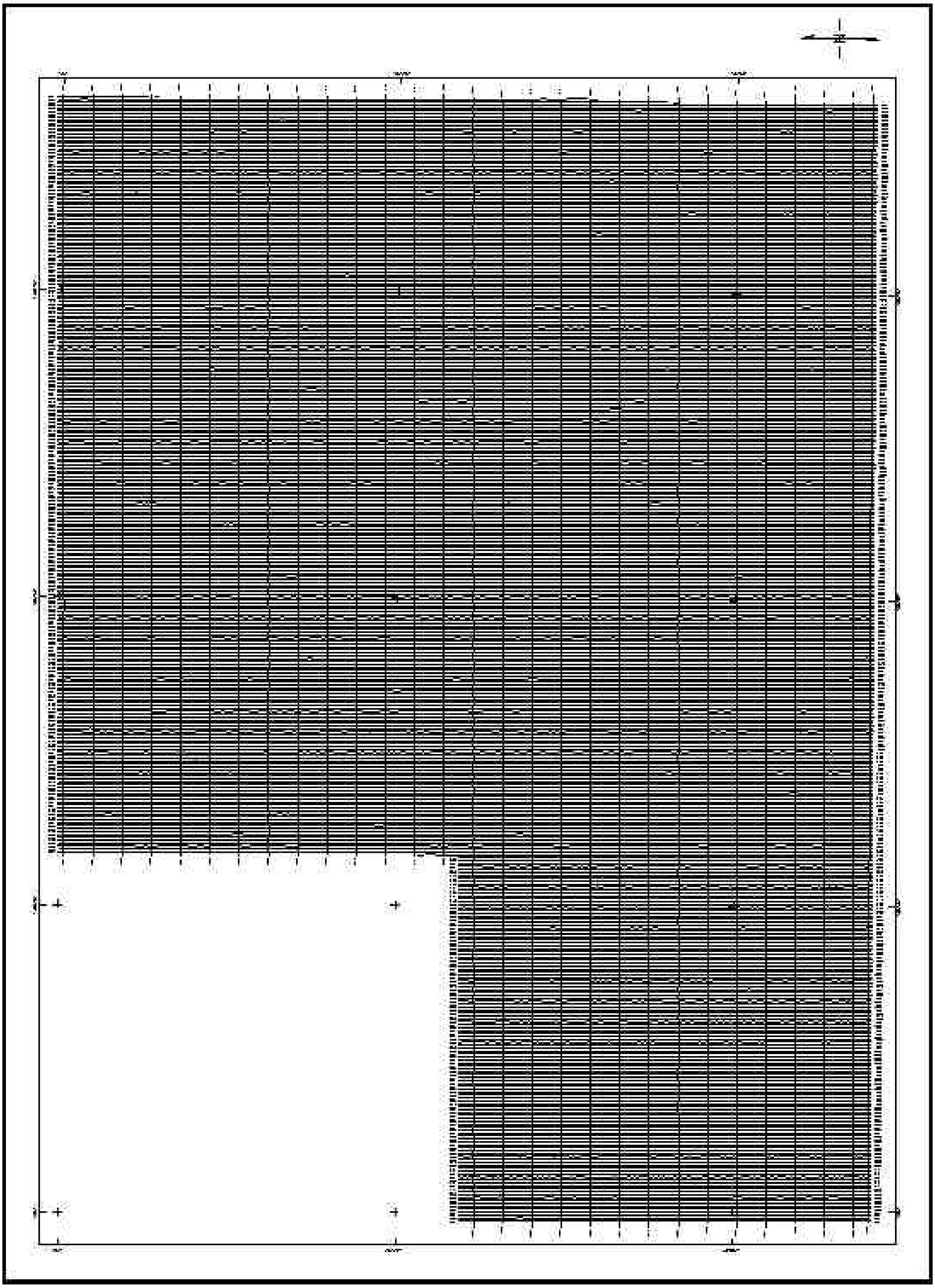
.ERS files covering each grid have been included on the accompanying CD-ROM.
Directory: Simpson_ext2/appendix_docs/digital
Format: ERMapper .ERS
Files:

File name	Description
README_gridded.txt	Gridded data README file
McDills_TMI_gda94_mga53.ers	Total magnetic intensity
McDills_1VD_gda94_mga53.ers	TMI 1st vertical derivative (2D Fourier)
McDills_AGC_1VD_gda94_mga53.ers	1VD with automatic gain control applied
McDills_RTP_gda94_mga53.ers	TMI reduced to the pole
McDills_1VD_RTP_gda94_mga53.ers	1VD of RTP (2D Fourier)
McDills_DTM_gda94_mga53.ers	Digital terrain model
McDills_TC_gda94_mga53.ers	Total count
McDills_K_gda94_mga53.ers	Potassium
McDills_U_gda94_mga53.ers	Uranium
McDills_Th_gda94_mga53.ers	Thorium
McDills_KThU_RGB_gda94_mga53.ers	Potassium-Thorium-Uranium (Red-Green-Blue) composite

APPENDIX 4.: HEIGHT CROSSOVER DIFFERENCES

A listing of all traverse and tie line crossover height differences has been included on the accompanying CD-ROM.
Directory: Simpson_ext2/appendix_docs
Format: MS-WORD 97
File: xover_summary.doc

APPENDIX 5.: FLIGHT PATH PLOT



APPENDIX 6.: QUALITY CONTROL PLOTS

Various quality control (QC) products were produced throughout the survey. These products were sent sequentially to the client at the time.
The QC products supplied were:

1. Cumulative plot of the thorium source test, background removed, Th window.
2. Cumulative plot of the background, Th window.
3. Cumulative plot of the low level test line, height corrected, Th window.
4. Radar altimeter height deviation map showing all deviations greater .then +/- 10 metres of the nominal terrain clearance.
5. Diurnal map showing every 5 minute period where the diurnal range exceeded 5 nT.
6. Flight path map showing separations greater than:
    1. 1.1 x nominal flight line spacing.
    2. 1.01 x nominal tie line spacing.
8. Aircraft velocity map
9. TMI 4th difference map with a threshold of 0.05 nT

APPENDIX 7.: SPECTROMETER CALIBRATIONS

A report on the spectrometer calibrations has been included on the accompanying CD-ROM.

Directory: Simpson_ext2/appendix_docs
Format: MS-WORD 97
File:

File name	Contains
report_rad_cals.doc	MOK cosmic and aircraft background parameters
	MOK stripping co-efficients
	MOK height attenuation and sensitivity parameters

APPENDIX 8.: FLYING SUMMARY

A weekly production summary of the flying operations has been included on the accompanying CD-ROM.

Directory: Simpson_ext2/appendix_docs
Format: MS-EXCEL 97
Files:

File name	Description
flying_summary.xls	VH-MOK weekly operations summary