Atlas Geophysics Report Number R2009016

# Victoria River Downs Gravity Survey

## Anglo Australian Resources NL

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# 1.0 Company Overview

Atlas Geophysics Pty Ltd is an Australian company based in Bayswater, Western Australia, whose mission is to provide the highest quality geophysical resource data to the mining, petroleum and exploration industry in a safe and timely manner. Through experience, innovation and excellence, the company will exceed its client's expectations and will continually develop its technologies and methodologies to maintain its reputation for being the best in the business.

The company specialises in the acquisition, processing and interpretation of potential field datasets, with particular emphasis on gravity. The directors of the company, Leon Mathews B.Sc. Hons (Geophysics), and Mark Jecks B.Sc. (Geophysics) have a combined total of over 15 years experience in the field of gravity and bring to the company, a young, vibrant and motivated approach to project management. Strategically, through development and research, the company aims to expand into other geophysical acquisition markets that encompass methods such electrical, electromagnetic, induced polarisation and reflection seismic. The company also has interests in developing an airborne platform capable of acquiring high quality magnetic and radiometric data so it can offer its clients a complete airborne and ground geophysical solution.

Atlas Geophysics Pty Ltd is committed to the values and principles of Occupational Health and Safety and Environment. To this end, the company aims to prevent injuries and occupational illness to its employees and minimise any adverse environmental impact its activities may have.

## 2.0 Project Brief

Atlas Geophysics project P2009016 required the acquisition and processing of 1,589 regional gravity stations on behalf of Anglo Australia Resources NL. The gravity survey was referred to as the "Victoria River Downs Gravity Survey".

The survey area was located on Victoria River Downs Station, approximately 250km south west of Katherine, in the Northern Territory

The company completed the acquisition of the dataset using exclusively helicopter-borne gravity methods. A single helicopter was used for the duration of the project.

The survey commenced on 12$^{th}$ August 2009. Acquisition was completed on the 21$^{st}$ August 2009, with the final data and operations report delivered shortly thereafter.

### 2.1 Location and Access

The gravity survey was broken up into two separate areas (see Figure 1). The larger area consisted of 1,329 new stations and was centred over Victoria River Downs station. The second smaller area was situated to the south of the main area (near to Mount Sanford Station) and consisted of 260 new stations.

The terrain in the survey area was quite challenging for the helicopter. The significant topography in the area combined with patchy scrub made it difficult for the helicopter crew to find suitable landing positions

Vehicle access in the area was facilitated by a network of good station tracks that ran in all directions from the station.

### 2.2 Survey Configuration

Gravity acquisition was conducted using a 1000m squared grid. One small section in the southern area was infilled to 500m.

The difficult terrain was not very suitable for the helicopter and consequently some stations were offset from their planned location during the survey.

Appendix A contains a station location plot of the acquired gravity stations.

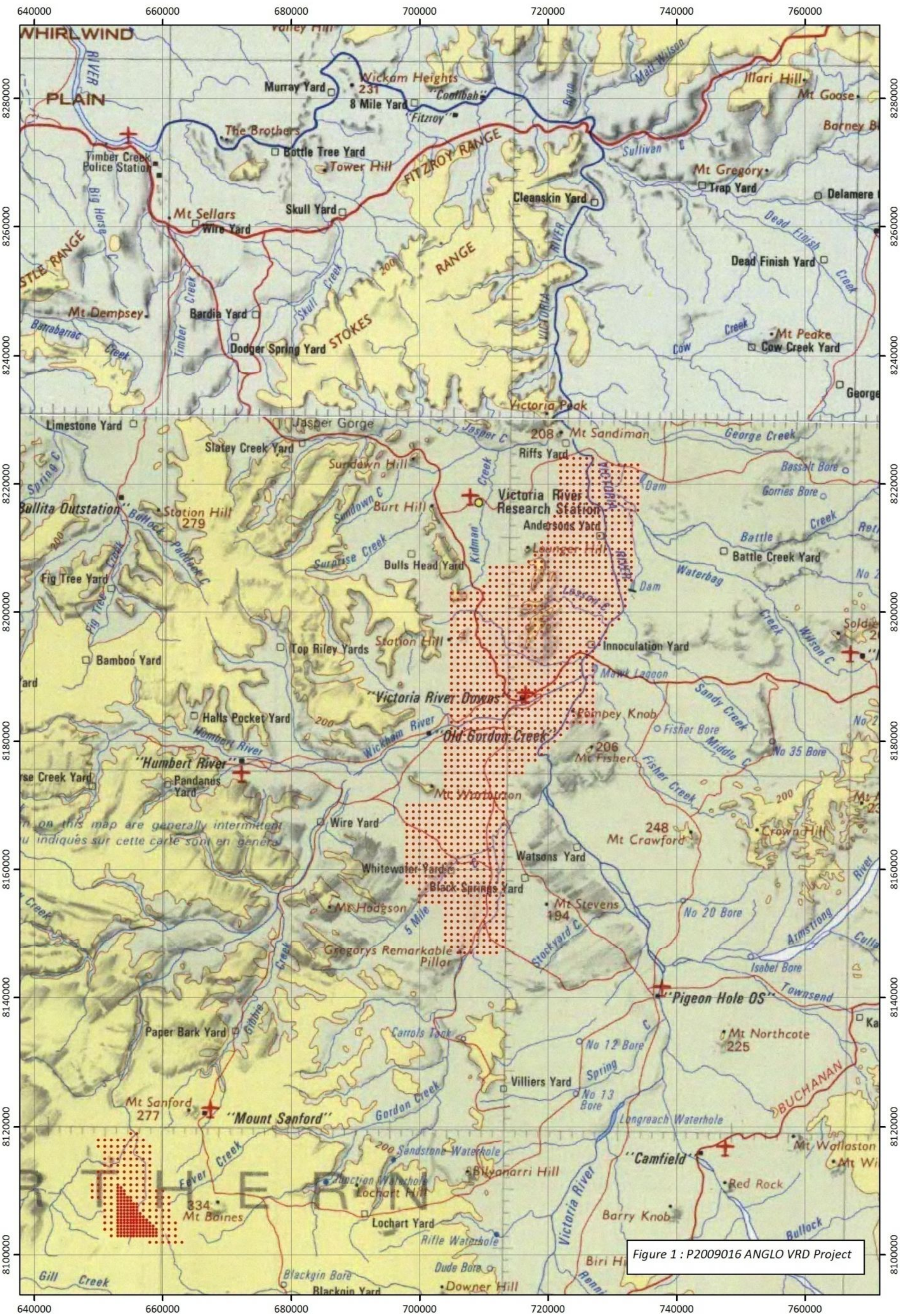


Figure 1 : P2009016 ANGLO VRD Project

## 3.0 Personnel and Subcontractors

Atlas Geophysics Pty Ltd engages only fit, motivated and safe working professionals to conduct its gravity operations. Acquisition staff members are from a range of backgrounds, usually from the geoscience or geotechnical fields, and all are trained in senior first aid, bush survival, and advanced four wheel driving. Overseeing the acquisition and processing is the company's team of geophysicists – a team with a combined total of over 15 years experience in the acquisition, processing and quality analysis of gravity data.

### 3.1 Project Supervision

Supervising the project from Perth Operations was company director, Mark Jecks. Mark has been involved in the acquisition, processing and interpretation of potential field data for over ten years and has directly overseen the acquisition and processing of over 400,000 gravity stations.

Mark was responsible for project supervision, as well as for conducting processing and quality analysis of the gravity data on a daily basis.

All final data processing, QA, reporting and delivery was also performed by Mark Jecks.

### 3.2 Acquisition/Other Personnel

Other personnel participating in field acquisition of the gravity data on this project were:

| | |
|---|---|
| Michael Ledsome | *Supervising Field Technician* |
| Harrison Irvin | *Field Technician* |

### 3.3 Subcontractors

Perth based helicopter operations company, Heliwest Pty Ltd, were chosen to supply the helicopters, pilots and engineering support. More information about this company may be found at www.heliwest.com.au

## 4.0 Equipment and Instrumentation

### 4.1 Glonass/GPS Receiver Equipment

Leading-edge dual-frequency GPS technologies from Leica Geosystems such as the GPS1200 have been utilised on the project to allow for post-processed level accuracy 3D positions. System specifications for the receivers utilised can be found in the attached brochures (Figures 2-4). Atlas Geophysics Pty Ltd is the first gravity acquisition company in Australia to utilise GNSS technology enabled receivers. The GPS1200 system is equipped with future proof GNSS technology which is capable of tracking all available GNSS signals including the currently available GLONASS. These new generation receivers, in conjunction with full GNSS tracking and processing, offer a new level of unmatched solution accuracy and reliability, especially when compared to existing conventional L1L2 GPS technologies.

The use of Glonass technology in addition to GPS provides very significant advantages:

- Increased satellite signal observations
- Markedly increased spatial distribution of visible satellites
- Reduced Horizontal and Vertical Dilution of Precision (DOP) factors
- Improved post-processed-kinematic (PPK) performance
- Decreased occupation times means faster acquisition

Two Leica GPS1200 geodetic grade receivers were utilised to conduct the survey. One receiver was used as a post-processed kinematic (PPK) rover in the helicopter, with the second receiver used as a base station for logging static data on the control station.

A GPS/Glonass antenna was mounted on the tail-boom of the helicopter, with the receiver mounted on a custom mount inside the rear cabin.

Navigation between gravity stations was facilitated by a Garmin 296 GPS receiver operating in autonomous mode.

### 4.2 Gravity Instrumentation

Complementing the company's GNSS/GPS technologies is the latest in gravity instrumentation from Scintrex Ltd, the Scintrex CG-5 (Figure 5). The CG-5 digital automated gravity meter offers all of the features of the low noise industry standard CG-3M micro-gravity unit, but is smaller and lighter. It also offers improved noise rejection. By constantly monitoring tilt sensors electronically, the CG-5 automatically compensates for errors in gravity meter tilt. Due to a low mass and the excellent elastic properties of fused quartz, tares are virtually eliminated.

The CG-5 can be transported over very rough terrain, on quad bikes, foot, vehicle or helicopter without taring or drifting. In terms of repeatability, the CG-5 outperforms all existing gravity meter technologies, with a factory quoted repeatability of better than 0.005 mGal.

Table 1 below lists the gravity meters used on the project:

| Gravity Meter Type | Gravity Meter Code | Gravity Meter Serial Number |
|---|---|---|
| Scintrex CG5 | A3 | 40269 |
| Scintrex CG5 | A5 | 40361 |

*Table 1: Gravity meters used on the project.*

## 4.3 Other Equipment

The company utilised the following additional equipment to fully support the operations:

- Two HP Laptop computers for data download and processing
- Three Iridium satellite phones for long distance communications and scheduled calls
- One Omnitrack tracking unit to track the position of the helicopter
- Personal Protective Equipment for all personnel
- Batteries, battery chargers, solar cells, UPS System
- Survey consumables
- Tools, engineering and maintenance equipment for vehicle and quadbike servicing
- First aid and survival kits
- Tyres and recovery equipment

# Leica GPS1200
## Fast, accurate, rugged and reliable

SMARTTRACK+

**GNSS technology**
GPS1200's SmartTrack+ measurement engine now utilizes two global navigation satellite systems increasing the number of tracked satellites. The new SmartTrack+ measurement engine tracks all available GNSS signals (L2C and GLONASS). More satellites means higher productivity, accuracy and reliability. SmartTrack+ acquires satellites within seconds, is ideal in urban canyons and obstructed areas where other receivers often fail. GPS1200 with SmartTrack+ is designed to support the future signals GPS L5 and Galileo.

**SmartCheck+**
Continuously checking provides the highest possible reliability. A unique, built-in integrity monitoring system checks all results immediately. SmartCheck+ now processes GPS and GLONASS measurements simultaneously for centimeter-accuracy, 20 Hz RTK at 30 km and more. Initialize within seconds and survey in obstructed areas with a GX1230/ATX1230 (GPS only) sensor or increase productivity with a GX1230 GG/ATX1230 GG (GPS and GLONASS).

**GLONASS**
For many years the GLONASS system was not reliable enough in terms of satellite availability and system performance. With recent launches and commitment from the Russian government, reliability and availability are significantly improved. Under normal conditions there are 2 to 5 additional satellites compared to a GPS only constellation – and even more satellites will be available over the next two years. Now is the time to invest in hybrid GNSS technology.

**"The GLONASS system should be created before 2008, as it was originally planned ... We have the possibility. Let us see what can be done in 2006 – 2007"**

(Russian President Vladimir Putin December 26th 2005).

Exceptionally rugged

Immune to bad weather

High contrast touch screen

With or without controller

RTK/DGPS communication

*Figure 2: Leica GPS1200 product brochure*

**GPS1200 receivers**

**GX1230 GG/ATX1230 GG**
- Universal receiver for all applications
- 14 L1 + 14 L2 (GPS)
- Support of L2C
- 12 L1 + 12 L2 (GLONASS)
- Data logging
- Full RTK and DGPS capability
- Use as rover or reference

**GX1230/ATX1230**
- Universal receiver for all applications
- 14 L1 + 14 L2 (GPS)
- Data logging
- Full RTK and DGPS capability
- Use as rover or reference

**GX1220/GX1210**
- Data logging
- 14 L1 + 14 L2 (GX1220)
- 14 L1 (GX1210)
- Option: DGPS

**Antenna technology**

All GPS1200 antennas include SmartTrack+ technology to deliver sub-millimeter phase center accuracy and high quality measurements even from low elevation GPS and GLONASS satellites. Built in ground plane suppresses multipath.

GPS1200 antenna and receiver technology deliver high precision measurements for the most demanding tasks. Antennas are light and rugged, built to survive falls from the top of a 2 m pole.

**SmartStation with SmartAntenna**

SmartStation is a TPS1200 with a ATX1230 (GG) SmartAntenna. All GPS and TPS operations are controlled from the TPS keyboard, all data are in the same database, all information is shown on the TPS screen. Touch the GPS key, let RTK determine the position to centimeter accuracy, then survey and stake out with the total station. You can do anything with SmartStation. You can also use SmartAntenna independently on a pole with a RX1250 controller.

- **Light, modular equipment**
  Use it the way that suits you best.
- **All on the pole**
  Light weight with excellent balance. Ideal for stakeout on construction sites and other demanding conditions.
- **Pole and minipack**
  Minimum weight in your hand when surveying for hours on end.
- **On a tripod or pillar**
  For geodetic control and reference stations.
- **All in the minipack**
  For 30 cm DGPS, GIS and seismic surveys.

Seamless dataflow

WORKING TOGETHER

FUNCTION integrated

LEICA SYSTEM 1200

Keyboard illumination

Use GPS1200 for everything
- For RTK, DGPS
- and static data logging
- As a rover or reference
- On a pole, tripod, pillar or in a minipack
- On construction machines, survey boats, or planes
- For every type of application

Choice of RTK pole

Leica Geo Office

CompactFlash cards

Plug-in Li-Ion batteries

TPS1200 Total Stations

*Figure 3: Leica GPS1200 product brochure*

# Leica GPS1200
## Technical specifications and system features

| GPS1200 receivers | GX1230 GG/ATX1230 GG | GX1230/ATX1230 | GX1220 | GX1210 |
|---|---|---|---|---|
| **GNSS technology** | SmartTrack+ | | | |
| **Type** | Dual frequency | Dual frequency | Dual frequency | Single frequency |
| **Channels** | 14 L1 + 14 L2 GPS 2 SBAS<br>12 L1 + 12 L2 GLONASS<br>72 Channels | | | |
| **RTK** | SmartCheck+ | SmartCheck | No | No |
| **Status indicators** | 3 LED indicators: for power | | | |

| GPS1200 receivers | GX1230 GG/GX1230/GX1220 | GX1210 | ATX1230 GG/ATX1230 |
|---|---|---|---|
| **Ports** | 1 power port, 3 serial ports | | logy port |
| **Supply voltage, Consumption** | Nominal 12 VDC<br>4.6 W receiver + controller + antenna | | Nominal 12 VDC<br>1.8 W |
| **Event input and PPS** | Optional:<br>1 PPS output port<br>2 event input ports | | |
| **Standard antenna**<br>**Built-in groundplane** | SmartTrack+ AX1202 GG<br>Built-in groundplane | SmartTrack AX1201<br>Built-in groundplane | SmartTrack+ ATX1230 GG<br>Built-in groundplane |

The following apply to all receivers except where stat

| | |
|---|---|
| **Power supply** | Two Li-Ion 3.8 Ah/7.2 V plug into receiver. One Li-Ion 1.9 Ah/7.2 V plugs into ATX1230 and RX1250. |
| **Plug-in Li-Ion batteries**<br>Same for GPS and TPS | Power receiver + controller + SmartTrack antenna for about 15 hours (for data logging).<br>Power receiver + controller + SmartTrack antenna + low power radio modem or phone for about 10 hours (for RTK/DGPS).<br>Power SmartAntenna + RX1250 controller for about 5 hours (for RTK/DGPS) |
| **External power** | External power input 10.5 V to 28 V. |
| **Weights** | Receiver 1.20 kg. Controller 0.75 kg (RX1250). SmartTra SmartAntenna 1.12 kg. Plug kg (1.9 Ah) and 0.19 kg (1. Carbon fiber pole with Sma and RX1210 controller: 1.8 All on pole: carbon fiber po RX1250 controller and plug |

| | | | |
|---|---|---|---|
| **Temperature**<br>ISO9022<br>MIL-STD-810F | Operation: Receiver | | -40° C to +65° C |
| | Antennas | | -40° C to +70° C |
| | Controllers | | -30° C to +65° C |
| | Controller RX1250c | | -30° C to +50° C |
| | Storage: Receiver | | -40° C to +80° C |
| | Antennas | | -55° C to +85° C |
| | Controllers | | -40° C to +80° C |
| | Controller RX1250c | | -40° C to +80° C |
| **Protection against water, dust and sand**<br>IP67, MIL-STD-810F | Receiver, antennas and controllers:<br>Waterproof to 1 m temporary submersion.<br>Dust tight | | |
| | | | hard surface.<br>nto |
| **Topple over on pole** | Receiver, antennas and controllers:<br>withstand fall if pole topples over. | | |
| | | | ruction |

*Figure 4: Leica GPS1200 technical specifications*

# SPECIFICATIONS

### Sensor Type
Fused Quartz using electrostatic nulling

### Reading Resolution
1 microGal

### Standard Field Repeatability
< 5 microGal

### Operating Range
8,000 mGal without resetting

### Residual Long-Term Drift (static)
Less than 0.02 mGal/day

### Range of Automatic Tilt Compensation
± 200 arc sec

### Tares
Typically less than 5 microGals for shocks up to 20 G.

### Automated Corrections
Tide, Instrument Tilt, Temperature, Noisy Sample, Seismic Noise Filter.

### Dimensions
31 cm (H) x 22 cm x 21 cm
12 in (H) x 8.5 in x 8 in

### Weight (including batteries)
8 kg, (17.5 lbs.)

### Battery Capacity
2 x 6Ah (10.8V) rechargeable Litium-Ion Smart Batteries. Full day operation in normal survey conditions with two fully charged batteries.

### Power Consumption
4.5 Watts at 25°C

### Standard Operating Temperature Range
-40°C to +45°C

### Ambient Temperature Coefficient
0.2 microGal/°C (typical)

### Pressure Coefficient
0.15 microGal/kPa (typical)

### Magnetic Field Coefficient
1 microGal/Gauss (typical)

### Memory
Flash Technology (data security)
Standard 12 MBytes

### Digital Data Output
RS-232 C and USB interface
Is optimized for Win XP™

### Analog Data Output
Strip-Chart Recorder

### Display Screen
¼ VGA 320 x 240 pixels

### Keypad
27 key alpha/numeric

### Standard System
- CG-5 Console
- Tripod base
- 2 rechargeable batteries
- Battery Charger, 110/240 V
- External Power 110/240 V
- RS-232 and USB Cables
- Carrying Bag
- Data dump and utilities software
- Operating Manual (CD)
- Transit Case

### GPS
Enables GPS station referencing from an external 12 channel smart GPS antenna being connected via the RS-232 port. Standard GPS accuracy: <15m DGPS (WAAS) < 3m. Client has the option to use other higher accuracy GPS receivers outputting NMEA data string through the serial port.

# OPTIONS

### High Temperature Option
For use in climates that may exceed the normal operating temperate of 45°C. Allows operating temperatures of up to 55°C. This option is intended to be used in climates above freezing and needs to be ordered at the time of purchase.

### Battery Belt
Suggested for cold weather operation.

# COMPLETE GRAVITY SOLUTIONS

### Special Applications
Please contact LRS Scintrex or your local representative.

### Training Programs
LRS Scintrex can provide training programs at our office in Canada or at your location.

### Application Software
LRS Scintrex can provide software packages to support your data processing, interpretation and mapping needs.

An ISO 9001:2000 registered company

* All specifications are subject to change without notice.


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*Figure 5: Scintrex CG-5 specifications*

# 5.0 Vehicle and Helicopter Transportation

## 5.1 Helicopters

A single Robinson R44 Raven II helicopter (call sign VH-TVL) was used to traverse between the gravity stations during acquisition (Photo 1). The machine performed well in the challenging conditions. The helicopter was serviced in accordance with CASA specifications, with 100 hourly services carried out at Alice Springs Airport. A second Robinson R44 Raven II helicopter (call sign VH-TVS) was utilised to complete the last few days of acquisition due to mechanical problems with VHT-VL.

The helicopters were equipped with an EPIRB device and comprehensive first aid and survival kits. Communications were via VHF radio and Iridium satellite phone.

Aviation fuel and oils were supplied by VRD Station.

## 5.2 Support Vehicles

Facilitating refuelling operations was a single 4WD Toyota Landcruiser utility. The vehicle was fitted with the following equipment:

- Iridium satellite phone
- Magellan FX324 navigation grade GPS receiver
- Spare navigation grade GPS receiver with batteries
- First aid and survival kit
- Two spare tyres
- Recovery equipment for tyre repair
- Recovery equipment including winch for bogging, stranding.
- Comprehensive tool-kit to effect in field repairs
- 10L of drinking water
- Flashing rotating beacon

All vehicles used on this project were supplied, serviced and maintained by Atlas Geophysics. The field crew carried out daily pre-start checks on all vehicles and these have been documented in Atlas Geophysics pre-start log books.


*Photo 1: Helicopter VH-TVL*

## 6.0 Camping / Accommodation

The survey crew were accommodated and messed at the Helimuster base located at Victoria River Downs for the duration of the survey.  The Helimuster personnel were very helpful and provided excellent services for all of the projects operational needs.

# 7.0 Communications, Internet and Scheduled Calls

The primary method of communication for the field crews was via Iridium satellite phones. The helicopter crews made scheduled calls to the field operations base at hourly intervals. In addition to scheduled calls, the position of the helicopter was reported to the operations base at 10 minute intervals using Omnitrack technology.

Internet connections for client contact and data server access were established using a BGAN satellite terminal.

## 8.0 Survey Methodology

All gravity data were acquired using Atlas Geophysics Pty Ltd helicopter-borne techniques. These techniques, which involve concurrent GPS and gravity acquisition, allow for rapid acquisition of very high quality data.

### 8.1 Gravity and GPS Control Establishment

A single primary GPS and gravity control station was established at Victoria River Downs Aerodrome (Table 2). At the station, a permanent monument was erected to mark and witness the station. The monument consisted of a 40cm star picket driven into the ground with about 10cm protruding alongside a small square concrete slab also set in concrete. The star picket marked the position of the GPS control station and the concrete slab the position of the gravity control station. A steel star picket of 1.25m length was placed within 0.5m of each station and carried an Atlas Geophysics Pty Ltd witness plaque numbered with a unique station number (Figure 6).

| Control Station ID | Lat / Long / Ht (GDA94, GRS80) | Observed Gravity (AAGD07 mGal) |
|---|---|---|
| GRVGPS0071<br>*VRD Aerodrome* | -16°24'06.2421"<br>131°00'45.4771"<br>125.108 | 978408.491 |

*Table2: Gravity and GPS control stations used to control the survey*

The details of all control stations have been recorded on Atlas Geophysics Pty Ltd control station summary sheets. The sheets include the geodetic coordinates, observed gravity value, station description, locality sketch, locality map and a digital photo of the station. The sheets are contained in Appendix B.


*Figure 6: Atlas Geophysics Pty Ltd survey witness plaque*

### 8.1.1 GPS Control

Primary GPS control was established at all control stations within the survey area and allowed all position and height information obtained from the gravity survey to be tied to the Geocentric Datum of Australia (GDA94) and Australian Height Datum (AHD).

Coordinates for the control stations were established using the 5 second static GPS data logged at the station whilst the gravity survey was underway. The static data has been submitted to Geoscience Australia's AUSPOS processing system to produce first-order geodetic control station coordinates accurate to better than 10mm for the x, y and z observables. Multiple days of static GPS data using different GPS antenna heights have been submitted to ensure accuracy and reliability of the solution.

Initial surveying was conducted using adopted control station coordinates since the AUSPOS system requires approximately two weeks before a Final Ephemeris Solution can be delivered. The adopted coordinates were derived from an autonomous GPS measurement at the control station giving an accuracy of better than 0.5m for x, y coordinates and better than 15m for the z coordinate. Once the final ephemeris solution for control station coordinates was delivered by AUSPOS, all control and field GPS measurements had the necessary DC shift applied to give accurate, absolute positions for east, north and elevation. The details of the control process have been summarised in a table included in Appendix C.

### 8.1.2 Gravity Control

Primary gravity control was established at the same location as the primary GPS control station. Once tied to the Australian Fundamental Gravity Network (AFGN), the gravity control station allowed all field gravity observations to be tied to the ISOGAL84 and AAGD07 gravity datum.

An accurate observed or absolute gravity value for the control station was established via "ABABA" ties with the project gravity meter to a nearby AFGN station located at Daly Waters. Table 3 summarises the control ties conducted. Expected accuracy of the tie survey would be better than 0.1 gu (or 0.01 mGal).

| Control Station ID | AFGN station tied to | Date of tie |
|---|---|---|
| GRVGPS0070<br>*VRD Aerodrome* | Daly Waters 1964910133 | 18/08/09 |

*Table 3: Gravity and GPS control stations used to control the survey*

## 8.2 GPS Data Acquisition, Processing and Quality Analysis

GPS-Glonass data were collected in static mode at each of the control stations and in kinematic mode on the helicopter using geodetic grade Leica GPS1200 receivers. Rigorous post-processing of the recorded kinematic data allowed for excellent GPS-Glonass ambiguity resolution and 3-D solution coordinate qualities better than 3cm for each of the gravity station locations. Atlas Geophysics QA procedures have ensured the final GPS-Glonass data have met and exceeded industry standard specifications.

### 8.2.1 GPS-Glonass Acquisition

Each gravity station location (GSL) was positioned using navigation grade Garmin receivers fitted to the cockpit of the helicopter. Accuracy of the positioning system was better than 5m and where possible, the helicopter crew landed as close to the programmed station location as possible. There were no stations omitted due to terrain or vegetation considerations.

For the kinematic helicopter operations, the GPS-Glonass sensor was mounted on the tail boom of the aircraft and phase data logged by the receiver inside the cabin. Data were logged at five second epochs onto Compact Flashcard (CF) for later downloading and processing. Static data were also concurrently logged at the primary GPS control station to allow for later kinematic processing.

### 8.2.2 GPS-Glonass Processing

The acquired raw GPS-Glonass data were processed nightly using Novatel Waypoint Grafnav v8.1 post-processing software (Figure 7). GrafNav is a fully-featured kinematic and static GPS/Glonass post-processing package that uses Waypoint's robust GPS/Glonass processing carrier phase kinematic (CPK) filter engine. The software is capable of processing raw kinematic GPS/Glonass data from most GPS/GNSS receivers and allows the user to process the roving data from as many as eight separate control stations to achieve accuracies at the centimetre level. The software can automatically switch from static to kinematic processing and has a fixed static solution for static initialisation of short or medium baselines that are below 30km. A float static solution is available for baselines longer than this. Kinematic Ambiguity Resolution (KAR) allows the session to start in kinematic mode and can help fix otherwise unrecoverable cycle slips. Ionospheric processing and modelling is also included with the software and can help improve accuracy, especially over long baselines. Advantages of the Waypoint processing engine over other packages include:

*Fast Processing* – The Grafnav engine is one of the fastest on the market. For a single base station, a 2.40 Mhz PIII CPU can expect to process GPS data at 670 epochs/second. This means that a 4-hour 2 Hz data set will process one direction in 22 seconds. For two bases, processing takes 250 epochs/second or about 1 minute for the same 4-hour data set. For 4 bases, these times are 50 epochs/second or about 5 minutes.

*Reliable OTF Processing* – Waypoint's on-the-fly KAR algorithm has had years of development and testing. Various implementations and numerous options are available to control this powerful feature.

*Multi-Base (MB) processing* – With Version 7.80, GrafNav now supports true multiple control station processing where all of the baselines are incorporated into one sophisticated Kalman filter. This can spatially decorrelate some of the error sources while also allowing integer ambiguity determination using the closest base station. Satellite drop-outs at one base will also be compensated by the others. The two biggest advantages are improved overall accuracies and much less operator effort required to process and QC such data.

*Accurate Static Processing* – Three modes of static processing are implemented in the main processing kernel.

*Dual Frequency Support* – Full dual frequency GPS processing comes with the software. For ambiguity resolution, this entails wide/narrow lane solutions for KAR, fixed static and quick static. The GrafNav kernel implements two ionospheric processing modes including the iono-free and relative models. The relative model is especially useful for airborne applications where initialization is near the base station, and this method is much less susceptible to L2 phase cycle slips.

*Forward and Reverse* – Processing can be performed in both the forward and reverse directions. GrafNav also has the ability to combine these two solutions to obtain a globally optimum one.

*GPS + GLONASS* – The GrafNav kernel has the ability to also process GPS+GLONASS data. This is especially advantageous for applications in forested areas, where the additional satellite coverage can improve accuracies.

*Velocity Determination* – Since the GrafNav kernel includes the L1 doppler measurement in its Kalman filter, velocity determination is very accurate. In addition to this, a considerable amount of code has been added specifically for the detection and removal of Doppler errors.

*High Dynamics* – The GrafNav kernel can handle extremely high dynamics from missiles, rockets, dropped ordinances, and fast flying aircraft.

*Long Baseline* - Because precise ephemeris and dual frequency processing is supported, long baselines accuracies can be as good as 0.1 PPM.

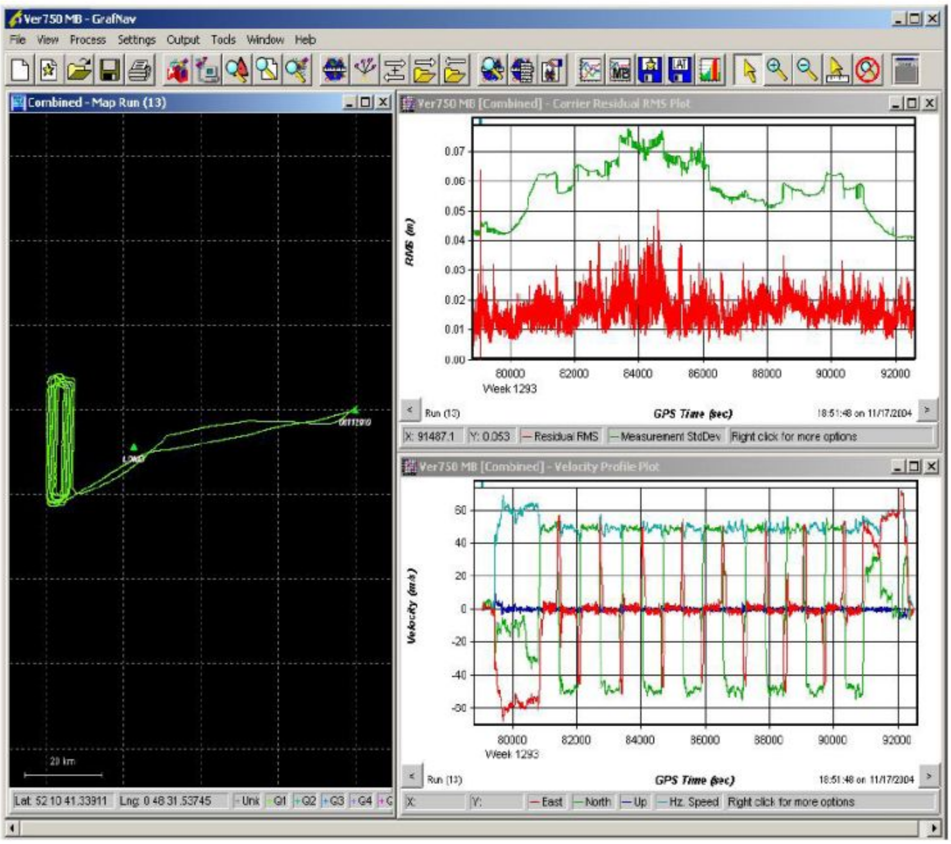


*Figure 7: Waypoint Grafnav Processing Software*

Once each epoch was processed to give a solution for the WGS84 position and elevation at ground level (i.e. corrected for sensor height), transformations between GPS-Glonass derived WGS84GDA94 coordinates to Map Grid of Australia (MGA) coordinates were conducted within Waypoint. For most practical applications, where a horizontal accuracy of only a metre or greater is required, GDA94 coordinates can be considered the same as WGS84. MGA94 coordinates were obtained by projecting the GPS-derived WGS84 coordinates using a Universal Transverse Mercator (UTM) projection with zone 52S. For more information about WGS84, GDA94 and MGA coordinates, the reader is asked to visit the Geoscience Australia website: http://www.ga.gov.au/geodesy/datums/gda.jsp.

Elevations above the Australian Height Datum (AHD) were modelled using Waypoint 8.1 software and the latest geoid model for Australia, AUSGEOID98. Information about the geoid and the modelling process used to extract separations (N values) can be found at http://www.ga.gov.au/geodesy/ausgeoid/. To obtain AHD elevation, the modelled N value is subtracted from the GPS derived WGS84/GRS80 ellipsoidal height (Figure 8).

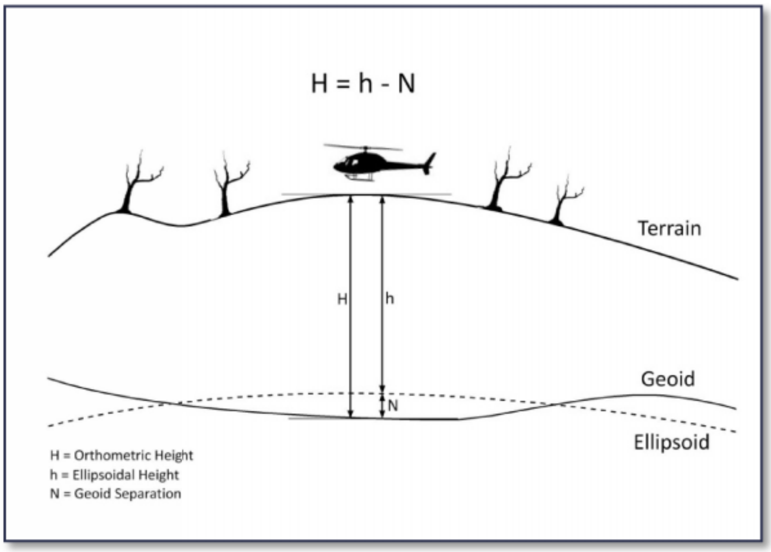



*Figure 8: Geoid-Ellipsoid Separation*

### 8.2.3 GPS/Glonass Quality Analysis

Rigorous quality analysis procedures were applied to the acquired GPS-Glonass data on a daily basis using Waypoint Grafnav's built in QA tools. Some of the tools used on this project include:

*Combined Separation Plot*: This plot shows the difference between the forward and reverse solutions (Figure 9). A perfect solution would have a separation of zero as this indicated the carrier phase ambiguities have been determined to be exactly the same value in both directions. A separation of better than 0.1m on a helicopter survey would indicate that the data is of high quality.

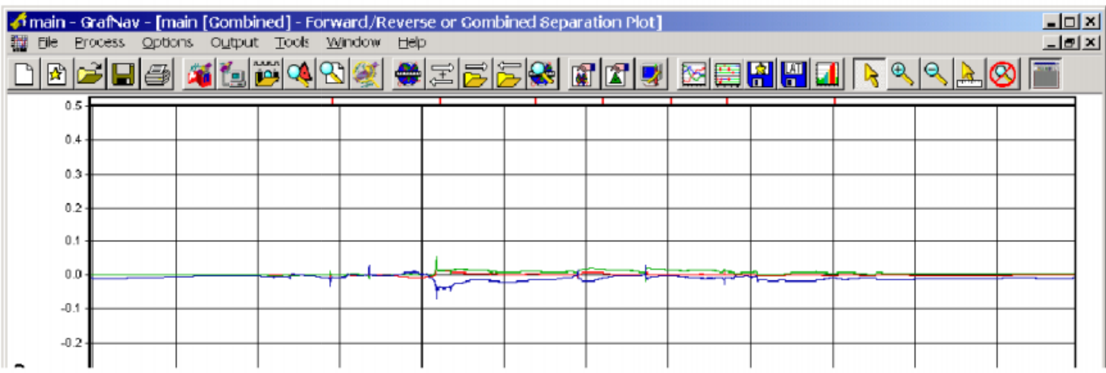



*Figure 9: Combined Separation Plot*

*Float of Fixed Ambiguity Status Plot*: This plot shows if the final solution is float or fixed (Figure 10). Fixed integer ambiguities generally have better accuracies (usually < 10cm accuracy). Ideally the plot should show fixed as this indicated an integer ambiguity fix on both forward and reverse directions.

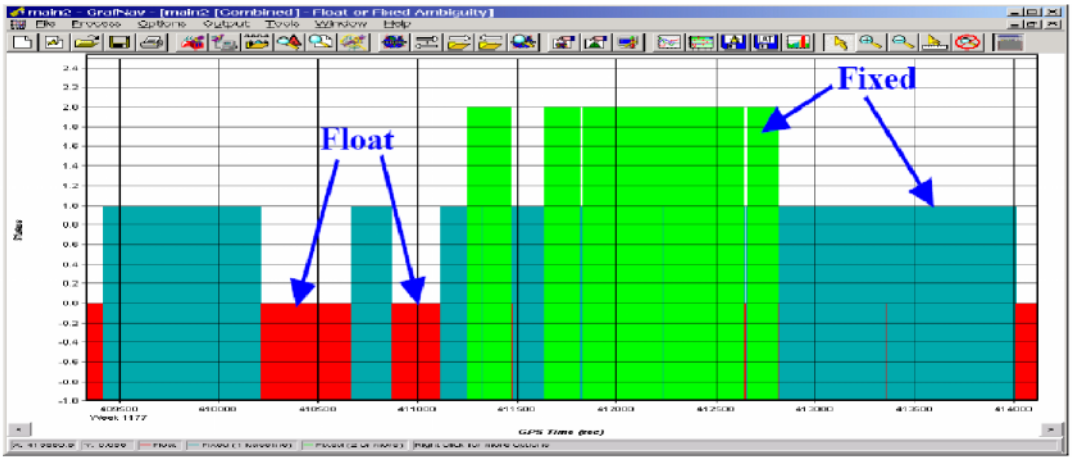



*Figure 10: Float of Fixed Ambiguity Status Plot*

*Quality Factor Plot*: This plot shows the quality of the final solution (Figure 11). There are five different quality factors plotted and these factors are also output in the Atlas Geophysics Pty Ltd GPS data file.

Quality 1 – Fixed Integer (Green)
Quality 2 – Stable Float (Aqua)
Quality 3 – Converging Float (Blue)
Quality 4 – DGPS or worse (Red)
Quality 5 – Single Point (Yellow)

Increasing quality factors indicate a worse solution. This is not a perfect indication, but it can be useful to isolate problems.

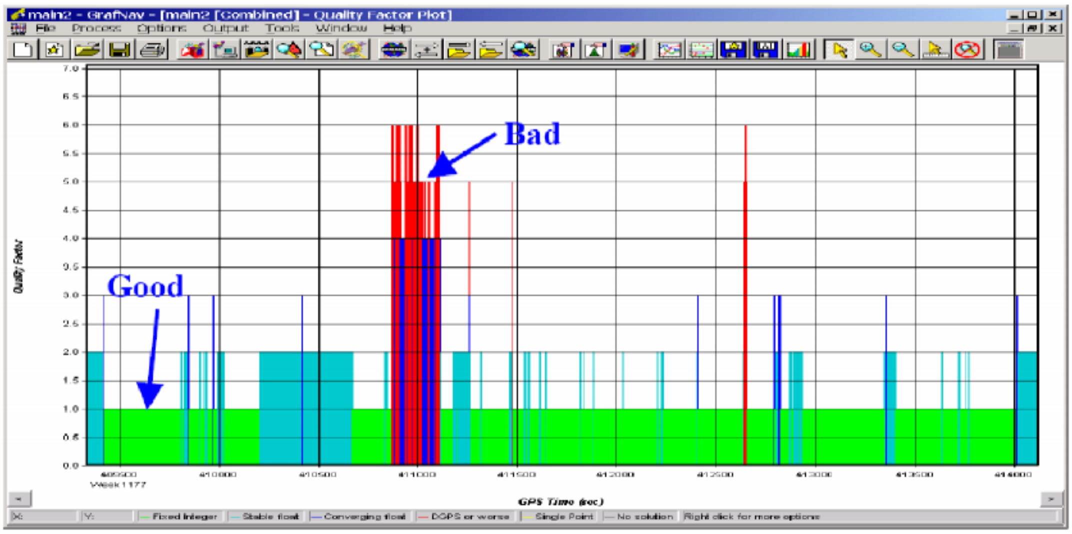



*Figure 11: Quality factor plot*

Complementing Waypoint GrafNav QA tools is the company's own in-house GPS quality analysis software. A module built into AGRIS (Atlas Geophysics Reduction and Interpretation Software) allows the user to import the Waypoint output files and examine quality factors such as station repeatability, coordinate velocity, dilution of precision, coordinate quality factor and standard error for each gravity station location. The procedure is carried out before merging the positional data with gravity data for final reduction to Bouguer Gravity. Comprehensive statics, repeatability analysis and histogram plotting are also performed.

QA procedures were applied to the GPS-Glonass data on a daily basis and any gravity stations not conforming to contract specifications were repeated by the company at no cost to the client.

## 8.3 Gravity Data Acquisition, Processing and Quality Analysis

Gravity data were gained using the company's rapid acquisition, high accuracy helicopter-borne techniques. The company's own in-house reduction and QA software was used to reduce the data on a daily basis to ensure quality and integrity. Final delivered data met and exceeded contract specifications.

### 8.3.1 Calibration of the Gravity Meters

The gravity meters used on the project were calibrated pre and post survey on Mundaring Weir – Mt Gungin calibration range (1980900317-1973910217) in Mundaring, Western Australia. The calibration process has validated the gravity meter's scale factor to ensure reduction of the survey data produces correct Observed Gravities from measured dial reading values.

Weekly tilt-tests and cycles were conducted to ensure the meter's drift and tilt correction factors were valid. Gravity meter drift rates were monitored on a day to day basis using AGRIS software.

### 8.3.2 Acquisition of the Gravity Data

Gravity data were acquired concurrently with GPS-Glonass data using Scintrex CG5 gravity meters (Photo 2). Data were acquired in two separate shifts of five to six hours duration, with each shift consisting of a single loop controlled by observations at the gravity control stations. Each loop contained a minimum of two repeated readings so that an interlocking network of closed loops was formed. A total of 5% repeats were acquired for quality control purposes. Repeat readings were evenly distributed on a time-basis throughout each of the gravity loops.

*Photo 2: Gravity observation in a creek bed*

The gravity acquisition crew consisted of a single gravity operator and pilot. The pilot was responsible for navigating to each station, and once at the station, the operator disembarked from the helicopter and acquired the gravity data. The observation point was usually situated in front of the aircraft, in the pilot's view. Under no circumstances were readings taken outside of the pilot's view as this can jeopardise the safety of the operator. As the helicopter always landed on flat ground, the error due to the gravity observation not being coincident with the GPS-Glonass observation (which is at the tail-boom) is minimal. A small latitude based error of less than 0.005 mGal would apply, but this is not seen to be appreciable on a regional gravity survey, so is not corrected for.

At each station, the gravity operator took a minimum of two gravity readings of 20 second duration so that any seismic or wind noise could be detected. Control station readings were set to 60 second duration. Before taking the reading, the operator ensured that the instrument tilt-reading was restricted to less than 5 arc-seconds and after the reading, not higher than 20 arc-seconds. In some instances on wet clay pans and salt lakes, it was impossible to keep tilt-readings under 50 arc seconds due to the soft nature of the ground. This was not found to adversely affect the quality of the data since the gravity meter's tilt correction compensated well for it. Tilt-testing prior to project commencement showed that the gravity meters performed well even at extreme tilts (better than 0.05 gu at +150/-150 arc-seconds).

If two separate readings did not agree to better than 0.03 mGal (0.01 mGal for control station readings), then the operator continued taking readings until the tolerance between consecutive readings was achieved. At the conclusion of the gravity reading, the final data display on the gravity meter was analysed to ensure the instrument was performing to specification and that the station observation provided data conforming to the project specifications. The operator also checked that the temperature, standard deviation and rejection values were within required tolerance before recording the reading. At each station, the operator recorded the gravity data digitally in the gravity meter as well as in an Atlas Geophysics Pty Ltd field book so that instrument drift and reading repeatability could be analysed easily whilst in the field. Data recorded at each GSL was assigned a unique station code and station number.

Repeat stations were marked with a biodegradable flagging tape for subsequent reoccupation. When reoccupying stations, the pilot positioned the helicopter as close to the original landing spot as possible (usually better than 10m). A small percentage of the repeat stations were positioned greater than 10m from the original location due to soft ground and/or windy conditions, but always on flat ground at the same level as the original observation. All repeat gravity observations were taken in exactly the same location, even if the helicopter landed slightly offset from the original position.

### 8.3.3 Processing of the Gravity Data

The acquired gravity data were processed using the company's in-house gravity pre-processing and reduction software, AGRIS. This software allows for full data pre-processing, reduction to Geoidal and Spherical Cap Bouguer Anomaly, repeatability and statistical analysis, as well as full quality analysis of the output dataset.

The software is capable of downloading Scintrex CG3/CG5 and Lacoste Romberg gravity data. Once downloaded, the gravity data is analysed for consistency and preliminary QA is performed on the data to check that observations meet specification for standard deviation, reading rejection, temperature and tilt values. Once the data is verified, the software averages the multiple readings and performs a merge with the GPS data (which it has also previously verified) and performs a linear drift correction and earth tide correction. Calculation of Free Air and Bouguer Anomalies is then performed using formulae employed by Geoscience Australia.

The following corrections were applied to the dataset to produce Spherical Cap Bouguer Anomalies on the GRS80 ellipsoid. For legacy reasons, Geoidal Bouguer Anomalies on the Australian Heigh Datum (AHD) have also been calculated. The formulae below produce data in $\mu ms^{-2}$ or gravity units. To convert to mGal, divide by a factor of 10.

***Instrument scale factor***: This correction is used to correct a gravity reading (in dial units) to a relative gravity unit value based on the meter calibration.

$$r_c = 10 \cdot (r \cdot S(r))$$

where,

$r_c$ corrected reading in gravit units
$r$ gravity meter reading in dial units
$S(r)$ scale factor (dial units/milliGal)

***Earth Tide Correction:*** The earth is subject to variations in gravity due to the gravitational attraction of the Sun and the Moon. These background variations can be corrected for using a predictive formula which utilises the gravity observation position and time of observation. The Scintrex CG5 gravity meter automatically calculates ETC but uses only an approximate position for the gravity observation so is not entirely accurate. For this reason, the Scintrex ETC is subtracted from the reading and a new correction calculated within AGRIS software. The full formula is listed in Appendix G.

$$r_t = r_c + g_{tide}$$

where,

$r_t$ tide corrected reading in gravity units
$r_c$ scale factor corrected reading in gravity units
$g_{tide}$ Earth Tide Correction (ETC) in gravity units

***Instrument Drift Correction:*** Since all gravity meters are mechanical they are all prone to instrument drift. Drift can be caused by mechanical stresses and strains in the spring mechanism as the meter is moved, knocked, reset, subjected to temperature extremes, subjected to vibration, unclamped etc. The most common cause of instrument drift is due to extension of the sensor spring with changes in temperature (obeying Hooke’s law). To calculate and correct for daily instrument drift, the difference between the gravity control station readings (closure error) is used to assume the drift and a linear correction is applied.

$$ID = \frac{r_{cs2} - r_{cs1}}{t_{cs2} - t_{cs1}}$$

where,

$ID$ Instrument Drift in gu/hour
$r_{cs2}$ control station 2nd reading in gravity units
$r_{cs1}$ control station 1st reading in gravity units
$t_{cs2}$ control station 2 time
$t_{cs1}$ control station 1 time

***Observed Gravity:*** The preceding corrections are applied to the raw gravity reading to calculate the earth’s absolute gravitational attraction at each gravity station. The corrections produced Observed Gravities on the AAGD07 and ISOGAL84 datums.

$$G_o = g_{cs1} + (r_t - r_{cs1}) - (t - t_{cs1}) \cdot ID$$

where,

$G_o$ Observed Gravity in gravity units (ISOGAL84 or AAGD07)
$g_{cs1}$ control station 1 known Observed Gravity in gravity units
$r_t$ tide corrected reading in gravity units
$r_{cs1}$ control station 1 reading in gravity units
$t$ reading time
$t_{cs1}$ control station 1 time
$ID$ instrument drift in gravity units/hour

***Theoretical Gravity 1980:*** The theoretical (or normal) gravity value at each gravity station is calculated based on the assumption that the Earth is a homogeneous ellipsoid. The closed form of the 1980 International Gravity Formula is used to approximate the theoretical gravity at each station location and essentially produce a latitude correction. Gravity values vary with latitude as the earth is not a perfect sphere and the polar radius is much smaller than the equatorial radius. The effect of centrifugal acceleration is also different at the poles versus the equator.

$$G_{t80} = 9780326.7715((1 + 0.001931851353(sin^2 l) / (SQRT(1 - 0.0066943800229(sin^2 l)))$$

where,

$G_{t80}$ Theoretical Gravity 1980 in gravity units
$l$ GDA94 latitude at the gravity station in decimal degrees

***Theoretical Gravity 1967:*** The theoretical (or normal) gravity value at each gravity station is calculated based on the assumption that the Earth is a homogeneous ellipsoid. The 1967 variant of the International Gravity Formula is used to approximate the theoretical gravity at each station location and essentially produce a latitude correction. Gravity values vary with latitude as the earth is not a perfect sphere and the polar radius is much smaller than the equatorial radius. The effect of centrifugal acceleration is also different at the poles versus the equator.

$$G_{t67} = (9780318.456 \cdot \left(1 + 0.005278895 \cdot sin^2(l) - 0.000023462 \cdot sin^4(l)\right))$$

where,

$G_{t67}$ Theoretical Gravity 1967 in gravity units
$l$ GDA94 latitude at the gravity station in decimal degrees

***Atmospheric Correction:*** The gravity effect of the atmosphere above the ellipsoid can be calculated with an atmospheric model and is subtracted from the theoretical gravity.

$$AC = 8.74 - 0.00099 \cdot h + 0.0000000356 \cdot h^2$$

where,

$AC$ Atmospheric Correction in gravity units
$h$ elevation above the GRS80 ellipsoid in metres

***Ellipsoidal Free Air Correction:*** Since the gravity field varies inversely with the square of distance, it is necessary to correct for elevation changes from the reference ellipsoid

(GRS80). Gravitational attraction decreases as the elevation above the reference ellipsoid increases.

$$EFAC = -(3.08768 - 0.00440\, sin^2 l) \cdot h + 7.2125 \cdot 10^{-7} \cdot h^2$$

where,

$EFAC$ Ellipsoidal Free Air Correction in gravity units
$l$ GDA94 latitude at the gravity station in decimal degrees
$h$ elevation above the GRS80 ellipsoid in metres

***Geoidal Free Air Correction:*** Since the gravity field varies inversely with the square of distance, it is necessary to correct for elevation changes from the reference geoid (AHD). Gravitational attraction decreases as the elevation above the reference geoid increases.

$$GFAC = \left(3.08768 - 0.0440 sin^2(l)\right) \cdot h - 0.000001442 \cdot h^2$$

where,

$GFAC$ Free Air Correction in gravity units
$l$ GDA94 latitude at the gravity station in decimal degrees
$h$ elevation above the reference geoid (AHD) in metres

***Spherical Cap Bouguer Correction:*** If a gravity observation is made above the reference ellipsoid, the effect of rock material between the observation and the ellipsoid must be taken into account. The mass of rock makes a positive contribution to the gravity value. The correction is calculated using the closed form equation for the gravity effect of a spherical cap of radius 166.7km, based on a spherical Earth with a mean radius of 6,371.0087714km, height relative the ellipsoid and rock densities of 2.67, 2.40 and 2.20 $tm^{-3}$ (gm/cc).

$$SCBC = 2\pi G\rho((1 + \mu) \cdot h - \lambda R)$$

where,

$SCBC$ Spherical Cap Bouguer Correction in gravity units
$G$ gravitational constant = $6.67428 \cdot 10^{-11} m^3 kg^{-1} s^{-2}$
ρ rock density (2.67,2.40 and 2.20 $tm^{-3}$)
$h$ elevation above the GRS80 ellipsoid in metres
R $(R_o + h)$ the radius of the earth at the station
$R_o$ mean radius of the earth = 6,371.0087714 km (on the GRS80 ellipsoid)
$\mu$ & $\lambda$ are dimensionless coefficients defined by:

$$\mu = ((1/3) \cdot \eta^2 - \eta)$$

where,

η $h/R$

$$\lambda = (1/3)\{(d + f\delta + \delta^2)[(f - \delta)^2 + k]^{\frac{1}{2}} + p + m \cdot ln(n/(f - \delta + [(f - \delta)^2 + k]^{\frac{1}{2}})\}$$

where,

$d$ $3 \cdot cos^2\alpha - 2$
$f$ $cos\alpha$

| | |
|---|---|
| $k$ | $sin^2\alpha$ |
| $p$ | $-6 \cdot cos^2\alpha \cdot \sin(\alpha/2) + 4 \cdot sin^3(\alpha/2)$ |
| δ | $(R_o/R)$ |
| $m$ | $-3 \cdot k \cdot f$ |
| $n$ | $2 \cdot [sin\,(\alpha/2) - sin^2(\alpha/2)]$ |
| $\alpha$ | $S/R_o$ with $S$ = Bullard B Surface radius = 166.735 km |

***Geoidal Bouguer Correction:*** If a gravity observation is made above the reference geoid, the effect of rock material between the observation and the ellipsoid must be taken into account. The mass of rock makes a positive contribution to the gravity value. The slab of rock makes a positive contribution to the gravity value. Rock densities of 2.67, 2.40 and 2.20 t/m$^{-3}$ (gm/cc) were used in the correction.

$$GBC = 0.4191 \cdot \rho \cdot h$$

where,

| | |
|---|---|
| $GBC$ | Geoidal Bouguer Correction in gravity units |
| ρ | rock density (2.67,2.40 and 2.20 tm$^{-3}$) |
| $h$ | elevation above the reference geoid (AHD) in m |

***Terrain Correction:*** The terrain correction accounts for variations in gravity values caused by variations in topography near the observation point. The correction accounts for the attraction of material above the assumed Bouguer slab and for the over-correction made by the Bouguer correction when in valleys. The terrain correction is positive regardless of whether the local topography consists of a mountain or a valley. Terrain corrections were not applied on this project as the survey area was flat and devoid of any appreciable topography.

***Ellipsoidal Free Air Anomaly:*** The Ellipsoidal Free Air Anomaly is the difference between the observed gravity and theoretical gravity that has been computed for latitude and corrected for the elevation of the gravity station above or below the reference ellipsoid.

$$EFAA = G_{oAAGD07} - (G_{t80} - AC) - EFAC$$

where,

| | |
|---|---|
| $EFAA$ | Ellipsoidal Free Air Anomaly in gravity units |
| $G_o$ | Observed Gravity on the AAGD07 datum in gravity units |
| $G_{t80}$ | Theoretical Gravity 1980 in gravity units |
| $AC$ | Atmospheric Correction in gravity units |
| $EFAC$ | Ellipsoidal Free Air Correction in gravity units |

***Geoidal Free Air Anomaly:*** The Geoidal Free Air Anomaly is the difference between the observed gravity and theoretical gravity that has been computed for latitude and corrected for the elevation of the gravity station above or below the reference geoid.

$$GFAA = G_{oISOGAL84} - G_{t67} + GFAC$$

where,

| | |
|---|---|
| $GFAA$ | Free Air Anomaly in gravity units |

$G_o$ Observed Gravity on the ISOGAL84 datum in gravity units
$G_{t67}$ Theoretical Gravity 1967 in gravity units
$GFAC$ Geoidal Free Air Correction in gravity units

***Spherical Cap Bouguer Anomaly:*** The Spherical Cap Bouguer Anomaly is computed from the Ellipsoidal Free Air Anomaly above by removing the attraction of the spherical cap calculated by the Spherical Cap Bouguer Correction.

$$SCBA = EFAA - SCBC$$

where,
$SCBA$ Spherical Cap Bouguer Anomaly in gravity units
$EFAA$ Ellipsoidal Free Air Anomaly in gravity units
$SCBC$ Bouguer Correction in gravity units

***Geoidal Bouguer Anomaly:*** The Geoidal Bouguer Anomaly is computed from the Geoidal Free Air Anomaly above by removing the attraction of the slab calculated by the Geoidal Bouguer Correction.

$$GBA = GFAA - GBC$$

where,
$GBA$ Geoidal Bouguer Anomaly in gravity units
$GFAA$ Geoidal Free Air Anomaly in gravity units
$GBC$ Geoidal Bouguer Correction in gravity units

***Complete Spherical Cap Bouguer Anomaly:*** This is obtained by adding the terrain correction to the Spherical Cap Bouguer Anomaly. The Complete Spherical Cap Bouguer Anomaly is the most interpretable value derived from a gravity survey as changes in the anomaly can be directly attributed to lateral density contrasts within the geology below the observation point.

$$CSCBA = SCBA + TC$$

where,
$CSCBA$ Complete Spherical Bouguer Anomaly in gravity units
$SCBA$ Spherical Cap Bouguer Anomaly in gravity units
$TC$ Terrain Correction in gravity units

***Complete Geoidal Bouguer Anomaly:*** This is obtained by adding the terrain correction to the Geoidal Bouguer Anomaly. The Complete Geoidal Bouguer Anomaly is the most interpretable value derived from a gravity survey as changes in the anomaly can be directly attributed to lateral density contrasts within the geology below the observation point.

$$CGBA = GBA + TC$$

where,
$CGBA$ Complete Geoidal Bouguer Anomaly in gravity units

| | |
|---|---|
| $GBA$ | Geoidal Bouguer Anomaly in gravity units |
| $TC$ | Terrain Correction in gravity units |

### 8.3.4 Quality Analysis of the Processed Gravity data

Following reduction of the data to Bouguer Anomaly, repeatability and QA procedures were applied to both the positional and gravity observations using AGRIS software. AGRIS checks the following as part of its QA processing:

- Easting Observation Repeatability and Histogram
- Northing Observation Repeatability and Histogram
- Elevation Observation Repeatability and Histogram
- Gravity Observation Repeatability and Histogram
- Gravity SD, Tilt XY, Temperature, Rejection, Reading Variance
- Gravity meter drift / closure
- Gravity meter loop time, drift per hour
- GPS Dilution of Precision, Coordinate Quality Factor, Standard Error
- Variation of surveyed station location from programmed location

QA procedures were applied to the gravity data on a daily basis and any gravity stations not conforming to contract specifications were repeated by the company at no cost to the client.

### 8.3.5 Additional Processing, Gridding and Plotting

Complementing the QA procedures is additional daily gridding, imaging and plotting of the elevation and gravity data. Once processed to Bouguer Anomaly and assessed for QA, data are imported into Geosoft Oasis Montaj or ChrisDBF software for gridding at 1/5$^{th}$ the station spacing to produce ERMapper compatible grid files. Resultant grids are contoured, filtered and interpreted using ERMapper and ArcMap software to check that data is smoothly varying and that no spurious anomalies are present. A first vertical, tilt angle and horizontal derivative filter are routinely applied to the data as these filters allow for excellent noise recognition. Once identified, any spurious stations can be field checked by the helicopter crew the following day and repeated if required.

Plotting of the acquired stations on a daily basis allowed for identification of any missed stations which were then gained the following day.

# 9.0 Results

The VRD gravity survey was completed with a minimum of fuss. The terrain was however quite challenging for helicopter gravity acquisition. A total of **1,589** new gravity stations were gained during the survey.

Final data have been delivered to a technically excellent standard and are presented both digitally and hardcopy as Appendices to this report.

## 9.1 Survey Timing and Production Rates

The acquisition crew began gravity data acquisition on Wednesday 12$^{th}$ August 2009 and completed acquisition on Thursday 20$^{th}$ July 2009.

An average of 152 new stations per helicopter per day was maintained for most of the survey, with some days yielding over 240 stations. Lower production days were mainly due to inclement weather and/or helicopter maintenance. A full production report can be found on the data CD (Appendix E).

## 9.2 Data Formats

Final reduced ASCII data for the project has been delivered in Atlas format as well as ASEG-GDF2 compatible format. Table 5 overleaf details the format of the final gravity database supplied. All fields are comma delimited

Raw GPS-GNSS and gravity data in their respective native formats have been included on the data CD as Appendix E. Table 4 below summarises the deliverables.

| Final Delivered Data | Format | Data DVD | Hardcopy |
|---|---|---|---|
| Gravity Database | Comma Space Delimited .csv<br>ASEG-GDF2 | • | |
| Raw Positional Data | AGRIS format, comma delimited | • | |
| Raw Gravity Data | Scintrex CG5 format | • | |
| Final Grids | ERMapper Grids .ers | • | |
| Final Tiff's | GeoTiff .tif | • | • |
| Logistics report | PDF .pdf | • | • |

*Table 4: Final Deliverables*

| Field Header | Field Description | Format | Units |
|---|---|---|---|
| PROJECT | Atlas Geophysics Project Number | A9 | None |
| STATION | Unique station ID | I8 | None |
| STATIONCODE | Unique station Code | A13 | None |
| TYPE | Observation Type : Base, Field or Repeat | A8 | None |
| MGAEAST | Coordinate Easting MGA94/GDA94 | F11.3 | m |
| MGANORTH | Coordinate Northing MGA94/GDA94 | F12.3 | m |
| ZONE | MGA Zone Number | F8.0 | NA |
| GDA94LAT | Coordinate Latitude GDA94 | F15.10 | DD |
| GDA94LONG | Coordinate Longitude GDA94 | F15.10 | DD |
| ORTHOHTM | Coordinate Elevation Orthometric | F9.3 | m |
| GRS80HTM | Coordinate Elevation Ellipsoidal | F9.3 | m |
| NAG98 | Geoid Separation | F8.3 | m |
| AMG84EAST | Coordinate Easting AMG84 | F11.3 | m |
| AMG84NORTH | Coordinate Northing AMG84 | F12.3 | m |
| DATE | Observation Date | I8 | None |
| TIME | Observation Time | I8 | None |
| DIALMGAL | Gravity Dial Reading | F9.3 | mGal |
| ETCMGAL | Earth Tide Correction (Longman) | F8.3 | mGal |
| SCALE | Scale Factor Applied to Dial Reading | F9.6 | None |
| OBSG84MGAL | Observed Gravity ISOGAL84 | F11.3 | mGal |
| OBSG84GU | Observed Gravity ISOGAL84 | F11.2 | gu |
| OBSGAAGD07GU | Observed Gravity AAGD07 | F13.2 | gu |
| OBSGAAGD007MGAL | Observed Gravity AAGD07 | F16.3 | mGal |
| DRIFTMGAL | Drift Applied to Dial Readings | F10.3 | mGal |
| TGRAV80GU | Theoretical Gravity 1980 | F11.2 | gu |
| TGRAV80MGAL | Theoretical Gravity 1980 | F12.3 | mGal |
| TGRAVGU | Theoretical Gravity 1967 | F11.2 | gu |
| GFACGU | Geoidal Free Air Correction | F8.2 | gu |
| GFACMGAL | Geoidal Free Air Correction | F9.3 | mGal |
| GFAAGU | Geoidal Free Air Anomaly | F8.2 | gu |
| GFAAMGAL | Geoidal Free Air Anomaly | F9.3 | mGal |
| GBC267GU | Geoidal Bouguer Correction 2.67 tm^-3 | F9.2 | gu |
| GBC240GU | Geoidal Bouguer Correction 2.40 tm^-3 | F9.2 | gu |
| GBC220GU | Geoidal Bouguer Correction 2.20 tm^-3 | F9.2 | gu |
| GBC267MGAL | Geoidal Bouguer Correction 2.67 tm^-3 | F11.3 | mGal |
| GBC240MGAL | Geoidal Bouguer Correction 2.40 tm^-3 | F11.3 | mGal |
| GBC220MGAL | Geoidal Bouguer Correction 2.20 tm^-3 | F11.3 | mGal |
| GBA267GU | Geoidal Bouguer Anomaly 2.67 tm^-3 | F9.2 | gu |
| GBA240GU | Geoidal Bouguer Anomaly 2.40 tm^-3 | F9.2 | gu |
| GBA220GU | Geoidal Bouguer Anomaly 2.20 tm^-3 | F9.2 | gu |
| GBA267MGAL | Geoidal Bouguer Anomaly 2.67 tm^-3 | F11.3 | mGal |
| GBA240MGAL | Geoidal Bouguer Anomaly 2.40 tm^-3 | F11.3 | mGal |
| GBA220MGAL | Geoidal Bouguer Anomaly 2.20 tm^-3 | F11.3 | mGal |
| TGRAV80ACGU | Theoretical Gravity 1980 Atmospheric Corrected | F11.2 | gu |
| EFACGU | Ellipsoidal Free Air Correction | F9.2 | gu |
| EFAAGU | Ellipsoidal Free Air Correction | F8.2 | gu |
| SCBC267GU | Spherical Cap Bouguer Correction 2.67 tm^-3 | F10.2 | gu |
| SCBC240GU | Spherical Cap Bouguer Correction 2.40 tm^-3 | F10.2 | gu |
| SCBC220GU | Spherical Cap Bouguer Correction 2.20 tm^-3 | F10.2 | gu |
| SCBA267GU | Spherical Cap Bouguer Anomaly 2.67 tm^-3 | F10.2 | gu |
| SCBA240GU | Spherical Cap Bouguer Anomaly 2.40 tm^-3 | F10.2 | gu |
| SCBA220GU | Spherical Cap Bouguer Anomaly 2.20 tm^-3 | F10.2 | gu |
| SCBA267MGAL | Spherical Cap Bouguer Anomaly 2.67 tm^-3 | F12.3 | mGal |

| | | | |
|---|---|---|---|
| SCBA240MGAL | Spherical Cap Bouguer Anomaly 2.40 tm^-3 | F12.3 | mGal |
| SCBA220MGAL | Spherical Cap Bouguer Anomaly 2.20 tm^-3 | F12.3 | mGal |
| DIFFEASTM | Repeat Error for Easting Observation | F8.3 | m |
| DIFFNORTHM | Repeat Error for Northing Observation | F8.3 | m |
| DIFFHTM | Repeat Error for Elevation Observation | F8.3 | m |
| DIFFOBSGMGAL | Repeat Error for Observed Gravit | F8.3 | mGal |
| DIFFOBSGGU | Repeat Error for Observed Gravity | F8.2 | gu |
| METERSN | Serial Number of Gravity Instrument | I8 | None |
| CLOSUREGU | Loop Closure in gu | F8.2 | gu |
| CLOSUREMGAL | Loop Closure in mGal | F8.3 | mGal |
| GRVBASE | Gravity Base | A11 | None |
| GPSBASE | GPS Base | A11 | None |

*Table 5: Final Gravity Database Format*

## 9.4 Data Repeatability

The repeatability of both the gravity and GPS data was excellent. In total, **82** gravity and GPS repeat stations were collected and analysed. As a percentage, this equates to **5.16%** of the total number of new gravity stations acquired. Repeat stations were acquired so that an even distribution between gravity loops was established and that all loops were interlocked. Descriptive statistics pertaining to the repeatability are contained in Table 6

The standard deviation of the gravity repeat deviations was **0.029 mGal** and the standard deviation of the GPS repeat deviations was **0.069 m**. These statistics confirm that the data has met and exceeded industry standard specifications.

| | GPS Repeat (mAHD) | Gravity Repeat (mGal) |
|---|---|---|
| Mean | 0.008 | -0.007 |
| Standard Error | 0.008 | 0.003 |
| Median | 0.004 | -0.008 |
| Mode | -0.048 | -0.014 |
| Standard Deviation | 0.069 | 0.029 |
| Sample Variance | 0.005 | 0.001 |
| Kurtosis | 0.442 | 0.414 |
| Skewness | -0.060 | -0.223 |
| Range | 0.352 | 0.161 |
| Minimum | -0.152 | -0.089 |
| Maximum | 0.200 | 0.072 |
| Sum | 0.690 | -0.597 |
| Count | 82 | 82 |

*Table 6: Repeat Statistics*

### 9.4.1 Repeatability Histograms

Histograms showing the distribution of repeat differences for both the gravity and GPS observations are shown in Figures 12 and 13.

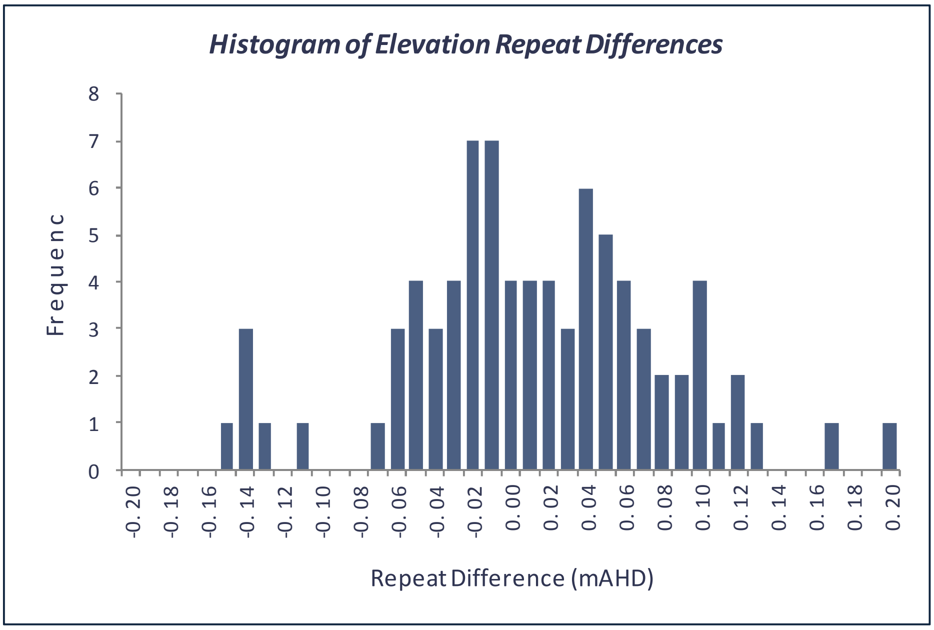



*Figure 12: Histogram of GPS Repeat Differences*

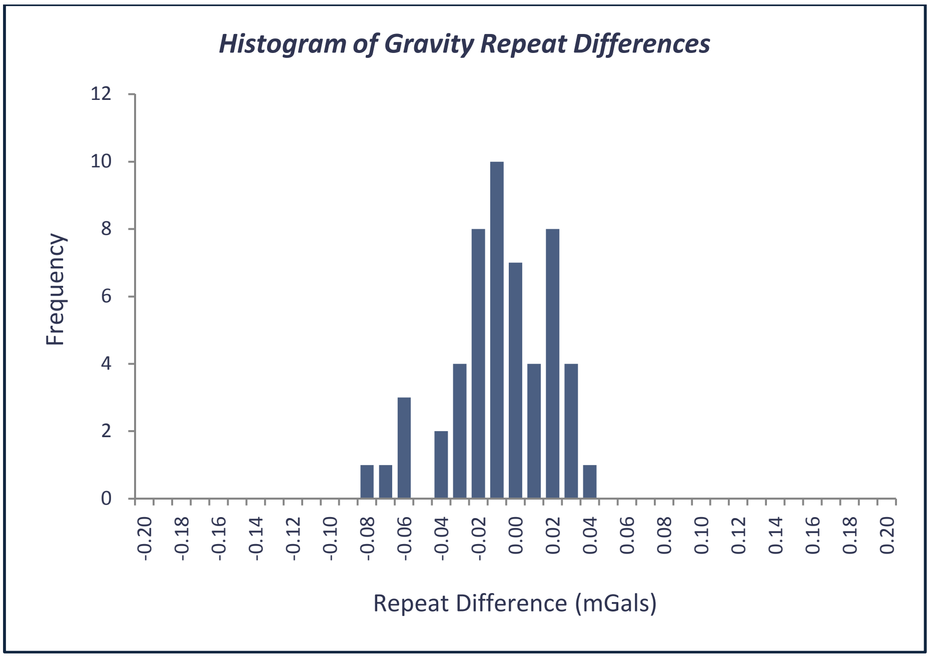



*Figure 13: Histogram of Gravity Repeat Differences*

## 9.5 Grids, Images and Plots

Final reduced data have been gridded using ChrisDBF software and a minimum curvature algorithm with multiple loops. All grids are provided in ERMapper compatible .ers format and are in units of mGals or m.

Grids for GPS Derived Elevation (GRS80), Spherical Cap Bouguer Anomaly (SCBA267) and 1st vertical derivative of Spherical Cap Bouguer Anomaly (SCBA267VD) were produced for this particular project.

The grids produced have been imaged using Geosoft Oasis Montaj mapping and processing software. Four plots of these images have been included with this report to assist in data interpretation (Appendix A). The plots have been included digitally on the data CD in GIS compatible Geotiff format.

*Station Location Plot:* The first plot displays the acquired gravity station locations overlayed on a 1:250,000 topographic map of the area and surrounds. As evident on the plot, some stations have been moved off the original programmed co-ordinates due to terrain considerations.

*GPS Derived Elevation:* This plot displays a pseudocoloured grid of the digital elevation data obtained from the gravity survey (GRS80 grid). A histogram equalisation colour stretch has been applied when pseudocolouring. Overlying the image data are contours created at varying intervals.

*Bouguer Anomaly 2.67 Contours:* This plot displays a pseudocoloured grid of Spherical Cap Bouguer Anomaly calculated with a rock density of 2.67 gm/cc. A histogram equalisation stretch has been applied when pseudocolouring. Overlying the image data are contours created at the appropriate interval.

*Vertical Derivative Image:* This plot displays pseudocoloured grid of the first vertical derivative of Spherical Cap Bouguer Anomaly calculated with a rock density of 2.67 gm/cc. A histogram equalisation stretch has been applied when pseudocolouring and sun shading from the north-east has been applied. This image represents the rate of change of the Bouguer anomaly and is useful for detecting lineaments and body edges, especially where there are large regional gradients present.

## 10.0 Project Safety

There were no incidents or accidents to report on this project. Weekly toolbox meetings were held to discuss project safety and address any staff member concerns. A Hazard Identification and Risk Assessment (HIRA) was carried out for all new tasks not covered under Atlas Geophysics Standard Operating Procedures (SOP's) as documented in the company's Health Safety Environment and Community (HSEC) field manual.

# 11.0 Conclusion

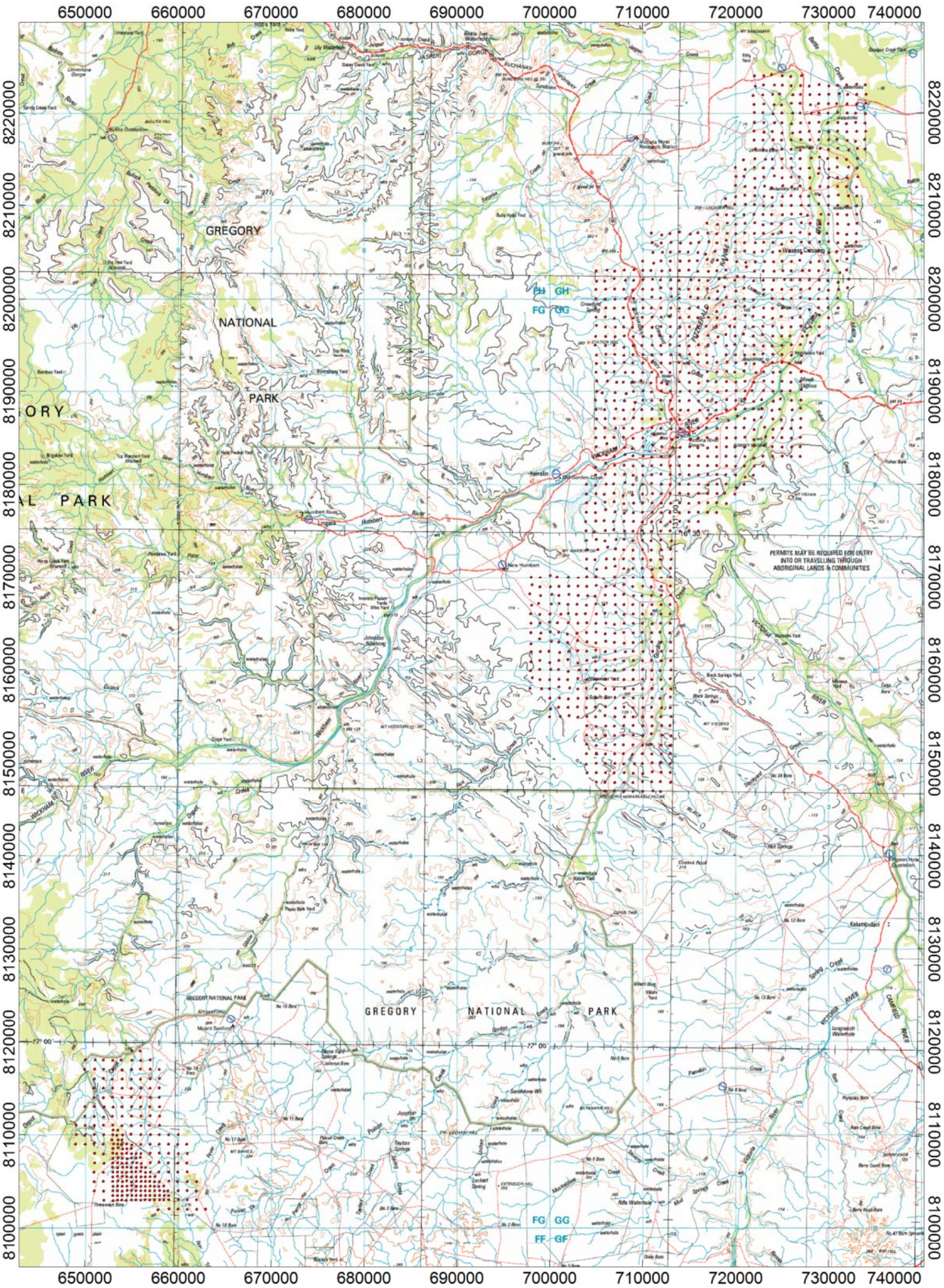
Atlas Geophysics Pty Ltd is confident that it has delivered high quality data to its client to a high standard and in the safest way possible.

The company was pleased to be involved in the acquisition and processing of the gravity data collected on this project and look forward to working with Anglo Australian Resources again in the future.

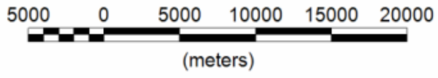
Leon Mathews
*Director*

Mark Jecks
*Director*

# APPENDIX A
## Plots and Images




Scale 1:500000




GDA94 / UTM zone 52S

ANGLO AUSTRALIAN RESOURCES NL

**P2009016 VRD GRAVITY SURVEY**

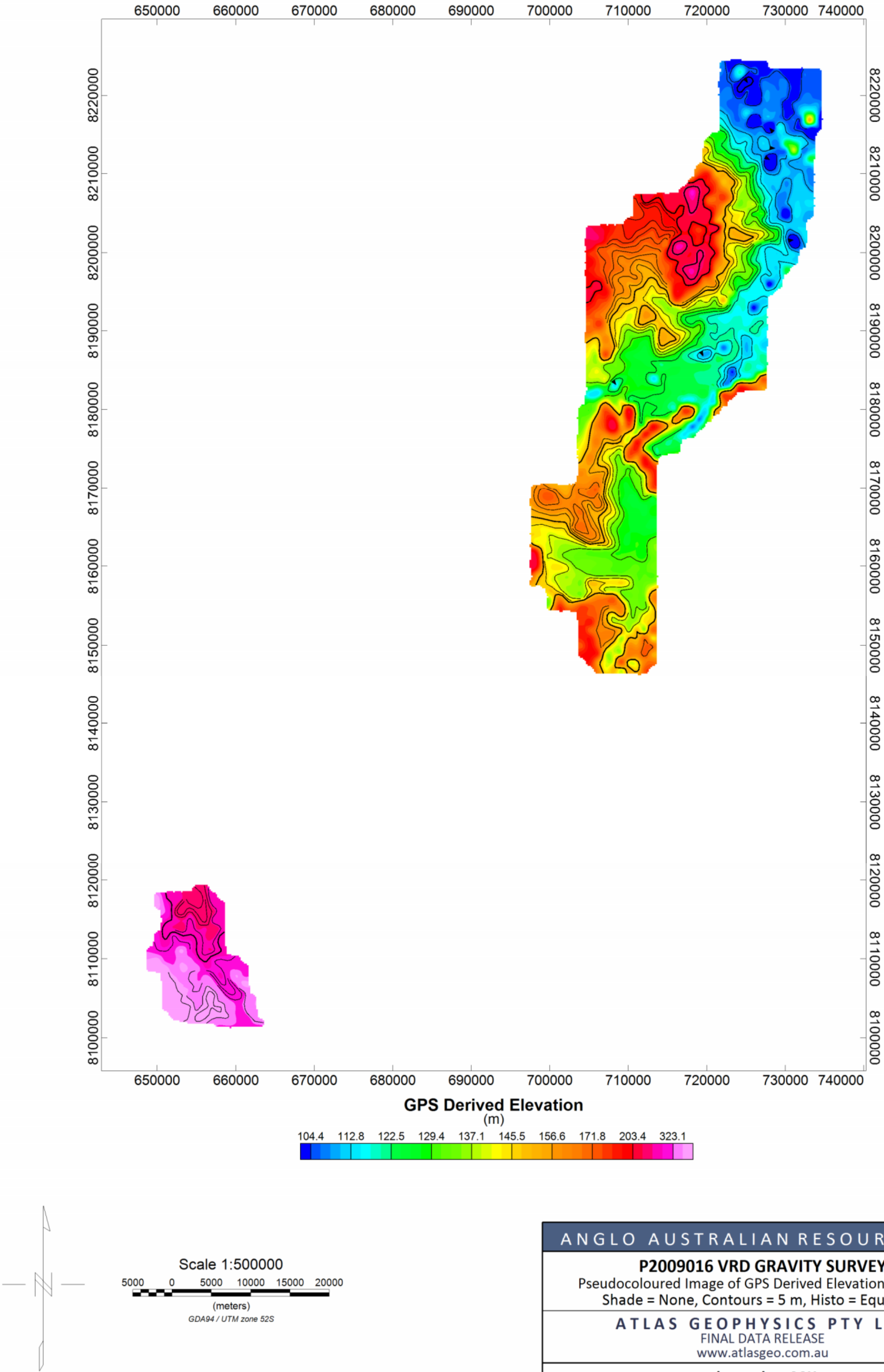
Plot of Gravity Station Locations

**ATLAS GEOPHYSICS PTY LTD**

FINAL DATA RELEASE

www.atlasgeo.com.au

***drawn by : MJJ***




ANGLO AUSTRALIAN RESOURCES NL

**P2009016 VRD GRAVITY SURVEY**

Pseudocoloured Image of GPS Derived Elevation GRS80 m

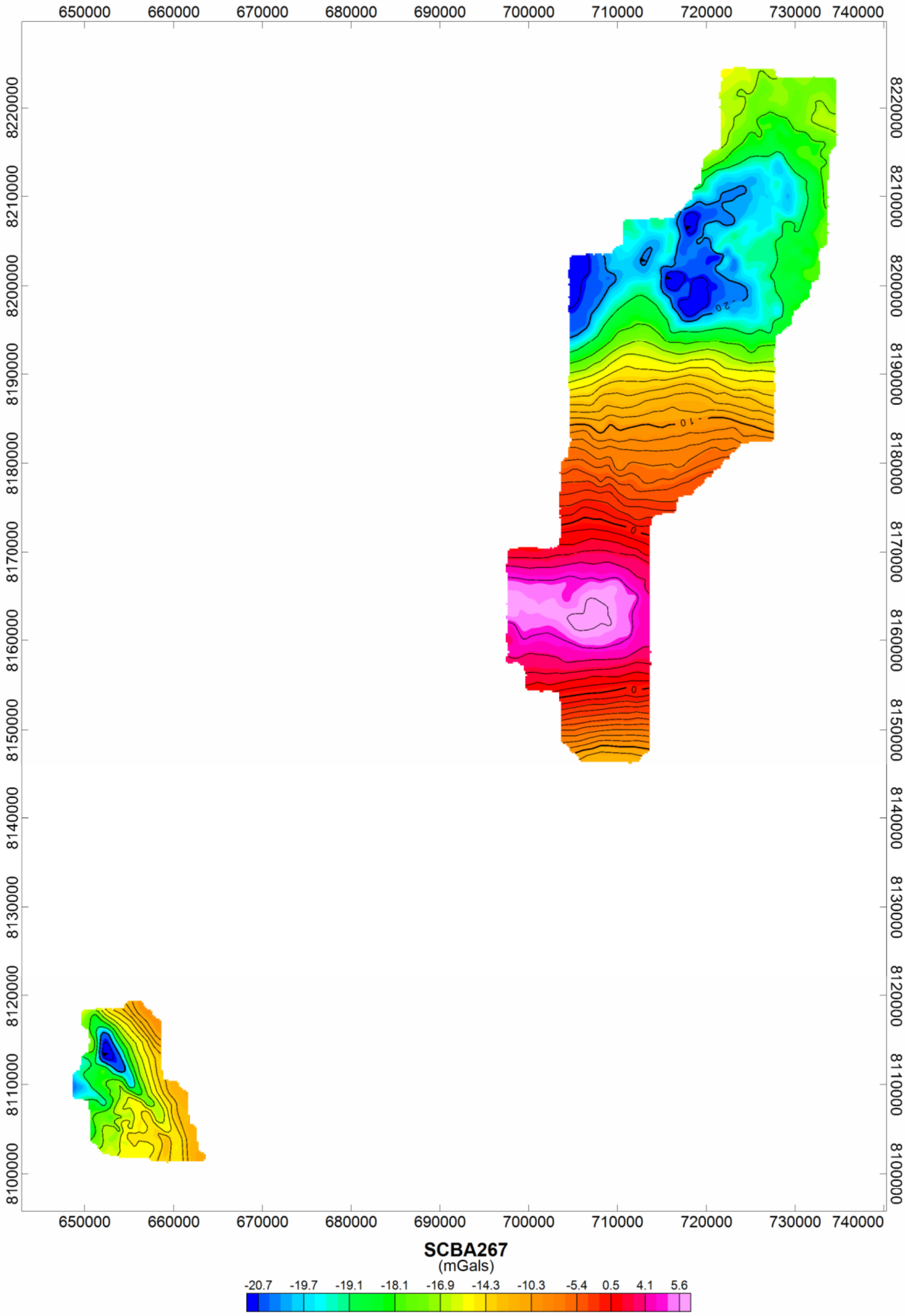
Shade = None, Contours = 5 m, Histo = Equalised

ATLAS GEOPHYSICS PTY LTD

FINAL DATA RELEASE

www.atlasgeo.com.au

***drawn by : MJJ***




Scale 1:500000

5000 0 5000 10000 15000 20000

(meters)

GDA94 / UTM zone 52S

ANGLO AUSTRALIAN RESOURCES NL

**P2009016 VRD GRAVITY SURVEY**

Pseudocoloured Image of SC Bouguer Anomaly 2.67 gm/cc

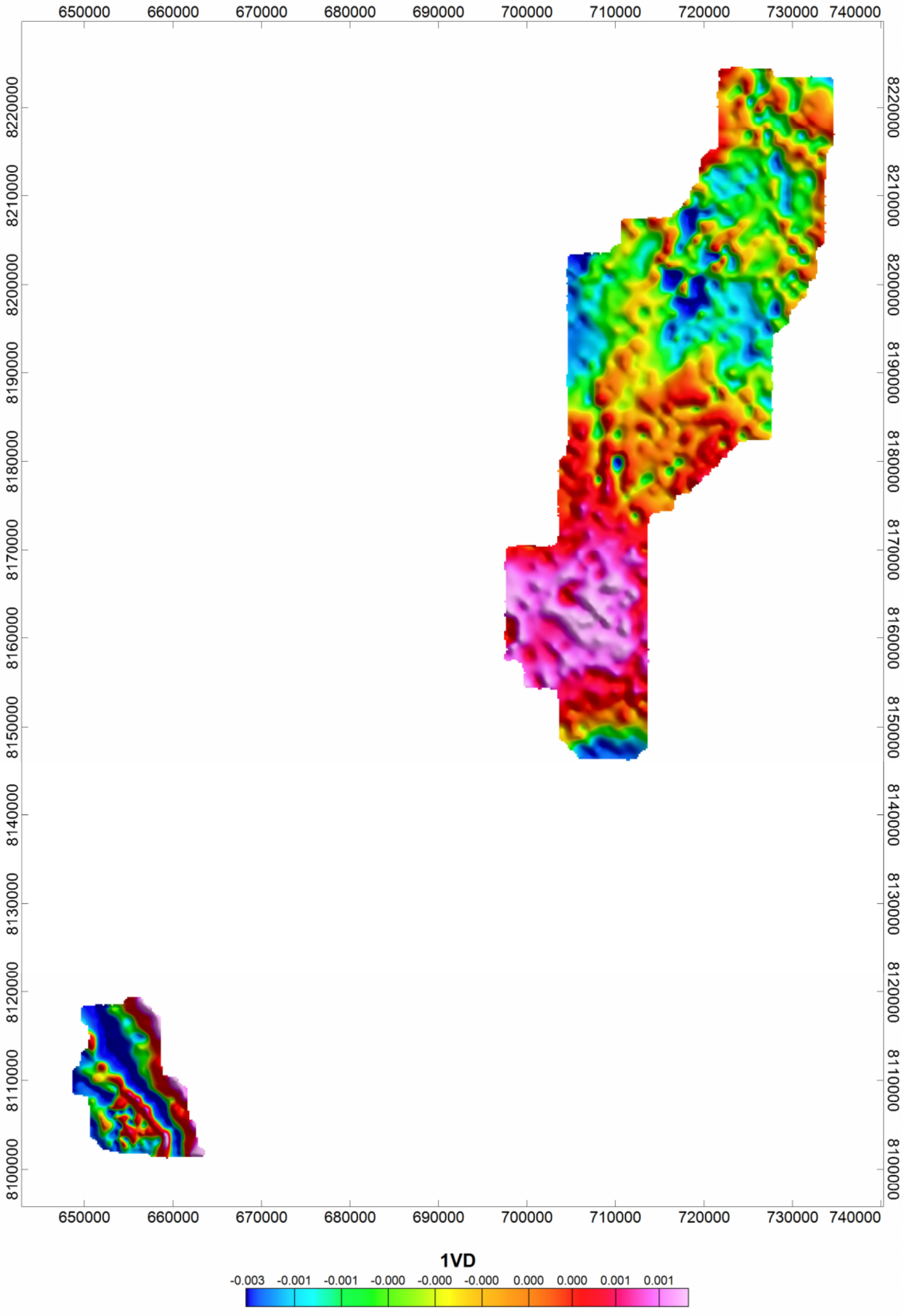
Shade = None, Contours = 1 mGal, Histo = Equalised

ATLAS GEOPHYSICS PTY LTD

FINAL DATA RELEASE

www.atlasgeo.com.au

***drawn by : MJJ***




Scale 1:500000

5000 0 5000 10000 15000 20000

(meters)

*GDA94 / UTM zone 52S*

ANGLO AUSTRALIAN RESOURCES NL

**P2009016 VRD GRAVITY SURVEY**

Pseudocoloured Image of 1VD of SC Bouguer Anomaly 2.67 gm/cc

Shade = NE, Contours = None, Histo = Equalised

**ATLAS GEOPHYSICS PTY LTD**

FINAL DATA RELEASE

www.atlasgeo.com.au

***drawn by : MJJ***

# APPENDIX B
## Control Station Descriptions

# GRVGPS0071 – Victoria River Downs A/S

| GDA 94/GRS80 | | MGA Z52 | | AMG Z52 | |
|---|---|---|---|---|---|
| *Latitude* | -16°24'06.2421" | *Easting* | 714,936.600 | *Easting* | 714,803.672 |
| *Longitude* | 131°00'45.4771" | *Northing* | 8,185,559.945 | *Northing* | 8,185,394.711 |
| *Ellipsoidal Height* | 125.108 | *Orthometric Height* | 88.691 | *Orthometric Height* | 88.691 |

## OBSERVED GRAVITY

| | |
|---|---|
| *AAGD07 mGal* | 978408.491 |
| *ISOGAL84 mGal* | 978408.516 |

### *Occupation Method/Location Details*

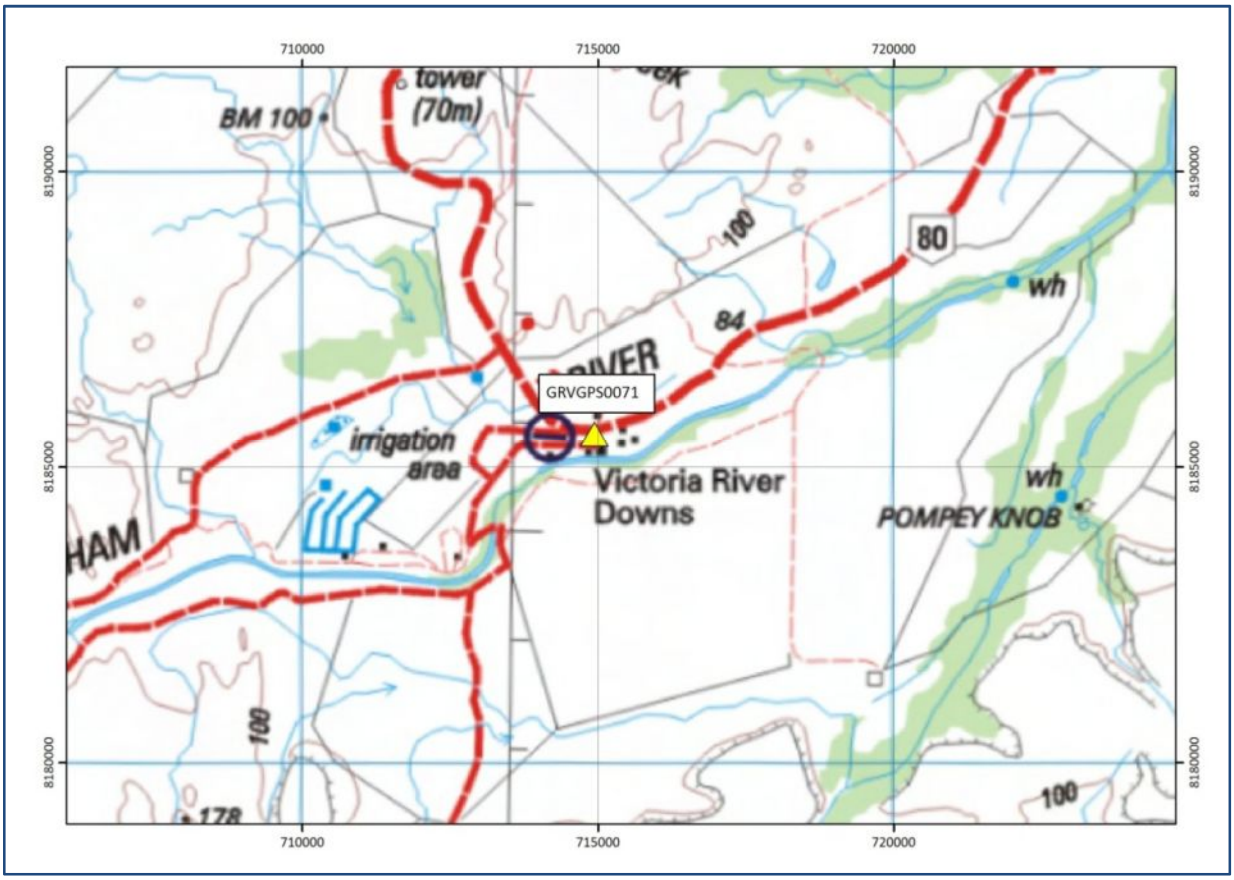
The GPS control point consists of a dumpy steel picket driven into the ground to a height of 10cm above ground level. The gravity control point consists of a small concrete slab (30cm square) concreted into the ground, opposite the GPS control point. The control station is witnessed by an Atlas Geophysics survey plaque attached to a 1.5 metre steel picket placed within 0.5m of both control points.

**Gravity Control** was established via multiple ABABA loops to AFGN gravity base station 1964910133 located at Daly Waters Aerodrome. Expected accuracy would be better than 1gu or 0.01mGal.

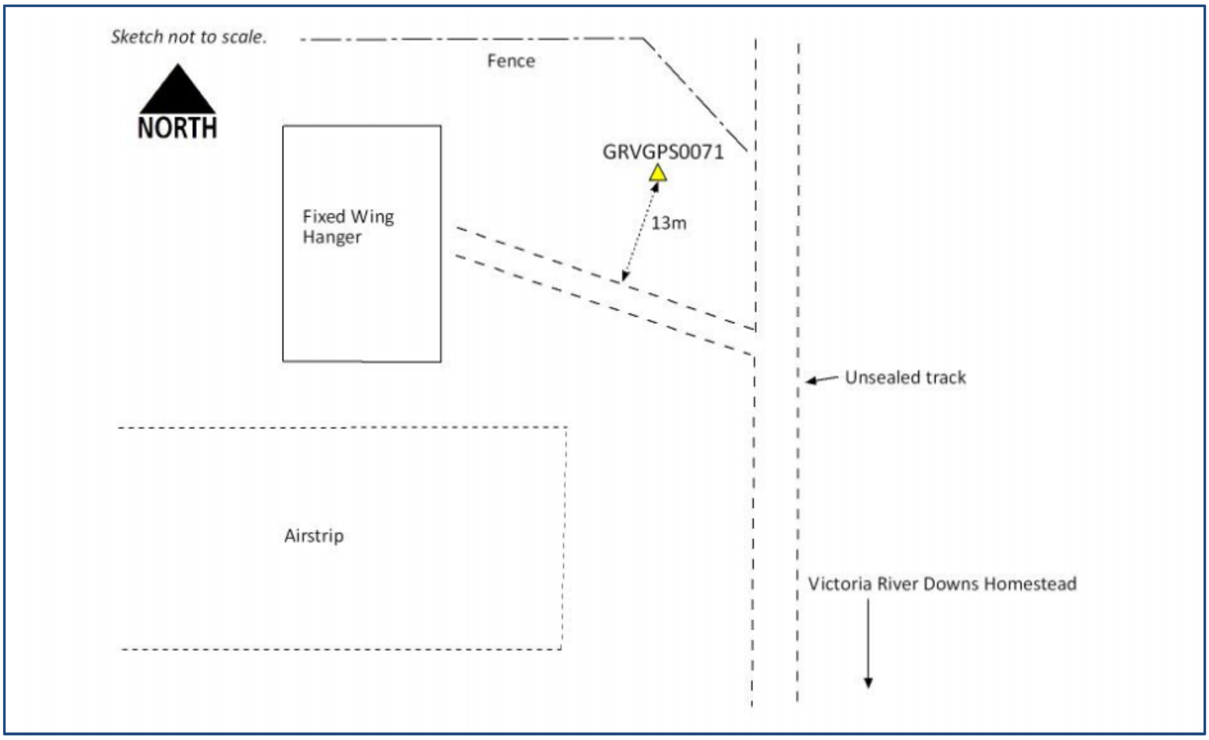
**GPS Control** was established using AUSPOS. Three separate +10 hour sessions were submitted to AUSPOS's online processing system where returned coordinates were accurate to better than 0.01m.

This control station is located approximately 30m east of the fixed wing hanger at Victoria River Downs Airstrip. The station can be accessed via the track that runs north from the homestead towards the airstrip. Victoria River Downs Station is located approximately 250km south west of Katherine in the Northern Territory.

*Photograph of Control Station GRVGPS0071 and surrounds*




*Location of Control Station GRVGPS0071*




*Locality Sketch of Control Station GRVGPS0071*

# APPENDIX C
## GPS Control Information

# GPS Control Station Information

Project P2009016
Client ANGLO
Area VRD
Zone 52

info@atlasgeo.com.au

## CONTROL STATION GRVGPS0071

| | |
|---|---|
| Receiver Type | Leica System 1200GG |
| Antenna Type | Leica AX1202GG |
| Antenna ARP Height | 1.582 |

### Adopted / Supplied Coordinates

| Waypoint | GRS80 Lat Deg | Min | Sec | GDA94 Long Deg | Min | Sec | MGA East | MGA North | GDA94 Height | AHD Height | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -16 | 24 | 6.23172 | 131 | 0 | 45.47804 | 714936.631 | 8185560.264 | 132.493 | | |

### AUSPOS Rapid Coordinates

| | GRS80 Lat Deg | Min | Sec | GDA94 Long Deg | Min | Sec | MGA East | MGA North | GDA94 Height | AHD Height | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |

### AUSPOS Final Coordinates

| | GDA94 Lat Deg | Min | Sec | GDA94 Long Deg | Min | Sec | MGA East | MGA North | GDA94 Height | AHD Height | N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Solution 01 | -16 | 24 | 6.24220 | 131 | 0 | 45.47700 | 714936.597 | 8185559.943 | 125.098 | 88.681 | 36.417 |
| Solution 02 | -16 | 24 | 6.24210 | 131 | 0 | 45.47700 | 714936.599 | 8185559.945 | 125.113 | 88.697 | 36.416 |
| Solution 03 | -16 | 24 | 6.24200 | 131 | 0 | 45.47720 | 714936.605 | 8185559.947 | 125.112 | 88.696 | 36.416 |
| **Solution AVG** | **-16** | **24** | **6.2421** | **131** | **0** | **45.4771** | **714936.6003** | **8185559.945** | **125.108** | **88.691** | **36.416** |

***Have you double checked your data entry?***

☑ Yes ☐ No

**SHIFTS REQUIRED (Add to GPS Field Files)**

| | MGA East | MGA North | GDA94 Height |
|---|---|---|---|
| SHIFT ADOPTED TO FINAL | -0.031 | -0.319 | -7.385 |
| SHIFT RAPID TO FINAL | 0.000 | 0.000 | 0.000 |
| SHIFT ADOPTED TO RAPID | 0.000 | 0.000 | 0.000 |

# APPENDIX D
# Longman's Earth Tide Correction Formula

```
input dLat (latitude)
input dLon (longitude)
input dDate (date)
*Date broken down into year, month and date
input dTime (time)

array pClndr[12]={0,31,59,90,120,151,181,212,243,273,304,334}
lYr=year
lMo=month
lDa=day

ny=(lYr-1900)
days=(dTime/24.0+lDa-1+pClndr[lMo-1])
lLeap=(ny/4)
if(lLeap/2=ny and lMo<3)then lLeap=lLeap-1
lDay=(ny*365+lLeap+lDa+pClndr[lMo-1])
dcent = (ny*365.0+lLeap+days+0.5)/36525)
dhrs = (ny*365.0+lLeap+days+0.5)*24.0)
ds = (dcent*8399.709299+4.7200234 34+(dcent*dcent)*4.40696e-5)
dp=(dcent*71.01800936+5.835124713-(dcent*dcent)*1.80545e-4-dcent*2.1817e-
7*(dcent*dcent)
dh=(dcent*628.3319509+4.88162792+(dcent*dcent)*5.27962e-6)
doln=(4.523588564-dcent*33.757153303+(dcent*dcent)*3.6749e-5)
dps=(dcent*0.030005226416+4.908229461+(dcent*dcent)*7.902463e-6)
des=(0.01675104-dcent*4.18e-5-(dcent*dcent)*1.26e-7)
dsoln=(sin(doln))
dci=(0.91369-cos(doln)*0.03569)
dsi=(sqrt(1.0-(dci*dci))
dsn=(dsoln*0.08968/dsi)
dcn=(sqrt(1.0-(dsn*dsn))
dtit=(dsoln*0.39798/(dsi*cos(doln)*dcn+1.0dsoln*0.91739*dsn))
det=(atan(dtit)*2.0)
if (det<0.0)then det=det+6.2831852)

dolm1=(ds-doln+det+sin(ds-dp)*0.1097 9944)
dolm=(dolm1+sin((ds-dp)*2.0)*0.0037674 74+sin(ds-
dh*2.0+dp)*0.0154002+sin((ds-dh)*2.0)*0.00769395)
dha=((dTime*15.0-180)*0.017453292519 9+dLon/57.295779513)
dchi=(dha+dh-atan(dsn/dcn))
dal=(dLat/57.295779513)
dct=(sin(dal)*dsi*sin(dolm)+cos(dal)*((dci+1.0)*cos(dolm-dchi)+(1.0-
dci)*cos(dolm+dchi))/2.0)
dda=(cos(ds-dp)*0.14325+2.60144+cos((ds-dp)*2.0)*0.0078644+cos(ds-
dh*2.0+dp)*0.0200918+cos((ds-dh)*2.0)*0.0146006)
dr=(6.378388/sqrt((1.0-((cos(dal)*cos(dal))*0.0067690 2+1.0)
r_1=(dda)
r_2=(dct)
r_3=(dr)
r_4=(dda)
r_5=(dda*dda)
r_6=(dct)
dgm=(dr80.49049*dda*(r_1*r_1)*((r_2*r_2)*3.0-1.0)+(r_3*r_3)*7.4e-
4*(r_5*r_5)*dct*((r_6*r_6)*5.0-3.0))
dols=(dh+des*2.0*sin(dh-dps))
dchis=(dha+dh)
dds=((des*cos(dh-dps)+1.0)*0.668881/(1.0-(des*des)))
dcf=(sin(dal)*0.39798*sin(dols)+cos(dal)*(cos(dols-
```