QUASAR RESOURCES
CURTIN SPRINGS GRAVITY SURVEY
July 2009

Report Number 09030
A. McCarthy

CLIENT
QUASAR RESOURCES

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Daishsat Geodetic Surveyors – 09030 Quasar Resources – Curtin Springs Gravity Survey
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1. INTRODUCTION

A precision GPS-Gravity survey was carried out by Daishsat Geodetic Surveyors between the 3rd and 8th of July on behalf of Quasar Resources Pty Ltd. A total of 1,234 stations were surveyed to the North of Curtin Springs Station in the Northern Territory.

Gravity data were acquired using Scintrex CG-5 gravity meters. Position and level data were obtained using Leica 1230GG geodetic grade GPS receivers collecting GPS and GLONASS positional information. All receivers were operating in post-processed kinematic mode. Data was acquired using Daishsat helicopter-borne survey methods.

Gravity data were reduced using standard reductions on the ISOGAL84 gravity network. Post processed GPS data was exported as MGA coordinates with levels expressed as metres above the Australian Height Datum.

2. SURVEY OVERVIEW

The Quasar Curtin Springs gravity survey covered an area of approximately 1200 km² in the central area of the Northern Territory. The survey was centered 50km north of Curtin Springs roadhouse located on the Lasseter Highway 100km east of Yulara.

The location of the survey is shown in Figure 1. Appendix A contains a plot of the final station locations and Appendix C contains the specifications for the survey.

Photo 1: Typical terrain in the survey area.
3. PERSONNEL AND EQUIPMENT

3.1 Personnel

The supervisor in charge of the project was Mark Rosewall. Mark was responsible for daily management of the job and for nightly data processing to ensure quality and integrity. Gravity and GPS measurements were carried out by:

Jon Nankivell    Mark Rosewall

The Helicopter pilots used for the project were:

Lee Mitchell   Chris Hall

Final data reduction, inspection and reporting were performed by the company Geophysicist, Grant Coopes.

3.2 Survey equipment

The following survey equipment was utilised on the gravity survey:

- Scintrex CG-5 digital gravity meters (A and N meters)
- Leica 1230GG dual frequency GPS receivers with GLONASS capability
- Notebook computers for data processing and backup
- Garmin 296 GPS receivers for helicopter navigation
- Garmin Handheld GPS receivers for vehicle navigation
- Various chargers, solar cells and batteries

3.3 Support vehicles

Due to the type of terrain and remote locations, 4WD Landcruiser and 4WD Isuzu Trucks were utilized as support vehicles for the surveys. To maintain the high Daishsat safety record, vehicles were fitted with a range of safety equipment including:

- One 20l jerry can of water
- Dual fuel tanks
- Two spare tyres
- UHF radio and satellite phone with car kit
- Self-recovery equipment including winches, snatch straps chains etc.
- Tyre pliers to effect tyre repairs in the field
- Tools and spares to enable field repairs as necessary
- Survival kits with EPIRB emergency locator beacons
- Trans track satellite vehicle monitoring and reporting systems
3.4 Helicopter

Due to the scale and accessibility of the stations within the survey areas the most efficient method of transport between stations is by helicopter. Daishsat utilizes Robinson R-44 Helicopters, a medium size utility helicopter with good maneuverability and proven reliability in harsh operating conditions typical of gravity survey operations.

![Photo 2: Robinson R-44 Helicopter used for gravity acquisition](image)

3.5 Accommodation

The crews were accommodated as close as practical to the survey areas with accommodation and meals provided by The Curtin Springs Road House.

3.6 Communications

The survey crew and support vehicles were equipped with hand-held Iridium satellite phones as well as UHF and VHF transceivers. “Omnitrack” satellite based tracking was used on all vehicles (including helicopters) to enable asset monitoring via a web interface.

Scheduled communications were made by the crew to the communications centre at the base camp at hourly intervals. Communication with the Perth and Murray Bridge offices was ongoing for the duration of the job.
4. GPS SURVEYING AND PROCESSING

4.1 Set out of the grid

This was done concurrently with the gravity data acquisition using navigation grade receivers operating in autonomous mode. Where possible, the readings were taken as close to the ideal coordinates as possible. As the receivers were operating in autonomous mode, set out accuracy was usually better than 10m.

Raw kinematic GPS data were logged by twin dual-frequency Leica 1230GG receivers inside the helicopter cabin, with the GPS antennas mounted on the tail boom. Static GPS data was logged at the base station using two Leica System 1230GG GPS receivers for later post-processing. The Leica 1230GG is a new generation GPS receiver making use of both the traditional US GPS satellite constellation and the newly available GLONASS satellite constellations for higher positional accuracy and reduced periods of poor satellite coverage.

Repeat stations were placed throughout the surveys to monitor any variations in positional accuracy. Repeats are placed with a washer tied with flagging and marked with the station number was used for future identification. At each station, the station number, position and RL were recorded digitally by the crew.

4.2 Survey datum and control

The gravity surveying, and hence any gravity reductions, used the Australian Height Datum (AHD) as the reference datum. New GPS/Gravity base stations were established at each of the three bases using three days worth of static data and connections to ITRF stations using Geoscience Australia’s online GPS processing system, AUSPOS. For more information on this system, please visit the Geoscience Australia website at http://www.ga.gov.au/geodesy/sgc/wwwgps/. Final deviations of better than 5mm were obtained for x, y and z, for all occupations. Appendix D contains the GPS base station information.

4.3 Processing of the position and level data

The raw GPS data was recorded onto the internal RAM of the GPS receivers. The data was downloaded nightly onto a laptop computer for post-processing using Waypoint’s premier processing software package – Grafnav V7.80. Waypoint combines the processing components, GrafNav and GrafNet, in a complete package.

GrafNav processes data for one baseline (e.g. one base and one remote). GrafNav is normally used for kinematic data which it is extremely well suited for. It can also process single static baselines. Receiver types can be mixed and matched via the use of a common format. This component of Waypoint was used for processing the kinematic data acquired each day.
GrafNav and GrafNet share the same processing engine that has been under continuous
development since its original inception by Waypoint in 1992. The core of this robust engine
is its carrier phase kinematic (CPK) Kalman filter. Some of the major advantages of
Waypoint's kernel are:

*Fast processing* - The GrafNav kernel is one of the fastest on the market. It will process ~0.8
epochs per MHz per second on a Pentium II.

*Robust Kalman filter* - From experience with processing GPS data from fast jets and NASA
sounding rockets, the processing kernel has become extremely robust. Efforts have been
made to account for all of the various data error possibilities given the different types of GPS
receivers that GrafNav/GrafNet can handle.

*Reliable OTF* - Waypoint's on-the-fly (OTF) algorithm, called Kinematic Ambiguity Resolution
(KAR), has had years of development and stresses reliability. Variations are implemented
for both single and dual frequencies, and numerous options are available to control this
powerful feature

*Accurate Static Processing* - Three modes of static processing are implemented in the
processing kernel. Fixed static is the most accurate. A quick static solution is also available
as an alternative, while the float and iono-free float solution is useful for long baselines.

Dual Frequency - Full dual frequency support comes with GrafNav/GrafNet. For ambiguity
resolution, this entails wide/narrow lane solutions for KAR, fixed static and quick static.
Ionospheric processing is very important with the peak of the ionosphere's cycle occurring in
2000. 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. Both GrafNav and GrafNet also have the ability to combine these two solutions to
obtain a globally optimum one.

*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
about of code has been added specifically for the detection and removal of Doppler errors.

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

For more information about Waypoint processing software, and in particular, GrafNav,
please visit the Waypoint [http://www.waypnt.com/grafnav_d.html](http://www.waypnt.com/grafnav_d.html).

MGA94 coordinates were obtained by simply projecting the GPS-derived WGS84
coordinates using a UTM projection with zone 52S. For all practicable purposes, the
WGS84 geodetic coordinates are equivalent to GDA94 geodetic coordinates, so no
transformation is necessary. For more information about GDA94 and MGA94, please visit
AHD heights were calculated via Waypoint software using the latest geoid model for Australia, AUSGEOID98. Information about the geoid and the modeling process used to extract separations (N values) can be found at [http://www.ga.gov.au/geodesy/ausgeoid/](http://www.ga.gov.au/geodesy/ausgeoid/). To obtain AHD heights, the modeled N value is subtracted from the GPS derived WGS84 ellipsoidal height (Figure 2).

\[ H_{\text{AHD}} = h_{\text{WGS84}} - N \]

Figure 2: Geoid-Ellipsoid separation

### 4.4 GPS Performance

Performance from the 1230GG receivers was excellent. There were no stations that required repeating due to GPS failure or poor coordinate quality.

Photo 3: Post process GPS base setup at Kulgera Airfield.
5. GRAVITY SURVEYING AND PROCESSING

5.1 Gravity data acquisition

Gravity observations were made concurrently with the GPS measurements. Two observations were made for each station, with each observation consisting of a 20-second or greater stacking time. Multiple observations were made at each station so that any seismic or instrumental noise could be immediately detected. The tolerance between readings was set at 0.05 of a dial reading (0.05 mGals). Vertical and horizontal levels were restricted to 5 arc seconds at all times. At each station, the station number, time and two gravity readings (in dial units) were recorded in DAISHSAT carbon-copy gravity field books. The Scintrex meters also automatically record the station, time and readings digitally to allow for downloading to computer.

5.2 Gravity base station

Gravity base stations were used for calculation of absolute gravity and drift determination. A new gravity base station – Base 0308 – was established at the Kulgera Airstrip. The observed gravity value for this base was calculated through completing multiple B-A-B gravity loops to AFGN stations located at the Yulara Airport Terminal. The expected accuracy of the tie control surveys is better than 0.01 mGals. Details of the gravity bases established for the survey are contained in Appendix D.

When in the field, base station readings were taken in the morning before the first observation and at evening after the last observation. When taking a base station reading, the observed gravity values were stacked over 60 seconds to ensure accuracy. Observations were repeated until the readings repeated to 0.010 of a dial reading or less.

5.3 Gravity data processing

Raw gravity data were processed on a daily basis to check for quality and integrity. This interim process produced a set of Bouguer Gravity values, which were contoured and imaged to provide a check for any anomalous readings that would need repeating. Geosoft GRAVRED software was used for the gravity reduction in the field.

Other software used on this project includes ArcView, ChrisDBF, and Oasis Montaj. The formulae used in the gravity reduction are listed below:

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

**Tidal correction**: This correction was used to correct for background variations due to changes in the relative position of the moon and sun. The Scintrex calculated ETC was removed and a new ETC calculated using Geosoft Formulae and the surveyed GPS latitude. The formula is too complex to list here.
**Instrument Drift:** Since gravity meters are mechanical, they are prone to drift (extension of the spring with heat, obeying Hooke’s law). If two base readings are taken one can assume that the drift between the two readings is linear and can therefore be calculated. The drift and tidal corrected value is referred to as the *observed gravity*.

**Theoretical Gravity:** The theoretical value of gravity was calculated using the 1967 variant of the International Gravity Formula and used to latitude correct the observed gravity.

\[
G_t = 978031.856 \times (1 + 0.005278895 \times \sin^2 \phi + 0.000023462 \times \sin^4 \phi)
\]

where \( \phi \) represents degrees of latitude

**Free-Air Correction:** Since gravity varies inversely with the square of distance, it is necessary to correct for changes in elevation between stations to reduce field readings to a datum surface (in this case, AHD).

\[
F_A = 0.308596 \times h_{AHD}
\]

**Bouguer Correction:** This correction accounts for the attraction of material between the station and datum plane that is ignored in the free-air calculation. A value of 2.67 gm/cc was used in the correction.

\[
B_C = 0.0419088 \times \rho \times h_{AHD}
\]

where \( \rho \) = density (2.67 gm/cc)

**Free Air Gravity:** This is obtained by applying the free air correction (FAC) to the observed gravity reading.

\[
FAG = G_{OBSG84} - G_t + FAC
\]

**Bouguer Gravity:** This is obtained when all the preceding reductions or corrections have been applied to the observed gravity reading.

\[
BG_{267} = G_{OBSG84} - G_t + FAC - BC
\]

### 5.4 Gravity meter calibration and scale factors

The gravity meter used had previously been calibrated on either the South Australian or Western Australian gravity calibration ranges. A derived scale factor from these calibrations is shown below:

<table>
<thead>
<tr>
<th>Meter</th>
<th>Serial No.</th>
<th>Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td>24921</td>
<td>1.000314</td>
</tr>
<tr>
<td>(N)</td>
<td>40373</td>
<td>1.000241</td>
</tr>
</tbody>
</table>
6. RESULTS

Raw and processed GPS and gravity data are contained on CDROM as Appendix E. Hardcopy plots of station location and coloured images are contained in Appendix A.

6.1 Stations Surveyed and Survey Progress

In total 1292 stations were acquired across the survey area consisting. Of these stations at total of 58 were revisited to ensure data accuracy and quality. A brief production summary for the survey is show in Table 1 below.

Production was excellent with the helicopter crew averaging over 245 stations per day. Due to CASA regulations restricting duty hours for pilots, some time was lost from direct production although the crews used this downtime to conduct helicopter and equipment maintenance and review the acquired data. There was no downtime due to geophysical or GPS equipment failure.

<table>
<thead>
<tr>
<th>Curtin Springs Gravity Survey 2009</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity stations acquired (including repeats)</td>
<td>1292 stations</td>
</tr>
<tr>
<td>Gravity station repeats</td>
<td>58%</td>
</tr>
<tr>
<td>New gravity stations acquired</td>
<td>1234 stations</td>
</tr>
<tr>
<td>Total accidents</td>
<td>0 accidents</td>
</tr>
<tr>
<td>Total hours lost from accidents</td>
<td>0 hours</td>
</tr>
</tbody>
</table>

*Table 1: Gravity Production Summary*

6.2 Data Repeatability

Analysis of the repeat data shows that measurement repeatability is very good for both GPS and gravity observations. Appendix B contains histograms and summary statistics from the analysis. Based on the repeat data, one can assume the following typical accuracies for the observables:

- Z position observation: $< 0.062m$
- Gravity observation: $< 0.036mGals$
APPENDIX A
Plots of station location / Images
APPENDIX B
Repeat Tabulation and Analysis

Histogram dAHD

Histogram dOBSG84

Summary Statistics

<table>
<thead>
<tr>
<th>Summary Table</th>
<th>dAHD</th>
<th>dOBSG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.002</td>
<td>-0.005</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.008</td>
<td>0.005</td>
</tr>
<tr>
<td>Median</td>
<td>0.014</td>
<td>-0.008</td>
</tr>
<tr>
<td>Mode</td>
<td>0.017</td>
<td>-0.008</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.062</td>
<td>0.036</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.198</td>
<td>0.981</td>
</tr>
<tr>
<td>Skewness</td>
<td>-0.126</td>
<td>0.198</td>
</tr>
<tr>
<td>Range</td>
<td>0.286</td>
<td>0.194</td>
</tr>
<tr>
<td>Minimum</td>
<td>-0.146</td>
<td>-0.085</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.140</td>
<td>0.109</td>
</tr>
<tr>
<td>Sum</td>
<td>0.128</td>
<td>-0.315</td>
</tr>
<tr>
<td>Count</td>
<td>58</td>
<td>58</td>
</tr>
</tbody>
</table>
### Quasar NT Regional Gravity Survey

<table>
<thead>
<tr>
<th><strong>Client</strong></th>
<th>Quasar Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survey Name</strong></td>
<td>Curtin Springs</td>
</tr>
<tr>
<td><strong>Gravity Operators</strong></td>
<td>Jon Nankivell, Mark Rosewall</td>
</tr>
<tr>
<td><strong>Pilots</strong></td>
<td>Lee Mitchell, Chris Hall</td>
</tr>
<tr>
<td><strong>Techniques Employed</strong></td>
<td>Post-Process GPS, Gravity</td>
</tr>
<tr>
<td><strong>Station Spacing</strong></td>
<td>1000m</td>
</tr>
<tr>
<td><strong>Line Spacing</strong></td>
<td>1000m</td>
</tr>
<tr>
<td><strong>Gravity Meters</strong></td>
<td>Scintrex CG-5 (A-meter &amp; N-meter)</td>
</tr>
<tr>
<td><strong>GPS Units</strong></td>
<td>Leica 1230GG Base &amp; Rovers</td>
</tr>
<tr>
<td><strong>Number of Points Surveyed</strong></td>
<td>1,292 new, 58 repeats</td>
</tr>
<tr>
<td><strong>Gravity Bases</strong></td>
<td>Daishsat Base 0308</td>
</tr>
<tr>
<td><strong>GPS Bases</strong></td>
<td>Daishsat Base 0308</td>
</tr>
<tr>
<td><strong>Date of Survey</strong></td>
<td>3rd to 8th July 2009</td>
</tr>
</tbody>
</table>
APPENDIX D
Base Station Information
GPS Gravity Base 0308 Curtin Springs

<table>
<thead>
<tr>
<th>MGA94</th>
<th>GDA94</th>
</tr>
</thead>
<tbody>
<tr>
<td>EASTING (m)</td>
<td>777644.670</td>
</tr>
<tr>
<td>NORTHING (m)</td>
<td>7197427.540</td>
</tr>
<tr>
<td>ZONE (UTM)</td>
<td>52</td>
</tr>
<tr>
<td>HEIGHT (AHD, m)</td>
<td>490.412</td>
</tr>
</tbody>
</table>

| LATITUDE (DMS) | 25° 18' 50.2932" S |
| LONGITUDE (DMS) | 131° 45' 28.0353" E |
| Ellipsoidal HT (m) | 493.701 |
| N (AUSGEOID98, m) | 3.289 |

OBSERVED GRAVITY

978781.125mGals (ISOGAL84)

SURVEYED BY

GPS - Daishsat using a multiple static sessions and the AUSPOS online GPS Processing system. Expected accuracy of station coordinates better than 0.005m.

Gravity – Daishsat using SCINTREX digital Gravity Meters conducting 2 B-A-B loops to the AFGN station located at the Yulara Airport terminal. The expected accuracy of the Gravity ties better than 0.01 mGals.

MISCELLANEOUS DETAILS

Daishsat base 308 is located North of the free campground at Curtain Springs Roadhouse along the rear boundary fence approx 25m from the farm gate that faces the Telstra tower.

Curtain Springs Roadhouse is located on the northern side of the Lasseter Highway approximately 120km east of Yulara. Access to the base is by vehicle through the free campground adjacent the Curtain Springs Roadhouse.