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GRAVITY DATA — KINGSTON AND STANLEY 1:250 000 SHEETS WESTERN AUSTRALIA

by S. I. Shevchenko

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

DEPARTMENT OF MINERALS AND ENERGY

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by

S. I. Shevchenko

Abstract

A total of 2314 stations were recorded on an irregular 4 × 4 km grid for two regional gravity surveys conducted by the Geological Survey of Western Australia over the KINGSTON and STANLEY 1:250 000 sheets in April and June 1998. The accuracy of the Bouguer gravity measurements is ±1.9 μms^{-2}.

The surveys cover an area of the eastern part of the Earaheedy and southern part of the Officer Basins. Two regional geophysical provinces are recognized in the area. In the Earaheedy Basin, the Palaeoproterozoic metamorphic and sedimentary rocks of the Earaheedy Group unconformably overlie Archaean granite–greenstones of the Yilgarn Craton, which outcrop in the southern part of the KINGSTON sheet. These rocks form the southern geophysical province. Major gravity and magnetic anomalies and lineaments in this province have a north-northwesterly strike and relate to greenstone units and adjacent faults in the basement. The granitic basement deepens to the northeast to a maximum depth of 5000 m, calculated from magnetic data. Easterly striking regional faults possibly form tilted blocks in the basement.

In the Officer Basin, the Neoproterozoic sedimentary rocks of the Sunbeam Group unconformably overlie the Mesoproterozoic sedimentary rocks of the Bangemall Supergroup. Dolerite sills intruded the Sunbeam Group, and possibly the Bangemall Supergroup. In this region, defined as the northern geophysical province, the major gravity and magnetic anomalies and lineaments have west-northwesterly and northeasterly trends and are interpreted as thrust and strike slip faults. Two major linear gravity structures are interpreted as deep-seated shear zones, possibly delineating the northern and southern margins of the Stanley Fold Belt. A regional positive gravity high is interpreted as high density Bangemall Supergroup under the Sunbeam Group; another positive gravity anomaly, in the northwestern part of the STANLEY sheet, is interpreted as a deep-seated feeder for the dolerite sills.

There is a good correlation of regional regolith geochemistry with gravity and magnetic features. Two areas are considered to be prospective for sulfide-related mineralization. The area of intersection of regional faults in the Wellington Range area coincides with a strong geochemical anomaly. There is another area of structurally controlled geochemical anomalies along the southern margin of the Stanley Fold Belt.

KEYWORDS: gravity data, aeromagnetic data, gravity and magnetic lineaments, structure, Earaheedy Basin, Archaean greenstones, mineralization

Introduction

In 1998, the Geological Survey of Western Australia (GSWA) carried out two regional gravity surveys of the KINGSTON* and STANLEY 1:250 000 map sheets (Fig. 1). Helicopters were used to transport the survey crews to sites, distributed on an irregular 4 × 4 km grid, with gravity meters and dual-frequency Global Positioning System (GPS) units provided by the Australian Geological Survey Organisation (AGSO) under the National Geoscientific Mapping Accord (NGMA).

The two surveys were conducted separately, but processed and interpreted for this Record as one dataset. The surveys were two of a series of combined regional regolith

* Capitalized names refer to standard 1:250 000 map sheets.

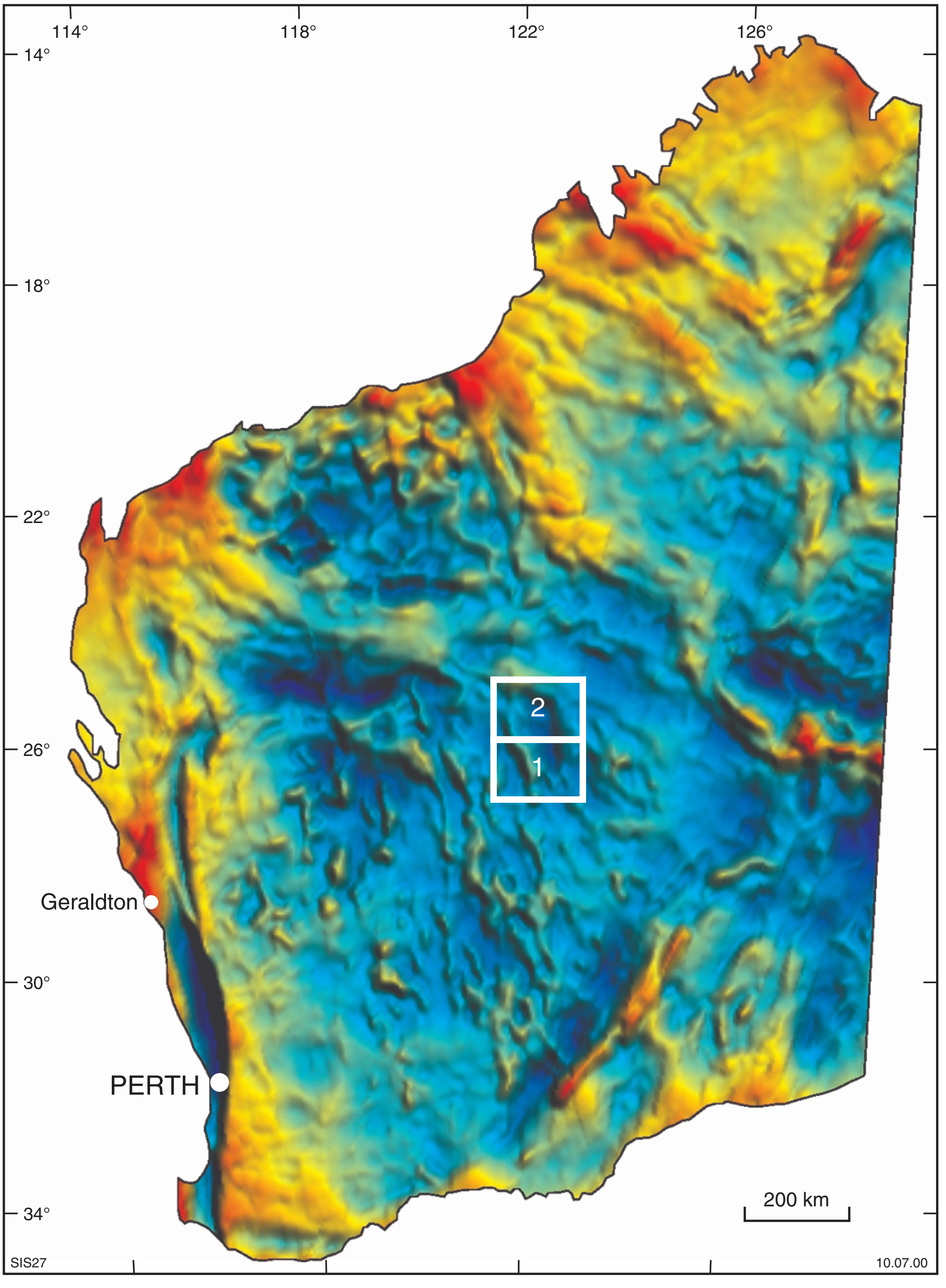

Figure 1. Location of the Kingston (1) and Stanley (2) gravity surveys. Background image is the Bouguer gravity of Western Australia created from the AGSO national gravity database. Datum is in AGD84

geochemistry and gravity surveys conducted in 1998 and 1999. Howard and Shevchenko (2000) described the general survey methodology.

This Record describes details of acquisition and processing of the new gravity data over KINGSTON and STANLEY, and includes a structural interpretation of the new gravity and existing aeromagnetic data.

Pye et al. (2000) and Morris et al. (2000) described the logistics and results of the geochemical programs for KINGSTON and STANLEY. The **Geological setting** of this Record is extracted from Morris et al. (2000) and Pye et al. (2000).

Geological setting

The five major tectonic units recognized on KINGSTON and STANLEY are: 1) Archaean granite–greenstones of the Yilgarn Craton (southwestern part of KINGSTON); 2) Palaeoproterozoic metamorphic and sedimentary rocks of the Earaheedy Group (deposited in the Earaheedy Basin); 3) Mesoproterozoic sedimentary rocks and dolerites assigned to the Bangemall Basin (Scorpion and Collier Groups); 4) Neoproterozoic Officer Basin (Sunbeam Group and Glenayle Dolerite); and 5) Palaeozoic sedimentary rocks of the Paterson Formation (deposited in the Gunbarrel Basin). The distribution of these rock types is shown in Figure 2.

Archaean granite–greenstones

The southwest part of KINGSTON is occupied by granitoid and greenstone rocks of the Archaean Yilgarn Craton, which forms crystalline basement on which Proterozoic rocks have been deposited.

Three types of granitoid rock were recognized by Bunting (1980). Of these, the most abundant is a fine- to coarse-grained adamellite with a weak gneissic foliation. The other two types are fine- to coarse-grained, deeply weathered granitoid with a strong gneissic foliation, and a coarse-grained biotite adamellite.

Scattered outcrops of Archaean granitoid rocks of the Malmac Inlier are found north of the Lee Steere Range on STANLEY. These rocks consist of metamorphosed medium- to coarse-grained, porphyritic granitic rocks (Commander et al., 1982).

The two greenstone belts exposed on KINGSTON comprise the Mount Eureka greenstone belt in the west, and the Gerry Well greenstone belt in the central southern part of the map sheet. The greenstones are intruded by syntectonic granitoid plutons. The Mount Eureka greenstone belt consists of metamorphosed mafic, ultramafic, and sedimentary rocks (chert, shale, banded iron-formation (BIF), and possible felsic volcanic rocks), and extends south onto DUKETON. The Gerry Well greenstone belt, which may be a northern extension of the Duketon belt, consists of BIF, chert, shale, amphibolite, dolerite, and felsic schist.

Earaheedy Group

The Earaheedy Group (about 5000 m thick) is dominated by siliciclastic sedimentary rocks, predominantly sandstone and shale, with subordinate limestone and granular iron-formation. Detrital zircons from the basal Yelma Formation provide a maximum age of 2.0 Ga (Pirajno and Jones, in prep.). The Earaheedy Group is deformed by the Stanley Fold Belt and was deposited between 2.0 and 1.76 Ga.

Yelma Formation

The Yelma Formation is the basal unit of the Earaheedy Group, and unconformably overlies Archaean granitic rocks, and is in turn conformably overlain by the Frere Formation. The thickness ranges from 3 m in southeast KINGSTON to 1500 m in the west, and is typically less than 100 m thick on STANLEY. It consists of sandstone, shale, and siltstone, with an upper dolomite unit (Sweetwaters Well Member).

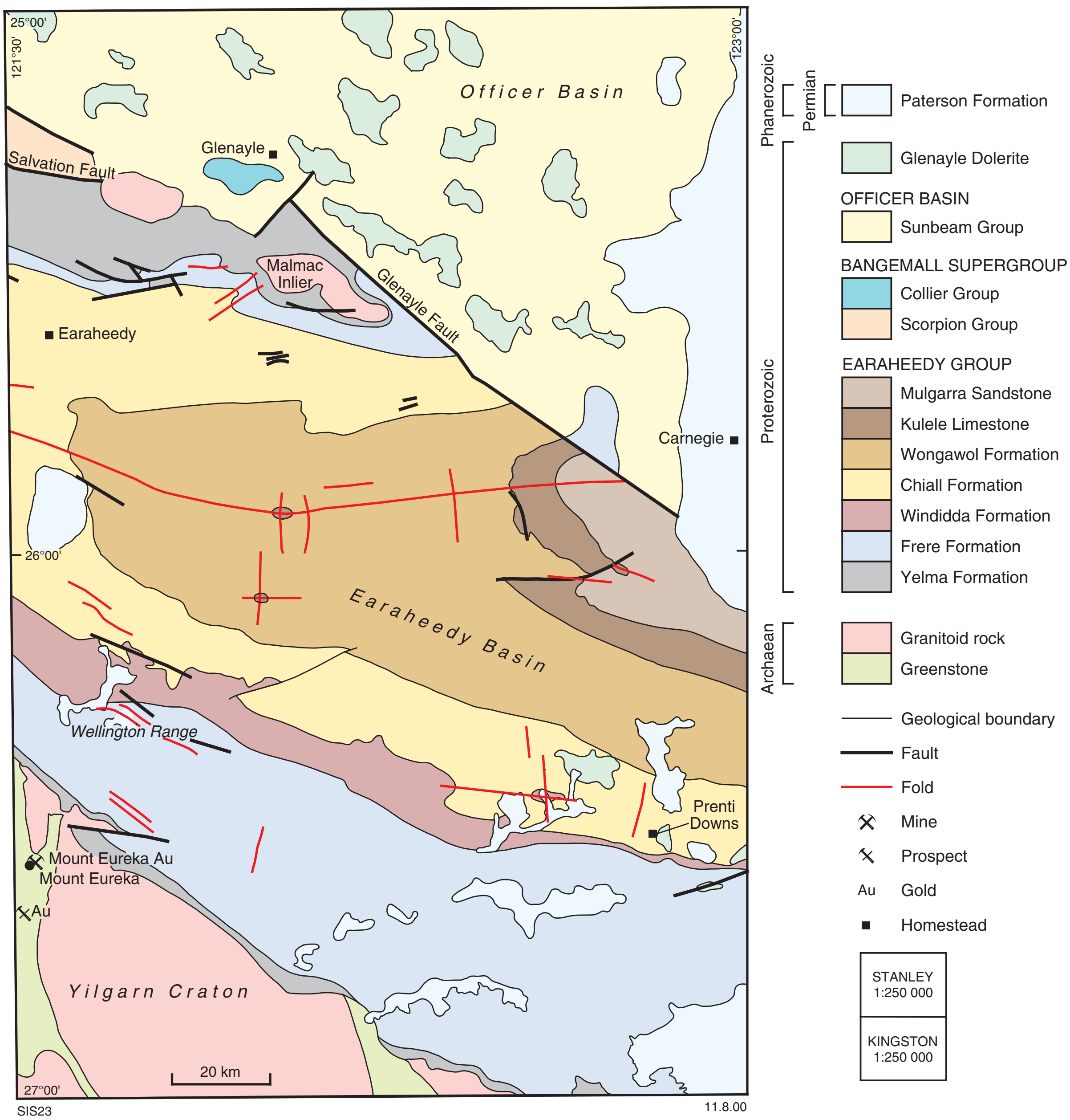

Figure 2. Generalized geological interpretation of KINGSTON and STANLEY (after Bunting (1980, 1986) and Myers and Hocking (1998))

Frere and Windidda Formations

The Frere Formation is an approximately 1200 m-thick unit of chemically deposited and mechanically reworked granular iron-formation, interbedded with iron-rich shale, fine-grained clastic rocks, and subordinate, carbonate-rich rocks. Several iron-formation members, between 10 and 50 m thick, form a series of parallel ridges in the Lee Steere Range area and Mudan Hills. These units are separated by three major bands of purple and cream shale. Each iron-formation member consists of alternating bands of hematitic shale and granular iron-formation, locally with chert horizons. The formation was deposited in a shallow-marine nearshore environment in mixed low- and high-energy settings (Bunting, 1986), probably on a passive continental margin (Jones et al., 2000). The ratio of iron formation to shale decreases from the west (on NABBERU) to the east (on KINGSTON and STANLEY), with increasing water depth (Jones, A. and Pirajno, F., 1999, pers. comm.).

On Kingston, the Frere Formation is conformably overlain by the Windidda Formation, a 1200 m-thick succession of carbonate-rich rocks and shale (Hall et al., 1977).

Chiall Formation

The Chiall Formation comprises the previously mapped 'Wandiwarra Formation' and 'Princess Ranges Quartzite' (Pirajno et al., 1999; Hocking et al., 2000; Fig. 2). These units have been reduced to member status. The Wandiwarra Member consists of shale and fine- to coarse-grained quartz sandstone, with locally developed glauconitic units. The shale is maroon to white and well cleaved, with fine-grained, sandstone intercalations. The Wandiwarra Member is conformably overlain by the Princess Ranges Member, a white, well-sorted arenite with siltstone interbeds. Cross-bedding, graded bedding, ripples, and clay intercalations are abundant.

Wongawol Formation

The Wongawol Formation is about 1500 m thick and marks a gradual fining-upwards transition from mature clastic sedimentation of the Princess Ranges Member of the Chiall Formation, to carbonate sedimentation of the Kulele Limestone. The unit consists of fine arkosic sandstone and shale, grading upwards into mudstone, sandstone, and shale. Sedimentary structures indicate a low-energy, very shallow marine to intertidal depositional setting (Jones, A. and Hocking, R. M., 1999, pers. comm.).

Kulele Limestone

The Kulele Limestone, a 300 m-thick unit overlying the Wongawol Formation, consists of stromatolitic limestone, cross-bedded calcarenite, and mudstone, and is characterized by metre-scale shallowing-upwards cycles.

Mulgarra Sandstone

The Mulgarra Sandstone is a mainly fine to medium grained quartz sandstone with minor carbonate bands, and locally developed glauconite. The basal 20 m are medium-grained, ferruginous quartz arenite. In the middle of the formation, there are some thin arenite beds with shale and pink limestone layers. The formation is thought to represent shallow-marine deposition, but it is unclear whether the sequence is transgressive or regressive, as there is evidence to support both models (Bunting, 1986). The total thickness of the formation cannot be determined because of poor exposure; however, it is estimated to be about 100 m thick. The Sunbeam Group and Permian Paterson Formation unconformably overlie the Mulgarra Sandstone.

Bangemall Supergroup

Parts of the Mesoproterozoic Bangemall Supergroup are exposed in the northern half of Stanley, including the Scorpion and Collier Groups.

Scorpion Group

The thick (10 km), folded sequence of sandstone, shale, conglomerate, and dolomite of the Scorpion Group is in faulted contact with the older Earaheedy Group along the Salvation Fault. The Scorpion Group probably correlates with the c. 1640 Ma Edmund Group to the west. Some areas previously mapped as Scorpion Group have now been assigned as Coonabildie Formation or Collier Group. The Sunbeam Group of the Officer Basin (Bagas et al., 1999) overlies the Scorpion Group to the north.

Collier Group

Collier Group rocks, which are now thought to be c. 1200 Ma, are only recognized south of Glenayle, where they consist of ripple-bedded and cross-bedded quartz sandstone, with locally developed quartz veins and stockwork (Hocking, R. M., 1999, pers. comm.).

Officer Basin

Sunbeam Group

Relatively undeformed sedimentary rocks on the northern part of STANLEY were initially assigned to the Bangemall Basin by Commander et al. (1982), and subsequently placed in the younger, Savory Basin succession by Williams (1992). The Savory Basin is now recognized as part of the Officer Basin, and Bagas et al. (1999) have assigned older rocks of the former Savory Basin to the Sunbeam Group. R. M. Hocking (1999, pers. comm.) suggested that both the (former) Savory Basin and Bangemall Basin rocks in the northern part of STANLEY should be assigned to the Coonabildie Formation or Brassey Range Formation, and included in the Sunbeam Group. This approach is adopted here, although subdivisions of the Sunbeam Group (Coonabildie Formation and Brassey Range Formation) are not shown on Figure 2, but their constituent lithologies are briefly discussed.

The Coonabildie Formation comprises interbedded siltstone and quartz arenite overlying a basal, laminated and bedded chert. It is a coarsening-upwards prodelta to delta-front sequence (Hocking, R. M., 1999, pers. comm.). Rocks shown by Commander et al. (1982) as Marlooyanoo Formation are now included in the Coonabildie Formation. The Brassey Range Formation conformably overlies the Coonabildie Formation on STANLEY. It is exposed as low hills jutting out of wind-blown sand in the northern third of the sheet. The majority of the unit is fine- and medium-grained, siliceous quartz arenite. Less common fine-grained sandstone and siltstone are also present (Hocking, R. M., 1999, pers. comm.). The unit is a delta front to fluvial deposit.

Glenayle Dolerite

The Glenayle Dolerite consists of dolerite and gabbro sills and dykes, which are widespread on STANLEY and in the eastern part of KINGSTON. The sills and dykes are concordant or slightly discordant in the Sunbeam Group, indicating they are post-Neoproterozoic. These intrusive rocks are fresh to weakly altered and largely composed of plagioclase (locally sericitized), clinopyroxene, ilmenite, with accessory biotite and titanomagnetite. More fractionated units contain abundant granophyric intergrowths (quartz and feldspar).

Paterson Formation

The Paterson Formation is an Early Permian, flat-lying, glacial and fluvioglacial succession, which can be divided into three lithofacies — tillite (non-bedded, poorly sorted, boulder conglomerate to pebbly, clayey siltstone), cross-bedded conglomeratic sandstone of fluvioglacial origin, and lacustrine siltstone. These rocks are deeply weathered, and in some places are completely capped by silcrete. Locally developed cross-bedding indicates a north to north-northeasterly transport direction. A polymictic boulder lag (originally glacial erratics and moraine) is widespread over the southern part of STANLEY, and scattered boulders are found in some areas resting on Earaheedy Group rocks.

Gravity data

Previous data

As part of regional gravity surveys across parts of Western Australia, the Bureau of Mineral Resources covered the area with an 11 × 11 km survey in 1969–70 (Fraser and Pettifer, 1980). The relatively poor accuracy of the Bouguer gravity (±10 μms^{-2}) is mainly due to low accuracy in the barometrically measured station heights (about ±1.8 m; Darby, 1970).

In 1995, the GSWA conducted a gravity survey over an area of 50 × 260 km across the northwestern part of the Officer Basin (formerly Savory Basin) for the purpose of structural interpretation. The helicopter survey covered part of the northwestern corner of STANLEY, with gravity stations reading on a 2 × 3 km grid and an accuracy of the Bouguer gravity of ±0.6 μms^{-2} (Daishsat Pty Ltd, 1995).

New gravity data

The 1998 GSWA helicopter-supported gravity survey acquired readings on an approximately 4 × 4 km grid on KINGSTON and STANLEY using dual-frequency GPS equipment to obtain accurate positions for the gravity stations. Some road traverses were also conducted, mainly for the purpose of operator training but also to fill in some gaps in the helicopter coverage. The survey specifications and procedures for both surveys are listed in Appendices 1–8.

The data were reduced to Bouguer gravity values for a density of 2670 kgm^{-3} and gridded to a 1500 m cell size (Fig. 3). The first vertical derivative (1VD) of the Bouguer gravity is shown in Figure 4.

Magnetic data

Two airborne magnetic surveys with north–south oriented lines were flown over STANLEY. In 1986, CRA conducted a survey in the central part of the sheet with a line spacing of 300 m. GSWA and AGSO in a joint venture flew another survey in 1999 over the rest of STANLEY with a line spacing of 400 m. In 1998, AGSO conducted an airborne magnetic survey over KINGSTON with east–west oriented lines and a line spacing of 400 m. The total magnetic intensity (TMI) image of 100 m grid-cell size of these surveys is shown in Figure 5.

Geophysical signatures

The area of investigation can be divided into two major regional geophysical provinces according to the patterns and sources of the gravity and magnetic anomalies. The southern geophysical province includes parts of the Yilgarn Craton and Earaheedy Basin. The northern province includes parts of the Officer and Bangemall Basins.

The regional structure of the Earaheedy Basin, an arcuate, asymmetrical syncline with an approximate easterly trending axis (Bunting, 1986), is not apparent on the Bouguer gravity image (Fig. 3). The axis of the regional 250 μms^{-2} negative anomaly (gn; Fig. 3) is oriented north-northwest, does not reflect the shape of the syncline, and probably represents a thick sedimentary section. The positive regional anomaly (go; Fig. 3) to the east can be explained by the shallowing of the basement, or more likely, by the presence of a higher density, sedimentary section underlying the Earaheedy Group. The positive northwesterly trending anomaly (gp; Fig. 3) to the west is an intrabasement feature. Using the infinite plate body formula and assuming a 150 kgm^{-3} density contrast between crystalline basement and the Earaheedy Group strata, a depth of 4 km to basement was estimated. Magnetic anomalies of this province, mainly from mafic intrusions in the basement, change from a high to low frequency gradually, suggesting that the basement deepens to the north under the Earaheedy Group (Fig. 5).

The positive, north-northwesterly oriented, linear and medium-wavelength (10–20 km) gravity anomalies (green lines in Fig. 6) are the most distinctive features in this area. These anomalies have high values of 200–250 μms^{-2} due to high-density rocks in the granitic basement, and are interpreted as greenstones (blue lines in Fig. 6). Most of them are coincident with positive high-intensity magnetic anomalies probably due to ultramafic and BIF rocks within the greenstones sequence.

There are three groups of these anomalies: western, central, and eastern. At the western edge of KINGSTON, anomaly ga (Fig. 6) is coincident with a high-intensity magnetic anomaly ma (Fig. 7), which occurs over the Mount Eureka greenstone belt. Another anomaly gb, parallel to ga on Figure 6, has a similar shape and is also interpreted as a narrow greenstone belt under Cainozoic cover. This structure has not been mapped at the surface. Interpretation of this greenstone belt is therefore tentative due to its small gravity response (40 μms^{-2}).

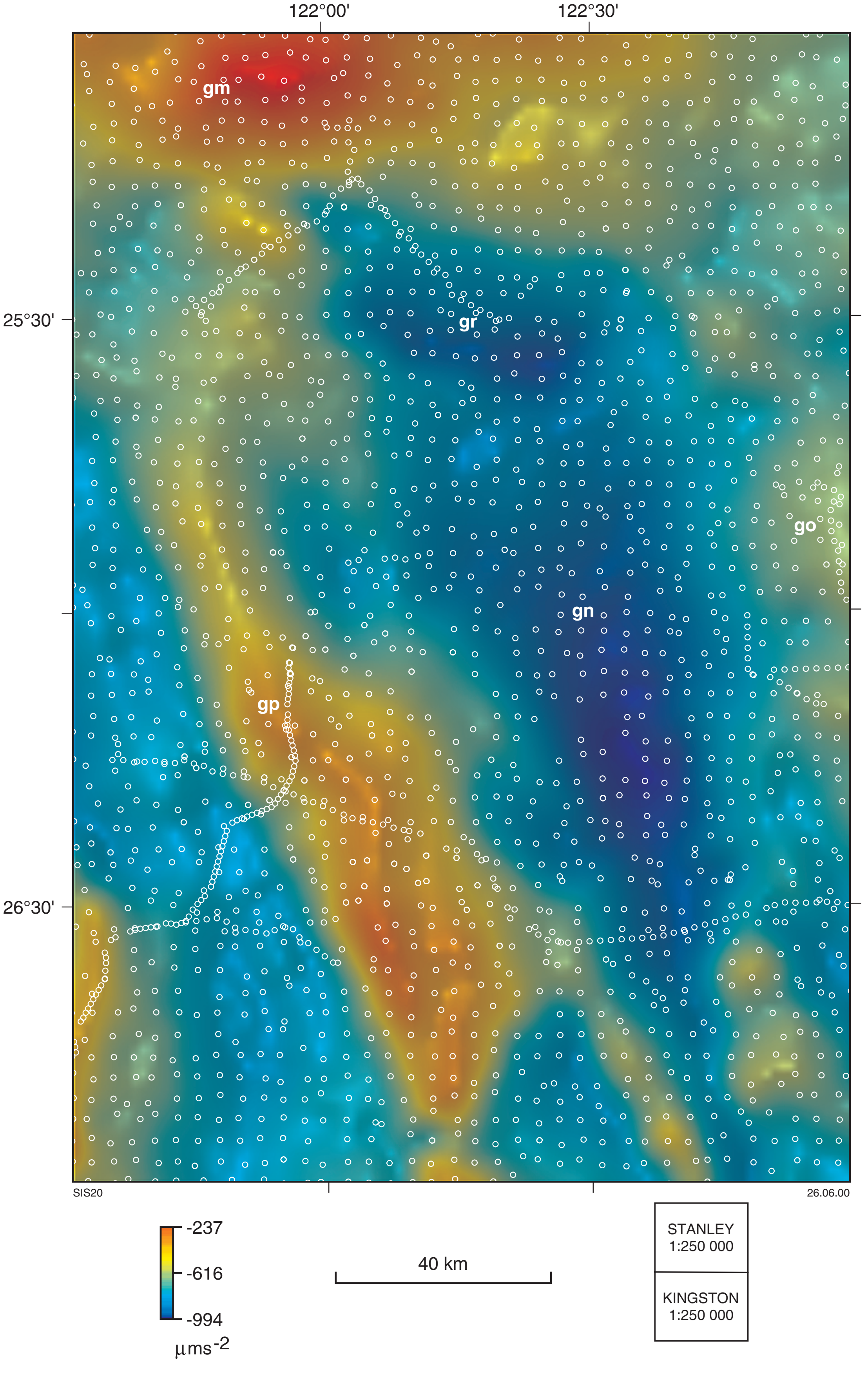

Figure 3. Bouguer gravity image. Circles show the locations of the gravity stations

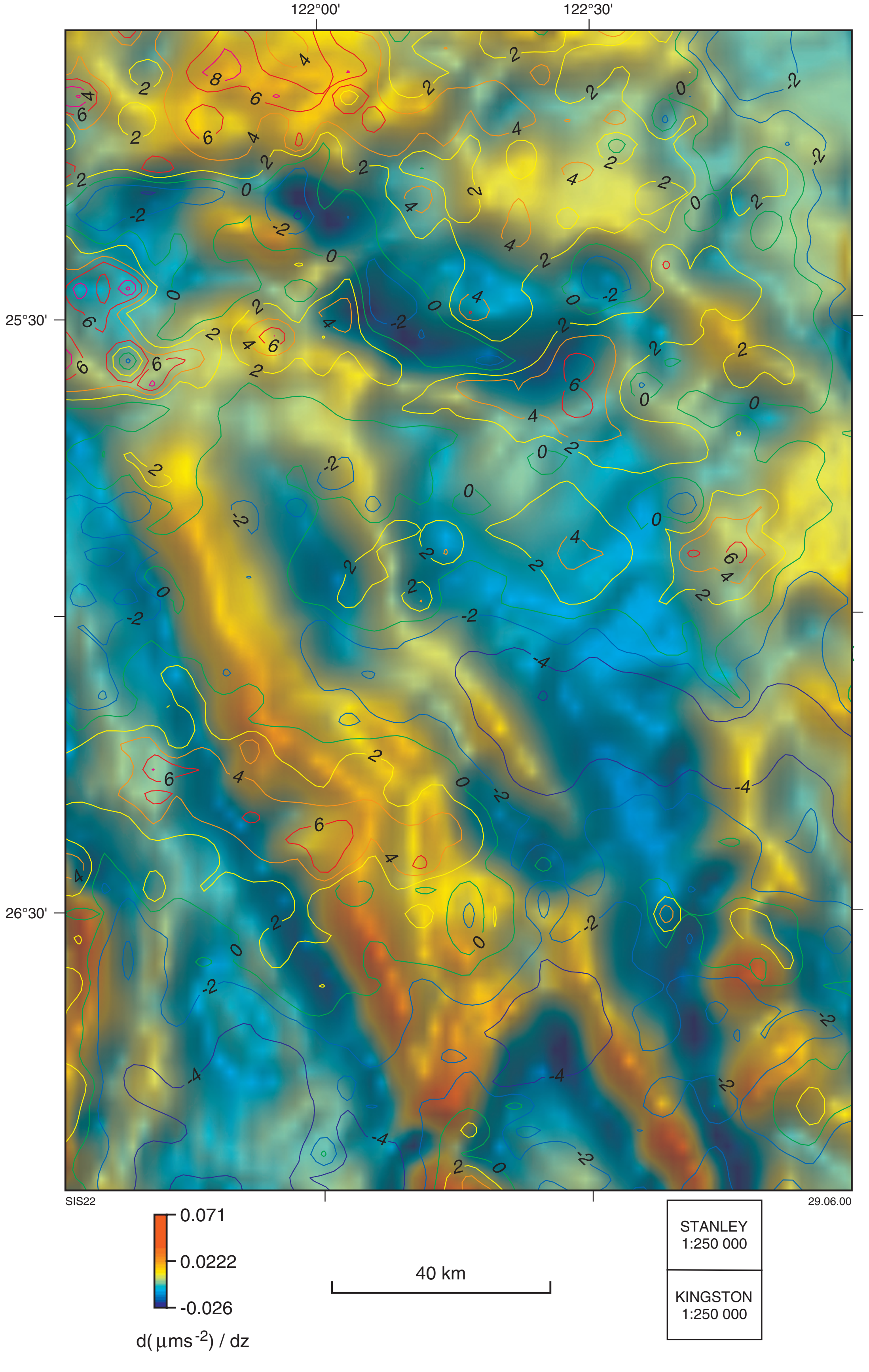

Figure 4. First vertical derivative of the Bouguer gravity with a chalcophile-index map (from Morris et al., 2000; Pye et al., 2000) as the contours

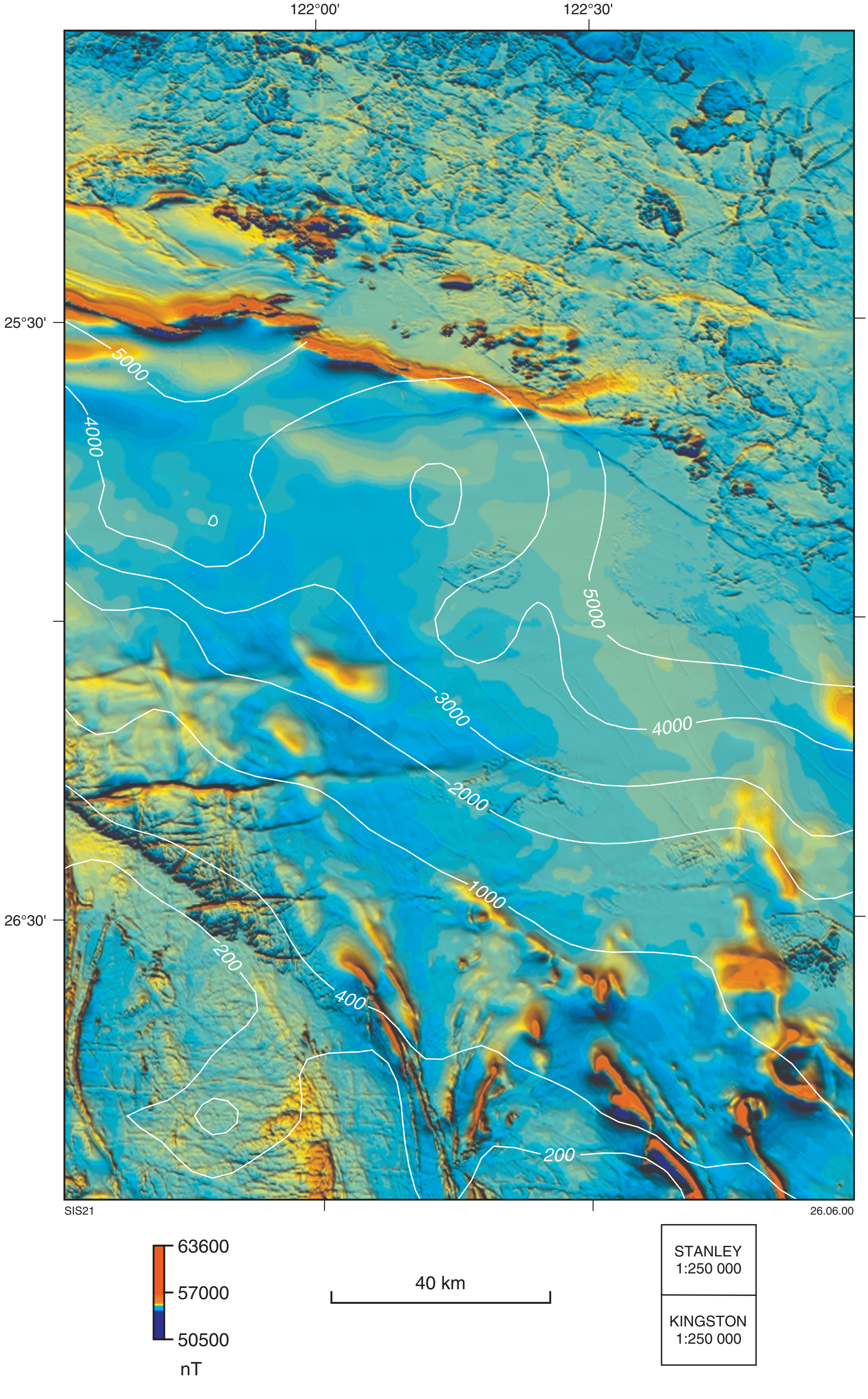

Figure 5. Total magnetic intensity with interpreted depth to basement as the contours in metres

The greenstones of the central part consist of several anomalies (gc–gf; Fig. 6) suggesting the presence of subparallel greenstone belts below the sediments. Some of these structures form a dome (gf; Fig. 6) in the southern part of KINGSTON. The high-intensity, linear magnetic anomalies are generally coincident with gravity anomalies in this area (Fig. 7). They decrease in intensity in the north and completely disappear at 26°30'S, suggesting deepening of the basement. The western and, less clearly, eastern parts of these greenstones are likely limited by pre-Proterozoic regional faults gg and gh (Fig. 6) in the basement. The fault gg also has a magnetic signature suggesting reactivation in post-Palaeoproterozoic time.

The third, eastern group of gravity (gi and gj; Fig. 6) and coincident magnetic anomalies (Fig. 7) form circular structures in the southeastern corner of KINGSTON. They also may be interpreted as greenstone belts.

The extensively developed gravity anomalies up to the Glenayle Fault are interpreted as greenstone units, thus indicating that the granite–greenstone rocks of the Yilgarn Craton floor the entire Earaheedy Basin (Figs 6 and 7).

Four major parallel, easterly trending lineaments from the TMI image (mb, mc, md and me; Figs 6 and 7) are interpreted as regional faults intruded by dykes of mafic composition. These faults extend up to 150 km to the west. Fault md (Fig. 7) displaces the rocks of the Earaheedy Basin by about 5 km, indicating post Palaeoproterozoic movements. Fault me was partly mapped by Bunting (1980) at the surface in the northwestern part of KINGSTON. The gravity anomaly gc is offset by this fault, with an apparent lateral displacement of about ?10 km along the lineament mc (Figs 6 and 7). These four faults are likely to form blocks with vertical offsets in the basement. Northwesterly trending lineaments mf, mh, and mi from the TMI image are more likely to be regional faults. They correlate well with the faults and folds mapped at the surface in the Wellington Range area (Figs 2 and 7).

The chalcophile-index map of Pye et al. (2000), shown on Figures 4 and 6, indicates a strong index anomaly in the western part of KINGSTON in the area where the lineaments mb, mc, md, and me intersect with gg, mg, and mf. Moreover, contours 0 and 2 of this anomaly (Figs 4 and 6) follow the lineament gg, indicating anomalous index values along this structure. The peak value (>4) of this anomaly (Fig. 4) is the highest index value on KINGSTON, and coincides with the intersection of the regional lineament gg with mb, mc, and mf in the Wellington Range area. This area of closely spaced faults (Figs 2 and 6), with the relatively tight folding, brittle deformation, and associated quartz veining, has potential for structurally controlled sulfide mineralization (Pye et al., 2000).

There are another three high chalcophile-index anomalies on KINGSTON coincident with gravity lineaments ga, gj, gl, and the southern part of gd (Fig. 6), which are mapped or interpreted as greenstones.

In the northern geophysical province on STANLEY, the positive regional gravity (Fig. 3) north of lineament gl (Fig. 6) may represent buried Bangemall Supergroup rocks beneath the Sunbeam Formation. The stratigraphic well, Trainor 1, 60 km north of STANLEY in the Officer Basin, intersected these high-density sedimentary rocks of 2650–2750 kgm^{-3}. They have been interpreted as Bangemall Supergroup beneath the low-density sediments (2350–2550 kgm^{-3}) of the McFadden Formation (Stevens and Adamides, 1996). In the northern geophysical province, regional gravity lineaments have mainly northwesterly and northeasterly trends. The northeasterly lineaments are probably strike-slip faults. Of these, go and gr (Fig. 7) also have a strong magnetic signature. The northwesterly lineaments are probably thrust faults and folds. A possibly deep-seated shear zone is interpreted along the lineament gl and is the major linear structure of this province and a structural boundary. The lineament coincides with the Salvation Fault in the west, which has been mapped on the surface. The Salvation Fault continues to the east and, on STANLEY, represents the northern limit of the Stanley Fold Belt. Another major easterly trending lineament (gn; Figs 6 and 7) is probably a deep shear zone, which forms the southern margin of the Stanley Fold Belt. This structure can be traced for about 100 km to the east. A high chalcophile-index anomaly coincides with this lineament (Figs 4 and 6), indicating the potential for structurally controlled sulfide mineralization.

Positive, short-wavelength (<10 km) gravity anomalies north of gl (Fig. 6) may be related to dolerite sills (Glenayle Dolerite; Hocking et al., 2000). A large, positive anomaly

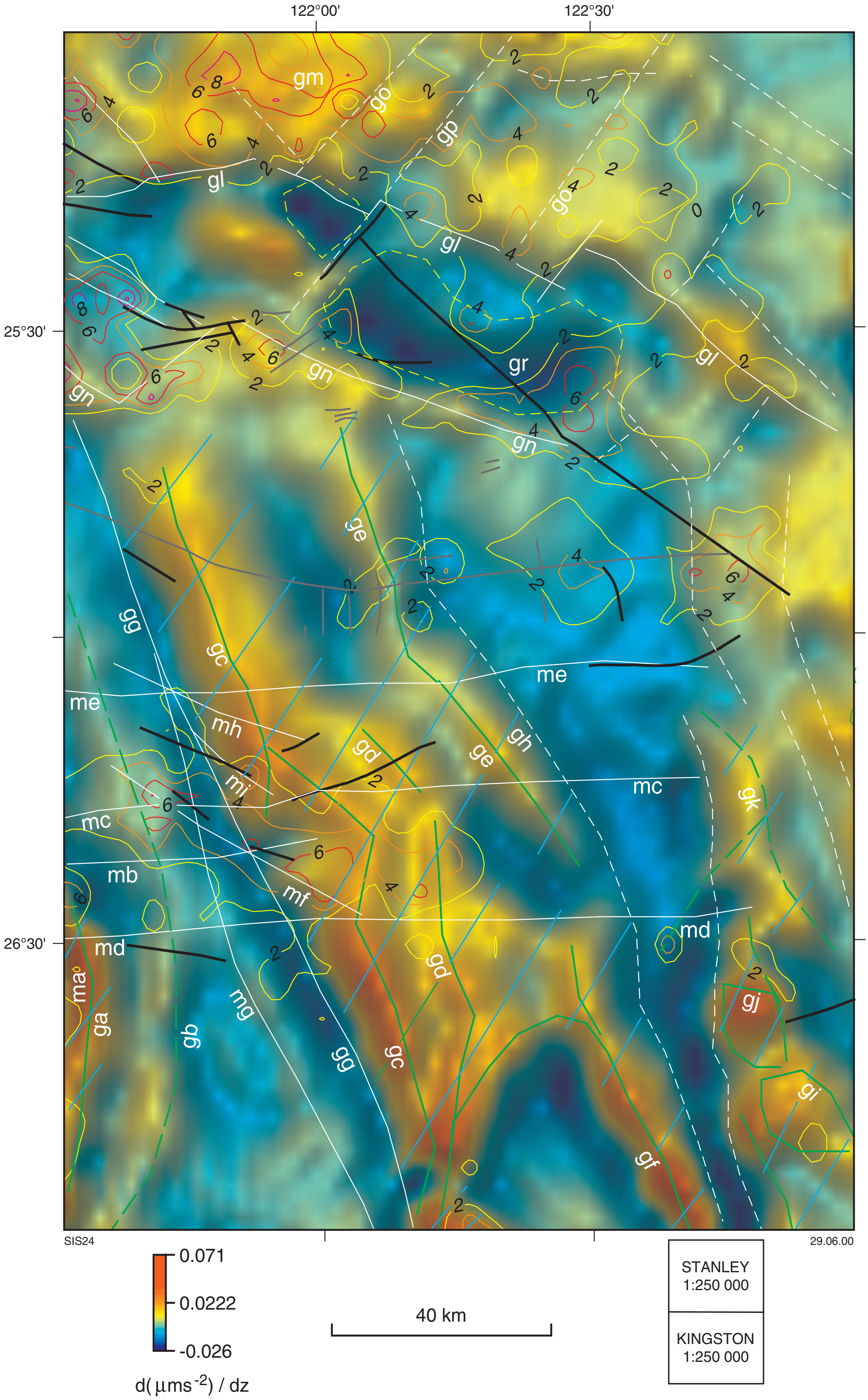

Figure 6. **First vertical derivative of Bouguer gravity with interpretation (solid lines — features interpreted with high confidence; dash lines, with less confidence). White lines — regional faults. Green lines — axes of the greenstone belts. Blue lines — greenstones exposed on the surface of the basement. Black thick lines — faults mapped at the surface. Grey thick lines — folds mapped at the surface. Yellow dash lines — Malmac Inlier granitic rocks. Yellow, red, orange, and purple contours — high-value anomalies of chalcophile-index map (Morris et al., 2000; Pye et al., 2000)**

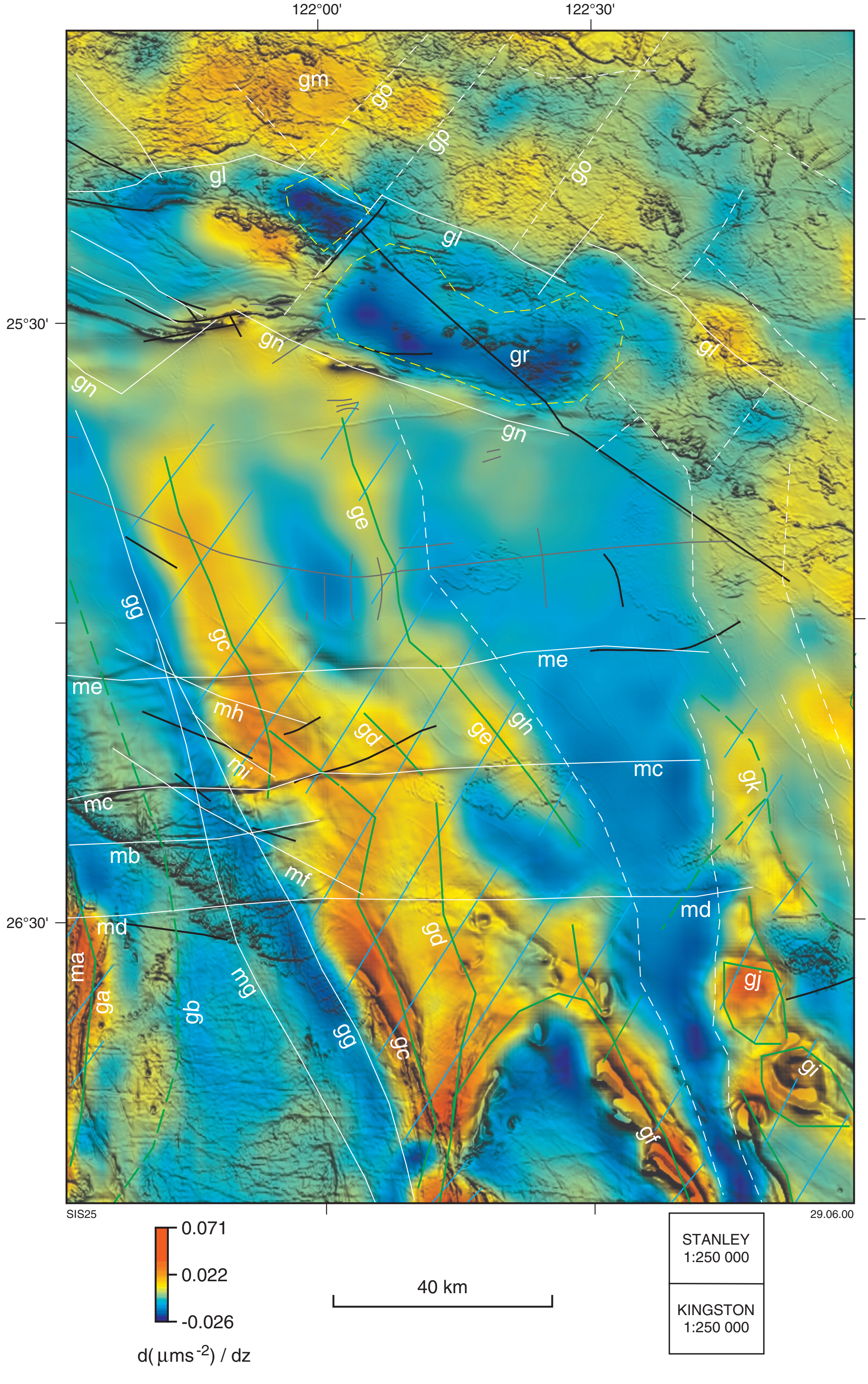

Figure 7. First vertical derivative Bouguer gravity (pseudocolour) and total magnetic intensity (intensity) with interpretation. See Figure 6 for explanation of features illustrated

on northwest STANLEY (gm; Fig. 6) is likely to represent a deep-seated mafic body, probably a feeder to the Glenayle Dolerite. Anomaly gm coincides with the highest values for platinum group elements (PGE) in the regolith (Morris et al., 2000). This suggests that the area has potential for magmatic ore deposits (Pirajno, F. and Morris, P., 2000, pers. comm.).

The negative gravity anomaly in central STANLEY (dashed yellow line in Fig. 6) possibly relates to granitic rocks of the Malmac Inlier. The inlier could be an uplifted basement block. Alternatively, its circular shape and lower density than the surrounding Earaheedy and Bangemall Basin rocks could be a coherent intrusive body within the sedimentary section (Pirajno, F., 2000, pers. comm.). A density analysis of the granitic and surrounding rocks is needed to confirm this interpretation.

Depth to magnetic basement

Granite–greenstone rocks of the Yilgarn Craton are exposed in the southwestern part of KINGSTON. Magnetic anomalies, mainly from dykes in the basement, change from a high to low frequency gradually, suggesting that the magnetic basement deepens to the north beneath the Earaheedy Group. Depths to magnetic basement (Fig. 5) were calculated using the Naudy automated method. This calculation indicates that the basement is covered by thin (200–300 m) Cainozoic sediments in the south-southwest and deepens to the northeast.

The magnetic response of the Frere Formation and other sedimentary units near the northern margin of the Earaheedy Basin, and dolerite sills within sedimentary rocks of the Bangemall Supergroup and Sunbeam Group, prevent reliable calculations of depth to magnetic basement in the northern and eastern parts of STANLEY. However, the contrast between the calculated depths of around 5000 m in the north and east of the Earaheedy Basin and the geologically estimated maximum thickness of 1500 m of exposed Yelma Formation, which presumably overlies the granitic basement in the eastern part of STANLEY, may be indicative of a steeply rising basement.

Conclusions

In conjunction with regional magnetic data, the gravity survey of the KINGSTON and STANLEY region provides new regional structural information in an area where only readings from widely spaced (11 × 11 km) gravity stations had been previously collected.

Two major geophysical regional provinces can be identified in the area, based on the patterns and sources of the gravity and magnetic anomalies. In the southern geophysical province, the Yilgarn Craton basement deepens towards the northeast, beneath the unconformably overlying Earaheedy Basin to a depth of 5000 m, as calculated from magnetic data. The major gravity anomalies and lineaments have north-northwesterly trends and relate to greenstones and adjacent faults. The area of the intersection of regional faults coincides with a strong chalcophile-index geochemical anomaly. This coincidence suggests that these faults may be the sites of mineralization.

The northern province is characterized by major gravity anomalies and lineaments, with northwesterly and northeasterly trends. Two major linear structures, interpreted as deep-seated shear zones, mark the northern and southern limits of the Stanley Fold Belt. A regional gravity high is associated with the buried, high density Bangemall Supergroup under the Sunbeam Group. The positive gravity anomaly in northwestern part of STANLEY is probably related to a deep-seated feeder for the Glenayle Dolerite.

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Appendix 1

Summary of operation and processing for the KINGSTON gravity survey

Organization: Geological Survey of Western Australia
Start date: 12 April 1998
Completion: 22 April 1998

	GPS	*Gravity*
Equipment	4 Ashtech Z12 receivers N223, N226, N900, N942	LaCoste and Romberg Model G × 5 units G20, G101, G132, G252, G460 Worden W169
Data recording and processing notebook computers	Pentium II 233 MHz, 32 Mb RAM; 80486DX 75 MHz, 8 Mb RAM; 80486DX 50 MHz, 4 Mb RAM	
Calibration		By AGSO 1998
Surveying transport	Helicopters J Bell 206B3 (Jet Ranger) × 2 Land Cruiser 4-wheel drive	
DOLA bench marks used	Kingston 1 to transfer the coordinates and height to 9961.7001 twice GK 71 for position and height control 9961.7001 to transfer the height to 9961.7002 twice NMF 666 to transfer the coordinates to 9961.7002	6491.9087 (Windidda isogal station) 5099.9922 (Wiluna isogal station)
New base stations	9961.7001, 9961.7002	9961.7001, 9961.7002
Survey method used to establish base stations	Static	4 gravimeters, two operators in one traverse
Survey method for ordinary stations	Kinematic with 100% repeats	1 gravimeter, 1 operator, two readings, 1184 stations 4 × 4 km irregular grid
Software for reductions and field processing	PRISM (Ashtech proprietary software package)	SERGRAV (GSWA in-house suite of programs) SURFER v. 5.01 (from Golden Software Inc.)
Office processing software		INTREPID v. 3.4 processing and gridding program ER Mapper v. 6.0 image processing system
Accuracy	$\sigma_{elevation} = \pm 0.6$ m $\sigma_{x,y} = \pm 5$ m	$\sigma_{gravity\ base\ stations} = \pm 0.2\ \mu ms^{-2}$ $\sigma_{stn} = \pm 0.4\ \mu ms^{-2}$
Total Bouguer accuracy		$\sigma_{survey} = \pm \sqrt{(1.8^2_{elev} + 0.2^2_{base\ stns} + 0.4^2_{stns} + 0.5^2_{abs.\ transf})}$ $= 1.9\ \mu ms^{-2}$

Appendix 2

Survey personnel for the KINGSTON gravity survey

Project manager	*Gravity survey manager*	*Gravity observers*	*Gravity field assistant*	*Helicopter company*	*Chief pilot*	*Pilots*	*Engineer*
D. Howard	S. Shevchenko	S. Baesjou E. Bosanquet E. Mikucki J. Moore J. Hansen N. Nasev	T. Davis	Helicopters Australia	M. Corbett	S. Eder C. Hole A. Regan	N. Luscombe

Appendix 3

Bench mark data and repeat measurements for the KINGSTON gravity survey

Table 3.1. Coordinates of DOLA[(a)] bench marks used to establish base stations and isogal stations

Name	*Comments*	*Type of mark*	*Type of datum/grid*	*Latitude (S)/ easting (m)*	*Longitude (E)/ northing (m)*	*AHD[(f)] height/ AMG[(e)] zone*	*Date surveyed*	*Method*	*Order*	*Horizontal/ vertical accuracy*	*Gravity value (μms^{-2})*	*Gravity error (μms^{-2})*
Kingston 1[(b)]	–	S[(c)]	AGD84[(d)]	26°34'14.20892"	121°31'52.75360"	532.800	01/03/1998	GPS[(g)]	2nd	10 ppm	–	–
			AMG84[(e)]	353725.115	7060272.941	51		GPS[(g)]	2nd	0.1 m		
GK 71[(b)]	Control	S[(c)]	AGD84[(d)]	26°22'49.56696"	122°10'34.18678"	465.854	30/03/1993	GPS[(g)]	2nd	10 ppm	–	–
			AMG84[(e)]	417817.662	7081911.617	51		SLEV[(h)]	3nd	12 √K (mm)		
NMF 666[(b)]	–	S[(c)]	AGD84[(d)]	26°30'21.72775"	122°59'56.58573"	443.000	01/04/1993	GPS[(g)]	2nd	10 ppm	–	–
			AMG84[(e)]	499905.495	7068263.817	51		GPS[(g)]	2nd	0.1 m		
9961.7001	GPS and	SP[(j)]	AGD84[(d)]	26°28'35.07407"	121°46'39.40968"	480.909	04/04/1999	GPS[(g)]	–	–	9788887.1	0.5
Banjo Well	gravity base		AMG84[(e)]	378158.039	7070965.434	51		GPS[(g)]	–	–		
9961.7002	GPS and	SP[(j)]	AGD84[(d)]	26°31'15.19114"	122°48'32.54268"	470.45	9/04/99	GPS[(g)]	–	–	9788982.3	0.2
Prenti Downs	gravity base		AMG84[(e)]	480974.109	7066604.890	51		GPS[(g)]	–	–		
5099.9922 Wiluna	AGSO isogal station	–	AGD84[(d)]	26°35'48"	120°13'18"	513	1964	GPS[(g)]	–	–	9789409.5	–
6491.9087 Windidda	AGSO isogal station	–	AGD84[(d)]	26°22'49"	122°10'34"	465	1964	MAP[(i)]	–	–	9789138.6	–

NOTES:
(a) Department of Land Administration
(b) Coordinates from DOLA
(c) Standard survey mark
(d) Australian Geodetic System 1984
(e) Australian Map Grid 1984
(f) Australian Height Datum
(g) Global Positioning System
(h) Spirit level
(i) From a map
(j) Star picket and metal peg

Table 3.2. Observed coordinate differences

Bench mark	Observed GPS[a] –1st time			Observed GPS[a]–2nd time			Differences		
	Easting (m)	*Northing (m)*	*AHD[b]height (m)*	*Easting (m)*	*Northing (m)*	*AHD[b] height (m)*	*d easting (m)*	*d northing (m)*	*d height (m)*
9961.7001	378158.039	7070965.434	480.909	378158.094	7070965.452	480.990	+0.05	+0.02	+0.09
9961.7002	480971.684	7066605.836	470.369	480972.013	7066605.827	470.544	+0.14	-0.01	+0.17
GK 71	417817.662[c]	7081911.617[c]	465.854[c]	417816.985	7081913.382	465.07	-0.68	+1.77	-0.78

NOTES: (a) Global Positioning System
(b) Australian Height Datum
(c) Department of Land Administration

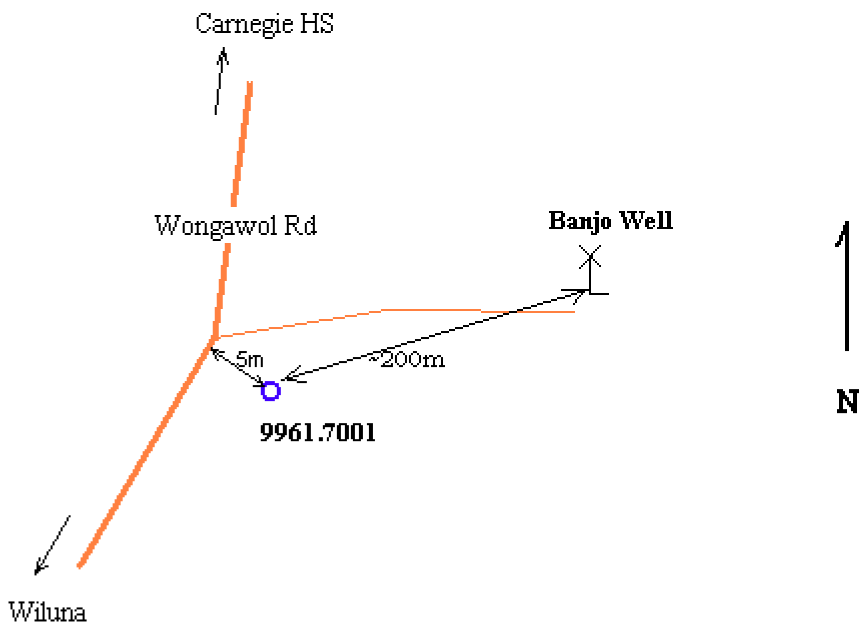
Table 3.3. Differences in gravity and GPS height repeat measurements

Station number	*Days between measurements*	*Elevation (m)*	*Observed gravity (μms^{-2})*
1105	1	+0.32	+0.2
1121	1	+0.13	-0.8
3164	3	-0.19	-0.3
4009	1	+0.36	+0.7
4165	1	+1.83	+1.2
1104	2	+0.41	-0.6
6033	1	-0.07	-0.3
Std		**0.61**	**0.4**

Appendix 4

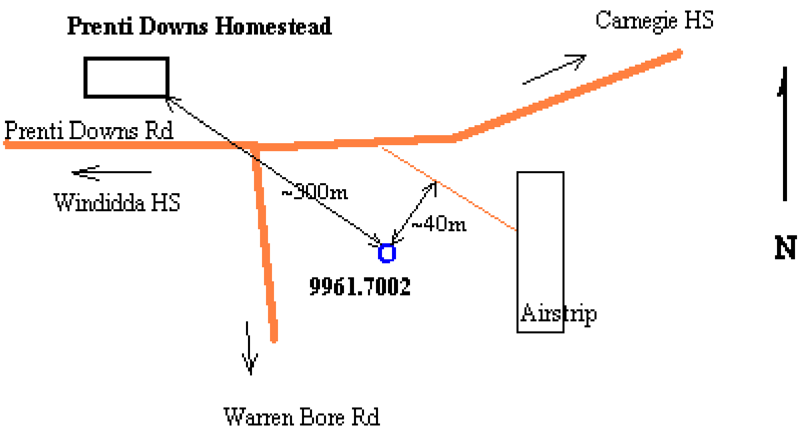
Established gravity and GPS base station descriptions for the KINGSTON gravity survey

Banjo Well base station (schematic)



Appendix 4 (continued)

Prenti Downs base station (schematic)



Appendix 5

Summary of operation and processing for the Stanley gravity survey

Organization: Geological Survey of Western Australia
Start date: 29 May 1998
Completion: 10 June 1998

	GPS	*Gravity*
Equipment	4 Ashtech Z12 receivers N223, N226, N900, N942	LaCoste and Romberg Model G × 5units G20, G101,G132, G252, G460
Data recording and processing notebook computers	Pentium II 233 MHz, 32 Mb RAM; 80486DX 75 MHz, 8 Mb RAM; 80486DX 50 MHz, 4 Mb RAM	
Calibration		By AGSO 1998
Surveying Transport	Helicopters J Bell 206B3 (Jet Ranger) × 2 Land Cruiser 4-wheel drive	
DOLA bench marks used	HP 24 T to transfer the coordinates and height to 9962.7001 GK 71 for the height control 9962.7001 to transfer the coordinates and height to 9962.7002 and 9962.7022 NMF 36T for the coordinates and height control	6491.9087 (Windidda isogal station)
New base stations	9962.7001, 9962.7002, 9962.7022	9962.7001, 9962.7002
Survey method used to establish base stations	Static	4 gravimeters, two operators in one traverse
Survey method for ordinary stations	Kinematic with 100% repeats	1 gravimeter, 1 operator, two readings, 1130 stations 4 × 4 km irregular grid
Software for reductions and field processing	PRISM (Ashtech proprietary software package)	SERGRAV (GSWA in-house suite of programs) SURFER v. 5.01 (from Golden Software Inc.)
Office processing software		INTREPID v. 3.4 processing and gridding program ER Mapper v. 6.0 image processing system
Accuracy	$\sigma_{elevation} = \pm 0.4$ m $\sigma_{x,y} = \pm 5$ m	$\sigma_{gravity\ base\ stations} = \pm 0.2\ \mu ms^{-2}$ $\sigma_{stn} = 0.7\ \mu ms^{-2}$
Total Bouguer accuracy		$\sigma_{survey} = \pm \sqrt{(1.2^2_{elev} + 0.2^2_{base\ stns} + 0.7^2_{stns} + 0.4^2_{abs.grav.transf})}$ $= 1.5\ \mu ms^{-2}$

Appendix 6

Survey personnel for the Stanley gravity survey

Project manager	*Gravity survey manager*	*Gravity observers*	*Gravity field assistant*	*Helicopter company*	*Chief pilot*	*Pilots*	*Engineer*
D. Howard	S..Shevchenko	E. Bosanquet J. Downing J. Hansen J. Moore S. McGuiness N. Nasev	T. Davis	Helicopters Australia	M. Corbett	S. Eder P. Legradi A. Regan	N. Luscombe

Appendix 7

Bench mark data and repeat measurements for the Stanley gravity survey

Table 7.1. Coordinates of DOLA[a] bench marks used to establish base stations and isogal stations

Name	*Comments*	*Type of mark*	*Type of datum/grid*	*Latitude (S)/ easting (m)*	*Longitude (E)/ northing (m)*	*AHD[f] height/ AMG[e] zone*	*Date surveyed*	*Method*	*Order*	*Horizontal/ vertical accuracy*	*Gravity value (μms^{-2})*	*Gravity error (μms^{-2})*
NMF 36T[b]	Control	S[c]	WGS84[d] AMG84[e]	25°45'56.05716" 468311.032	122°41'07.24919" 7150080.121	481.33 51	01/05/1996	GEOD[g] SLEV[h]	1st 2nd	7.5 ppm 0.1 m	–	–
FY 10[b]	Control	S[c]	WGS84[d] AMG84[e]	25°24'41.46286" 419444.090	122°12'01.40691" 7189083.871	518.24 51	10/05/89	DIG[j] SLEV[h]	5th 4th	500 m 18 √K (mm)	–	–
HP 24T[b]	–	S[c]	WGS84[d] AMG84[e]	25°23'53.63830" 499905.495	122°13'21.08010" 7068263.817	554.77 51	01/03/1998	GEOD[g] SLEV[h]	2nd 2nd	10 ppm 0.1 m	–	–
9962-7001 Glenayle Stn	GPS and gravity base	SP[k]	WGS84[d] AMG84[e]	25°15'47.66872" 404157.413	122°02'58.42297" 7205404.413	522.681 51	24/05/99	GPS[i] GPS[i]	–	–	9788140.3	0.4
9961-7002 Prenti Downs	GPS and gravity base	SP[k]	WGS84[d] AMG84[e]	25°47'49.28613" 497181.542	122°58'23.70673" 7146634.457	439.200 51	25/05/99	GPS[i] GPS[i]	–	–	9788631.3	0.2
9962-7022 Prenti Downs	GPS base only	SP[k] –	WGS84[d] AMG84[e]	25°47'35.96247" 497188.142	122°58'23.94672" 7147044.310	441.202 51	05/06/99	GPS[i] GPS[i]	–	–	–	–
6491.9087 Windidda	AGSO isogal station	–	AGD84[l]	26°22'49"	122°10'34"	465	1964	MAP[j]	–	–	9789138.6	–

NOTES:
(a) Department of Land Administration
(b) Coordinates from DOLA
(c) Standard survey mark
(d) World Geodetic System 1984
(e) Australian Map Grid 1984
(f) WGA Spheroidal Height
(g) Geodetic
(h) Spirit level
(i) Global Positioning System
(j) Digitized from a map
(k) Star picket and metal peg
(l) Australian Geodetic Datum 1984

Table 7.2. Observed coordinate differences

Bench mark	Observed GPS[a] –1st time			Observed GPS[a]–2nd time			Differences		
	Easting (m)	*Northing (m)*	*AHD[b] height (m)*	*Easting (m)*	*Northing (m)*	*AHD[b] height (m)*	*d easting (m)*	*d northing (m)*	*d height (m)*
NMF 36T	468311.032	7150080.121	481.33	468311.006	7150080.220	481.37	-0.03	+0.10	+0.05
FY 10	417817.662	7081911.617	518.24	–	–	518.27	–	–	+0.03

NOTES: (a) Department of Land Administration
(b) Global Positioning System
(c) Australian Height Datum

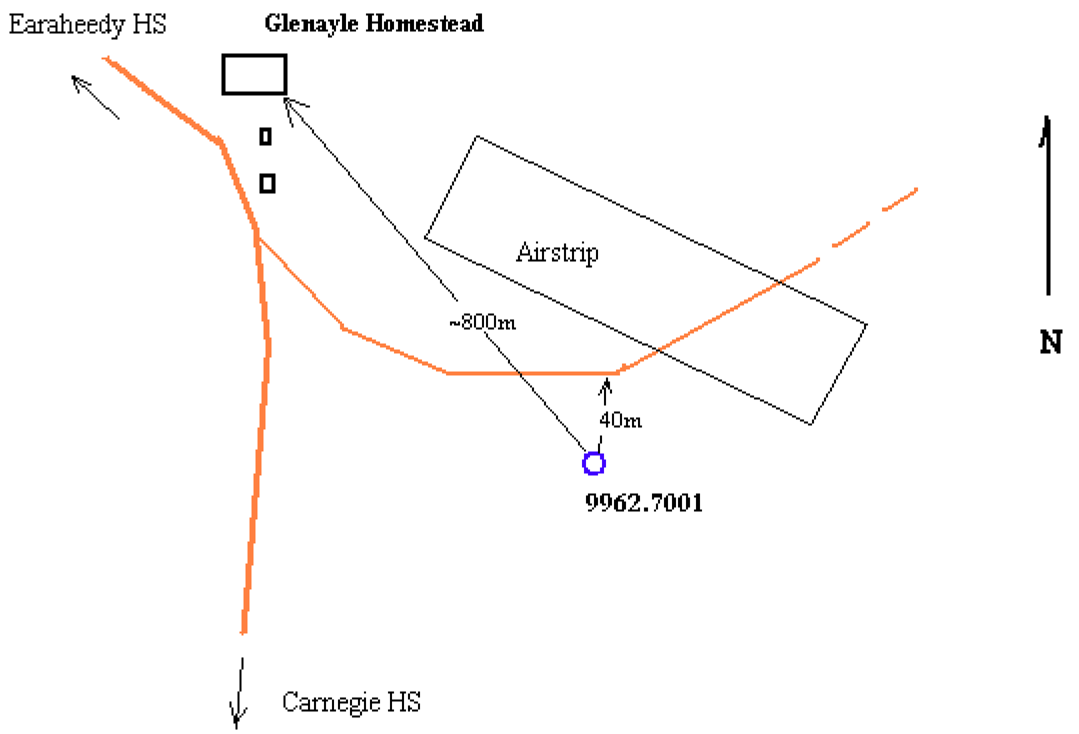
Table 3.3. Differences in gravity and GPS height repeat measurements

Station number	*Days between measurements*	*Elevation (m)*	*Observed gravity (μms⁻²)*
2066	1	+0.21	-0.8
8010	2	-0.16	-0.2
8012	2	-0.16	-0.2
1046	1	-0.56	-0.4
1147	1	+0.43	0
3116	5	-0.23	-0.3
5058	1	-0.24	+0.1
4027	2	+0.7	-0.6
4052	1	+0.2	+2.3
3066	1	-0.28	+0.5
5058	4	+0.35	+0.4
4086	7	+0.12	+2.3
6075	2	+1.5	-0.3
Std		**0.36**	**0.7**

Appendix 8

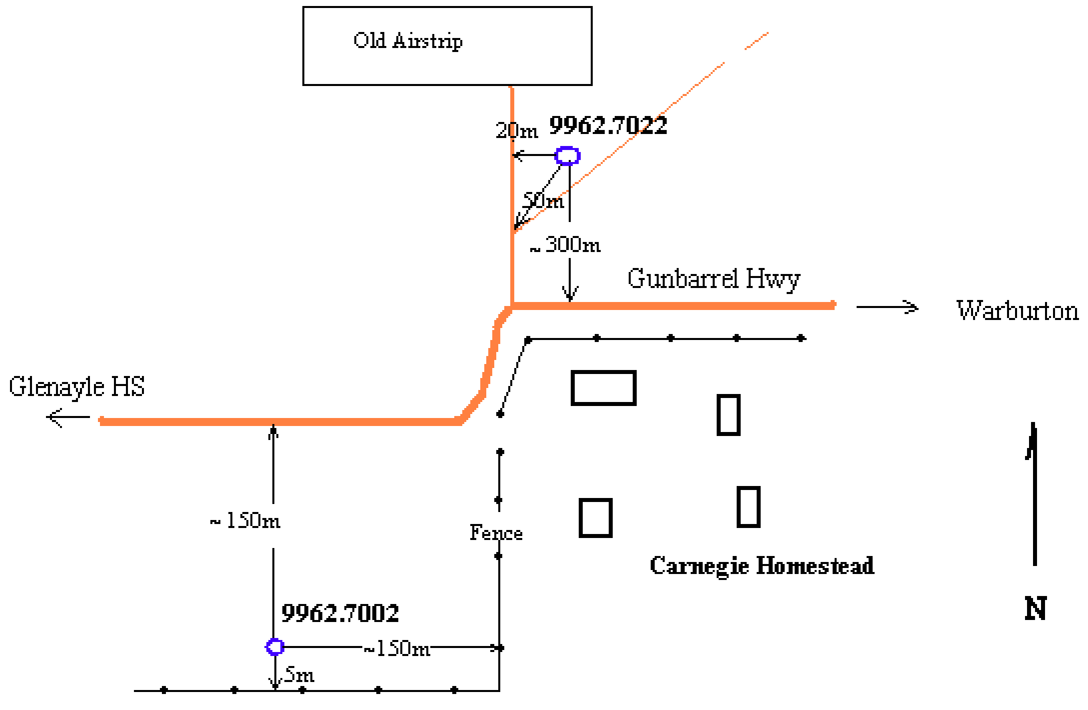
Established gravity and GPS base station descriptions for the STANLEY gravity survey

Glenayle base station (schematic)



Appendix 8 (continued)

Carnegie base station
(schematic)



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KINGSTON

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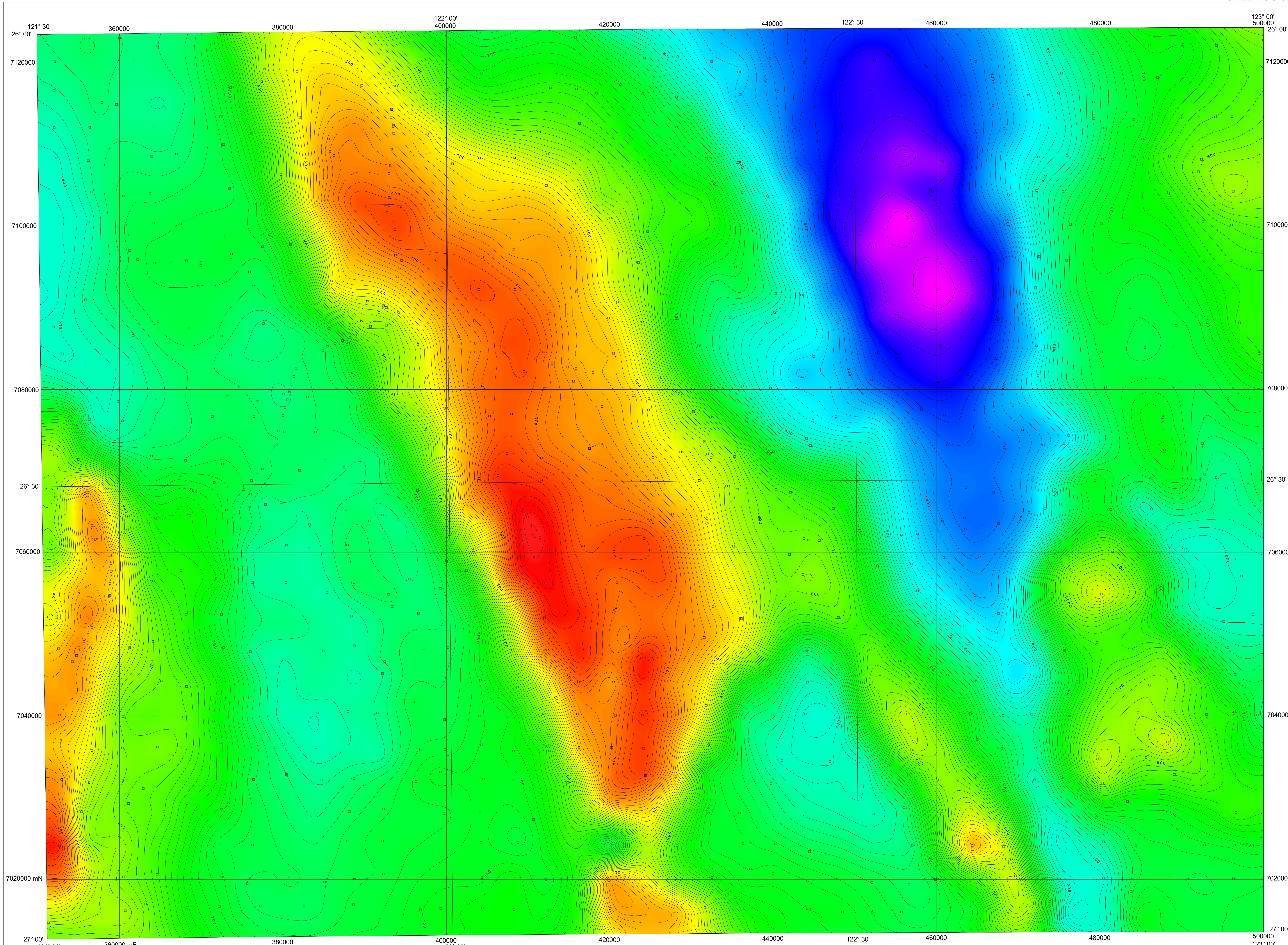
1:250 000 BOUGUER GRAVITY

SHEET SG 51-10



-238
-389
-540
-692
-843
-994

Gravity units

Gravity unit	1μms[-2]
Contour value	— 200 —
Gravity station	□
Acquisition date:	April 1999
Acquired by:	Geological Survey of Western Australia
Nominal station spacing:	4 km
Gravity meter:	LaCoste and Romberg G
Gravity survey accuracy:	1.9μms[-2]
Positioning:	Ashtech Z-12 dual frequency GPS
Horizontal accuracy:	5 m
Vertical accuracy:	0.6m
Data reduction by:	GSWA
Bouguer density:	2670 kgm[-3]
Terrain correction:	Not applied
Geodetic datum:	WGS84
Height datum:	AHD
Gridding software:	Intrepid 3.4
Grid cell size:	1500m
Contour interval:	10 μms[-2]
Image processing software:	ER Mapper 5.5
Project geophysicist:	S.Shevchenko
Processing:	S.Shevchenko
Map compilation:	J. H. Watt

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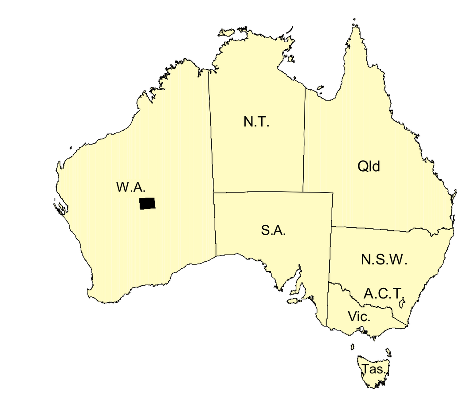

NABBERU SG 51-5	STANLEY SG 51-6	HERBERT SG 51-7
WILUNA SG 51-9	KINGSTON SG 51-10	ROBERT SG 51-11
SIR SAMUEL SG 51-13	DUKETON SG 51-14	THROSSELL SG 51-15

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HORIZONTAL DATUM: WORLD GEODETIC SPHEROID 1984
Grid lines indicate 20 000 metre interval of the Map Grid Australia Zone 51

GDA
The Map Grid Australia (MGA) is based on the Geocentric Datum of Australia 1994 (GDA94).
GDA94 is compatible within one metre of the Global Positioning System (GPS) satellite datum WGS84

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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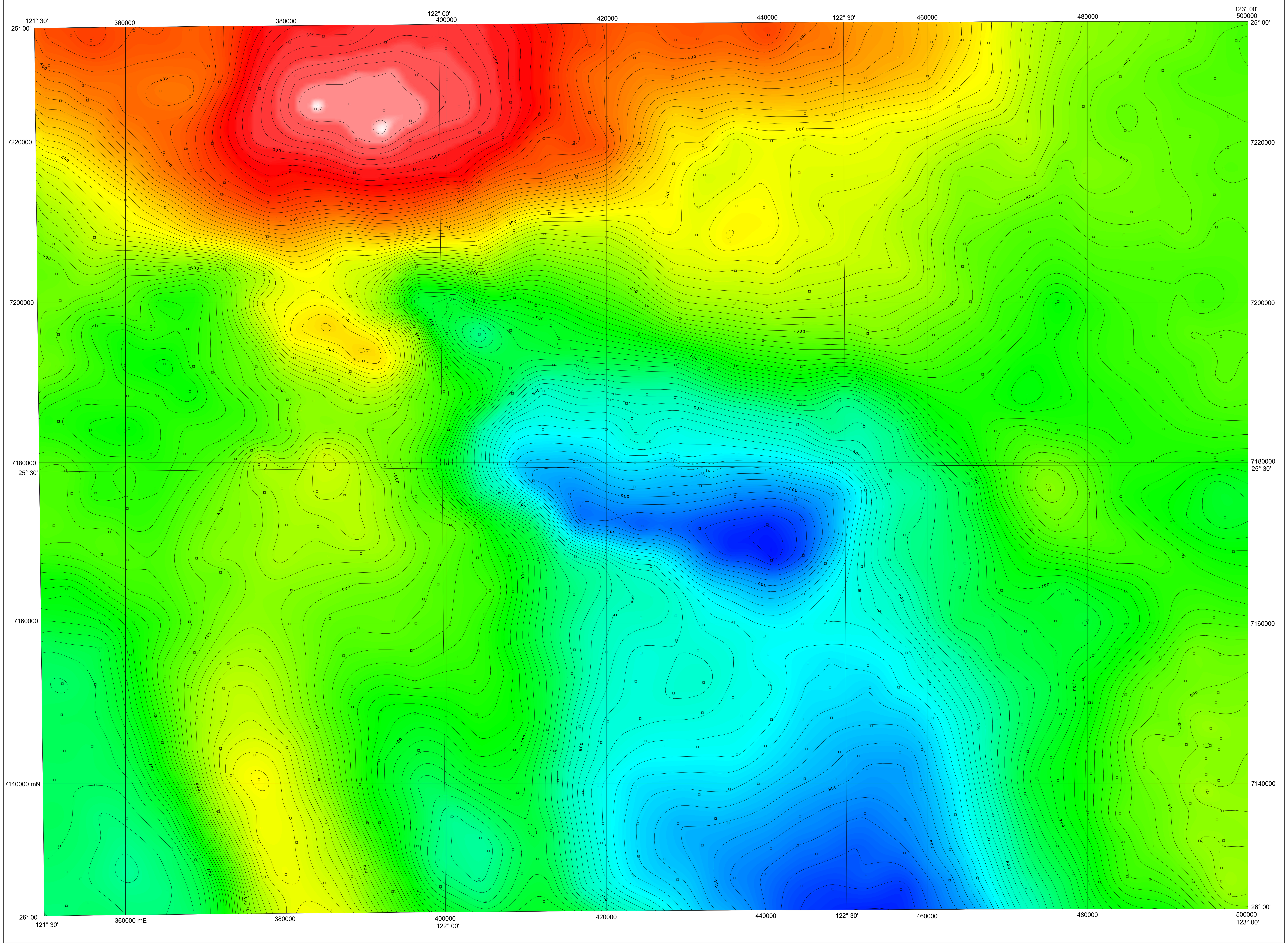
SHEET SG 51-6



Gravity unit	1μms^{-2}
Contour value	— 200 —
Gravity station	□
Acquisition date	June 1999
Acquired by	Geological Survey of Western Australia
Nominal station spacing	4 km
Gravity meter	LaCoste and Romberg G
Gravity survey accuracy	1.5μms^{-2}
Positioning	Ashtech Z-12 dual frequency GPS
Horizontal accuracy	5 m
Vertical accuracy	0.4 m
Data reduction by	GSWA
Bouguer density	2670 kgm^{-3}
Terrain correction	Not applied
Geodetic datum	WGS84
Height datum	AHD
Gridding software	Intrepid 3.4
Grid cell size	1500 m
Contour interval	10μms^{-2}
Image processing software	ER Mapper 5.5
Project geophysicist	S. Shevchenko
Processing	S. Shevchenko
Map compilation	J. H. Watt

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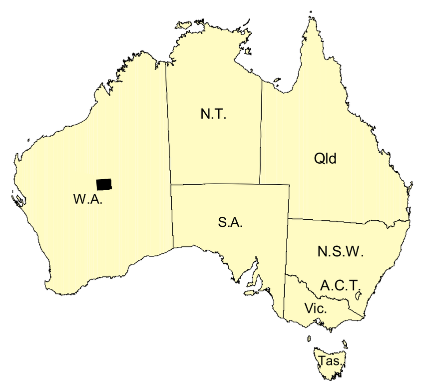

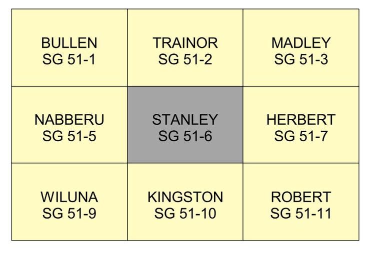

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HORIZONTAL DATUM: WORLD GEODETIC SPHEROID 1984
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GDA94 positions are compatible within one metre of the datum WGS84 positions.

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