

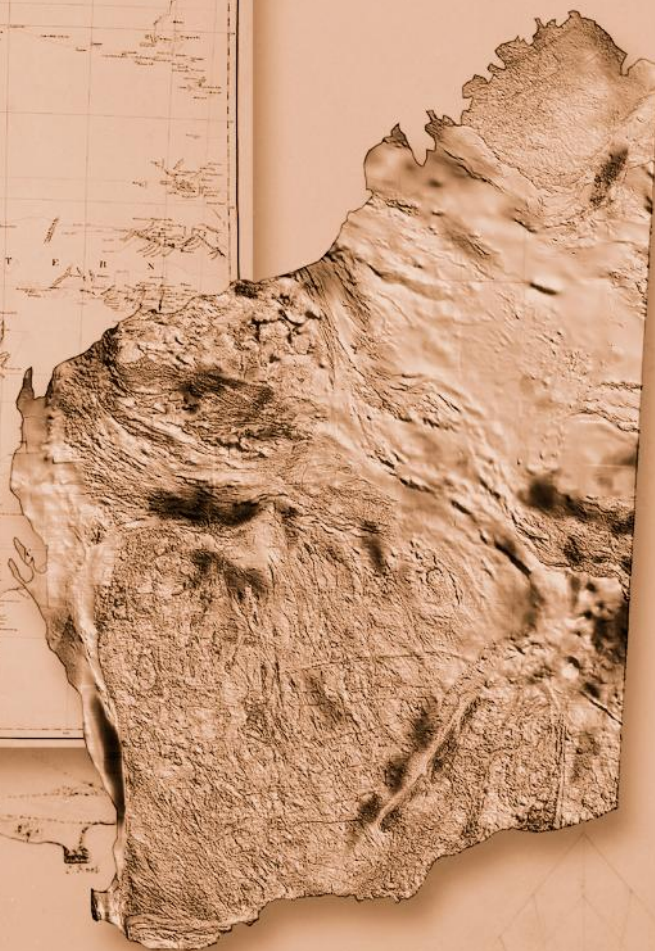
**RECORD
2000/15**

GRAVITY DATA — FRASER RANGE REGION WESTERN AUSTRALIA



GOVERNMENT OF
WESTERN AUSTRALIA

by **S. I. Shevchenko**



**GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
DEPARTMENT OF MINERALS AND ENERGY**



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

Record 2000/15

GRAVITY DATA — FRASER RANGE REGION, WESTERN AUSTRALIA

by

S. I. Shevchenko

Perth 2000

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Gravity data—Fraser Range region, Western Australia

by

S. I. Shevchenko

Abstract

A total of 1253 stations were recorded on an irregular 4×4 km grid for the regional gravity survey conducted by the Geological Survey of Western Australia over the Fraser Range region in September 1998. The accuracy of the Bouguer gravity measurements is $\pm 2.3 \mu\text{ms}^{-2}$.

The Fraser Range region forms part of the Mesoproterozoic Albany–Fraser Orogen that extends along the southern and southeastern margin of Western Australia. Three major tectonic units are recognized within the orogen in this region: the Northern Foreland, which is dominated by Archaean granite–greenstones of the Yilgarn Craton; the Biranup Complex comprising granite gneiss (Dalyup Gneiss and Coramup Gneiss) together with metamorphosed mafic rock of the Fraser Complex; and the Nornalup Complex, which is composed of quartzofeldspathic gneiss. All show distinct gravity and magnetic signatures. The regional faults have a northeasterly trend and can also be mapped on gravity images.

Gravity interpretation and geochemistry data show that the Cundeelee Fault is the major regional fault in the area. It represents the boundary between the Yilgarn Craton and the Northern Foreland of the Albany–Fraser Orogen.

The major southeasterly trending gravity and magnetic anomalies northwest of the Cundeelee Fault correlate well with the greenstone belts in the Yilgarn Craton. The northeasterly trending gravity and magnetic lineaments east of the Cundeelee Fault are interpreted as faults or mafic intrusions, or layered bodies within the Fraser Complex.

The Cundeelee Fault and the adjacent greenstones have some potential for gold mineralization. In the northwestern part of the survey area, where regolith geochemistry shows anomalous gold values, greenstones can be inferred from the gravity data to lie below the Cainozoic rocks, which partly covers the Albany–Fraser Orogen.

KEYWORDS: gravity surveys, aeromagnetic surveys, gravity anomalies, magnetic anomalies, structure, Fraser Complex, Archaean, greenstones, gold, mineralization.

Introduction

In September 1998, the Geological Survey of Western Australia (GSWA) carried out a regional gravity survey of six 1:100 000 map sheets in the Fraser Range area (Fig. 1, Plate 1), namely COONANA* (3535), ZANTHUS (3635), YARDILLA (3434), SYMONS HILL (3534), FRASER RANGE (3433), and HARMS (3533). Helicopters were used to transport the survey crews to the survey sites, distributed on an irregular grid of approximately 4×4 km. Gravity meters and Global Positioning System (GPS) units were provided by the Australian Geological Survey Organisation (AGSO) under the National Geoscience Mapping Accord (NGMA).

The gabbroic rocks of the Fraser Range Complex have recently been a focus for nickel exploration (Morris et al., 2000). The survey described herein was part of a series of combined regional regolith 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 gravity data for the survey over the Fraser Range region, and qualitative interpretation of the new gravity and existing aeromagnetic data. Morris et al. (2000) described the logistics and results of the geochemical program. The **Geological setting** section of this Record is from Morris et al. (2000).

Geological setting

The Fraser Range region includes granitic rocks and greenstones of the Archaean Yilgarn Craton (Griffin, 1990), high-grade Proterozoic metamorphic rocks of the Albany–Fraser Orogen (Myers, 1985, 1990a, 1995), and Tertiary sedimentary rocks of the Eucla Basin (Hocking, 1990), as shown in Figure 2. A summary of the geology of the Fraser Range region is presented here, and reference should be made to the above publications for more detailed information.

Albany–Fraser Orogen

The northerly trending Albany–Fraser Orogen truncates, at a high angle, granite–greenstones of the Yilgarn Craton (Gee, 1979; Myers, 1985). Rocks of this orogen represent a continent–continent collision of the Yilgarn Craton margin with east Antarctica, between 1300 and 1100 Ma (Myers, 1993, 1995). Myers (1990a) divided the Albany–Fraser Orogen into the Northern Foreland and the Biranup and Nornalup Complexes, based on lithology and structure (Fig. 2). The Biranup Complex, which includes the Fraser Complex, is composed of high-grade quartzofeldspathic gneisses and layered basic intrusions that are isoclinally folded and tectonically interleaved. The Nornalup Complex comprises less intensely deformed, high-grade orthogneiss and paragneiss intruded by granitoids.

* Capitalized names refer to standard 1:100 000 map sheets, unless otherwise specified.

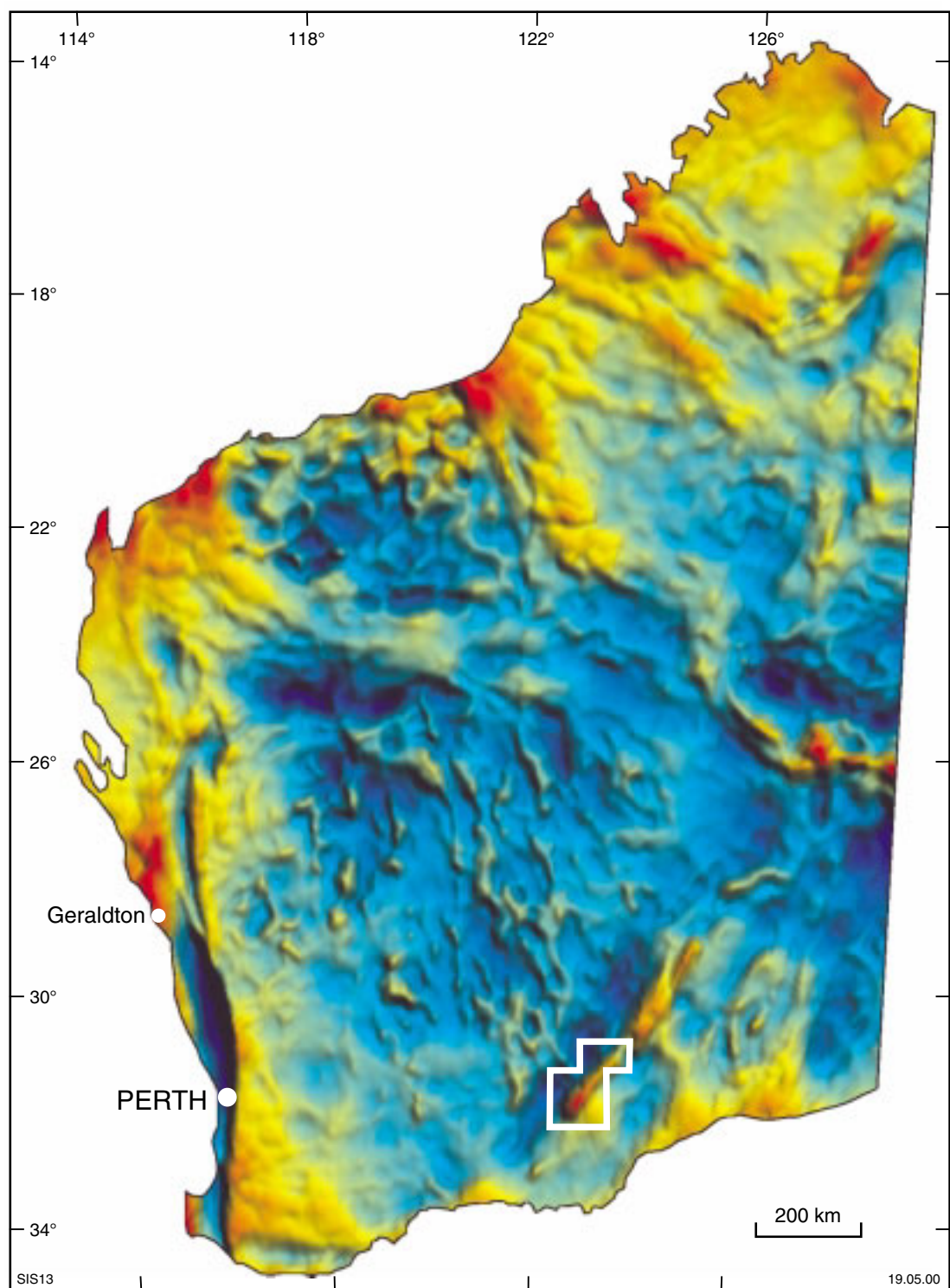


Figure 1. Location of the Fraser Range gravity survey on the Bouguer gravity image of Western Australia

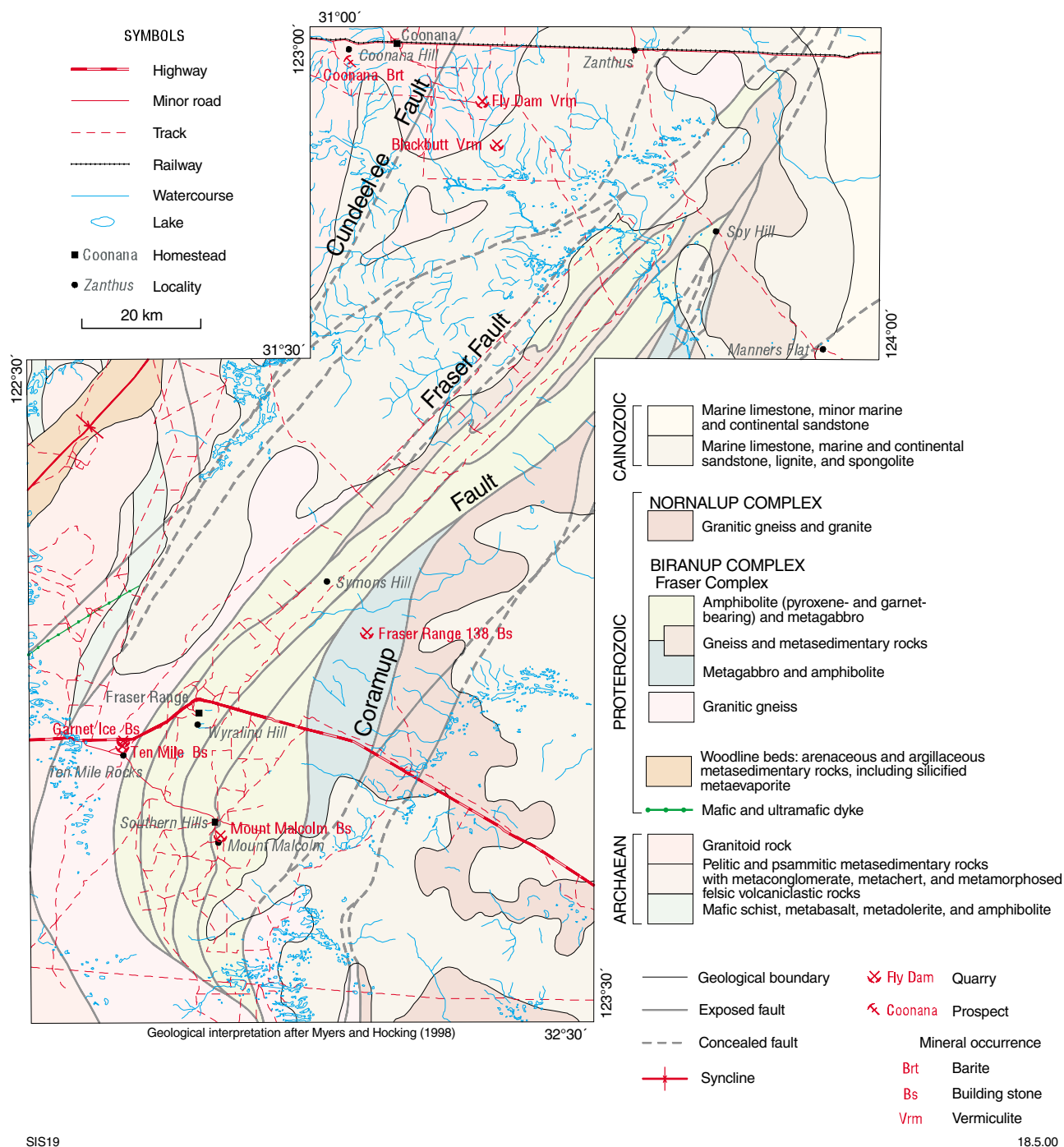


Figure 2. Simplified geology and stratigraphy of the Fraser Range area

Northern Foreland

The southern and southeastern margin of the Yilgarn Craton forms the Northern Foreland of the Albany–Fraser Orogen (Myers, 1990a; Nelson et al., 1995), and consists of enclaves of Archaean granite–greenstones and Proterozoic sedimentary rocks, overprinted by cataclastic and gneissic fabrics and intruded by dolerite dykes (Myers and Hocking, 1998).

Archaean granite–greenstones

Archaean rocks of the Fraser Range region comprise a granite–greenstone association that is typical of the Eastern Goldfields Province (Griffin, 1990). Greenstone successions consist of metamorphosed mafic, ultramafic, and felsic volcanic rocks and associated volcanoclastic and clastic sedimentary rocks and minor chemical sedimentary rocks (predominantly chert). The greenstones have been intruded by granitoid rocks, and both greenstones and granitoids have been subsequently deformed.

Greenstones are multiply deformed, and range in metamorphic grade from greenschist to lower amphibolite facies. The resultant structures are commonly dominated by strong north-northwesterly trends (Gee, 1979; Griffin, 1989).

Proterozoic intrusive rocks

Regional-scale Proterozoic intrusive rocks belong to the Widgiemooltha Dyke Swarm (Myers, 1990b), which, in the Fraser Range region, is restricted to the eastern part of the Jimberlana Dyke. The Jimberlana Dyke, dated at 2411 Ma (Fletcher et al., 1987), is one of the largest east–west trending Proterozoic dykes in the eastern part of the Yilgarn Craton, and dominated by cumulate-textured gabbro, containing orthopyroxene, clinopyroxene, and plagioclase. Minor ultramafic rocks (Fletcher et al., 1987) record ultramafic material from west of the project area.

Woodline beds

The Woodline beds outcrop poorly in the western part of the Fraser Range region, where they consist of mildly deformed and metamorphosed quartzite and less common phyllite. The rocks have been recrystallized under greenschist-facies metamorphic conditions, and rest unconformably on Archaean granite–greenstones (Griffin, 1989).

Numerous dolerite dykes of the Gnowangerup dyke swarm intruded subparallel with the margin of the Albany–Fraser Orogen, within 100 km of the margin of the Yilgarn Craton. Although dykes found in the Yilgarn Craton are commonly undeformed and unmetamorphosed, those within the Albany–Fraser Orogen are intensely deformed, recrystallized, and commonly found as thin layers and lenses parallel to the main foliation within the gneisses (Myers, 1993).

Biranup Complex

The Biranup Complex consists of the Dalyup Gneiss, the Coramup Gneiss, and the Fraser Complex (Myers, 1990a; Condie and Myers, 1999). The Dalyup Gneiss includes granite gneiss

that is marginal to the Fraser Complex (Fig. 2) and is derived from 1700–1600 Ma monzogranite and granodiorite. The granitic Coramup Gneiss, adjacent to the Fraser Complex in the southeast, has been included with the Nornalup Complex in this discussion because of its similar geophysical characteristics.

Fraser Complex

The Fraser Complex consists largely of mafic igneous rocks derived from one or more layered, igneous intrusions as 2–5 km-thick and >100 km-long thrust sheets (Myers, 1985, 1995). These highly deformed rocks have been tectonically interleaved with metasedimentary rocks (quartzite, banded iron-formation, and pelitic rocks) and intruded by granitoid gneiss. The whole sequence has been further metamorphosed and deformed to granulite facies. Along the northwestern margin, granulite-facies rocks are overprinted by amphibolite- and then greenschist-facies metamorphism. The southeastern margin of the Fraser Complex is not exposed.

Fletcher et al. (1991) suggested that the Fraser Complex was tectonically emplaced into the upper crust at 1268 ± 20 Ma, shortly after crystallization of the complex under granulite-facies conditions at 1301 ± 6 Ma (Clark et al., 1999). Rapid uplift and emplacement of the complex and adjacent gneisses is supported by isotopic age data, including Sm–Nd (Fletcher et al., 1983; Fletcher et al., 1991), sensitive high-resolution ion microprobe (SHRIMP) U–Pb (Nelson, 1995; Nelson et al., 1995), whole rock Rb–Sr (Arriens and Lambert, 1969; Bunting et al., 1976), and K–Ar (references contained within Nelson et al., 1995). Nelson et al. (1995) and Condie and Myers, (1999) related the emplacement of the Fraser Complex to a major continent–continent collision event at c. 1300 Ma.

Nornalup Complex

The Nornalup Complex (Fig. 2) is dominated by quartzofeldspathic gneiss derived from granitoid and pelitic rocks (Myers, 1990a). Rocks of the Nornalup Complex outcrop poorly in the Fraser Range region, and are unconformably overlain by sedimentary rocks of the Eucla Basin. Two phases of granite emplacement are recognized in the Nornalup Complex. The earlier phase at c. 1300 to 1280 Ma (Nelson et al., 1995), which also intruded the Biranup Complex, was recrystallized at a later stage under granulite-facies conditions, mainly as gneiss. The second phase consists of granite sheets and plutons intruded into this gneiss between c. 1190 to 1130 Ma (Myers, 1993; Nelson et al., 1995).

The degree of deformation increases towards the Fraser Complex, whereas deformation intensity and metamorphic grade decreases to the southeast (Myers, 1990a, 1993).

Eucla Basin

The structure and stratigraphy of the Eucla Basin have been discussed by Hocking (1990). Sedimentary rocks of the Eucla Basin unconformably overlie the eastern margin of the Fraser

Complex in the Fraser Range region. These rocks range in age from Early Cretaceous to Holocene (Hocking, 1990) and consist mainly of marine and lacustrine deposits. In the Fraser Range region, most of these rocks consist of Eocene carbonate-rich sedimentary rocks and less common sandstone, lignite, and spongilite. There are outcrops of quartz-rich siltstone and sandstone of the Eundynie Group, which contain abundant sponge spicules (Griffin, 1989), on the margins of some salt lakes in the Fraser Range region. This unit was deposited in drainage systems, now defined by major lakes, during a Tertiary marine transgression (Bunting et al., 1974).

Gravity data

Previous data

In 1956, the Bureau of Mineral Resources (BMR, now AGSO) conducted two gravity traverses across the Fraser Fault — one along the railway line east of Kalgoorlie, and the other along the Eyre Highway east of Norseman (Gunsen and van der Linden, 1956).

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

New gravity data

The 1998 GSWA helicopter-supported regional regolith geochemistry and gravity survey acquired readings on a grid of approximately 4×4 km using dual-frequency GPS equipment to obtain accurate positions for the gravity stations. The survey specifications and procedures are listed in Appendices 1–4. Details of the survey methodology are described in Howard and Shevchenko (2000).

The data were reduced to Bouguer gravity values for a density of 2670 kg/m^3 and gridded to a 1000 m cell size (Fig. 3). The first vertical derivative (1VD) of the Bouguer gravity is shown in Figure 4.

A regional gravity grid measuring 4×4 km, with 2×2 km infill in selected areas, was surveyed by AGSO over the WIDGIEMOOLTHA, NORSEMAN, and BOORABBIN 1:250 000 sheet areas between September and November 1998 (Jonson and Lo, 1999). The HeliGrav system and helicopters, vehicles, and quad bikes were used to conduct the survey. The accuracy of the Bouguer gravity was $0.37 \mu\text{ms}^{-2}$ for the survey and the standard deviation of the measured elevations is 0.04 m. These data were incorporated into the GSWA dataset where they overlap the GSWA survey on the YARDILLA and FRASER RANGE 1:100 000 map sheets. The combined data was gridded with a 500 m grid and stitched to the main dataset for interpretation (see **Geophysical signatures**).

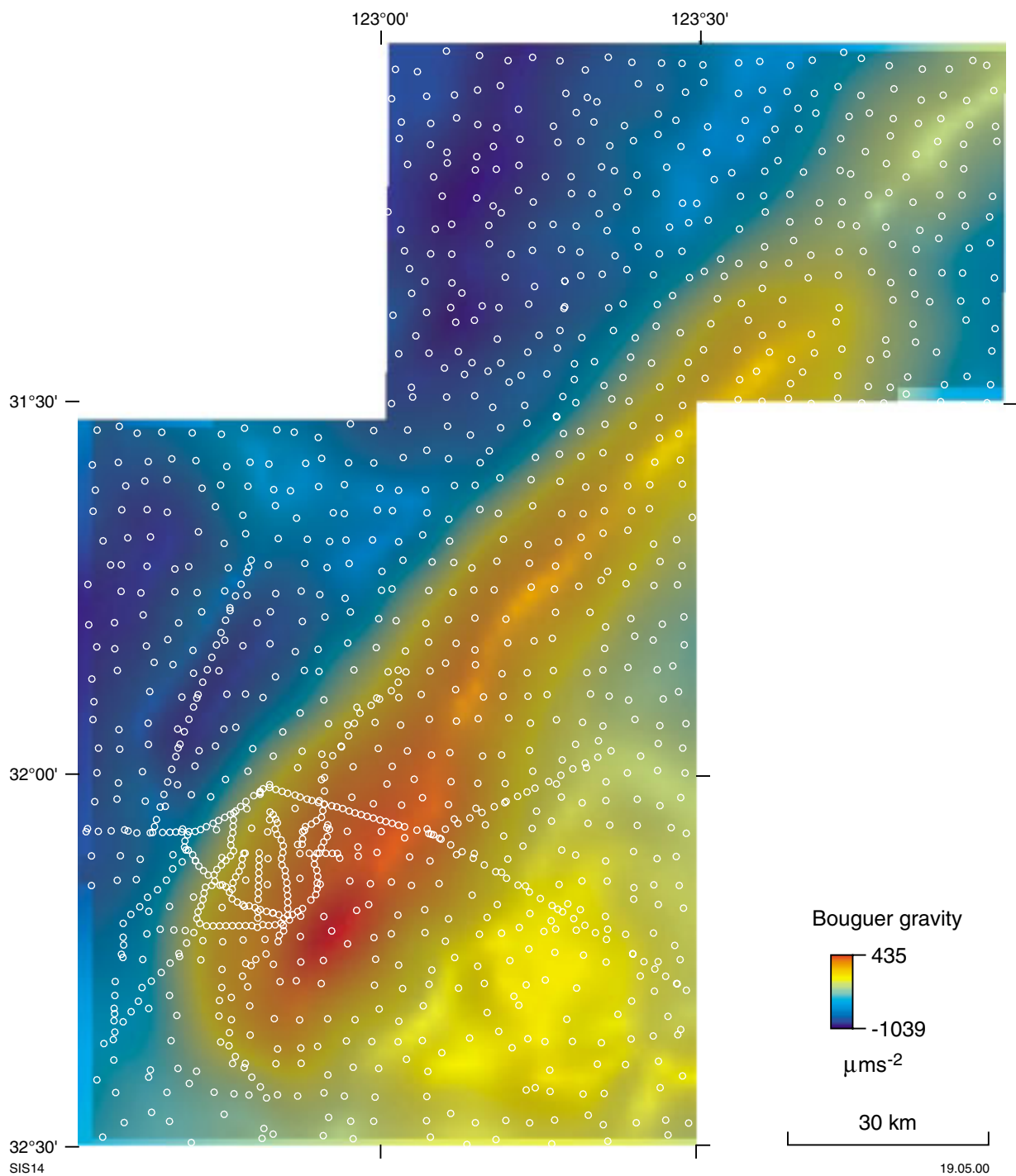


Figure 3. Image of Bouguer gravity for the Fraser Range area from the new data collected on an irregular grid of 4×4 km. White dots are gravity stations

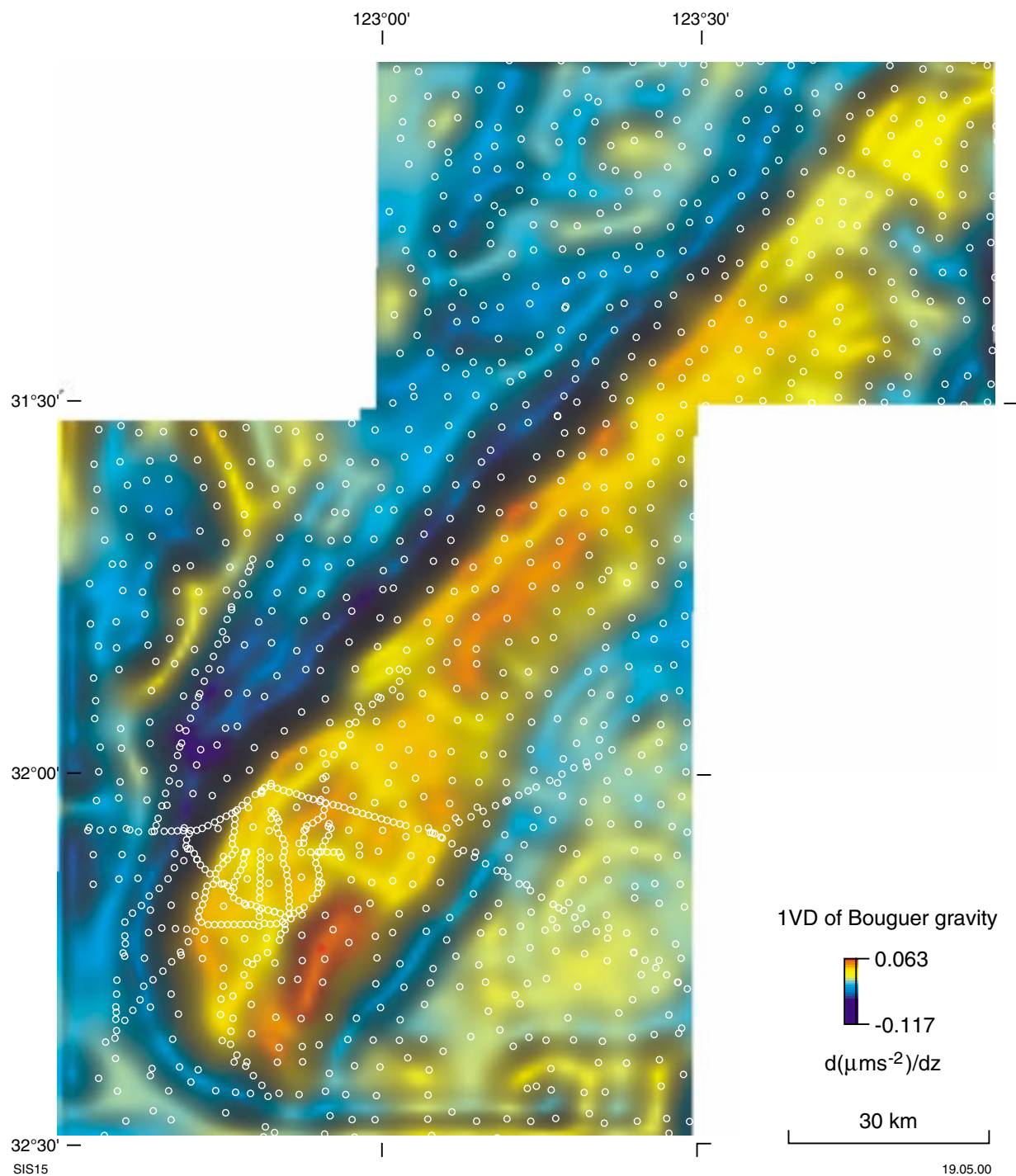


Figure 4. Image of first vertical derivative of the Bouguer gravity for the Fraser Range area. White dots are gravity stations

Magnetic data

Three regional airborne magnetic surveys with east–west oriented lines spaced 1600 m apart, for which the average sample interval is 60 m, were flown over the Fraser Range Complex by the BMR. Two surveys were conducted in 1958 and 1959 over the WIDGIEMOOLTHA and NORSEMAN 1:250 000 sheets and another survey were flown in 1981 over the ZANTHUS and BALLADONIA 1:250 000 sheets. The total magnetic intensity (TMI) image of 400 m grid-cell size is shown on Figure 5.

Geophysical signatures

The major regional geological provinces in the Fraser Range region have specific geophysical signatures as outlined below.

Northern Foreland

Yilgarn Craton

In the Yilgarn Craton northwest of the Cundeelee Fault (Fig. 6) the northerly–northwesterly trending greenstone belts are the most distinctive features, shown by both the magnetic and, particularly, the gravity data. The greenstones structures (orange lines on Figs 6 and 7) are evident as positive gravity and magnetic anomalies in response to high density and highly magnetic mafic and ultramafic rocks, whereas the surrounding granitic rocks are of lower density and nonmagnetic. Geophysically, they are isotropic. New greenstone structures have been identified in the western part of survey area during this study.

Gravity and magnetic data also highlight the position of the Jimberlana and Binneringie Dykes as narrow, east-northeasterly and northerly oriented, positive gravity and magnetic anomalies (Figs 6 and 7). The Binneringie Dyke extends from the Yilgarn Craton towards the Fraser Complex, across the Northern Foreland of the Biranup Complex, implying a Mesoproterozoic age, whereas the Jimberlana Dyke swings towards the Cundeelee Fault and is truncated by this fault, consistent with an early Palaeoproterozoic age.

The Cundeelee Fault can be interpreted as a distinctive regional gravity lineament corresponding to a steep gradient (Fig. 6). This fault truncates all northeasterly trending Archaean greenstones against the Biranup Complex, and forms the boundary between the Yilgarn Craton and the Albany–Fraser Orogen. The regional geochemistry data correlate well with the gravity data in this area. Regolith geochemistry reveals high values of standard scores for a chalcophile index for As, Au, Bi, Cd, Sb, and Mo over the Archaean greenstones and along regional faults in the western part of the project area. The geochemical data also indicate that the strong association of elevated index values and regional faults in this area could indicate zones of fault-controlled gold mineralization in the western part of the project area (Morris et al., 2000). For example, the two

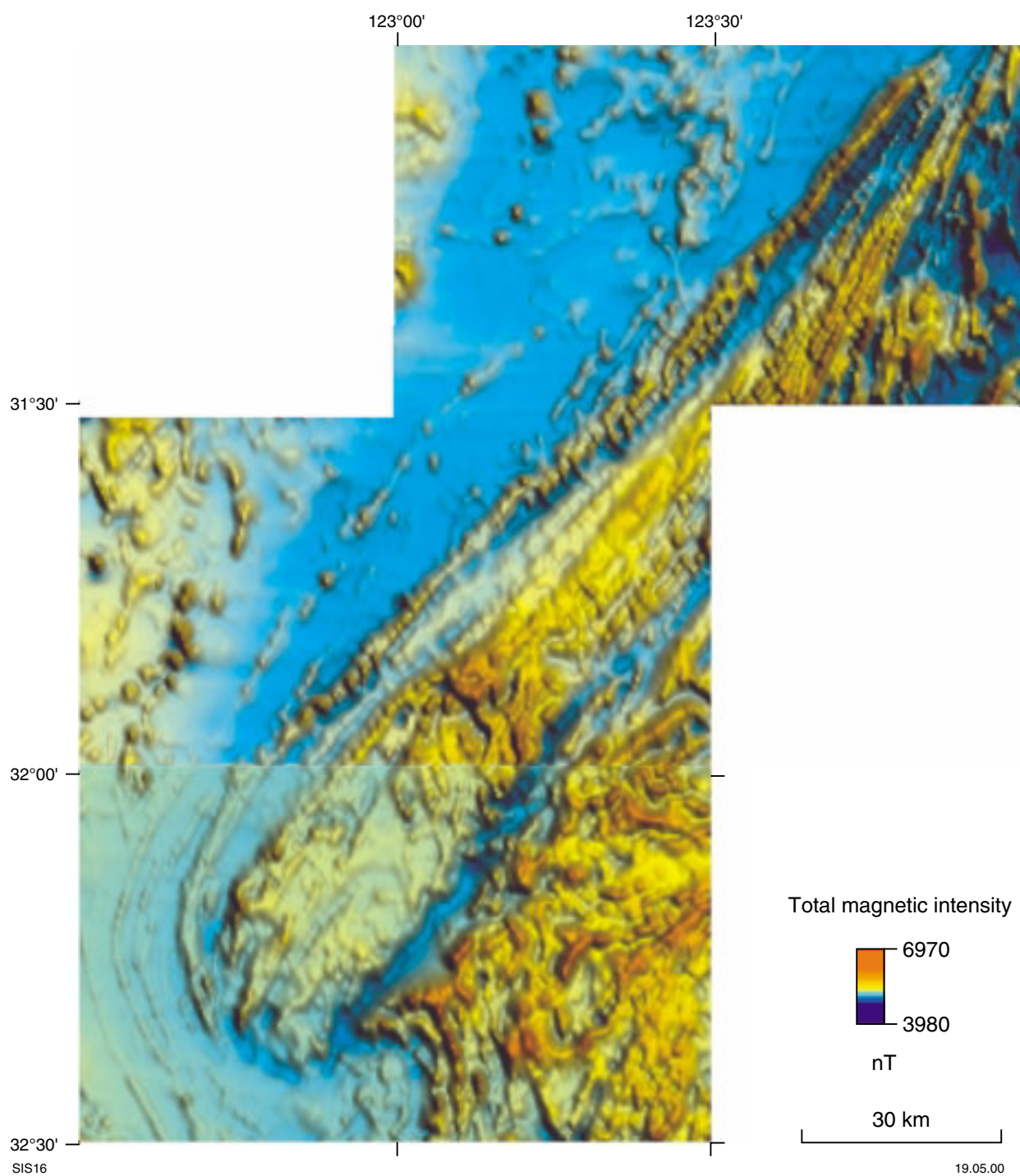


Figure 5. Image of total magnetic intensity for the Fraser Range area

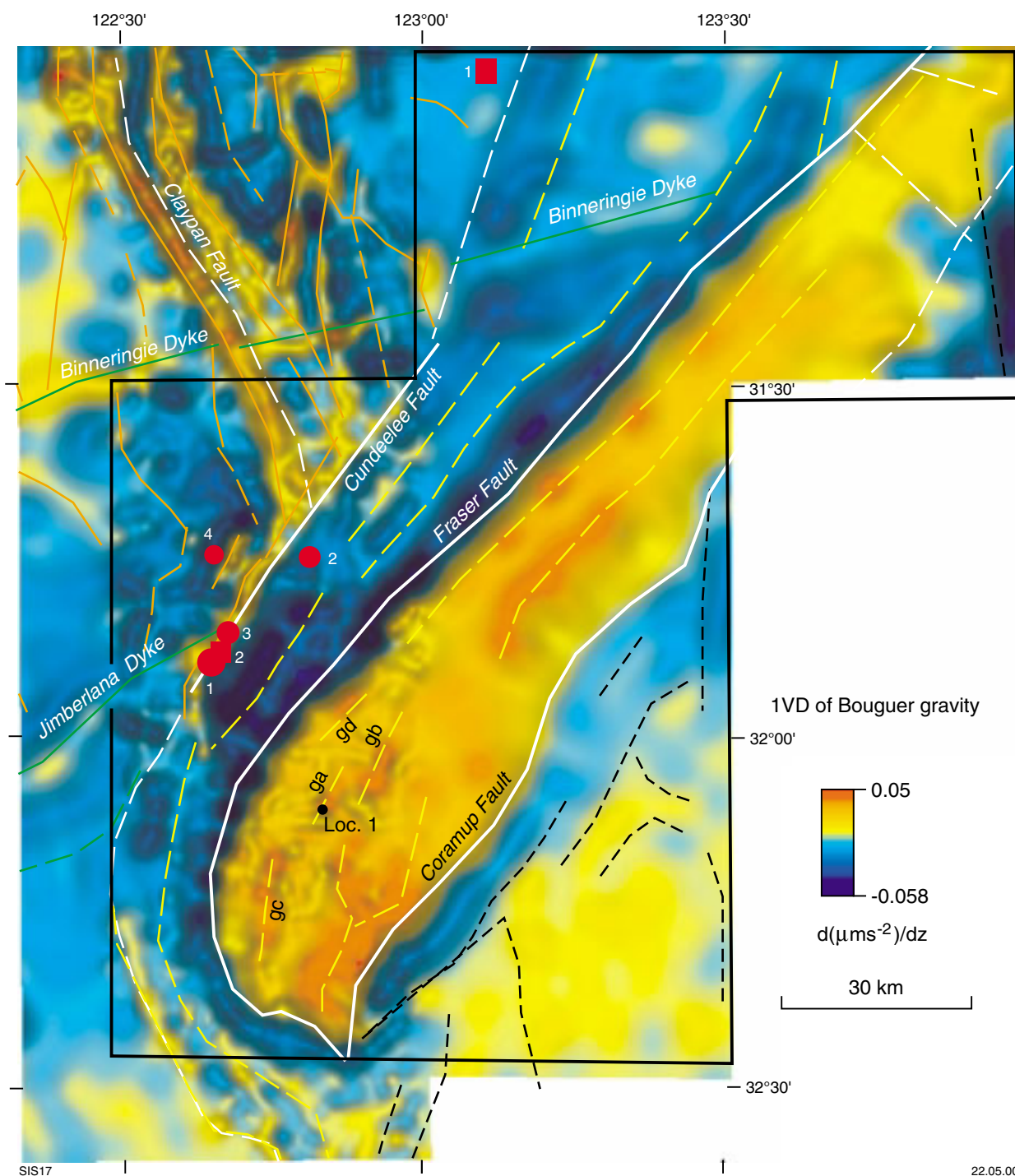


Figure 6. Image of first vertical derivative of the Bouguer gravity for the Fraser Range area from the new and AGSO data, with interpretation. Black solid line = area of the Fraser Range gravity survey. Red squares = highest chalcophile indices, red circles = highest gold concentrations (13-26 ppb) in the survey area. Orange lines = interpreted greenstone structures, dark-green dashed line = dyke, yellow dashed lines = high-density and highly magnetic layered bodies, black dashed lines = interpreted regional faults (from gravity data), and white dashed lines = faults

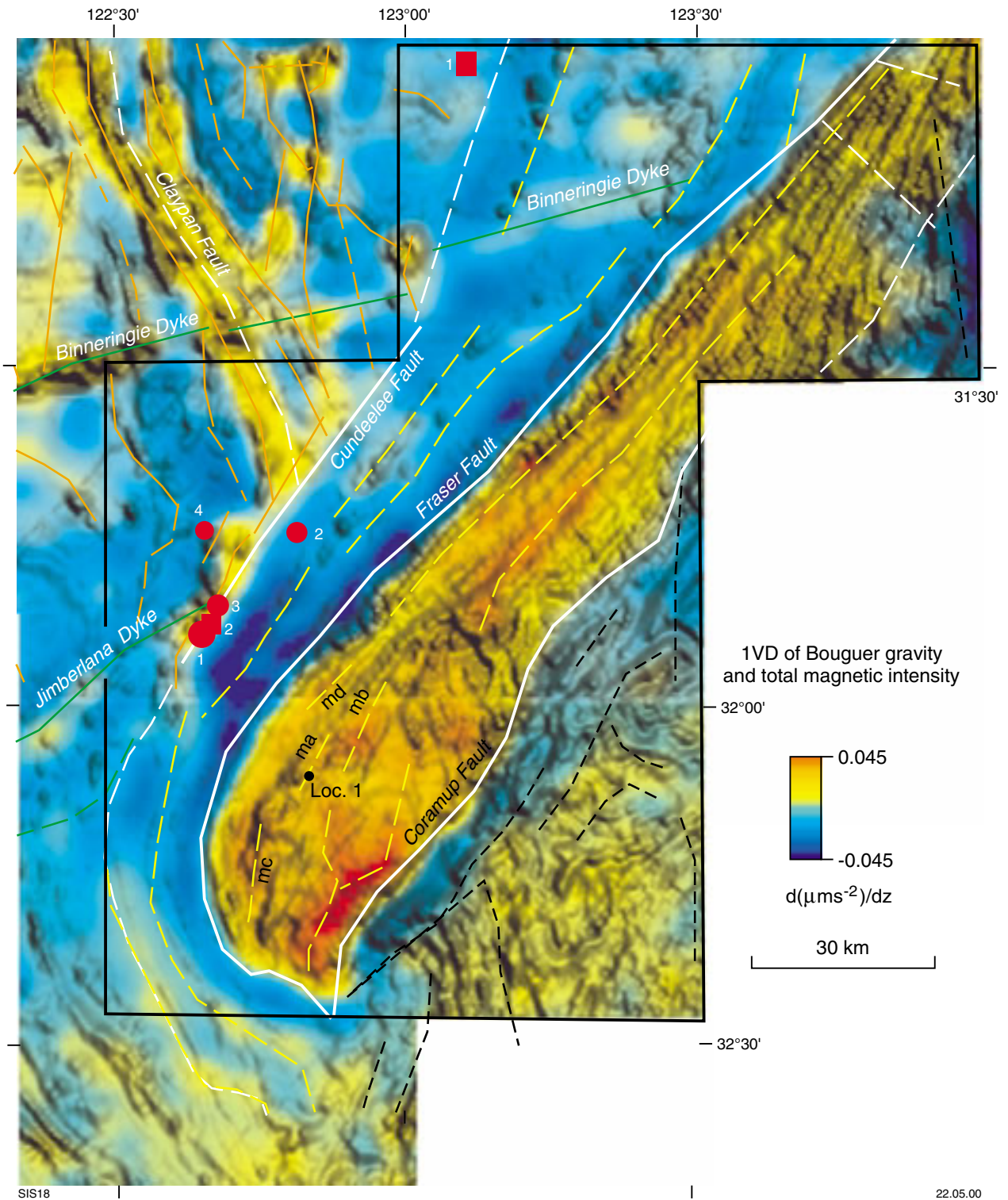


Figure 7. Image of first vertical derivative of the Bouguer gravity (pseudocolour) and total magnetic intensity (intensity) of the Fraser range area with interpretation. Black solid line = area of the Fraser Range gravity survey. Red squares = highest chalcophile indices, red circles = highest gold concentrations (13-26 ppb) in the survey area. Orange lines = interpreted greenstone structures, dark-green dashed line = dyke, yellow dashed lines = high-density and highly magnetic layered bodies, black dashed lines = interpreted regional faults (from gravity), and white dashed lines = faults

highest chalcophile indices (red squares labelled 1 and 2 on Figs 6 and 7) and the three highest gold concentrations (13–26 ppb; red circles labelled 1, 2, and 3 on Figs 6 and 7) are associated with the Cundeelee Fault as interpreted from the regional gravity gradient. The fourth-highest gold value (12 ppb; red circle labelled 4 on Figs 6 and 7) is also in a zone of the steep gravity gradient that can be interpreted as a fault or the edge of a greenstone belt or a combination of both.

Biranup Complex

Rocks between the Cundeelee and Fraser Faults (Fig. 2) consist mainly of nonmagnetic granitic gneiss (Dalyup Gneiss; Condie and Myers, 1999), characterized by a constant magnetic field of about 4750 ± 40 nT (Fig. 5). There are few linear and narrow, approximately 2 km-wide anomalies with magnetic intensities of 20–100 nT and gravity anomalies of 10–15 μms^{-2} (Fig. 6). These anomalies are subparallel to the strike of structures in the complex. The complex contains folded and faulted rocks along a northeasterly axis, which swing to the southeast around the Fraser Complex in the southern part of the survey area (shown by yellow dashed lines on Figs 6 and 7). These gravity and magnetic anomalies commonly coincide. There is little outcrop in this area to explain these anomalies. High-density and highly magnetic layered bodies within the complex or dolerite dykes, described by Myers (1990a), could be the source of these anomalies. Several samples of granitic gneiss collected for petrophysical analysis from the Garnet Ice quarry (Fig. 2) are nonmagnetic and have a density of 2740 kg/m^3 .

Fraser Complex

The Fraser Complex is apparent on the Bouguer gravity image as a gravity high, with a maximum Bouguer gravity of approximately $360 \mu\text{ms}^{-2}$ and residual positive anomaly of $1600 \mu\text{ms}^{-2}$ (Fig. 3). The anomaly confirms that the complex is composed of high-density material, mostly basic rocks as described by Wilson (1969). The Fraser Fault has a steep gradient on the 1VD image (Fig. 6), implying a significant throw. From geological and gravity data, Wilson (1969) suggested that the Fraser Fault is a reverse fault. The five tectonic subdivisions of the Fraser Complex, as proposed by Myers (1985) on geological grounds, cannot be recognized from the existing regional potential field data.

Immediately east of the Fraser Fault, the complex has a specific magnetic response — a series of linear, high-frequency ($0.001 - 0.0005 \text{ cy/m}$), northeasterly oriented magnetic anomalies subparallel the fault (Figs 5 and 7). The sparse regional gravity data cannot resolve whether these magnetic anomalies have similar gravity. However, the northeastern trend of the residual regional gravity anomalies on the 1VD image (yellow dashed lines on Fig. 6) indicates a density variation across the complex. In the southwestern part of the complex, the detailed gravity data reveal linear positive anomalies (ga, gb, gc, gd on Fig. 6) coinciding with high-frequency magnetic anomalies (ma, mb, mc, md on Fig. 7). These anomalies could be caused by high-density and highly magnetic layered bodies within the complex.

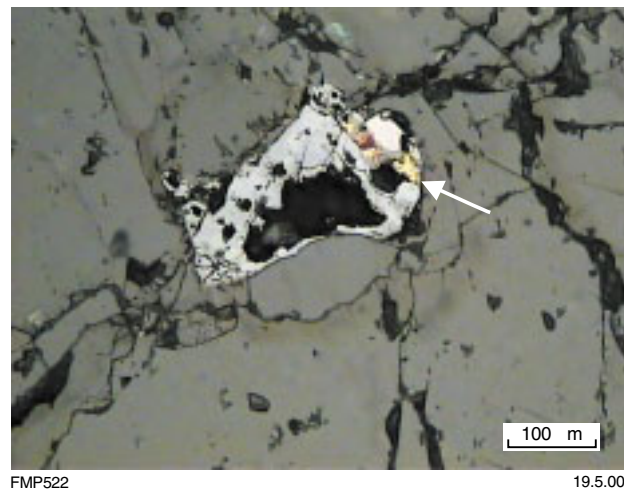


Figure 8. Photomicrograph showing a gold inclusion

Several samples of mafic granulites were collected for petrophysical analysis from localities coincident with gravity–magnetic anomalies in the complex. (Loc. 1 on Figs 6 and 7). The measurements indicate high magnetic susceptibility ($2500\text{--}3000 \times 10^{-5}$ SI) and high density (2970 kg/m^3).

Sample GSWA 13521 from a granulite rock is composed of approximately 15–20% by volume of hypersthene, 50% plagioclase, 20% quartz, 7–8% magnetite, and minor other oxides. Magnetite forms interstitial blebs, one of which is altered to martite (hematite) and contains an inclusion of a gold particle about $28 \mu\text{m}$ long, shown in Figure 8. However, a geochemical analysis of this sample did not reveal anomalous concentrations of gold or other metals. Nevertheless, the presence of this gold is intriguing and its association with an oxidized magnetite suggests either a low-temperature hydrothermal origin or a primary association of magnetite–oxide. This granulite has undergone high-temperature (800°C), moderate-pressure (600–700 Mpa) metamorphism (Clark et al., 1999) and was probably derived from a quartz gabbro or diorite (Pirajno, F., 2000, pers. comm.).

The high content of magnetite and high-density hypersthene explains the highly anomalous magnetic and density values of the sample. The association of the gold with magnetite suggests that further investigation is necessary.

Nornalup Complex

The Coramup Fault is the western boundary of the Nornalup Complex (Fig. 6), which can be distinguished from the Fraser Complex by the steep regional gravity gradient on the Bouguer gravity anomaly image (Fig. 4). This structure is clearer in the gravity data than in the magnetic data (Fig. 5).

The stable gravity field over the complex suggests that there is no significant density variation in the granitic rocks of the complex and large mafic intrusions are absent. The positive regional Bouguer gravity anomaly of approximately $30 \mu\text{ms}^{-2}$ over the central part of the complex in the survey area (Fig. 3), which decreases to a value of approximately $-300 \mu\text{ms}^{-2}$ towards the northeast, can be explained as a regional gravity trend, related to deep crustal geometry or structures at depth. The small variation of $5\text{--}10 \mu\text{ms}^{-2}$ over the complex is more likely to be caused by a combination of thickness variations within the Cainozoic sediments and lithological variations within the complex. The lineaments shown in black on Figures 6 and 7 are most likely regional faults.

The Nornalup Complex is a highly magnetic area with the linear high-frequency anomalies similar to those of the Fraser Complex. There is no correlation between gravity lineaments and magnetic anomalies. There are northeasterly oriented magnetic anomalies parallel to the folding and faulting in the complex, but there is no dominant orientation direction of the anomalies in the complex. This may be related to the lesser intensity of deformation in the Nornalup Complex rocks (Myers, 1990a) than in those of the Biranup Complex.

Conclusions

In conjunction with regional magnetic data, the new regional gravity survey of the Fraser Range region provides new regional structural information in an area where previously only readings from widely spaced ($11 \times 11 \text{ km}$) gravity stations had been collected.

The Northern Foreland (including the Yilgarn Craton), the Biranup Complex (including Fraser Complex), and Nornalup Complex have different gravity and magnetic signatures. Previously unmapped greenstones have been interpreted in the northwestern part of the survey area using the new gravity data. The regional geochemistry associated with the new gravity data indicates that the northwestern part of the survey area is prospective for gold mineralization, particularly within the greenstones, along the Cundeelee Fault, and within the magnetite-rich zones of the Fraser Complex.

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Appendix 1

Summary of operation and processing for the Fraser Range gravity survey

Organization: Geological Survey of Western Australia

Start date: 9 September 1998

Completion: 21 September 1998

	<i>GPS</i>	<i>Gravity</i>
Equipment	4 Ashtech Z12 receivers N223, N226, N900, N942	5 LaCoste and Romberg Model G 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	2 Helicopters J Bell 206B3 (Jet Ranger) 1 Land Cruiser 4-wheel drive	
DOLA Bench marks used	NORSEMAN 136 to transfer coordinates to 9863–7001 NORSEMAN 134 for position and height control NORSEMAN 137 for position and height control FRASER for position and height control 9863–7001 to transfer coordinates to 9862–7002	6491.9096 (Zanthus Isogal station) 9692.2601 (Norseman Isogal station)
New base stations	9863–7001, 9863–7002	9863–7000, 9863–7002
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, 1253 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 processing and gridding program (v. 3.4), ER Mapper image processing system (v. 6.0)
Accuracy	$\sigma_{\text{elevation}} = \pm 0.7 \text{ m}$, $\sigma_{x,y} = \pm 5 \text{ m}$	$\sigma_{\text{gravity base stations}} = \pm 0.3 \mu\text{s}^{-2}$ $\sigma_{\text{gravity ordinary stations}} = \pm 0.5 \mu\text{s}^{-2}$
Total Bouguer accuracy		$\sigma_{\text{survey}} = \pm \sqrt{(2.2^2_{\text{elev}} + 0.3^2_{\text{base stns}} + 0.5^2_{\text{ord stns}})} = 2.3 \mu\text{s}^{-2}$

Appendix 2

Survey personnel

<i>GSWA</i>		<i>Contractors</i>	
Project manager:	P. Morris	Helicopter company:	Helicopters Australia
Gravity survey manager:	S. Shevchenko	Chief pilot:	M. Corbett
Gravity observers:	S. Baesjou	Pilots:	P. Legradi
	B. Groenwald		R. Humphrey
	J. Hansen		A. Regan
	A. Lee	Engineer:	Kush
	S. McGuinness		
	M. Painter		
Gravity field assistant:	A. Riganti		
	J. Watt		

Appendix 3

Bench mark data

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

Name	Comments	Type of mark	Type of grid	Latitude (S) / Easting	Longitude (E) / Northing	AHD height ^(f) / AMG ^(e) Zone	Date surveyed	Method	Order	Horizontal accuracy / Vertical accuracy	Gravity value (μms^{-2})	Gravity error (μms^{-2})
Norseman 136 ^(b)	–	S ^(c)	AGD84 ^(d) AMG84 ^(e)	32°01'01.18904" 483117.695	122°49'16.44458" 6457654.076	425.742 51	–	GEOD ^(g) SLEV ^(h)	3rd 3rd	30 ppm 12 rootK (mm)	–	–
Norseman 134 ^(b)	Control	S ^(c)	AGD84 ^(d) AMG84 ^(e)	32°00'43.81151" 481081.407	122°47'58.85897" 6458185.558	433.626 51	–	GEOD ^(g) SLEV ^(h)	3rd 3rd	30 ppm 12 rootK (mm)	–	–
Norseman 137 ^(b)	Control	S ^(c)	AGD84 ^(d) AMG84 ^(e)	32°01'38.03016" 487093.791	122°51'47.95896" 6456525.545	415.576 51	–	GEOD ^(g) SLEV ^(h)	1st 3rd	7.5 ppm 12 rootK (mm)	–	–
Fraser ^(b)	Control	S ^(c)	AGD84 ^(d) AMG84 ^(e)	32°03'03.070" 480785.909	122°47'47.28720" 6453897.181	571.889 51	01/07/1996	GEOD ^(g) SLEV ^(h)	3rd 3rd	30 ppm 12 rootK (mm)	–	–
9863-7000 Fraser	Gravity base only	SP ^(k)	AGD84 ^(d)	32°01'47"	122°47'30"	424	05/09/1998	MAP ⁽ⁱ⁾	–	–	9793831.7	0.3
9863-7001 Fraser	GPS base only	SP ^(k)	AGD84 ^(d) AMG84 ^(e)	32°01'47.54992" 480340.085	122°47'30.45707" 6456221.652	424.955 51	05/09/1998	GPS ⁽ⁱ⁾ GPS ⁽ⁱ⁾	– –	–	–	–
9863-7002 Zanthus	GPS and gravity base	SP ^(k)	AGD84 ^(d) AMG84 ^(e)	31°02'03.29423" 554193.556	123°34'04.33250" 6566452.115	264.217 51	17/09/1998	GPS ⁽ⁱ⁾ GPS ⁽ⁱ⁾	– –	–	9792835.7	0.1
9692.2601 Norseman	AGSO Isogal station		AGD84 ^(d)	32°11'48"	121°47'16"	290	1996	MAP ⁽ⁱ⁾	–	–	9794045.3	–
6491.9096 Zanthus	AGSO Isogal station		AGD84 ^(d)	31°02'03"	123°34'04"	465 1964	MAP ⁽ⁱ⁾	–	–	9790344.4	–	–

NOTES:

(a) Department of Land Administration
(e) Australian Map Grid 1984
(g) Geodetic

(b) Coordinates from DOLA
(i) Global Positioning System
(k) Star picket and metal peg

(c) Standard survey mark
(f) Australian Height Datum
(h) Spirit level

(d) Australian Geodetic Datum
(j) From a map

Table 3.2. Observed coordinate differences

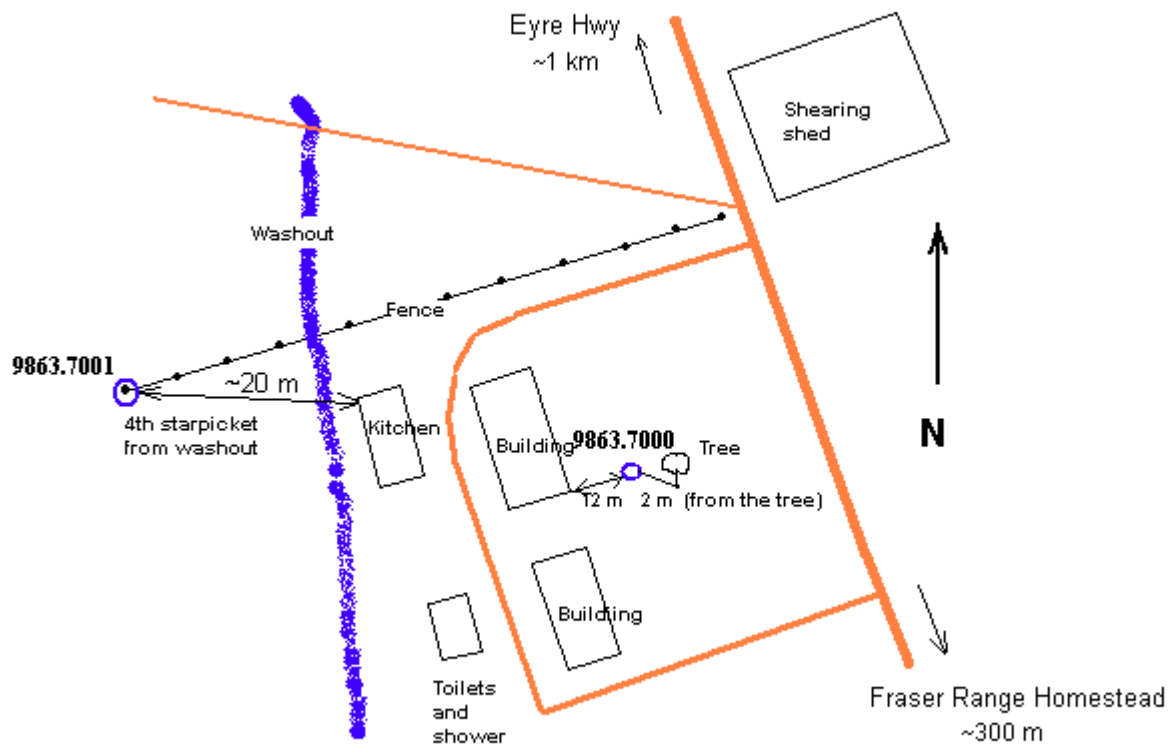
<i>Bench mark</i>	<i>DOLA^(a)</i>			<i>Observed GPS^(b)</i>			<i>Differences</i>		
	<i>Easting</i> (<i>m</i>)	<i>Northing</i> (<i>m</i>)	<i>AHD^(c) height</i> (<i>m</i>)	<i>Easting</i> (<i>m</i>)	<i>Northing</i> (<i>m</i>)	<i>AHD^(c) height</i> (<i>m</i>)	<i>d Easting</i> (<i>m</i>)	<i>d Northing</i> (<i>m</i>)	<i>d height</i> (<i>m</i>)
Norseman 134	481081.407	6458185.558	433.626	481081.427	6458185.589	433.460	+0.02	+0.03	-0.16
Norseman 137	487093.791	6456525.545	415.576	487093.738	6456525.435	415.821	-0.06	-0.17	+0.25
Fraser	480785.909	6453897.181	571.889	480785.868	6453897.050	571.926	-0.04	-0.13	+0.04

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

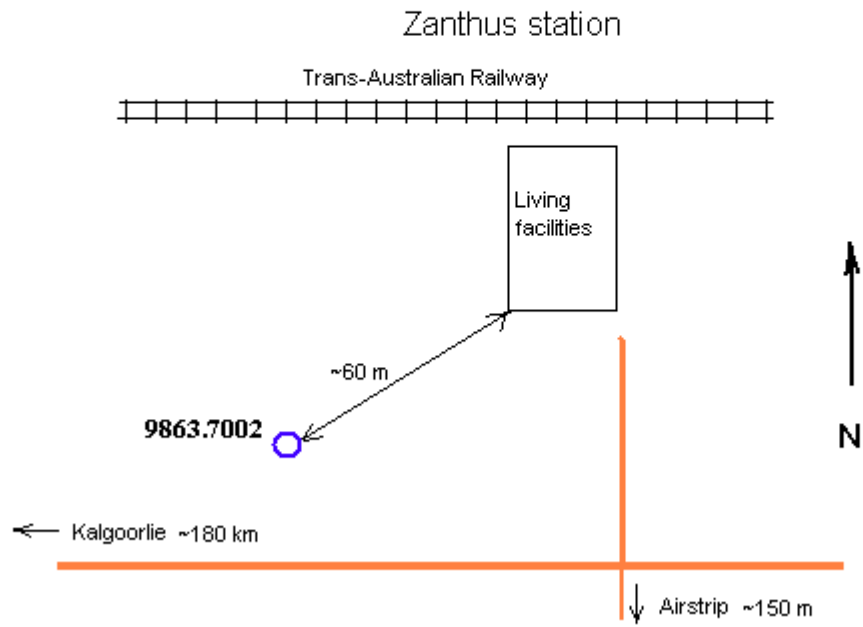
Appendix 4

Established gravity and GPS base station descriptions (schematic)

Fraser Range base station



Zanthus gravity station





FRASER RANGE REGION
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

FRASER RANGE REGION

1:250 000 BOUGUER GRAVITY

