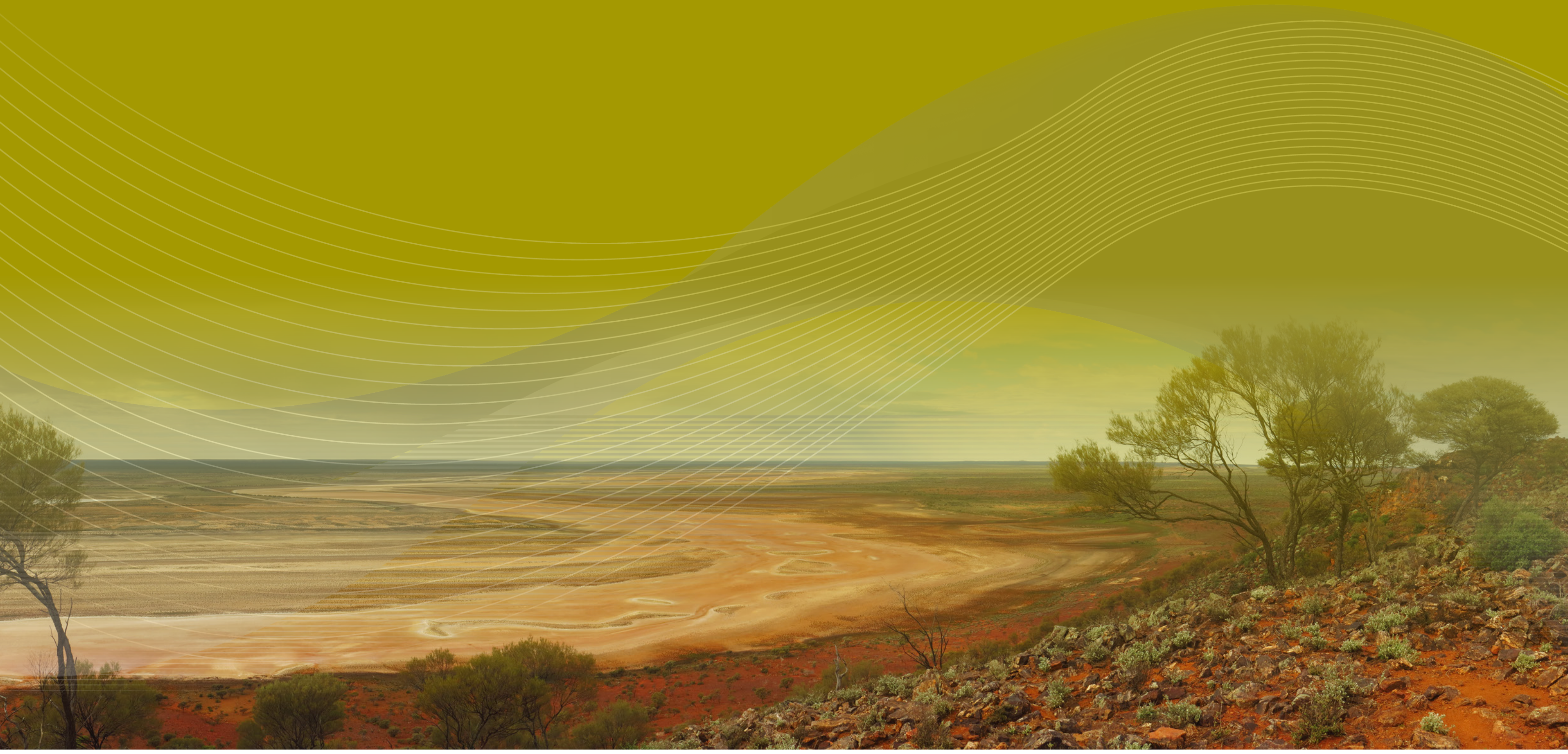
Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

RECORD 2017/13

COMPILATION OF GEOPHYSICAL MODELLING RECORDS, 2017

compiled by
RE Murdie and L Brisbout



Geological Survey of Western Australia

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Perth 2017

Geological Survey of Western Australia

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Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownaminya Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph taken by I Zibra for the Geological Survey of Western Australia

Contents

Compilation of geophysical modelling records, 2017

Introduction

This Atlas of records documents the geophysical forward modelling using aeromagnetic and gravity anomaly data along various geological cross-sections within Western Australia. These forward modelled cross-sections have been generated to:

1. support the production of the geological maps by increasing rigour of the interpreted cross-sections

2. aid the interpretation of seismic data in large deep crustal sections.

In addition, there are other specific instances where geophysical forward modelling was required.

In most cases, the sections are populated by densities representative of the type of rock predicted to be in that location in the profile. In any models related to a geological map series, the shapes of the bodies were also adjusted to assist with the fit of the data. In the seismic sections, the shapes of the polygons were generally assumed to be fixed by the seismic interpretation. Very few sections have actual measured physical property data as input.

As with all potential field modelling, there is always a non-uniqueness problem of density and magnetic intensity against shape and depth of body. Therefore, these models are examples of consistent geometries and property distribution; they are not definitive models.

Deep seismic reflection line 10GA-CP1

(Pilbara Craton, Capricorn Orogen)

JA Goodwin[1], G Heinson[2] and RE Murdie

Location

Maps: Mount Bruce (SF 50-11), Turee Creek (SF 50-15)

Zone: MGA Zone 50

End coordinates: 505312E 7388790N to 574151E 7512403N

Length: 180 km

Scale of interpretation: 1:250 000

Type of modelling: 2D forward modelling of gravity and magnetics and 2D magnetotelluric (MT) inversion of a profile.

This south-southeast to north-northwest-oriented section is coincident with deep reflection seismic line 10GA-CP1 (Johnson et al., 2011, 2013) that transects the Hamersley and Fortescue Basins of the Pilbara Craton and the Ashburton Basin of the Capricorn Orogen (Fig. 1).

Tectonic units

Archean granite–greenstones of the Rocklea Inlier form basement to the Paleoproterozoic Hamersley and Fortescue Basins of the Pilbara Craton (Thorne et al., 2011a). The middle to lower crust along the northern part of the transect comprises the unexposed Carlathunda Seismic Province (Korsch et al., 2011). Volcano-sedimentary rocks of the Fortescue Group (Blake et al., 2004) and distal marine sedimentary rocks of the Hamersley Group (Thorne and Trendall, 2001) overlie the Archean granite–greenstones. The southern margin of the Hamersley and Fortescue Basins is unconformably overlain by siliciclastic sedimentary rocks of the Turee Creek and Ashburton Basins that consist of the Turee and Shingle Creek Group and the Wyloo Group, respectively. The Fortescue and Hammersley Groups are interpreted to underlie the Turee Creek and Ashburton Basins (Thorne et al., 2011b). The Bandee Seismic Province forms the middle crust of the Capricorn Orogen at the southern end of the transect.

Structure

The Hardey and Turner Synclines and the Rocklea Inlier form the main regional-scale structures within the Pilbara Craton. These structures formed during the 2215–2154 Ma Ophthalmia Orogeny (Rasmussen et al., 2005) and affected rocks of the Shingle Creek Group and older deposits. Rocks in the overlying Ashburton Basin were deformed during the 1820–1770 Ma Capricorn Orogeny (Thorne and Seymour, 1991; Sheppard et al., 2010).

Three major trans-crustal faults were imaged in the section. The Baring Downs Fault, which at depth forms the boundary between the Bandee and Carlathunda Seismic Provinces, dips steeply to the northeast. The Nanjilgardy Fault is also a steep, north–east-dipping structure, but is interpreted to be a transpressive flower structure at the surface. In the shallow crust, the Soda Well Fault dips steeply to the northeast, but the angle shallows at depth.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia gravity merged grid of Western Australia (GSWA, 2013a), with points sampled every 440 m (Fig. 2b). Additional gravity points had been taken along the seismic line in addition to the statewide 2.5 km coverage. Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Magnetic data were taken from the State 80 m merged map (GSWA, 2013b).

MT data were also collected along this profile at 5 km spacing for broadband instruments (200 – 0.005 Hz) and 15 km spacing for long-period instruments (0.1 – 0.0001 Hz).

Forward modelling

All modelling was performed in Modelvision v.11.0 software. The starting model was taken from the interpretation of seismic line 11GA-CP1 and modified so that the calculated potential field anomalies fitted the observed anomalies better without significantly changing the seismic form lines.

Forward modelling results

Values for density and magnetic susceptibility used in the modelling are listed in Table 1.

The northern end of the line is dominated by high-amplitude, short-wavelength magnetic anomalies (Fig. 2b), and high-amplitude gravity anomalies (Fig. 2d), which can be associated with banded iron-formation (BIF) of the Hamersley Group in the Turner Syncline. A significant amount of remanence is associated with the Hamersley

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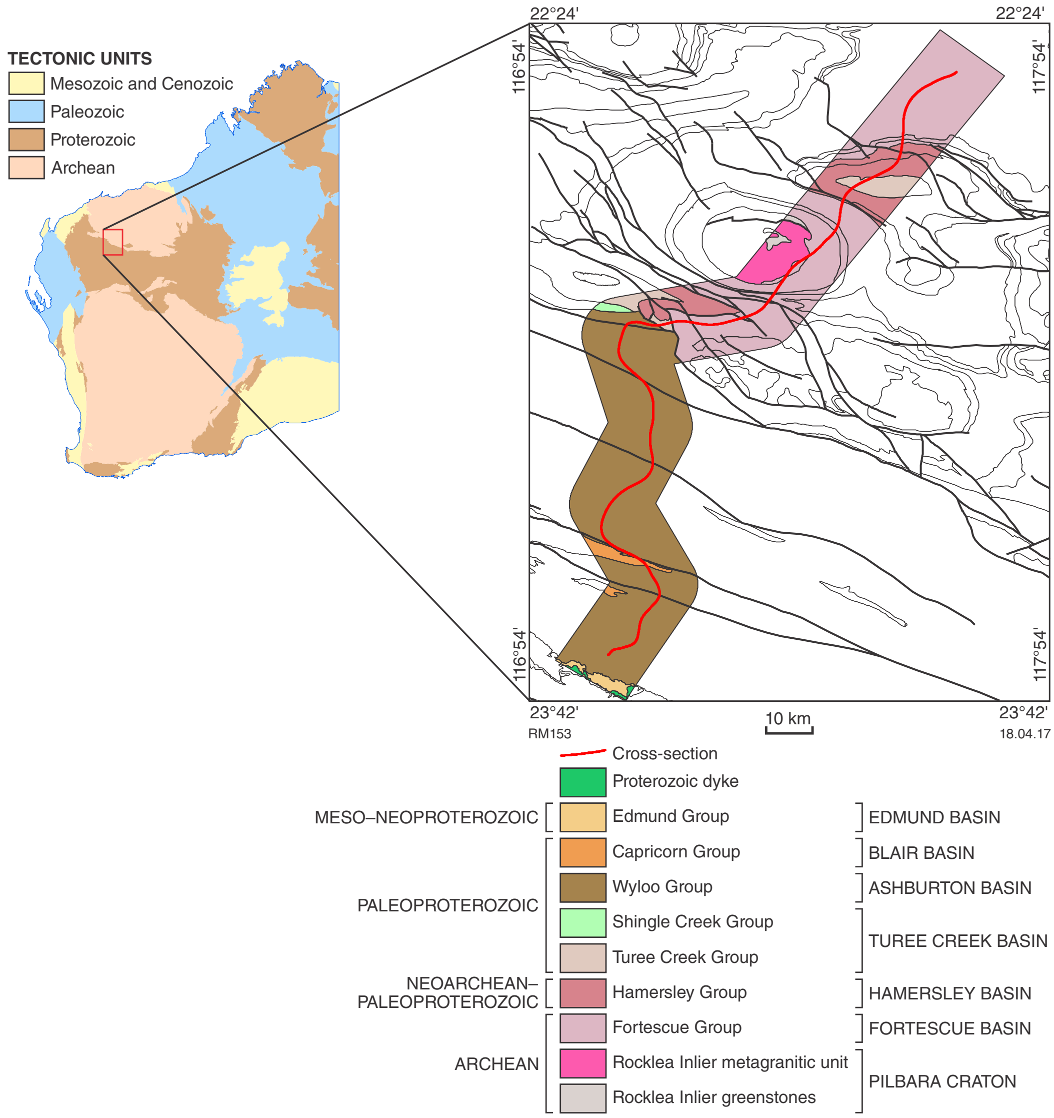

Figure 1. Simplified 1:500 000 interpreted bedrock geology map of the Hamersley and Fortescue Basins (Pilbara Craton) and the Ashburton Basin (Capricorn Orogen) showing location of cross-section A–B

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-CP1. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Rock type*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Upper Wyloo Group	Sedimentary siliciclastic	2.67	
	Lower Wyloo Group	Sedimentary siliciclastic	2.70 – 2.80	
	Turee Creek Group	Sedimentary siliciclastic	2.80	
	Hamersley Group	Sandstone and BIF	3.20	0.10 – 0.20
	Fortescue Group	Mafic rocks	2.85 – 2.90	
	Pilbara granite–greenstones	Granites with greenstones	2.58 – 2.70	
	Carlathunda Seismic Province	Lower crust	2.90	
	Bandee Seismic Province	Middle crust	2.80	0.05
	Lower Bandee Seismic Province	Lower crust	2.90	
	Upper mantle	Mantle	3.20	

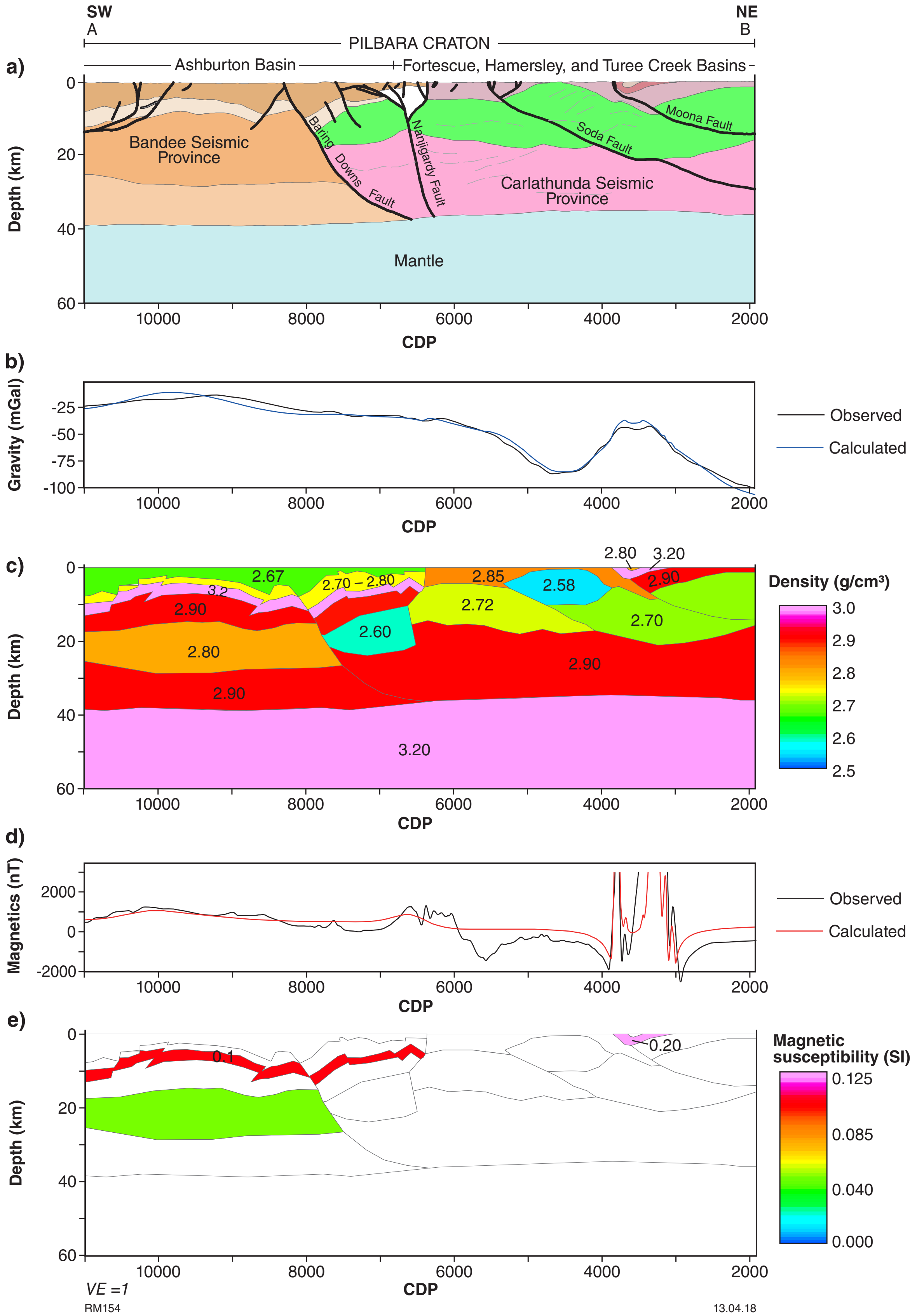

Figure 2. Profiles of the seismic line 10GA-CP1 showing: a) lithological section from the interpretation of seismic data; b) observed and calculated gravity anomaly profile; c) section of density per lithology; d) observed and calculated gravity anomaly profile; e) section of magnetic susceptibility per lithology

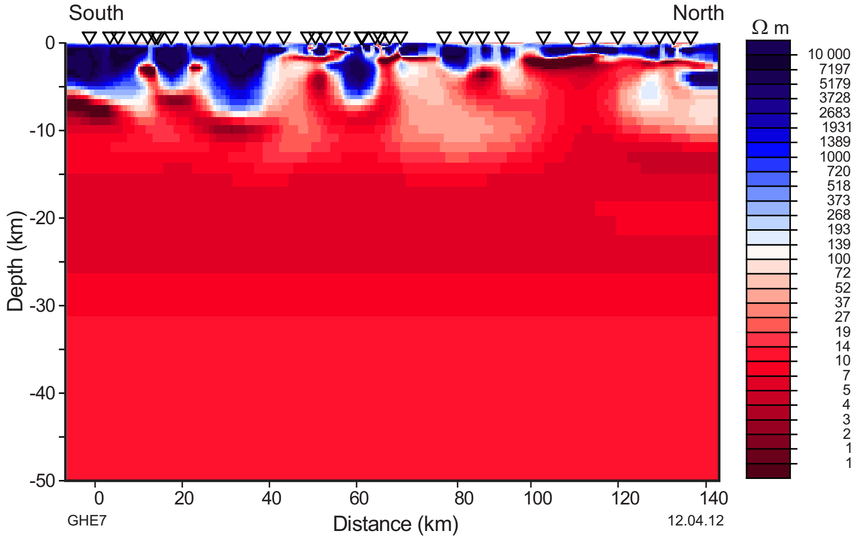

Figure 3. 2D resistivity section for line 10GA-CP1. The bandwidth of the inversion was 200 – 0.1 Hz. The profile orientation was taken to be 30°E of geographic north (with geological strike perpendicular to the profile)

Group, and hence the signals are far stronger than have been modelled (Guo et al., 2011).

The Fortescue Group is dominated by mafic volcanic and volcaniclastic rocks and has a much smoother magnetic signature.

The strong magnetic signal in the region of the Nanjilgardy Fault are from BIF within the Hardey Syncline, but are off-section to this line and were therefore not modelled.

The Ashburton Basin is modelled as a gentle dome (Fig. 2a) with a strong magnetic signature, which appears to be truncated at the Baring Downs Fault. This also appears to be the boundary between higher density rocks in the south compared to the relative low gravity at the northern end. These high-density rocks could have originated in the Bandee Seismic Province, but an alternative model would place layers of Hamersley and Fortescue Groups underlying the Ashburton Basin. The addition of the Hamersley Group gives a better fit to the regional magnetic anomaly (Goodwin, 2011).

MT inversions

Modelling and inversion of the MT data was done using the WinGLink software, which utilizes the 2D inversion code of Rodi and Mackie (2001). More details on the data processing can be found in Heinson et al. (2011).

Inversion results

The final plot of the MT along the profile of 10GA-CP1 (Fig. 3) (Heinson et al., 2011) is the simplest model which fits the observed MT responses. Only the broadband responses were used in the inversions. The resistivity structure appears fairly uniform. It consists of a thin conductive sedimentary layer at the top, underlain by a very resistive layer 2–10 km thick, which thickens at the southern end of the profile. This is underlain by a very conductive (~1 Ω) region. Below this region, the model cannot be resolved as the conductive layer does not allow the current to flow any deeper. This fact also prevents any structures within the basins to be imaged. During the processing, many responses showed evidence of 3D structure and possible anisotropic conduction which was not modelled here.

Long-period data were not modelled due to the low quality and 3D features.

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Deep seismic reflection line 10GA-CP2

(Capricorn Orogen)

JA Goodwin[1], G Heinson[2] and RE Murdie

Location

Maps: Edmund (SF 50-14), Mount Phillips (SF 50-2), Glenburgh (SG 50-6)

Zone: MGA Zone 50

End coordinates: 384572E 7202534N to 474094E 7404580N

Length: 180 km

Scale of interpretation: 1:250 000

This section is a southeast–northwest-oriented section that is coincident with deep seismic reflection line 10GA-CP2 (Johnson et al., 2011, 2013) that transects the central part of the Capricorn Orogen (Fig. 1).

Tectonic units

The oldest rocks are present at the southern end of the line. The Glenburgh Terrane comprises granitic and gneissic rocks of the 2555–2430 Ma Halfway Gneiss and the 2005–1970 Ma Dalgaringa Supersuite and medium- to high-grade metasedimentary rocks of the 2240–2125 Ma Moogie Metamorphics. The lower crust of the Glenburgh Terrane, the MacAdam Seismic Province, has a distinctly different seismic character and may represent a separate distinct tectonic unit (Korsch et al., 2011). The northern part of the line is underlain by the unexposed Bandee Seismic Province that continues from the southern end of line 10GA-CP1 (Johnson et al., 2011, 2013). The Glenburgh Terrane was intruded by voluminous granitic stocks and batholiths of the 1820–1775 Ma Moorarie Supersuite and 1680–1620 Ma Durlacher Supersuite that appear in the seismic section as distinct, nonreflective bodies (Johnson et al., 2011, 2013). These bodies also contain areas of highly reflective material that are interpreted to be rafts of low-grade metasedimentary rocks of the 1840–1810 Ma Leake Springs Metamorphics (Johnson et al., 2011, 2013). Magmatic intrusions of the Durlacher Supersuite are also interpreted to underlie younger sedimentary rocks of the Edmund Basin along the northern part of the section. These rocks are unconformably overlain by discontinuous, coarse clastic sedimentary rocks of the 1679–1610 Ma Mount Augustus Sandstone. The 1679–1067 Ma Edmund and Collier Basins are the youngest depositional units in the Capricorn Orogen and unconformably overly siliciclastic sedimentary rocks of the Ashburton Basin along the northern part of the line. The Edmund Basin attains a maximum thickness of 7 km on the southern side of the Godfrey Fault (Cutten et al., 2016). Extension on the Talga, Godfrey, and Lyons River Faults formed several half grabens into which the fine-grained siliciclastic and carbonate sedimentary rocks were deposited (Martin and Thorne, 2004; Cutten et al., 2016). Highly reflective packages within the Edmund Basin are interpreted to be dolerite sills of the 1465–1452 Ma Narimbunna and 1084–1067 Ma Kulkatharra Dolerite that were emplaced in the upper parts of the basin (Cutten et al., 2011, 2016). The southern end of the line transects siltstones and sandstones of the Permian Lyons Group of the Southern Carnarvon Basin.

Structure

The major crustal structures in this profile all dip moderately to the south and separate areas of differing structural, magmatic, and metamorphic history (Sheppard et al., 2010; Johnson et al., 2013). The suture between Glenburgh Terrane – MacAdam Seismic Province and the Bandee Seismic Province, identified as the Lyons River Fault (Johnson et al., 2011, 2013), offsets the Moho and in the middle crust splays into the Ti Tree Shear Zone and Edmund Fault (Johnson et al., 2011, 2013). The Talga Fault that soles onto the Godfrey Fault at depth is interpreted to be a major crustal shear zone that forms part of the north-verging fold and thrust system of the Ophthalmia Orogeny.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) gravity merged grid of Western Australia (GSWA, 2013a), with points sampled every 440 m (Fig. 2b). Additional gravity points had been taken along the seismic line in addition to the statewide 2.5 km coverage. Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Magnetic data were taken from the State 80 m merged map (GSWA, 2013b).

MT data were also collected along this profile at a 5 km spacing for broadband instruments (200 – 0.005 Hz) and 15 km spacing for long-period instruments (0.1 – 0.0001 Hz).

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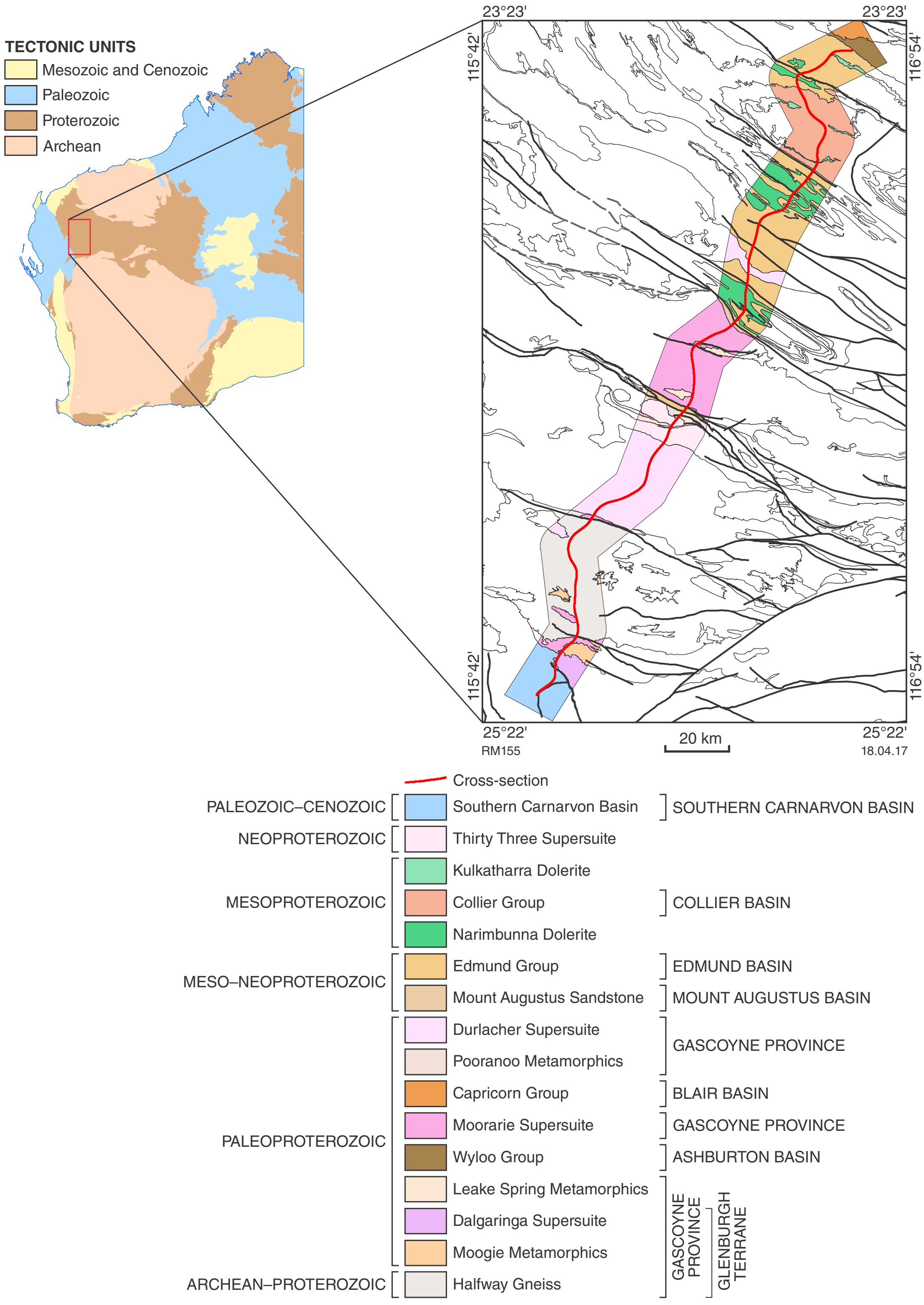

Figure 1. Central Capricorn region; simplified 1:500 000 interpreted bedrock geology map showing location of cross-section A–B

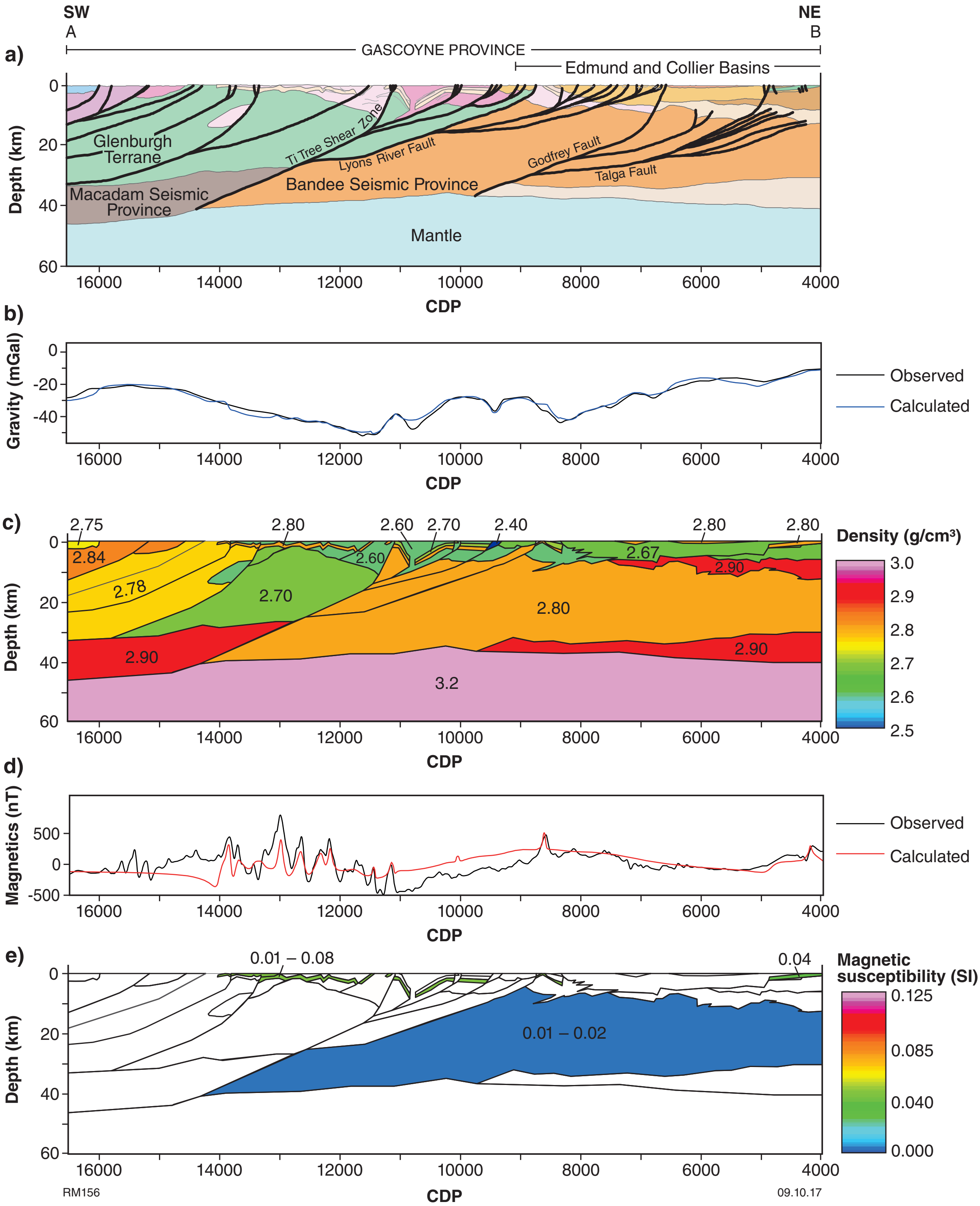

Figure 2. Profiles of the seismic line 10GA-CP2 showing: a) lithological section from the interpretation of seismic data; b) observed and calculated gravity anomaly profile; c) section of density per lithology; d) observed and calculated gravity anomaly profile; e) section of magnetic susceptibility per lithology

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-CP2. The colour column refers to colours used in Figure 2a

Colour	*Lithological unit*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Southern Carnarvon Basin	Sedimentary	2.75	
	Kulkatharra Dolerite	Dolerite	2.80	0.04
	Collier Group	Sedimentry siliciclastic	2.80	
	Edmund Group	Siliciclastic and carbonate sediments	2.67	
	Upper Wyloo Group	Sedimentry siliciclastic	2.67	
	Lower Wyloo Group	Sedimentry siliciclastic	2.90	
	Mount Augustus Sandstone	Sandstone	2.40	
	Durlacher Supersuite	Granitic	2.60	
	Dalgaringa Supersuite	Granitic	2.80	
	Moorarie Supersuite	Granitic	2.80	
	Leake Springs Metamorphics	Metasedimentary siliciclastic	2.80	0.01 – 0.08
	Pooranoo Metamorphics	Metasedimentary siliciclastic	2.70	
	Glenburgh Terrane	Granitic gneiss	2.70 – 2.78	
	Bandee Seismic Province	Middle crust	2.80	0.01 – 0.02
	MacAdam Seismic Province	Lower crust	2.90	
	Lower crust	Lower crust	2.90	
	Upper mantle	Mantle	3.20	

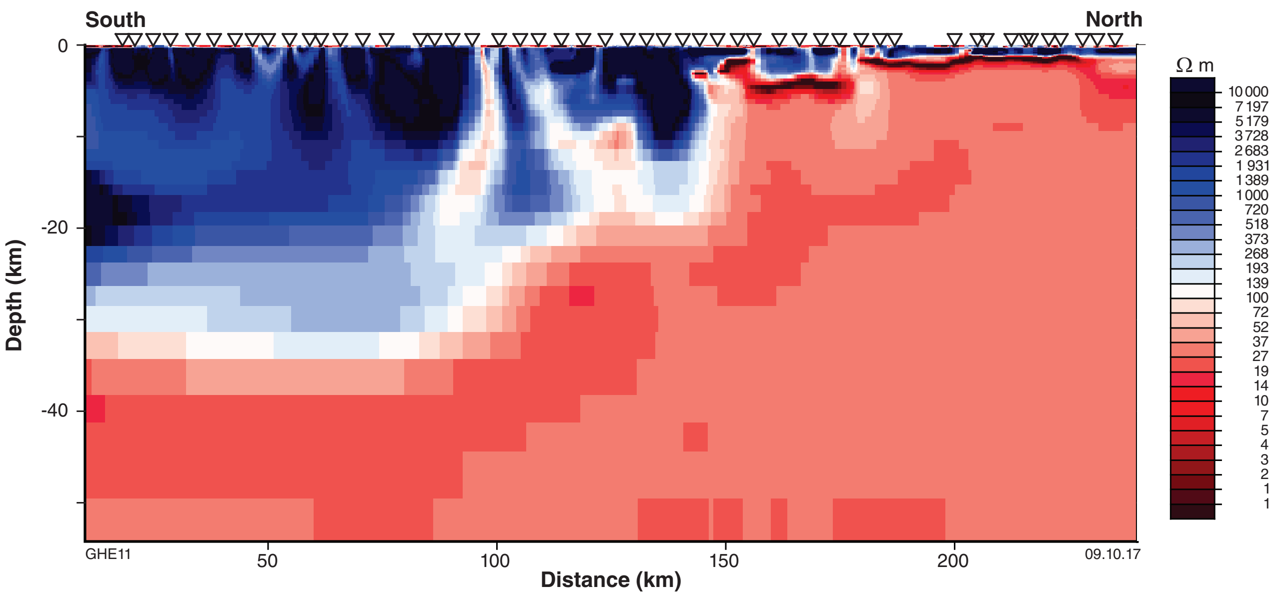

Figure 3. 2D resistivity section for line 10GA–CP2. The bandwidth of the inversion was 200 – 0.1 Hz. The profile orientation was taken to be 30°E of geographic north (with geological strike perpendicular to the profile)

Forward modelling

The section was modelled down to a depth of 60 km (Fig. 2c). All modelling was performed in Modelvision v.11.0 software. The starting point from the model was the seismic interpretation from 11GA-CP2 (Goodwin, 2011).

Forward modelling results

Values for density and magnetic susceptibility used in the modelling can be found in Table 1.

The gravity profile features a long wavelength low with lower troughs within it (Fig. 2b). The regional low is provided by a low density section of the Glenburgh Terrane juxtaposed against the relatively high densities of the Moogie Metamorphics (Fig. 2a). One prominent trough is formed by the Mount Augustus Sandstone of very low density. Others are formed by greater or lesser extents of granitic rocks of the Moorarie and Durlacher Supersuites.

The gravity high at the northern end of the profile is modelled as high densities (Fig. 2c) within the Ashburton Basin, which is in contrast to their moderate densities in the model of 10GA-CP1 (Goodwin, 2011).

The dolerite sills in the Edmund Basin and sections of Leake Springs Metamorphics provide the short-wavelength magnetic features (Fig. 2d) across the profile.

MT inversions

Modelling and inversion of the MT data was done using the WinGLink software which utilizes the 2D inversion code of Rodi and Mackie (2001). More details on the data processing can be found in Heinson et al. (2011).

Inversion results

The broadband responses were inverted for 2D structure. Responses were found to have various amounts of static shift. At frequencies higher than 0.1Hz the electrical structure was found to be only 2D and was aligned with the strike of both the geological and magnetic structures. However, at a few sites some bandwidths showed 3D features.

The final resistivity model (Fig. 3; Heinson et al., 2011) shows a northern section that is very similar to that of profile 10GA-CP1 (Goodwin et al., 2011) with a thin conductive sedimentary layer, followed by a 2–10 km-thick resistive layer, and finally a very conductive layer. Due to the current preferentially staying in the lower conductive layer, no features are resolved below this. Within the Edmund and Collier Basins, little structure is resolved.

In the southern part, the phase tensors become more uniform. There appears to be an electrical contrast between the Bandee Seismic Province and the Glenburgh Terrane. At the surface this is the northern edge of the Moorarie Supersuite. This electrical contrast dips at a similar angle to the Lyons River Fault, which is the suture between the Pilbara Craton and the Glenburgh Terrane. There is possibly a conductive shear zone in the approximate position of the Ti Tree Shear Zone. However, most of the crust to the south is highly resistive, typical of Archean crust. This is the area interpreted from the seismic profile as being the Glenburgh Terrane, indicating an Archean origin.

Long-period data were not modelled due to the low quality and 3D features.

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Deep seismic reflection line 10GA-CP3

(Narryer Terrane, Glenburgh Terrane)

JA Goodwin[1], G Heinson[2] and RE Murdie

Location

Maps: GLENBURGH (SG 50-6) and BYRO (SG 50-10)

Zone: MGA Zone 50

End coordinates: 460676E 7112874N to 466603E 7206006N

Length: 99 km

Scale of interpretation: 1:250 000

This south–north-oriented section is coincident with deep seismic reflection line 10GA-CP3 (Johnson et al., 2011a, 2013) that transects the Glenburgh Terrane of the Capricorn Orogen and the northern part of the Narryer Terrane of the Yilgarn Craton (Fig. 1).

Tectonic units

The Eoarchean to Neoarchean Narryer Terrane of the Yilgarn Craton is predominantly composed of granite and granitic gneiss with subordinate greenstone units (Williams and Myers, 1987; Nutman et al., 1991). It is sutured to the Glenburgh Terrane along the Cardilya Fault, but in the middle to upper crust this fault is truncated by the Errabiddy Shear Zone. This regional-scale shear zone contains imbricate slices of the Narryer Terrane, the 2758–2585 Ma Warrigal Gneiss, and high-grade metasedimentary rocks of the 2001–1955 Ma Camel Hills Metamorphics (Johnson et al., 2010, 2011b), and granitic intrusions of the 1961–1645 Ma Bertibubba Supersuite, which form the first common magmatic component of the two terranes (Sheppard et al., 2004). The Glenburgh Terrane is dominated by granitic rocks of the 2555–2430 Ma Halfway Gneiss and granitic stocks and plutons of the 2005–1975 Ma Dalgaringa Supersuite, which formed in a continental-margin magmatic arc along the southern margin of the terrane (Sheppard, 2004; Sheppard et al., 2004; Johnson et al., 2010, 2011b). High-grade metasedimentary rocks of the 2240–2125 Ma Moogie Metamorphics (Johnson et al., 2010; 2011a) are locally present. The lower crust of the Glenburgh Terrane, the MacAdam Seismic Province, has a distinctly different seismic character and may represent a separate distinct tectonic unit (Korsch et al., 2011). Both the Glenburgh Terrane and MacAdam Seismic Province are interpreted to have been thrust beneath the Narryer Terrane during the 2005–1950 Ma Glenburgh Orogeny (Johnson et al., 2011a, 2013).

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Structure

At the surface the Errabiddy Shear Zone separates the Narryer Terrane from the Glenburgh Terrane (Johnson et al., 2011a). However, the deep seismic reflection line indicates that the moderately south dipping Cardilya Fault is actually the suture zone (Johnson et al., 2011b, 2013). Although the Errabiddy Shear Zone appears to merge onto the Cardilya Fault, it is probably a later backthrust formed during the collisional phase of the 2005–1950 Ma Glenburgh Orogeny (Korsch et al., 2011). The Glenburgh Terrane and MacAdam Seismic Province are interpreted to have been thrust beneath the Narryer Terrane (Johnson et al., 2011, 2013), offsetting and duplicating the Moho where it is intersected by the Cardilya Fault. 'Fault 1' is interpreted from magnetic worm data and seismic interpretation as a fault separating different domains of the Narryer Terrane.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) gravity merged grid of Western Australia (GSWA, 2013a), with points sampled every 440 m (Fig. 2b). Additional gravity points have been taken along the seismic line in addition to the statewide 2.5 km coverage. Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Magnetic data were taken from the State 80 m merged map (GSWA, 2013b).

MT data were also collected along this profile at a 5 km spacing for broadband instruments (200 – 0.005 Hz) and a 15 km spacing for long-period instruments (0.1 – 0.0001 Hz).

Forward modelling

The section was modelled down to a depth of 60 km (Fig. 2c). All modelling was performed in Modelvision v.11.0 software. The starting point from the model was the seismic interpretation from 11GA-CP3 (Goodwin, 2011; Johnson et al., 2011a).

Forward modelling results

Values for density and magnetic susceptibility used in the modelling are listed in Table 1.

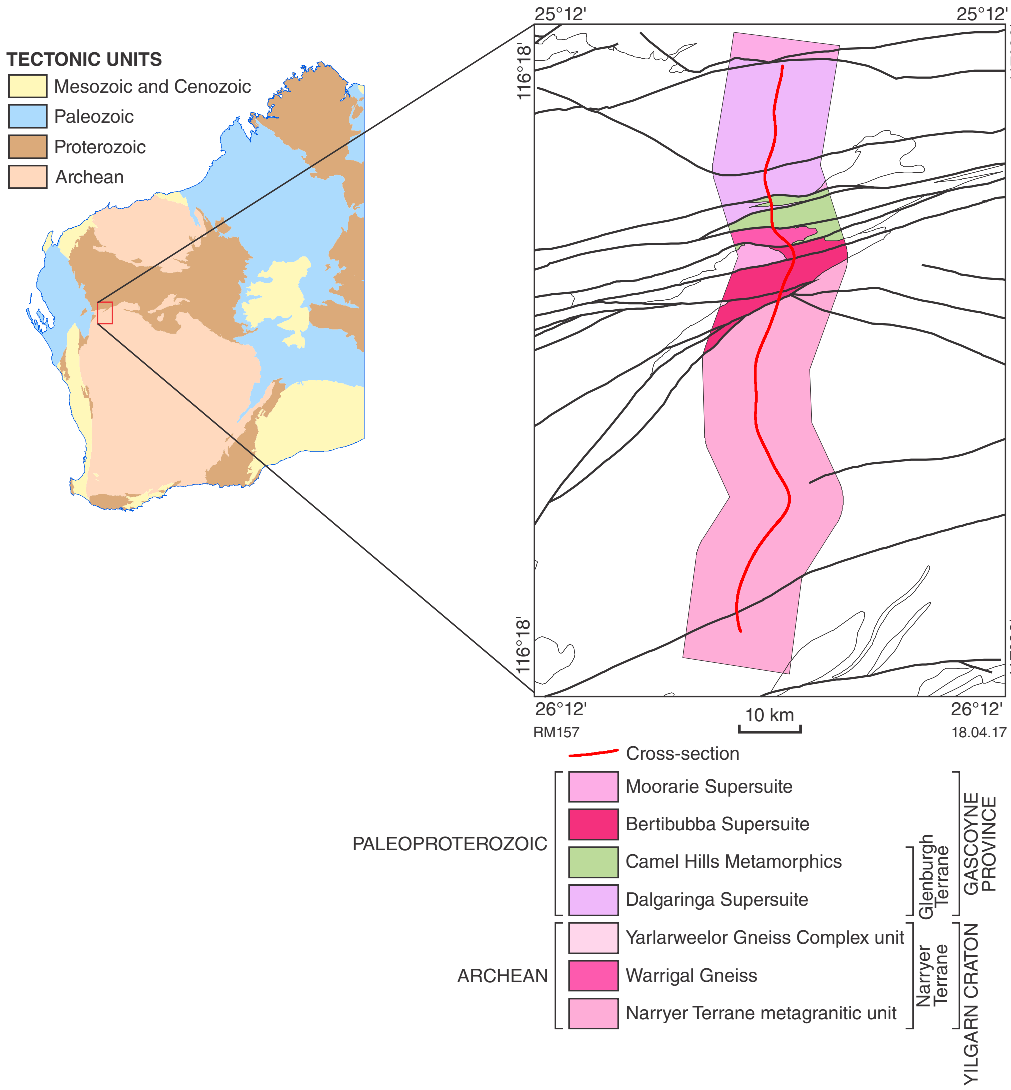

Figure 1. Simplified 1:500 000 interpreted bedrock geology map of the Narryer and Glenburgh Terranes showing location of cross-section A–B

Regional gravity lows (Fig. 2b) in the area (Hackney, 2004) and passive seismic data (Reading et al., 2012) are reinforced by the forward model, which shows that the crust has been significantly thickened, and that there are two Mohos caused by where the Glenburgh Terrane has been thrust beneath the Narryer Terrane (Fig. 2a). The Warrigal Gneiss and Bertibubba Supersuite granites form a gravity low in the centre of the profile (Fig. 2b). The low at the northern end of the profile corresponds to granitic rocks of the Dalgaringa Supersuite. Both have very low magnetic susceptibilities (Goodwin, 2011). However, there are short-wavelength magnetic anomalies in this region (Fig. 2d), which may correspond to the Camel Hills Metamorphics and the Nardoo Granite of the Dalgaringa Supersuite. The Moogie Metamorphics produce a local gravity high towards the northern end of the profile. In the south, the Narryer Terrane has been divided into an upper and lower region on the basis of magnetic signals (Fig. 2e), and has a distinctly higher base at the southern end. The interpretation was assisted by magnetic worms, which support the change in properties along the structure labelled ‘Fault 1’. The short-wavelength features were interpreted to be 500 m thick banded iron-formations (BIF), which were not imaged in the seismic interpretation.

MT inversions

Modelling and inversion of the MT data was done using the WinGLink software which utilizes the 2D inversion code of Rodi and Mackie (2001). More details on the data processing can be found in Heinson et al. (2011).

Inversion results

Phase tensors along this line were relatively uniform indicating a 2D structure. There was a slight change taking place around the location of the Errabiddy Shear Zone.

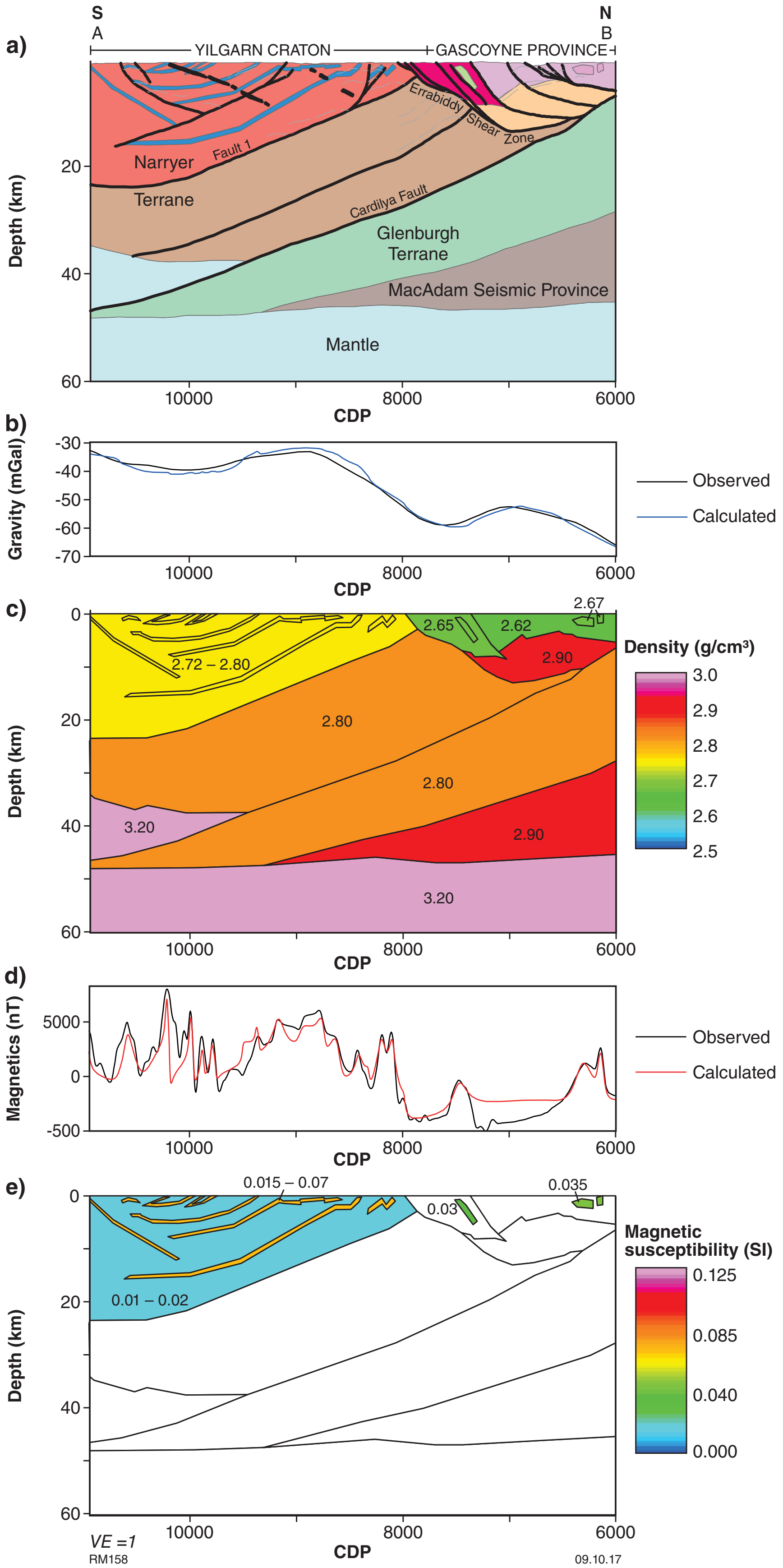

Figure 2. **Profiles of the seismic line 10GA-CP3 showing: a) lithological section from the interpretation of seismic data; b) observed and calculated gravity anomaly profile; c) section of density per lithology; d) observed and calculated gravity anomaly profile; e) section of magnetic susceptibility per lithology**

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-CP3. The colour column refers to colours used in Figure 2a

Colour	*Lithological unit*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Nardoo Granite	Granite	2.670	0.035
	Camel Hills Metamorphics	Metasedimentary siliciclastic	2.650	0.030
	Bertibubba Supersuite and Warrigal Gneiss	Granite and metagranite	2.650	
	Dalgaringa Supersuite	Gneissic granites	2.620	
	Moogie Metamorphics	Psammitic schists	2.900	
	Narryer Terrane			
	BIF	BIF	2.720 – 2.800	0.015 – 0.070
	Upper crust	Granitic	2.700 – 2.800	0.010 – 0.020
	Middle crust	Middle crust	2.800	
	Glenburgh Terrane	Granitic gneiss	2.800	
	MacAdam Seismic Province	Lower crust	2.900	
	Upper mantle	Mantle	3.200	

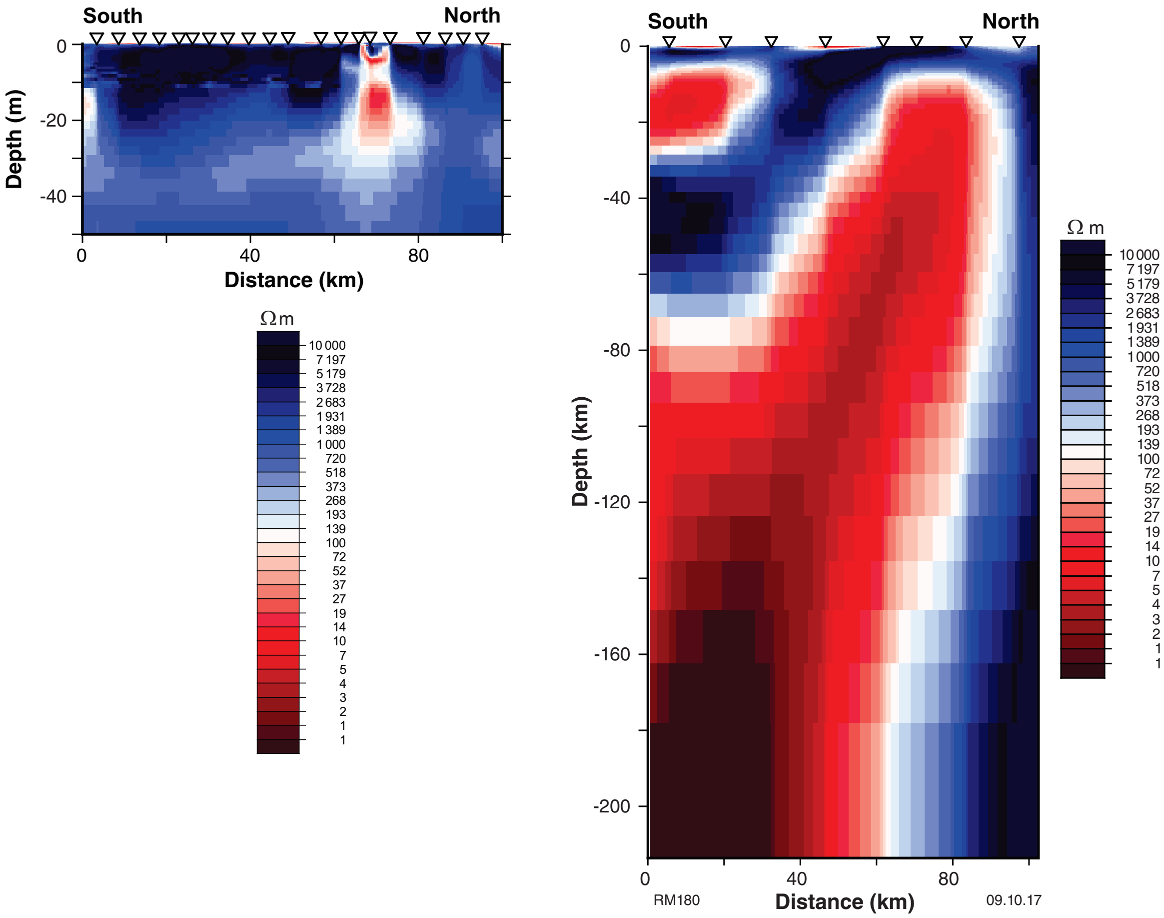

Figure 3. Profiles of the seismic line 10A-CP3 showing: a) broadband 2D resistivity section for line 10GA-CP3; b) long period 2D resistivity section for line 10GA-CP3

The long-period tensors were also uniform with a slight convergence to the north, which may indicate a flow of current aligned with the Errabiddy Shear Zone.

The inversion results of the broadband responses (Fig. 3a) show a simple resistive background with a conductive feature aligned with the Errabiddy Shear Zone. This feature does not intersect the surface, but the surface expression of it coincides with a relatively wide region of low resistivity.

Long-period data were of good enough quality to invert with seven of the eight stations modelled (Fig. 3b) as the response over the Errabiddy Shear Zone was too anisotropic to model. The low-resistivity feature seen in the broadband data is imaged to much greater depths with the low-period data and appears to dip to the south.

From these results the Errabiddy Shear Zone is clearly shown in both sections and shows complex geometry near the surface (Heinson et al., 2011). It appears to be near vertical, but dips to the south at depth.

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Seismic line 10GA-YU1

(Narryer Terrane, Murchison Domain, Yilgarn Craton)

JA Goodwin[1], PR Milligan[1], LA Gallardo[2], and RE Murdie

Location

Maps: Byro (SG 50-10), Belele (SG 50-11), Cue (SG 50-15), Sandstone (SG 50-16), Youanmi (SH 50-4)

Zone: MGA Zone 50

End coordinates: 495489E 7119410N to 649399E 6898721N

Length: 286 km

Type of modelling: 2D forward modelling of gravity and magnetics, 2D inversions of joint gravity and magnetics, and 3D magnetotelluric (MT) inversion of a profile.

This is a northwest–southeast section that crosses from the Narryer Terrane (starting at the end of seismic line 11GA-SC1) into the Cue–Murchison greenstone belt and finishes in the Windimurra Igneous Complex where it meets with seismic lines 10GA-YU2 and 10GA-YU3 (Fig. 1).

Tectonic units

The whole section lies within granite–greenstone terranes of the Yilgarn Craton. The Narryer Terrane in the northwest is interpreted to contain the oldest fragments of the Earth's crust (Kinny et al., 1988; Nutman et al., 1991) and is separated from the Youanmi Terrane by the northwest-dipping Yalgar Fault. The main part of the section lies across the granite–greenstone Murchison Domain of the Youanmi Terrane. It consists of greenstone belt volcanic rocks accompanied by widespread synvolcanic plutons and granitic magmatism, including post-tectonic granites (Ivanic, 2012; Van Kranendonk et al., 2013). The Windimurra Igneous Complex in the southeast is a large, relatively intact, mafic–ultramafic intrusion with economic vanadium deposits (Ivanic and Brett, 2015).

Structure

The Cargarah Shear Zone is a dextral transpressional shear within the Narryer Terrane. The northwest-dipping Yalgar Fault divides the Narryer Terrane from the Youanmi Terrane (Myers, 1990). The kilometre-wide shear zones of the Weld Range area, Carbar Faults and Chundaloo–Cuddingwarra fault system all dip towards the northwest (Romano et al., 2013). The Wattle Creek Shear Zone cuts through the Yarraquin Seismic Province dipping to the east. Above this in the upper crust, in which the fabric changes orientation, and the faults to the southeast, the Cundimurra, Tuckabianna, and Yarloo Shear Zones all dip to the west.

Geophysical data

A new gravity grid was created by combining data collected along the Youanmi seismic transect (at a 400 m station spacing) with existing gravity data from the Australian National Gravity Database (ANGD) (Wynn and Bacchin, 2009). The new grid created from this process was used in the forward and inverse modelling in the area (Gessner et al., 2014). Topographic data were taken from the Australian Height Datum (AHD). Sample points were extracted at the locations of the Common Depth Points (CDP) of the seismic profile (Costelloe and Jones, 2014).

Magnetic data were extracted from the Geological Survey of Western Australia (GSWA) State gridded data (GSWA, 2013).

Magnetotelluric (MT) data were also collected at 5 km spacing along this profile for broadband instruments and 15 km spacing for long-period instruments (Milligan et al., 2014).

Physical property values were taken from tabular data in Emerson (1990), Telford et al. (1990), and Rudnick and Fountain (1995). Values used in this modelling are found in Table 1.

Forward modelling

Geoscience Australia, in collaboration with GSWA, conducted the Youanmi Deep Crustal Seismic Reflection Survey (10GA-YU1) in 2011 (Korsch, et al., 2014). The purpose of this survey was to image deep crustal structures and the crust–mantle boundary. Data were recorded to 20 s of two-way travel time (~60 km deep, assuming an average crustal velocity of 6000 m/s).

A crucial part of the seismic interpretation process is to test the interpretation against other data. In this case, the seismic interpretation was tested against gravity data

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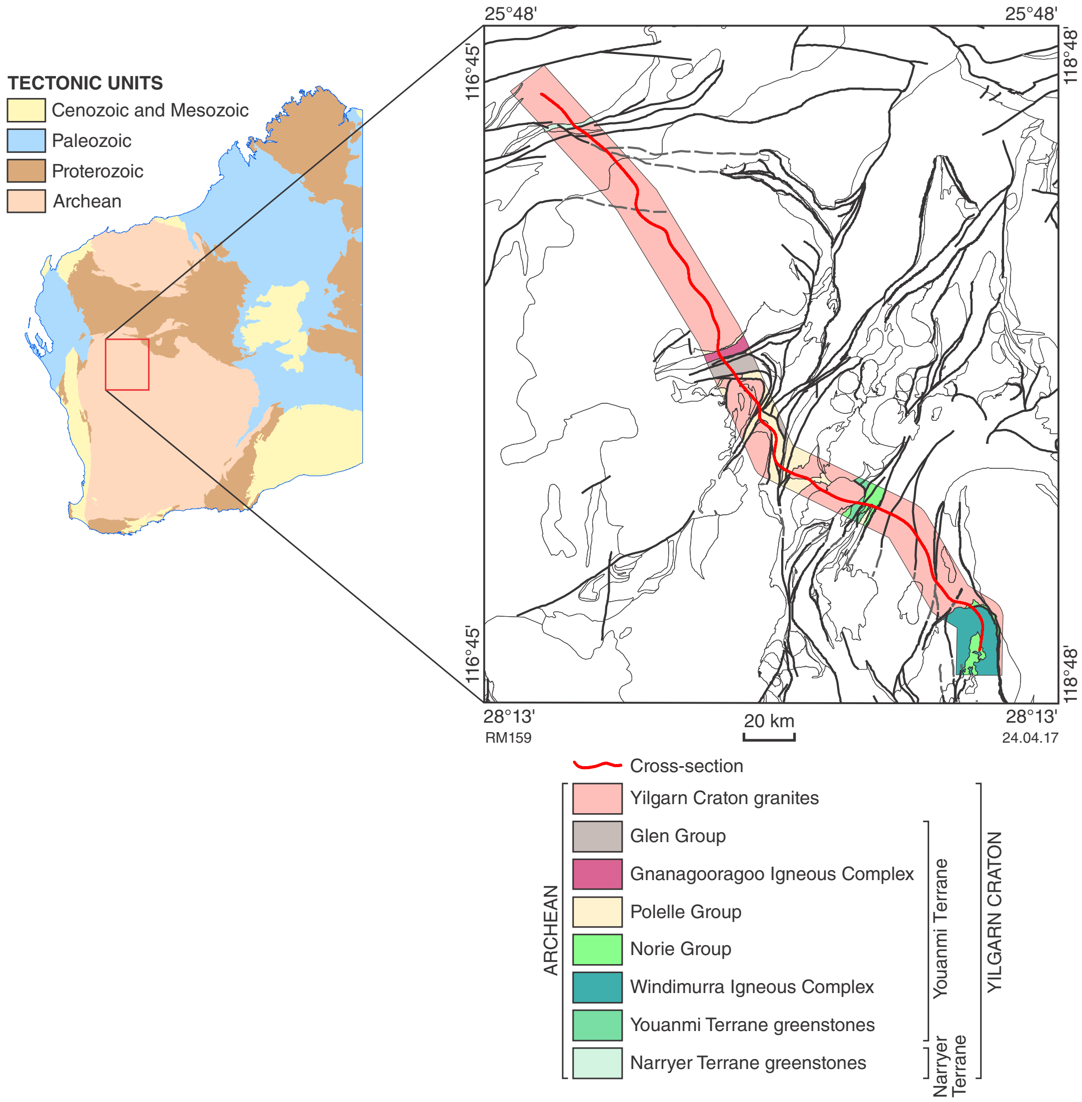

Figure 1. Narryer and northern Murchison region 1:500 000 interpreted bedrock geology map showing location of the seismic line 10GA-YU1 (in red) along which the section was modelled

through 2D forward modelling using ModelVision v.11.0 software. 2.5D modelling was performed by extending the polygons 100 km to each side, perpendicular to the profile. Only gravity modelling was performed as the magnetic profile is dominated by short-wavelength anomalies. They relate to near-surface features and therefore were not included in this regional-scale modelling study.

Forward modelling results

The section was modelled against gravity data down to a depth of 60 km (Gessner et al., 2014). The model was the interpretation from data of the 10GA-YU1 seismic line (Fig. 2a; Korsch et al., 2014) and the densities were modified to achieve a fit with the observed data.

The gravity profile (Fig. 2b) shows a regional trend, dipping to the southeast, which was modelled as differing densities within the mid-lower crust and may represent metamorphic or compositional variations within the Murchison Domain and Yarraquin Seismic Province.

In the northwest, the first peak of the profile is in the vicinity of the Cargarah Shear Zone and some banded iron-formation (BIF) within the Jack Hills Formations of the Narryer Terrane. There is a steep negative gradient to the southeast, which has been modelled as near-surface sediments.

Along the central portion of the profile, shorter-wavelength anomalies correlate well with greenstone belts (Fig. 2c) (density: 2.95 – 3.1 g/cm^3) embedded in a background of granites (density: 2.59 – 2.66 g/cm^3). For example, the Weld Range and different branches of the Meekatharra greenstone belt form the three main peaks of approximately 30 mgal each, in the centre of the profile. The Windimurra Igneous Complex forms a large peak at the southeastern end of the profile and can be correlated with similar peaks in the seismic and gravity profiles of 10GA-YU2 and 10GA-YU3.

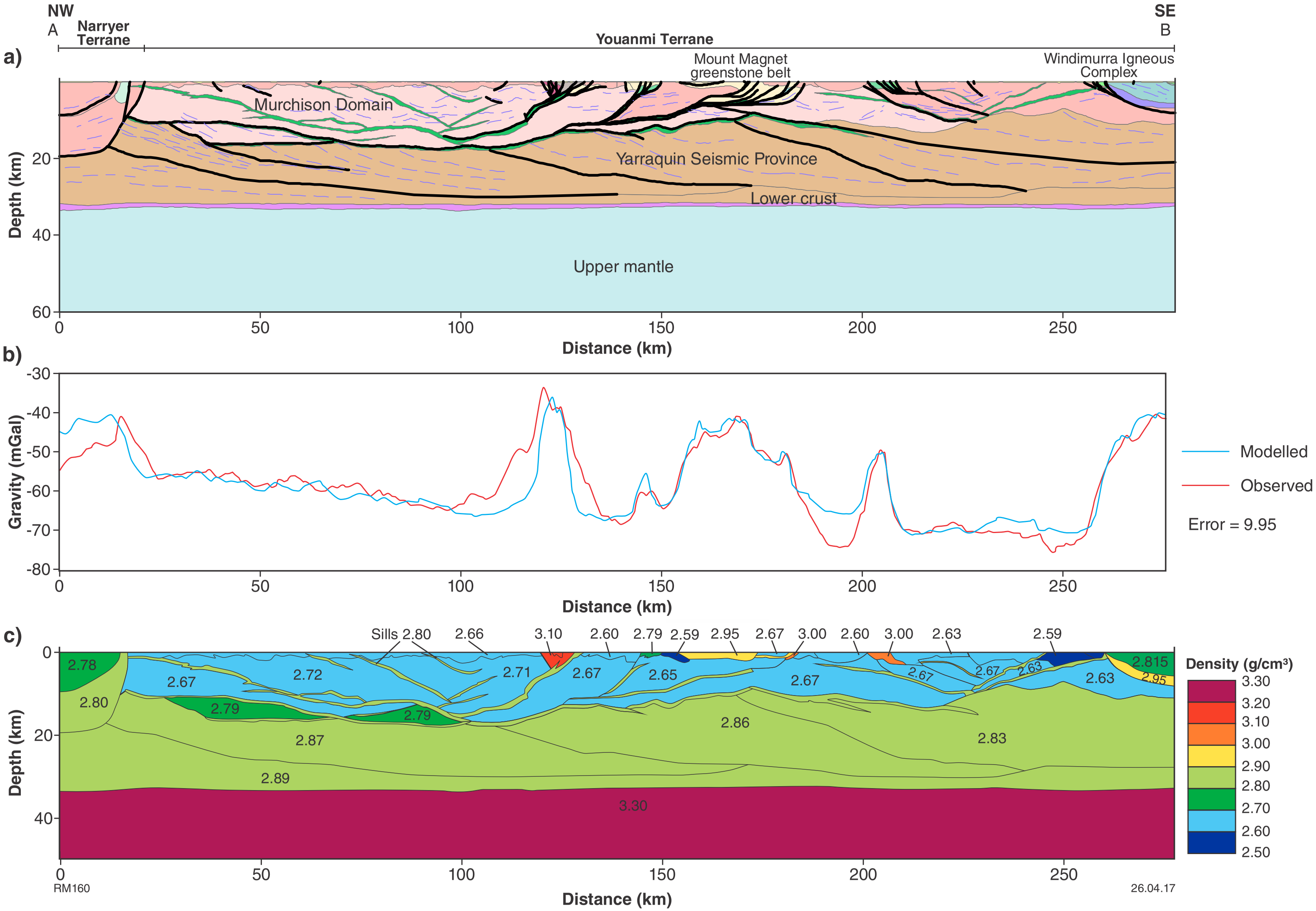

Figure 2. Forward modelling of seismic line 10GA-YU: a) lithological interpretation of the seismic line from Romano et al. (2013) and Zibra et al. (2014); b) observed and calculated gravity anomaly profile from Gessner et al. (2014); c) profile of density in g/cm³ per lithology

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-YU1. The colour column refers to colours used in Figure 2a

Colour	*Lithological unit*	*Map code*	*Rock type*	*Density (g/cm³)*
	Proterozoic sills	P_-WK-od	Dolerite	2.800
	Windimurra Igneous Complex			
	Mafic rocks	A-ANwl-xol-oml, A-ANwr-xogp-od, A-ANwb-mog	Mafic rocks	2.815
	Ultramafic rocks	A-ANwu-xmad-oa	Ultramafic rocks	2.950
	Murchison Domain			
	Upper crustal granites	A-SDB-mg, A-TUcu-mg, A-BRG-gm, A-g-Y	Granitic rocks	2.590 – 2.660
	Greenstone belts	A-NO-xmb-f, A-mb-YYO, A-PO-xb-f	Selection of greenstone rocks, mainly mafic	2.950 – 3.100
	Low reflectivity crust	A-AN-xmg-o, A-GL-xb-s	Granitic rocks	2.630 – 2.790
	Narryer Terrane			
	Upper crust	A-xmh-mi-YNA	Granites and greenstone	2.780
	Lower crust	A-xmgn-g-YNA	Mid-crustal rocks	2.800
	Yarraquin Seismic Province		Mid-crustal rocks	2.830 – 2.890
	Moho transition zone		Moho transition zone	2.890
	Upper mantle		Mantle	3.300

Inversions

Joint magnetic and gravity inversions

Joint inversions of the gravity and magnetic data were performed to search for multiple geophysical models that are structurally matching and fit multiple datasets. Cross-products of the density and magnetization distributions are calculated for the upper 18 km, using the method of Gallardo (2007) as applied by Gallardo and Thebaud (2012) and Gallardo et al. (2012). To cope with the effect of a crooked geometry of the line, the magnetic data were reduced to pole, using the average parameters for that area for 1998, viz.: inclination –61.43°, declination +0.3°, and intensity 56 184 nT. No correction was made for possible areas of magnetic remanence. A constant value of 80 mgal was added from the gravity data.

MT inversions

MT data were processed in the frequency domain using the Bounded Influence Remote Reference Processing (Chave et al., 1987; Chave and Thomson, 2004) and then modelled in 3D using the ModEM code of Egbert and Kelbert (2012).

Inversion results

Joint magnetic and gravity inversions

The results of cross-gradient inversion are presented as a geospectral image which combines information on density and magnetization contrasts (Fig. 3c). The values are set to be maintained between reasonable bounds for average rock property types. Properties along the profile are deemed to be accurate, whereas depth estimates are less reliable.

The observed gravity profile (Fig. 3b) shows that a southeasterly decreasing trend in the gravity corresponds with an overall decrease of the less reflective upper crust towards the south. The magnetic profile shows a broad elevated anomaly near CDP 5000.

Both the gravity and magnetic data display many short-wavelength variations with coinciding peaks near the greenstones and igneous complexes along the profile (Fig. 3a). There are areas that display a correlation between low-gravity and flat-magnetic anomalies between the Tuckabianna Synform and the Windimurra Igneous Complex. There are also two narrow features where high-gravity values coincide with low-magnetic anomalies, one near CDP 8000 and a second one, possibly a dyke, near CDP 15 000.

The northern part shows a stronger magnetic response, and the inversion predicts a relatively magnetic and moderately dense lower-crustal affinity for the Narryer Terrane. Rocks with properties similar to these are predicted to form the middle crust along most of the section, with the exception of the area near the Windimurra Igneous Complex, where mafic and ultramafic rocks are predicted to be much denser. The overall pattern suggests that the region of

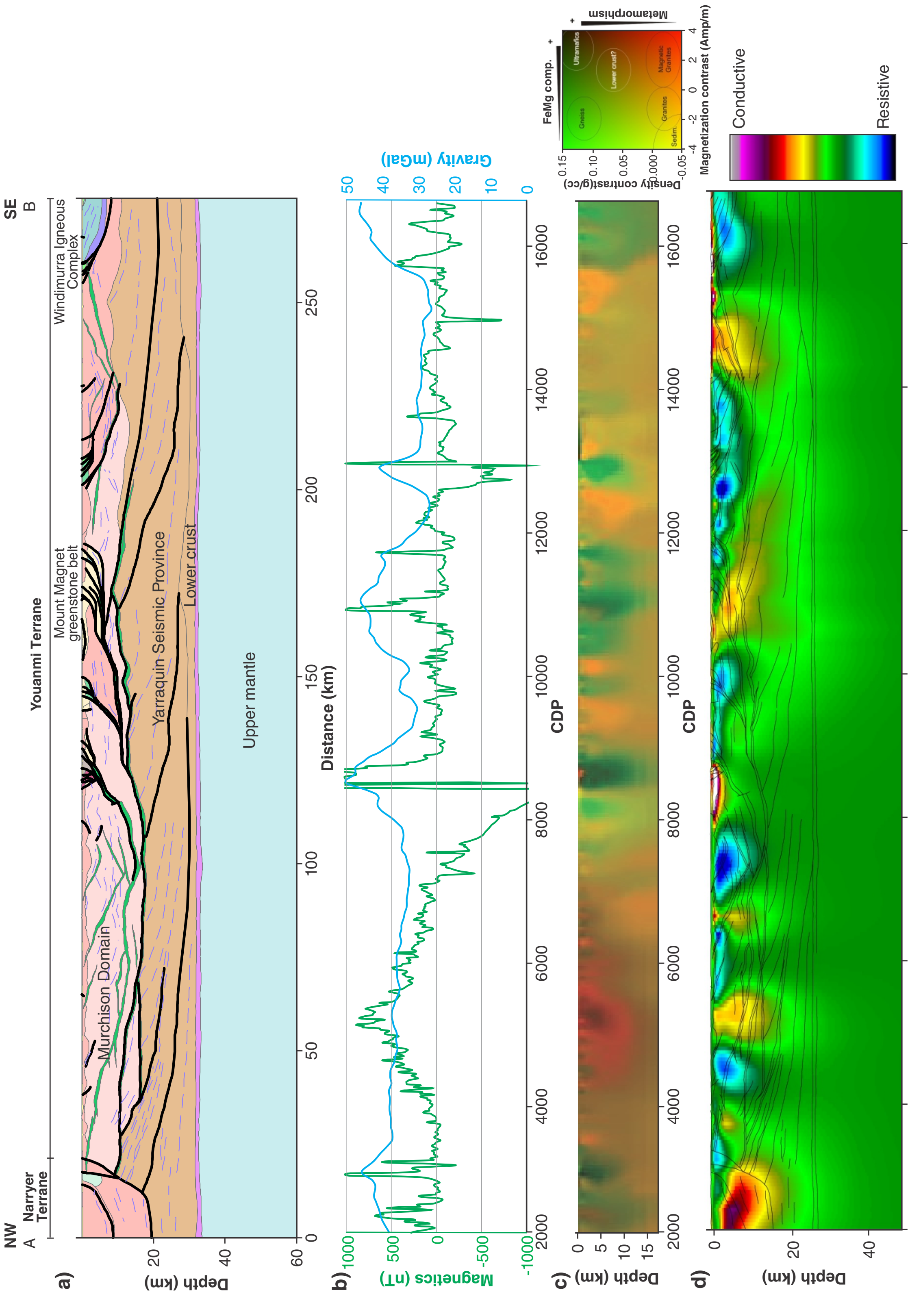

Figure 3. Inversion results of the seismic line 10GA-YU1: a) lithological interpretation of the seismic line from Romano et al. (2013); b) gravity and magnetic profiles used in the joint inversion; c) joint magnetic and gravity inversion geospectral image with a colour legend on the side; d) MT profile from Milligan et al. (2014) overlain with line work from the seismic interpretation of Romano et al. (2013) and Zibra et al. (2014)

relatively magnetic and moderately dense lower-crustal rocks in 10GA-YU1 correlates well with the Yarraquin Seismic Province.

In the central and southern portions of the line, features with common physical properties alternate with a 10–20 km wavelength, which suggests a variation between low and moderate levels of magnetization and a large range of densities. The green areas of Figure 3c coincide with the greenstones of the Meekatharra and Weld Rand areas.

MT inversions

The MT model (Fig. 3d) generally shows the upper crust to be resistive, but with conductive areas which are thought to be related to areas of conductive sills (Milligan et al., 2014). At the western end there is an area of high conductivity, which correlates to the location of the Narryer Terrane. At CDP 7000 there is a strongly resistive area bounded by a triangle of sills. A conductive zone at CDP 8300 dips to the southeast and relates to the surface location of the Weld Range area. Other mafic areas of the Meekatharra greenstone also seem to correlate with high conductivity zones, e.g. CDP 9800, CDP 10 800, and CDP 12 950. High conductivity areas at CDP 15 000–16 000 are in similar areas as highly faulted granites. The Windimurra Igneous Complex does not form an MT feature in this profile.

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Seismic line 10GA-YU2

(Youanmi Terrane, Yilgarn Craton)

JA Goodwin[1], PR Milligan[1], LA Gallardo[2], and RE Murdie

Location

Maps: Kirkalocka (SG 50-3), Youanmi (SH 50-4), Sandstone (SG 50-16), Leonora (SH 51-5), Sir Samuel (SG 51-13)

Zone: MGA Zones 50 and 51

End coordinates: 628891E 6871551N to 878026E 6909320N

Length: 273 km

Type of modelling: 2D forward modelling of gravity and magnetics, 2D inversions of joint gravity and magnetics, and 3D magnetotelluric (MT) inversion of a profile.

This is a west to east section that crosses the Murchison and Southern Cross Domains of the Youanmi Terrane within the Yilgarn Craton. It terminates across the Ida Fault in the Eastern Goldfields Superterrane (Fig. 1).

Tectonic units

The Windimurra Igneous Complex is a large, relatively complete, mafic–ultramafic intrusion in the Murchison Domain with economic vanadium deposits (Ivanic et al., 2010). The profile crosses a series of Murchison granites. Thereafter, it crosses into the Southern Cross Domain, which consists mainly of granites with some greenstone belts, such as the Sandstone greenstone belt (Chen, 2005) and the tip of the Booylgoo Range greenstone belt. Finally, the profile crosses the Agnew greenstone belt, which is exploited for gold (Stewart, 2001; Duuring et al., 2012).

Structure

The main structures in this section are the Youanmi Fault, which defines the boundary between the Murchison and Southern Cross Domains and the Ida Fault. The Ida Fault is probably incorporated within the Waroonga Shear Zone and constitutes the boundary between the Youanmi Terrane and the Eastern Goldfields Superterrane.

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Geophysical data

A new gravity grid was created by combining data collected along the Youanmi seismic transect (at a 400 m station spacing) with existing gravity data from the Australian National Gravity Database (ANGD) (Wynn and Bacchin, 2009). The new grid created from this process was used in the forward and inverse modelling in the area (Gessner et al., 2014). Topographic data were taken from the Australian Height Datum (AHD). Sample points were extracted at the locations of the Common Depth Points (CDP) of the seismic profile (Costelloe and Jones, 2014).

Magnetic data were extracted from the Geological Survey of Western Australia (GSWA) State gridded data (GSWA, 2013).

Magnetotelluric (MT) data were also collected at 5 km spacing along this profile for broadband instruments and 15 km spacing for long-period instruments (Milligan et al., 2014).

Physical property values were taken from tabular data in Emerson (1990), Telford et al. (1990), and Rudnick and Fountain (1995). Values used in this modelling are found in Table 1.

Forward modelling

Geoscience Australia, in collaboration with GSWA, conducted the Youanmi Deep Crustal Seismic Reflection Survey (10GA-YU2) in 2011 (Korsch et al., 2014). The purpose of this survey was to image deep crustal structures and the crust–mantle boundary. Data was recorded to 20 s of two-way travel time (~60 km deep, assuming an average crustal velocity of 6000 m/s).

A crucial part of the seismic interpretation process is to test the interpretation against other data. In this case, the seismic interpretation was tested against gravity data through 2D forward modelling using ModelVision v.11.0 software. 2.5D modelling was performed by extending the polygons 100 km to each side, perpendicular to the profile. Only gravity modelling was performed as the magnetic profile is dominated by short-wavelength anomalies. They relate to near-surface features and therefore were not included in this regional-scale modelling study.

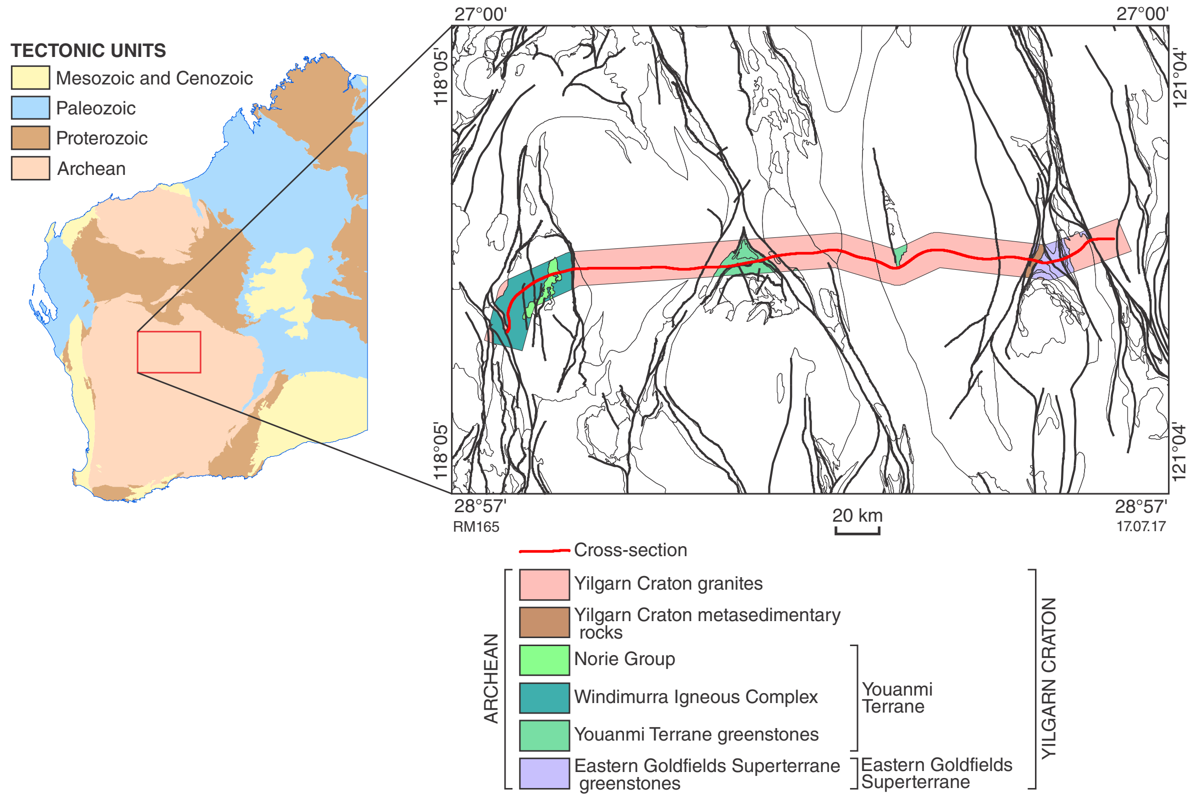

Figure 1. Murchison region 1:500 000 simplified interpreted bedrock geology map showing location of the seismic line 10GA-YU2 (in red) along which the section was modelled

Forward modelling results

The 10GA-YU2 seismic section was forward modelled down to a depth of 60 km (Gessner et al., 2014). The model was the interpretation from data of the 10GA-YU2 seismic line (Fig. 2a; Korsch et al., 2014) and the densities were modified to achieve a fit with the observed data.

In the west, the Windimurra Igneous Complex is interpreted to cause a high-amplitude gravity peak of 60 mgal which, in the gravity profile, matches poorly with the observed data. The model was restricted by the geometries interpreted from the seismic section. In this case, a better fit may have been achieved by the subdivision of the Windimurra Igneous Complex into smaller bodies.

The Sandstone greenstone belt is modelled as a V-shaped, high-density body. The Agnew greenstone belt also produces a gravity high of 30 mgal, but at lower amplitude than the others as it is interpreted to be underlain by the Lawlers Tonalite, which is modelled with a slightly lower density (2.67 g/cm^3) than the rest of the upper crust (2.67 – 2.76 g/cm^3). This body is suggested by Blewett et al. (2010) to explain the synextensional volcanism in the area, but the inclusion of this body adds a steep gravity gradient into the model, which is not seen in the observed data (Fig. 2b).

The granites of the Eastern Goldfields have been modelled with higher density than those of the Youanmi Terrane (Fig. 2c).

The Yarraquin Seismic Province has been modelled with relatively high densities of 2.83 – 2.89 g/cm^3 and is overlain by the low reflectivity Youanmi granites. This upper and lower crustal division is not seen in the Eastern Goldfields, with the crustal granites being continuous from the upper through to the lower crust, although the profile does not extend far into the Eastern Goldfields.

Inversions

Joint magnetic and gravity inversions

Joint inversions of the gravity and magnetic data were performed to search for multiple geophysical models that are structurally matching and fit multiple datasets. Cross-products of the density and magnetization distributions are calculated for the upper 18 km using the method of Gallardo (2007) as applied by Gallardo and Thebaud (2012) and Gallardo et al. (2012). To cope with the effect of a crooked geometry of the line, the magnetic data were reduced to pole, using the average parameters for that area for 1998, viz.: inclination –61.43°, declination +0.3°, and intensity 56 184 nT. No correction was made for possible areas of magnetic remanence. A constant value of 80 mgal was added from the gravity data.

MT inversions

MT data were processed in the frequency domain using the Bounded Influence Remote Reference Processing

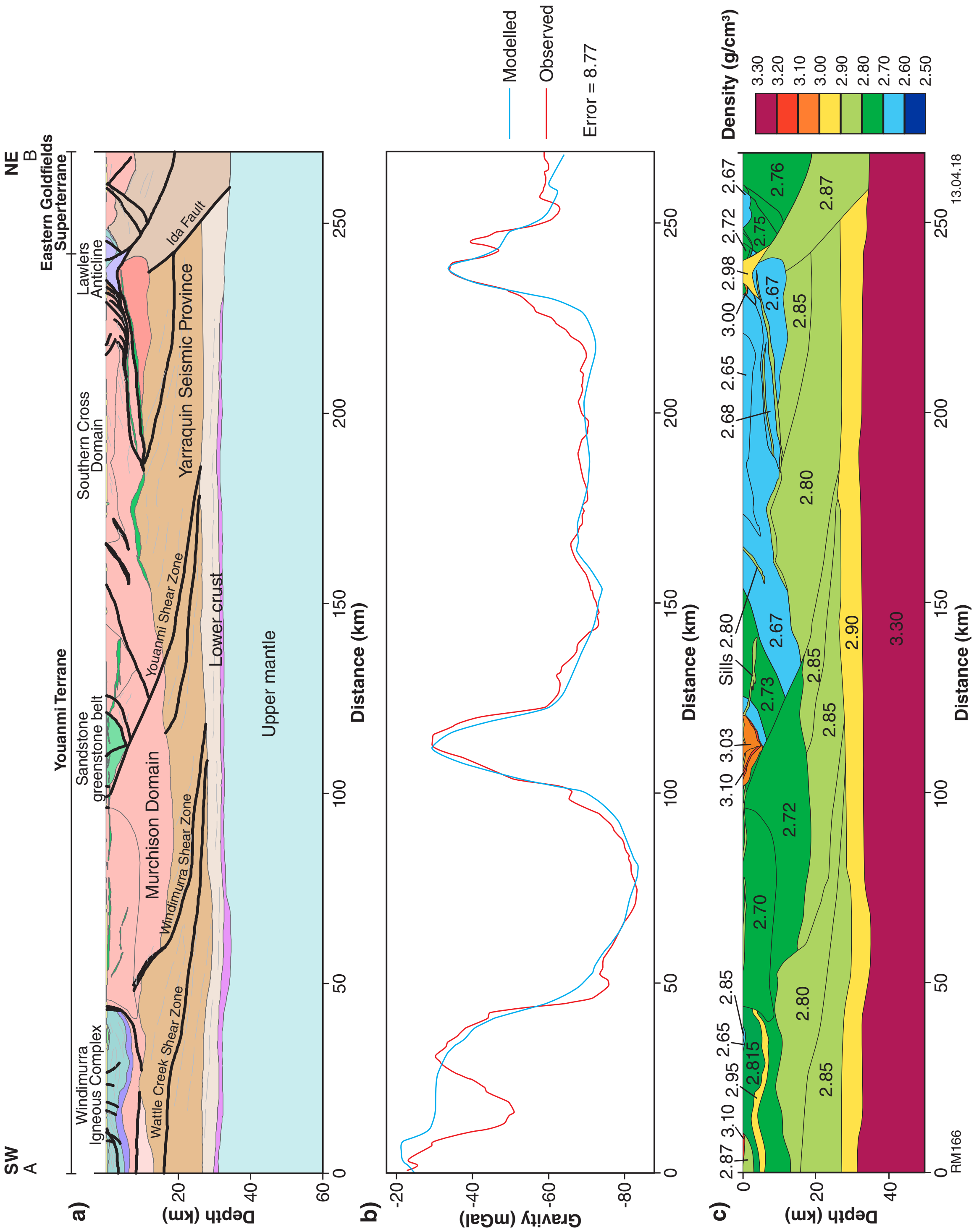

Figure 2. Forward modelling of the 10GA-YU2 seismic line: a) lithological interpretation of the 10GA-YU2 seismic line from Zibra et al. (2014); b) observed and calculated gravity anomaly profile from Gessner et al. (2014); c) profile of density in g/cm³ per lithology

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-YU2. The colour column refers to colours used in Figure 2a

Colour	*Lithological unit*	*Map code*	*Rock type*	*Density (g/cm³)*
	Proterozoic sills	P_-WK-od	Dolerite	2.800
	Windimurra Igneous Complex			
	Mafic rocks	A-AN-xmg-o	Selection of mafic rocks	2.815
	Ultramafic rocks	A-ANwu-xmad-oa	Ultramafic rocks	2.950
	Norie Group	A-Nom-mb	Mafic rocks	2.85
	Youanmi Terrane upper mid-crustal granites including low reflectivity crust	A-SDB-mg, A-TU-mg, A-BRG-gm, A-JU-mg	Granitic rocks	2.650 – 2.730
	Eastern Goldfields Superterrane upper crustal granites	A-g-Y, A-mgs-Y	Granitic rocks	2.720 – 2.760
	Lawlers Tonalite		Granitic rocks	2.670
	Eastern Goldfields Superterrane greenstones	A-b-YEG, A-f-YEG, A-o-YEG, A-u-YEG	Various greenstone rocks	2.720 – 3.000
	Eastern Goldfields Superterrane mid-crust		Mid-crustal rocks	2.870
	Youanmi Terrane Greenstone belts	A-mb-YEG, A-mu-YYO	Various greenstone rocks	2.98–3.1
	Yarraquin Seismic Province		Mid-crustal rocks	2.830 – 2.890
	Lower crust		Lower crustal rocks	2.900
	Moho transition zone		Moho transition zone	2.900
	Upper mantle		Mantle	3.300

(Chave et al., 1987; Chave and Thomson, 2004) and then modelled in 3D using the ModEM code of Egbert and Kelbert (2012).

Inversion results

Joint inversion results

The gravity and magnetic profiles (Fig. 3b) show short-amplitude anomalies in the vicinity of the Windimurra Igneous Complex and Lawlers Anticline. Within the Windimurra Igneous Complex, broad peaks of high gravity coincide with a pattern of shorter wavelength magnetic anomalies.

There is a pronounced magnetic trough and gravity high between CDP 9000 and CDP 10 000 near the Sandstone greenstone belt.

A gravity low is coincident with a magnetic low amplitude between the Windimurra Igneous Complex and the Sandstone greenstone belt and again between the Sandstone greenstone belt and the Lawlers Anticline.

In general, features with common physical property gradients (Fig. 3c) alternate at longer wavelengths in 10GA-YU2, compared to 10GA-YU1, probably because fewer greenstone belts are intersected.

Similarly to 10GA-YU1, the topography of relatively magnetic and moderately dense lower crust imaged in this section correlates well with the topography of the Yarraquin Seismic Province. The Yarraquin Seismic Province in section 10GA-YU2 has a similar shape to the response seen in the MT profile.

MT results

The conductivity features seen in the MT profile (Fig. 3d) are interpreted to be related to coincident features that are seen in the seismic interpretation (Fig. 3a; Milligan et al., 2014; Zibra et al., 2014). The upper crustal layers and granitic plutons are interpreted to be more resistive as indicated in the deepening of the upper crust around CDPs 8000–11 000 and a corresponding resistive anomaly. This may represent the heart of the Archean Craton (Milligan, 2012; Milligan et al., 2014). The Windimurra Igneous Complex on this line is shown by a thinning of the upper crust. The mafic dykes and sills are seen at CDP 14 800 at a depth of about 8 km. Granites are known to be low-conductivity structures (i.e. highly resistive). It is therefore interpreted that the low conductivity at 10 km depth between CDP 15 300 and CDP 16 200 is the Lawlers Tonalite. Outcropping mafic rocks of the Lawlers Anticline have high conductivities and the crust of the Eastern Goldfields is generally more conductive.

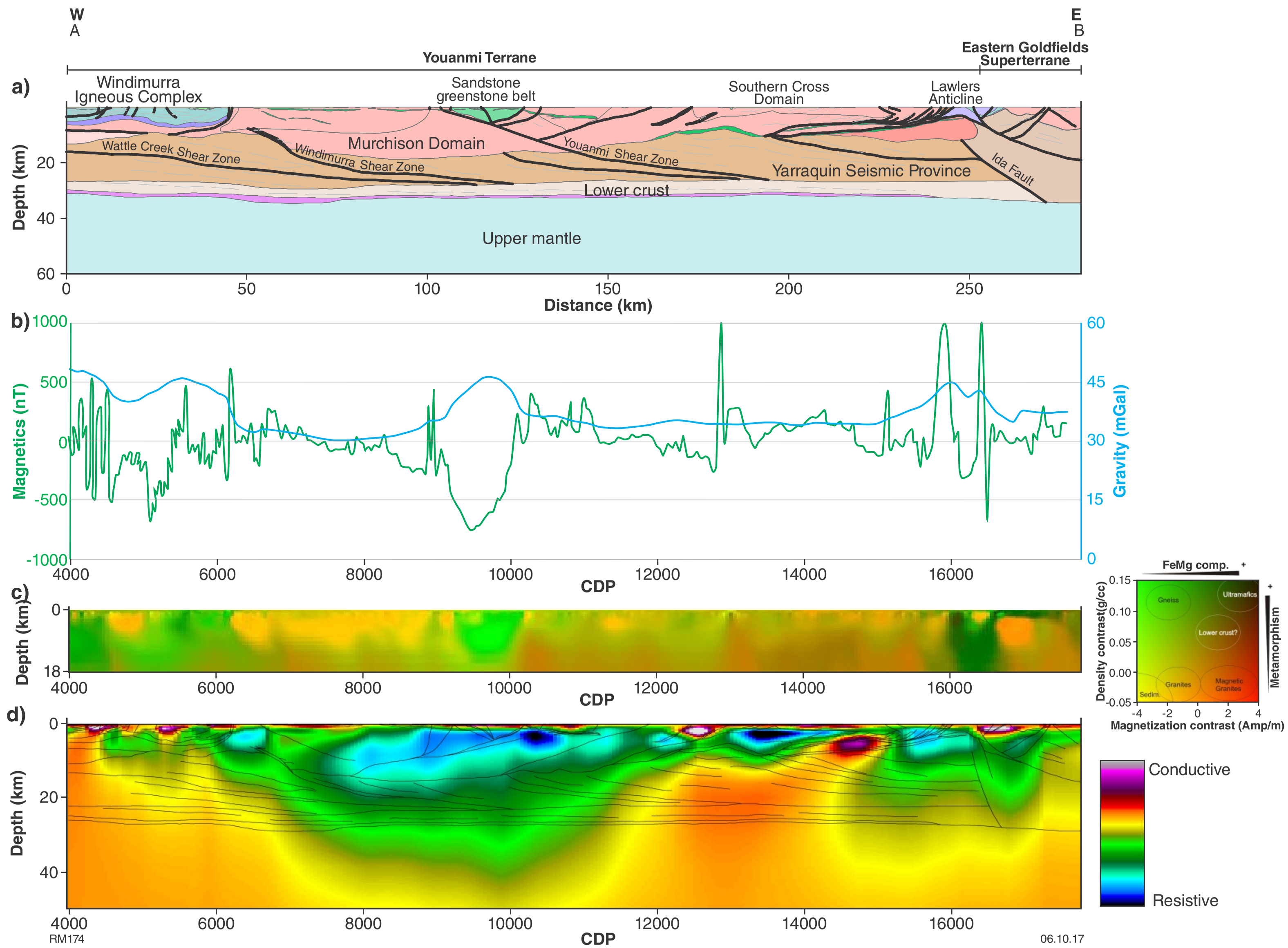

Figure 3. Inversion results of the seismic line 10GA-YU2: a) lithological interpretation of the 10GA-YU2 seismic line from Zibra et al. (2014); b) gravity and magnetic profiles used in the joint inversion; c) joint magnetic and gravity inversion geospectral image with a colour legend on the side; d) MT profile from Milligan et al. (2014) overlain with line work from the seismic interpretation of Ivanic (2014)

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Seismic line 10GA-YU3

(Murchison Domain, Yilgarn Craton)

JA Goodwin[1], PR Milligan[1], LA Gallardo[2], and RE Murdie

Location

Maps: Kirkalocka (SG 50-3), Youanmi (SH 50-4)

Zone: MGA Zone 50

End coordinates: 566437E 6897822N to 667047E 6869956N

Length: 105 km

Type of modelling: 2D forward modelling of gravity and magnetics, 2D inversions of joint gravity and magnetics, and 3D magnetotelluric (MT) inversion of a profile.

This is a west to east section that crosses the Mount Magnet greenstone belt and Windimurra Igneous Complex of the Murchison Domain of the Yilgarn Craton (Fig. 1). It joins the 10GA-YU1 and 10GA-YU2 seismic lines and gravity profiles.

Tectonic units

The Mount Magnet greenstone belt is part of a corridor of greenstones between Meekatharra and Mount Magnet (Archibald, 1982) and hosts several gold-producing mines. The Windimurra Igneous Complex is a large, relatively intact, mafic–ultramafic intrusion in the Murchison Domain with economic vanadium deposits (Ivanic et al., 2010). Autochthonous granites separate the mafic belts. Many of them lie along shear zones. Together with their corresponding seismic reflection data from the other two seismic lines, the true orientation of the features can be deduced.

Structure

The Wattle Creek Shear Zone is a major feature which is interpreted to penetrate to the lower crust. It bounds the western edge of the Mount Magnet greenstone belt and accommodates the emplacement of the Lakeside Granite to the west. The Cundimurra Shear Zone is seen as a set of east-dipping listric structures rooted beneath the Windimurra Igneous Complex. The Yarloo Shear Zone bounds the west side of the Windimurra Igneous Complex (Ivanic et al., 2014).

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Geophysical data

A new gravity grid was created by combining data collected along the Youanmi seismic transect (at a 400 m station spacing) with existing gravity data from the Australian National Gravity Database (ANGD) (Wynn and Bacchin, 2009). The new grid created from this process was used in the forward and inverse modelling in the area (Gessner et al., 2014). Topographic data were taken from the Australian Height Datum (AHD). Sample points were extracted at the locations of the common depth points (CDP) of the seismic profile (Costelloe and Jones, 2014).

Magnetic data were extracted from the Geological Survey of Western Australia (GSWA) State gridded data (GSWA, 2013).

Magnetotelluric (MT) data were also collected along this profile at 5 km spacing for broadband instruments and 15 km spacing for long period instruments.

Physical property values were taken from tabular data in Emerson (1990), Telford et al. (1990), and Rudnick and Fountain (1995). Values used in this modelling are found in Table 1.

Forward modelling

Geoscience Australia, in collaboration with GSWA, conducted the Youanmi Deep Crustal Seismic Reflection Survey (10GA-YU3) in 2011 (Korsch, et al., 2014). The purpose of this survey was to image deep crustal structures and the crust–mantle boundary. Data was recorded to 20 s of two-way travel time (~60 km deep, assuming an average crustal velocity of 6000 m/s).

A crucial part of the seismic interpretation process is to test the interpretation against other data. In this case, the seismic interpretation was tested against gravity data through 2D forward modelling using ModelVision v.11.0 software. 2.5D modelling was performed by extending the polygons 100 km to each side, perpendicular to the profile. Only gravity modelling was performed as the magnetic profile is dominated by short-wavelength anomalies. They relate to near-surface features and therefore were not included in this regional-scale modelling study.

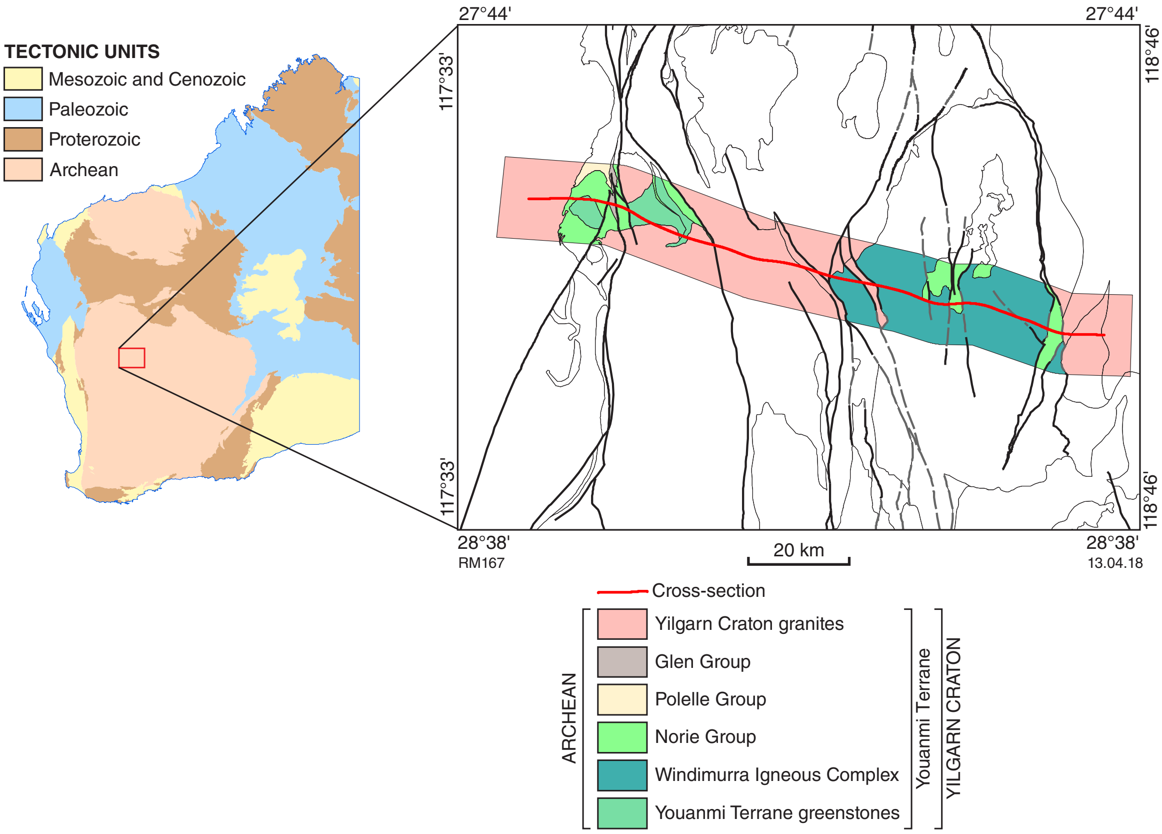

Figure 1. **Murchison region 1:500 000 interpreted bedrock geology map showing location of the seismic line 10GA-YU3 (in red) along which the section was modelled**

Forward modelling results

The section was modelled against gravity data down to a depth of 60 km (Gessner et al., 2014). The model geometry was the interpretation from data of the 10GA-YU3 seismic line (Fig. 2a; Korsch et al., 2014) and the densities were modified to achieve a fit with the observed data.

The regional trend of the gravity field (Fig. 2b) has been accommodated by a thickening lower crust from east to west. Two broad-wavelength peaks dominate the profile and are interpreted to correspond to the Mount Magnet greenstone belt and Windimurra Igneous Complex. Short-wavelength features within the Windimurra Igneous Complex are not accounted for by features in the seismic line and have not been added into the model. The Windimurra Igneous Complex is layered, with the lower layer being a high-density ultramafic zone (2.95 g/cm^3). Above this, the lower zone has a density associated with its pyroxenitic to anothositic composition of (2.815 g/cm^3) (Ivanic and Brett, 2015). The middle and upper zones have also been modelled individually and show layers dipping towards the centre (Fig. 2c).

Inversions

Joint magnetic and gravity inversions

Joint inversions of the gravity and magnetic data were performed to search for multiple geophysical models that are structurally matching and fit multiple datasets. Cross-products of the density and magnetization distributions are calculated for the upper 18 km using the method of Gallardo (2007) as applied by Gallardo and Thebaud (2012) and Gallardo et al. (2012). To cope with the effect of a crooked geometry of the line, the magnetic data were reduced to pole, using the average parameters for that area for 1998, viz. inclination –61.43°, declination +0.3°, and intensity 56 184 nT. No correction was made for possible areas of magnetic remanence. A constant value of 80 mgal was added from the gravity data.

MT inversions

MT data were processed in the frequency domain using the Bounded Influence Remote Reference Processing (Chave et al., 1987; Chave and Thomson, 2004) and then modelled in 3D using the ModEM code of Egbert and Kelbert (2012).

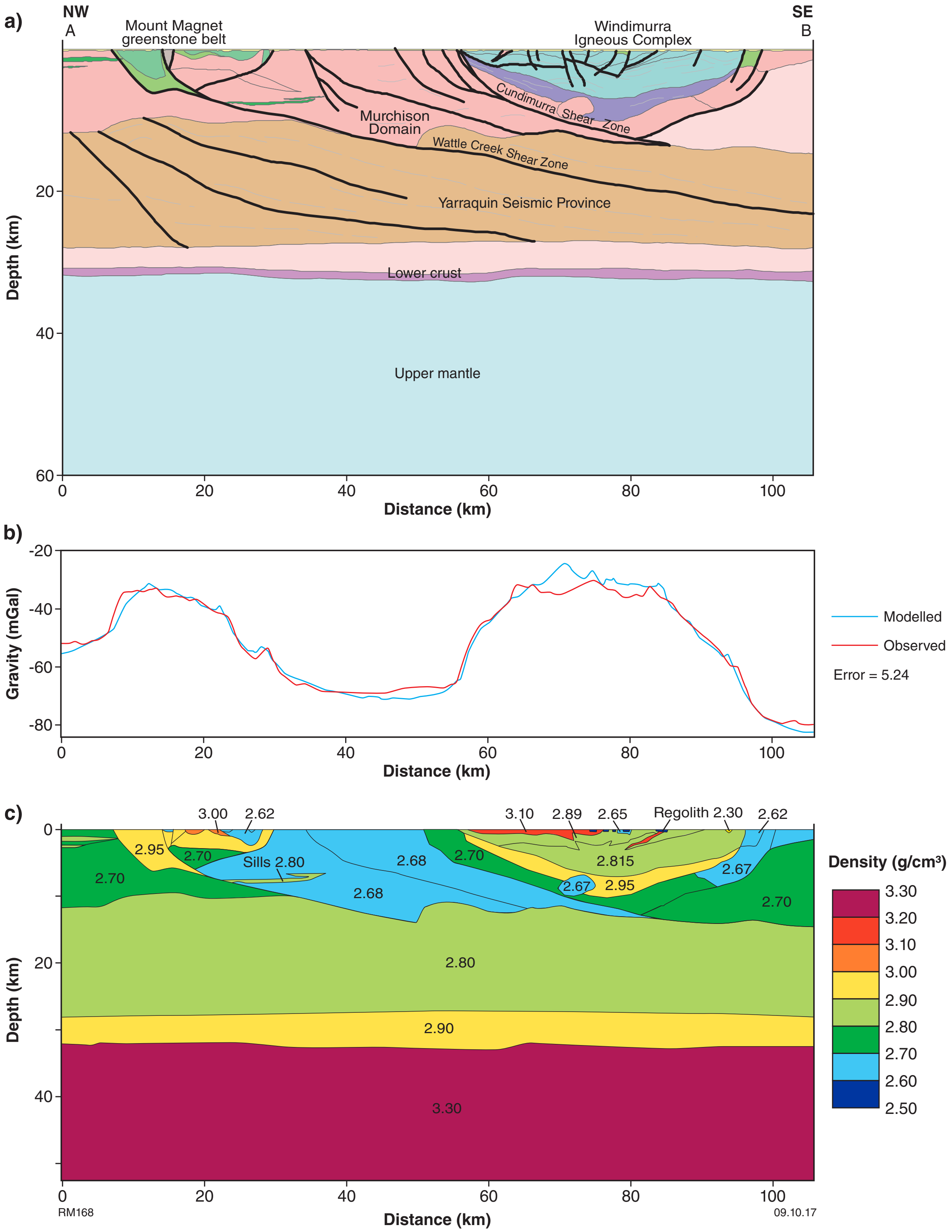

Figure 2. Forward modelling of seismic line 10GA-YU3: a) lithological interpretation of the seismic line from Ivanic et al. (2014); b) observed and calculated gravity anomaly profile from Gessner et al. (2014); c) profile of density in g/cm³ per lithology

Table 1. Summary of the physical properties used in the gravity model of the seismic line 10GA-YU3. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*
	Regolith			2.300
	Kantie Murdana Volcanics Member*	A-ANK-jmg-md	Rhyolitic rocks	2.650
	Windimurra Igneous Complex			
	Upper Zone	A-ANK-jmg-md, A-ANwz-xoml-am	Norite and anorthosite	3.100
	Middle Zone	A-NNwm-xog-oml	Troctolitic rocks	2.890
	Lower Zone	A-NNwl-xol-oml	Olivine-rich gabbros	2.815
	Ultramafic Zone	A-ANwu-xmad-oa	Peridotites	2.950
	Murchison Domain granites	A-TU-mg, A-BR-g, A-SDBmg, A-JU-mg	Granitic rocks	2.680 – 2.700
	Mount Magnet greenstone belt	A-mu-YYO, A-NOm-mb, A-NOy-xf-cib, A-GLr-xs-b	Mixture of mafic, ultramafic rocks, and BIF	2.950 – 3.000
	Low reflectivity crust		Granitic rocks	2.700
	Yarraquin Seismic Province		Mid-crustal rocks	2.800
	Lower crust		Lower crustal rocks	2.900
	Moho transition zone		Moho transition zone	2.900
	Upper mantle		Mantle	3.300

NOTE: *Too small to be imaged on seismic section, but included in gravity modelling

Inversion results

Joint magnetic and gravity results

In the gravity and magnetic field profiles and the inversion model along 10GA-YU3 (Fig. 3b), broad peaks of high gravity (45 mGal) coincide with a pattern of shorter-wavelength magnetic anomalies within the region of the Windimurra Igneous Complex.

The Mount Magnet greenstone belt stands out as a prominent feature of high gravity (30 mGal) and relatively low magnetization in the upper crust, except for a spike interpreted to be related to banded iron-formations (BIF) at Mount Magnet. Even though the strongest magnetic signature of the greenstone belt can be easily interpreted only extend to depths of 8 km, some magnetization is still smeared down to depths of over 15 km (Fig. 3c). This is an artefact common in unconstrained inversions of large potential field anomalies, whether they are jointly or individually inverted. This artefact therefore needs to be considered during interpretation of these geospectral images, when assessing what is geologically plausible.

The area between the Mount Magnet greenstone belt and the Windimurra Igneous Complex (Fig. 3a) consists of the low-density and weakly to moderately magnetic Cundimurra Monzogranite. The Cundimurra Monzogranite is underlain by the Yarraquin Seismic Province, which is also seen in the inversion to extend below and east of the Windimurra Igneous Complex.

MT inversion results

The MT inversion model (Fig. 3d) shows high surface conductivities in the vicinity of the Windimurra Igneous Complex, which is interpreted to be related to the layered mafic upper zone (Milligan et al., 2014). High conductivities are also seen in the region of the Mount Magnet greenstone belt and also at depth in this region. The resistive nature of the upper crust is shown by the low conductivity area between CDP 7000 and CDP 8000, where the crust is suggested to mainly consist of granites.

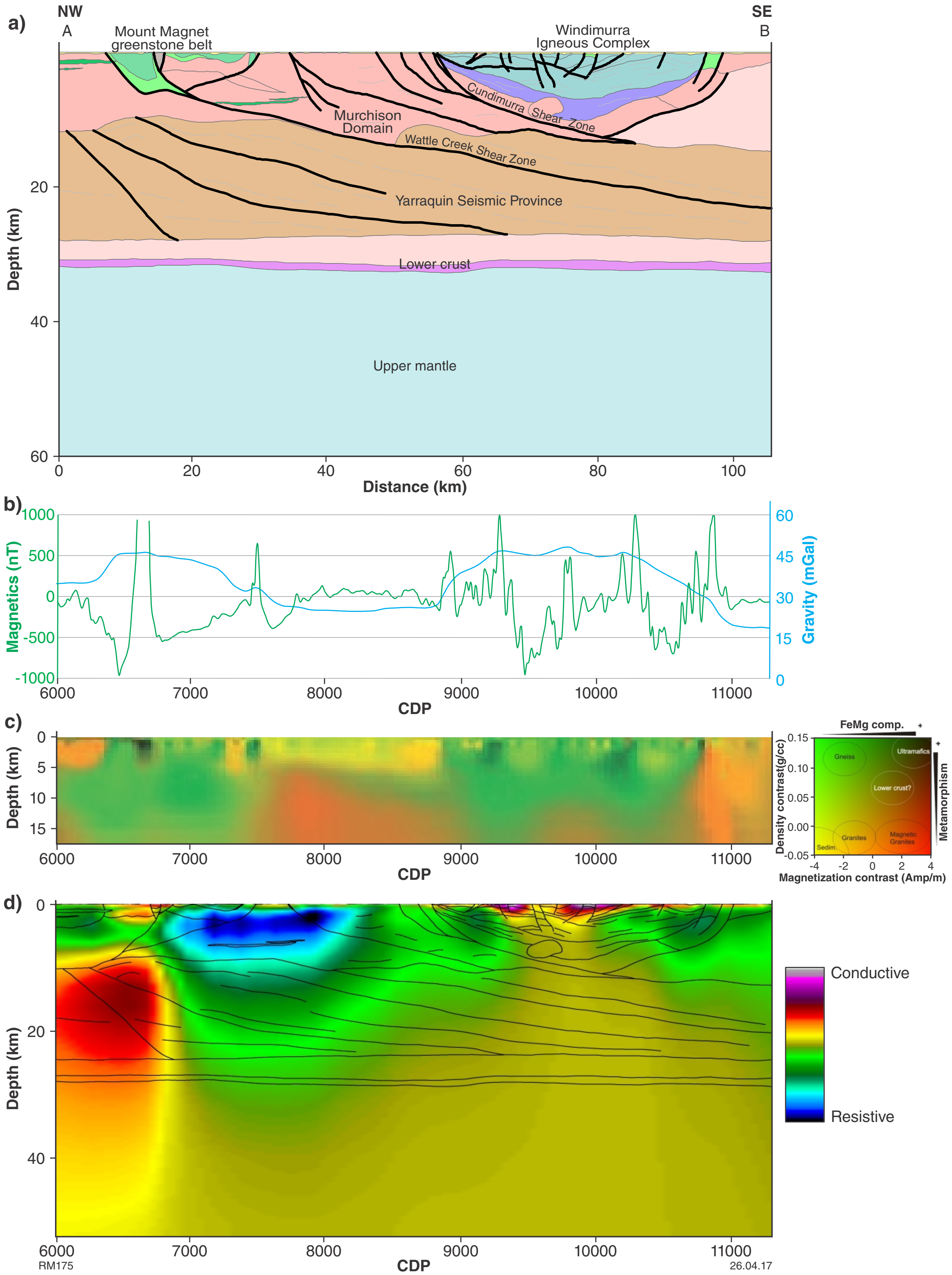

Figure 3. **Inversion results of the seismic line 10GA-YU3: a) lithological interpretation of the seismic line from Ivanic et al. (2014); b) gravity and magnetic profiles used in the joint inversion; c) joint magnetic and gravity inversion geospectral image with a colour legend on the side; d) MT profile from Milligan et al. (2014) with line work from the seismic interpretation of Ivanic et al. (2014) overlain**

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Seismic line 11GA-SC1

(Southern Carnarvon Basin, Narryer Terrane)

JA Goodwin* and RE Murdie

Location

Maps: YARINGA (SG 50-9) and BYRO (SG 50-10)

Zone: MGA Zone 50

End coordinates: 238617E 7100022N to
468429E 7115734N

Length: 259.3 km

Scale of interpretation: 1:250 000

The seismic survey traverses from the Southern Carnarvon Basin in the west to the Narryer Terrane of the Yilgarn Craton in the east, where it almost joins the westernmost end of seismic line 10GA-YU1 (Fig. 1).

Tectonic units

The seismic line 11GA-SC1 passes through Cenozoic and Cretaceous calcareous and carbonate rocks of the Gascoyne Platform and through the Carboniferous–Permian glacigenic sediments and sedimentary rocks of the Byro Sub-basin, which are both part of the Southern Carnarvon Basin (Hocking, 2000; Mory and Backhouse, 1997). The Southern Carnarvon Basin is interpreted to sit on the Pinjarra Orogen basement (Myers, 1990a) in the west and the Narryer Terrane in the east. The Glenburgh Terrane forms a small wedge in the centre of the section (Johnson et al., 2012). There is an intensely faulted section of crust under the eastern Carnarvon Basin, which has been interpreted as the Errabiddy Shear Zone. The Badgeradda Group forms a small basin between the Badgeradda Fault and the Narryer Terrane, which crops out east of the Meerberrie Fault. The Yarraquin Seismic Province is the name given to the lower crust in the eastern part of the profile (Korsch et al., 2014).

Structure

We follow the structural interpretation of Korsch et al. (2014). The Darling Fault is a major trans-crustal structure, which extends to the Moho. The Darling Fault separates the Pinjarra Orogen, which constitutes the basement of the western part of the Southern Carnarvon Basin, from the Narryer Terrane of the Yilgarn Craton to the east. The Glenburgh Terrane is a wedge between the Darling Fault and the Madeline Fault. The Errabiddy Shear Zone is interpreted as a set of imbricate faults in the upper 16 km of the crust, just to the east of the Madeline Fault, and probably contains rocks of both the Glenburgh and Narryer Terranes (Johnson et al., 2011). The Ballythanna Fault is a trans-crustal fault which cuts up through the Byro Sub-basin, dividing them into two small basins. To the north it joins the Meeberrie Fault. Although the Meeberrie Fault is interpreted as an internal fault within the Narryer Terrane, it cuts the depth of the crust to the Moho, and represents the eastern limit of the Byro Sub-basin and the western limit of the surface exposure of the Narryer Terrane. The Narryer Terrane is separated from the rest of the Yilgarn Craton by the northwest dipping Yalgar Fault (Myers, 1990b).

Geophysical data

The gravity data used in the forward modelling were extracted from Bacchin et al. (2008). The seismic interpretation used in this modelling was derived from Korsch et al. (2014, figure 2).

Physical property values were taken from tabled data from Emerson (1990), Telford et al. (1990), and Rudnick and Fountain (1995).

Forward modelling

Geoscience Australia, in collaboration with the Geological Survey of Western Australia, conducted the Southern Carnarvon Deep Crustal Seismic Reflection Survey (11GA-SC1) in 2011 (Korsch et al., 2013). The purpose of this survey was to image deep crustal structures and the crust–mantle boundary. Data were recorded to 20 seconds of two-way travel time (~60 km deep, assuming an average crustal velocity of 6000 m/s) (Costelloe and Jones, 2014).

A crucial part of the seismic interpretation process is to test the interpretation against other data. In this case, the seismic interpretation was tested against gravity data through 2D forward modelling using ModelVision v.11.0 software.

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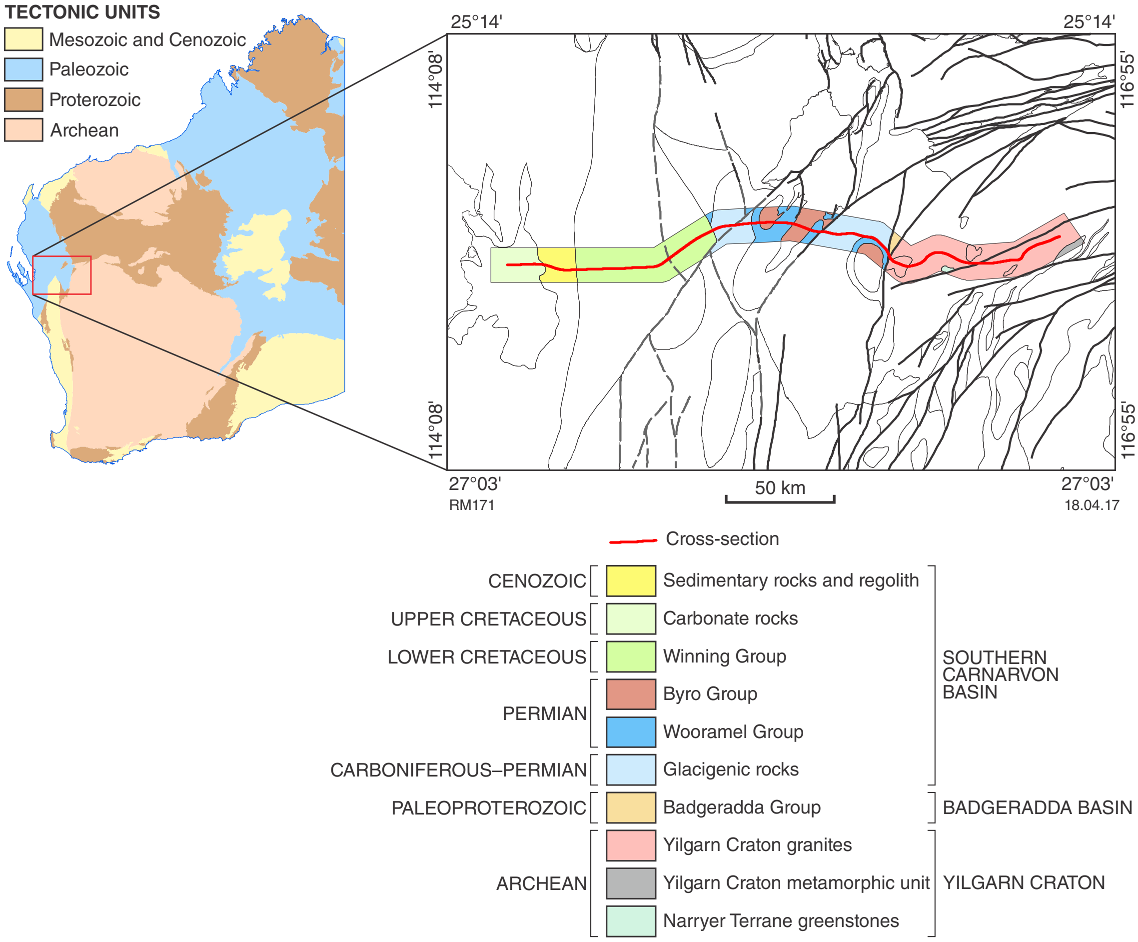

Figure 1. Southern Carnarvon Basin 1:500 000 interpreted bedrock geology map showing the location of seismic line 11GA-SC1

Forward modelling results

A density of 3.30 g/cm^3 is used to reflect the density of the upper mantle (Poudjom Djomani et al., 2001). This creates a regional trend which matches the topography seen on the Moho (Fig. 2b).

Mid (10–20 km) to lower (20–40 km) crustal layers (Fig. 2a) match the observed gravity profile when using densities of 2.70 – 2.85 g/cm^3. These densities correlate with amphibolite to granulite facies and felsic to intermediate rocks (Rudnick and Fountain, 1995).

The upper crustal portion of the Narryer Terrane, between 100 and 260 km, consists of amphibolite to granulite facies and felsic rocks and was modelled with densities in the range of 2.60 – 2.82 g/cm^3 (Rudnick and Fountain, 1995).

The Southern Carnarvon Basin is modelled with a density of 2.40 g/cm^3 (Fig. 2c) typical of sedimentary rocks (Emerson, 1990; Telford et al., 1990) and overlies the Pinjarra Orogen Terrane and the western part of the Narryer Terrane.

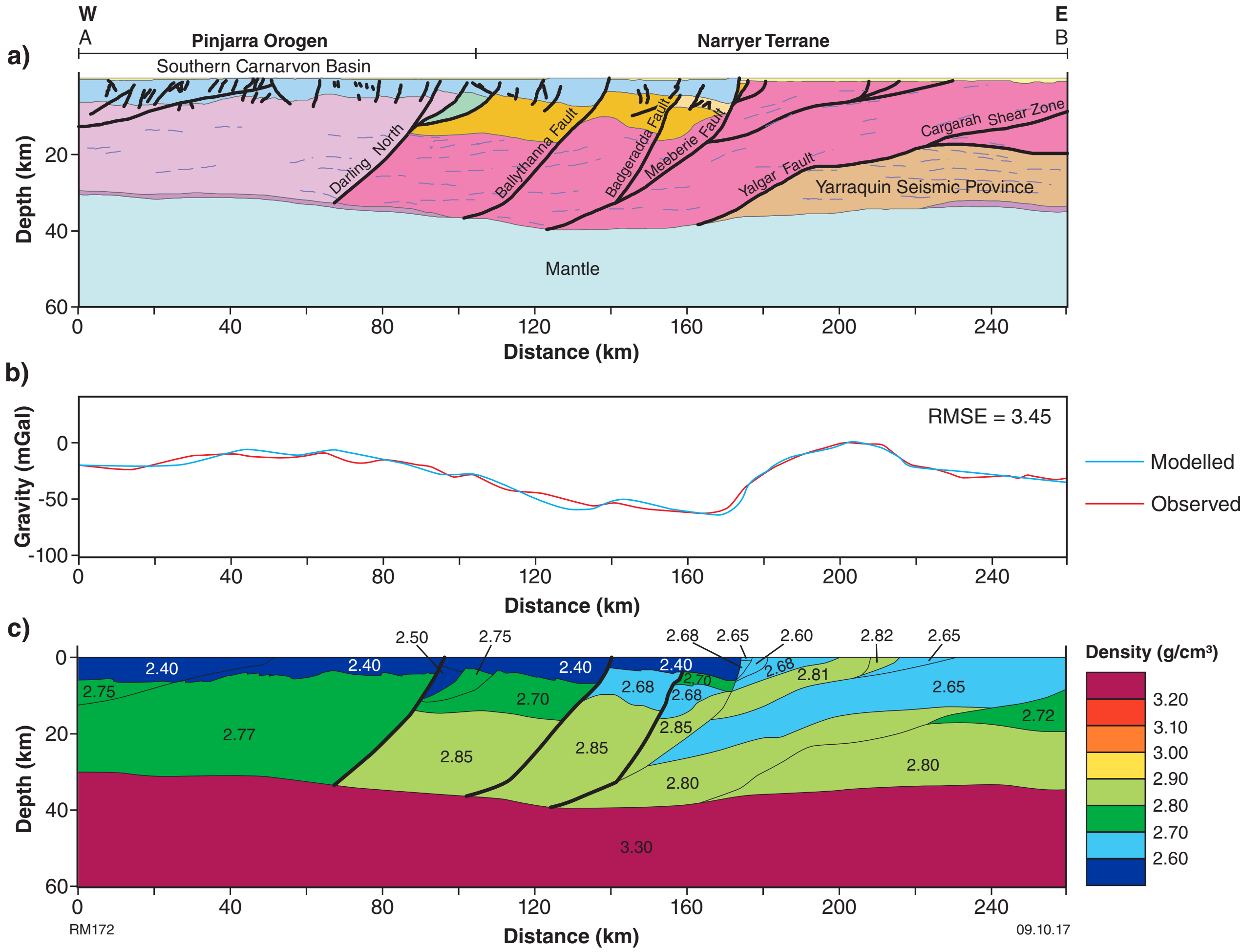

Figure 2. Profiles of 11GA-SC1 seismic line showing: a) lithological interpretation from Korsch et al. (2014); b) observed and calculated gravity anomaly profile from Gessner et al. (2014); c) profile of density in g/cm³ per lithology

Table 1. Summary of the physical properties used in the gravity model of the seismic line 11GA-SC1. The colour column refers to colours used in Fig. 2a

Colour	*Lithological unit*	*Rock type*	*Density (g/cm³)*
	Southern Carnarvon Basin	Sediments	2.40
	Pinjarra Orogen	Metasediments and meta-igneous rocks	2.75 – 2.77
	Glenburgh Terrane	Granitic gneiss	2.75
	Badgeradda Group	Sediments	2.68 – 2.70
	Errabiddy Shear Zone	Sheared metagranites	2.70 – 2.75
	Narryer Terrane		
	Upper crust	Granitic crust	2.60 – 2.82
	Lower crust	Lower crust	2.80 – 2.85
	Yarraquin Seismic Province	Lower crust	2.80
	Upper mantle	Mantle	3.30

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Seismic line 11GA-YO1

(Yilgarn Craton, Officer Basin, Musgrave Province)

JA Goodwin*, J Duan* and RE Murdie

Location

Maps: THROSSEL (SG 51-15), WESTWOOD (SG 51-16), YOWALGA (SG 51-12), TALBOT (SG 52-9), BENTLEY (SG 52-5), and SCOTT (SG 52-6)

Zone: MGA Zones 51 and 52 (all coordinates are given as if in zone 52)

End coordinates: 048967E 6980695N to 426636E 7229522N

Length: 484 km

Type of modelling: 2D forward modelling of gravity and magnetics, and 3D magnetotelluric (MT) inversion of a profile

This is a southwest- to northeast-oriented section that follows the 11GA-YO1 seismic line from the Officer Basin to the Musgrave Province (Fig. 1).

Tectonic units

Officer Basin

The Officer Basin is a Neoproterozoic to Devonian basin, which formed part of the Centralian Superbasin (Walter et al., 1995). It is covered in this area by Permian and Cretaceous rocks of the Canning and Gunbarrel Basins, respectively (Hocking, 1994). The stratigraphy used in the seismic interpretation is constrained by several petroleum wells and stratigraphic drillholes (Shell Company of Australia Ltd, 1983; Grey et al., 2005).

The Cambrian Table Hill Volcanics lie unconformably on top of the Neoproterozoic rocks and are part of the extensive Kalkarindji Large Igneous Province (Evins et al., 2009). They consist of basalt flows which are highly reflective in the seismic section.

Along the seismic line, the Officer Basin consists of the Buldya Group and its constituent formations comprise siltstone, sandstone, quartzite, dolomite, and other evaporative rocks (Grey et al., 2005). The stratigraphy of the upper Officer Basin is derived from drillholes as it does not outcrop from underneath the Phanerozoic rocks. The base of the basin outcrops along the southern margin of the Musgrave region. The glaciogene/shallow marine Wahlgu Formation lies unconformably on top of the Buldya group in areas where it has not been eroded (Grey et al., 2005).

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The Browne Formation lies near the base of the Officer Basin. It consists of several evaporite horizons. These horizons are several hundred metres thick and have been deformed and mobilized during the late Neoproterozoic to early Cambrian Petermann or Delamerian Orogenies, and now form large salt diapirs that protrude through the remaining stratigraphy of the Officer Basin (Simeonova and Iasky, 2005).

Under the Officer Basin is a sequence of metasedimentary rocks, which were intruded by igneous rocks. This sequence is considered to be distinct from the Yilgarn Basement and has been termed the Manunda Basin. It does not outcrop, but has been sampled in drillcores and is imaged in the 11GA-YO1 seismic line and earlier seismic profiles (Harrison, 1973). It consists of two grabens and appears to reach a maximum thickness of 6 km (Korsch et al., 2013).

In the southwest of the profile, underlying the Officer Basin, is the Yamarna Terrane, the eastern part of the Eastern Goldfields Superterrane in the Yilgarn Craton. The Yamarna Terrane is rarely exposed but several sets of lineaments, proposed to be unexposed belts of greenstone or banded iron-formation, are interpreted from aeromagnetic data. The granites of the Yamarna Terrane are of similar age and origin to those in the Kalgoorlie and Kurnalpi Terranes of the Eastern Goldfields Superterrane (Pawley et al., 2009). The term Yamarna Terrane is applied only to the upper crustal low-reflectivity layers which have a maximum thickness of 13 km.

The middle and lower crust of the Yamarna Terrane is termed the Babool Seismic Province. It is only seen in seismic section, but never in an outcrop or a drillcore (Korsch et al., 2013). It has distinctive apparent northeast dipping reflectors. The lower crust is differentiated by its moderately reflective character with subhorizontal layering.

Musgrave Province

The Musgrave Province refers to all rocks formed during or affected by the 1220–1150 Ma Musgrave Orogeny (Howard et al., 2013). It is exposed between younger volcano-sedimentary successions of the Officer Basin to the south, Canning Basin to the northwest, and Amadeus Basin to the north. Rocks of the Musgrave Province are dominated by granulite facies Mesoproterozoic felsic orthogneisses and paragneisses.

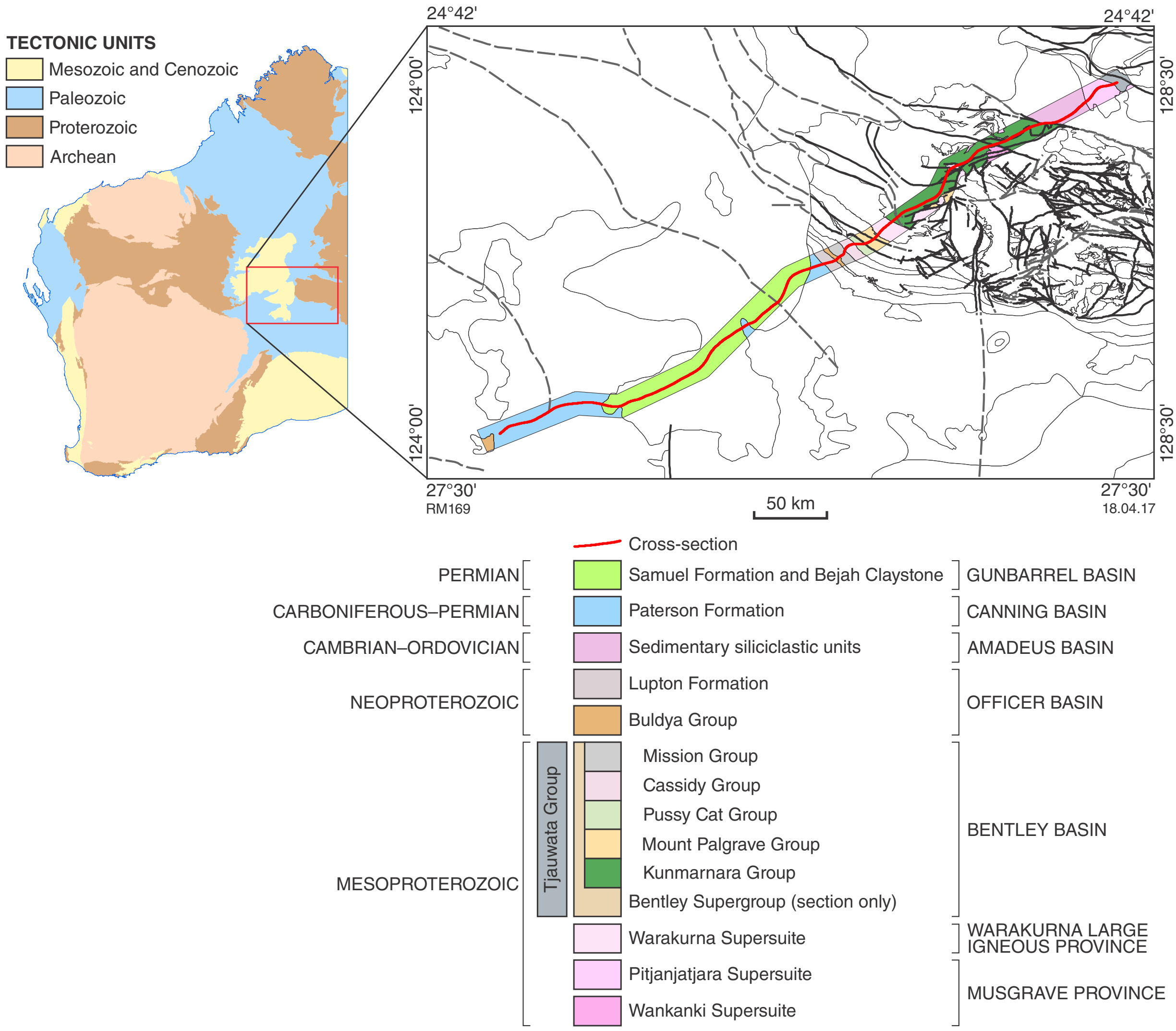

Figure 1. Officer Basin and Musgrave Province 1:500 000 interpreted bedrock geology showing location of seismic line 11GA-YO1

The Musgrave Province is overlain by volcano-sedimentary rocks of the Bentley Basin, which were deposited into the failed intracontinental Ngaanyatjarra Rift at the onset of the 1085–1040 Ma Giles Event (Evins et al., 2010). The basal component of the Bentley Basin is the Kunmarnara Group, which constitutes a sedimentary succession that is overlain by basalts and minor felsic rocks (Howard et al., 2011). The Giles mafic–ultramafic layered intrusions were emplaced along bounding faults of the various lithotectonic zones of the Musgrave Province basement. They intruded into the Kunmarnara Group. The present day thickness of approximately 10 km of the Giles Intrusion probably underestimates the original size of the extensive outpourings.

Bimodal volcanic and sedimentary rocks overlie the Kunmarnara Group. In the Talbot Sub-basin, the Bentley Supergroup, from top to bottom, consists of the Mission Group (lower sedimentary and upper basaltic parts), Cassidy Group (four mafic–felsic volcanic cycles), Pussy Cat Group (bimodal volcanics and sedimentary units), and Mount Palgrave Group (ignimbrites). The Bentley Supergroup shows weak folding, and greenschist facies metamorphism in the south of the Musgrave Region, but pervasive deformation and granulite facies metamorphism in the north (Quentin de Gromard et al., 2016). The Tjauwata Group is the northern equivalent of the Bentley Supergroup within the Bentley Basin. The Winburn Granite is a large, composite, synvolcanic pluton of the Warakurna Supersuite that intrudes the Mount Palgrave Group and is geochemically equivalent to extrusive units of the Mount Palgrave Group (Smithies et al., 2013).

The northeast end of the seismic profile intersects a thick sequence of Bentley Supergroup rocks intruded by granites of the Warakurna Supersuite that were generated during the Giles Event (Howard et al., 2013; Carlsen et al., 2003; Simeonova and Iasky, 2005).

The middle crust under the Musgrave Region is termed the Musgrave Province(?) as it is possibly equivalent to basement rocks exposed in the eastern Musgrave Province. They are seen in thrust slices in the Wanarn areas (Quentin de Gromard et al., 2016), but it is more likely that the granitic basement formed during the 1220–1150 Ma Musgrave Orogeny.

The Tikelmungulda Seismic Province is the nonreflective lower crust below the Musgrave mid crust (Korsch et al., 2013). If the mid crust is of Musgrave origin, then the Tikelmungilda Seismic Province is the product of two periods of mafic underplating during the Musgrave Orogeny and Giles Event. Alternatively it may consist of a mafic underplate and an older felsic basement of the Wankanki Supersuite. However, if the mid crust is of exotic origin, the origin of the Seismic Province would also be unknown.

Structure

The lower crust is moderately reflective with subhorizontal reflectors, which is very similar to the character of the Yilgarn Craton. Above this, the Babool Seismic Province is dominated by strong northeast dipping reflectors which sole out onto the lower crust.

The Officer Basin overlies the Yamarma Terrane and Manunda Basin. The Officer Basin thickens to the northeast, suggesting that it was an extensional basin with the Windularra Fault being the basin bounding fault. The Windularra fault has probably been reactivated during the Neoproterozoic causing basin inversion (Korsch et al., 2013). Faults interpreted within the seismic section are generally thrust faults dipping to the northeast, which sole out into the Browne Formation. The deformation during the Petermann or Delemerian Orogenies caused the salt diapirs to deform and, due to gravitation instability, rise through the lower layers of the overlying basin (Carlsen et al., 2003; Simeonova and Iasky, 2005).

The west Musgrave Province has a dominant northwest crustal structure, which was established during or before the Musgrave Orogeny, and later reactivated during the Musgrave Orogeny, the Giles Event, and the Petermann Orogeny (Smithies et al., 2015). The Musgrave Orogeny was an intracratonic extensional regime (Wade et al., 2006; Wade, 2008). The Giles event was a long-lived, failed intracontinental rift. The Bentley Basin represents the fill of the failed rift of the Giles Event, the Ngaanyatjarra Rift, which includes the Talbot Sub-basin, the smaller Blackstone Basin, and the poorly defined Finlayson Sub-basin (Evins et al., 2010).

The Petermann Orogeny produced east-trending shear zones along the northern margin of the Musgrave Province. They divide the province into two domains, characterized by different structural styles and metamorphic grades, and cut into the deeper crust. These zones include the south dipping Woodroffe Thrust and Mitika Faults interpreted in the seismic profile (Fig. 2a) to cut right down to the mantle (Howard et al., 2013; Quentin de Gromard et al., 2016). In more recent interpretations of the seismic line, both the Mitika Fault and Woodroffe Thrust are interpreted to dip at a steeper angle and that the Woodroffe Thrust soles onto the Mitika Fault (Fig. 2e; (Quentin de Gromard et al., 2015).

Geophysical data

Gravity data for the modelling were taken from the Gravity anomaly map of the Australian region 3rd edtion (Bacchin et al., 2008). Original gravity points vary in separation between 2.5 and 11 km and the interpolated grid had a nominal cell size of 800 m.

Magnetic data were extracted from Milligan et al. (2010). Flight line spacing was 500 m and the product gridded data had a cell size of 80 m.

Magnetotelluric (MT) data were also collected along this profile at a 5–10 km spacing for broadband instruments for a total of 72 sites and 10–15 km spacing for long-period instruments (31 sites). Data were of good quality as there is very little anthropogenic noise in that area (Duan et al., 2013).

Physical property values were taken from tabular data in Emerson (1990) and Telford et al. (1990) and shown in Table 1.

Forward modelling, gravity and magnetics

All gravity and magnetic modelling was performed in ModelVision v.11.0. The interpretation from the seismic line (Korsch et al., 2013, Howard et al., 2013) was used as an initial starting model. This was the primary constraint during modelling, although the objective was to test the validity of the interpretation with respect to gravity and magnetic data. Modelling was also carried out along a profile parallel to the seismic line, but those models are not included in this Record.

Results, gravity, and magnetics

The lowest unit of the model is the upper mantle. It was given a uniform density of 3.31 g/cm^3. The deeper Moho under the Musgrave Province due to thickening in the Petermann Orogeny (Goodwin et al., 2013) generates a regional Bouguer low.

The Officer Basin is modelled as one unit, comprising low-density sediments overlying the Yilgarn Craton (Emerson, 1990). This causes the regional slope of the Bouguer anomaly, which offsets the low, which was produced by the deeper Moho. Local Bouguer lows are generated by the salt diapirs which have even lower (2.35 g/cm^3) densities.

The mid crustal rocks of the Yilgarn Craton are not exposed, hence the densities for the Babool and Tikelmungulda Seismic Provinces were derived from average values found in Rudnick and Fountain (1995) and Christensen and Mooney (1995).

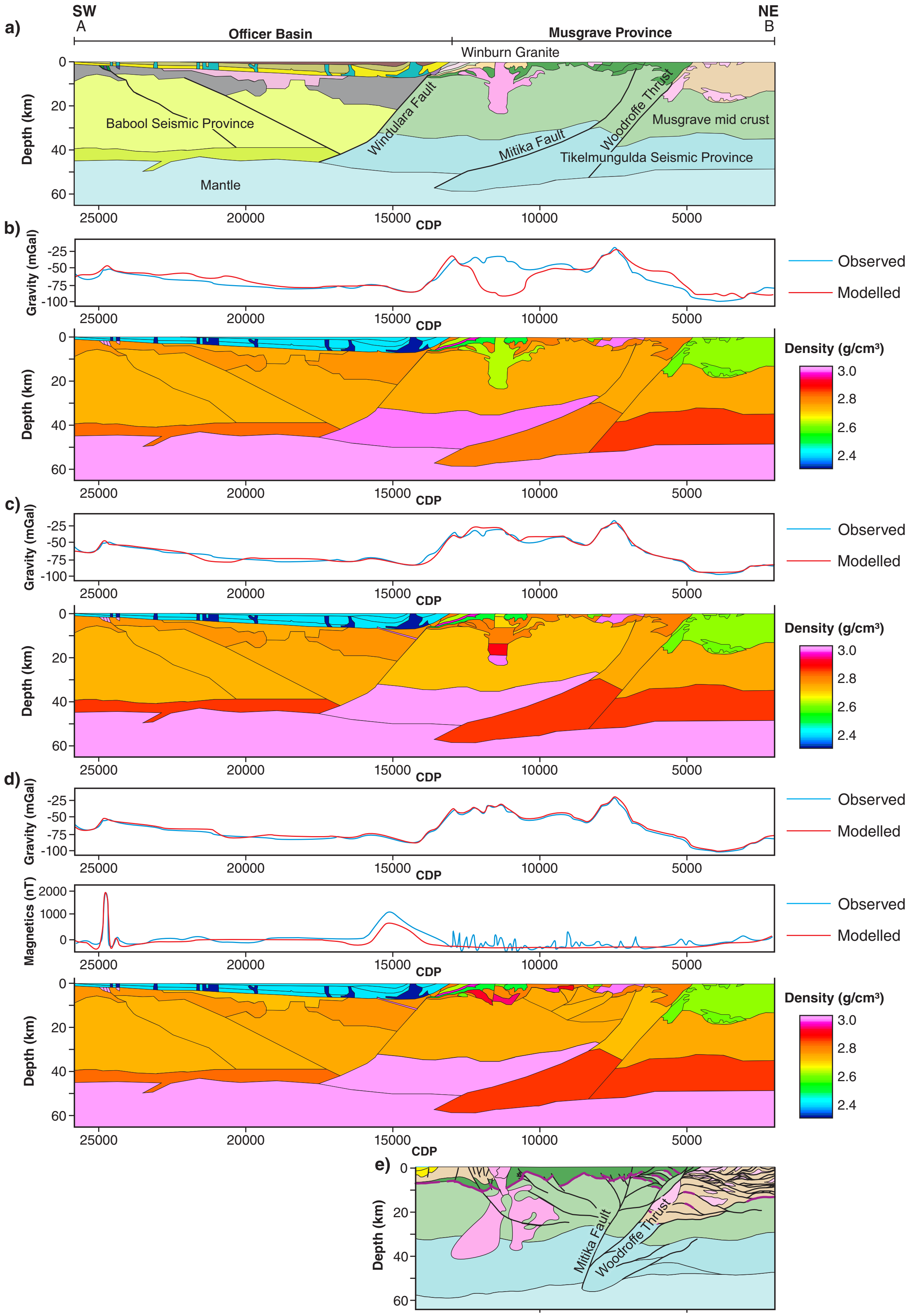
a)
SW
A
NE
B
Officer Basin
Musgrave Province
Winburn Granite
Babool Seismic Province
Windulara Fault
Woodroffe Thrust
Musgrave mid crust
Mitika Fault
Tikelmungulda Seismic Province
Mantle
Depth (km)
CDP
b)
Gravity (mGal)
Observed
Modelled
Density (g/cm³)
c)
d)
Magnetics (nT)
e)

Figure 2. **(opposite) Profiles along the seismic line 11GA-YO1 showing: a) lithological interpretation of the 11GA-YO1 seismic line. Polygon names within the Officer Basin refer to the unit at the base of the polygon and include the units above it until the next named polygon (see text for details of the geological units); b) density model with observed and calculated gravity anomaly profile for initial model from the seismic interpretation; c) density model with observed and calculated gravity anomaly profile for a graduated density model of the Winburn Granite; d) density model with observed and calculated gravity anomaly profile for a reduced volume model of the Winburn Granite (the observed and calculated magnetic anomaly is also shown); e) lithological profile of the current interpretation of the Winburn Granite and configuration of the Mitika Fault and Woodroffe Thrust**

Table 1. **Summary of physical properties used in the final density model (Fig. 2d). Note that the Winburn Granite was given a density to fit the model rather than an average granite density. It is therefore anomalously high for a granite**

Colour	*Modelled unit*	*Rock type*	*Density (g/cm³)*
	Officer Basin		
	Table Hill Volcanics	Sediments	2.40
	Husar Formation	Sediments	2.40
	Buldya Group	Sediments	2.40
	Salt[(a)]	Salt	2.35
	Yilgarn Craton		
	BIF and mafics[(a)]	BIF and mafic rocks	3.00 – 3.20
	Manunda Basin	Metasediments	2.71
	Yamarna Terrane	Basement	2.74 – 2.77
	Babool Seismic Province	Mid crust	2.74 – 2.90
		Lower crust	2.81
	Musgrave Province		
	Other granites	Granitic rocks	2.60
	Bentley Supergroup		
	Mission Group	Sediments and basalts	2.82
	Cassidy Group	Mafic and felsic rocks	2.53
	Pussy Cat Group	Bimodel volcanics and sediments	2.60
	Mount Palgrave Group	Ignimbrite	2.77
	Undivided Bentley Supergroup	Mixed sediments and mafic rocks	2.50 – 2.80
	Warakurna Supersuite		
	Winburn granite	Granite	2.85
	Giles Suite	Mafic and ultramafic rocks	3.00
	Bentley Supergroup		
	Kunmarnara Group	Sandstone, conglomerate, and basalt	2.80
	Musgrave mid crust	Mid crust	2.71 – 2.75
	Tikelmungulda Seismic Province	Lower crust	2.86 – 3.00
	Upper mantle	Mantle	3.32

NOTES: (a) Not imaged on seismic section

The mid-crust of the Musgrave Province is relatively thin compared to the Babool mid-crust. Hence, the Tikelmungulda Seismic Province is relatively thick compared to the lower crust of the Babool Seismic Province. These features of the Musgrave Province, along with the high density of the Bentley Supergroup (bimodal volcanics and minor sediments with an average density of 2.80 g/cm^3), produce a Bouguer high across the province. Across the Musgrave Province, differences in the gravity signal can be attributed to differing thicknesses of the Bentley Supergroup.

The Winburn Granite caused controversy during modelling as seismic data suggested that it was a large granitic body with an associated low density of 2.64 g/cm^3 (Fig. 2b). However, this was not supported by the gravity data as it generates a large gravity low, which is not reflected in the Bouguer anomaly. If the granite would be modelled with layers that are progressively denser as the layer gets deeper and therefore reflecting a fractionated magma chamber, a better fit is likely to be achieved (Fig. 2c).

Alternatively, the Winburn Granite may only be 0.3 to 1 km thick (Fig. 2d) (Goodwin et al., 2013). In the most recent interpretation (Fig. 2e; Quentin de Gromard et al., 2015) the Winburn Granite is a thin, funnel-shaped intrusion of more limited extent than the large body initially proposed in the first model, but at greater depth than shown in the most recent model of Goodwin et al. (2013).

The magnetic profile along the line is dominated by short-wavelength features, which are more related to near-surface features, which are not related to the crustal-scale features interpreted from the gravity and seismic profiles. Hence, only the anomalies associated with greenstone belts were modelled.

The greenstone belts of the Yamarna Terrane can be seen in the magnetic highs in the west of the profile at Common Depth Point (CDP) 25 000 and 16 000. The greenstone belts are modelled as dipping slabs with high densities (3.20 g/cm^3) and a high magnetic susceptibility, which is consistent with a mafic body with banded iron-formations (BIF). The feature at CDP 16 000 is a thin body which dips shallowly to the north, whereas the two features at CDP 25 000 are small steeply dipping bodies.

MT Inversions

The MT data showed different dimensional characteristics depending on whether they were in the southwestern section (>MT station 27 [BL27], CDP 13 250) or northeastern section (<BL27). The southwestern section showed 1D or 2D character at less than 10 s, 2D or weak 3D character at periods of less than 100 s and 3D character at longer periods. The northeast section showed 2D and weak 3D character at periods of less than 10 s and 3D character at periods greater than this.

A 3D inversion code 'ModEM' (Egbert and Kelbert, 2012) was used to invert the MT data along the seismic line using the full impedance tensors. The main features of the profile were also present in an earlier 2D inversion, giving confidence in the reliability of these features. A mesh of 79 × 79 × 34 elements was used and the resultant graph (Fig. 3) was extracted along the CDP localities.

MT Results

The final MT inversion graph (Fig. 3) shows several major resistive features which may relate to geological features in the crust (Duan et al., 2013).

In the northeastern part of the line from sites BL01 (CDP 2000) to BL07 (CDP 5000), there is a low resistivity area in the middle and lower crust. This feature is truncated by a southwest-dipping boundary (station BL07, CDP 5000), which corresponds to the location of the Woodroffe Thrust. From stations BL07 (CDP 5000) to BL25 (CDP 12 800), there is a section of very high resistivity of about 4000 Ωm throughout the whole crustal thickness. The change in character of the mid-crustal resistivity profile from stations BL07 to BL27 from very high resistivity and to lower resistivity between stations BL27 to BL54 (CDP 21 098) is coincident with a low in the gravity and may reflect the change from the Musgrave Province in the northeast to the Yilgarn Craton and Officer Basin in the southwest.

The shallow very low resistivity layer (10 Ωm) from stations BL27 to BL73 (CDP 25 600), shown in red, indicates a sedimentary basin and has a corresponding gravity low. This low resistivity layer is interpreted to be the Officer and Manunda Basins. The thickness of this layer is approximately 4 km with a length of 200 km. Underlying this layer, from BL58 (CDP 22 105) to BL73 is a high resistivity (5000 Ωm) structure in the crust, which also corresponds to a gravity high and may correspond to the greenstone belts in the Yamarna Terrane (Duan et al., 2013).

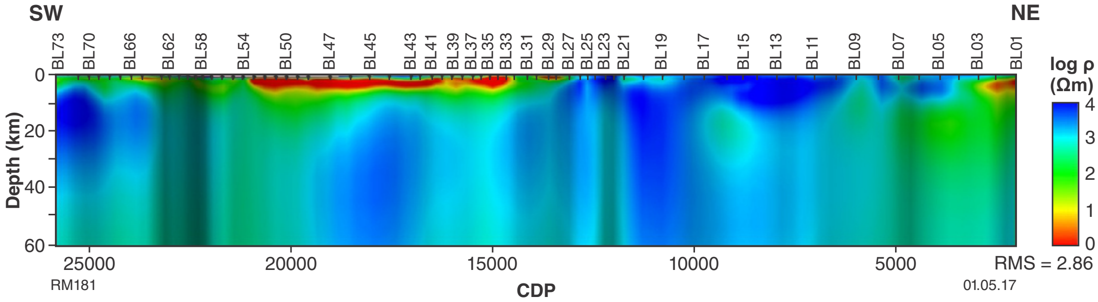

Figure 3. Image of the results of the MT 3D inversion showing the conductivity along the section in Fig. 2

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ATLEY 2741, 1:100 000 geological map

(Sandstone greenstone belt, Southern Cross Domain, Yilgarn Craton)

RE Murdie

Location

Maps: YOUANMI (SH 50-4) and ATLEY (2741)

Zone: MGA Zone 50

End coordinates: 697164E 6891946N to 745243E 6891936N

Length: 48 km

Scale of interpretation: 1:100 000

This is an east–west section that crosses the southern part of the Sandstone greenstone belt (Fig. 1).

Tectonic units

The Sandstone greenstone belt is a refolded syncline of greenstone stratigraphy sitting on the edge of the Southern Cross Domain. No regional stratigraphy has been established across the domain, but the local stratigraphy has been determined from mapping and drillcore although lack of outcrop precludes correlation of the northern part of the greenstone with the better exposed northern part found on SANDSTONE.

The Sandstone greenstone belt in the south is a mafic-dominated succession, which at its base consists of a foliated basalt (Chen, 2005). Above the basalt are thin deposits of banded iron-formation (BIF) and cherts intercalated with clastic sedimentary rock and intruded by gabbroic sills. This is overlain by a tremolite–cholorite and then by a tholeiitic basalt and a thick layer of BIF intruded by gabbroic sills. Above this is another mafic layer with thin units of BIF. The top of the sequence is an ultramafic layer, but the stratigraphic relationship between this and the lower layers is not known.

The greenstone belt has fault-bounded contacts with the surrounding Archean granites, which are typically poorly exposed. They are dominated by monzogranites with subordinate granodiorites. Strongly deformed granitic rocks are mapped with, and adjacent to, the major shear zones (Chen, 2005).

Structure

The major fault in this area is the Youanmi Shear Zone, which forms the boundary between the Murchison Domain in the west and the Southern Cross Domain in the east. From the seismic reflection surveys of 2010 it was shown to be a trans-crustal fault going all the way to the mantle (Wyche et al., 2014). It dips to the east and, with the west-dipping Edale Fault, bounds the Sandstone greenstone belt.

The Sandstone greenstone belt is a refolded syncline. The original F1 east-trending syncline has been overprinted by the F2 syncline with box-fold geometry and disrupted by brittle faults (Chen, 2005).

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data was taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Physical property data was compiled from Williams (2009) and Gessner et al. (2014; Table 1).

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software. All models are 2.5D with the polygons extending for 100 km perpendicular either side of the viewed profile.

Initial conceptual models were compiled from the cross-section on the map sheet (Chen, 2003) and interpretation of the 10GA-YU2 seismic line (Wyche et al., 2014), which traverses close to section A–B (Fig. 2a).

Results

The section across the Sandstone greenstone belt was modelled down to a depth of 35 km (Fig. 2c) and is heavily based on the modelling of seismic line 10GA-YU2 (Wyche at al., 2014). The broad peak seen in the section can be attributed to the higher density of the Sandstone greenstone belt with the variations in the peak accounted for by the depth of the mafic rocks. The only unit modelled within the greenstone is the slightly higher density ultramafic unit in the centre (Fig. 2c). There are BIF throughout the greenstone as seen in the magnetic peaks and profile, but they are too narrow to be picked out in the gravity data.

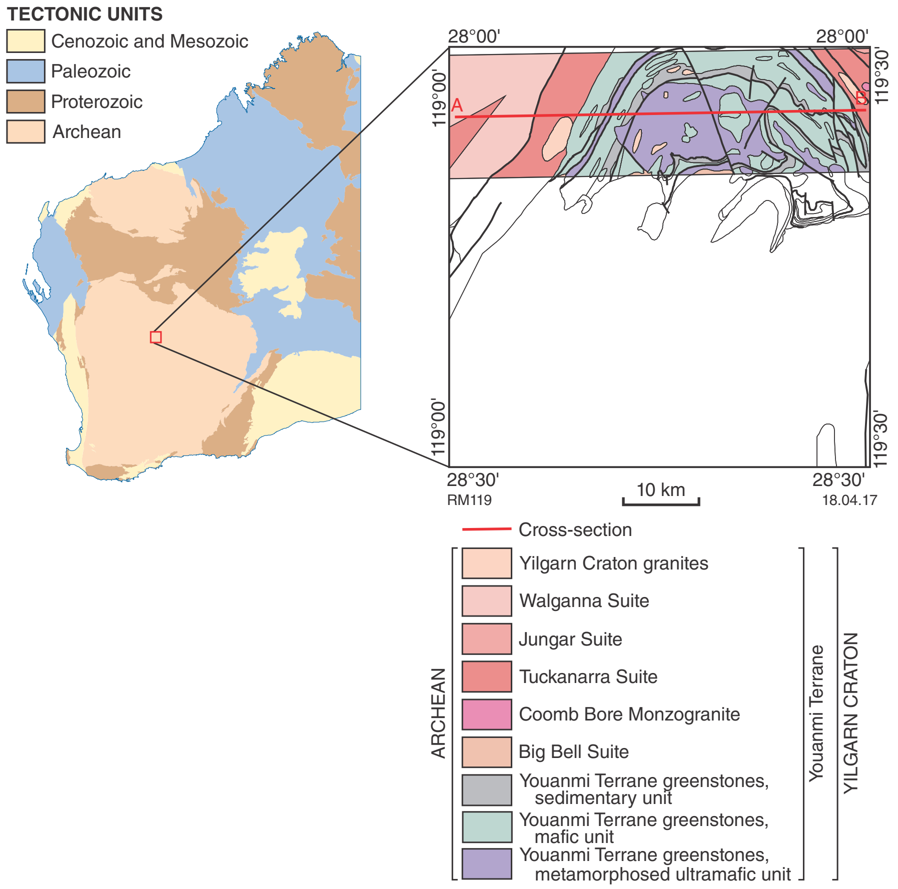

Figure 1. **Location of sheet Atley with simplified interpreted bedrock geology within 8 km of cross-section A–B**

Table 1. **Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a**

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Post-tectonic granite	A-g, A-gn	Granite	2.61	
	Youanmi Terrane greenstone (Unaly Hill greenstone belt)		Mafic, undivided	2.88	
	Youanmi Terrane greenstone (Sandstone greenstone belt)	A-b, A-o, A-og, A-bv, A-bf, A-bk, A-ba	Mafic	2.85	
		A-ci	BIF*		0.07 — very high
		A-s	Schist		
		A-u	Ultramafic	2.89	
	Sheared and foliated granite	A-gmf	Foliated granite	2.56	
	Murchison granites		Granite	2.55	
	Southern Cross granites		Granite	2.50	
	Yarraquin Seismic Province			2.85	
	Lower crust			2.90	

NOTE: *Not shown on section

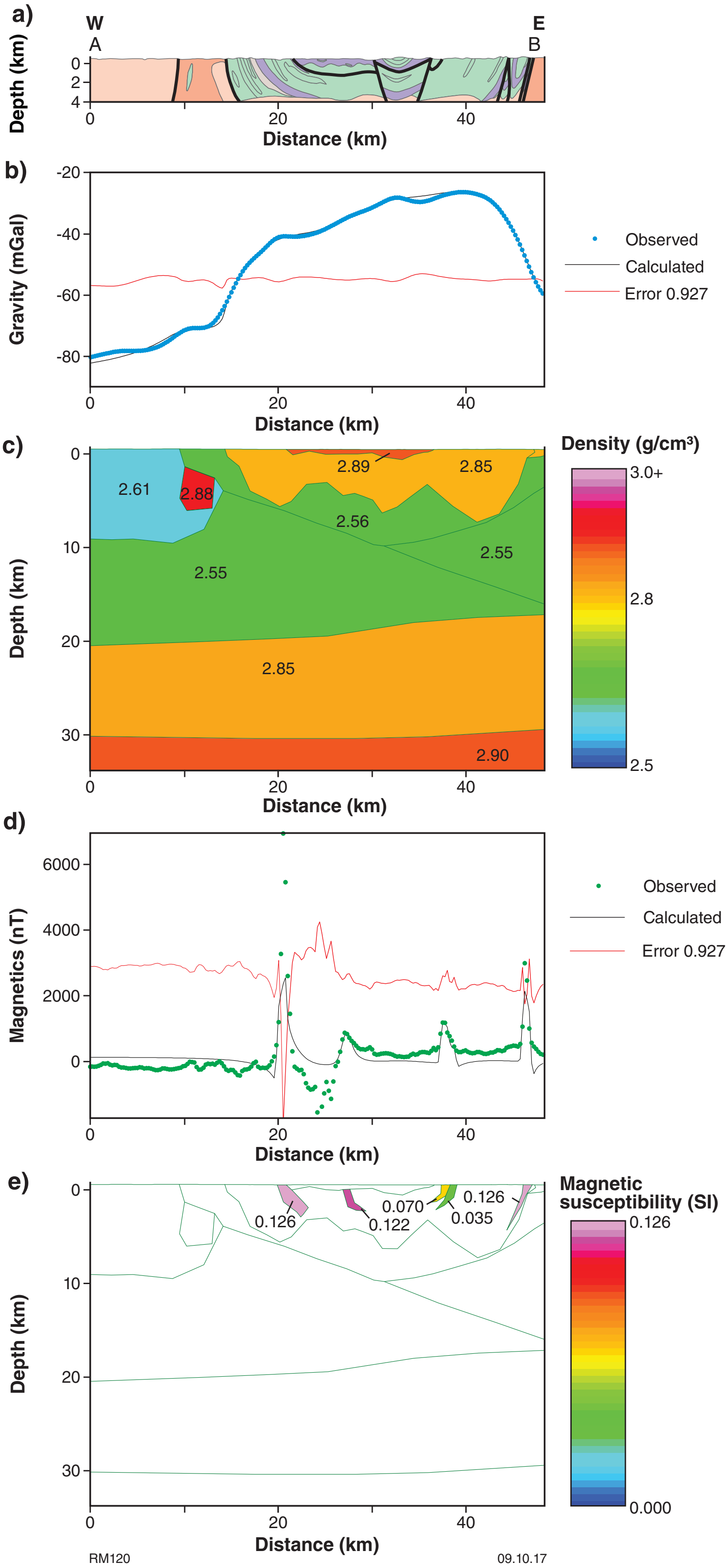

Figure 2. Profiles of cross-section A–B showing: a) lithological section from sheet Atley; b) observed and calculated gravity anomaly profile with error line, modelled down to 35 km for later use within a 3D regional model; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line, modelled down to 35 km for later use within a 3D regional model; e) section of magnetic susceptibility per lithology

The Unaly Hill greenstone belt outcrops just on the edge of the map and is seen in this section as a small gravity high in the west of the section and modelled as a blind body of mafic density. However, in this section (as opposed to section A–B of SANDSTONE) it has a zero magnetic susceptibility (Fig. 2b,c).

Although this section contains the Youanmi Shear Zone, which divides the Murchison Domain from the Southern Cross Domain, both domains are largely composed of granites and hence there is negligible density contrast between them. However, it appears that the Southern Cross granitic rocks have a stronger magnetic signal than the Murchison rocks (Fig. 2d).

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Badja 2240, section A–B, 1:100 000 geological map

(Yalgoo Dome, Murchison Domain, Yilgarn Craton)

RE Murdie and I Zibra

Location

Maps: Yalgoo (SH 50-2) and Badja (2240)

Zone: MGA Zone 50

End coordinates: 451212E 6741044N to 473331E 6820809N

Length: 30 km

Scale of interpretation: 1:100 000

The A–B section is a northwest–southeast section that crosses from the Edamurta greenstone belt and then across a series of granodiorites and tonalities of the Badja geological map (Zibra et al., 2016; Fig. 1).

Tectonic units

Cross-section A–B cuts through the western margin of the Yalgoo Dome, a large elliptical structure (50 × 100 km), which includes a granite–migmatite core overlain by a greenstone envelope. The dome formed at c. 2750 Ma via multiple emplacements of diapir-like plutons into older greenstones. Within the dome, we identify four granitic suites, each with a distinctive geochemical signature and age of emplacement, which suggest a protracted tectono-magmatic history lasting >300 Ma. The main infrastructure of the Yalgoo Dome formed at c. 2750 Ma by the emplacement of voluminous granite (i.e. the Goonetarra Granodiorite) and is associated with remelting of the older (c. 2950 Ma) Kynea Tonalite. This main dome-forming event is responsible of the main geometry of the granite–greenstone contact, as described in the next section. A north-trending dyke swarm of granitic composition was emplaced near the core of the dome at c. 2700 Ma.

The last magmatic episode is marked by the intrusion of late-orogenic, low-Ca granitic bodies, not intersected by the cross-sections. These undated units are likely to be equivalent to the late-orogenic (2640–2600 Ma), low-Ca plutons, extensively exposed throughout the craton.

Structure

First-order structural features in the Yalgoo Dome include domal patterns of foliation and lithological boundaries, causing greenstone packages to dip mainly west along the western side of the dome (e.g. at Edamurta, section A–B) and to dip east along the eastern side of the dome. Another prominent feature is represented by the radial pattern of lineation and fold axes. The granite–greenstones contact represents a large-scale normal shear zone developed during the latest stages of emplacement of the c. 2750 Ma granite suite. The main foliation along this high-strain zone developed from near-solidus to low-amphibolite facies conditions. At c. 2700 Ma the dome recorded a minor overprint (north–south-trending regional foliation visible in the Edamurta area), associated with the emplacement of a granitic dyke swarm with transitional tonalite–trondhjemite–granite composition. This event can be temporally linked to the emplacement of the Lakeside Pluton along the eastern side of the dome.

The emplacement of the low-Ca suite was associated with the development of a narrow high-strain aureole in the host Goonetarra Granodiorite. This late magmatic event probably post-dated most of the regional structures.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA, 2015) gravity merged grid of Western Australia (Fig. 2b). The magnetic profile was extracted at the same location from the GSWA 2014 merge of the total magnetic intensity of Western Australia (GSWA, 2014; Fig. 2d). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Physical property data were estimated from Yilgarn average values (Table 1).

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The A–B section was modelled to a depth of 4 km (Fig. 2c,e).

Generally, the gravity profile reflected the slight difference in densities between the Goonetarra Granodiorite and the slightly denser Kynea Tonalite. The extent of the tonalite under the granodiorite is defined by the gravity high. The Edamurta greenstone belt shows as a high-density feature in the northwest of the profile (Fig. 2c).

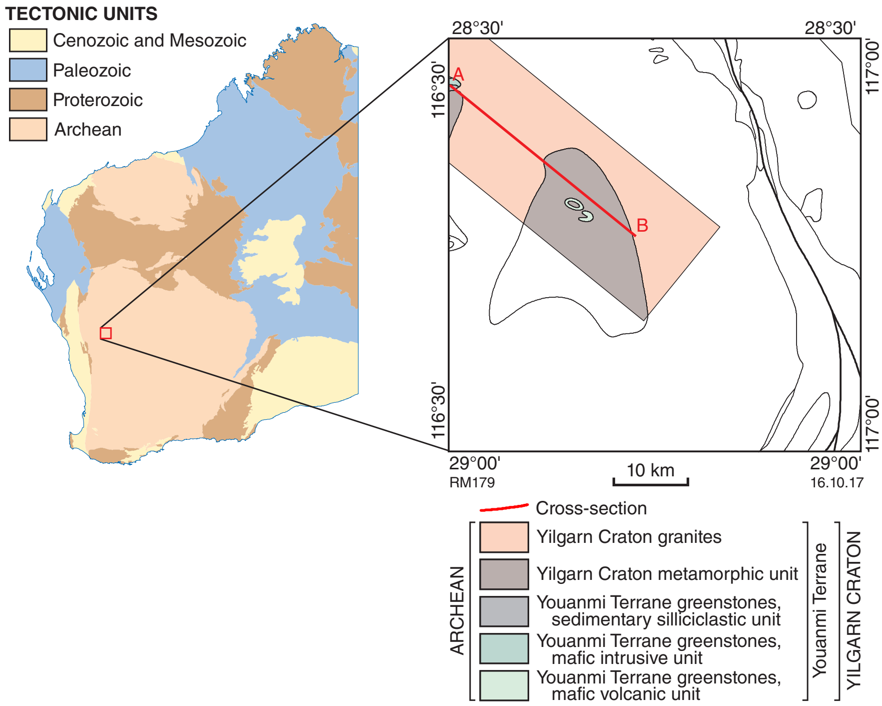

Figure 1. Location of BADJA map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Youanmi Terrane greenstones			
	BIF	A-mib-YYO	2.83	0.0170
	Migmatite inclusions	A-mwas-YYO	2.70 – 2.78	0.0150 – 0.0220
	General greenstone units	A-mls-YYO	2.83 – 2.85	0.0850 – 0.1260
	Gooneterra Granodiorite	A-ANgo-jgmfe-mgtn, A-ANgo-gmp, A-AMgo-mgmu	2.66 – 2.67	0.0050
	Edamurta Gabbro	A-ANed-oad, A-ANed-mog	2.85	0.0000
	Kynea Tonalite	A-THky-mgti	2.70 – 2.74	0.0000 – 0.0101

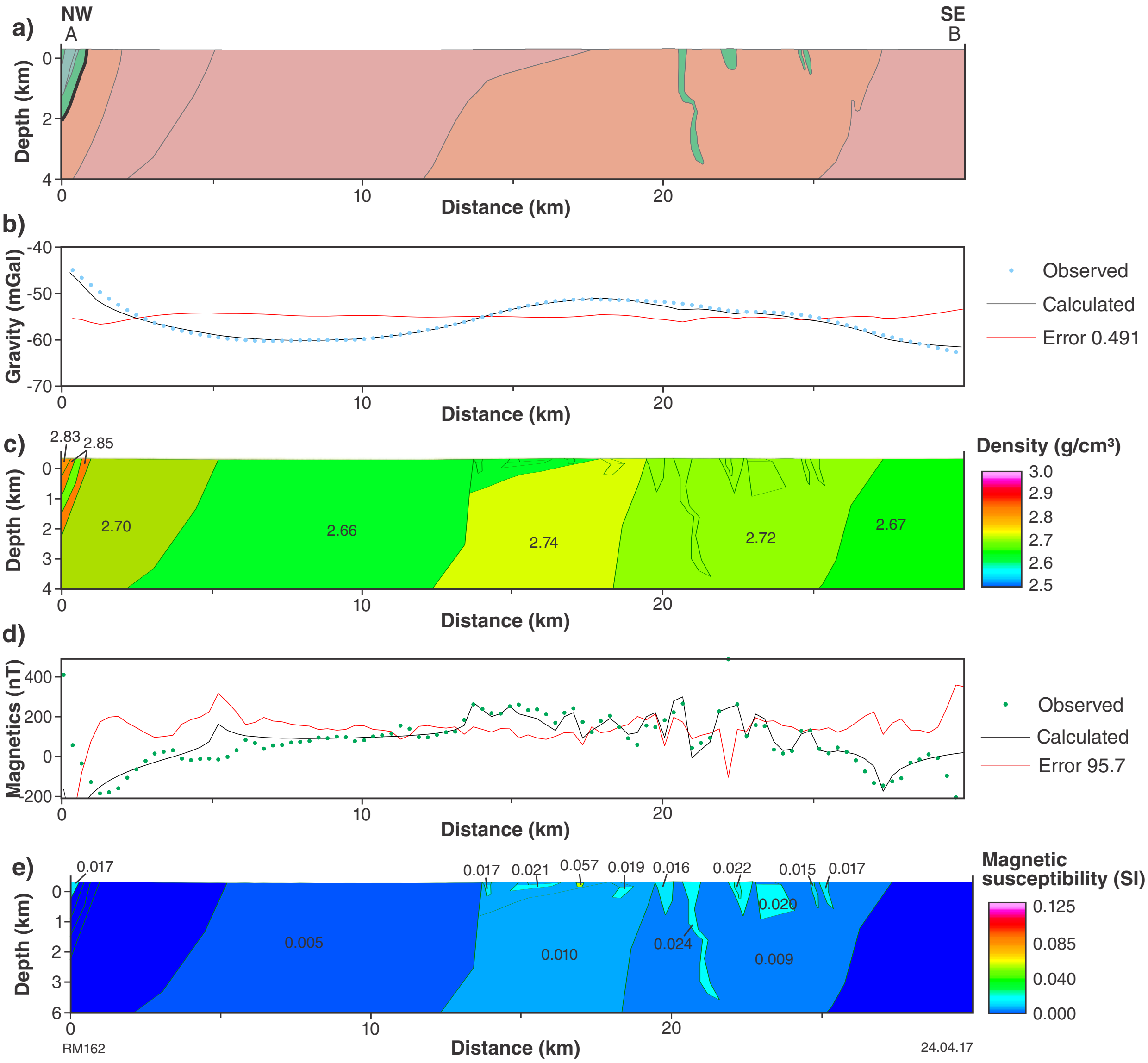

Figure 2. Profiles along cross-section A–B showing: a) lithological section on Badja map sheet; b) observed and calculated gravity anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

The banded iron-formation within the Edamurta greenstone belt accounts for the magnetic peak in the northwest. The granodiorite has a very low smooth magnetic signal, although closer to the tonalite, there are some magnetic spikes. These are probably migmatite inclusions. They are mapped in the field and seen in the magnetic signature over the Kynea Tonalite in the central part of the section (Fig. 2d). The Kynea Tonalite itself has a low magnetic susceptibility (Fig. 2e), but this varies slightly, as does the density along the profile (Fig. 2c).

References

Geological Survey of Western Australia 2014, Magnetic anomaly grid (80 m) of Western Australia (2014 – version 1), 16 September 2014 update: Geological Survey of Western Australia, digital data layer.

Geological Survey of Western Australia 2015, Gravity anomaly grid (400 m) of Western Australia (2015): Geological Survey of Western Australia, digital data layer.

Zibra, I, Ivanic, TJ, Chen, SF, Clos, F, Li, J, Gu, P, Meng, Y and Wang, C 2016, Badja, WA Sheet 2240: Geological Survey of Western Australia, 1:100 000 Geological Series.

BADJA 2240, section C–D, 1:100 000 geological map

(Yalgoo Dome, Murchison Domain, Yilgarn Craton)

RE Murdie and I Zibra

Location

Maps: YALGOO (SH 50-2) and BADJA (2240)

Zone: MGA Zone 50

End coordinates: 489331E 6808650N to 499920E 6812397N

Length: 30 km

Scale of interpretation: 1:100 000

The C–D section is a southwesterly to northeasterly trending section that crosses the Yalgoo–Singleton greenstone belt from the BADJA geological map (Zibra et al., 2016; Fig. 1).

Tectonic units

Cross-section C–D cuts through the eastern margin of the Yalgoo Dome, a large elliptical structure (50 × 100 km), which includes a granite–migmatite core overlain by a greenstone envelope. The dome formed at c. 2750 Ma through multiple emplacements of diapir-like plutons into older greenstones. Within the dome, the authors identified four granitic suites, each with a distinctive geochemical signature and age of emplacement, which suggest a protracted tectono-magmatic history lasting >300 Ma. The main infrastructure of the Yalgoo Dome formed at c. 2750 Ma by the emplacement of voluminous granite (i.e. the Goonetarra Granodiorite) and is associated with remelting of the older (c. 2950 Ma) Kynea Tonalite. This main dome-forming event is responsible for the geometry of the granite–greenstone contact, as described in the next section. A north-trending dyke swarm of granitic composition was emplaced near the core of the dome at c. 2700 Ma.

The last magmatic episode is marked by the intrusion of late-orogenic, low-Ca granitic bodies, not intersected by the cross-sections. These undated units are likely to be equivalent to the late-orogenic (2640–2600 Ma), low-Ca plutons extensively exposed throughout the craton.

Structure

First-order structural features in the Yalgoo Dome include domal patterns of foliation and lithological boundaries, causing the greenstone packages mainly to dip west along the western side of the dome (e.g. at Edamurta), and to dip east along the eastern side of the dome (in the Golden Grove area, section C–D). Another prominent feature is represented by the radial pattern of lineation and fold axes. The granite–greenstone contact represent a large-scale normal shear zone developed during the latest stages of emplacement of the c. 2750 Ma granite suite. The main foliation along this high-strain zone developed from near-solidus to low-amphibolite facies conditions. At c. 2700 Ma the dome recorded a minor overprint (north–south-trending regional foliation, visible in the Edamurta area) associated with the emplacement of a granitic dyke swarm with transitional tonalite–trondhjemite–granite (TTG) composition. This event can be temporally linked with the emplacement of the Lakeside Pluton along the eastern side of the dome.

The emplacement of the low-Ca suite was associated with the development of a narrow high-strain aureole in the host Goonetarra Granodiorite. This late-magmatic event probably post-dated most of the regional structures.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA, 2015) gravity merged grid of Western Australia (Fig. 2b). The magnetic profile was extracted at the same location from the GSWA 2014 merge of the total magnetic intensity of Western Australia (GSWA, 2014; Fig. 2d). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Physical property data were estimated from Yilgarn average values (Table 1).

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The C–D section was modelled to a depth of 4 km (Fig. 2c,e).

Generally the gravity profile is determined by few points and therefore should be viewed as an overview only (Fig. 2b). The general shape of the profile reflects the traverse from the Goonetarra Granodiorite to across the denser Yalgoo–Singleton greenstone belt (Fig. 2a). A lower density quartzite member in the middle of the greenstone units provides the flattening of the anomaly.

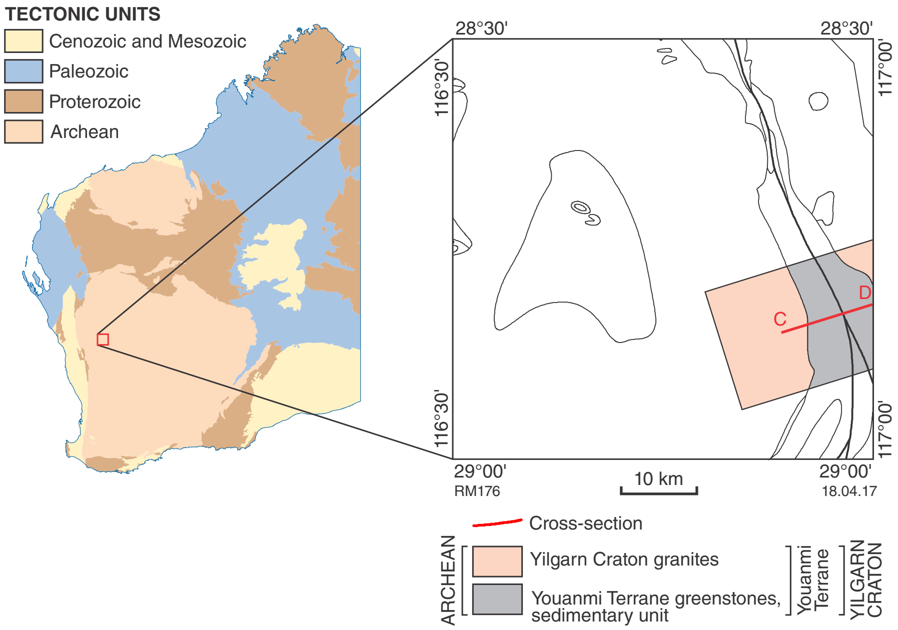

Figure 1. Location of Badja map sheet with simplified interpreted bedrock geology within 8 km of bordering cross-section C–D

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Lithological unit*	*Map code*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Youanmi Terrane greenstones (Yalgoo–Singleton greenstone belt)	A-mhs-YYO, A-mods-YYO, A-maps-YYO	Greenstone	2.83 – 2.85	0.085 – 0.126
	Gooneterra Granodiorite	A-ANgo-mgms, A-ANgo-gmp, A-ANgo-mgmu	Granodiorite	2.66 – 2.67	0.005
	Warriedar Suite	A-ANW-ap	Ultramafic		
	Glen Group				
	Mougooderra Formation	A-GLm-mhs, A-GLm-sc			
	Polelle Group	A-PO-mib, A-PO-mbs, A-PO-bb	Siliciclastic	2.77 – 2.78	0.000
	Gossan Hill Formation				
	Minjar Member	A-MUgm-xf-s	Siliciclastic	2.87	0.014
	Scuddles Member	A-MUgu-fdp	Dacite	2.88	0.000
	Golden Grove Member	A-MUgg-xfc-zs	Rhyodacite	2.84	0.000
	Gossan Valley Member	A-MUgv-fr	Rhyolite	2.78	0.000

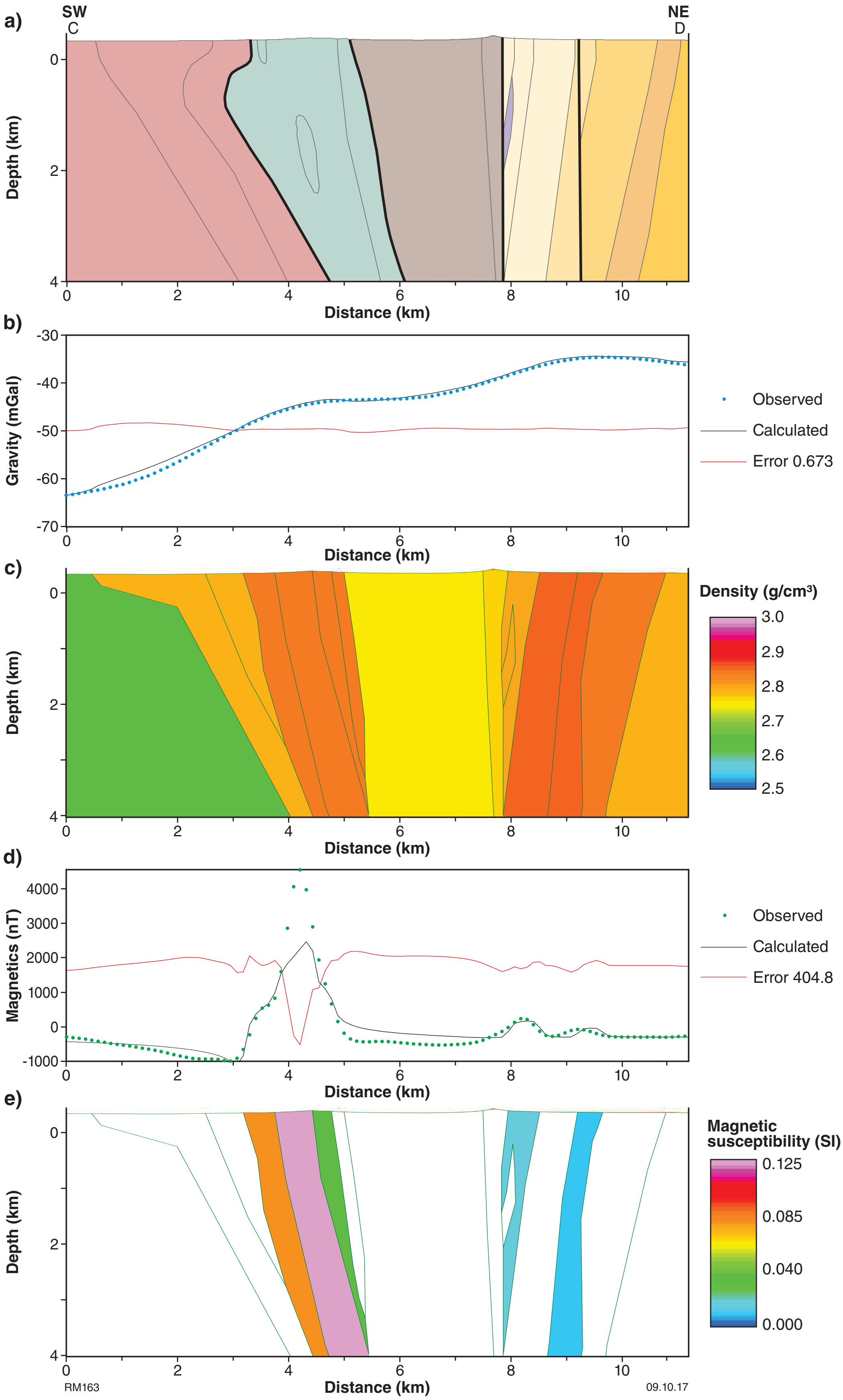

Figure 2. Profiles along cross-section C–D showing: a) lithological section sheet Badja; b) observed and calculated gravity anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

The magnetic data, although of higher density in actual readings than the gravity, show a very simple profile (Fig. 2d). The magnetic peaks can be associated with specific units of the greenstone belt having significant magnetic susceptibility (Fig. 2e).

References

Geological Survey of Western Australia 2014, Magnetic anomaly grid (80 m) of Western Australia (2014 – version 1), 16 September 2014 update: Geological Survey of Western Australia, digital data layer.

Geological Survey of Western Australia 2015, Gravity anomaly grid (400 m) of Western Australia (2015): Geological Survey of Western Australia, digital data layer.

Zibra, I, Ivanic, TJ, Chen, SF, Clos, F, Li, J, Gu, P, Meng, Y and Wang, C 2016, Badja, WA Sheet 2240: Geological Survey of Western Australia, 1:100 000 Geological Series.

Bungar 2539, section A–B, 1:100 000 geological map

(Narndee Igneous Complex, Murchison Domain, Yilgarn Craton)

RE Murdie and TJ Ivanic

Location

Maps: Ninghan (SH 50-7) and Bungar (2539)
Zone: MGA Zone 50
End coordinates: 601540E 6789870N to 645300E 6789870N
Length: 44 km
Scale of interpretation: 1:100 000

This section is an east–west section that crosses the centre of the Narndee Igneous Complex (Fig. 1).

Tectonic units

The Narndee Igneous Complex is a large mafic–ultramafic layered intrusion assigned to the Boodanoo Suite, Annean Supersuite, dated at 2800 ± 6 Ma (Ivanic et al., 2010). It is located in the central Youanmi Terrane, western Yilgarn Craton. To the west, the complex is bounded by a shear zone hosting Tuckanarra Suite granitic rocks (Ivanic et al., 2012) and to the east it is bounded by splays off the Challa Shear Zone.

Overlying the complex are felsic volcanic and sedimentary rocks belonging to the Yaloginda Formation Member (Van Kranendonk et al., 2013). Also in upper parts of the complex are sill-like synemplacement granitic rocks of the Mount Kenneth Suite.

The Narndee Igneous Complex is prospective for orthomagmatic Cr–Ni–Cu–PGE (e.g. at Milgoo). The overlying volcano-sedimentary rocks also host small volcanogenic massive sulphide (VMS) deposits.

Structure

The overall synformal geometry of the well-layered lower and middle zones of the Narndee Igneous Complex has been truncated by a large-scale regional, north–south-trending shear zone. A large sheared lens of the complex lies to the far east of the line of section. Several smaller brittle faults trending north–south show about a 1 km displacement. Tuckanarra Suite metagranitic rocks are foliated parallel to the shear zones to the west and are likely to be syndeformational. These also host a sheared lens of the Kiabye greenstone belt to the west of the complex, which hosts Norie Group lithologies that are predominantly mafic. A large domal pluton of the Rothsay Suite is present to the southeast of the section (Ivanic, 2016).

Geophysical data

A gravity profile was extracted from the GSWA 2013 gravity merged grid of Western Australia (version 2) (GSWA, 2013) with points sampled every 440 m (Fig. 2b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were estimated from mineral modal proportions in petrographic thin sections. These values were interpolated to corresponding lithologies in the vicinity of Bungar (Table 1).

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The section was modelled to a depth of 5 km (Fig. 2c,e).

The Narndee Igneous Complex has an overall synformal geometry (Fig. 2a). This geometry is consistent with the concentric, inward-dipping, and broadly conformable igneous layering inferred by Ivanic et al. (2010). The complex extends down to a vertical thickness of approximately 5 km.

The Bouguer high (Fig. 2b) is accounted for by the high-density rocks of the lower zone and even higher density rocks of the ultramafic zone of the complex (Fig. 2c), which is only exposed farther north.

The complex is mantled by granitic material to the east and west. Plutons of Rothsay Suite granitic rocks are likely to intrude under large parts of the complex too.

The overlying volcanic and sedimentary units are thin (~0.5 km) and relatively flat lying. The Mount Kenneth Suite unit is conformably overlying the upper zone of the complex. It is gently west dipping at approximately 10°.

Steeply dipping shear zones and brittle faults transecting the complex, plutons of the Mount Kenneth Suite, and Norie Group rocks are consistent with gravity data.

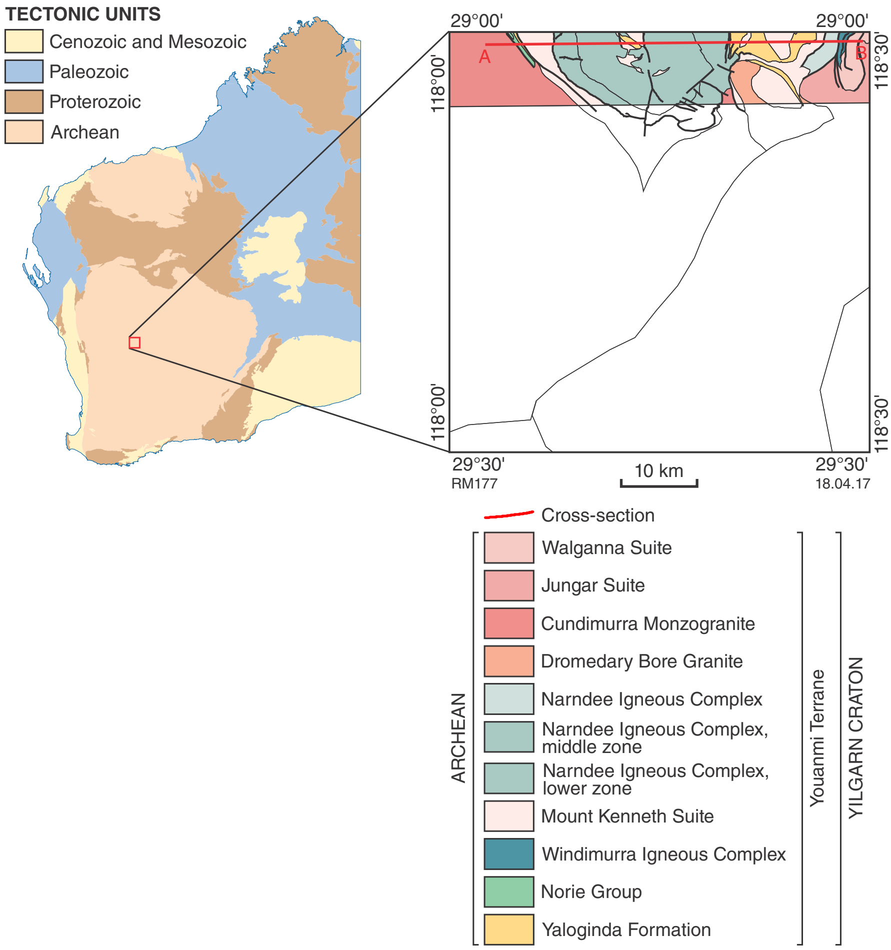

Figure 1. Location of the Bungar map sheet with simplified interpreted bedrock geology within 8 km of bordering cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*
	Walgoo Monzogranite	A-BRwa-gmv	Granite	2.700
	Tuckanarra Suite	A-TU-mg, A-TU-mgmu		
	Cundimurra Monzogranite	A-TUcu-mgms, A-TUcu-mgmu	Monzogranite	2.685
	Rothsay Suite	A-ANR-mgms	Monzogranite	
	Narndee Igneous Complex			
	Metagabbro	A-Anna-mog	Gabbro	2.890 – 3.000
	Middle zone	A-ANnm-mog, A-ANnm-mat, A-ANnm-ot, A-ANnm-ax, A-ANnm-oh, A-ANnm-om	Mafic–ultramafic horizons	2.850 – 2.900
	Lower zone	A-ANnl-mog, A-ANnl-ax, A-ANnl-mat, A-ANnl-ao, A-ANnl-omh, A-ANnl-moma, A-ANnl-om	Mafic–ultramafic horizons	2.920
	Ultramafic zone	A-ANnu-xap-ao	Ultramafic rocks	3.000
	Mount Kenneth Suite	A-ANK-jmgg-mog, A-ANK-mgs, A-ANK-mg	Granitic rocks	2.680 – 2.710
	Windimurra Igneous Complex	A-ANwi-xmog-mg, A-ANwz-am	Mafic–ultramafic rocks	2.900 – 2.950
	Norie Group	A-NO-mba	Mafic unit	2.700
	Yaloginda Formation	A-NOy-mfa, A-NOy-mts, A-NOy-md	Metamorphosed rocks	2.700 – 2.800

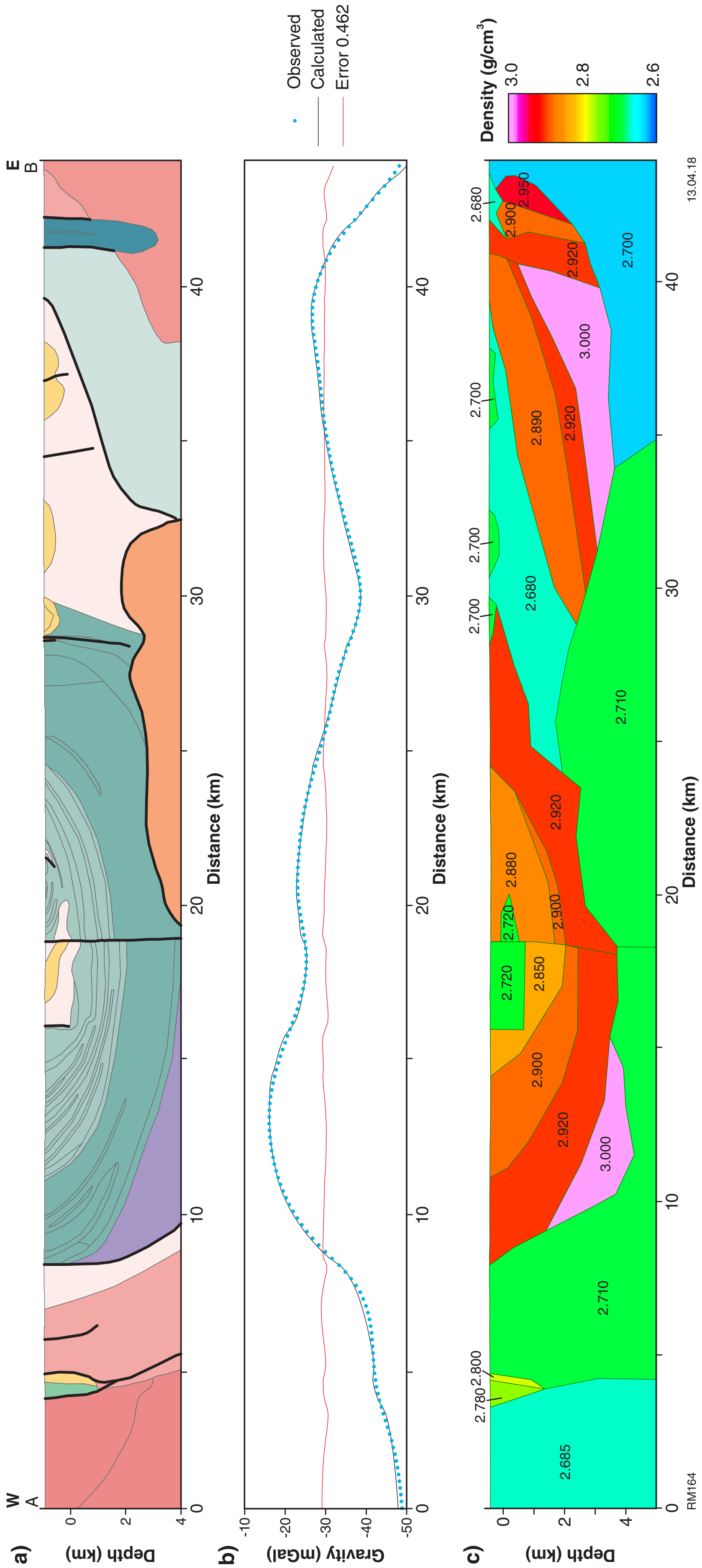

Figure 2. Profile of section A–B showing: a) lithological section on BUNGAR map sheet; b) observed and calculated gravity anomaly profile with error line; c) section of density per lithology

References

Geological Survey of Western Australia 2013, Gravity anomaly grid (400 m) of Western Australia (2013 – version 2), 11 November 2013 update: Geological Survey of Western Australia, digital data layer.

Ivanic, TJ, Wingate, MTD, Kirkland, CL, Van Kranendonk, MJ and Wyche, S 2010, Age and significance of voluminous mafic–ultramafic magmatic events in the Murchison Domain, Yilgarn Craton: Australian Journal of Earth Sciences, v. 57, p. 597–614.

Ivanic, TJ, Van Kranendonk, MJ, Kirkland, CL, Wyche, S, Wingate, MTD and Belousova, E 2012, Zircon Lu–Hf isotopes and granite geochemistry of the Murchison Domain of the Yilgarn Craton: evidence for reworking of Eoarchean crust during Meso–Neoarchean plume-driven magmatism: Lithos, v. 148, p. 112–127.

Ivanic, TJ 2016, Bungar, WA Sheet 2539: Geological Survey of Western Australia, 1:100 000 Geological Series.

Van Kranendonk, MJ, Ivanic, TJ, Wingate, MTD, Kirkland, CL and Wyche, S 2013, Long-lived, autochthonous development of the Archean Murchison Domain, and implications for Yilgarn Craton tectonics: Precambrian Research, v. 229, p. 49–92.

Diorite 4347, section A–B, 1:100 000 geological map

(Bentley Basin, west Musgrave Province)

RE Murdie, R Quentin de Gromard and HM Howard

Location

Maps: Bentley (SG 52-5) and Diorite (4347)

Zone: MGA Zone 52

End coordinates: 323871E 7206577N to 335817E 7207596N

Length: 12 km

Scale of interpretation: 1:100 000

This is a west to east section through the Wanarn area (Fig. 1).

Tectonic units

The Wanarn area is dominated by rocks of the Kunmarnara Group, the basal volcano-sedimentary sequence deposited within the Bentley Basin. The Bentley Basin was formed during the intracontinental Ngaanyatjarra Rift which took place within the 1085–1040 Ma Giles Event (Evins et al., 2010; Howard et al., 2011). The Bentley Basin developed on the high-grade metamorphic basement of the Musgrave Province. In the Wanarn area, two basement components have been identified: the c. 1600 Ma Warlawurru Supersuite (Quentin de Gromard et al., 2016) and the Pitjantjatjara Supersuite of the 1220–1150 Ma Musgrave Orogeny. To the north, the Bentley Supergroup is unconformably overlain by Cambro–Ordovician units that were deposited into the Amadeus Basin. These sedimentary units, in turn, were unconformably overlain by the Permian Paterson Formation, which was deposited into the Canning Basin.

Structure

The Wanarn area forms a wedge structure that is bounded to the south by the steeply south-dipping Mitika Fault and to the north by the shallow south-dipping Woodroffe Thrust. Mylonitic deformation is pervasive throughout the area and tectonic interleaving of metagranite slivers within paragneiss represents the tectonic style of the area. Distinct ductile flow directions are evident from stretching lineations and shear sense indicators. Two main directions are observed: north to northeast-directed thrusting interleaves orthogneisses and metagranites of the c. 1600 Ma Warlawurru Supersuite into paragneisses of the MacDougall Formation, and west-directed thrusting interleaves metagranites of the 1220–1150 Ma Pitjantjatjara Supersuite into the MacDougall Formation.

Geophysical data

Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. The gravity coverage of this area is only at 11 km spacing, which is not a dense enough coverage to generate a definable model.

Physical property data were estimated from global average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The section A–B was modelled down to a depth of 4 km (Fig. 2c).

This is an area of subdued magnetic signature (Fig. 2b) where all the units have low and subtly different magnetic susceptibilities to produce the low-amplitude magnetic anomalies. The Pitjantjatjara metagranite (Fig. 2a) has the highest susceptibilities in the area. Where thrust sheets expose this lithology at the surface, it results in a coincident magnetic anomaly.

The schist in the MacDougall Formation also produces anomalies where it outcrops. The Mummawarrawarra Basalt has a high susceptibility and is inferred at this location based on its magnetic anomaly.

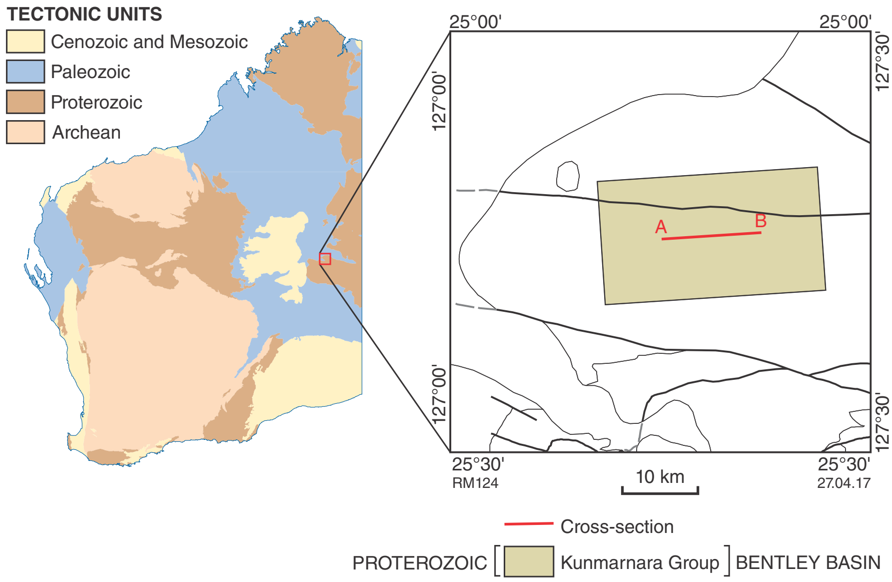

Figure 1. Location of Diorite map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Magnetic susceptibility (SI)*
	Mummawarrawarra Basalt	P_-KRm-mbb	Metabasalt	0.019
	MacDougall Formation	P_-KRd-mhs	Schist	0.002 – 0.003
		P_-KRd-mte	Granofels	0.000 – 0.003
		P_-KRd-mtn	Psammitic gneiss	0.001 – 0.004
	Pitjantjatjara Supersuite	P_-PJ-mg	Metagranite	0.004 – 0.008
		P_-PJ-mgnb	Metamonzogranite	0.000
	Warakurna Supersuite	P_-WK-mg	Metamonzogranite	0.001

References

Evins, PM, Smithies, RH, Howard, HM, Kirkland, CL, Wingate, MTD and Bodorkos, S 2010, Redefining the Giles Event within the setting of the 1120–1020 Ma Ngaanyatjarra Rift, west Musgrave Province, Central Australia: Geological Survey of Western Australia, Record 2010/6, 36p.

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Howard, HM, Werner, M, Smithies, RH, Evins, PM, Kirkland, CL, Kelsey, DE, Hand, M, Collins, AS, Pirajno, F, Wingate, MTD, Maier, WD and Raimondo, T 2011, The geology of the west Musgrave Province and the Bentley Supergroup — a field guide: Geological Survey of Western Australia, Record 2011/4, 116p.

Quentin de Gromard, R, Howard, HM and Smithies, RH 2016 Diorite, WA sheet 4347: Geological Survey of Western Australia, 1:100 000 Geological Series.

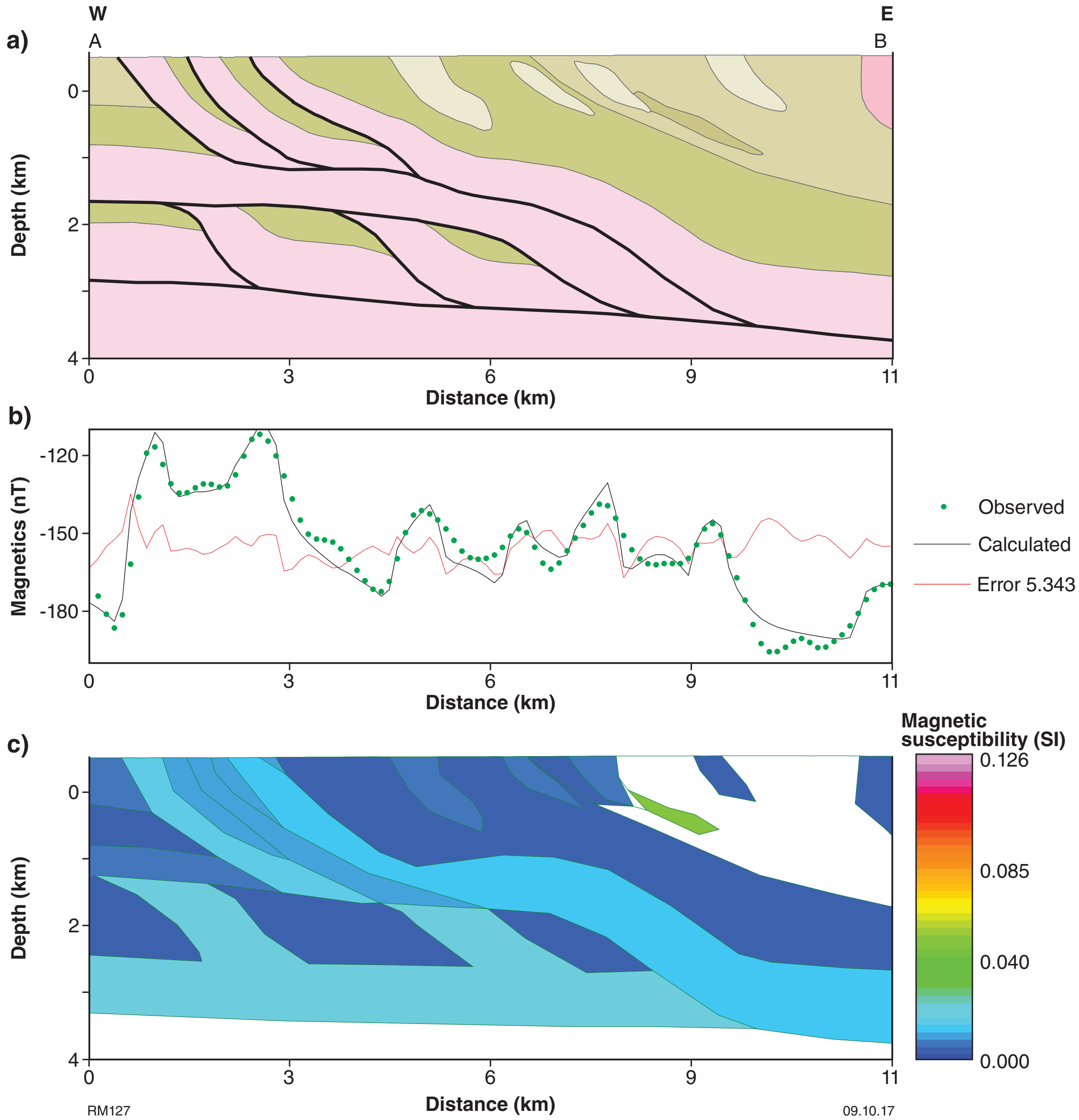

Figure 2. **Profile of section A–B showing: a) lithological section from sheet DIORITE; b) observed and calculated magnetic anomaly profile with error line; c) section of magnetic susceptibility per lithology**

Diorite 4347, section C–D–E, 1:100 000 geological map

(Bentley Basin, west Musgrave Province)

RE Murdie, R Quentin de Gromard and HM Howard

Location

Maps: Bentley (SG 52-5) and Diorite (4347)

Zone: MGA Zone 52

End coordinates: 338558E 7185457N to
345769E 7203100N to
342075E 7221532N

Length: 37.8 km

Scale of interpretation: 1:100 000

This section runs approximately south to north through the Wanarn area (Fig. 1).

Tectonic units

The Wanarn area is dominated by rocks of the Kunmarnara Group, the basal volcano-sedimentary sequence deposited within the Bentley Basin. The Bentley Basin was formed during the intracontinental Ngaanyatjarra Rift which took place within the1085–1040 Ma Giles Event (Evins et al., 2010; Howard et al., 2011). The Bentley Basin developed on the high-grade metamorphic basement of the Musgrave Province. In the Wanarn area, two basement components have been identified: the c. 1600 Ma Warlawurru Supersuite (Quentin de Gromard et al., 2016) and the Pitjantjatjara Supersuite of the 1220–1150 Ma Musgrave Orogeny. To the north, the Bentley Supergroup is unconformably overlain by Cambro–Ordovician units that were deposited into the Amadeus Basin. These sedimentary units, in turn, were unconformably overlain by the Permian Paterson Formation, which was deposited into the Canning Basin.

Structure

The Wanarn area forms a wedge structure that is bounded to the south by the steeply south-dipping Mitika Fault and to the north by the shallow south-dipping Woodroffe Thrust. Mylonitic deformation is pervasive throughout the area and tectonic interleaving of metagranite slivers within paragneiss represents the tectonic style of the area. Distinct ductile flow directions are evident from stretching lineations and shear sense indicators. Two main directions are observed: north- to northeast-directed thrusting interleaves orthogneisses and metagranites of the c. 1600 Ma Warlawurru Supersuite into paragneisses of the MacDougall Formation, and west-directed thrusting interleaves metagranites of the 1220–1150 Ma Pitjantjatjara Supersuite into the MacDougall Formation.

Geophysical data

Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. The gravity coverage of this area is only at 11 km spacing, which is not a dense enough coverage to generate a definable model.

Physical property data were estimated from global average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The section C–D–E was modelled down to a depth of 4 km (Fig. 2c).

In the north, the sedimentary rocks of the Paterson formation (Fig. 2a) have no magnetic susceptibility and blanket all underlying units. The Warakurna Supersuite has a low susceptibility (Fig. 2c) and causes the low rise in magnetic anomaly (Fig. 2b) below the Paterson Formation.

The small peaks in the northern half of the profile are generated where the folds of the Pitjantjatjara Supersuite are exposed at the surface. This also produces the main peak in the southern half of the profile. Where the granofels and schist layers of the MacDougall formation come to the surface, small magnetic peaks show in the southern end of the profile.

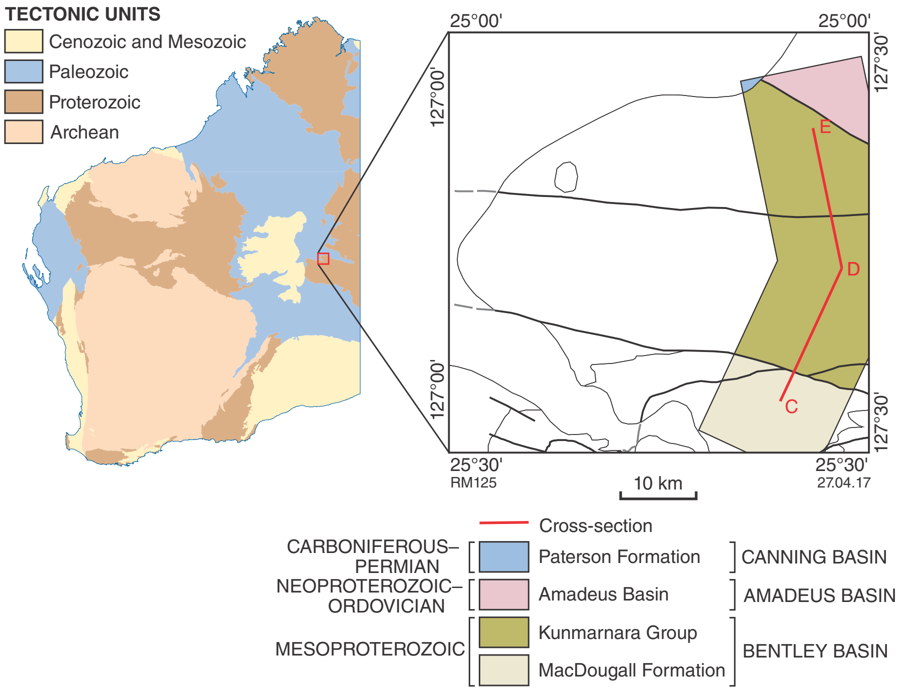

Figure 1. Location of DIORITE map sheet with simplified interpreted bedrock geology within 8 km of cross-section C–D–E

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2

Colour	*Modelled unit*	*Map code*	*Rock type*	*Magnetic susceptibility (SI)*
	Paterson Formation	CP-_pa-sepg	Conglomerate/sandstone	0.000
	MacDougall Formation	P_-KRd-mhe	Granofels	0.000
		P_-KRd-mhs	Psammitic schist	0.011 – 0.048
		P_-KRd-mt	Metamorphosed arkose	0.021 – 0.058
		P_-KRd-mte	Granofels	0.008 – 0.022
		P_-KRd-mtn	Psammitic gneiss	0.000 – 0.015
		P_-KRd-mxym	Mylonite	0.000
	Kunmarnara Group	P_-KR-xmd-mb	Metamorphosed siliciclastic and mafic rocks	0.000
	Warakurna Supersuite	P_-WK-g	Granite	0.007
	Pitjantjatjara Supersuite	P_-PJ-mg	Metagranite	0.002 – 0.057
		P_-PJ-mgmg	Metamonzogranite	–
		P_-PJ-mgnb	Metamonzogranite	–
	Warlawurru Supersuite	P_-WR-mg	Metasyenogranite	0.000

References

Evins, PM, Smithies, RH, Howard, HM, Kirkland, CL, Wingate, MTD and Bodorkos, S 2010, Redefining the Giles Event within the setting of the 1120–1020 Ma Ngaanyatjarra Rift, west Musgrave Province, Central Australia: Geological Survey of Western Australia, Record 2010/6, 36p.

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Howard, HM, Werner, M, Smithies, RH, Evins, PM, Kirkland, CL, Kelsey, DE, Hand, M, Collins, AS, Pirajno, F, Wingate, MTD, Maier, WD and Raimondo, T 2011, The geology of the west Musgrave Province and the Bentley Supergroup — a field guide: Geological Survey of Western Australia, Record 2011/4, 116p.

Quentin de Gromard, R, Howard, HM and Smithies, RH 2016 Diorite, WA sheet 4347: Geological Survey of Western Australia, 1:100 000 Geological Series.

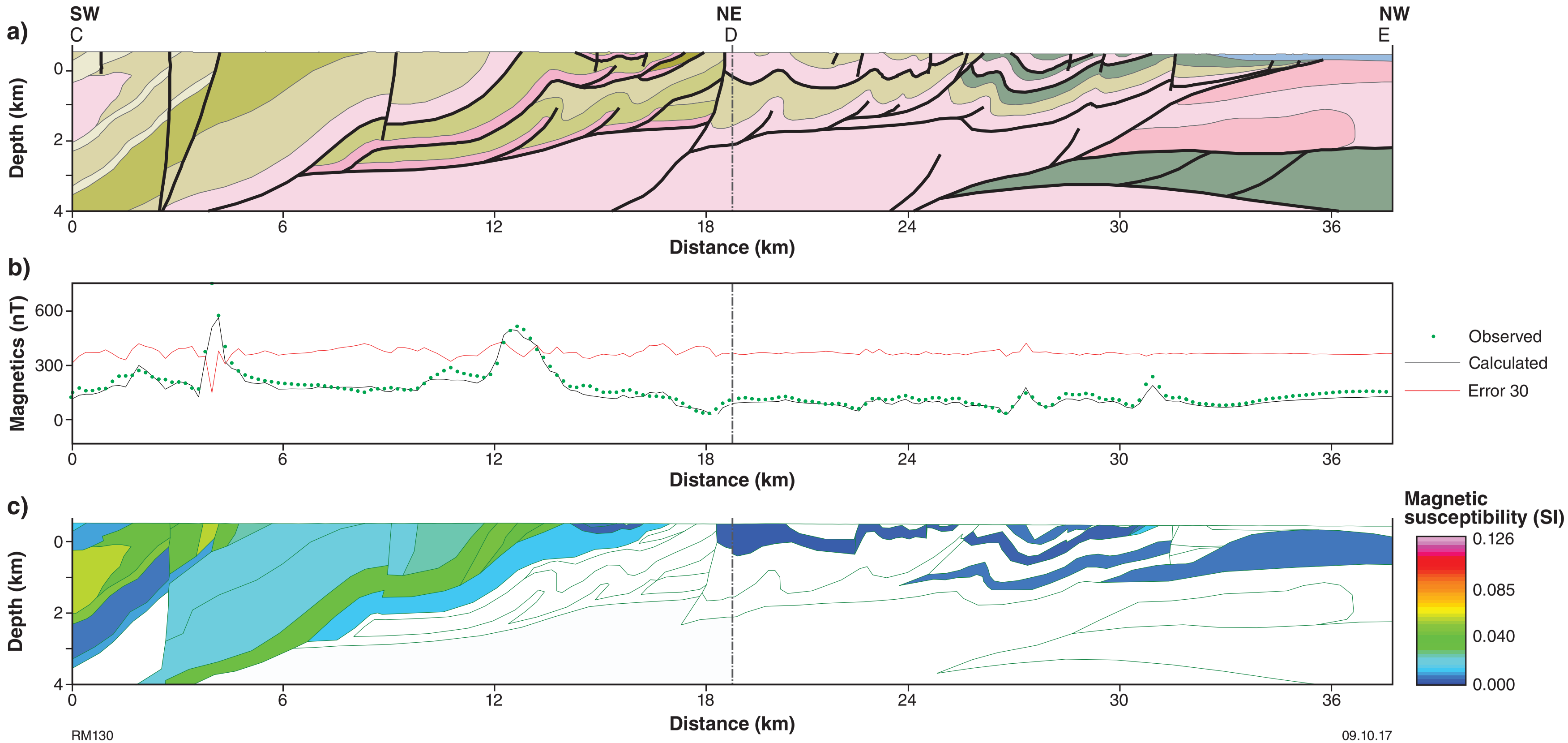

Figure 2. Profile of section C–D–E showing: a) lithological section from sheet Diorite; b) observed and calculated magnetic anomaly profile with error line; c) section of magnetic susceptibility per lithology

GOLDEN POINT 4246, 1:100 000 geological map

(Bentley Basin, west Musgrave Province)

RE Murdie, R Quentin de Gromard and HM Howard

Location

Maps: BENTLEY (SG 52-5) and GOLDEN POINT (4246)

Zone: MGA Zone 52

End coordinates: 251066E 7123118N to 290092E 7154141N

Length: 50 km

Scale of interpretation: 1:100 000

This section runs southwest to northeast on sheet GOLDEN POINT (Quentin de Gromard et al., 2015) through the northwestern edge of the Talbot Sub-basin in the Bentley Basin (Fig. 1).

Tectonic units

The Bentley Basin was formed during the intracontinental Ngaanyatjarra Rift which took place within the 1085–1040 Ma Giles Event (Evins et al., 2010; Howard et al., 2011). The basin sequence of the Bentley Supergroup consists of felsic and mafic volcanic and volcaniclastic rocks, and interlayered sedimentary rocks that unconformably overlie the high-grade metamorphic basement rocks of the Musgrave Province, mainly in the Mamutjarra Zone. Several sub-basins form components of the larger Bentley Basin, including the Blackstone, Finlayson, and Talbot Sub-basins (Howard et al., 2011). The Blackstone and Finlayson Sub-basins are dominated by units of the lower part of the Bentley Supergroup (Kunmarnara and Tollu Groups), whilst the Talbot Sub-basin is dominated by the upper part of the Bentley Supergroup (i.e. the Mount Palgrave, Kaarnka, Pussy Cat, Cassidy, and Mission Groups). To the south, the Bentley Supergroup is unconformably overlain by units that were deposited into the Officer Basin, namely the Buldya Group and Lupton Formation.

Structure

In the Talbot Sub-basin the volcanic succession generally shallowly dips (≤30°) south to southwest (in the western part of the sub-basin) and west (in the eastern part of the sub-basin). Locally the succession is steeply dipping (up to 85°) in the east of the sub-basin adjacent to the Barrow Range Anticline. The upper part of the Bentley Supergroup forms outcrops that extend east from the Warburton Community to the Barrow Range (approximately 40 km southwest of the Jameson Community). This part of the sequence extends laterally for a distance of over 90 km. The lower part of the sequence, the northwestern part of the Warburton Range, strikes northwest to southeast and the range bends around to strike east to west in the east.

Near Mount Harvest, the Townsend Quartzite (Buldya Group) is exposed in a graben on the western end of the Warburton Range. The Pussycat Group at Mount Harvest forms the hinge of an open south-verging anticline. South-directed reverse faults affect the northern limb of the anticline. Units within the northern limb all dip moderately (~40°) to the northeast up to the exposure of the underlying Warakurna Supersuite granite. The granite is heavily intruded by dolerite dykes, and on the northern part of the section line (5 km northeast of Golden Point), metamorphosed siliciclastic rocks of the MacDougall Formation (Kunmarnara Group) are exposed within an anticline. To the northeast at point B the authors interpret granites of the Pitjantjatjara Supersuite to form the basement of the MacDougall Formation.

Geophysical data

A gravity profile was extracted from the GSWA 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were estimated from global average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The section A–B was modelled down to a depth of 4 km (Fig. 2a).

The Bouguer anomaly shows a broad rise over the centre of the profile (Fig. 2b). This was modelled with various units of the Warakurna Supersuite and has a relatively high density of 2850 g/cm^3 (Fig. 2c). Such density values are unusually high for granites/syenogranites. However, the granites are intruded by high density dolerite. Hence, the

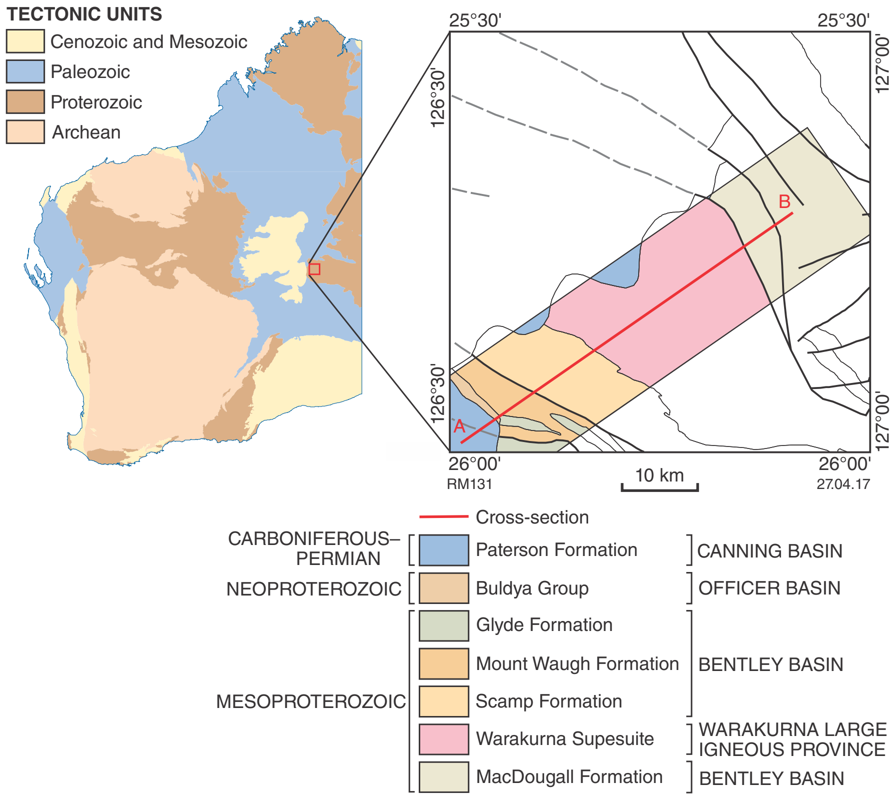

Figure 1. Location of Golden Point map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B

average density is reflecting the high proportion of dolerites within the larger granitic intrusion.

The magnetic profile has been modelled to obtain a good fit (Fig. 2d). Nevertheless, to achieve this goal the major Warakurna Supersuite has been subdivided into smaller subdivisions (Fig. 2e) with a generally slightly higher magnetic susceptibility than the surrounding sedimentary rocks and rhyolites.

The dolerites are strongly magnetic and provide most of the peaks within the magnetic profile.

Within the MacDougall formation the schist appears to produce the magnetic peaks.

References

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Quentin de Gromard, R, Howard HM and Smithies, RH 2015 Golden Point, WA sheet 4246: Geological Survey of Western Australia, 1:100 000 Geological Series.

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Dolerite dykes	P_-od	Dolerite	3.0	0.064 – 0.012
	Buldya Group	P_-BU-xs-k	Mixed sedimentary	2.6	0.010
	Townsend Quartzite	P_-BUw-stz	Quartzite	2.5	0.005
	Cassidy Group				
	Thomas Rhyolite	P_-CAt-frp	Rhyolite	2.6	
	Gombuggura Rhyolite	P_-CAo-frp	Rhyolite	2.6	0.030
	Wururu Rhyolite	P_-CAu-frp	Rhyolite	2.6	0.009 – 0.047
	Pussy Cat Group				
	Glyde Formation	P_-PUg-xbb-s	Basalt/sandstone	2.8	0.011
		P_-PUg-bbg	Basalt	2.9	0.030
	Mount Palgrave Group				
	Mount Waugh Formation	P_-PGw-fr	Bhyolite	2.65	0.010 – 0.020
		P_-PGs-bb	Basalt	2.65	0.010
	Scamp Formation	P_-PGs-fr	Rhyolite	2.67	0.000 – 0.020
		P_-PGs-frfp	Pumiceous rhyolite	2.67	0.020 – 0.040
		P_-PGs-frwp	Pumiceous rhyolite	2.67	0.020 – 0.040
		P_-PGs-frl	Rhyolitic breccia	2.67	0.020 – 0.040
	Warakurna Supersuite	P_-WK-g	Granite	2.67	0.017 – 0.066
		P_- WK-ge	Syenite		
		P_-WK-grh	Syenogranite	2.85	0.017 – 0.066
		P_-WK-grl	Syenogranite		
	MacDougall Formation	P_-KRd-mhe	Granofels	2.67	0.022
		P_-KRd-mhs	Schist	2.67	0.000
		P_-KRd-mtq	Quartzite	2.67	0.000
	Pitjantjatjara Supersuite	P_-PJ-mg	Metagranite	2.61	0.028

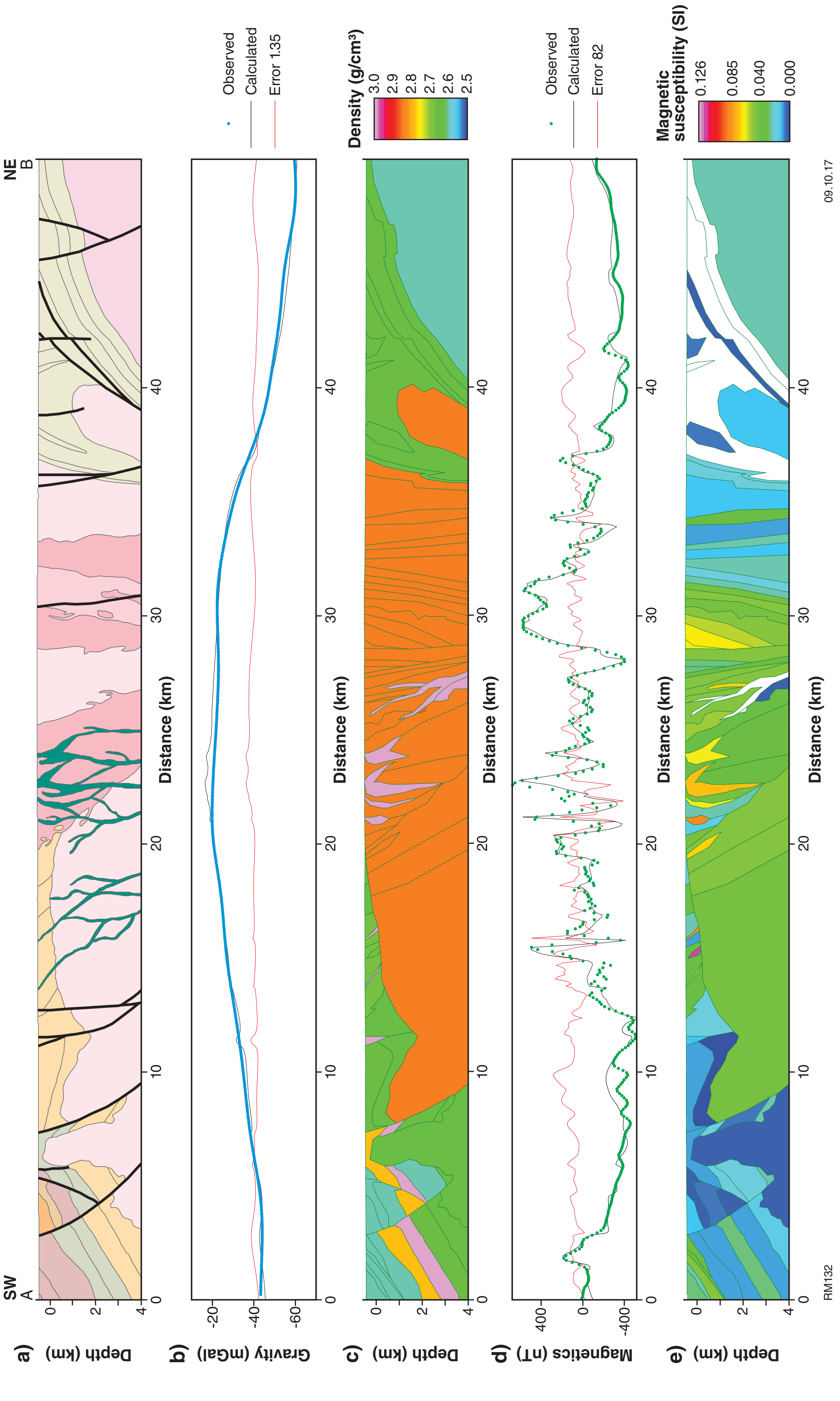

Figure 2. Profile of section A–B showing: a) lithological section from sheet GOLDEN POINT; b) observed and calculated Bouguer anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

Lake Percy 2934, section A–B, 1:100 000 geological map

(Lake Johnston greenstone, Yilgarn Craton)

RE Murdie and SS Romano

Location

Maps: Boorabbin (SG 51-13) and Lake Percy (2934)

Zone: MGA Zone 51

End coordinates: 241089E 6467582N to 256367E 6484292N

Length: 22.6 km

Scale of interpretation: 1:100 000

This is a southwest to northeast section across the Lake Johnston greenstone belt (Fig. 1).

Tectonic units

Greenstones in Lake Percy are in the northernmost part of the Lake Johnston greenstone belt. They are located in the southern part of Southern Cross Domain of the Youanmi Terrane in the Yilgarn Craton. The greenstones are intruded by strongly to weakly sheared monzogranite and granodiorite, ranging in age from 2720 to 2660 Ma (Romano et al., 2014).

The greenstone succession itself is dominated by mafic volcanic rocks with discrete ridges of banded iron-formation (BIF) and associated komatiites and poorly exposed felsic rocks. A felsic volcaniclastic conglomerate found in a drillcore in the centre of the greenstone belt on Lake Percy has been dated at 2735 ± 5 Ma (GSWA 207573, preliminary data).

Steeply dipping southwesterly to northeasterly trending Proterozoic mafic dykes of the Widgiemooltha Supersuite are crosscutting the Archean granite and greenstones, in particular the Binneringie Dyke.

West of the greenstone belt is a large area of migmatites and tonalite–trondjhemite–granite (TTG) exposed, presumably presenting a lower crustal level.

Structure

The geometry of the Lake Johnston greenstone belt is an overall wedge-shaped synclinal structure, with a north-northwesterly to south-southeasterly trending axis, folded around several granite domes of laccolithic shape (2770–2710 Ma). Younger granites ranging from 2695–2640 Ma are either crosscutting the stratigraphy or aligned within the regional strain pattern.

Pre-2260 Ma structures and units are generally truncated and transposed by east-dipping shear zones. A major regional scale feature is the northwesterly to southeasterly trending Koolyanobbing Shear Zone (KSZ), which has transposed and overprinted the eastern limb of the greenstone belt.

East of the greenstone belt, synkinematic monzogranites (c. 2660 Ma) are aligned parallel to the KSZ. This ductile synkinematic regional-scale crustal zone can be traced along the western side of the greenstone belt for at least 100 km. Only small slivers of an older, strongly deformed granitic gneiss are preserved along the shear zone on the eastern margin of the greenstone belt.

Geophysical data

The magnetic profiles were extracted from the Geological Survey of Western Australia (GSWA) 2014 merge of the total magnetic intensity (TMI) of Western Australia (GSWA, 2014) along the position of the cross-section A–B on the Lake Percy map (Romano, 2015; Fig. 2b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Gravity modelling was not done as the data density in this area was not sufficient enough to provide a representative profile.

Physical property data were estimated from Yilgarn average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software. All models are 2.5D with polygons extending perpendicular to the profile.

Results

The section A–B was modelled down to a depth of 4 km (Fig. 2c).

The magnetics profile was defined by a smooth background with one large peak and several smaller peaks (Fig. 2b). These peaks can all be associated with units within the Lake Johnston greenstone. The stronger unit is an isolated/transposed greenstone silver, dominated by BIF and ultramafic rocks. The smaller peaks can be associated with narrow ridges of BIF and komatiite within the main greenstone belt (Fig. 2a,c). The slightly elevated signal on the eastern side of the greenstone belt is caused by a higher fluid flow and caught up greenstone and granite slivers along a major shear zone.

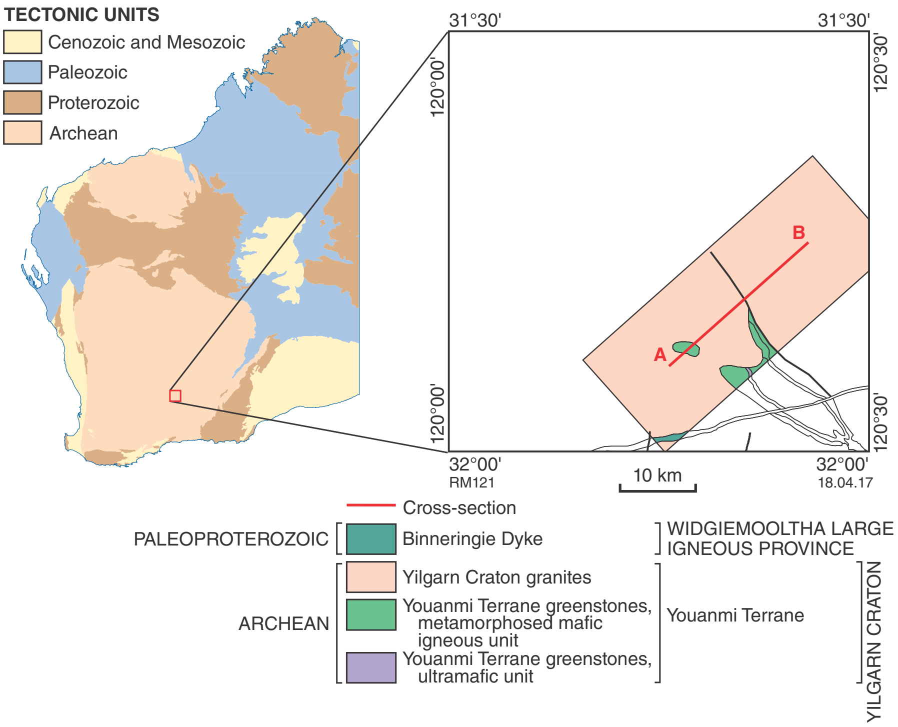

Figure 1. **Location of Lake Percy map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B**

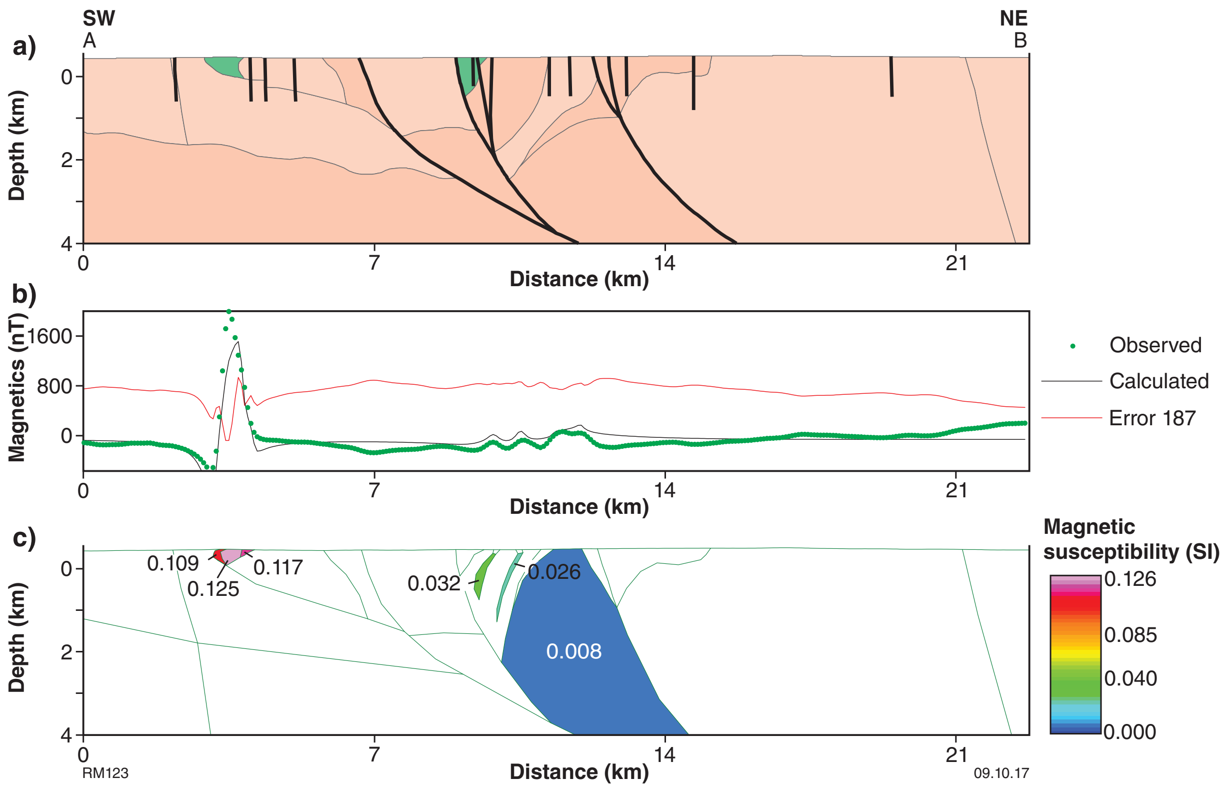

Figure 2. **Profiles across the section A–B showing: a) lithological section from sheet Lake Percy; b) observed and calculated magnetic anomaly profile with error line; c) section of magnetic susceptibility per unit lithology**

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Magnetic susceptibility (SI)*
	Yilgarn Craton granites	A-gm-Y, A-gmfp-Y, A-gn-Y	Granite	0.000
	Yilgarn Craton metagranites	A-mg-Y, A-mgi-Y, A-mgss-Y, A-mgnY	Metagranite	0.000 – 0.008
	Youanmi Terrane greenstones	A-mwa-YYO, A-xmwa-mhs-YYO A-xcx-uk-YYO	Basalt BIF and komatiite	0.010 – 0.032 0.050 – 0.125

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LAKE PERCY 2934, section C–D, 1:100 000 geological map

(Lake Johnston greenstone, Yilgarn Craton)

RE Murdie and SS Romano

Location

Maps: BOORABBIN (SG 51-13) and LAKE PERCY (2934)

Zone: MGA Zone 51

End coordinates: 250812E 6459171N to 260297E 6469290N

Length: 13.8 km

Scale of interpretation: 1:100 000

This is a southwest to northeast section across the Lake Johnston greenstone belt (Fig. 1).

Tectonic units

Greenstones in LAKE PERCY are in the northernmost part of the Lake Johnston greenstone belt. They are located in the southern part of Southern Cross Domain of the Youanmi Terrane in the Yilgarn Craton. The greenstones are intruded by strongly to weakly sheared monzogranite and granodiorite, ranging in age from 2720 to 2660 Ma (Romano et al., 2014).

The greenstone succession itself is dominated by mafic volcanic rocks, with discrete ridges of banded iron-formation (BIF) and associated komatiites and poorly exposed felsic rocks. A felsic volcaniclastic conglomerate found in a drillcore in the centre of the greenstone belt on LAKE PERCY has been dated at 2735 ± Ma (GSWA 207573, preliminary data).

Steeply dipping southwesterly to northeasterly trending Proterozoic mafic dykes of the Widgiemooltha Supersuite are crosscutting the Archean granite and greenstones, in particular the Binneringie Dyke.

West of the greenstone belt is a large area of migmatites and tonalite–trondjhemote–granite (TTG) is exposed, presumably presenting a lower crustal level.

Structure

The geometry of the Lake Johnston greenstone belt is an overall wedge-shaped synclinal structure, with a north-northwesterly to south-southeasterly trending axis, folded around several granite domes of laccolithic shape (2770–2710 Ma). Younger granites ranging from 2695–2640 Ma are either crosscutting the stratigraphy or are aligned within the regional strain pattern.

Pre-2260 Ma structures and units are generally truncated and transposed by east-dipping shear zones. A major regional scale feature is the northwest–southeast-trending Koolyanobbing Shear Zone (KSZ), which has transposed and overprinted the eastern limb of the greenstone belt.

East of the greenstone belt, synkinematic monzogranites (c. 2660 Ma) are aligned parallel to the KSZ. This ductile synkinematic regional-scale crustal zone can be traced along the western side of the greenstone belt for at least 100 km. Only small slivers of an older, strongly deformed granitic gneiss are preserved along the shear zone on the eastern margin of the greenstone belt.

Geophysical data

The magnetic profiles were extracted from the Geological Survey of Western Australia (GSWA) 2014 merge of the total magnetic intensity (TMI) of Western Australia (GSWA, 2014) along the position of the cross-section A–B on the LAKE PERCY map (Romano, 2015; Fig. 2b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points. Gravity modelling was not done as the data density in this area was not sufficient enough to provide a representative profile.

Physical property data were estimated from Yilgarn average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software. All models are 2.5D with polygons extending perpendicular to the profile.

Results

This profile is parallel to profile A–B on sheet LAKE PERCY (Romano, 2015). The magnetic profile has a smooth background with several discrete peaks (Fig. 2b). Each can be associated with units within the greenstone belt. Two strands of the Binneringie Dyke of the Widgiemooltha Supersuite form two strong magnetic peaks in the west (Fig. 2c).

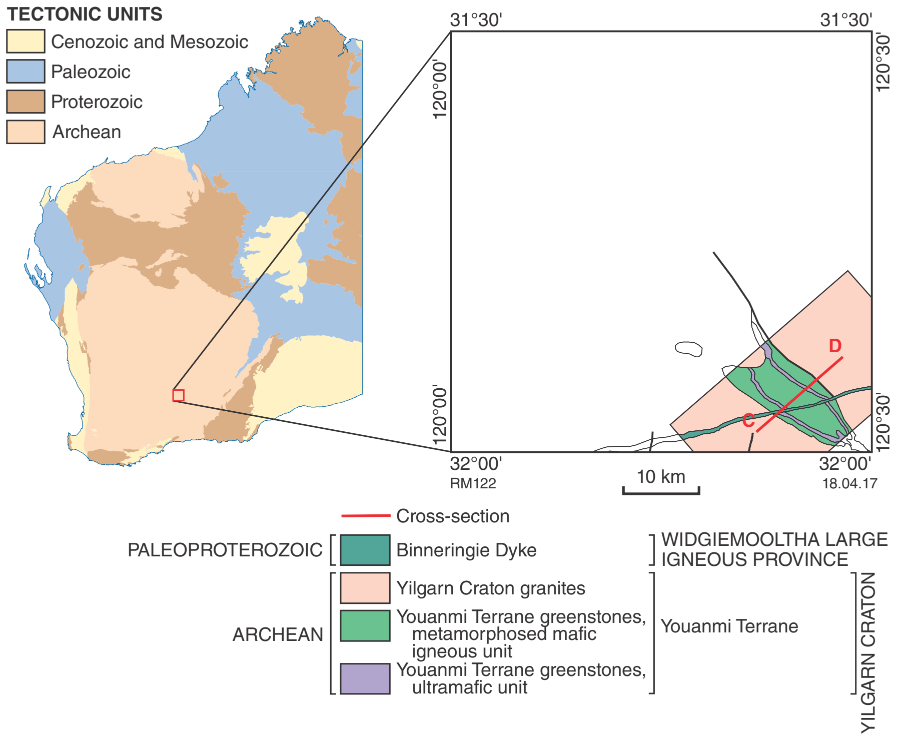

Figure 1. **Location of Lake Percy 1:100 000 map sheet with simplified interpreted bedrock geology within 8 km of cross-section C–D**

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Magnetic susceptibility (SI)*
	Binneringie Dyke	P_-Wlbi-o	Dolerite	0.085
	Yilgarn Craton granites	A-gm-Y, A-gmfp -Y, A-gmys-Y	Granite	0.000 – 0.008
	Yilgarn Craton metagranites	A-mgi-Y, A-mgss-Y	Metagranite	
	Youanmi Terrane greenstones	A-mwa-YYO, A-xmwa-mhs-YYO	Metamorphosed igneous rocks	0.000 – 0.125
		A-xfdv-mhs-YYO	Felsic volcanic and sedimentary rocks	
		A-mba-YYO	Basalt rocks	
		A-xcx-uk-YYO	BIF and komatiite	0.010 – 0.032

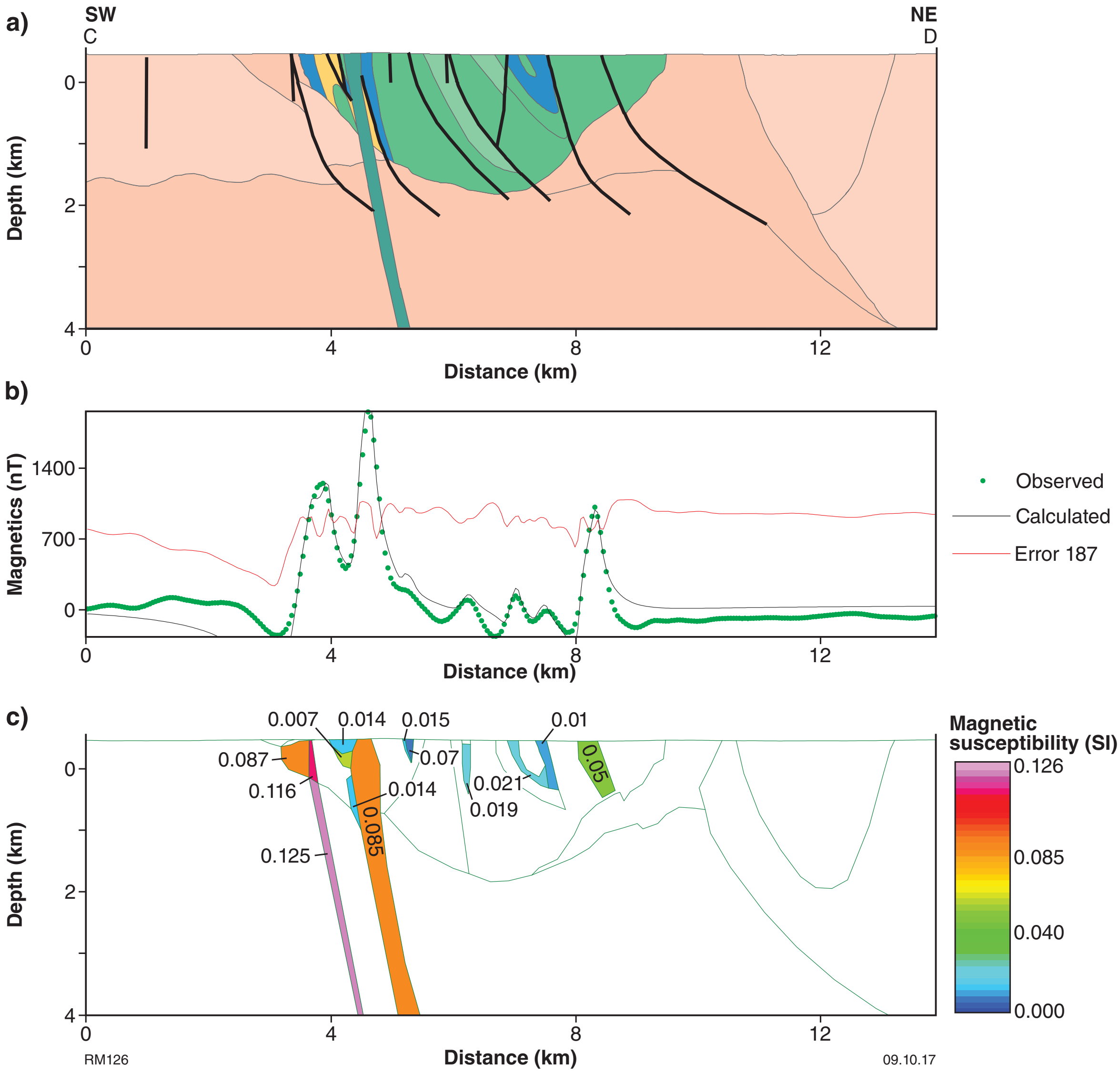

Figure 2. **Profiles across the section C–D showing: a) lithological section from Lake Percy 1:100 000 map sheet; b) observed and calculated magnetic anomaly profile with error line; c) section of magnetic susceptibility per unit lithology**

Minor magnetic peaks in the central part of the greenstone belt are caused by narrow units of BIF and adjacent komatiites. The slightly elevated signal in the eastern part of the profile is the result of increased fluid flow along the eastern side of the greenstone belt limb. This has been affected by the Koolyanobbing Shear Zone, and also the monzogranites with an age of c. 2710 Ma west of the greenstone belt and synkinematic flow-banded monzogranites dated at 2660 Ma (Romano et al., 2014) to the east.

References

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RICHENDA 3963, 1:100 000 geological map

(Lamboo Province, Speewah and Kimberley Basins, Kimberley)

RE Murdie and C Phillips

Location

Maps: LENNARD RIVER (SE 51-8) and RICHENDA (3963)

Zone: MGA Zone 51

End coordinates: 725141E 8063877N to 765861E 8094172N

Length: 50.7 km

Scale of interpretation: 1:100 000

This is a southwest- to northeast-oriented section that crosses from the Lamboo Province into the Kimberley Basin on the southwest edge of the Kimberley (Fig. 1).

Tectonic units

The Lamboo Province, comprising the Marboo Formation (tubiditic metasandstone) and the Ruins Dolerite, forms the basement of this section. The rocks were then deformed during the 1870–1850 Ma Hooper Orogeny (Griffin et al., 1993, 1994; Tyler and Griffin, 1993). They are intruded by felsic unit and overlain by the cogenetic White Water Volcanics of the Paperbark Suite during the Hooper Orogeny (Phillips et al., 2015).

Unconformably overlying the basement rocks is the 1835 Ma Speewah Basin. These sediments show a transgressive–regressive cycle from fluvial to shallow-marine and return to a fluvial setting in an interior continental basin (Phillips et al., 2015).

Unconformably overlying the Speewah Basin is the 1800 Ma Kimberley Basin. It is filled with the Kimberley Group shallow-marine sediments and basaltic lavas of the Carson Volcanics, which were laid down in a south-sloping basin (Gellatly et al., 1970).

The intrusive Hart Dolerite and extrusive Carson Volcanics form the Hart–Carson Large Igneous Province of 1797 ± 11 Ma. The Hart Dolerite is a massive mafic with lesser felsic granophyre layers and intruded into the Speewah and Kimberley Basins (Sheppard et al., 2012).

Structure

The 1835–1740 Ma Speewah and Kimberley Groups are situated within basins of the same names and are largely undeformed. The Hart Dolerite intrudes the Speewah and lower Kimberley Group as it is thought to be a product of a plume- or post-orogenic plate-margin reorganization (Griffin et al., 1994; Sheppard et al., 2012).

The Paperbark Suite is thought to have been formed from extensive magmatic reworking of the Archean and Palaeoproterozoic Kimberley Craton margin following northwesterly subduction (Griffin et al., 2000).

The Lamboo Province records the deformation and metamorphism of northwesterly directed subduction during the 1835–1810 Ma Halls Creek Orogeny (Tyler et al., 1995; Griffin et al., 2000; Sheppard et al., 2001; Page et al., 2001).

Geophysical data

Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2014). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Modelling

All modelling was performed in GM-SYS software run within the Oasis Montaj software. A 2D profile along the line of the cross-section of sheet RICHENDA was modelled (Phillips et al., 2015). Values of magnetic susceptibility used in the modelling are given in Table 1.

Only magnetic modelling was performed as there were too few gravity points along the section to create a profile.

Results

The section (Fig. 2a) shows sediments with relatively low magnetic susceptibility (Fig. 2b) against the nonmagnetic rocks of the Paperbark Suite and Marboo Formation.

The bands of Ruins Dolerite within the Marboo Formation form a large magnetic and negative peak, implying remanent magnetization of this part of the dolerite. The Ruins Dolerite also appears to have imparted a low magnetization to the rocks in its immediate vicinity.

The units of the Speewah Group shown in this section are nonmagnetic, except for a small syncline of the Landsdowne Arkose in the pop-up section at about 42 km along the profile (Fig. 2c), which may have a small susceptibility. This susceptibility fits the model at the eastern end of the syncline, but generates an unwanted peak at the western end. Alternatively, with no susceptibility, the western end has a better fit, but the eastern end is poorer.

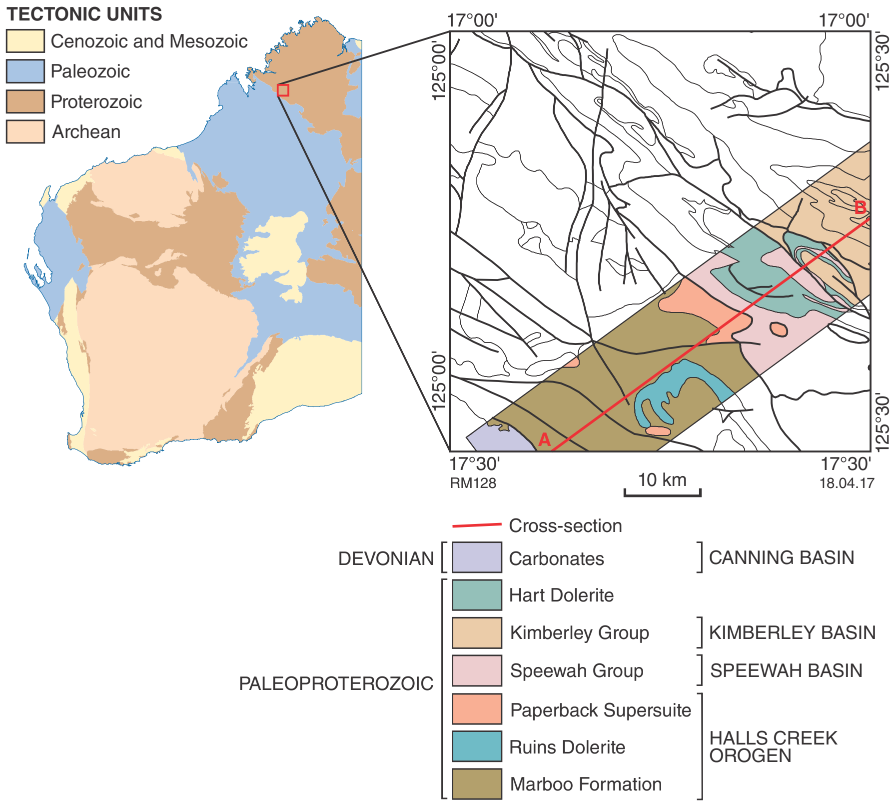

Figure 1. Location of sheet Richenda with simplified interpreted bedrock geology within 8 km of cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Magnetic susceptibility (SI)*
	Milliwindi Dolerite	E_-KJM-od	0.013
	Hart Dolerite and granophyre	P_-ha-od, P_-ha-gv	0.009 – 0.037
	Kimberley Group		
	Pentecost Sandstone	P_-KMp-st	–
	Elgee Siltstone	P_-KMe-xsl-kd	–
	Warton Sandstone	P_-KMw-st	–
	Carson Volcanics	P_-KMc-bb, P_-KMc-sta	0.010
	King Leopold Sandstone	P_-KMl-st	0.080
	Speewah Group		
	Lansdowne Arkose	P_-SPo-sta	–
	Tunganary Formation	P_-SPt-st	–
	O'Donnell Formation	P_-SPn-stq	–
	Ruins Dolerite	P_-ru-mod	–
	Paperbark Supersuite		
	Felsic unit	P_-PB-xg-o	–
	White Water Volcanics	P_-PBww-f	–
	Marboo Formation	P_-mr-mh	–

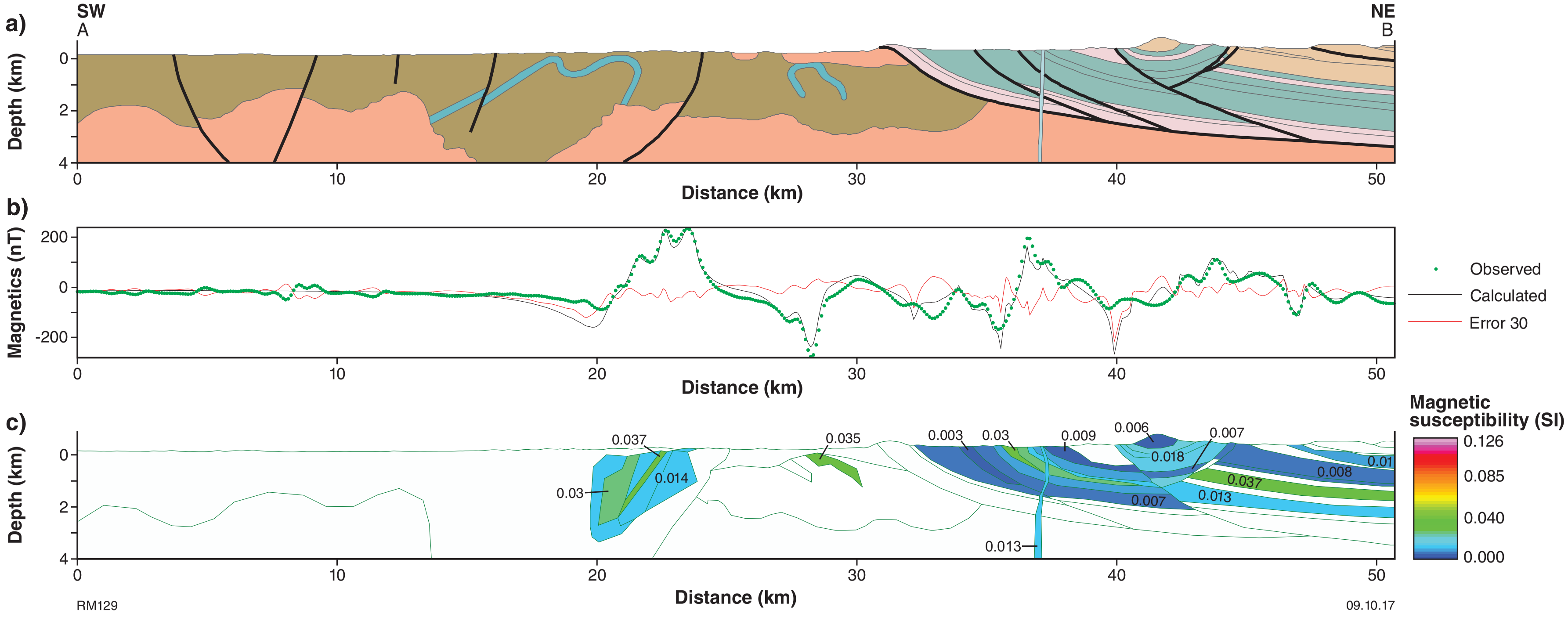

Figure 2. Profiles across section A–B from sheet RICHENDA showing: a) lithological section; b) observed and calculated magnetic anomaly profile with error line; c) section of magnetic susceptibility per lithology

This may indicate that some alteration may have affected it along one of the limbs or bounding faults of the syncline.

The Hart Dolerite has a high susceptibility with the granophyre layer in the middle having a relatively higher susceptibility than the dolerite/gabbro layers.

The King Leopold Sandstone, and one band within the Carlson Volcanics, displays a low susceptibility. Other units within the Kimberley Group do not show any magnetization, although they are only represented by small volumes within the section.

The Milliwindi Dolerite dyke provides a minor peak in the magnetic profile.

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Sandstone 2742, section A–B, 1:100 000 geological map

(Sandstone and Gum Creek greenstone belts, Southern Cross Domain, Yilgarn Craton)

RE Murdie

Location

Maps: Youanmi (SH 50-4) and Sandstone (2742)
Zone: MGA Zone 50
End coordinates: 709070E 6905700N to 743250E 6905725N
Length: 34 km
Scale of interpretation: 1:100 000

This east- to west-oriented section crosses the northern part of the Sandstone greenstone belt (Fig. 1).

Tectonic units

The Sandstone greenstone belt is a refolded syncline of greenstone stratigraphy sitting on the edge of the Southern Cross Domain. No regional stratigraphy has been established across the domain, but the local stratigraphy has been determined from mapping and drillcores, although a lack of outcrop precludes correlation of the northern part of the greenstone with the better exposed southern part found on sheet Atley.

The Sandstone greenstone belt in the north is a mafic-dominated succession overlain by fine-grained clastic sedimentary rocks (Tingey, 1985; Chen, 2005) with intercalated banded iron-formations (BIF).

The greenstones have fault-bounded contacts with the surrounding Archean granites which are typically poorly exposed. They are dominated by monzogranites with subordinate granodiorites. Strongly deformed granitic rocks are mapped with, and adjacent to, the major shear zones (Tingey, 1985; Chen, 2005).

Structure

The major fault in this area is the Youanmi Shear Zone, which forms the boundary between the Murchison Domain in the west and the Southern Cross Domain in the east. From the seismic reflection surveys of 2010 it was shown to be a trans-crustal fault going all the way to the mantle (Wyche et al., 2014). It dips to the east and with the west-dipping Edale Fault bounds the Sandstone greenstone belt.

The Sandstone greenstone belt is a refolded syncline. The original F1 east-trending syncline has been overprinted by the F2 syncline with box-fold geometry and is disrupted by brittle faults (Chen, 2005).

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were compiled from Williams (2009) and Gessner et al. (2014) (Table 1).

Modelling

All forward modelling was performed in 2.5D in the GM-SYS software run within the Oasis Montaj software.

Initial conceptual models were generated from a combination of the cross-section on the Sandstone map sheet (Chen and Painter, 2005) and interpretation of the 10GA-YU2 seismic line (Zibra et al., 2014) which traverses close to the A–B section.

Results

The section across the Sandstone greenstone belt was modelled down to a depth of 35 km (Fig. 2c) as part of the modelling of seismic line 10GA-YU2. The broad gravity peak seen in the section can be attributed to the higher density of the Sandstone greenstone belt (Fig. 2b). The only unit modelled within the greenstone are the metasediments and the ultramafic unit with the slightly higher density in the centre (Fig. 2c). There are BIF throughout the greenstone as shown in the magnetic peaks (Fig. 2d) and the profile (Fig. 2e). Nevertheless, they are too narrow to be identified in the gravity data. The Unaly Hill greenstone belt outcrops just on the edge of the map and appears in this section as a small gravity high in the west of the section. It is modelled as a blind body of mafic density. This also contributes to a broad shallow peak in the magnetic signal.

Although this section contains the Youanmi Shear Zone, which divides the Murchison Domain from the Southern Cross Domain, both domains are largely composed of granites. Consequently, there is only negligible density contrast between both. However, it appears that the Southern Cross granites have a stronger magnetic signal than the Murchison granites.

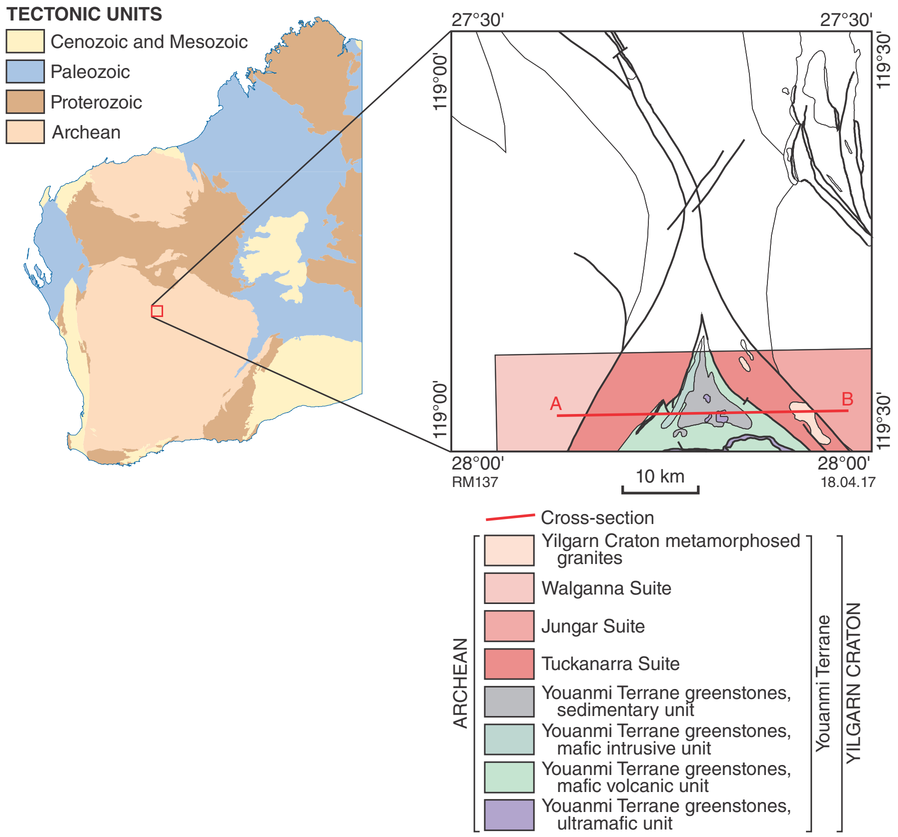

Figure 1. Location of sheet SANDSTONE with simplified interpreted bedrock geology within 8 km of cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Yilgarn Craton granites	A-g-Y, A-gm-Y	2.61	0.019
	Youanmi Terrane greenstone (Unaly Hill greenstone belt)		2.86	0.027
	Youanmi Terrane greenstone (Sandstone greenstone belt)			
	Mafic units	A-mba-YSA, A-mogs-YSA, A-bb-YSA A-mbbs-YSA	2.85	0.000
	BIF	A-cib-YSA		0.009 – 0.033
	Metasediments and ultramafic rocks	A-sh-YSA, A-mu-YSA	2.89	0.000
	Yilgarn Craton sheared and foliated granite	A-mgms-Y, A-mgss-Y, A-mgn-Y	2.56 – 2.72	0.000 – 0.046
	Murchison Terrane granitic rocks		2.55 – 2.58	0.001
	Southern Cross Terrane granitic rocks		2.50 – 2.57	0.024
	Yarraquin Seismic Province		2.85	0.000
	Lower crust		2.90	0.000

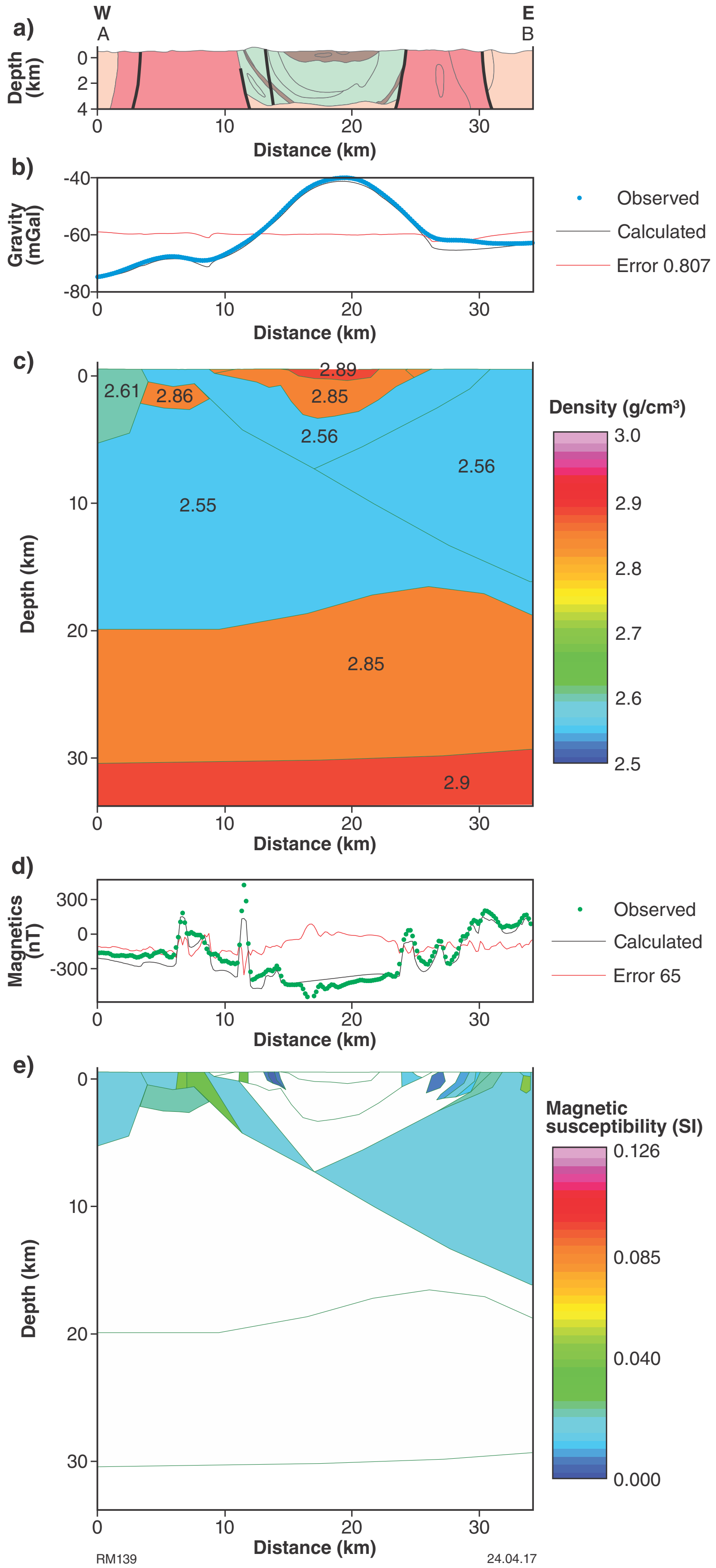

Figure 2. Profiles across section A–B from sheet Sandstone showing: a) lithological section;b) observed and calculated gravity anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

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SANDSTONE 2742, section C–D, 1:100 000 geological map

(Gum Creek greenstone belt, Southern Cross Domain, Yilgarn Craton)

RE Murdie

Location

Maps: YOUANMI (SH 50-4) and SANDSTONE (2742)

Zone: MGA Zone 50

End coordinates: 733230E 6938422N to 746262E to 6938450N

Length: 13 km

Scale of interpretation: 1:100 000

This east–west section crosses the southern end of the Gum Creek greenstone belt (Fig. 1).

Tectonic units

The Gum Creek greenstone belt has also been mapped as a synclinal structure, although only the southern extend is present on this map sheet. In this region, the structure consists of an interlayered sequence of metabasalts, banded iron-formations (BIF) and cherts which have a distinctive magnetic signature. They are overlain by a sequence of monotonous basalts, which is probably a continuation of the previous basalt, but without environments to form the BIF and cherts (Beeson et al., 1993; Tingey, 1985). Lenses of ultramafic and gabbroic rock are found within the basalt layers.

The greenstones have fault-bounded contacts with the surrounding Archean granites, which are typically poorly exposed. They are dominated by monzogranites with subordinate granodiorites. Strongly deformed granitic rocks are mapped with, and adjacent to, the major shear zones (Chen, 2005).

Structure

The Gum Creek greenstone belt has been mapped in less detail than the Sandstone greenstone belt, but also has a synclinal form with the Youno Downs Syncline hinge passing close to the eastern edge of the greenstone rocks.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were compiled from Williams (2009) and Gessner et al. (2014; Table 1).

Modelling

All forward modelling was performed in 2.5D in the GM-SYS software run within the Oasis Montaj software.

Initial conceptual models were generated from the cross-section on sheet SANDSTONE (Chen and Painter, 2005).

Results

Section C–D across the Gum Creek greenstone belt was modelled down to a depth of 4 km (Fig. 2c). The gravity anomaly appears as a broad peak (Fig. 2b), which reflects the denser greenstone units within the vicinity of the surrounding granites.

The units in the west of the belt are mapped as BIF and amphibolite, which generally implies a higher density. Therefore, by modelling with appropriate densities, they appear to be truncated at shallower depths than in the cross-section (Fig. 2c) more shallowly than in the section (Fig. 2a).

The magnetic profile was not modelled. However, the magnetic profile (Fig. 2d) shows two extremely strong magnetic susceptible units, which relate, in position, to the two sets of BIF.

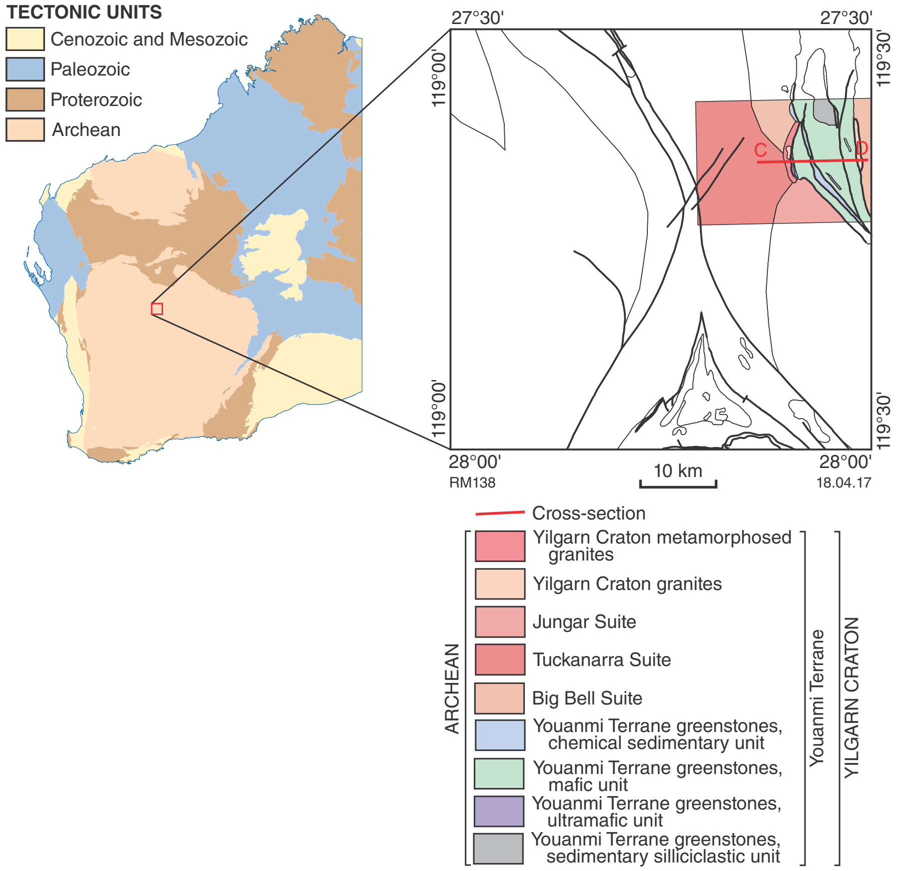

Figure 1. Location of sheet Sandstone with simplified interpreted bedrock geology within 8 km of cross-section C–D

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*
	Youanmi Terrane greenstones (Gum Creek greenstone belt)			
		A-bb-YGC	Basalt	2.85 – 2.92
		A-bs-YGC	Spinifex-textured basalt	2.85 – 2.86
		A-cib-YGC	BIF	2.90 – 2.96
		A-mba-YGC	Amphibolite	2.82
		A-mogs-YGC	Schistose metagabbro	
		A-musr-YGC	Tremolite schist	2.75
		A-og-YGC	Gabbro	
		A-up-YGC	Peridotite	2.94
	Youanmi Terrane granites (Southern Cross Terrane granites)			
		A-g-Y	Granites	2.57 – 2.58
		A-xg-mb-Y	Granites with mafic rocks	2.72
		A-mgms-Y	Metagranites	2.70

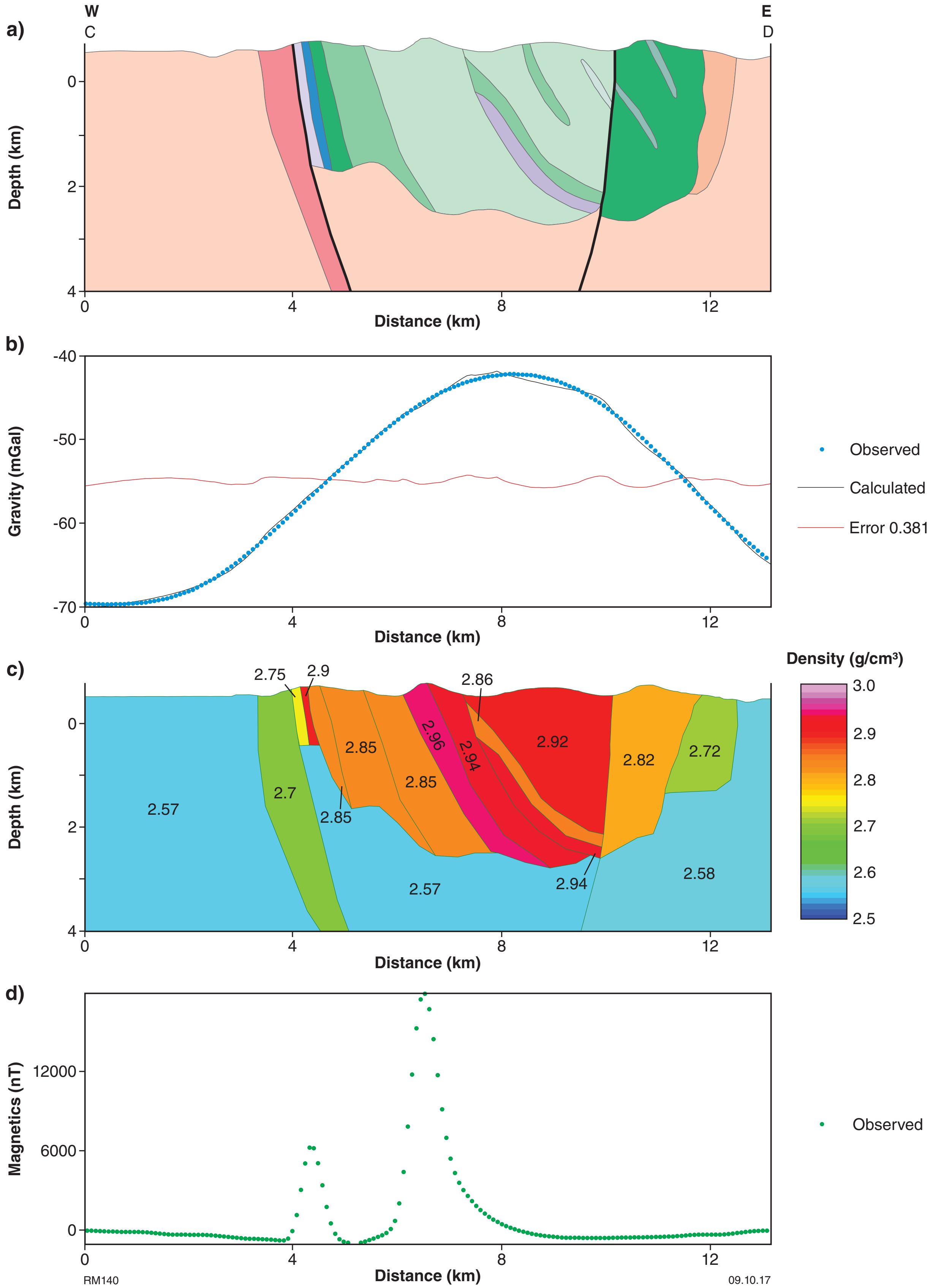

Figure 2. Profiles across section C–D from sheet SANDSTONE showing: a) lithological section; b) observed and calculated gravity anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

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WARBURTON RANGE 4245, section A–B, 1:100 000 geological map

(Bentley Basin, west Musgrave Province)

RE Murdie, HM Howard and R Quentin de Gromard

Location

Maps: TALBOT (SG 52-9) and WARBURTON RANGE (4245)
Zone: MGA Zone 52
End coordinates: 260189E 7097398N to 282811E 7122205N
Length: 33.1 km
Scale of interpretation: 1:100 000

This is a southwest–northeast section on the western part of sheet WARBURTON RANGE (Howard et al., 2014) within the Talbot Sub-basin of the Bentley Basin (Fig. 1).

Tectonic units

The Bentley Basin was formed during the intracontinental Ngaanyatjarra Rift which took place within the 1085–1040 Ma Giles Event (Evins et al., 2010; Howard et al., 2011). The basin sequence of the Bentley Supergroup consists of felsic and mafic volcanic and volcaniclastic rocks, and interlayered sedimentary rocks that unconformably overlie the high-grade metamorphic basement rocks of the Musgrave Province, mainly in the Mamutjarra Zone. Several sub-basins constitute components of the larger Bentley Basin, including the Blackstone, Finlayson, and Talbot Sub-basins (Howard et al., 2011). The Blackstone and Finlayson Sub-basins are dominated by units of the lower part of the Bentley Supergroup (Kunmarnara Group and Tollu Group), whilst the Talbot Sub-basin is dominated by the upper part of the Bentley Supergroup (Mount Palgrave, Kaarnka, Pussy Cat, Cassidy and Mission Groups). To the south, the Bentley Supergroup is unconformably overlain by units that were deposited into the Officer Basin, namely the Buldya Group and Lupton Formation.

Structure

In the Talbot Sub-basin the volcanic succession generally shallowly dips (≤30°) south to southwest (in the western part of the sub-basin) and west (in the eastern part of the sub-basin). Locally the succession is steeply dipping (up to 85°) in the east of the sub-basin adjacent to the Barrow Range Anticline. The upper part of the Bentley Supergroup forms outcrops that extend east from the Warburton Community to the Barrow Range (approximately 40 km southwest of Jameson Community). This part of the sequence extends laterally for a distance of over 90 km. In the northwest, the exposure in the Warburton Range strikes northwest to southeast and the range bends around to strike east to west in the east.

In the northern part of sheet WARBURTON RANGE, there is an open south-verging anticline with south-directed reverse faults in its northern limb through the Pussy Cat Group. Farther north, dolerite dykes intrude granite of the Warakurna Supersuite, which the authors regard to be the magma chamber from which the Talbot volcanic rocks were generated.

Geophysical data

A gravity profile was extracted from the GSWA 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were estimated from global average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj software.

Results

The section A–B was modelled down to a depth of 4 km. The gravity profile shows moderate variations with a central peak including a lower amplitude peak on either side (Fig. 2b). The geology of the area comprises various low-density sedimentary and rhyolitic rocks layered with high-density basalts (Fig. 2a). As a consequence many ‘edge anomalies’ are seen in the error line. The central peak is generated by the basalts of the Glyde Formation.

In the northern end, the generally lower gravity is caused by the presence of rhyolites of the Mount Waugh and Scamp Formations (Fig. 2c), overlying a large body of Warakurna Supersuite granite. The slight rise in the gravity here is probably due to an increase in the volume of dolerite intrusions within the granite.

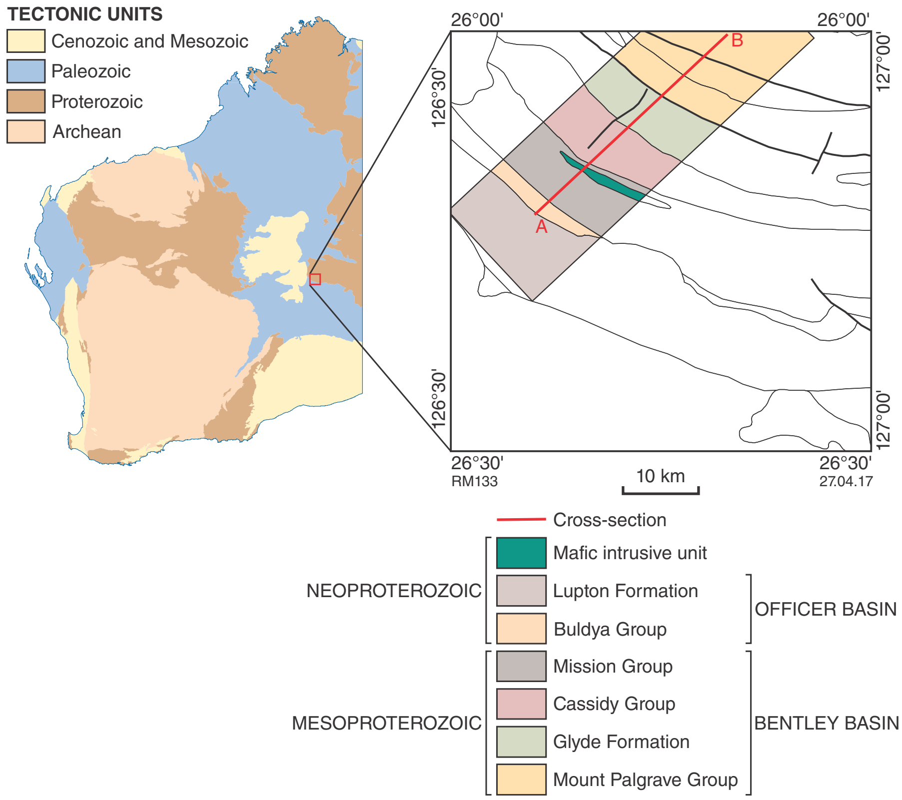

Figure 1. Location of Warburton Range map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B

The sedimentary rocks of the Lupton Formation, Buldya Group and Townsend Quartzite are slightly less dense than the sandstones and basalts of the Milesia Formation, which generates the slight rise in gravity at the southern extreme of the profile.

Generally, the sedimentary rocks have a low magnetic susceptibility (Fig. 2e), although one sandstone unit in the Milesia Formation has been modelled with an unusually high susceptibility. Nevertheless, this may be an artefact of the modelling close to the overlying basalt with strong susceptibility. Remanent magnetisation has not been accounted for in these models. There appears to be a low susceptibility within the rhyolites. The dykes within the rhyolites probably are the source of the high-frequency signal within the main rhyolite body.

The magnetic profile is poorly matched although the gross shape is coarsely fitted (Fig. 2d). A better fit could be obtained by more detailed modelling of the highly magnetic units, which are generating the peaks. Factors, such as the layering within rhyolite units, and the influence of the Warakurna dolerite and remanent magnetism should be considered.

References

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Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm³)*	*Magnetic susceptibility (SI)*
	Proterozoic dyke	P_-WK-od	Dolerite	2.90	0.010
	Lupton Formation	P_-lu-se	Diamictite	2.60	0.037
	Buldya Group	P_-BU-xs-k	Mixed sedimentary	2.60	0.036
	Townsend Quartzite	P_-BUw-stz	Quartzite	2.60	0.038
	Mission Group				
	Milesia Formation	P_-MIm-xs-bb	Sandstone/basalt	2.70	0.042
		P_-MIm-sp	Sandstone/conglomerate	2.67	0.035
		P_-MIm-sti	Sandstone	2.40	0.059
		P_-MIm-xst-bb	Sandstone/basalt	2.50	0.045
		P_-MIm-bb	Basalt	2.75 – 2.85	0.041 – 0.081
		P_-MIm-st	Sandstone	2.40	0.079
	Lilian Formation	P_-MIl-sh	Shale	2.50	0.035
	Frank Scott Formation	P_-MIf-kds	Dolomite	2.67	0.051
	Cassidy Group				
	Miller Basalt	P_-CAm-bb	Basalt	2.85	0.096
	Hilda Rhyolite	P_-CAh-frp	Rhyolite	2.45	0.049
		P_-CAh-frpa	Rhyolite	2.45	0.050
	Warubuyu Basalt	P_-CAw-xbb-s	Basalt/sandstone	2.85	0.050
	Thomas Rhyolite	P_-CAt-frp	Rhyolite	2.45	0.045
	Gurgadi Basalt	P_-CAg-bbg	Basalt	2.85	0.048
		P_-CA-sl	Siltstone/mudstone	2.40	0.000
	Gombuggura Rhyolite	P_-CAo-frp	Rhyolite	2.40	0.059
		P_-CA-sf	Siltstone/sandstone	2.40	0.000
	Wururu Rhyolite	P_-CAu-frp	Rhyolite	2.45	0.045
	Pussy Cat Group				
	Glyde Formation	P_-PUg-xbb-s	Basalt/sandstone	2.85	0.077
		P_-PUg-bbg	Basalt	2.90	0.068
		P_-PU-frp	Rhyolite	2.45	0.000
	Mount Palgrave Group				
	Mount Waugh Formation	P_-PGw-fr	Rhyolite	2.67	0.000
	Scamp Formation	P_-PGs-fr	Rhyolite	2.50	0.000
		P_-PGs-frwp	Pumiceous rhyolite	2.50	0.070
	Warakurna Supersuite	P_-WK-od	Intrusive mafic	2.90	0.000
		P_-WK-ge	Quartz syenite	2.67	0.000

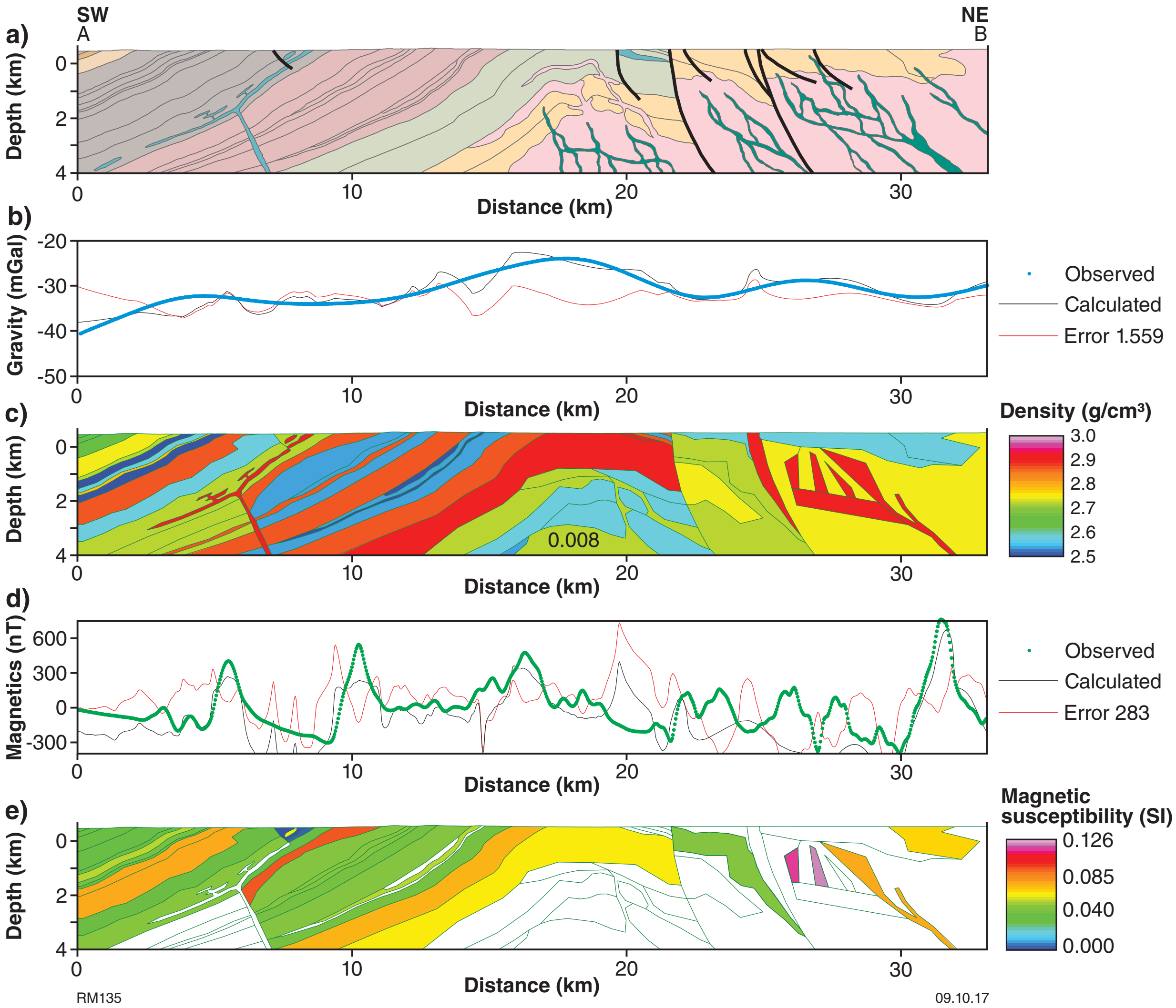

Figure 2. Profile of section A–B showing: a) lithological section from sheet WARBURTON RANGE; b) observed and calculated Bouguer anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

WARBURTON RANGE 4245, section C–D, 1:100 000 geological map

(Bentley Basin, west Musgrave Province)

RE Murdie, HM Howard and R Quentin de Gromard

Location

Maps: TALBOT (SG 52-9) and WARBURTON RANGE (4245)
Zone: MGA Zone 52
End coordinates: 288764E 7084635N to 293791E 7100311N
Length: 16.5 km
Scale of interpretation: 1:100 000

This is a southwest to northeast section on the eastern part of sheet WARBURTON RANGE (Howard et al., 2014) within the Talbot Sub-basin of the Bentley Basin (Fig. 1).

Tectonic units

The Bentley Basin was formed during the intracontinental Ngaanyatjarra Rift which took place within the 1085–1040 Ma Giles Event (Evins et al., 2010; Howard et al., 2011). The basin sequence of the Bentley Supergroup consists of felsic and mafic volcanic and volcaniclastic rocks, and interlayered sedimentary rocks that unconformably overlie the high-grade metamorphic basement rocks of the Musgrave Province, mainly in the Mamutjarra Zone. Several sub-basins constitute components of the larger Bentley Basin, including the Blackstone, Finlayson, and Talbot Sub-basins (Howard et al., 2011). The Blackstone and Finlayson Sub-basins are dominated by units of the lower part of the Bentley Supergroup (Kunmarnara Group and Tollu Group), whilst the Talbot Sub-basin is dominated by the upper part of the Bentley Supergroup (Mount Palgrave, Kaarnka, Pussy Cat, Cassidy and Mission Groups). To the south, the Bentley Supergroup is unconformably overlain by units that were deposited into the Officer Basin, namely the Buldya Group and Lupton Formation.

Structure

In the Talbot Sub-basin, the volcanic succession generally shallowly dips (≤30°) between south to southwest (in the western part of the sub-basin) and west (in the eastern part of the sub-basin). Locally the succession is steeply dipping (up to 85°) in the east of the sub-basin adjacent to the Barrow Range Anticline. The upper part of the Bentley Supergroup forms outcrop that extends east from the Warburton Community to the Barrow Range (approximately 40 km southwest of Jameson Community). This part of the sequence extends laterally for a distance of over 90 km. In the northwest, the exposure in the Warburton Range strikes northwest to southeast and the range bends around to strike east to west in the east.

In the northern part of the sheet WARBURTON RANGE, there is an open south-verging anticline with south-directed reverse faults in its northern limb through the Pussy Cat Group. Farther north, dolerite dykes intrude granite of the Warakurna Supersuite which the authors regard to be the magma chamber from which the Talbot volcanic rocks were generated.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) 2013 400 m gravity merged grid of Western Australia (GSWA, 2013a). Magnetic data were extracted along the same profile from the 80 m magnetic compilation of Western Australia (GSWA, 2013b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were estimated from global average values and are listed in Table 1.

Modelling

All modelling was performed in the GM-SYS software run within the Oasis Montaj platform.

Results

The section CD was modelled down to a depth of 4 km (Fig. 2a).

The gravity signal is generated from only seven data points, hence a detailed model could not be obtained. However, the slope of the Bouguer gravity anomaly reflects the consistently smooth and shallow dip of the succession to the south (Fig. 2b). Since there is no obvious difference in the densities between the basalts and sedimentary rocks of the Milesia Formation and the basalts and rhyolites of the Cassidy Group (Fig. 2c), the slope is probably the result of a regional trend.

The magnetic anomaly shows two distinct peaks (Fig. 2d), which can be associated with the Miller Basalt in the north and some sandstone and basalt layers in the Milesia Formation. Deposits such as the Thomas Rhyolite and Gurgardi Basalt also have low susceptibility signals (Fig. 2e).

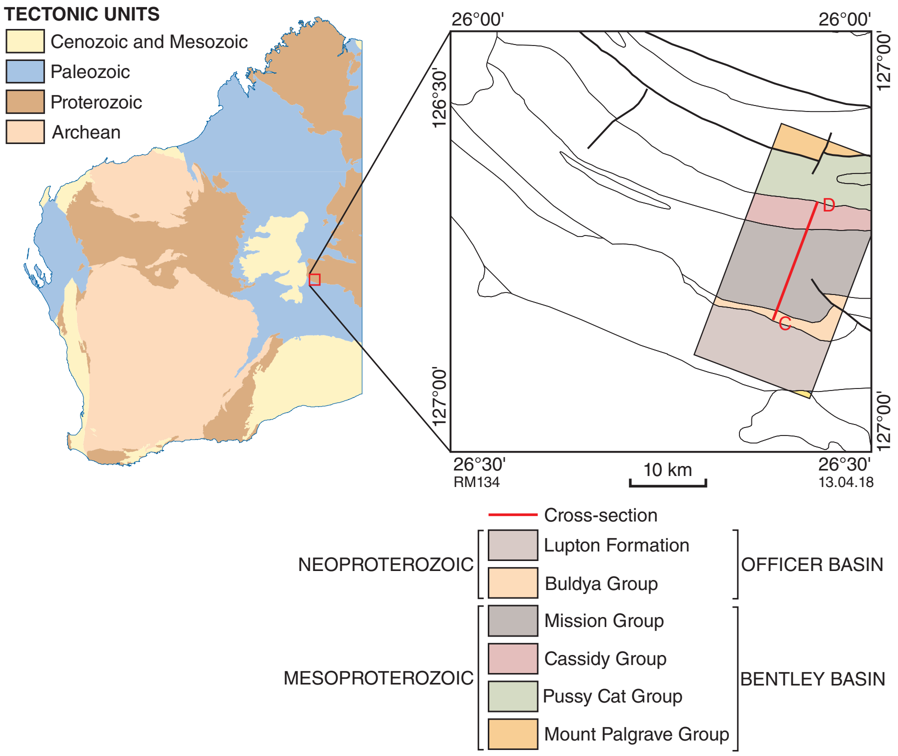

Figure 1. Simplified interpreted bedrock geology of WARBURTON RANGE map sheet showing the location of cross-section C–D

References

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Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Townsend Quartzite	P_-BUw-stz	Quartzite	2.20	0.000
	Mission Group				
	Milesia Formation	P_-MIm-xs-bb	Sandstone/basalt	2.55	0.000
		P_-MIm-sp	Sandstone/conglomerate	2.67	0.000
		P_-MIm-sti	Sandstone	2.30	0.064
		P_-MIm-xst-bb	Sandstone/basalt	2.50	0.073
		P_-MIm-bb	Basalt	2.75	0.005
		P_-MIm-st	Sandstone	2.75	0.036
	Lilian Formation	P_-MIl-sh	Shale	2.50	0.000
	Frank Scott Formation	P_-MIf-kds	Dolomite	2.67	0.000
	Gamminah Conglomerate	P_-MIg-sg	Conglomerate	2.20	0.021
	Cassidy Group				
	Miller Basalt	P_-CAm-bb	Basalt	2.85	0.100
	Hilda Rhyolite	P_-CAh-frp	Rhyolite	2.45	0.042
		P_-CAh-frpa	Rhyolite	2.45	0.042
	Warubuyu Basalt	P_-CAw-xbb-s	Basalt/sandstone	2.85	0.024
		P_-CAw-sf	Siltstone/sandstone	2.40	0.021
	Thomas Rhyolite	P_-CAt-frp	Rhyolite	2.45	0.038
	Gurgadi Basalt	P_-CAg-bbg	Basalt	2.85	0.040
	Wururu Rhyolite	P_-CAu-frp	Rhyolite	2.45	0.000
	Pussy Cat Group				
	Glyde Formation	P_-PUg-xbb-s	Basalt/sandstone	2.70	0.000
		P_-PUg-bbg	Basalt	2.80	0.000
		P_-PU-frp	Rhyolite	2.67	0.000
	Warakurna Supersuite	P_-WK-od	Dolerite	2.90	0.000

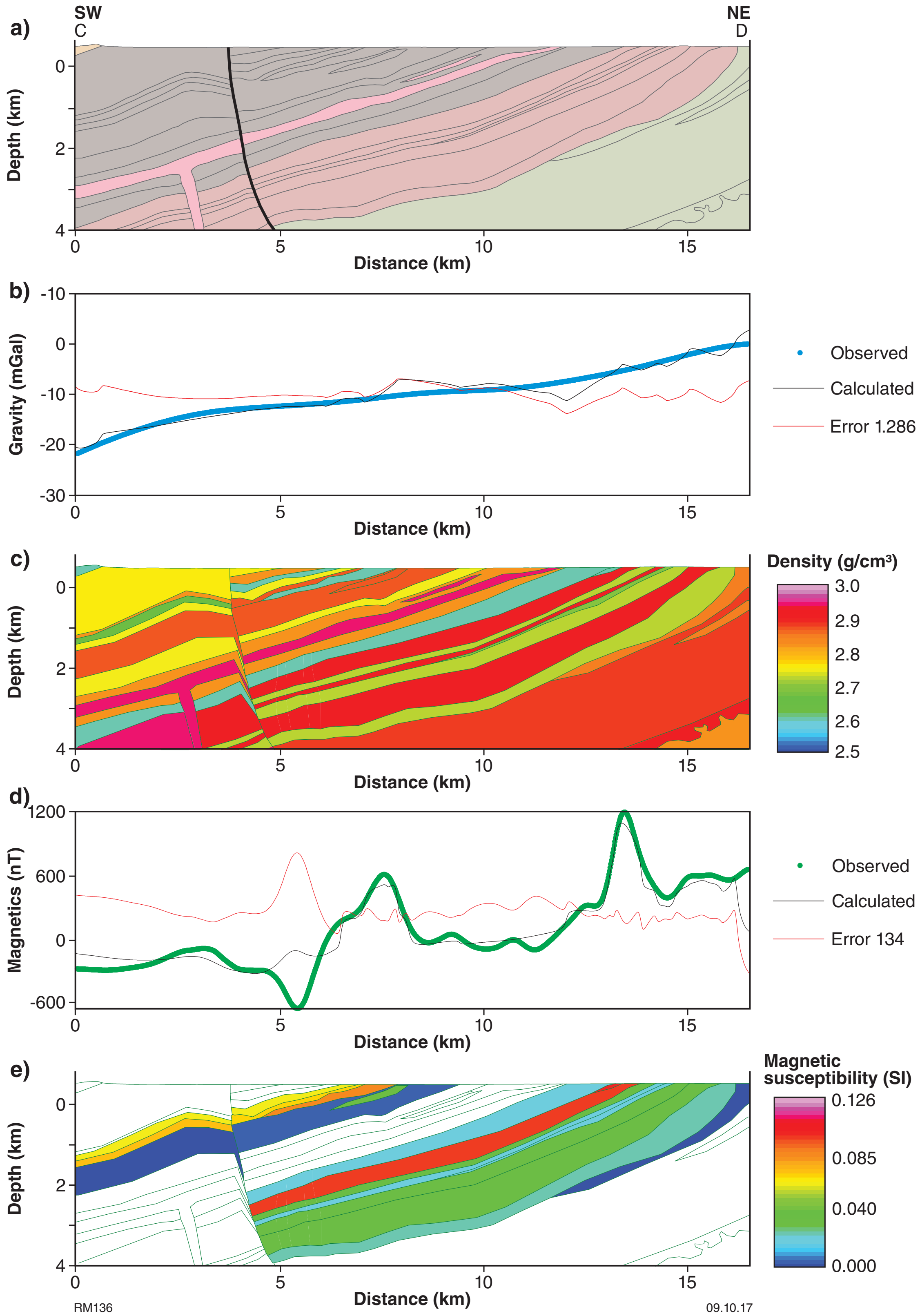

Figure 2. Profile of section C–D showing: a) lithological section from sheet WARBURTON RANGE; b) observed and calculated Bouguer anomaly profile with error line; c) section of density per lithology; d) observed and calculated magnetic anomaly profile with error line; e) section of magnetic susceptibility per lithology

YALGOO 2241, section A–B, 1:100 000 geological map

(Youanmi Terrane, Yilgarn Craton)

LI Brisbout and TJ Ivanic

Location

Maps: YALGOO (SH 50-2) and YALGOO (2241)

Zone: MGA Zone 50

End coordinates: 459178E 6877779N to 483201E 6883813N

Length: 24.8 km

Scale of interpretation: 1:100 000

The east-northeasterly trending section A–B traverses a regional-scale anticline in the north of the Yalgoo greenstone belt, Yilgarn Craton (Fig. 1).

Tectonic units

The Yalgoo greenstone belt comprises the Norie, Polelle, and Glen Groups (Van Kranendonk et al., 2013) supracrustal rocks and Annean Supersuite mafic–ultramafic intrusive rocks. The supracrustal rocks are dominantly tholeiitic to komatiitic basalts with lesser banded iron-formation (BIF) and andesite. However, the Glen Group unconformably overlies the Polelle and Norie Groups and is dominated by siliciclastic sedimentary rocks. Ten kilometre-scale layered mafic–ultramafic bodies dated at c. 2793 Ma (GSWA 198299; MTD Wingate, 2016, written comm., 4 May) intrude at the uppermost part of the Norie Group and the lower parts of the Polelle Group. One such intrusion, the Noongal Gabbro, intrudes in the northernmost part of the belt.

Crosscutting the Polelle Group are foliated tonalitic to granodioritic rocks of the Warbadoo Tonalite (Rothsay Suite) to the east and equigranular monzogranite of the Walganna Suite (Ivanic et al., 2012) to the north and east. This area is host to several gold prospects and a multitude of pegmatite mineral deposits including the Carlaminda Blue lepidolite occurrence.

Structure

The overall form of the northern part of the Yalgoo greenstone belt is a north–south trending, tight anticline, which is crosscut by north to south trending, steeply dipping greenschist facies shear zones. Bedding is steeply inclined and the hinge of the anticline is estimated to be steeply south plunging. In addition, a splay of shear zones and an unconformity are present to the southeast of the line of section, see cross-section C–D on sheet YALGOO.

Geophysical data

Bouguer gravity, aeromagnetic, and topographic data were sampled every 500 m along the profile. Gravity data were sampled from the Geological Survey of Western Australia (GSWA) merged Bouguer gravity grid of Western Australia (GSWA, 2013). Gravity data have not been terrain corrected. Gravity stations on YALGOO are spaced in a c. 2.5 km grid. Aeromagnetic data were sampled from the GSWA merged magnetic grid of Western Australia (GSWA, 2014). On YALGOO, aeromagnetic data is available at 400 m line spacing, with several higher resolution surveys. The topography was sampled from Shuttle Radar Topography Mission version 3 (SRTM3) grid (International Center for Tropical Agriculture, 2004).

Physical property data from Williams (2009) and Emerson (1990) were used to attribute density and magnetic susceptibility values to the forward model and are detailed in Table 1.

Magnetic and gravity forward modelling

2D magnetic and gravity forward modelling was done with Oasis Montaj's GM-SYS (version 8.2) software. No regional trend was removed from either the Bouguer gravity or aeromagnetic data. Aeromagnetic data were reduced to the pole. Gravity stations were placed at 0 m above the topographic surface and magnetic flight lines were placed at an elevation of 80 m above the topographic surface.

Results

The section was modelled to a depth of 6 km, and the units at the western and eastern ends were extended horizontally by about 100 km to avoid edge effects. The initial model was the preliminary cross-section A–B on sheet YALGOO; a simplified version is shown in Fig. 2a. Where necessary, the physical properties and geometries of the preliminary cross-section were adjusted until the cross-section was more consistent with the potential field data. Densities and susceptibilities attributed to the modelled units are shown in Table 1.

The main feature of the observed Bouguer gravity is a 20 mgal relative gravity high (Fig. 2b) that is accounted for by a greenstone belt with densities of 2.82 – 2.86 g/cm^3 (Fig. 2c) extending down to a depth of approximately 6 km.

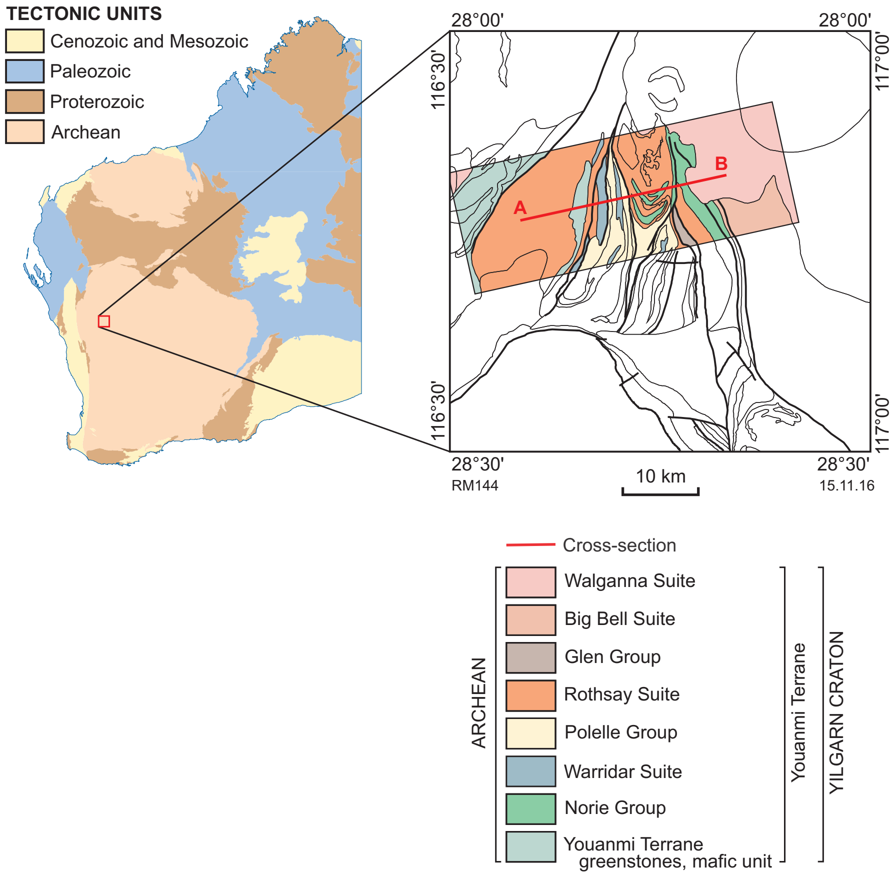

Figure 1. **Location of YALGOO map sheet with simplified interpreted bedrock geology within 8 km bordering of cross-section A–B**

The lower observed Bouguer gravity at the western and eastern ends of the section is attributed to felsic intrusives with densities of 2.66 – 2.70 g/cm^3. Density modelling of the eastern end of the section suggests that the Walganna Supersuite granite may intrude the anticline at depth (Fig. 2c).

The high-amplitude, high-frequency magnetic anomalies (Fig. 2d) are consistent with steeply dipping ultramafic talc–tremelite–serpentine magnetite schist of the Warriedar Suite and metamorphosed BIF of the Norie Group (Fig. 2e).

Although this section contains the Youanmi Shear Zone, which divides the Murchison Domain from the Southern Cross Domain, both domains are largely composed of granites. Consequently, there is only negligible density contrast between both. However, it appears that the Southern Cross granites are more magnetic than the Murchison granites.

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Williams, NC 2009, Mass and magnetic properties for 3D geological and geophysical modelling of the southern Agnew–Wiluna greenstone belt and Leinster nickel deposits, Western Australia: Australian Journal of Earth Sciences, v. 56, p. 1111–1142.

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Walganna Suite	A-BRG-gme	Monzogranite	2.665	0.000
	Rothsay Suite; Warbadoo Tonalite	A-ANoo-mgg	Metagranodiorite	2.700	0.000
	Rothsay Suite; Warbadoo Tonalite	A-ANoo-xmgmn-mggs	Monzogranite augen gneiss	2.660	0.000
	Rothsay Suite; Warbadoo Tonalite	A-ANoo-mgti	Migmatitic tonalite	2.650	0.000
	Rothsay Suite; Warbadoo Tonalite	A-ANoo-mggs	Schistose metagranodiorite	2.700	0.000
	Polelle Group; Yilgaddy Andesite Member	A-POyy-xfa-bd	Andesite	2.860	0.000
	Polelle Group; Singleton Basalt Member	A-POys-bs, A-POys-mbbs	Basalt	2.860	0.000
	Polelle Group; Carlaminda Komatiite Member	A-POyc-mus	Schistose metabasalt	2.860	0.000
	Polelle Group; Carlaminda Komatiite Member	A-POyc-mut	Serpentinite	2.860	0.000
	Norie Group	A-NO-bs	Basalt	2.820	0 – 0.200
	Norie Group	A-NO-mbs	Mafic schist	2.820	0 – 0.100
	Norie Group	A-NO-mib	BIF	2.820	0 – 0.500
	Norie Group	A-NO-bbg	Basalt	2.820	0.000
	Warriedar Suite	A-ANW-od	Dolerite	2.860	0.000
	Warriedar Suite	A-ANW-moda	Amphibolite dolerite	2.830 – 2.860	0.000
	Warriedar Suite	A-ANW-masr	Ultramafic schist	2.830	0.015
	Warriedar Suite; Olive Queen Gabbro	A-ANoq-mod	Metagabbro	2.820	0.500
	Warriedar Suite; Noongal Gabbro	A-ANno-od, A-Anno-odp, A-ANno-xmoda-mgs	Dolerite	2.820	0.000
	Warriedar Suite; Noongal Gabbro	A-ANno-ogl	Leucogabbro	2.820	0.000
	Warriedar Suite; Noongal Gabbro	A-ANno-xod-mib	BIF	2.820	0.100
	Warriedar Suite; Noongal Gabbro	A-ANno-moa	Amphibolite	2.820	0.100
	Youanmi Terrane Greenstones	A-xmus-mg-YYO	Ultramafic schist	2.750	0.000
		A-ANno-ogl	Leucogabbro	2.820	0.000
		A-ANno-xod-mib	BIF	2.820	0.010
	Youanmi Terrane greenstones	A-xmus-mg-YYO	Ultramafic schist	2.750	0.000

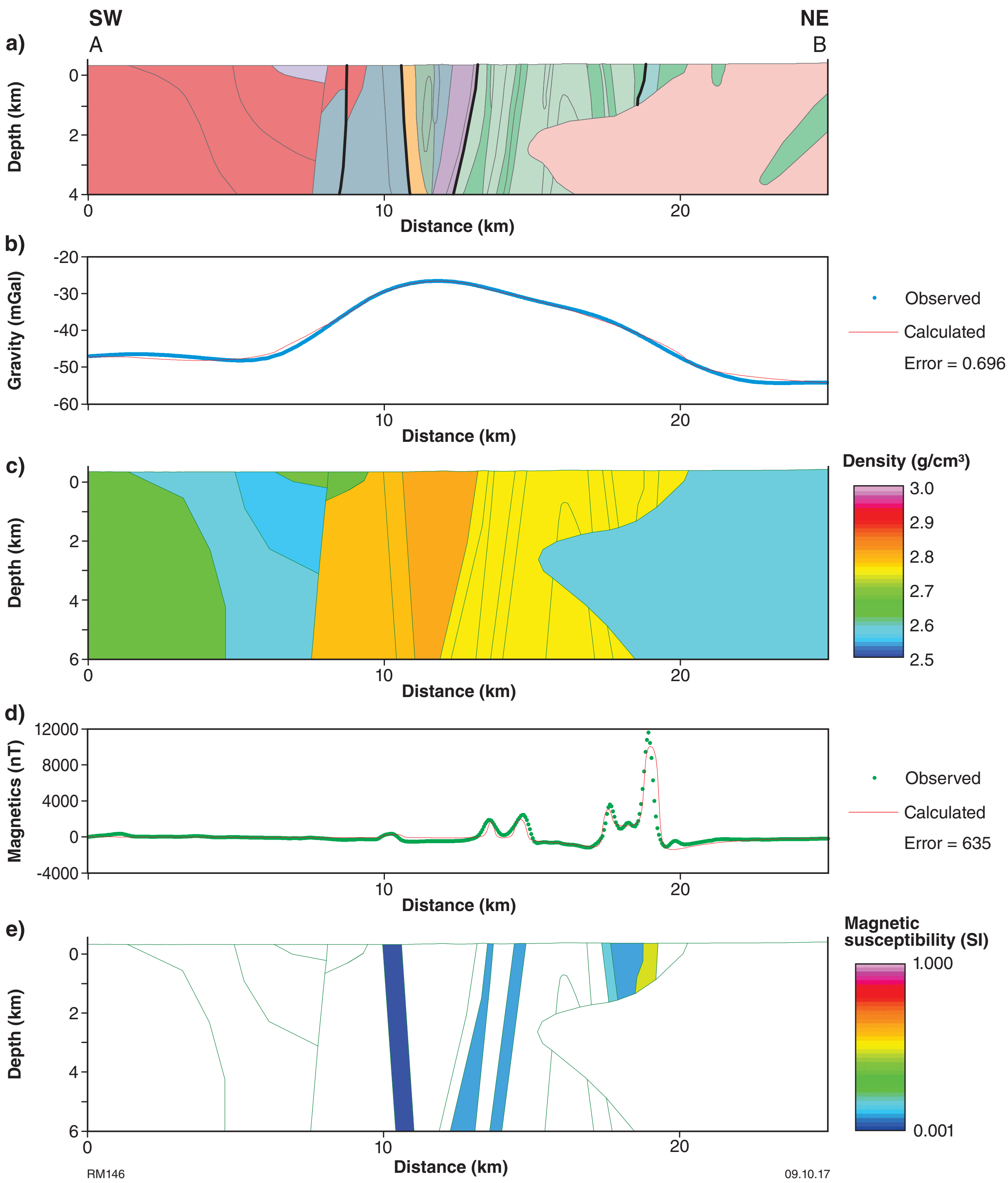

Figure 2. Gravity and magnetic forward model of section A–B: a) simplified cross-section from YALGOO map sheet, legend shown in Table 1; b) observed and calculated Bouguer gravity data; c) density model; d) observed and calculated magnetic susceptibility data; e) magnetic susceptibility model

YALGOO 2241, section C–D, 1:100 000 geological map

(Youanmi Terrane, Yilgarn Craton)

LI Brisbout and TJ Ivanic

Location

Maps: YALGOO (SH 50-2) and YALGOO (2241)

Zone: MGA Zone 50

End coordinates: 464859E 6854865N to 488243E 6856304N

Length: 23.4 km

Scale of interpretation: 1:100 000

The east- to west-trending section C–D traverses the Yalgoo greenstone belt with the granitic 'Yalgoo Dome' to the west (Ivanic et al., 2015). It lies approximately 26 km south of section A–B (Fig. 1 in that section).

Tectonic units

The Yalgoo greenstone belt hosts supracrustal rocks of the Norie, Polelle, and Glen Groups (Van Kranendonk et al., 2013) and mafic–ultramafic intrusive rocks of the Annean Supersuite. The supracrustal rocks are dominantly tholeiitic to komatiitic basalts with lesser banded iron-formation (BIF) and andesite. However, the Glen Group, which unconformably overlies the Polelle and Norie Groups, is dominated by siliciclastic sedimentary rocks. Ten kilometre-scale layered mafic–ultramafic bodies of the Warriedar Suite dated at c. 2793 Ma (GSWA 198299; MTD Wingate, 2016, written comm., 4 May) intrude the Norie Group and the lower parts of the Polelle Group. In this region, these units are typically 0.5 km thick.

Crosscutting the Polelle Group are foliated tonalitic to granodioritic rocks of the Goonetarra Granodiorite (Rothsay Suite) to the east and foliated granodiorite to monzogranite of the Big Bell Suite (Ivanic et al., 2012) to the north and east. This greenstone belt is host to several gold prospects and, to the north, a multitude of pegmatite mineral deposits.

Structure

The overall form of the southern part of the Yalgoo greenstone belt is a north–south-trending, open syncline, which is unconformably overlain by the Mougooderra Formation siliciclastic basin. These are crosscut by north–south trending, steeply dipping greenschist facies shear zones (e.g. the Mulloo Shear Zone in the central eastern part of the section). Bedding is moderately inclined within older greenstone units and shallower (possibly ≤10°) within the Mougooderra Formation. The Badja Shear Zone at the eastern margin of the Goonetarra Granodiorite is interpreted to have a normal sense of shear with granite-up, greenstone-down movement. A shear zone is also present at the western margin of the Big Bell Suite metagranodiorites to the east of the section with a shear sense consistent with minor thrusting. A splay of shear zones lies to the north and the northwest of this section and is interpreted to be associated with vertical tectonic activity of the 'Yalgoo Dome'. In greenstones to the north of this section is a large-scale tight isoclinal fold (see section A–B).

Geophysical data

Bouguer gravity, aeromagnetic, and topographic data were sampled every 500 m along the profile. Gravity data were sampled from the Geological Survey of Western Australia (GSWA) merged Bouguer gravity grid of Western Australia (GSWA, 2013). Gravity data have not been terrain corrected. Gravity stations on YALGOO are spaced around a 2.5 km grid. Aeromagnetic data were sampled from the GSWA 2014 merged magnetic grid of Western Australia (GSWA, 2014). On YALGOO, aeromagnetic data are available at 400 m line spacing, with several higher resolution surveys. The topography was sampled from Shuttle Radar Topography Mission version 3 (SRTM3) grid (International Center for Tropical Agriculture, 2004).

Physical property data from Williams (2009) and Emerson (1990) were used to attribute density and magnetic susceptibility values to the forward model and are detailed in Table 1.

Magnetic and gravity modelling

2D magnetic and gravity forward modelling was done with Oasis Montage's GM-SYS (version 8.2) software. No regional trend was removed from either the Bouguer gravity or aeromagnetic data. Aeromagnetic data were reduced to the pole. Gravity stations were placed 0 m above the topography, and magnetic flight lines were placed at an elevation of 80 m above the topographic surface.

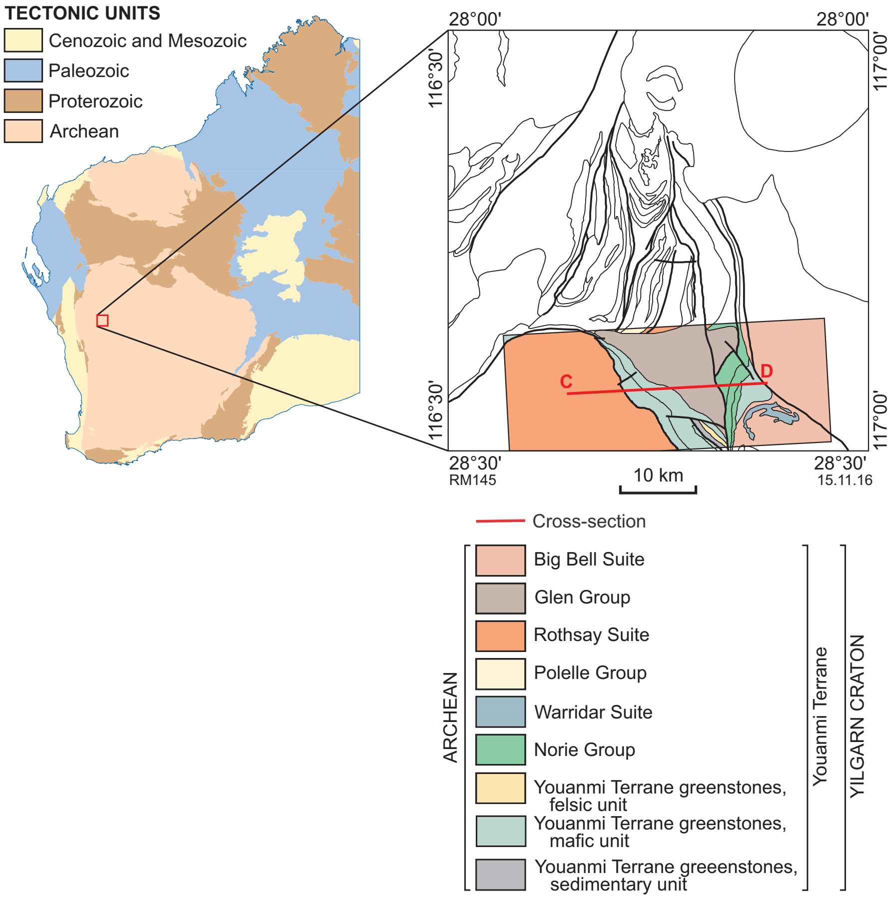

Figure 1. Location of YALGOO map sheet with simplified interpreted bedrock geology within 8 km of cross-section C–D

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used Figure 2a

Colour	*Modelled unit*	*Map code*	*Rock type*	*Density (g/cm^3)*	*Magnetic susceptibility (SI)*
	Big Bell Suite	A-SDB-mgg	Metagranodiorite	2.65	0.00
	Glen Group; Mougooderra Formation	A-GLm-mhs	Pelite and psammite	2.68	0.00
	Goonetarra Granodiorite	A-ANgo-mgms, AANgo-mgmu A-ANgo-mgtn	Metamonzogranite	2.67	0.00
	Goonetarra Granodiorite	A-ANgo-xmgtn-mgmu	Tonalite gneiss		
	Norie Group	A-NO-bb, ANO-bbd	Basalt	2.83	0.00
	Norie Group	A-NO-mbs	Mafic schist	2.83	0.00
	Norie Group	A-NO-frt	Volcaniclastic rocks (± BIF)	2.70 – 2.80	0.00 – 0.08
	Warriedar Suite	A-ANW-od	Dolerite	2.83	0.00
	Warriedar Suite	A-ANW-ap	Peridotite with BIF	2.83	0.02
	Youanmi Terrane Greenstones	A-mwa-YYO	Amphibolite	2.75 – 2.83	0.00 – 0.03
	Youanmi Terrane Greenstones	A-mbs-YYO, A-mbbs-YYO	Mafic schist	2.83 – 2.85	0.00 – 0.05
	Youanmi Terrane Greenstones	A-bb-YYO, A-bbw-YYO	Basalt (± BIF)	2.85	0.00 – 0.15
	Youanmi Terrane Greenstones	A-mba-YYO, A-mogs-YYO	Amphibolite, metagabbro with BIF	2.85	0.00
	Youanmi Terrane Greenstones	A-cib-YYO	BIF and ferruginous banded chert	2.83	0.20 – 0.70

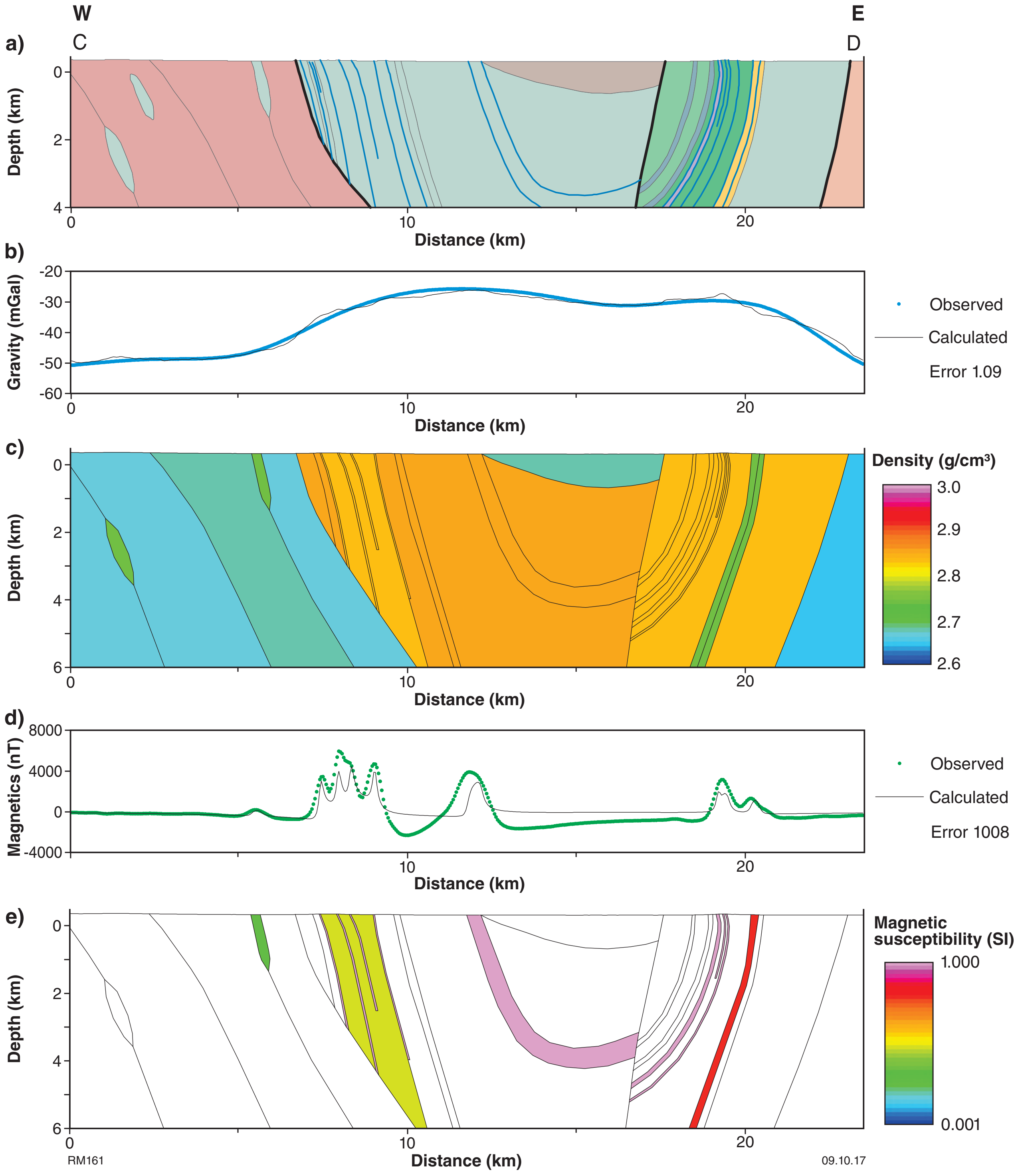

Figure 2. Gravity and magnetic forward model of section C–D: a) simplified cross-section from sheet YALGOO, legend shown in Table 1; b) observed and calculated Bouguer gravity data; c) density model; d) observed and calculated magnetic susceptibility data; e) magnetic susceptibility model

Results

The 25 km-long section was modelled to a depth of 6 km. The initial model was the preliminary cross-section C–D on sheet YALGOO. Where necessary, the physical properties and geometries of the preliminary cross-section were adjusted until the cross-section was consistent with the potential field data.

Section C–D traverses the southern part of the Yalgoo greenstone belt; to the east of the granitic 'Yalgoo Dome' and to the west of metagranitic rocks of the Big Bell Suite (Fig. 2a). The observed Bouguer gravity data is dominated by two gravity highs (Fig. 2b) that are attributed to a greenstone belt with densities of 2.70 – 2.85 g/cm^3 (Fig. 2c). High density is attributed to large volumes of tholeiitic basalt to depths of approximately 6 km, which are either unassigned Youanmi Terrane basalts or have been assigned to the Norie Group.

The slight Bouguer gravity low within the greenstone belt is attributed to a ~600 m-thick unit of sedimentary rocks (i.e. the unconformably overlying and shallowly dipping Mougooderra Formation) that thicken eastwards and have a density of 2.68 g/cm^3. The Bouguer gravity lows at the ends of the section (Fig. 2b) are attributed to felsic intrusives with densities of 2.65 – 2.67 g/cm^3 (Fig. 2c).

The observed magnetic data are featureless with the exception of several high-amplitude, high-frequency anomalies (Fig. 2d) that were produced by steeply dipping BIF and ferruginous chert (Fig. 2e).

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Geological Survey of Western Australia 2014, Magnetic anomaly grid (80 m) of Western Australia (2014 – version 1): Geological Survey of Western Australia, digital data layer.

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Youanmi 2640, section A–B, 1:100 000 geological map

(Yuinmery greenstone belt, Murchison Domain, Yilgarn Craton)

RE Murdie and TJ Ivanic

Location

Maps: Youanmi (SH 50-4) and Youanmi (2640)

Zone: MGA Zone 50

End coordinates: 679898E 6840876N to 694927E 6837860N

Length: 15.3 km

Scale of interpretation: 1:100 000

This is an east–west section that crosses the Yuinmery greenstone belt with the Youanmi Shear Zone to the west and Yuinmery Shear Zone to the east (Fig. 1).

Tectonic units

The Yuinmery greenstone belt consists primarily of mafic volcanic rocks of the Norie Group, felsic to intermediate volcanic rocks of the Yuinmery Volcanics Member, tonalitic rocks of the Mount Kenneth Suite dated at 2813 ± 4 Ma, and gabbroic sills of the Annean Supersuite (Van Kranendonk et al., 2013). It lies to the northeast of the Youanmi Igneous Complex (Ivanic et al., 2010).

This greenstone belt hosts volcanogenic massive sulfide (VMS) mineralization, e.g. the Just Desserts copper–gold deposit within the Yuinmery Volcanics Member and significant gold mineralization along the Youanmi Shear Zone to the west and in the vicinity of the Youanmi townsite.

Archean granitic rocks surround and underlie the greenstones and are dominated by strongly deformed granitic rocks of the Tuckanarra Suite (Ivanic et al., 2012). These are distributed along regional-scale ductile shear zones. Massive monzogranite of the Walganna Suite lies to the south of the section and crosscuts all other Archean rocks in the region.

Structure

The overall synformal geometry of the greenstone belt has been dissected by large-scale, north–south-trending shear zones, including the Youanmi and Yuinmery Shear Zones. The belt has also been truncated to the south of the section by foliated metagranitic rocks of the Tuckanarra Suite. In the east of the section, a smaller antiformal sequence of Norie Group rocks is present. The axis of this sequence is intruded by Mount Kenneth Suite tonalitic rocks, and to the south it is truncated by a large pluton of the Walganna Suite.

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) gravity merged grid of Western Australia (GSWA, 2015) with points sampled every 150 m (Fig. 2b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data were compiled from Ivanic et al. (2014) and (Ivanic and Brett, 2015). These values were interpolated to corresponding lithologies in the vicinity of this section (Table 1).

Modelling

All modelling was performed in the GM-SYS modelling software run within the Oasis Montaj platform. 2.5D modelling was performed where the polygons were extended by 100 m perpendicular to the strike of the profile.

Results

The section was modelled down to a depth of 6 km (Fig. 2c). The model was refined across the cross-section of the same location (Fig. 2a) from sheet Youanmi (Fig. 1) extending down to a depth of 4 km.

A tight syncline, formed from dense rocks of the Yuinmery Volcanics Member and Annean Supersuite within surrounding lower density granites, is consistent with a positive gravity anomaly (Fig. 2b). This structure extends down to a vertical thickness of approximately 5.5 km.

The overall Bouguer high is mainly attributed to the high-density rocks of mafic and ultramafic intrusive rocks of the Annean Supersuite, which underlie the western portion of the line of section. The eastern part of the section consists of mafic volcanic rocks of the Norie Group with an anticlinal structure down to a depth of approximately 3 km.

To the east, the greenstone belt is surrounded by granitic material, and to the west by the Walganna Suite intruding shallowly up to a depth of 1.5 km.

The Yuinmery Volcanics Member is a thin (<1 km) and volumetrically minor unit.

The steeply dipping (about 80° east and west, respectively) nature of the Youanmi and Yuinmery Shear Zones is consistent with the gravity data.

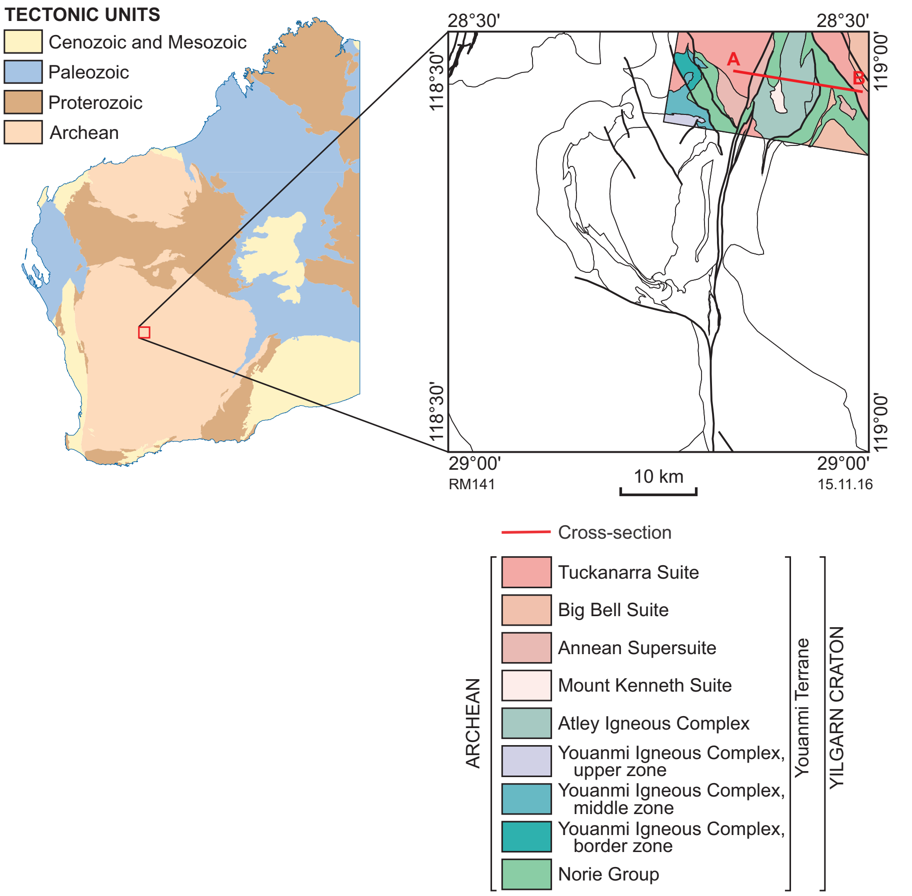

Figure 1. Location of YOUANMI map sheet with simplified interpreted bedrock geology within 8 km of cross-section A–B

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Density (g/cm³)*
	Walganna Suite	A-BRG-gm	2.62
	Tuckanarra Suite	A-TU-mg, A-TU-mgm, A-TU-mgmu, A-TU-mgms	2.61
	Annean Supersuite		
	Dolerite rocks	A-AN-jmod-mib, A-AN_mod, A-AN-moga, A-AN-og	2.80
	Gabbro	A-AN-xmat-musr, A-AN-ogly, A-AN-xog-od, A-AN-mog	2.88
	Ultramafic rocks	A-AN-xmat-mas	2.85
	Mt Kenneth Suite	A-AN-xog-od, A-ANK-g	2.61 – 2.67
	Courlbarloo Tonalite	A-ANcb-gth	2.67
	Norie Group		
	Ultramafic rocks	A-NO-xmus-mod, A-NO-mus, A-NO_musr	2.70
	Mafic rocks	A-NO-bs, A-NO_bbg, A-NO_mbs, A-NO_xbk-mus	2.80
	Yaloginda Formation	A-NOy-fdp, A-NOy-xfrp-frx	2.66
	Yuinmery Volcanics Member	A-NOyy-fdx, A-NOyy-frx, A-NOyy-xmfs-mib, A-NOyy-mbs, A-NOyy-mfrs	2.67

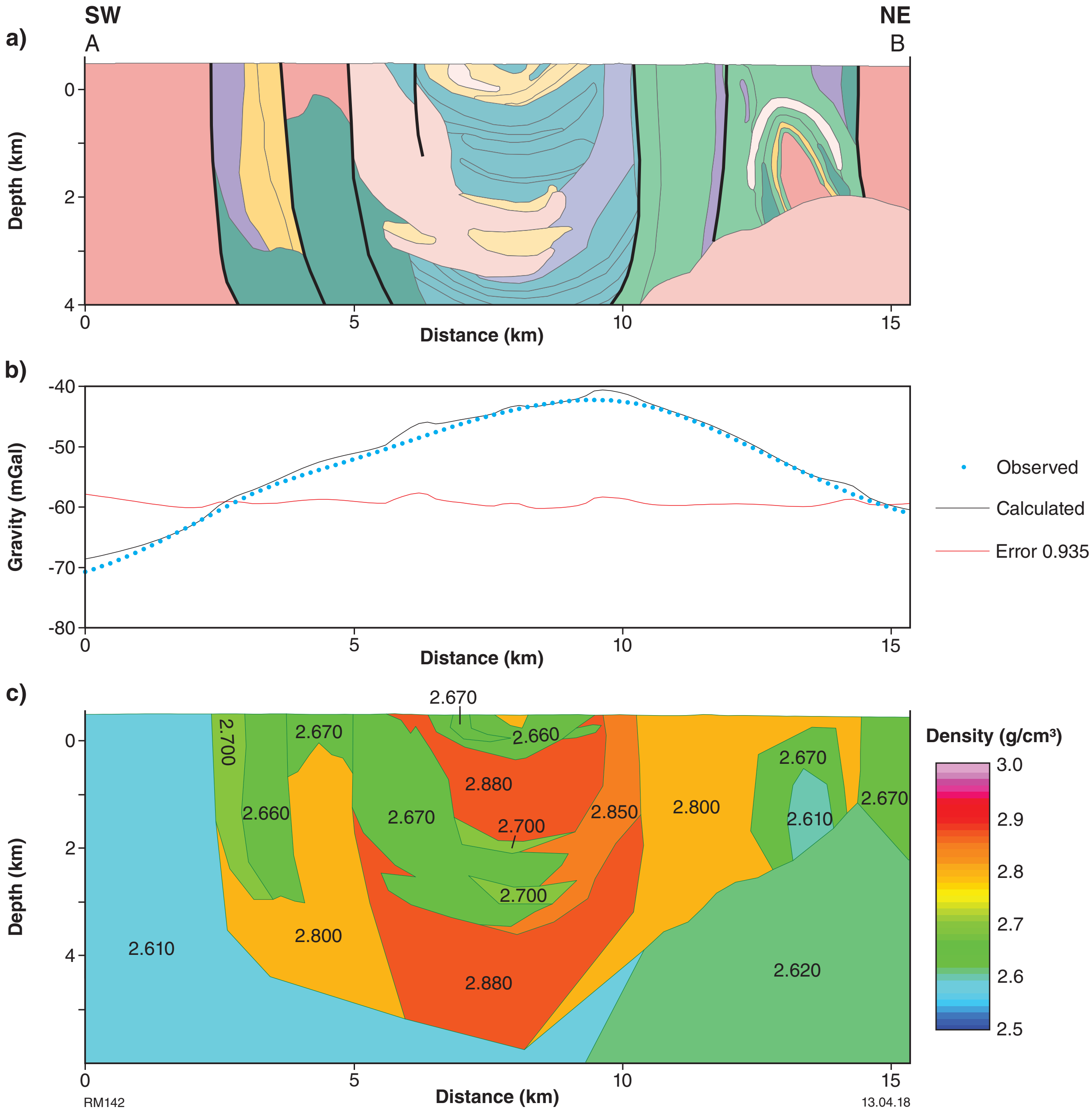

Figure 2. Profile of section A–B showing: a) lithological section from sheet Youanmi; b) observed and calculated Bouguer anomaly profile with error line; c) section of density per lithology

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YOUANMI 2640, section C–D, 1:100 000 geological map

(Youanmi Igneous Complex, Murchison Domain, Yilgarn Craton)

RE Murdie and TJ Ivanic

Location

Maps: YOUANMI (SH 50-4) and YOUANMI (2640)

Zone: MGA Zone 50

End coordinates: 657078E 6816849N to 684033E 6823561N

Length: 27.8 km

Scale of interpretation: 1:100 000

This section is oriented east to west and crosses the centre of the Youanmi Igneous Complex and the overlying units of the Youangarra Volcanics Member. It also crosses the Youanmi Shear Zone to the east (Fig. 1).

Tectonic units

The Youanmi Igneous Complex is a large mafic–ultramafic layered intrusion, which is assigned to the voluminous Meeline Suite of the Annean Supersuite (Ivanic et al., 2010), dated at 2819 ± 9 Ma (Gill, 2011). It is located in the central Youanmi Terrane, western Yilgarn Craton and hosts several orthomagmatic Ti–V and Cr–Ni–Cu–PGE deposits. To the east, the complex is bounded by the Youanmi Shear Zone, and to the west by the crosscutting Walgoo Monzogranite of the Bald Rock Supersuite (Ivanic et al., 2012).

Overlying the complex is the Youangarra Volcanics Member (Ivanic, 2014), host to the Freddie Well and Pincher Well volcanogenic massive sulfide (VMS) deposits. It comprises felsic volcanic and volcaniclastic rocks, banded iron-formation (BIF) and a few subordinate lithologies.

Archean granitic rocks surround and underlie the greenstones and are dominated by massive to weakly deformed monzogranite. Strongly deformed granitic rocks of the Tuckanarra Suite (Ivanic et al., 2012) are commonly distributed along regional-scale ductile shear zones or adjacent to granite–greenstone contacts.

Structure

The overall tabular to slightly synformal geometry of the Youanmi Igneous Complex has been truncated by a large-scale regional, north–south-trending dextral shear zone, the Youanmi Shear Zone. Subsequently, several smaller brittle faults trending northwest–southeast display <1 km sinistral displacement. The Tuckanarra Suite metagranitic rocks are foliated parallel to the Youanmi Shear Zone and are likely to be syndeformational. Large tabular plutons of the Walganna Suite (Ivanic, 2014) are present to the east and the west of the section. Many plutons of this suite with a similar geometry have been identified in the Youanmi Seismic lines (e.g. 10GA-YU2, 30 km to the north of this section). Examples are provided in Ivanic et al. (2014).

Geophysical data

A gravity profile was extracted from the Geological Survey of Western Australia (GSWA) gravity merged grid of Western Australia (GSWA, 2015) with points sampled every 280 m (Fig. 2b). Topographic data were taken from the Shuttle Radar Topography Mission (SRTM) at the same points.

Physical property data was compiled from Ivanic et al. (2014) and Ivanic and Brett (2015). These values were interpolated to corresponding lithologies in the vicinity of the Youanmi Shear Zone (Table 1).

Modelling

All modelling was performed in the GM-SYS modelling software run within the Oasis Montaj platform. 2.5D modelling was performed where the polygons were extended by 100 m perpendicular to the strike of the profile.

Results

The section was modelled down to a depth of 9 km (Fig. 2c). The model was refined across the cross-section of the same location (Fig. 2a) from the Youanmi map (Fig. 1) extending down to a depth of 4 km.

The geometry of the Youanmi Igneous Complex was shown to be synformal to slightly downwarped and tabular. The geometry is also consistent with the concentric, inward-dipping igneous layering inferred in Ivanic et al. (2010). The complex extends down to a vertical thickness of approximately 4.5 km.

The Bouguer high is attributed to the high-density rocks of a possibly ultramafic zone of the complex, which underlies the lower zone and does not outcrop at the surface.

The complex is mantled by granitic material to the west, and there is evidence for large rafts of metagabbro within these granitic plutons.

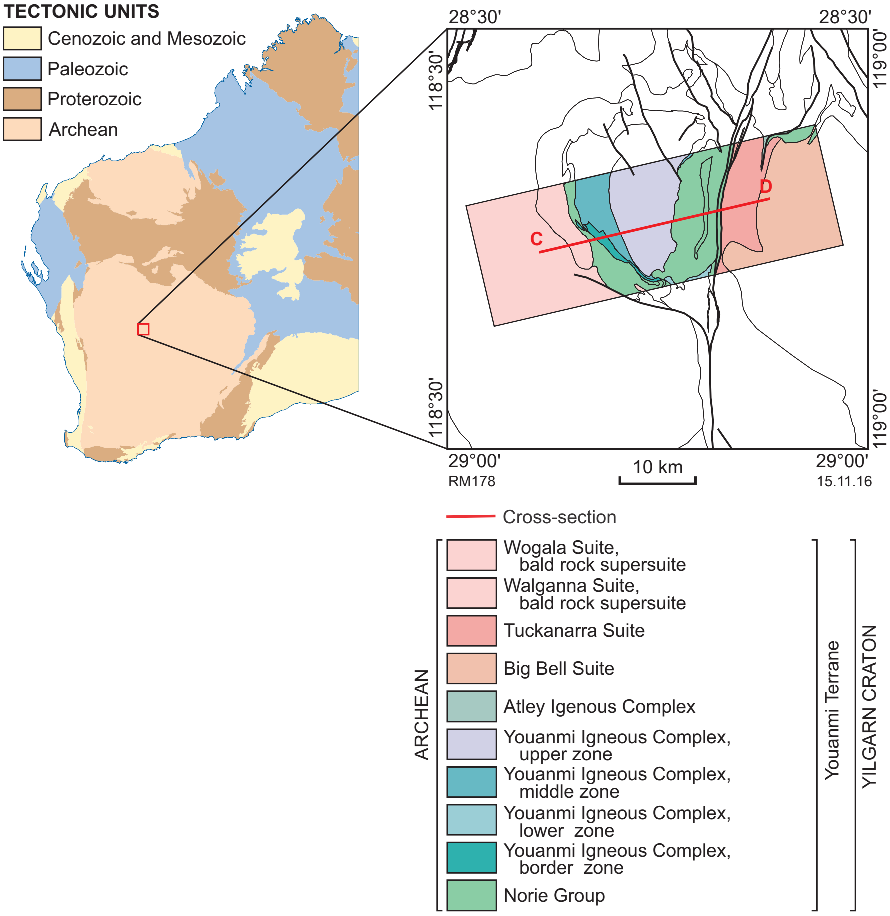

Figure 1. Location of Youanmi map sheet with simplified interpreted bedrock geology within 8 km of cross-section C–D

Table 1. Petrophysical properties of modelled units and the corresponding map codes and lithologies. The colour column refers to colours used in Figure 2a

Colour	*Modelled unit*	*Map code*	*Density (g/cm³)*
	Bald Rock Supersuite		
	Walganna Suite	A-BRG-jgmp-md, A-BRG-gm	2.610 – 2.630
	Walgoo Monzogranite	A-BRwa-gm, A-BRwa-gmpv	2.610 – 2.620
	Tuckanarra Suite	A-TU-mgss, A-TU-xmgn-mgp	2.610 – 2.622
	Annean Supersuite	A-AN-jmod-mib	
	Youanmi Igneous Complex		
	Unassigned gabbro	A-ANyo-mog	2.800
	Upper zone leucogabbro	A-ANyz-xam-ogl, A-ANyz-ogl, A-ANyz-xogl-amy	2.700
	Upper zone magnetite cumulate	A-ANyz-am	2.800
	Middle zone gabbro	A-ANym-xog-ogx, A-ANym-xom-og	2.700
	Lower zone gabbro	A-ANyl-xogx-mat	2.800
	Ultramafic zone peridotite	A-ANyu-xap-ax	2.900
	Border zone dolerite	A-ANyb-od	2.780
	Norie Group *Youangara Volcanics Member*	A-NOyg-mbs, A-NOyg-xmcb-mrs, A-NOyg-mfd, A-NOyg-xmib-mrs, A-NOyg-xmib-mfs, A-NOyg-xmfsh-g	2.600 – 2.800

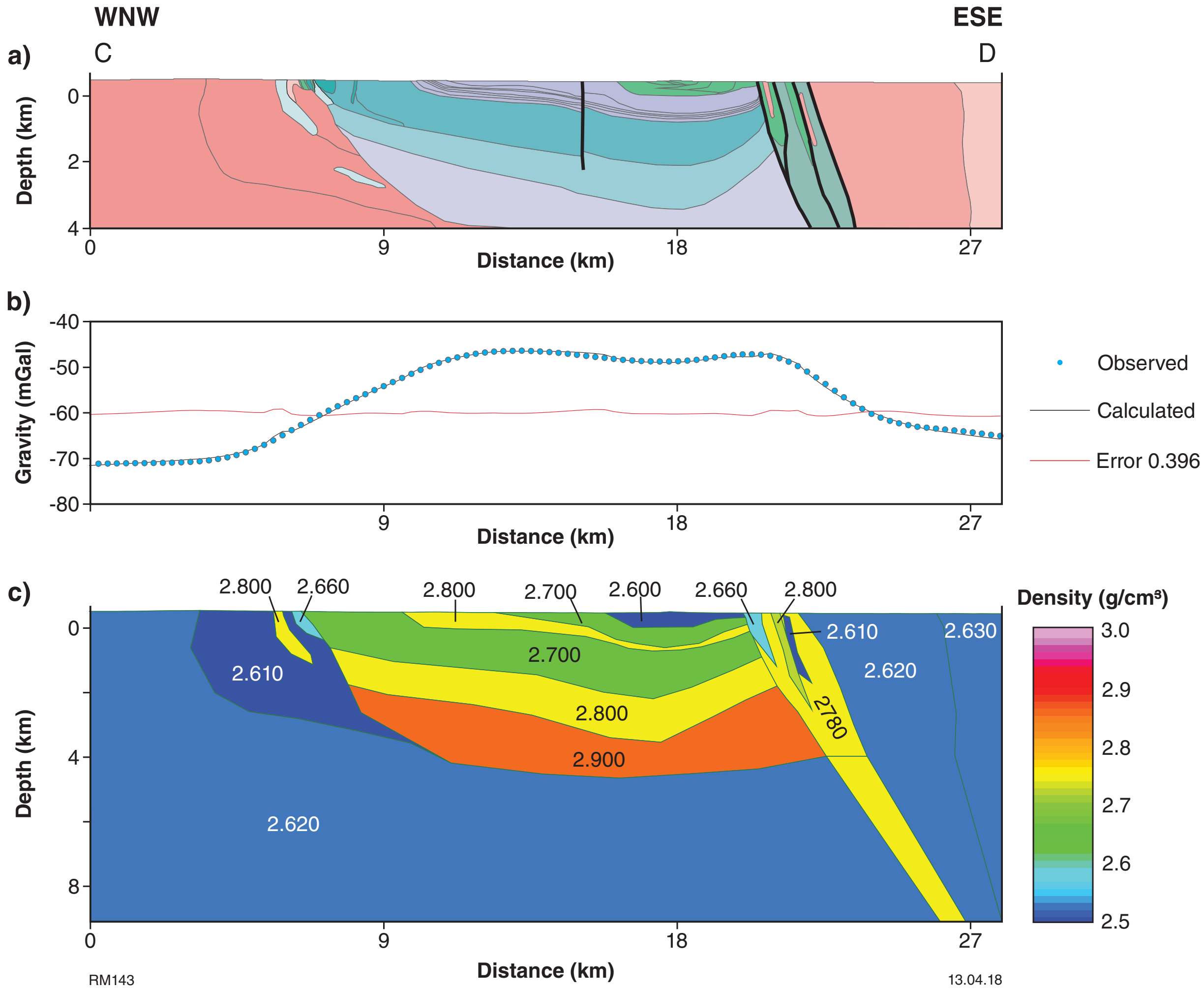

Figure 2. Profile of section C–D showing: a) lithological section from sheet Youanmi; b) observed and calculated Bouguer anomaly profile with error line; c) section of density per lithology

The Youangarra Volcanics Member is a thin (~0.5 km) and relatively flat-lying unit conformably overlying the upper zone of the complex. It is gently west dipping at approximately 10°.

The steep east-dipping nature of the Youanmi Shear Zone down to at least the base of the upper crust is consistent with gravity data.

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