Potential field studies along the 13GA-EG1 Eucla-Gawler deep crustal seismic reflection line

Ruth E Murdie*
Geological Survey of Western Australia
Department of Mines and Petroleum
East Perth, WA 6004

Lucy Brisbout
Geological Survey of Western Australia
Department of Mines and Petroleum
East Perth, WA 6004

John Brett
Geological Survey of Western Australia
Department of Mines and Petroleum
East Perth, WA 6004

Catherine V Spaggiari
Geological Survey of Western Australia
Department of Mines and Petroleum
East Perth, WA 6004

Klaus Gessner
Geological Survey of Western Australia
Department of Mines and Petroleum
East Perth, WA 6004

Rian A Dutch
Geological Survey of South Australia
Department of State Development
Adelaide SA 5000

Stephan Thiel
Geological Survey of South Australia
Department of State Development
Adelaide SA 5000

Tom W Wise
Geological Survey of South Australia
Department of State Development
Adelaide SA 5000

Mark J Pawley
Geological Survey of South Australia
Department of State Development
Adelaide SA 5000

**presenting author asterisked*

SUMMARY

This paper highlights the complimentary potential field studies that have been done in parallel to the interpretation of the 13GA-EG1 Eucla–Gawler deep crustal reflection seismic line. Gravity and magnetic images have been interpreted and potential field data has been modelled using edge detection, forward modelling and inversions to pick out the main domains and structures. Seismic, MT and drill core analysis has been progressing in parallel to the potential field investigations. The different approach taken here was to allow more freedom and independence in the interpretations originating from the potential field studies, rather than constraining them with a predefined architecture from the seismic interpretation. Initial results show gravity and magnetic worms correlating with interpreted structures and domain boundaries. Inversions show the 3D distribution of magnetic susceptibility and densities associated with major features such as the Mundrabilla Shear Zone and folded feature seen in the Nawa Domain. This paper summarises the main findings from the potential field studies, which, in conjunction with the parallel studies, allows for a more robust understanding of the crustal architecture and assessment of the mineral potential of the region.

Key words: Seismic reflection, Eucla-Gawler, gravity, magnetic, modelling.

INTRODUCTION

The 13GA-EG1 deep crustal seismic reflection survey was acquired to image an east-west, full crustal-scale profile of the Precambrian basement that lies below Neoproterozoic to Cenozoic basin cover. Most of the basement is covered by younger basins such as the Neoproterozoic Officer Basin, Cretaceous Bight Basin and the Cenozoic Eucla Basin, which obscure the geology that relates to the amalgamation of the South and West Australian Cratons. To the west, seismic line 13GA-EG1 links to the existing deep crustal seismic reflection line 12GA-AF3, which imaged the Albany-Fraser Orogen and Yilgarn Craton margin (Spaggiari and Tyler, 2014). Seismic line 13GA-EG1 follows the Trans Australia Railway from Haig in Western Australia (the end of 12GA-AF3), through to Tarcoola in South Australia, traversing the Madura and Coompana Provinces, and the western Gawler Craton (Dutch et al., 2015a). Geological understanding of this region is dependent on drill cores, and results from the Eucla basement stratigraphic drilling program (Spaggiari and Smithies, 2015) showed that the basement rocks are structurally and lithologically diverse, consistent with the existence of distinct terranes.

The main tectonic units are separated by large shear zone systems. From west to east seismic line 13GA-EG1 crosses three tectonic units; the Madura Province, the Coompana Province, which is separated from the Madura Province by the Mundrabilla Shear Zone, and finally the western Gawler Craton, which is structurally separated from the Coompana Province along the interpreted west-dipping Jindarnga Shear Zone (Dutch et al, 2015b). Within the western Gawler Craton, seismic line 13GA-EG1 crossed several lithostratigraphic subdivisions defined by their potential field signature, geochronological constraints, lithostratigraphy and tectonic history. From west to east, these are the Nawa, Christie and Wilgena Domains. The eastern end of seismic line 13GA-EG1 is at Tarcoola, which intersects the southern end of the north-south 08GA-OM1 seismic line (Korsch et al., 2010).

Magnetotelluric (MT) data were also acquired along the seismic line 13GA-EG1 (Thiel et al., 2015). In the western Gawler Craton, these data show that major fault zones have low resistivities and are subvertical. Another noticeable feature is a folded conductive area in the Nawa Domain that is imaged to a depth of ~15 km. Electrical conductors are at different angles to interpreted seismic reflectors suggesting that they are imaging different geological features and processes.

Gravity data was collected at 400 m intervals along 13GA-EG1. Pre-existing data is between 2.5 km and 9 km spacing. Regional magnetic data is available at 200 m line spacing in Western Australia and 400 m line spacing in South Australia (www.dmp.wa.gov.au and sarig.pir.sa.gov.au). Petrophysical data was collated from the Geological Survey of South Australia database and statistics calculated provide input for forward modelling of the potential field data of the Gawler Craton (van der Wielen et al., 2015). More petrophysical data has been made available from the cores acquired during the Eucla drilling program which will be used in future modelling.

Seismic Interpretation

The seismic line 13GA-EG1 is 834 km long and crosses from Western Australia into South Australia. Processing and interpretation has been undertaken in two stages, with the eastern end of the line in South Australia completed first (Doublier et al, 2015; Dutch et al., 2015b).

The main aim of 13GA-EG1 was to:

a) Characterise the architecture of the boundaries of the Madura Province, Coompana Province and western Gawler Craton
b) Investigate the internal character of the different geological provinces to better understand the geological evolution of the Australian Continent.
c) Help constrain and understand the major structures observed in potential field data and magnetotelluric data
d) Consider the implications of the crustal architecture for mineral potential.

The interpretation of the western Gawler Craton part of the seismic line showed an overall westward dipping architecture of the main shear zones (Dutch et al., 2015b). The Moho showed deepening in two places from about 42 km in the east to about 53 km depth under the Nawa and Christie Domains (Kennett and Chopping, 2015). In general, the crust shows three layers: a reflective lower crust; a discontinuous, weakly reflective middle crust; and a moderately reflective upper crust (Doublier et al., 2015). Towards the eastern and western ends of the Gawler Craton section, the lower reflective crust increases in thickness in the absence of the non-reflective middle crust.

The westward dipping shear zones are typically listric and show apparent thrust or duplex geometries post-dating early extension. These structures have probably undergone a protracted history of repeated movement and reactivation, including transpression and transtension with movement in and out of the plane of the seismic profile (Dutch et al., 2015b)

The focus of this paper is to pull the interpretations of the potential fields of both the Western and Southern Australian portions of seismic line 13GA-EG1 together with the seismic interpretation . Interpretation of the western Gawler Craton component of 13GA-EG1 can be found in Dutch et al (2015a). Initial results for the remainder of the line show a gently undulating Moho which shallows beneath the western Coompana Province (Forrest Zone), and a non-reflective zone associated with the Mundrabilla Shear Zone.

Observations from potential field studies and the seismic interpretation

Forward modelling of the potential fields were performed on the western Gawler Craton part of the seismic line to limit the possible inconsistencies between the preliminary interpretations between the seismic interpretation and the potential field modelling (van der Wielen et al., 2015). Inversions were also completed to give an idea of the distributions of high and low densities and susceptibilities.

Interpreted bedrock maps compiled by CV Spaggiari and Wise et al., (2016) from drill core data and gravity and magnetic images are used in this analysis. Previously interpreted shear zones in SA were downloaded as spatial data from the SARIG website ((https://sarig.pir.sa.gov.au/Map). Faults and shear zones define the edges of the different geological divisions within the Gawler Craton, with each division having distinct magnetic and gravity signatures (Figure 1).

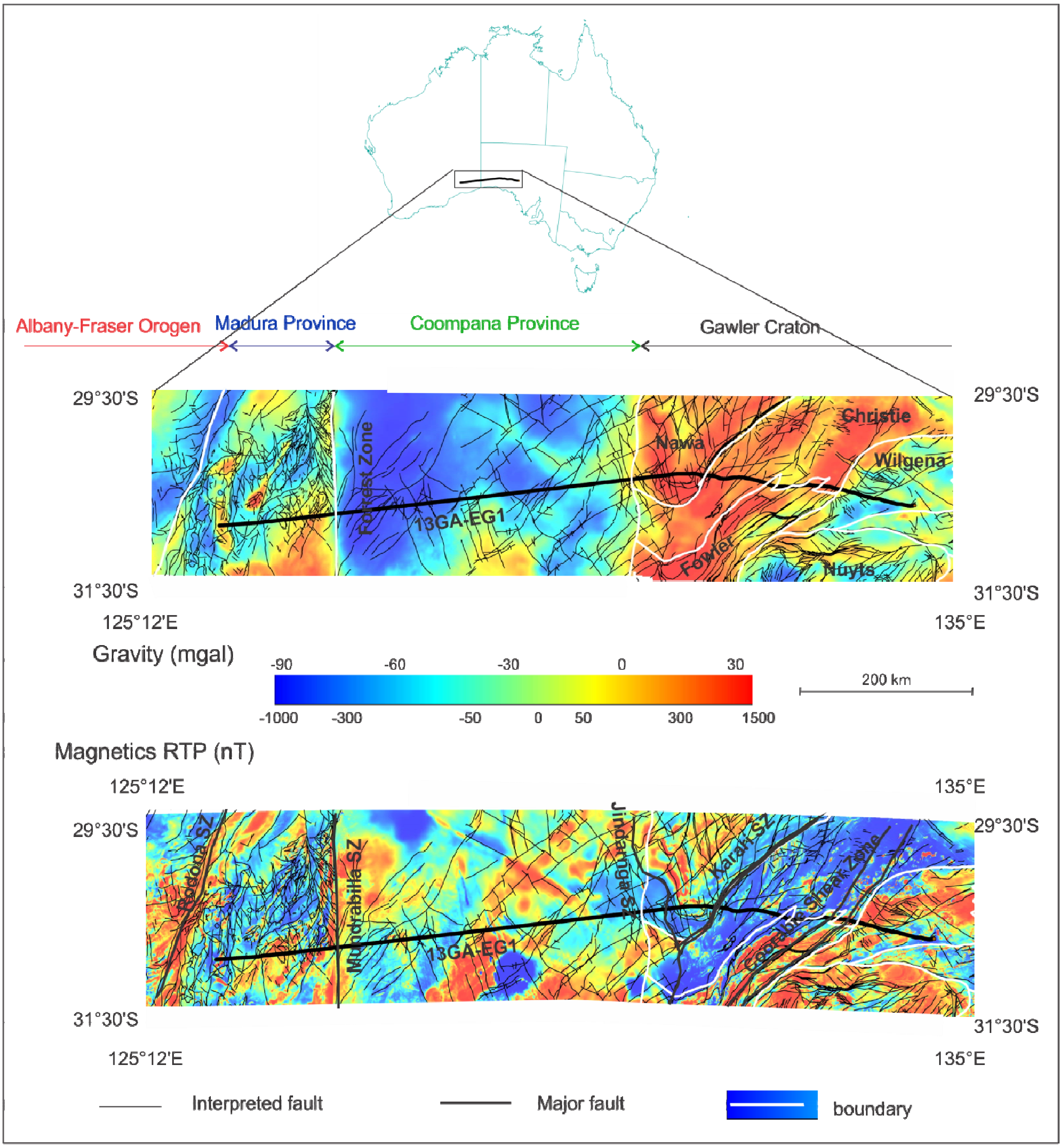

Figure 1. Gravity and RTP magnetic images as background to the main structural elements along the 13GA-EG1 seismic line

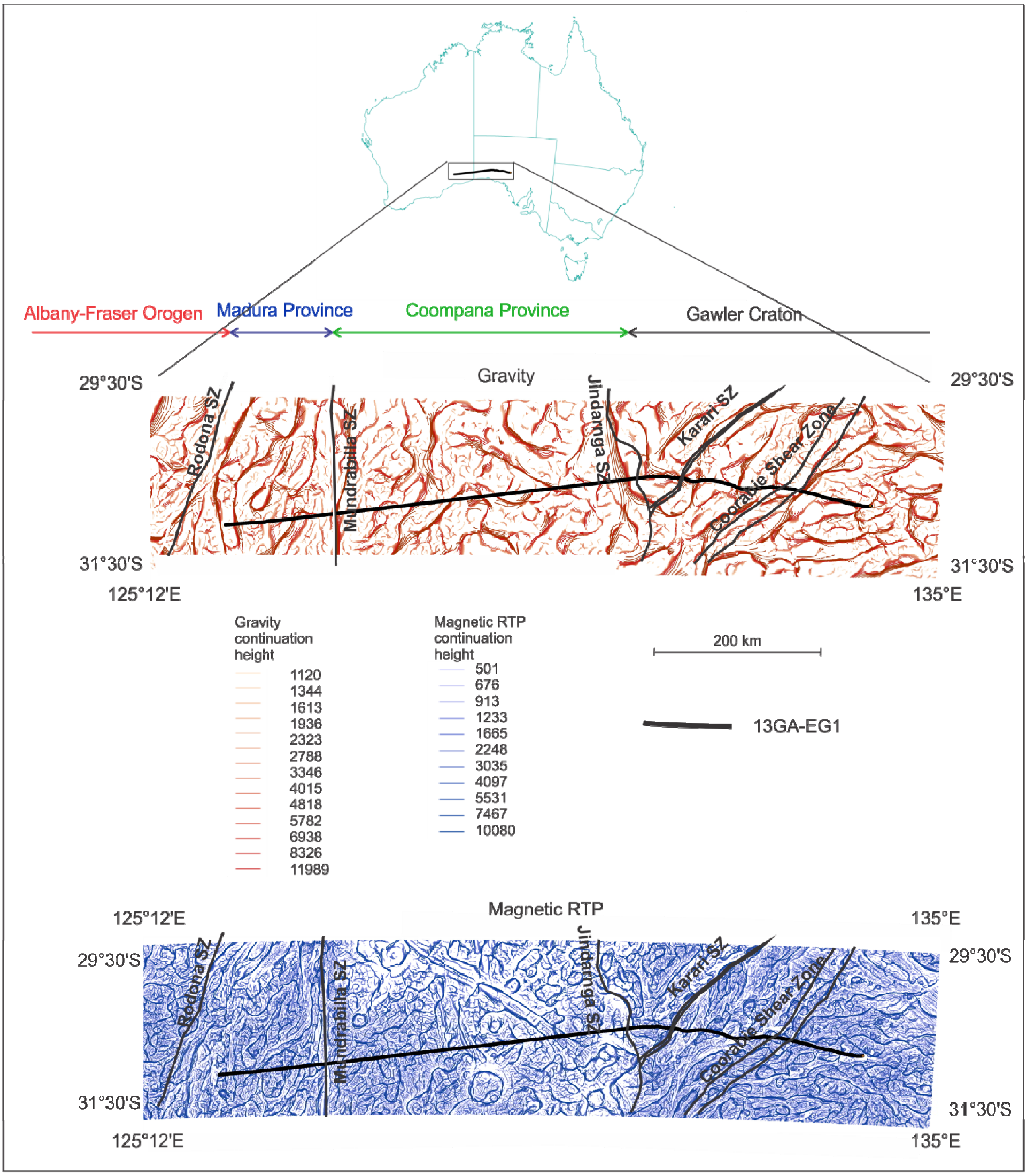

Figure 2 Gravity and RTP magnetic worms generated from the Intrepid WormE multi-scale edge-detection algorithm.

Observations of the seismic and potential field characteristics, as well as the modelling by edge detection and inversions of the tectonic components observed in 13GA-EG1, are described from west to east.

The Rodona Shear Zone defines the edge of the Albany–Fraser Orogen and separates reworked Archean Yilgarn Craton rocks and Proterozoic metasedimentary rocks and intrusions of the Albany–Fraser Orogen from the dominantly oceanic crust of the Madura and Coompana Provinces that lie between the Albany–Fraser Orogen and Gawler Craton (Spaggiari and Smithies, 2015). The Rodona Shear Zone is a wide, northeast trending set of linked shear zones, locally with high magnetic intensities, that in seismic line 12GA-AF3 dip moderately to the east (Spaggiari et al., 2014). Strong magnetic and gravity worms (Figure 2) follow the eastern edge of the shear zone. Inverse modelling also shows the high susceptibility units in the shear zone, although the dips are steeper than those imaged in seismic line 12GA-AF3, as is often the case in unconstrained inversions.

The Madura Province is the region between the Rodona Shear Zone and the Mundrabilla Shear Zone, and consists of Proterozoic oceanic to oceanic-arc crust intruded by ferrogabbroic and granitic rocks of the 1200-1120 Moodini Supersuite (Spaggiari and Smithies, 2015). Generally, the magnetic signature in the Madura Province is low, with isolated peaks picking out a dominantly north to northeast-trending fabric. This fabric is drawn into the Mundrabilla Shear Zone with sinistral shear sense. Close to the Mundrabilla Shear Zone, areas of more intense magnetics are present and the gravity also rises to a broad peak. These features are interpreted as Moodini Supersuite intrusions (Spaggiari et al., 2015), and are prominent in 1VD Bouguer gravity. The long wavelength component of this gravity gradient is enhanced in upward continued (15 km) Bouguer gravity data. The Loongana oceanic arc (Haig Cave Supersuite; Spaggiari and Smithies, 2015) stands out as prominent gravity features with associated gravity worms within the Madura Province. In seismic line 13GA-EG1 the fabric of the middle and lower crust of the western edge of the Madura Province contains apparent eastward dipping shear zones that sole onto subhorizontal reflectors, similar to those observed in the middle to lower crust of the Albany–Fraser Orogen in seismic line 12GA-AF3 where the lower crust contains the Gunnadorrah Seismic Province (Spaggiari et al., 2014).

The Mundrabilla Shear Zone is a prominent, north-south structure which is laterally continuous to the north before its signature is obscured by the Officer Basin. It is a zone of partial demagnetisation, high magnetic granites and steep gravity gradient, and based on its linearity over at least 400 km and clear sinistral shear sense is interpreted to be subvertical (Spaggiari and Smithies, 2015). Magnetic and gravity inversions and initial interpretations of seismic line 13GA-EG1 confirm this overall structure and add detail to the shear sense fabrics (Figure 3). Eastwards of the Mundrabilla Shear Zone, in seismic line 13GA-EG1 the middle and lower crust loses the dominant easterly dip observed to the west of the shear zone.

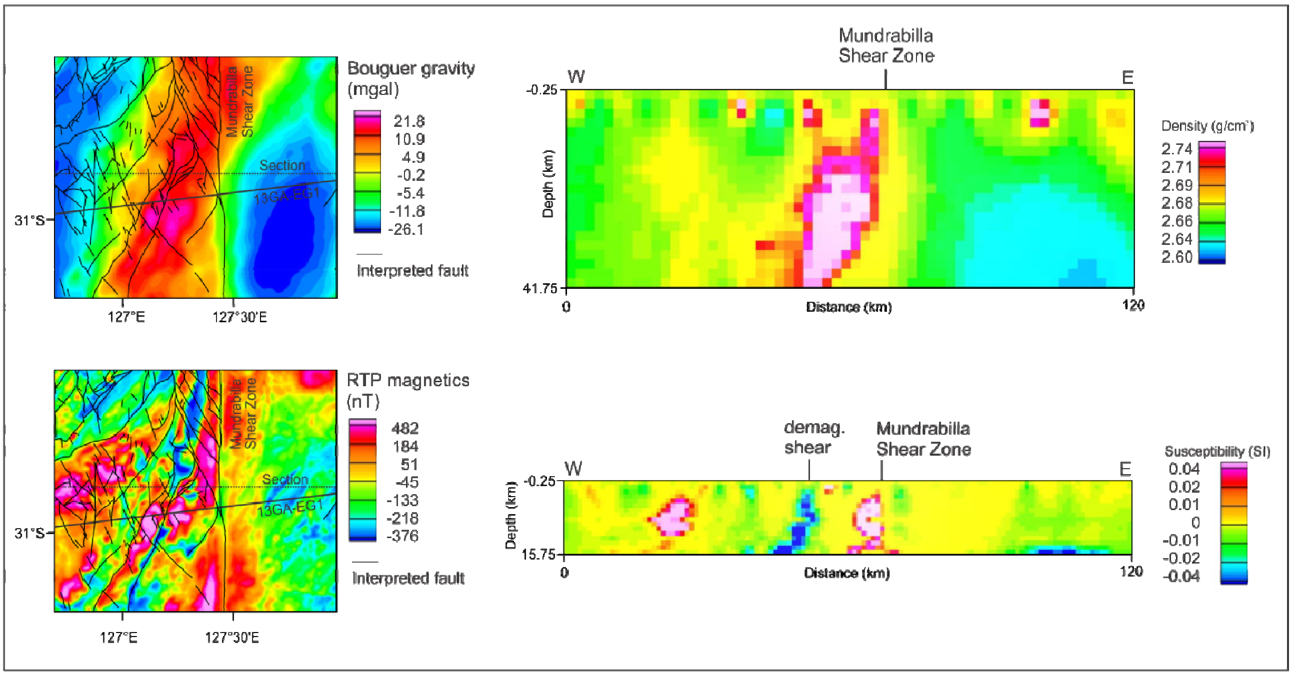

Figure 3. Gravity and magnetic unconstrained inversions over the Mundrabilla Shear Zone showing the demagnetised zone and the entrainment of susceptible and high density features within the shear zone.

The Coompana Province also has oceanic crustal heritage and a common genesis with the Madura Province, but is interpreted to have undergone episodic subduction recycling (Spaggiari et al., 2016). High magnetic signals in a northeast-trending group of circular features are interpreted as highly magnetic granitic intrusions of the 1200–1120 Ma Moodini Supersuite. These features carry strong magnetic worms, but have very little gravity contrast, although the gravity data is quite sparse in the eastern portion of this area.

In addition to the magnetic highs, the Coompana Province hosts some distinctive circular areas of strong negative magnetic signature, which implies some remanence. However, these features have very weak gravity signals, although the gravity data is sparse in this area and the signals may be shallow. More modelling of these bodies is given by Foss et al. (this volume).

The eastern Coompana Province is characterised by a broad gravity low. Structures observed in the magnetic data generally trend northeast. However, one linear feature that is wide enough to have a gravity signal as well as a magnetic signal, and trends clearly from the northwest to the southeast, is interpreted to be a dyke that may be part of the a set of dykes that intruded the Neoproterozoic Officer Basin (Wise et al., 2016).

The Jindarnga Shear Zone is interpreted as the eastern edge of the Coompana Province and is correlated with a steep positive gradient in the gravity. This is interpreted to mark the boundary of the western Gawler Craton, with the Coompana Province either thrust onto the craton, or unconformably overlying it (Dutch et al., 2015b). This change in gravity carries a continuous and consistent gravity worm which is consistent with a domain boundary interpretation. Domain boundaries within the western Gawler Craton have strong correlations with both magnetic and gravity worms, although some worms suggest that the boundaries would be more appropriately drawn in slightly different locations (Heath et al., 2009). From the Jindarnga Shear Zone to the Wilgena Domain at the eastern end of seismic line 13GA-EG1, the fabric in the middle to lower crust has a strong westerly dip (Doublier et al., 2015).

The Nawa and Fowler Domains of the western Gawler Craton may have the Neoarchean Mulgathing Complex or equivalent as basement rocks. The Nawa Domain has virtually no surface exposure so the geology has come almost entirely from relatively few drill holes. Paleoproterozoic sedimentation and intrusive activity in the Nawa Domain is similar in age and genesis to that in the Fowler Domain. The Nawa Domain contains a series of northeast-trending shears that dip to the northwest. Further to the northeast in the Nawa Domain, these structures trend east-west with dips to the north (Korsch et al., 2010; Baines et al., 2011). A series of contrasting magnetic signatures, which range from the very high to the very low, appear to wrap around in a large-scale, tight fold at the southwestern end of the Nawa Domain. Magnetic and gravity inversions show this to be a synform which appears to be inclined to the west (Figure 4). However, the upper crustal reflectors in the seismic image suggest there may be an antiformal structure in this area. The magnetic and gravity inversions correlate well with a similar-shaped feature observed in the MT profile. Furthermore, the structure in the MT can be traced to <30 km deep, whereas the one in the gravity inversion extends to about 40 km deep. This would indicate that the synformal feature extends into the middle and lower crust. (Thiel et al, 2015). Further modelling is needed to reconcile these differing interpretations.

The Fowler Domain is a region of metamorphic rocks with high magnetic intensity comprising mafic and granitic intrusions interleaved with metasedimentary rocks (Reid and Dutch, 2105). Seismic line 13GA-EG1does not cross the Fowler Domain, but the gravity and magnetic signals are dominated by broad high anomalies which are traversed by northeast-trending faults. Worms in this area correlate to intruding granites (Heath et al., 2009).

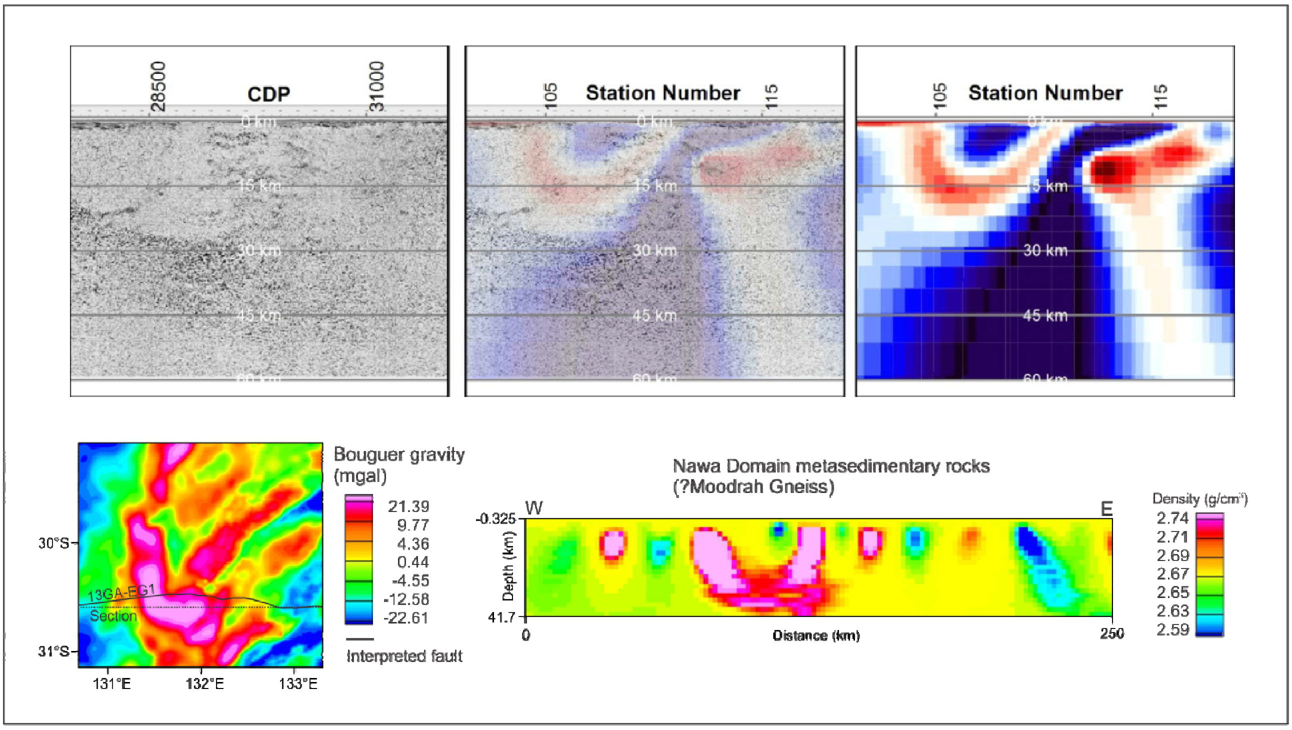

Figure 4. Comparison of the seismic, MT and gravity and magnetic inversions across the hinge of the folded structure in the Nawa Domain.

- **a) Seismic migrated stack over the Nawa feature (Doublier et al., 2015)**
- **b) MT data overlain on the seismic stack (Thiel et al., 2015)**
- **c) MT data over the Nawa feature (Thiel et al., 2015)**
- **d) Location of the gravity section over the Nawa feature in relation to the seismic line**
- **e) Unconstrained gravity inversion over the feature in the Nawa Domain**

The Karari Shear Zone divides the Nawa from the Christie Domain. In map view it contains strong magnetic slivers which appear to have been entrained into the shear zone. A magnetic feature and also a worm define the shear zone, although they are offset by about 5 km to the north of the previously drawn boundary (Heath et al., 2009).

The Wilgena and Christie Domains form the Neoarchean core of the Gawler Craton. They are both composed of the Mulgathing Complex and are separated by the Coorabie Shear Zone. They have been divided on the basis of their magnetic signature and younger geological history; the Wilgena Domain being dominated by units of high magnetic intensity and the Christie Domain having a very low magnetic background and isolated peaks which help define the fabric. In the Wilgena Domain seismic line 13GA-EG1 shows the upper crustal fabric dips to the east, although the lower crust contains the same westwards dipping fabric observed beneath the Christie and Nawa Domains. The metamorphic grade also decreases from the Christie to the Wilgena Domain (Reid and Dutch, 2015).

CONCLUSIONS

Interpretation of all available geophysical data, combined with drillholes into the basement rocks, has led to a better understanding of the Archean and Proterozoic architecture beneath Neoproterozoic to Eocene basins in southwestern Australia. These rocks hold clues to the amalgamation of this region of Proterozoic Australia.

Multi-scale edge detection or worming, although often disregarded, has shown good correlation, especially within the western Gawler Craton mapped features. They have helped in delineating deeper features within areas with no surface outcrop and lower intensity signals.

Inversions, even early-stage unconstrained inversions, show a strong correlation between features observed in the magnetics, gravity and MT. They indicate different geophysical domains or regions that can be correlated with geological domains or regions interpreted in deep crustal-scale seismic lines. Features in the inversions suggest the geometry at depth (e.g. dip direction and dip) of density and susceptibility contrasts. Structures modelled correspond to features imaged in the deep crustal seismic profile (e.g. the Mundrabilla Shear Zone) and MT data (e.g. folded metasedimentary rocks in the Nawa Domain).

ACKNOWLEDGMENTS

Published with permission from the Executive Director of the Geological Survey of Western Australia and the Director of the Geological Survey of South Australia.

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