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).

1 Geoscience Australia, GPO Box 378, Canberra ACT 2601

2 Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico

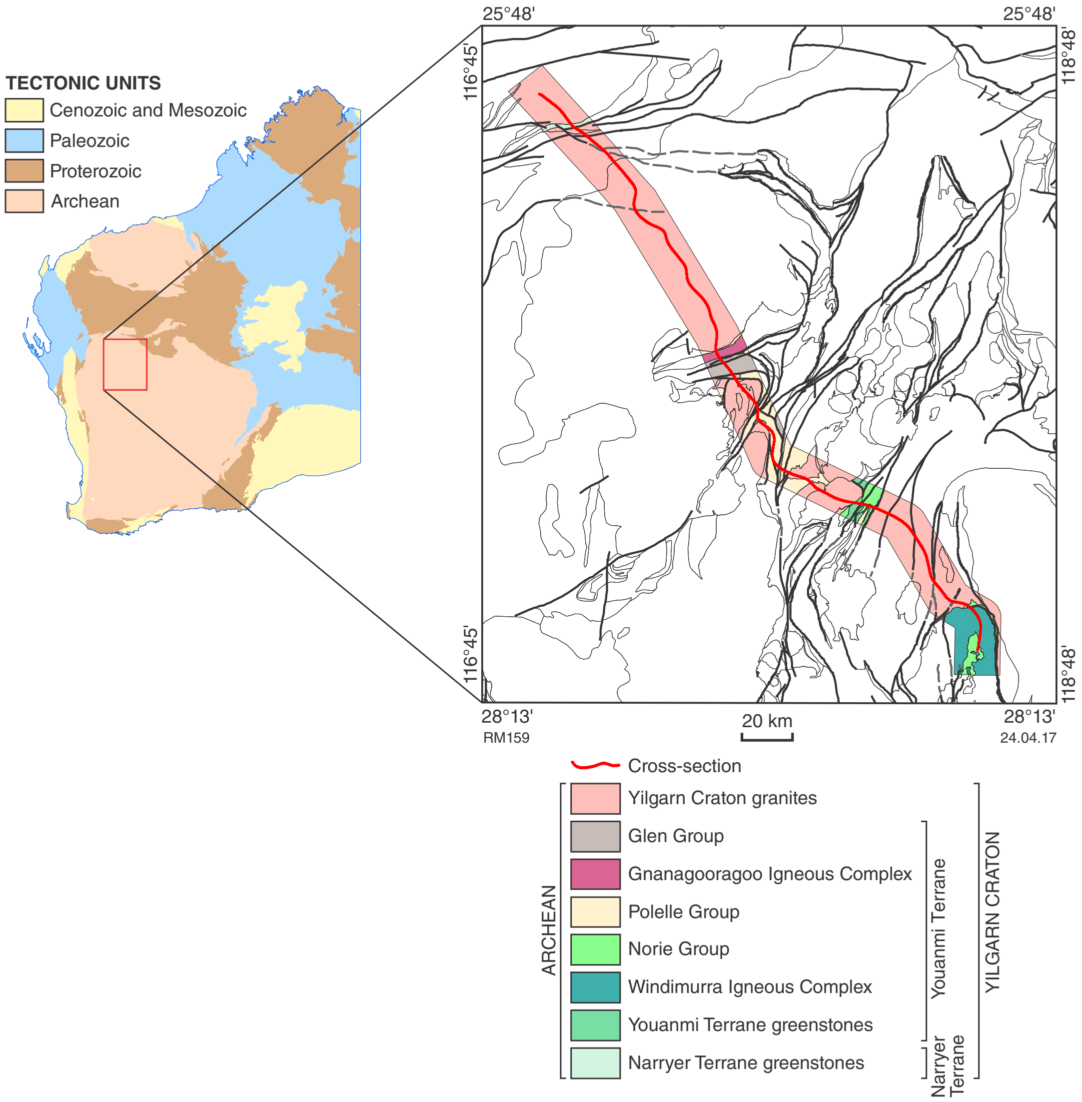

Figure 1. Narryer and northern Murchison region 1:500 000 interpreted bedrock geology map showing location of the seismic line 10GA-YU1 (in red) along which the section was modelled

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.

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.

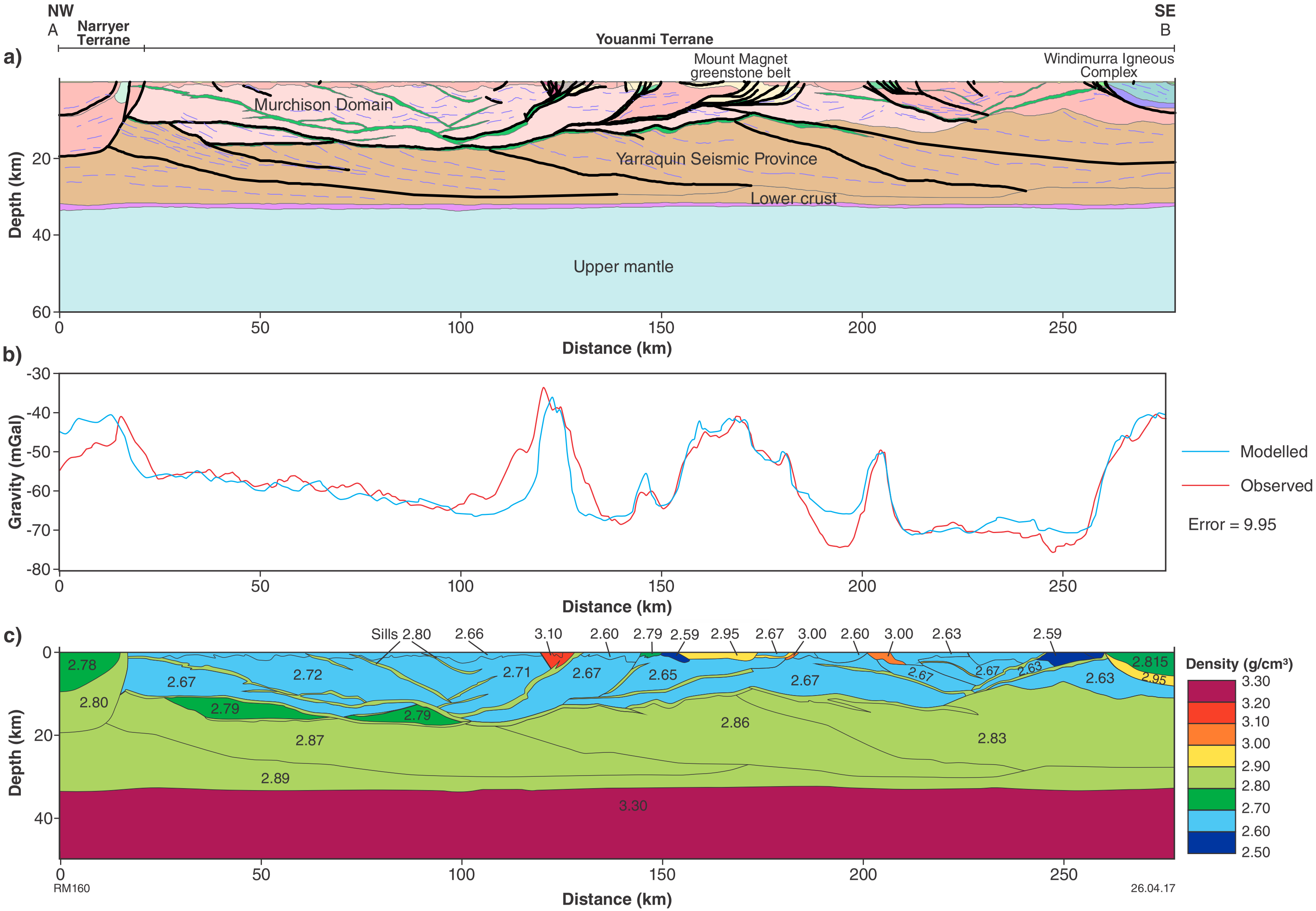

Figure 2. Forward modelling of seismic line 10GA-YU: a) lithological interpretation of the seismic line from Romano et al. (2013) and Zibra et al. (2014); b) observed and calculated gravity anomaly profile from Gessner et al. (2014); c) profile of density in g/cm³ per lithology

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

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.

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

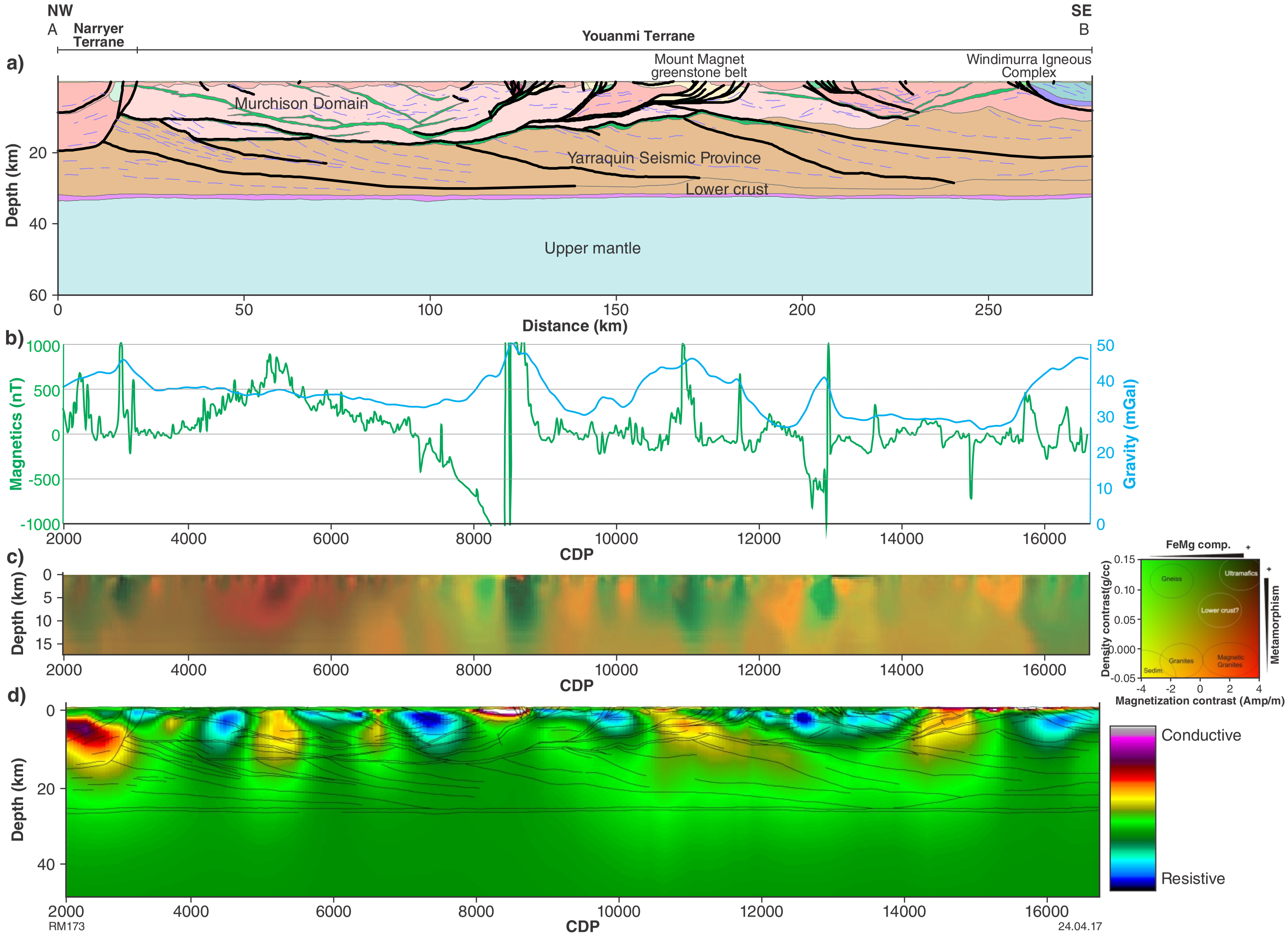

Figure 3. Inversion results of the seismic line 10GA-YU1: a) lithological interpretation of the seismic line from Romano et al. (2013); b) gravity and magnetic profiles used in the joint inversion; c) joint magnetic and gravity inversion geospectral image with a colour legend on the side; d) MT profile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

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 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.

References

Chave, AD and Thomson, DJ 2004, Bounded influence magnetotelluric response function estimation: Geophysical Journal International, v. 157, no. 3, p. 988–1006.

Chave, AD, Thomson, DJ and Ander, ME 1987, On the robust estimation of power spectra, coherences, and transfer functions: Journal of Geophysical Research, v. 92, no. B1, p. 633–648.

Costelloe, RD and Jones, LEA 2014, Youanmi seismic survey 2010: acquisition and processing, *in* Youanmi and southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 1–6.

Egbert, GD and Kelbert, A 2012, Computational recipes for electromagnetic inverse problems: Geophysical Journal International, v. 189, p. 251–267.

Emerson, DW 1990, Notes on mass properties of rock-density, porosity, permeability: Exploration Geophysics, v. 21, p. 209–216.

Gallardo, LA 2007, Multiple cross-gradient joint inversion for geospectral imaging: Geophysical Research Letters, v. 34, no. 19, p. L19301.

Gallardo, LA, Fontes, SL, Meju, MA, Buonora, MP and Lugao, PP 2012, Robust geophysical integration through structure-coupled joint inversion and multispectral fusion of seismic reflection, magnetotelluric, magnetic and gravity images: examples from Santos Basin, offshore Brazil: Geophysics, v. 77, p. B237–B251.

Gallardo, LA and Thebaud, N 2012, New insights into Archean granite–greenstone architecture through joint gravity and magnetic inversion: Geology, v. 40, p. 215–218.

Geological Survey of Western Australia 2013, Magnetic anomaly grid (80 m) of Western Australia (2013 – version 2): Geological Survey of Western Australia, digital data layer.

Gessner, K, Jones, T, Goodwin, JA, Gallardo, LA, Milligan, PR, Brett, J and Murdie, RE 2014, Interpretation of magnetic and gravity data across the Southern Carnarvon Basin, and the Narryer and Youanmi terranes, *in* Youanmi and Southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* TJ Ivanic, S Wyche and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 65–77.

Ivanic, TJ 2012, 2815–2800 Ma mafic intrusions of the Murchison: a variety of mantle sources, magmatic processes, and mineralization, *in* GSWA 2012 Extended Abstracts: promoting the prospectivity of Western Australia: Geological Survey of Western Australia, Record 2012/2, p. 3–5.

Ivanic, TJ and Brett, J 2015, The Windimurra Igneous Complex, Yilgarn Craton: an Archean layered intrusion revealed by seismic data and 3D modelling: Geological Survey of Western Australia, Record 2015/12, 32p.

Kinny, PD, Williams, IS, Froude, DO, Ireland, TR and Compston, W 1988, Early Archaean zircon ages from orthogneisses and anorthosites at Mount Narryer, Western Australia: Precambrian Research, v. 38, p. 325–341.

Korsch, RJ, Blewett, RS, Wyche, S, Zibra, I, Ivanic, TJ, Doublier, MJ, Romano, SS, Pawley, MJ, Johnson, SP, Van Kranendonk, MJ, Jones, LEA, Kositcin, N, Gessner, K, Hall, CE, Chen, SF, Patison, N, Kennett, BLN, Jones, T, Goodwin, JA, Milligan, P and Costelloe, RD 2014, Geodynamic implications of the Youanmi and southern Carnarvon deep seismic relection surveys: a ~1300 km traverse from the Pinjarra Orogen to the eastern Yilgarn Craton, *in* Youanmi and southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 147–166.

Milligan, PR, Duan, J, Fomin, T, Nakamura, A and Jones, T 2014, The Youanmi magnetotelluric (MT) transects, *in* Youanmi and Southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 13–21.

Myers, JS 1990, Yilgarn Craton — Western Gneiss Terrane, *in* Geology and mineral resources of Western Australia: Geological Survey of Western Australia, Memoir 3, p. 13–32.

Nutman, AP, Kinny, PD, Compston, W and Williams, IS 1991, SHRIMP U–Pb zircon geochronology of the Narryer Gneiss Complex, Western Australia: Precambrian Research, v. 52, p. 275–300.

Romano, SS, Ivanic, TJ, Korsch, RJ, Wyche, S, Van Kranendonk, MJ, Jones, LEA, Zibra, I, Blewett, RS, Jones, T, Milligan, P, Doublier, MP, Pawley, MJ, Gessner, K, Hall, CE, Patison, N, Kennett, BLN and Chen, SF 2013, Preliminary interpretation of the northern section of deep seismic line 10GA-YU1: Narryer Terrane to Murchison Domain of the Youanmi Terrane, *in* Youanmi and Southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 123–128.

Rudnick, RL and Fountain, DM 1995, Nature and composition of the continental crust: a lower crustal perspective: Review of Geophysics, v. 33, p. 267–309.

Telford, WM, Geldart, LP and Sheriff, RE 1990, Applied geophysics: Cambridge University Press, Cambridge, United Kingdom, 770p.

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.

Wynn, P and Bacchin, M (compilers) 2009, Index of gravity surveys (2nd edition): Geoscience Australia, Record 2009/007, 1832p.

Zibra, I, Gessner, K, Pawley, MJ, Wyche, S, Chen, SF, Korsch, RJ, Blewett, RS, Jones, T, Milligan, P, Jones, LEA, Doublier, MP, Hall, CE, Romano, SS, Ivanic, TJ, Patison, N, Kennett, BLN and Van Kranendonk, MJ 2014, Preliminary interpretation of deep seismic line 10GA-YU2: Youanmi Terrane and western Kalgoorlie Terrane, *in* Younami and Southern Carnarvon seismic and magnetotelluric (MT) workshop 2013 *compiled by* S Wyche, TJ Ivanic and I Zibra: Geological Survey of Western Australia, Record 2013/6, p. 87–96.