Forward modelling along the Southern Carnarvon deep seismic reflection line – Using gravity data to investigate seismic interpretations

James Goodwin
Geoscience Australia
Canberra, ACT
james.goodwin@ga.gov.au

SUMMARY

Forward modelling was undertaken to test the architecture of the Southern Carnarvon deep seismic reflection survey (11GA-SC1) interpretation against gravity data. The seismic data extends to ~60 km depth and images the crust-mantle boundary (Mohorovičić discontinuity) allowing it to be incorporated in the forward modelling.

Using average density values for the upper mantle, granulite to amphibolite facies mid to lower crustal rocks, and upper crustal felsic and sedimentary rocks, a model was generated which explains the observed gravity anomalies and is consistent with the seismic interpretation.

This work highlighted areas where the seismically inferred models were inconsistent with the gravity data and the importance of understanding regional trends, such as those generated by the crust-mantle boundary. The modelling undertaken in this study reflects the most up to date understanding of the regional geology in this area.

Key words: Forward modelling; gravity; Southern Carnarvon; Narryer Terrane; Pinjarra Orogen.

INTRODUCTION

The Southern Carnarvon deep seismic reflection survey (11GA-SC1) was collected in 2011 for the purpose of imaging deep crustal structures and the crust-mantle boundary (Mohorovičić discontinuity). The seismic line traverses from the Southern Carnarvon Basin in the west, to the Narryer Terrane in the east (a 260 km transect in total), recording 20 seconds of two-way travel time (data to ~60 km depth). A crucial part of the seismic interpretation process is to test the interpretations against other data. In this case, forward models were generated to test the seismic interpretation against gravity data.

The primary objective of this process was to determine where the seismically inferred models correlate with the observed gravity data and where inconsistencies exist. Postulating why these inconsistencies exist can provide a new perspective on the crustal architecture.

METHOD

Gravity data used in this study was extracted from the Bouguer Gravity Anomaly Map of Australia (2010), using the dataset resampler tool in Intrepid v4.5, along the 11GA-SC1 seismic line.

The 20 second two-way travel time (TWT) seismic reflection data was converted to 60 km depth using an average crustal velocity of 6000 m/s (i.e. 1 second of two-way travel time is equal to 3 km depth).

Forward modelling was performed using ModelVision v11.0 software, where two-dimensional polygons were drawn to match the seismic interpretation of Korsch *et al.* (2013). To avoid edge effects the section was extended 200 km in strike length (100 km either side of the profile) and 100 km beyond the ends of the seismic line. Density values were attributed to the geological bodies interpreted from the seismic data so that their gravity response could be compared with the observed gravity data.

The forward modelling method shown here is limited in that it approximates 3D geology with 2D bodies that are extended into 3D space by extending their strike length. This means that geology that is not perpendicular to the seismic line will not be represented accurately and features to either side of the profile (but not on it) can have an effect on the gravity profile that is not represented in the model. Also, forward modelling of gravity data is inherently non-unique and the consistency between the seismic interpretation and the observed gravity data shown here represents the validity of a single interpretation. However, the modelling does provide an important first-order test on the interpreted architecture and geology of this region.

The common depth point (CDP) is a unique point on an individual reflector from which seismic reflection information is recorded. The CDP number is referred to in the results section to indicate the location along the seismic line.

RESULTS

Figure 1a is a two layer model comprised of the crust and upper mantle. The crust is modelled with a density of 2.83 g/cm^3 to reflect the mean density of continental crust (Christensen and Mooney, 1995) and the upper mantle is modelled with a density of 3.30 g/cm^3 (Poudjom Djomani, *et* *al.* 2001). This model highlights the gravity trend associated with the upper mantle, which creates a broad wavelength regional low of about -40 mGal at CDP 8000. This regional trend increases to the east and west and varies with the depth of the crust-mantle boundary.

Figure 1b adds the geometry of the Southern Carnarvon Basin to the two layer model described above. The Southern Carnarvon Basin is modelled with a density of 2.40 g/cm^3 to reflect the density of sedimentary rock (Emerson, 1990). This model highlights the contrast caused by the west end of the Southern Carnarvon Basin at CDP 6400, where it is faulted against the Narryer Terrane (Figure 1b). However, an average crustal density of 2.83 g/cm^3 for the crust fails to account for gravity anomalies seen throughout the rest of the line, and so more detail in the crust is required.

Following the seismic interpretation of Korsch *et al.* (2013), the remaining crustal layers of the Narryer Terrane, Errabiddy Shear Zone, Paradise Zone and Pinjarra Orogen were included (Figure 1c). Mid (10-20 km) to lower (20-40 km) crustal layers matched the gravity profile well with densities of 2.70 – 2.85 g/cm^3. These densities represent amphibolite to granulite facies felsic to intermediate rocks (Rudnick *et al,*. 1995). The upper crustal portion of the Narryer Terrane, between CDP 3400 – 6200, consists of amphibolite to granulite facies felsic rocks, which were modelled with densities in the range of 2.60 – 2.82 g/cm^3 to reflect this (Rudnick *et al.,* 1995).

Figure 1c highlights the best fit possible using the geometries given in the seismic interpretation, however, the gravity profile suggests that the geology is more complex than what is represented in the interpretation and so further divisions were required to represent this (Figure 1d). The divisions were made based on form lines in the seismic interpretation for the western potion of the Narryer Terrane, which was divided into upper and lower crustal blocks to reflect an increase in density with depth (Figure 1d). Similarly, the amphibolite to granulite facies felsic rocks of the Narryer Terrane between CDP 3400 – 6200 were divided so that the central block could be represented as a denser layer to those on the east and west (Figure 1d). Together, these changes allowed the gravity high of -1 mGal at the western end of the line to be modelled with an improved fit to the observed data.

The final modification was to the upper crustal block (2 – 11 km depth) between CDP 10000 – 10500. This block was originally modelled with a density of 2.76 g/cm^3 (Figure 1c), as part of the Pinjarra Orogen. However, the gravity profile suggests there is a low density feature in this region, and so the density was changed to 2.50 g/cm^3 to account for this (Figure 1d). This suggests that this upper crustal block has a density significantly different to that of the average for the Pinjarra Orogen.

CONCLUSIONS

The forward models shown here highlight the regional trends associated with the crust-mantle boundary and the Southern Carnarvon Basin. Both of these have a significant effect on the gravity profile in this region and their trends can be modelled using the deep seismic reflection interpretation.

Overall, the interpretation of seismic reflection data from 11GA-SC1 is plausible as the inferred geological structures can reproduce the observed gravity data using acceptable densities.

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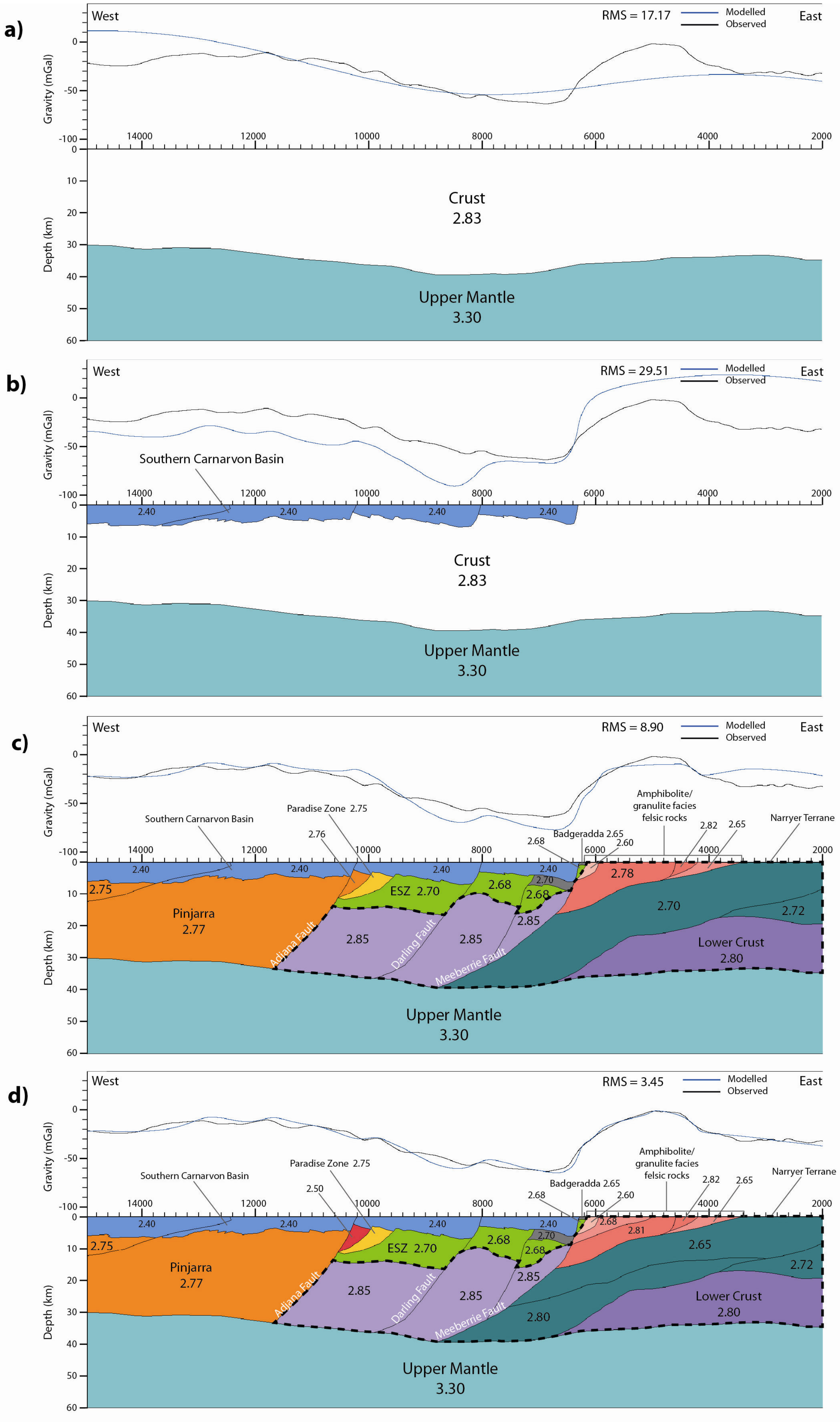
a)
West
RMS = 17.17
Modelled
Observed
East
Gravity (mGal)
0
-50
-100
14000
12000
10000
8000
6000
4000
2000
Depth (km)
10
20
30
40
50
60
Crust
2.83
Upper Mantle
3.30
b)
West
RMS = 29.51
Modelled
Observed
East
Southern Carnarvon Basin
2.40
Crust
2.83
Upper Mantle
3.30
c)
West
RMS = 8.90
Modelled
Observed
East
Southern Carnarvon Basin
Paradise Zone 2.75
2.76
Badgeradda 2.65
2.68
2.60
Amphibolite/
granulite facies
felsic rocks
2.82
2.65
Narryer Terrane
2.75
Pinjarra
2.77
ESZ 2.70
2.68
2.70
2.85
2.78
2.72
Adjana Fault
Darling Fault
Meeberrie Fault
Lower Crust
2.80
Upper Mantle
3.30
d)
West
RMS = 3.45
Modelled
Observed
East
Southern Carnarvon Basin
Paradise Zone 2.75
2.50
Badgeradda 2.65
2.68
2.60
Amphibolite/
granulite facies
felsic rocks
2.82
2.65
Narryer Terrane
2.75
Pinjarra
2.77
ESZ 2.70
2.68
2.70
2.85
2.81
2.72
Adjana Fault
Darling Fault
Meeberrie Fault
2.80
Lower Crust
2.80
Upper Mantle
3.30

Figure 1. Forward models of the Southern Carnarvon seismic line (11GA-SC1) using the geometries outlined in the seismic interpretation of Korsch *et al.* (2013). A progression of models is shown that highlights the effect of a) the upper mantle, b) the upper mantle and Southern Carnarvon Basin, c) crustal layers and, d) crustal layers sub-divided to achieve a better fit with the observed gravity data. The extent of the Narryer Terrane is shown with a dashed black line.

ESZ = Errabiddy Shear Zone, RMS = root mean square (statistical measure of the magnitude of variation between the observed and modelled gravity anomalies, where higher values represent a greater level of mismatch). All density values are displayed as g/cm^3.