Geometry of the margins of the North Australian Craton and correlations with upper crustal structures

Fatemeh Amirpoorsaeed
Monash University
fatemeh.amirpoorsaeed@monash.edu

Peter Betts
Monash University
peter.betts@monash.edu

Anindita Samsu
Monash University
anindita.samsu@monash.edu

Robin Armit
Monash University
robin.armit@monash.edu

Alexander Cruden
Monash University
sandy.cruden@monash.edu

SUMMARY

The margins of the North Australian Craton (NAC) are major lithospheric boundaries that correspond to zones of intense faulting in the upper crust. The sutures defining the edges of the eastern and southern margin of the NAC have different geometries. The eastern margin (Mount Isa Inlier) is characterised by a west-dipping geometry that dips toward the interior of the craton (inward), whereas the southern margin (Arunta Inlier) dips to the south away from the craton interior (outward). The causes of these different geometries are not well-understood, nor is their influence on later phases of deformation. We have used gravity, magnetic and seismic reflection data to investigate the influence of the NAC margin geometry on the distribution and connectivity of structures in the upper crust. These geophysical data were used to interpret major crustal boundaries, including major sutures and shallow structures.

Three major structures occur on the eastern margin of Mount Isa Inlier: the Gidyea Suture Zone, the Pilgrim Fault Zone, and the Western Edge Fault. Each of these major structures dips towards the interior of the craton. Our interpretation reveals the presence of shallow listric structures that sole out into regional decollements, which are antithetic to the major crust-penetrating faults. We observe two major sutures along the southern margin of the Arunta Inlier: the Willowra Suture and the Warrumpi Suture. The Willowra Suture represents the southernmost edge of the NAC. Seismic reflection data reveals that the structural style is very different to that of Mount Isa. Faults in the footwall of Willowra Suture are more widely spaced and penetrate through the crust to the Moho. There is no obvious link between the geometry of this margin and upper crustal structures. By comparing these findings from the Mount Isa and Arunta Inliers we can establish relationships between the structural architecture and the geometry of the craton margin.

Key words: North Australian Craton, Craton Margin, Seismic Reflection, Gravity, Magnetic, Crustal Structures

INTRODUCTION

Craton margins are characterized by dipping discontinuities and wedge-shaped crustal and lithospheric geometries (Snyder, 2002; Snyder et al., 2014) where younger orogenic belts comprising rheologically weaker rocks are interpreted to have collided with older, stronger rocks of the craton. Craton margins are also identified as locations of elevated topography, regions of higher metamorphic grade (Dirks and Jelsma, 2006), and boundaries or transitions in lithospheric geometry that are imaged in geophysical data (Betts et al., 2016; Goleby et al., 2009; Korsch et al., 2012). The geometry of a craton margin can be described by the dip and dip direction its bounding major crustal- or lithospheric-scale structure to define two main inward dipping and outward dipping categories (**Figure 1**). Craton margins can be structurally complex as they often record multiple episodes of extension and inversion that may also reactivate pre-existing structures. The structures associated with craton margins also act as pathways for fluid migration and circulation in the crust (Figure 1) (Drummond et al., 1998; Groves and Santosh, 2020; Menzies et al., 2007; Zhang et al., 2005), thereby contributing to mineral endowment (Begg et al., 2009).
Here we focus on the east and south margins of the North Australian Craton (NAC) (**Figure 2**). Although previous studies have highlighted the geometries of these boundaries to some extent (Betts et al., 2016; Betts and Lister, 2002; Korsch and Doublier, 2016), how structures associated with these margins have influenced deformation patterns during reactivation events is poorly understood. We use potential field data, seismic reflection, surface geology and structural geology maps to create detailed cross sections of craton margins, and to map shallow fault networks in the footwall and hanging wall. Forward modelling of geophysical datasets is carried out to link the known surface geology to the interpreted geophysical profiles. We then define an compare the style of deformation at both margins. We show that the NAC has boundaries that both dip inwards (eastern margin) and outwards (southern margin) and that these different geometries have impacted patterns of crustal scale deformation.

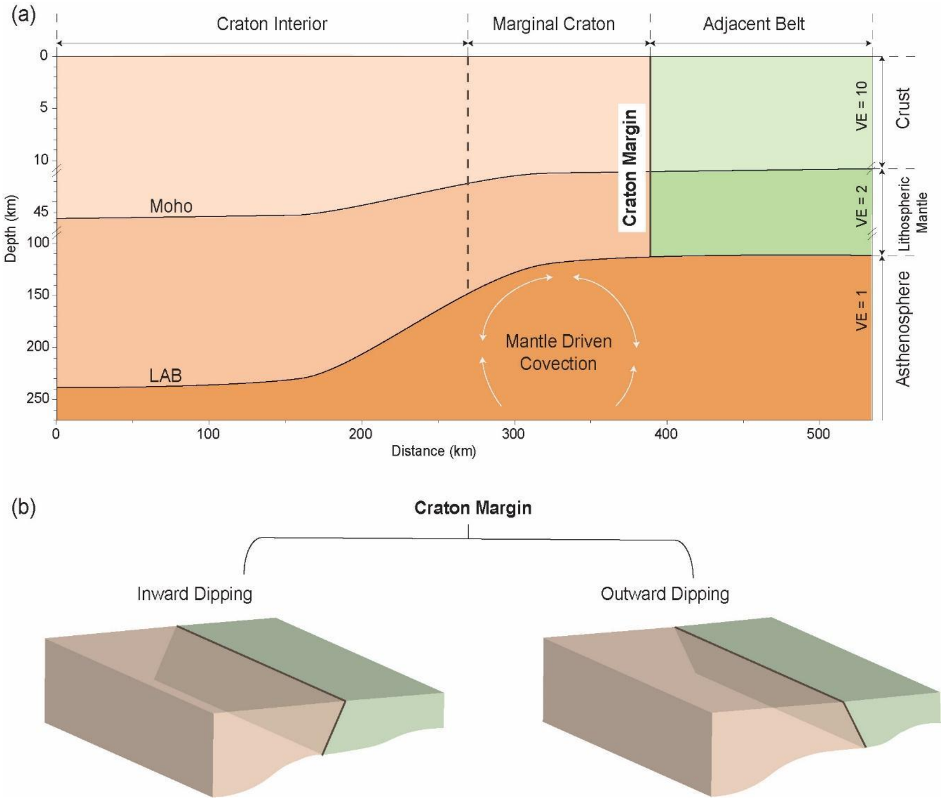

Figure 1. (a) Schematic illustration of Craton margin. Noticeable Vertical Exaggeration (VE) and prominence of the lithosphere–asthenosphere boundary (LAB) edge illustrated at 1/1 scale (Hoggard et al 2020).

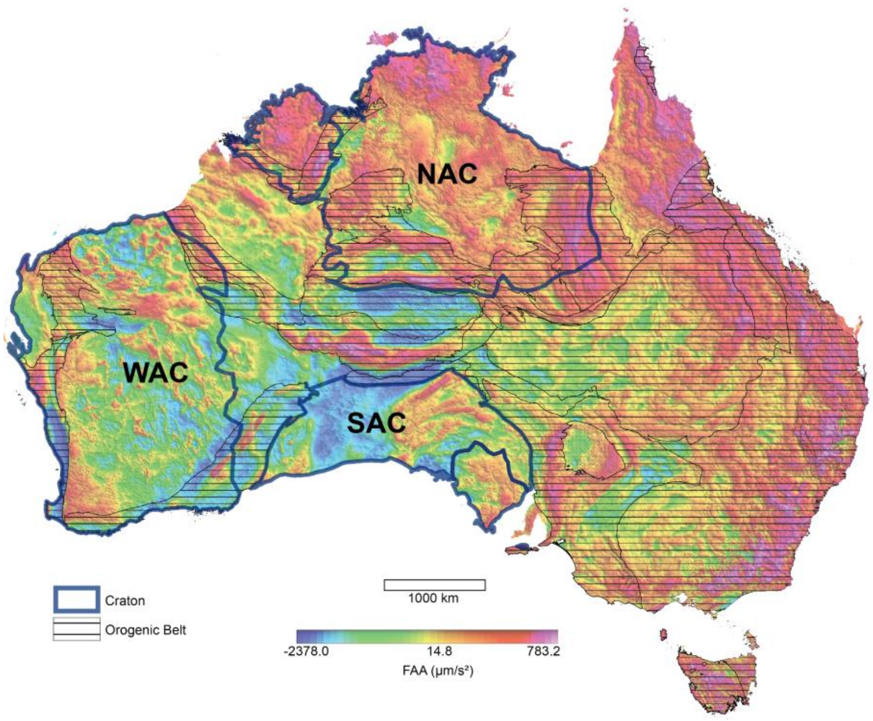

Figure 2. National Gravity Grids of Australia 2019: Free Air Anomaly (FAA), color RGB FAA anomaly on top of shaded grey scale FAA. The dark blue polygons represent the cratons of Australia, North Australian Craton (NAC). West Australian Craton (WAC) and South Australian Craton (SAC). The polygons with horizontal line patterns show the orogenic and mobile belts in Australia (Betts et al., 2006).

Inward Dipping Geometry - Mount Isa Inlier

The Mount Isa Inlier underlies the eastern margin of the NAC (Figure 3). This major lithospheric boundary between Mount Isa Block and Numil Seismic Block, coincides with a zone of intense faulting. To investigate how the geometry of the eastern NAC margin influenced the distribution of upper crustal structures, we first identified major crustal boundaries at the edge of the Mount Isa Inlier, including sutures and fault zones. We combined gravity, magnetic, and seismic reflection data, constrained by geological maps, to identify three major crustal-scale structures that correspond to the known Gidyea Suture Zone, Pilgrim Fault Zone, and the Western Edge Fault (Figure 3).

We identified a system of listric faults that sole into the regional decollements that, in turn, connect with the suture or major fault (Figure 5). The entire margin records localized deformation over a distance of ~300 km parallel to the margin. There is a significant rheological contrast between the Mount Isa Block and adjacent Numil Block, with different seismic signature. It has resulted in more asymmetric deformation that is localized on the major faults at the craton margin at the beginning of extension. This pattern shows a zone of high deformation on the east side of the Gidyea Suture (Figure 5). Asymmetrical graben structures bounded by steeply-dipping normal faults occur in the hanging wall of the Cloncurry Fault. Estimates of bulk extensional strain in narrow rifts are typically < 30%, which is consistent with the current understanding of extension during a normal rifting event.

A number of episodes of shortening on the eastern margin of the NAC gave rise to a complex history of inversion ((Cawood and Korsch, 2008). Three distinctive belts are present in the Mount Isa Inlier: the Eastern Fold Belt, Kalkadoon-Leichhardt Belt, and the Western Fold Belt. The seismic reflection data show different styles of shortening-related structures east and west of the inlier (Drummond et al., 1998). The Eastern Fold Belt is a highly mineralized zone that has a thin-skinned style structure that evolved into thick-skinned inversion. Thin-skinned tectonics dominate the Eastern Fold Belt, where sedimentary and volcanic rocks have been thrust to the west along shallowly east-dipping upper-crustal detachments cut by steeply east-dipping reverse faults (Drummond et al., 1998).

Outward Dipping Geometry - Arunta Inlier

The Arunta Inlier forms the southernmost outcropping part of the transition from the NAC. It generally strikes east-west, as do its larger internal structures, the Willowra and Warumpi Sutures (Figure 4). The crust thickens to the south. In the adjacent Tanami and Davenport Provinces the Moho lies at about ~36 km. However, to the southern Arunta Inlier the Moho depth is ~55 km as a thick part of the lithosphere to a thicker part (Goleby et al., 2009; Kirkby and Duan, 2019) (Figure 6) (Kirkby and Duan, 2019). The east-west oriented structural grain of the Arunta inlier has two major sutures that are antithetic to one another (Figure 6). The seismic reflection data confirm the presence of two major sutures, Willowra Suture and Warumpi Suture.

The Arunta Inlier margin is outward dipping structure. This deformation style is dominated by crustal penetrating structures. This zone has the characteristics of wide rifts. There is small contrast between the faults form at the craton belt boundary. The deformation style is symmetric with a wide deformed zone in the strong mobile belt to the south of the craton (Corti et al., 2013), the crustal thickness is relatively over a width greater than lithosphere thickness, and there is a large number of separated basins extending over a width of ~500 km.

The structures on the north side of the Willowra Suture and the suture are crustal penetrating structures, a typical signature of thick-skinned inversion (Figure 6) (Goleby et al., 2009). Several of the crustal-penetrating structures are interpreted as fundamental to the establishment of the current architecture of the region. Although, the Arunta Inlier sitting between the Willowra and Warrumpi Sutures have different architecture. Reflection seismic and gravity data and seismic modelling suggest that the crust of the Southern Arunta Inlier, along the Warrumpi Suture, has been thrust beneath the overriding lower crust and uppermost mantle of the Central Arunta (Goleby et al., 1989). A complex history of uplift and deformation took place on moderately dipping faults. The surface exposure of the Warrumpi Suture is the Redbank Zone. The Redbank is the structural boundary between the Arunta Inlier and Central Australia. It has a planar geometry to depth of about 35 km, and is interpreted to have displaced the mantle by as much as 5 km (Goleby et al., 1989). This supports a "thick-skinned" model for the evolution of this region.

Conclusion

NAC margins correspond to zones of intense faulting in the upper crust along major lithospheric boundaries. The geometries defining the eastern and southern margins of the NAC are fundamentally different. Eastern margins dip toward the craton interior (inward) while southern margins dip southward away from the craton interior (outward). There is not a complete understanding of the causes and effects of these different geometries. In the east, there are three major fault zones: the Gidyea Suture Zone, the Pilgrim Fault Zone, and the Western Edge Fault. These structures dip towards the interior of the craton. We interpret shallow listric structures as solenoidal decollements that are opposed to major crustal penetrating faults. On the southern margin of the NAC, Arunta Inlier, there are two major sutures: the Willowra Suture and the Warrumpi Suture. The seismic reflection data indicate that the structural style is very different from Mount Isa's. The faults that penetrate the Moho crust are more widely spaced in the footwall of the Willowra Suture. The geometry of this margin does not appear to be related to the structure of the upper crust. It can be concluded that there is a correlation between structural architecture and geometry of the craton margin by comparing these two margins.

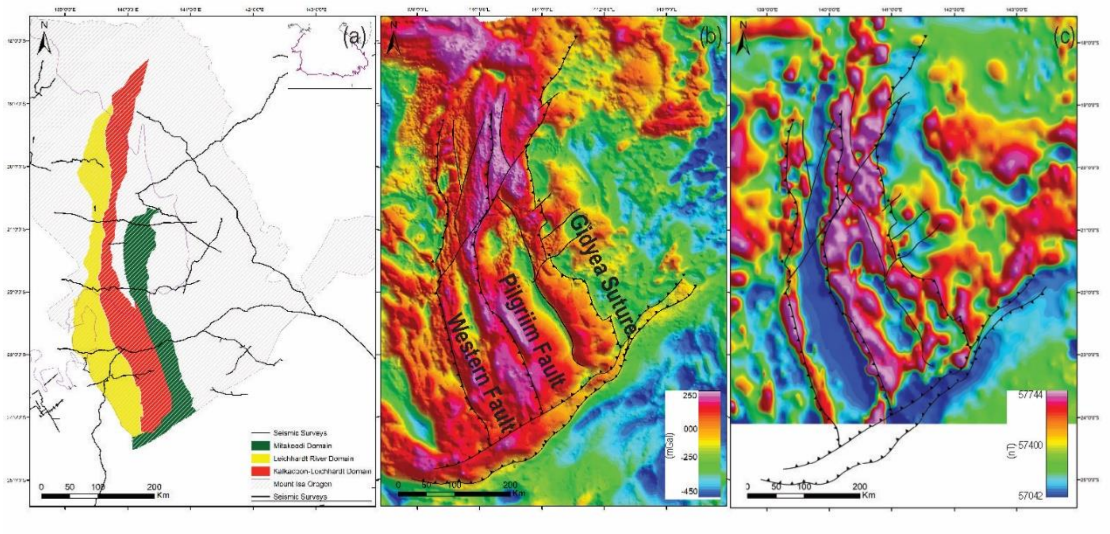

Figure 3. Mount Isa, the NAC eastern margin. a) Geological provinces and main structures. b) Free Air Anomaly (FAA), color RGB FAA anomaly on top of shaded grey scale FAA. c) Total Magnetic Intensity (TMI), color RGB TMI anomaly on top of shaded grey scale TMI.

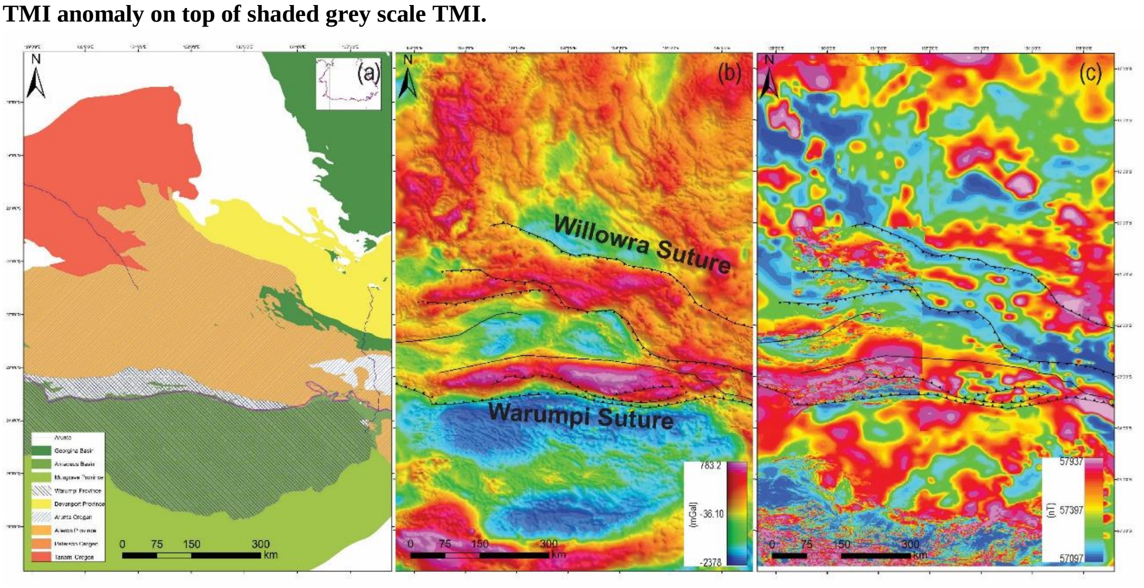

Figure 4. Arunta, the NAC southern margin. a) Geological provinces and main structures. b) Free Air Anomaly (FAA), color RGB FAA anomaly on top of shaded grey scale FAA. c) Total Magnetic Intensity (TMI), color RGB TMI anomaly on top of shaded grey scale TMI.

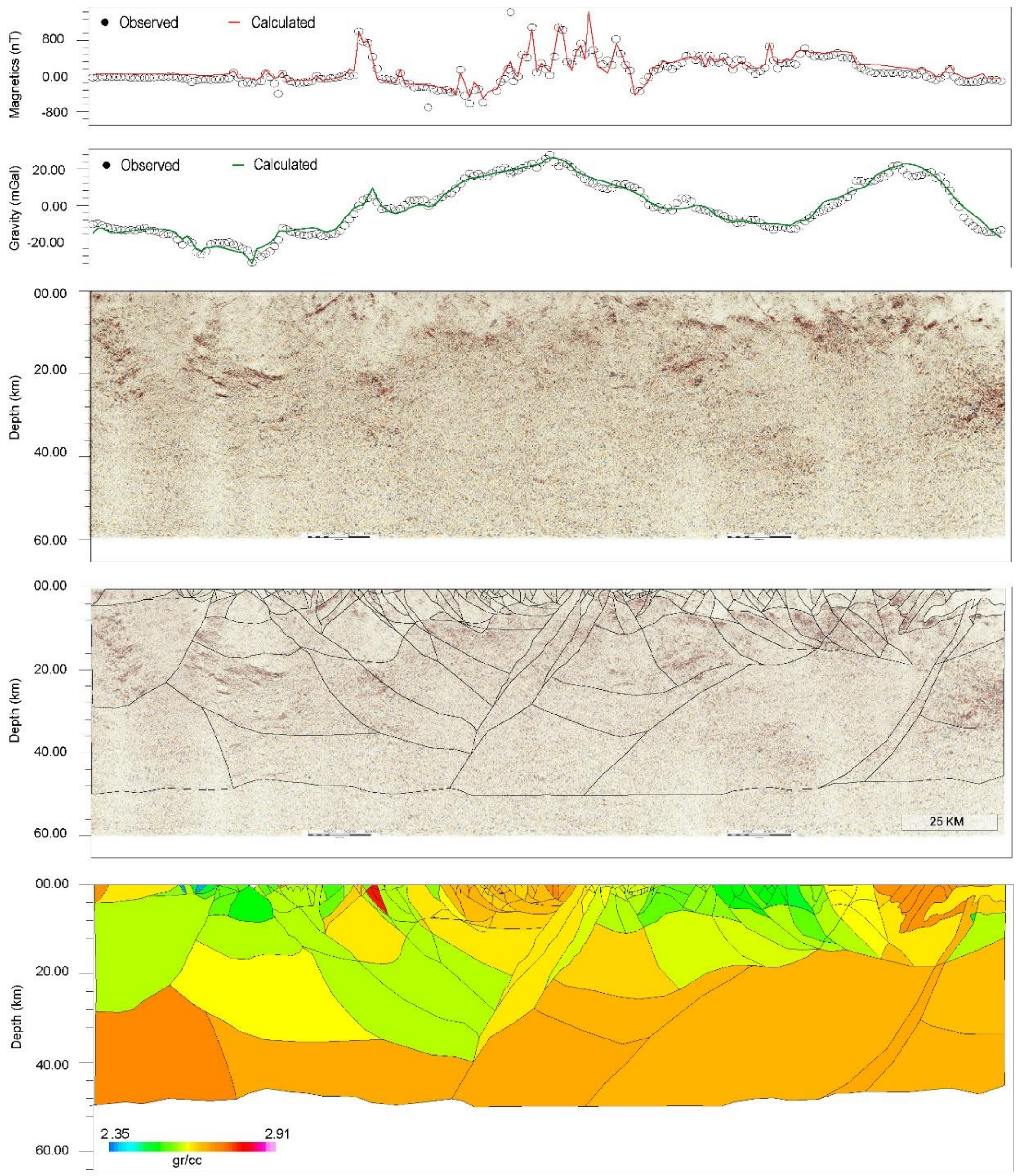

Figure 5. Line 1994-MTI-01 across Mount Isa Inlier. From top: observed and calculated magnetic response, observed and calculated gravity response, raw seismic reflection profile, structural interpretation of seismic reflection profile, density interpretation.

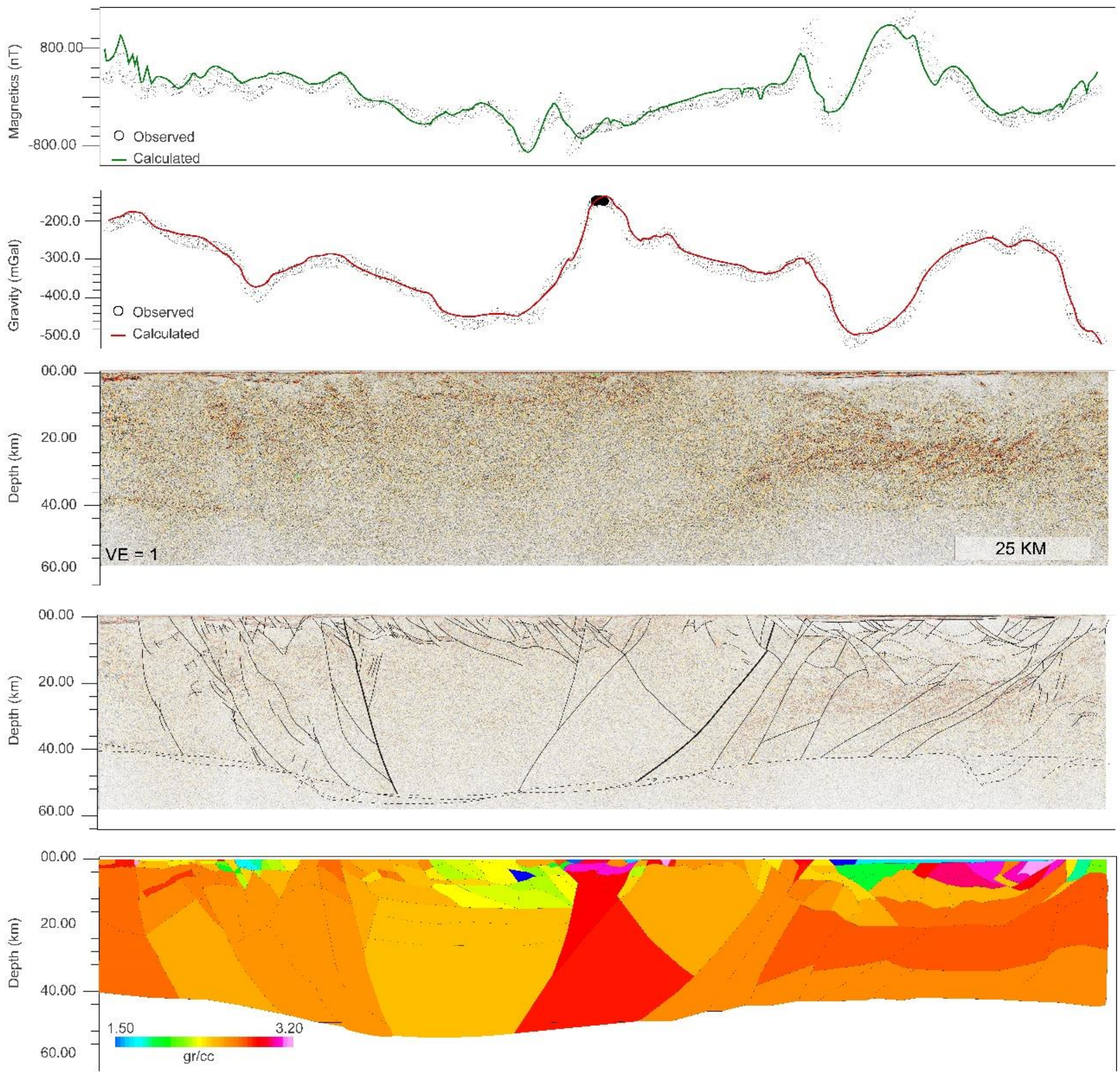

Figure 6. Line 09GA-GA1across Arunta Inlier. From top: observed and calculated magnetic response, observed and calculated gravity response, raw seismic reflection profile, structural interpretation of seismic reflection profile, density interpretation.

REFERENCES

Begg, G., Griffin, W., Natapov, L., O'Reilly, S. Y., Grand, S., O'Neill, C., Hronsky, J., Djomani, Y. P., Swain, C., and Deen, T., 2009, The lithospheric architecture of Africa: Seismic tomography, mantle petrology, and tectonic evolution: Geosphere, v. 5, no. 1, p. 23-50.

Betts, P., Armit, R., Stewart, J., Aitken, A., Ailleres, L., Donchak, P., Hutton, L., Withnall, I., and Giles, D., 2016, Australia and nuna: Geological Society, London, Special Publications, v. 424, no. 1, p. 47-81.

Betts, P. G., Giles, D., Mark, G., Lister, G., Goleby, B. R., and Aillères, L., 2006, Synthesis of the Proterozoic evolution of the Mt Isa Inlier: Australian Journal of Earth Sciences, v. 53, no. 1, p. 187-211.

Betts, P. G., and Lister, G., 2002, Geodynamically indicated targeting strategy for shale-hosted massive sulfide Pb–Zn–Ag mineralisation in the Western Fold Belt, Mt Isa terrane: Australian Journal of Earth Sciences, v. 49, no. 6, p. 985-1010.

Cawood, P. A., and Korsch, R., 2008, Assembling Australia: Proterozoic building of a continent: Precambrian Research, v. 166, no. 1-4, p. 1-35.

Corti, G., Iandelli, I., and Cerca, M., 2013, Experimental modeling of rifting at craton margins: Geosphere, v. 9, no. 1, p. 138-154.

Dirks, P. H., and Jelsma, H. A., 2006, The structural-metamorphic evolution of the northern margin of the Zimbabwe craton and the adjacent Zambezi belt in northeastern Zimbabwe, Geological Society of America.

Drummond, B. J., Goleby, B. R., Goncharov, A. G., Wyborn, L., Collins, C., and MacCready, T., 1998, Crustal-scale structures in the Proterozoic Mount Isa Inlier of north Australia: their seismic response and influence on mineralisation: Tectonophysics, v. 288, no. 1-4, p. 43-56.

Goleby, B. R., Huston, D. L., Lyons, P., Vandenberg, L., Bagas, L., Davies, B. M., Jones, L. E., Gebre-Mariam, M., Johnson, W., and Smith, T., 2009, The Tanami deep seismic reflection experiment: An insight into gold mineralization and Paleoproterozoic collision in the North Australian Craton: Tectonophysics, v. 472, no. 1-4, p. 169-182.

Goleby, B. R., Shaw, R. D., Wright, C., Kennett, B. L., and Lambeck, K., 1989, Geophysical evidence for'thick-skinned'crustal deformation in central Australia: Nature, v. 337, no. 6205, p. 325-330.

Groves, D., and Santosh, M., 2020, Craton and thick lithosphere margins: The sites of giant mineral deposits and mineral provinces: Gondwana Research.

Kirkby, A., and Duan, J., 2019, Crustal structure of the eastern Arunta region, Central Australia, from magnetotelluric, seismic, and magnetic data: Journal of Geophysical Research: Solid Earth, v. 124, no. 8, p. 9395-9414.

Korsch, R., and Doublier, M., 2016, Major crustal boundaries of Australia, and their significance in mineral systems targeting: Ore Geology Reviews, v. 76, p. 211-228.

Korsch, R., Huston, D., Henderson, R., Blewett, R., Withnall, I., Fergusson, C. L., Collins, W. J., Saygin, E., Kositcin, N., and Meixner, A., 2012, Crustal architecture and geodynamics of North Queensland, Australia: insights from deep seismic reflection profiling: Tectonophysics, v. 572, p. 76-99.

Menzies, M., Xu, Y., Zhang, H., and Fan, W., 2007, Integration of geology, geophysics and geochemistry: a key to understanding the North China Craton: Lithos, v. 96, no. 1-2, p. 1-21.

Snyder, D., 2002, Lithospheric growth at margins of cratons: Tectonophysics, v. 355, no. 1-4, p. 7-22.

Snyder, D., Hillier, M., Kjarsgaard, B., De Kemp, E., and Craven, J., 2014, Lithospheric architecture of the Slave craton, northwest Canada, as determined from an interdisciplinary 3-D model: Geochemistry, Geophysics, Geosystems, v. 15, no. 5, p. 1895-1910.

Zhang, X.-H., Liu, Q., Ma, Y.-J., and Wang, H., 2005, Geology, fluid inclusions, isotope geochemistry, and geochronology of the Paishanlou shear zone-hosted gold deposit, North China Craton: Ore Geology Reviews, v. 26, no. 3-4, p. 325-348.