Geology, geophysics, geochemistry of a hidden Palaeoproterozoic ocean-continent transition in the northern Gawler Craton

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SUMMARY

Craton margins are known to host many major deposit styles across the globe, and constraining the spatial and temporal relation between permissive geometries and thermal drivers for alteration processes are key for identifying prospective terranes.
Orthogonal deep crustal reflection seismic profiles provide insight into the three-dimensional crustal architecture of the north-western Gawler Craton, South Australia. Correlating between north-south seismic line 08GA-OM1 and east-west seismic line 13GA-EG1, has enabled the interpretation of a major crustal boundary separating the core of the Gawler Craton from re-worked crustal provinces to the west and north. We use seismic character, potential fields and magnetotellurics to locate and constrain the geometry of this major boundary, and isotopic signatures from sparse drillholes to characterize the crustal age and composition either side of the interpreted boundary.
In recent years, isotopic evidence has been used to infer the presence of early Palaeoproterozoic oceanic crust having existed between the Gawler and Yilgarn Cratons. We present a new model for the north-western Gawler Craton, locating a transitional region between a cratonic core and this oceanic crust, and suggest that the craton margin was ~100 km inboard of current interpretations.

Key words: seismic reflection, magnetotellurics, isotope geochemistry, tectonics

INTRODUCTION

Understanding the spatial location and nature of cratonic margins and trans-lithospheric structures is important for two reasons; 1) they aid in understanding crustal architecture and history, and 2) are a key ingredient in determining the mineral prospectivity for certain deposit styles (e.g. Ni-Cu Sulphides; Begg et al., 2010). Consequently, the relationships between crustal blocks of the Gawler Craton, and the Coompana and Musgrave provinces has significance in terms of potential mineral endowment, as well as more broadly as these regions are areas of large uncertainty in plate reconstruction models and commonly used to constrain Proterozoic plate reconstructions, both of Australia and globally (e.g. Betts and Giles., 2006; Wade et al., 2007; Swain et al., 2008; Payne, Hand et al., 2008; Aitken, Betts et al., 2016; Betts et al., 2016). However despite the importance, the location and nature of the boundary between the Gawler Craton, and Coompana and Musgrave provinces is unclear (Reid and Hand, 2012).

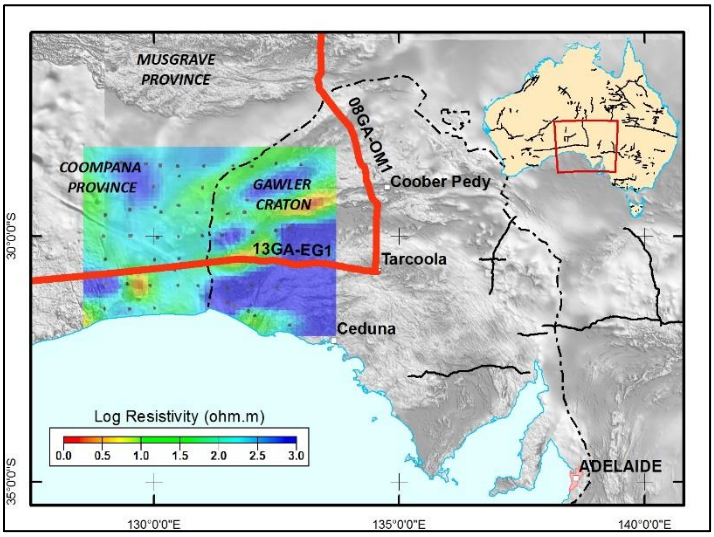

Figure 1: Location of the seismic lines crossing the north-western margin of the Gawler Craton, with respect to adjoining provinces. Dashed line shows the margin of the Gawler Craton as defined from aeromagnetics (greyscale background). Preliminary mid-crustal depth slice of 3D conductivity modelling shows anomalous conductivity (red) and resistivity (blue).

Whilst geophysical methods can identify where major structural discontinuities are, geochronological and geochemical constraints are required in order to characterise the age and composition of the crust on either side. Sm-Nd and Lu-Hf isotopic systems are used to determine whether an igneous protolith is derived from an evolved (crustal) source, a juvenile (mantle) source, or a mixed source.
The Coompana and Musgrave provinces are interpreted to have been built on a vast tract of c. 1900-2000 Ma oceanic crust (i.e. the Mirning Sea) that developed outboard of the Gawler and Yilgarn cratons, before being reworked and recycled through multiple magmatic and deformation events (Kirkland et al., 2017). Therefore a compositional boundary must have existed between the

isotopically more evolved Gawler Craton to the southeast (Reid and Hand, 2012) and the isotopically more juvenile Musgrave and Coompana provinces to the northwest (Wade et al., 2008; Kirkland et al., 2017).

The boundary has generally been placed at the northwestern-most margin of the Nawa Domain (Figure 1), a prominent feature on aeromagnetic images. Baines et al,. (2011) proposed that the boundary is the Middle Bore Fault, buried beneath the northern Nawa Domain and associated with significant potential field gradients. However, a north-south two-dimensional resistivity model derived from magnetotelluric data has failed to reveal a major electrical discontinuity associated with an ancient suture between the two provinces (Selway et al., 2011).

New and reinterpreted seismic data, regional 3D electrical conductivity models derived from the AusLAMP experiment and isotopic constraints allow us to further examine the relationship between the Gawler Craton and Coompana Province and suggest a possible tectonic model and revised location for the Gawler-Coompana/Musgrave margin. We suggest that the aeromagnetic imagery is merely depicting the extent of an upper-crustal Fe-rich metasedimentary package, and a more significant, trans-lithospheric boundary, i.e. an ocean-continent transition, is hidden beneath the basin. These results will help in constraining and understanding the Proterozoic evolution of Australia.

RESULTS

Seismic

From two orthogonal deep seismic sections (13GA-EG1 and 08GA-OM1; Figures 1,2), across the western and northern margin of the Gawler Craton, respectively, we observe that the trend and dip of major structures and crustal blocks is remarkably consistent for a multiply-reworked craton margin. Major structures generally strike to the north-east, dip moderately to the north-west and can in several cases be correlated on both profiles based on the seismic character of the crustal blocks they offset. We interpret a change from broadly reflective mid-upper crust toward the core of the Gawler Craton, through a region of stacked, inclined reflectors (Wirinjinna Seismic Subdomain; Figure 2), to a dominantly non-reflective mid-upper crust to the north and west to signify a change in mid-upper crustal protoliths. This abrupt change occurs across the Jindarnga Shear Zone in the south west, and the Big Swamp Bore-Cadney Park shear zones to the north.

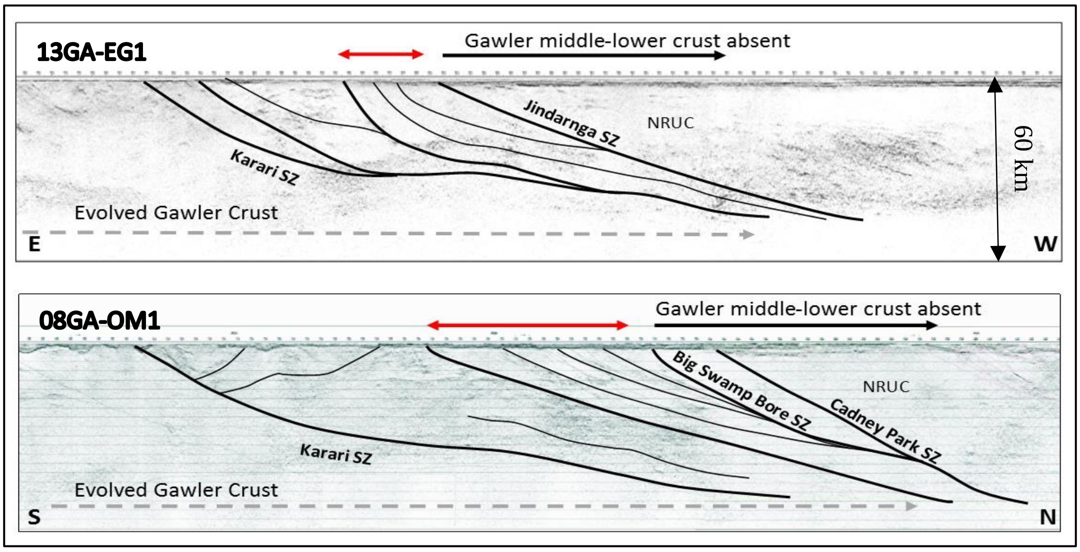

Figure 2: Crustal seismic sections and partial interpretations, 13GA-EG1 (after Doublier et al., 2015) and 08GA-OM1 (after Korsch et al., 2010). Red arrows show the extent of the multiply-reworked Wirinjinna Seismic Subdomain

Magnetotellurics

Preliminary 3D resistivity modelling of AusLAMP long-period magnetotelluric stations, on a roughly 400 km x 400 km grid with a 50 km site spacing across the western margin of the Gawler Craton has revealed a highly resistive mid-upper crust associated with the Gawler Craton, typical of Archaean cratonic regions (Jones et al., 2012). Generally parallel with, but significantly in-board of the previously interpreted margin of the Gawler Craton is a broad transition between such highly resistive mid-upper crust towards the cratonic core, and a much more heterogeneous and generally more conductive crustal column associated with the Coompana Province, (Figure 1).

An elongate corridor of anomalous conductivity striking east-northeast towards Coober Pedy (Figure 1), may suggest that such Palaeo-Mesoproterozoic reworking exploited pre-existing structures (e.g. Karari Shear Zone, Figure 2) in the Gawler Craton interior, or perhaps is related to anomalous conductivity extending beneath the Gawler Craton itself at depths greater than 100 km (Thiel and Heinson, 2013).

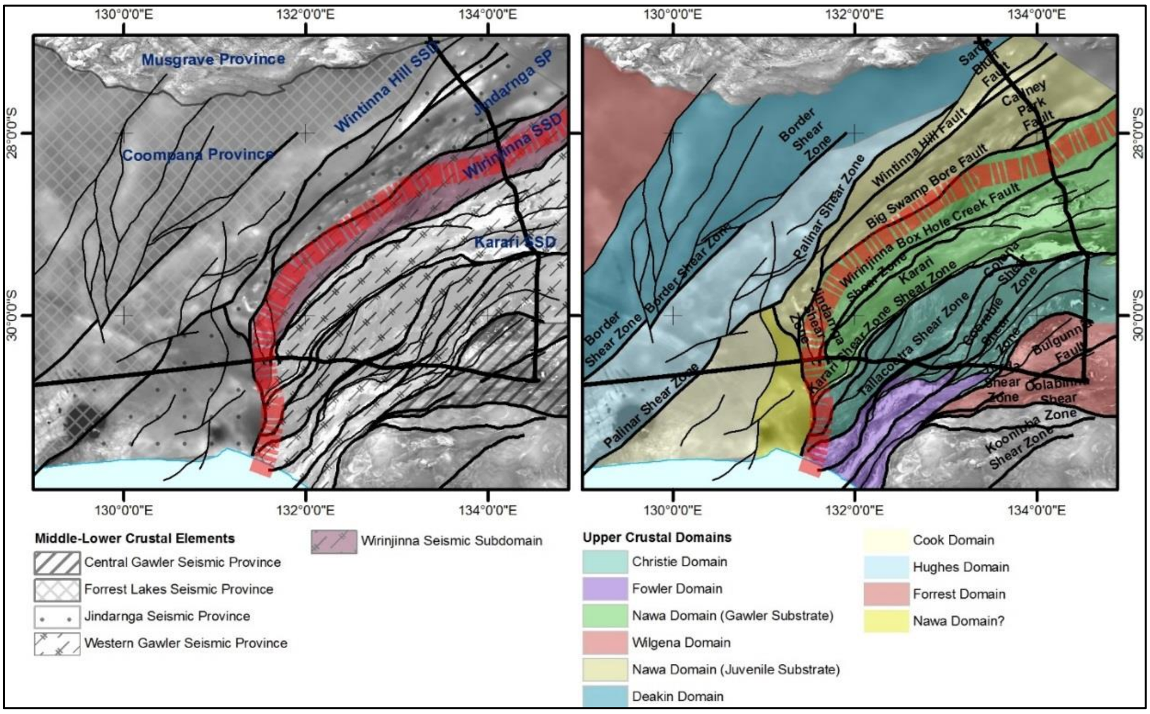

Figure 3: Mid-lower crustal elements and upper crustal domains defined by seismic interpretation and interpolated between lines using potential field imagery (modified after Doublier et al., 2015 and Wise et al., 2015). Dashed red line indicates the location of the proposed c. 1900-2000 Ma ocean-continent transition (OCT) at the revised Gawler Craton margin.

CONCLUSIONS

Kirkland et al (2017) discuss the wider isotopic evidence for a c. 1900-2000 Ma oceanic tract, whilst we concentrate on the interaction of this crust with the northwestern margin of the Gawler Craton. Isotopic constraints from drillholes Mallabie 1 (eastern Coompana Province, Wade et al., 2007), Middle Bore 1 (northern Nawa Domain, Howard et al., 2011) and numerous examples from the western Coompana Province (e.g. Kirkland et al., 2017), place juvenile crust with depleted mantle model ages of no more than 2000Ma to the west and north of the Cadney Park and Jindarnga shear zones (Figure 2), whereas the isotopic signature of the protoliths to the south and east of these structures require a more evolved crustal input with significantly older model ages(e.g. OBD drillholes, central Nawa Domain; Howard et al., 2011). Therefore, a change in mid–lower crustal composition and protolith age is recorded across the Wirinjinna Seismic Subdomain, (Figure 3), a zone of imbricated, highly reflective middle-upper crust, outboard of the Karari Seismic Subdomain, and ~100 km to the southeast of where the cratonic margin is currently mapped. We therefore interpret the Wirinjinna Seismic Subdomain as a multiply-deformed and re-worked ocean-continent transition (OCT) between the c. 2450 Ma Gawler Craton and c. 1900 Ma oceanic crust (Figure 4). Given the predominantly ocean-ward dipping major structures, we suggest that this was an extended passive margin, prior to re-activation.

We interpret the enhanced conductivity in the Coompana Province to be caused by Palaeo-Mesoproterozoic reworking of c. 1900-2000 Ma oceanic crust, not typically seen within the interior of the Gawler Craton. It can therefore be inferred that the resistivity gradient between conductive Coompana and resistive Gawler crusts is a proxy for a Palaeo-Mesoproterozoic margin.

This model would suggest that the Gawler Craton and Coompana Province were autochthonous, with the Mirning Sea (Kirkland et al., 2017) forming between the Gawler and Yilgarn Cratons.

The boundary is overlain by a metasedimentary sequence (i.e. the Nawa Domain) that effectively obscured the OCT, particularly with potential field imagery being dominated by high amplitude, high frequency signal arising from highly magnetic and variably dense Fe-rich metasedimentary units. This explains why it is difficult to reconcile major structural boundaries based on potential field datasets alone, and shows the benefits of joint interpretation of disparate data sets to obtain an understanding of 3D architecture.

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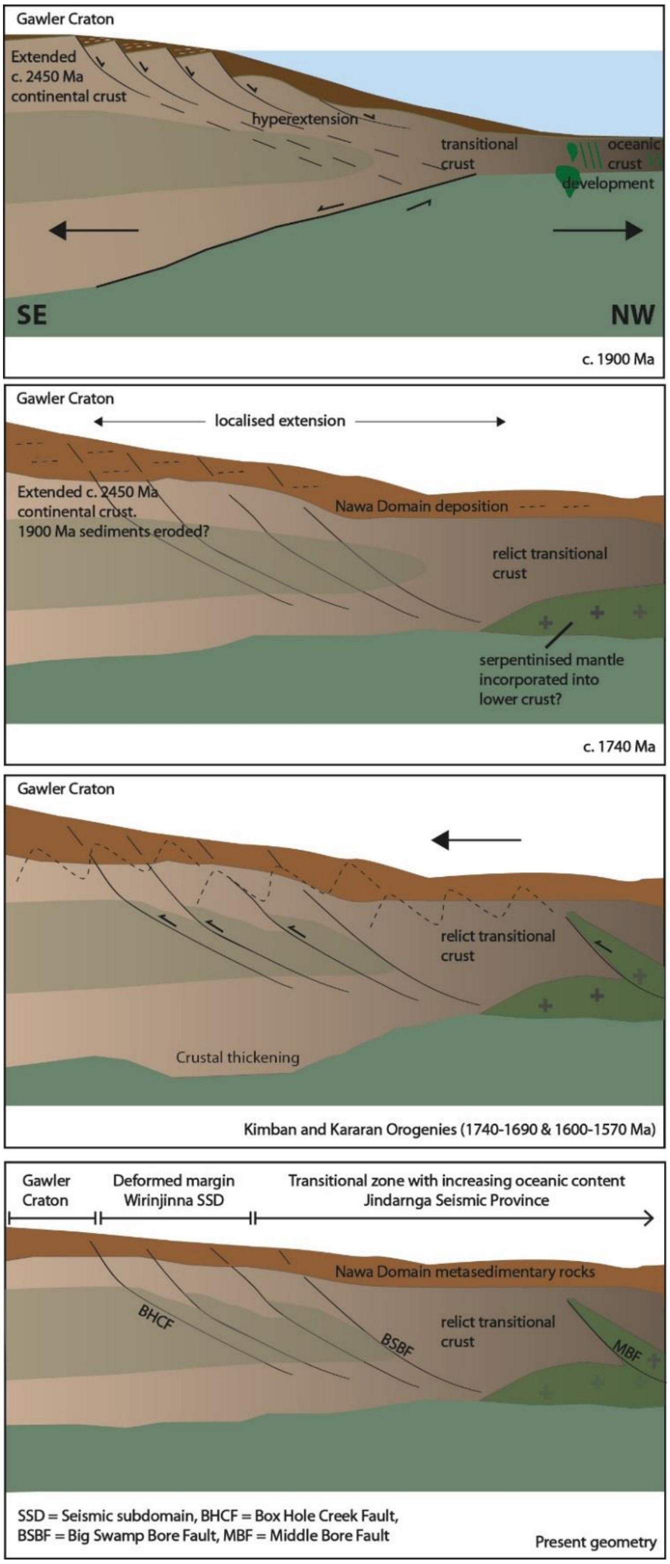

Figure 4: Schematic interpretation for the development and subsequent re-working of the proposed north-western margin of the Gawler Craton

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