Metasomatic/depletion events affecting Cratons and “cratons”

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SUMMARY

We integrate seismic tomographic models and filtered gravity anomaly maps to investigate the compositional variations in the SCLM of Australia. We find zones of relative enrichment and depletion coinciding with the spatial extent of major thermal events. Anomalous regions of enrichment may represent subduction metasomatism of the lithospheric mantle, or refertilisation due to asthenospheric upwelling. Regions of apparent depletion signify high-degree melt extraction from a previously more enriched lithosphere.

Key words: Gravity, Seismic Tomography, Lithosphere, Craton

INTRODUCTION

Cratons are stable, continental regions that have been isolated from tectonothermal re-working for >1 Ga (Lee et al., 2010). A product of major mantle depletion events, strong and buoyant harzburgitic residuum protects cratonic regions from subsequent deformation. By virtue of preservation from re-working on timescales greater than 1 Ga, cratons can only be Proterozoic and older, and generally comprise the core of continents, the margins of which are the focus of reactivation.

Much debate surrounds the mechanisms by which cratons achieve a thick depleted root (cratonisation) and thereby achieve stability (isopycnicity) over such long timescales (e.g. Bedard, 2018; Condie, 2018; Herzberg, 2018; Wyman, 2017, and references within). The destabilisation, or de-cratonisation, of cratonic roots (e.g. Wyoming Craton, Snyder et al., 2017; North China Craton, Wang et al., 2018) has also been the subject of recent interest, as metasomatism of a previously stable sub-continental lithospheric mantle (SCLM) has been linked to magmatic-associated ore deposits (e.g. Skirrow et al., 2018).

Here, we integrate continental-scale seismic tomographic data and long-wavelength gravity data with the aim of mapping regions of melt extraction (depletion) and metasomatism/re-fertilisation (enrichment) in the SCLM of the Australian continent. We use Mg# (100Mg/(Mg+Fe)) as a measure of enrichment/depletion as the Mg:Fe composition of olivine reflects metasomatic processes (driving the bulk composition toward the Fe-rich end member, fayalite), or melt extraction (driving the bulk composition toward the Mg-rich end member, forsterite).
Our results identify regions of depleted lithosphere beneath the Western Australian cratons, whilst the “cratonic” regions of Northern and Southern Australia show apparent enrichment consistent with a metasomatised SCLM. Regions of relative enrichment and depletion in central and southern-central Australia provide interesting cases of upwelling asthenosphere-SCLM interaction in the Proterozoic (e.g. Smithies et al., 2011; Smithies et al., 2014; Gorczyk et al., 2016).

METHOD

The lithospheric mantle is highly heterogeneous across all scales, however, thermal perturbations affect our ability to map compositional variations in mantle peridotites using geophysics. In particular, higher temperatures decrease shear wave velocity (Vs) and lower density. Conversely, whilst compositional variations alter Vs and density such that depletion reduces density and increases Vs (Griffin et al., 1999; O’Reilly et al., 2001), while enrichment produces the opposite effects). Relating Vs and density therefore serves to reduce the effect of temperature variations. The relationship between ρ/Vs and Mg# is defined in Afonso et al (2010).

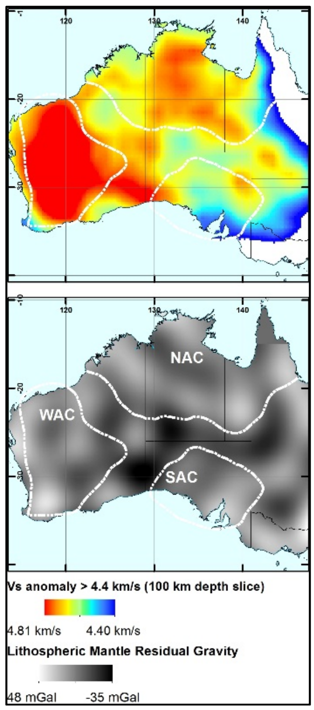

Figure 1. Top; Shear wave velocity 100 km depth slice from AuSREM (Kennett et al., 2013). Bottom; Wavelength-filtered gravity anomaly map (after Sandwell et al., 2014) showing variations beneath the crust. White dashed lines represent the approximate location of the North, South and West Australian Cratonic regions (NAC, SAC and WAC).

Here, we use the above relationship and available spatial proxies, >500 km wavelength gravity anomalies as a proxy for density, (Figure 1 bottom, e.g. Czarnota et al., 2014) and Vs depth slices (Figure 1 top) and the following method (Figure 2) to produce a map of relative enrichment/depletion (relative changes in Mg#) across the continent.

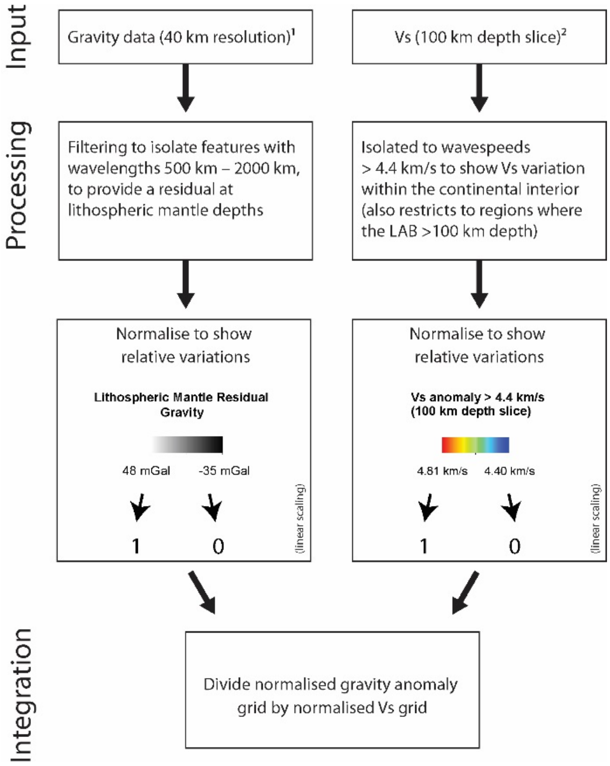

Figure 2. Processing methodology using spatial proxies to investigate the ρ/Vs : Mg# relationship. ([1] Figure 1 bottom; Sandwell et al., 2014. [2] Figure 1 top; Kennett et al., 2013)

RESULTS

The resulting continental-scale compositional map (Figure 3) shows regions of relative enrichment/depletion in the SCLM. Blue colours indicate regions of relative depletion (higher Mg#), resulting from negative gravity anomalies and fast Vs. Green-white colours indicate positive gravity anomalies and slow Vs suggesting relative enrichment/fertile lithosphere, (lower Mg#).

To give an indication of the reliability of these results, other data types, geological and geophysical are discussed with respect to mapped zones of relative enrichment and depletion (Figure 3):

1. The continent-ocean transition zone south of central-Western Australia (Whittaker et al 2008), coincides with the transition between depleted continental lithosphere, and fertile, oceanic lithosphere.
2. Depletion zones in Western Australia show a close association with the location of Archean cratons.
3. A region of relative enrichment beneath the West Musgrave Province coincides with the focus of c. 1070 Ma mafic and felsic magmatism associated with the Giles event and the Warakurna large igneous province (LIP) (Alghamdi et al., 2018).
4. The Gawler Craton, and parts of the North Australian Craton are relatively enriched, likely due to subduction-related metasomatism during the Proterozoic (Skirrow et al., 2018, Thiel et al., 2013)
5. A zone of relative depletion in south western Queensland may be associated with a thermal event producing granites of the Thomson Orogen (Abdullah and Rosenbaum, 2018).
6. Regions of highly anomalous apparent depletion and enrichment are present between the WAC and the Gawler Craton.
    a. The enriched region E1 coincides with the location of the Gunnadorrah Seismic Province (Spaggiari and Tyler, 2014; Sippl et al., 2017), and may suggest "freezing" of enriched lithospheric mantle on to the base of the thin crust of the Madura Province and Albany Fraser Orogen.
    b. The depleted region D1, in the Coompana Province likely represents a high-degree of melt extraction during the 1200-1140 Ma magmatic event (Dutch et al., 2018), and is associated with highly resistive lithosphere in 2D magnetotelluric models (Thiel et al., 2018).

Broad (>1000 km in length/width) regions of apparent enrichment of the SCLM appear to be the product of metasomatic modification during subduction cycles, e.g. northern and South Australia (Figure 3). Whilst more focused zones of enrichment ~500 km, may signify regions of upwelling asthenosphere (plume or otherwise) refertilising the lithosphere, e.g. associated with the Warakurna LIP (Figure 3).

In summary, regions typically referred to as cratons exhibit varying degrees of enrichment/depletion, from depleted in the WAC, to generally enriched in the SAC (Gawler) and NAC. A region of apparent depletion between the Gawler and WAC (D1), coincident with high electrical mantle resistivities (Thiel et al., 2018) has a craton-like geophysical signature, yet is not known to have an evolved Archean crustal substrate (Kirkland et al., 2017) typically associated with cratonic regions.

CONCLUSIONS

We integrate continental-scale gravity data and seismic tomography using the relationship ρ/Vs:Mg# (Afonso et al., 2010) to provide a control on relative depletion/enrichment of the sub-continental lithospheric mantle (SCLM). Our results broadly mirror the extent of major thermal events from the Archean to the Phanerozoic. Intriguing zones of relative enrichment and depletion are noted between the WAC and the Gawler Craton and will be the focus of future work.

These findings have implications for mapping lithospheric blocks and the discontinuities that separate them. Such lithospheric-scale discontinuities are important zones of fluid and mass transfer through the lithosphere that can result in the formation of ore deposits and localise episodic lithosphere deformation.

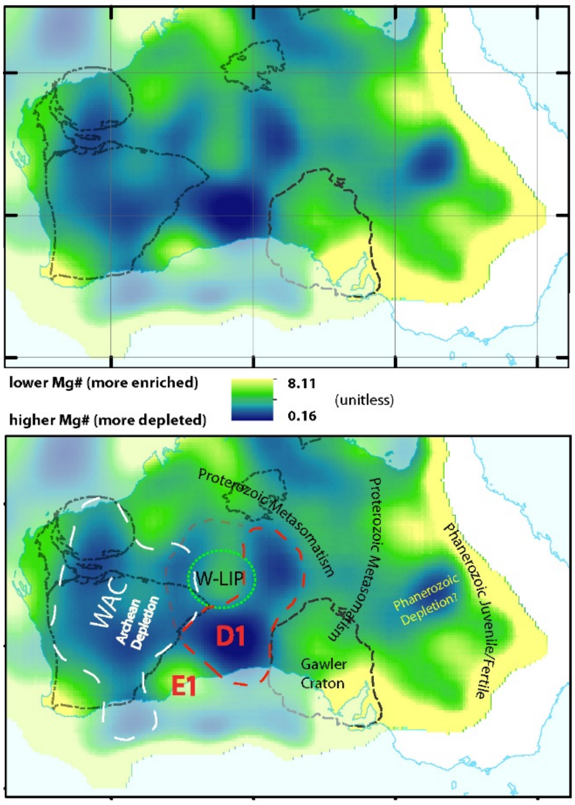

Figure 3. Top; uninterpreted SCLM compositional map with the location of Archean crustal elements (black dashed lines; Raymond et al., 2018). Bottom; interpretation showing zones of relative enrichment and depletion. WAC = West Australian Craton; W-LIP = focus of the Warakurna Large Igneous Province.

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