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Lithospheric discontinuities in Central Australia

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ABSTRACT

Lithospheric discontinuities are elusive, with properties that are strongly frequency dependent. Results from a temporary deployment of broadband stations along a north-south transect through Central Australia, and the permanent arrays ASAR and WRA, are used to evaluate the spatial coherence of lithospheric features, particularly mid-lithospheric discontinuities. We exploit stacked station autocorrelograms that provide an estimate of *P*-wave reflectivity beneath stations, with imaging methods exploiting teleseismic arrivals. We use both common conversion point (CCP) stacking from *Ps* receiver functions and reflection point imaging using the autocorrelation of the *P* wavetrain. The results tie well for the Moho and have a good general correspondence for deeper levels. Although indications of mid-lithospheric discontinuities from changes in the frequency of reflectivity occur at similar depths, the spatial continuity of specific features at high frequency (around 2 Hz) is of the order of 10–15 km. Broader trends can be tracked across the profile, but no strong lithospheric interfaces can be mapped, except for a south dipping feature traversing the lithosphere on the southern part of the profile that is likely to be a former mantle detachment zone.

1. Introduction

Full characterisation of the seismic structure of the lithosphere requires the integration of many different classes of data and analysis techniques. The broad scale features can be sought with surface wave tomography, which can provide information on both seismic shear wavespeed and anisotropy. The vertical gradients of wavespeed can then be used to place constraints on the transition from the lithosphere to the asthenosphere (e.g., Yoshizawa and Kennett, 2015). Variations in the distribution of azimuthal and radial anisotropy with depth tie to the presence of lithospheric discontinuities (e.g., Yuan and Romanowicz, 2010; Yuan and Levin, 2014; Yoshizawa, 2014). Higher-frequency information from body-waves provides more constraints on finer-scale structure, either in transmission or refraction. For the Australian continent, Kennett et al. (2017) have shown how a multi-scale heterogeneity model can be constructed that is compatible with a wide range of seismological observations. This model incorporates deterministic large-scale structure and stochastic representations of intermediate and fine scales. The amplitude of the smaller scale variations are modest (< 1%). These rapid variations in seismic wavespeeds at short scales (~10–20 km horizontally, ~0.5 km vertically) superimposed on slower background variations are able to produce apparent discontinuities from constructive interference, which show distinct frequency dependence. For low-frequency incident waves, receiver functions can be interpreted in terms of models with a few major discontinuities, though contrasts may be exaggerated.

We here use data from a relatively dense profile of portable seismic instruments through Central Australia from the BILBY experiment (2008–2010) to examine the continuity and character of lithospheric discontinuities. The north-south BILBY profile passes the permanent array stations at Warramunga (WRA) and Alice Springs (ASAR), affording the opportunity to look locally at structures in more detail. We combine information from surface wave analysis, receiver functions and autocorrelation techniques to track the discontinuities and examine their expression in different frequency bands. Sippl (2016) has presented detailed receiver-function analysis for this profile so we already have strong constraints on the crust-mantle transition. We therefore focus on the continuity of potential mid-lithospheric discontinuities, and the character of the lithosphere-asthenosphere transition.

2. Tectonic setting

The BILBY profile spans from the northern part of the South Australian Craton to the North Australian Craton, crossing the complex central Australian belt which has been deformed in the 570–530 Ma Petermann Orogeny and the 450–300 Ma Alice Springs Orogeny (Fig. 1). The Arunta and Musgrave Blocks have been uplifted in these orogenic events, leaving jumps in crustal thickness of over 10 km,

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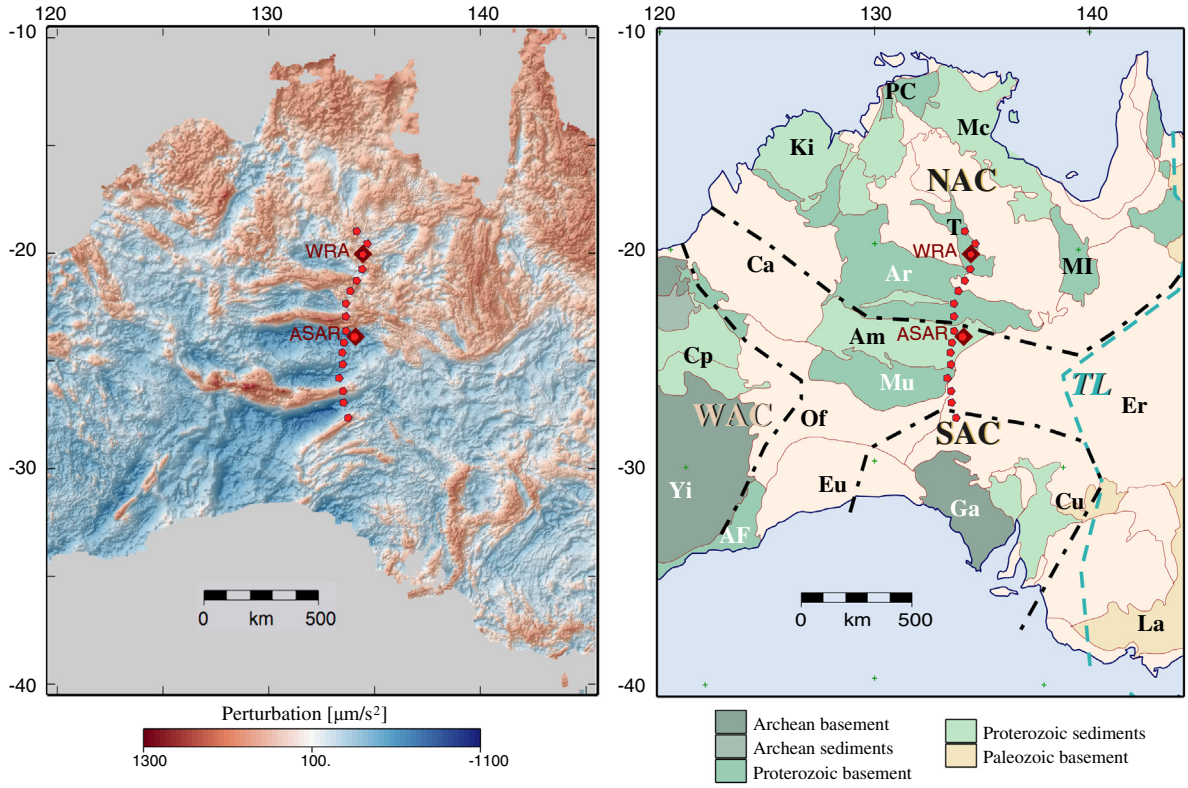

Fig. 1. (a) Free-air gravity anomalies in central Australia (data from Geoscience Australia). (b) Simplified representation of the main tectonic features of central Australia. Chain-dotted lines mark outlines of the major cratons (NAC - North Australian Craton, SAC- South Australian Craton, WAC- West Australian Craton). The Tasman line (TL) in dashed cyan is based on the reinterpretation by Direen and Crawford (2003). Key to marked features: AF - Albany-Fraser Belt, Ar - Arunta Block, Am - Amadeus Basin, Ca - Canning Basin, Cp - Capricorn Orogen, Cu - Curnamona Craton, Er - Eromanga Basin, Eu - Eucla Basin, Ga - Gawler Craton, Ki - Kimberley Block, La - Lachlan Orogen, Mc - MacArthur Basin, MI - Mt. Isa Block, Mu - Musgrave Block, Of - Officer Basin, PC - Pine Creek Inlier, T - Tennant Creek Block, Yi - Yilgarn Craton. The location of the portable seismic stations from the BILBY experiment used for tracking lithospheric discontinuities are shown in red, along with the permanent stations WRA and ASAR. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

summarised by Korsch and Doublier (2016), and consequent major gravity anomalies (Fig. 1). As noted by Fishwick and Reading (2008) and Kennett and Iaffaldano (2013), the mantle lithosphere beneath the Central Australian zone does not show any notable evidence of the deformation cycles. Indeed shear wavespeeds at around 100 km depth are among the highest anywhere on the continent. Wavespeeds above 80 km are somewhat reduced compared with the average for the cratonic regions, but the distribution in images generated with Pn wave tomography is somewhat patchy (Sun and Kennett, 2016a).

Sippl (2016) provides an account of the tectonic history of the region, so here we concentrate on the features along the profile of portable instruments. The southern end of the denser station deployment lies in the northern part of the South Australian Craton, which mainly consists of Paleo- and Meso-proterozoic rocks around a small nucleus of Archean meta-sedimentary and volcanic rocks. The dominantly Meso-proterozoic Musgrave province has been uplifted, and around the line of profile displays a crustal pop-up structure with middle to lower crustal rocks raised by around 10 km compared with the surroundings (e.g., Korsch and Doublier, 2016). This feature produces the southernmost of the major east-west gravity anomalies in Fig. 1a.

The basement rocks of the Arunta province probably underlie the relatively thick sediments (up to 8 km) of the Amadeus basin. Lower crustal rocks are brought close to the surface by the steeply dipping Redbank Shear zone, with a sharp Moho step up to the north (Korsch et al., 1998). This thrust is thought to have been reactivated during the Alice Springs orogeny. This 20 km Moho step also produces a strong east-west oriented gravity anomaly. The Paleo-proterozoic rocks continue north of the Arunta province in the Tennant Creek Inlier traversed by the profile. Sippl (2016) suggests the presence of a further Moho step just south of station WRA (Fig. 1).

3. Receiver-based studies

Much of the available information on lithospheric discontinuities comes from the application of receiver function methods. The converted *S* waves from incident teleseismic *P* waves are commonly used to determine crustal thickness, but frequently contamination by crustal multiples obscures the potential signal from discontinuities within the mantle component of the lithosphere. In consequence, incident *S* waves have been favoured because the *P* conversions arrive ahead of the crustal multiples. From the interpretation of such *Sp* receiver functions there have been widespread reports of a *S* velocity reduction at depths around 80–120 km (e.g., Abt et al., 2010; Chen et al., 2014; Ford et al., 2010; Tharimena et al., 2016). Such depths lie within the lithosphere for stable shield regions and the features have been identified as mid-lithosphere discontinuities (MLD) (e.g., Abt et al., 2010; Chen et al., 2014; Selway et al., 2015). In tectonically active areas with thin lithosphere, the wavespeed reduction has been interpreted as the lithosphere-asthenosphere boundary (LAB).

Normally receiver function studies of the deeper lithosphere exploit lower frequencies so as to reduce noise and concentrate attention on the dominant structures (e.g., 0.03–1 Hz for incident *P*, and 0.03–0.5 Hz for incident *S*). For such frequency bands, the vertical resolution is about 15 km.

An alternative approach to explore lithospheric discontinuities is to extract *P* wave reflectivity from continuous or earthquake waveforms at higher frequencies (0.5–4 Hz) that allow resolution of finer-scale lithospheric structures, down to ~1 km in depth extent (Kennett, 2015).

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