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Radially anisotropic 3-D shear wave structure of the Australian lithosphere and asthenosphere from multi-mode surface waves

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ABSTRACT

A new radially anisotropic shear wave speed model for the Australasian region is constructed from multi-mode phase dispersion of Love and Rayleigh waves. An automated waveform fitting technique based on a global optimization with the Neighbourhood Algorithm allows the exploitation of large numbers of three-component broad-band seismograms to extract path-specific dispersion curves covering the entire continent. A 3-D shear wave model is constructed including radial anisotropy from a set of multi-mode phase speed maps for both Love and Rayleigh waves. These maps are derived from an iterative inversion scheme incorporating the effects of ray-path bending due to lateral heterogeneity, as well as the finite frequency of the surface waves for each mode. The new S wave speed model exhibits major tectonic features of this region that are in good agreement with earlier shear wave models derived primarily from Rayleigh waves. The lateral variations of depth and thickness of the lithosphere–asthenosphere transition (LAT) are estimated from the isotropic (Voigt average) S wave speed model and its vertical gradient, which reveals correlations between the lateral variations of the LAT and radial anisotropy. The thickness of the LAT is very large beneath the Archean cratons in western Australia, whereas that in south Australia is thinner. The radial anisotropy model shows faster SH wave speed than SV beneath eastern Australia and the Coral Sea at the lithospheric depth. The faster SH anomaly in the lithosphere is also seen in the suture zone between the three cratonic blocks of Australia. One of the most conspicuous features of fast SH anisotropy is found in the asthenosphere beneath the central Australia, suggesting anisotropy induced by shear flow in the asthenosphere beneath the fast drifting Australian continent.

1. Introduction

The 3-D shear wave structure of the Australian upper mantle has been investigated by a number of researchers in the last two decades, building on a series of seismic experiments undertaken throughout Australia since the pioneering transportable seismic array project SKIPPY (van der Hilst et al., 1994). A number of Australian upper mantle models have been proposed using a variety of methods, with different styles of approximations (e.g., Debayle and Kennett, 2000a,b; Simons et al., 2002; Yoshizawa and Kennett, 2004; Fishwick et al., 2005, 2008; Fichtner et al., 2010; Fishwick and Rawlinson, 2012). These models have revealed the robust large-scale features of the continental lithosphere of Australia; i.e., faster wave speeds in the Archean and Proterozoic cratons in the West, North and South Australia (Fig. 1) and slower wave speeds in the eastern Phanerozoic margin. Most of these works have, however, been based primarily on the observations of Rayleigh waves on the vertical component of motion, and hence the shear wave models are primarily based on SV wave information.

There are only a few exceptions that constructed radially anisotropic models of Australia, incorporating Love waves (e.g., Debayle and Kennett, 2000a, 2010). Debayle and Kennett (2000a) proposed the first three-dimensional radial anisotropy model of the Australasian upper mantle from the simultaneous inversion of Love and Rayleigh waves. This early model identified the large-scale features of both isotropic S wave speed as well as radial anisotropy, although the horizontal resolution is limited since only small numbers of paths (about 800 for both Love and Rayleigh waves) were available in their mapping. More recently, Fichtner et al. (2010) obtained a 3-D radial anisotropy model working with full waveform tomography using three component seismograms. Their method is highly sophisticated in that complex wave propagation phenomena in 3-D structure can be taken into account in their modeling, though the method is computationally demanding and requires high quality three-component seismic waveform data, which tend to limit the numbers of paths (about 3000) that can be used in their tomographic mapping.

The anisotropic heterogeneity in the Australian region has also been investigated through global-scale studies (e.g., Gung et al., 2003; Debayle et al., 2005). Gung et al. (2003) revealed the

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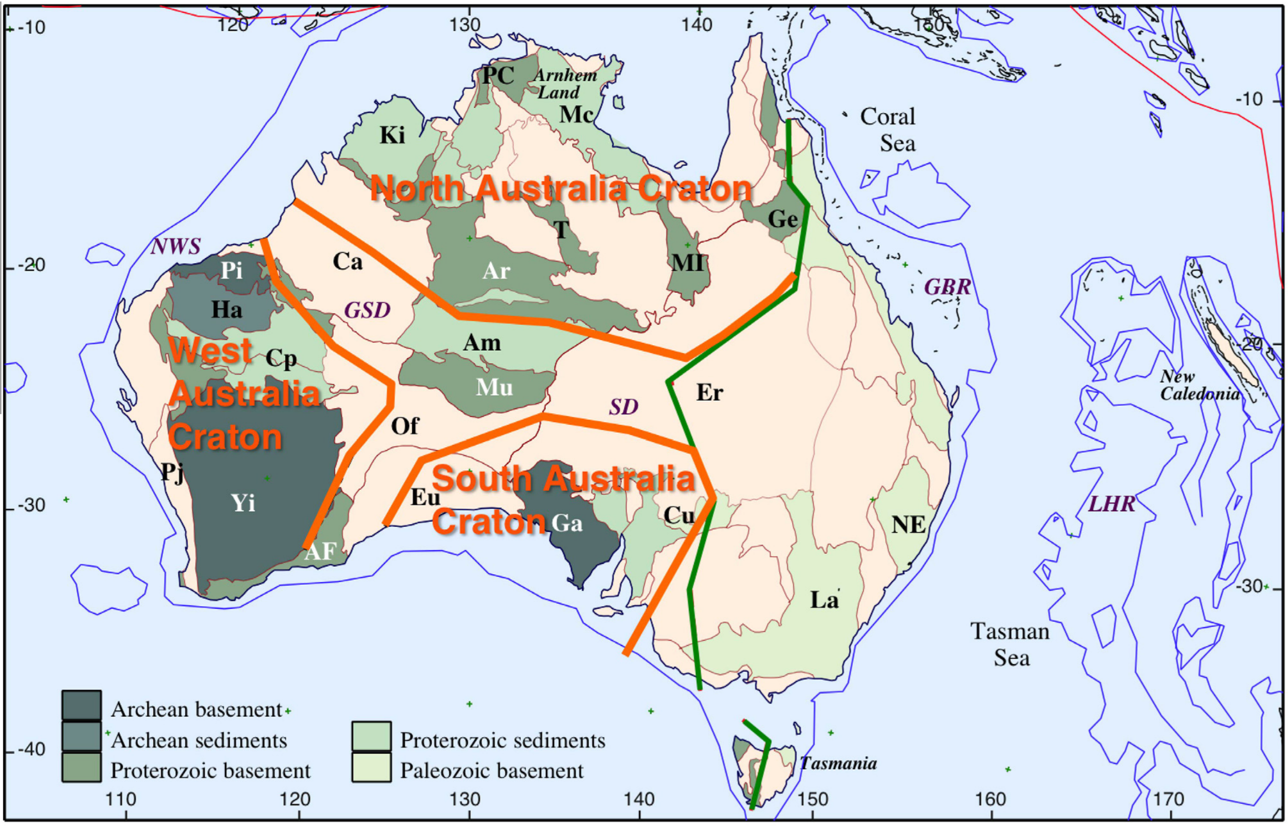

Fig. 1. A tectonic map of Australia and surrounding region. Orange solid lines represent boundaries of major cratonic blocks (North, South and West Australia Cratons) and green solid line Tasman Line. AF – Albany-Fraser belt, Ar – Arunta Block, Am – Amadeus Basin, Ca – Canning Basin, Cp – Capricorn Orogen, Cu – Curnamona Craton, Er – Eromanga Basin, Eu – Eucla Basin, Ga – Gawler Craton, Ge – Georgetown inlier, Ha – Hamersley Basin, Ki – Kimberley Block, La – Lachlan Orogen, Mc – MacArthur Basin, MI – Mt Isa Block, Mu – Musgrave Block, NE – New England Orogen, Of – Officer Basin, PC – Pine Creek Inlier, Pi – Pilbara Craton, Pj – Pinjarra Orogen, T – Tennant Creek Block, Yi – Yilgarn Craton, NWS – Northwest Shelf, GBR – Great Barrier Reef, LHR – Lord Howe Rise, SD – Simpson Desert, GSD – Great Sandy Desert. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

existence of faster SH wave speed anomalies than SV waves beneath the continental areas. These faster anomalies of the horizontally polarized shear wave compared with the vertically polarized one were argued to represent the effects of strong shear beneath the continental lithosphere. Debayle et al. (2005) reported anomalously strong azimuthal anisotropy beneath Australian lithosphere in comparison with other continental regions, by employing a global surface wave tomography incorporating azimuthal anisotropy. Such observations are likely to reflect the lattice preferred orientation caused by the strong shear beneath the fast moving Australian continent, migrating northward with a speed of about 7 cm per year. The seismological evidence of anomalous anisotropy beneath Australia can be a key to unveiling the effects of basal drag beneath the thick continental lithosphere and tectonic history of the long-lived Archean/Proterozoic cratons that comprise the major portions of the present-day continental plate of Australia, though the global-scale models provide us with only a large-scale view of the continental upper mantle. There is, therefore, still plenty of room for the construction of a new high-resolution regional-scale 3-D model of the Australian upper mantle including radial anisotropy, encompassing the entire continent with enhanced ray coverage.

In this study, we use a large data set covering the whole Australian continent to obtain a high resolution regional 3-D radial anisotropy model of the Australasian region. We employ a three-stage inversion scheme of surface wave tomography (Kennett and Yoshizawa, 2002; Yoshizawa and Kennett, 2004) to retrieve a new three-dimensional shear wave model from multi-mode phase speeds of both Love and Rayleigh waves incorporating the effects of finite frequency and off-great-circle propagation. An earlier version of this model presented in this paper has been used as one of three models employed in the construction of the latest reference upper mantle model of Australia (AuSREM – Mantle Component) by Kennett et al. (2013).

The main objective of this paper is to retrieve the three-dimensional distribution of radially anisotropic shear wave speeds beneath the Australasian region with improved path coverage for both Love and Rayleigh waves, and to estimate the plausible depth range of the lithosphere–asthenosphere transition beneath the continent, which will be a key to the better understanding of plate tectonics and mantle dynamics underneath the long-lived and fast moving continent of Australia.

2. Data and method for multi-mode phase speed measurements

Dispersion curves of multi-mode surface waves are extracted from a fully nonlinear waveform fitting scheme (Yoshizawa and Kennett, 2002b; Yoshizawa and Ekström, 2010), based on the exploration of model parameter space using the Neighbourhood Algorithm (Sambridge, 1999). The original method developed by Yoshizawa and Kennett (2002b) has recently been improved by employing several empirical criteria to implement automatic data selection and outlier detection as described by Yoshizawa and Ekström (2010). In this section, we briefly explain the process of nonlinear waveform fitting for estimating multi-mode dispersion curves along a specific path, as well as the data set of observed phase speeds used in this study.