



The apparently isotropic Australian upper mantle

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[1] We investigate shear wave splitting measurements performed on two years of data recorded at stations deployed in the TASMAL experiment, a network of 20 broadband seismological stations designed to record data on each side of the controversial Tasman Line in Australia. Whereas a subset of measurements previously performed on one year of data exhibited a curvilinear pattern similar to that of the Tasman Line, suggesting anisotropy frozen in the lithosphere, considering the whole data set drastically changes the situation: apparent isotropy in the Australian upper mantle is observed at numerous stations. This apparent isotropy together with the EW or NS orientations of the polarization plane of the fast S wave (ϕ) observed at some stations is consistent with a two-layer anisotropic system underneath the Australian continent, with a perpendicular orientation of ϕ in each layer. From the latest tomographic results, the transition between the Precambrian western and Phanerozoic eastern Australia appears to define blocks of various thickness. Unlike the situation across the TESZ in Europe, these blocks do not seem to be correlated with a different behavior in terms of seismic anisotropy. **Citation:** Heintz, M., and B. L. N. Kennett (2006), The apparently isotropic Australian upper mantle, *Geophys. Res. Lett.*, 33, L15319, doi:10.1029/2006GL026401.

1. Introduction and Background

[2] The development of lattice preferred orientation of olivine, the main constituent of the upper mantle, results in a variation of seismic wave speed with propagation direction. Despite several factors complicating the simple image of the present day mantle flow (e.g., textures from past deformational events, shear style, temperature, volatile content), the study of seismic anisotropy allows an approach to the dynamics of deep Earth processes in a way that cannot be achieved by other geophysical methods.

[3] Seismic anisotropy is commonly investigated through shear wave splitting: an incoming polarised S-wave encountering an anisotropic medium is split into two quasi S-waves with perpendicular polarisations propagating with different velocities. The orientation of the fast S-wave (ϕ) is assumed to be a proxy for the orientation of the crystallographic axes of anisotropic minerals. The delay Δt between the arrival time of the two quasi S-waves is proportional to the thickness and intrinsic anisotropy of the anisotropic layer, the orientation of the ray path with respect to the elastic tensor and the vertical coherence of the anisotropic fabric.

[4] A comparison between ϕ and the absolute plate motion (APM) can help in understanding the active deformation of the asthenospheric mantle. On the other hand, comparison with shallow geological trends provides hints on the imprint of past deformational events on the lithosphere; the mechanical coupling between the crust and the upper mantle can be investigated. This is of particular interest along major suture zones and in the scope of plate tectonic reconstructions: if ϕ is parallel to the orientation of a major suture, this reveals a preferential orientation of mantle rocks that took place during large scale transcurrent motions along the suture, frozen after thermal relaxation and leaving imprints of the past tectonic events on the lithosphere (e.g., the Trans-European Suture Zone (TESZ) [Wylegalla *et al.*, 1999]).

[5] Tomographic models performed at the scale of the Australian continent [e.g., *Debayle and Kennett*, 2000a; *Fishwick et al.*, 2005; *Simons et al.*, 1999] highlight a large contrast in shear wave speed anomalies in the vicinity of 140°E longitude, between the Precambrian western and Phanerozoic eastern parts of Australia. To some extent, this feature can be seen as analogous to the complex boundary between the Archaean Baltic Shield and the Neoproterozoic-Palaeozoic mobile belts of western Europe, the TESZ [e.g., *Babuska and Plomerova*, 2004; *Cotte et al.*, 2002].

[6] The contrast observed in the Australian upper mantle could be correlated to the hypothetical Tasman Line (TL) whose definition was originally based on the separation of geological outcrops of Precambrian and younger basement [Hill, 1951]. A recent review [Direen and Crawford, 2003] shows the lack of consistency between the various lineaments believed to define a given age and tectonic origin for the TL as described by many authors [e.g., *Gunn et al.*, 1997; *Scheibner*, 1974; *Shaw et al.*, 1996; *Veivers and Powell*, 1984]. Despite this controversy, the strong contrast between Precambrian and Phanerozoic Australia observed in tomography is an undisputed feature, here referred to as the 'tomographic TL'.

[7] Considering the TL as a geological suture, the effect of displacements along it would imprint the lithosphere on a lateral scale that would exceed the lateral resolution obtained from body wave analysis (~50 km). A different behaviour in terms of shear wave splitting on each side of the tomographic TL would therefore be a good indication that the TL is a lithospheric scale suture.

[8] A recent study [Fishwick, 2006] has refined the concept of tomographic TL; the transition between the western and eastern parts of the continent appears to be a series of steps within the lithosphere (background of Figure 1a) similar to what is observed across the TESZ [Babuska and Plomerova, 2004].

[9] The TASMAL experiment, a deployment of 20 broadband recorders from north Queensland to south Victoria, has been designed to record data on each side of

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the controversial TL over a 2 year period. The time span of recording enables the achievement of a good backazimuthal coverage and hence the extraction of a pattern of seismic anisotropy. *Heintz and Kennett* [2005] presented a continental scale shear wave splitting investigation, analysing data recorded since 1992 within the framework of various short term deployments (6–9 months) together with one year of data recorded at the TASMAL stations.

[10] The aim of the present paper is to highlight the need for long term seismic deployments to adequately study continental upper mantle deformation, and to see whether the pattern of seismic anisotropy as defined through shear wave splitting analysis is correlated with the variation in thickness of the different lithospheric blocks constituting the tomographic TL.

2. Data and Method

[11] The data presented here have been recorded at the stations deployed in the TASMAL experiment. For completeness sake, results obtained at stations from previous experiments located in the same geographical region are also plotted (Figure 1).

[12] The shear wave splitting measurements are performed on core refracted shear waves using the *Silver and Chan* [1991] algorithm. To increase reliability and remove subjectivity associated with manual picking, part of the data has been processed using an automated scheme [*Teanby et al.*, 2004]: a measurement window is manually picked and an increment is set up to automatically vary the start and end time of this window. For each window thus defined, ϕ and dt are computed following *Silver and Chan* [1991], assuming a single horizontal anisotropic layer. Cluster analysis is then used to identify stable regions, and hence the shear wave analysis window corresponding to the measurement with the smallest errors on ϕ and dt . The influence of filtering has been systematically checked.

[13] Results are classified into three different categories (see [*Heintz and Kennett*, 2005] for details). For simplicity, only good and null results are displayed. A null measurement does not show any energy on the transverse component associated with the arrival of the core phase of interest on the radial component. This may be due either to an absence of anisotropy or to an initial polarisation of the incoming wave parallel or perpendicular to the fast anisotropy direction.

3. Observations and Discussion

[14] Figure 1 shows the results obtained after analysis of one (Figure 1b) and two years (Figure 1c) of data. On Figure 1b we also plot the results obtained at SKIPPY stations SA04, SB01 and SB05 [*Heintz and Kennett*, 2005]. These results together with those obtained at stations TL04 and TL14 highlight a ϕ parallel to the structural trend of the TL as defined by *Scheibner* [1974], in good agreement with *Clitheroe and Van Der Hilst* [1997]. The kink in the shape of the line is particularly well observed between stations SB05 and TL14 where ϕ varies from NE-SW to NW-SE.

[15] It seemed at this stage that the fossil deformation associated with the geological TL could be recorded in the pattern of seismic anisotropy. A small amount of data

obtained from events with a limited backazimuthal coverage in a region with a highly heterogeneous upper mantle may however lead to erroneous results. We expect to get a more reliable pattern of anisotropy taking into account the whole TASMAL data set and to determine whether the TL could be considered as a suture zone along which large scale transcurrent motions would have left imprints in the lithosphere.

[16] Station TL01 appeared as one of the best constrained station after one year of data analysis, showing an average ϕ of 24° computed on fair measurements (Figure 1b). Considering the entire data set, many null measurements have been computed at station TL01 for events over a large backazimuthal range (110° – 214°), and we now conclude that there is good evidence for apparent isotropy.

[17] The same observation is made at station TL16: a \sim EW orientation of ϕ consistent with a regional pattern (TL15 and SB05) is highlighted (Figure 1b) after one year of data analysis. Considering the whole data set, we measure 7 nulls for events with backazimuths between 8 and 146° , suggesting apparent isotropy.

[18] If measurements performed at TL14 primarily seemed to highlight a preferential NW-SE orientation (Figure 1b) which approximately coincided with the kink in the shape of the TL [*Scheibner*, 1974], taking into account the entire data set and the various null measurements obtained for events in the backazimuthal range 10 – 300° , it appears however that the upper mantle beneath TL14 is likely to be apparently isotropic (Figure 1c).

[19] Data recorded at station TL18 similarly exhibit a large scattering revealing an apparent isotropy.

[20] Over the two years of data recording, shear wave splitting measurements revealed strong evidence for apparent isotropy in the upper mantle below station TL12 and the large scattering in terms of the orientations of ϕ for events with various backazimuths measured at station TL08 also suggests apparent isotropy.

[21] Considering measurements of shear wave splitting performed at the above mentioned stations over a 2-year period of recording, the Australian upper mantle appears to be characterised by apparent isotropy. This agrees with observations previously made by various authors at the Australian permanent stations [*Barruol and Hoffmann*, 1999, *Ozalaybey and Chen*, 1999, *Vinnik et al.*, 1992], as well as previous measurements performed at station YE02 located in the vicinity of CAN in east Australia [*Heintz and Kennett*, 2005].

[22] Isotropy is observed across the 4 domains of various lithospheric thickness constituting the transition from Precambrian to Phanerozoic Australia (Figure 1a). Unlike the TESZ, the four domains do not differ in the orientation of anisotropy in the lithospheric mantle and the TL therefore does not appear to be a suture *sensu stricto*.

[23] The recent surface waves tomography [*Debayle*, 1999; *Debayle and Kennett*, 2000b] (hereinafter referred to as DDK) and [*Simons and Van Der Hilst*, 2003; *Simons et al.*, 2002] (hereinafter referred to as SVS) agree for a two layered anisotropic Australian upper mantle, with a change in the anisotropic pattern around 150 km depth. At shallow depths, DDK account for anisotropy reflecting past deformational episodes frozen in the lithosphere; ϕ is EW

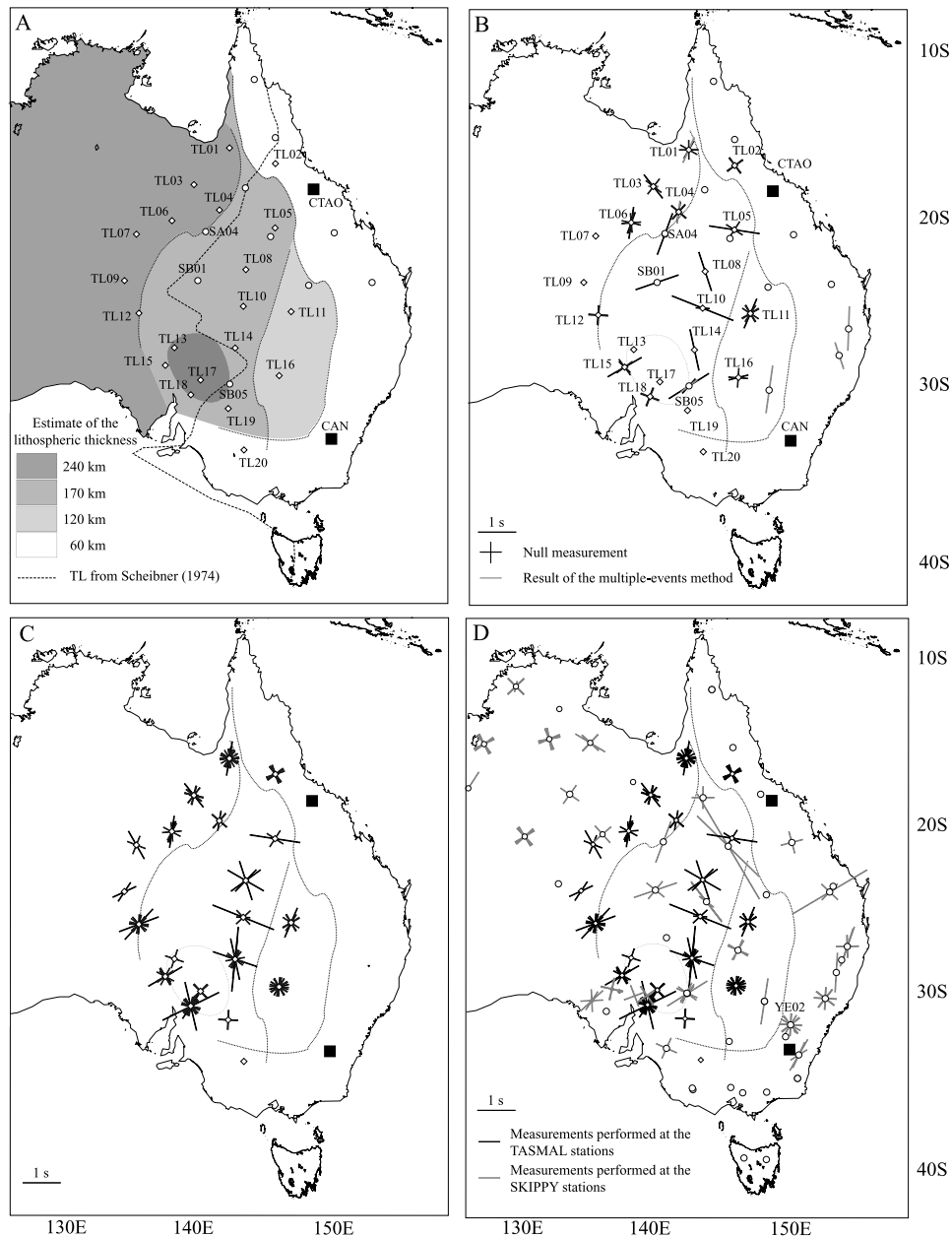


Figure 1. (a) The background colours indicate the variations in term of thickness of the lithosphere, as interpreted from surface wave tomographic results (S. Fishwick, personal communication, 2006). The names of the stations which results are discussed in the text are indicated. The dashed black line represents the Tasman Line as defined by *Scheibner* [1974]. (b–d) Measured orientations of ϕ . The length of the line is proportional to dt . Good and null measurements are shown for: Figure 1b shows one year of data analysis at the TASMAL and three SKIPPY stations together with results of the multiple-event method computed at some stations [*Heintz and Kennett, 2005*] (grey lines), Figure 1c shows two years of data analysis at the TASMAL stations, Figure 1d shows the same as Figure 1b together with measurements performed at stations deployed within the first three stages of the SKIPPY experiment (grey lines). On each of these figures, the faint black lines represent the various lithospheric blocks of different thickness as highlighted on Figure 1a.

oriented below the central part of the continent and more NW-SE toward its eastern margin. Good correlation between azimuthal anisotropy from surface waves and *in situ* stress orientations could also account for a control by present day plate dynamics and a decoupling between the lithospheric and asthenospheric stresses [*Hillis and Reynolds, 2003*]. SVS acknowledge uncertainties regarding the direction of the azimuthal anisotropy, but suggest a complex pattern hardly compatible with any geological trend.

[24] In the lower layer, the orientation of ϕ is roughly parallel to the APM, although SVS note a large deviation from APM in the eastern part of the continent, suggesting a complex morphology of the mantle flow around the edge of the Precambrian core.

[25] How would a two-layered anisotropic upper mantle be translated in terms of apparent ϕ and dt measured under the assumption of a single horizontal layer of anisotropy as

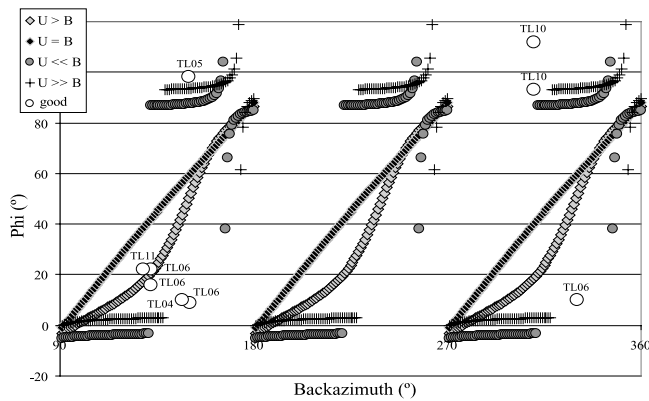


Figure 2. Apparent ϕ vs backazimuth of the incoming wave modelled using two layers of anisotropy. ϕ is oriented N84°E in the upper layer (U) and N356°E in the bottom layer (B). Four situations are considered with respect to the prevalence of intrinsic anisotropy in each layer. Good results obtained at stations showing no obvious evidence of isotropy are plotted as white circles.

commonly used in core refracted shear wave splitting analysis?

[26] According to *Silver and Savage* [1994], the apparent ϕ and dt would exhibit systematic variations as a function of the incoming polarisation with a $\pi/2$ periodicity.

[27] Simple two-layer models with the orientation of ϕ in the upper layer perpendicular to ϕ in the bottom layer (as could be the case regarding the previous results from surface wave tomography), with the same intrinsic anisotropy in both layers, would result in splitting parameters consistent with apparent isotropy (i.e., null results measured independently of the backazimuth, Figure 2). If the intrinsic anisotropy in one layer prevails compared to the other, one orientation will be observed preferentially depending on the backazimuth of the event. Although not accounting for apparent isotropy, the either EW or NS orientations of ϕ measured at stations TL04, TL05, TL06, TL10 and TL11 could fit with the results of a two-layer model (Figure 2). This is in good agreement with a previous study led by *Girardin and Farra* [1998] at the GEOSCOPE station CAN which highlighted a two-layer system underneath the station composed of an upper layer down to 140 km depth with ϕ oriented EW and a 40 km thick bottom layer with a NS oriented fast direction, parallel to the APM of the Australian plate.

[28] In the southeastern part of the continent (Figure 1d), we highlight a few consistent NS orientations of ϕ in contradiction with SVS's observation of large deviation from APM in this region accounting for a complex morphology of the asthenospheric flow around the Precambrian core. We rather observe a good parallelism between ϕ and the APM and even with the structural trend of the New England fold belt [*Heintz and Kennett*, 2005].

4. Conclusion

[29] In order to adequately investigate continental upper mantle deformation via shear wave splitting measurements, results obtained from short term deployments should be

analysed with caution. A small amount of data recorded in a region with a highly heterogeneous upper mantle can indeed lead to a limited number of measurements for which interpretation can potentially be very misleading: the present study is a typical example. Whereas subsets of data from the 2-year TASMAL experiment show potential evidence of deformation frozen into the lithosphere, considering the whole data set leads toward apparent isotropy observed over a large lateral scale. The APM of Australia being relatively fast, a lack of asthenospheric flow underneath the Australian plate and hence isotropy is hardly conceivable. This observed apparent isotropy is rather the result of measurements performed under the assumption of a single layer of anisotropy when two layers with perpendicular orientations of ϕ might be present. The transition between Precambrian and Phanerozoic Australia is made of a series of steps in the lithosphere, defining blocks of various thickness. Unlike the situation across the TESZ, the four domains do not differ in the orientation of anisotropy in the lithospheric mantle and the TL does not appear as a suture sensu stricto.

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