Introduction

Seismic anisotropy, i.e. the variation of seismic wave speed with propagation direction, provides information on material flow and therefore the dynamics in the earth's interior. Seismic anisotropy appears to be strong in the upper mantle and in the lowermost mantle (the D’), where strains related to horizontal flow in the large scale mantle convection system tend to be large.

Here we show evidence for strong seismic anisotropy in the D” using waveforms of shear waves diffracted along the core-mantle boundary. The seismic anisotropy appears strong to the south of the African Large Low Shear Velocity Province (LLSVP). The anisotropy rotates or weakens towards the LLSVP boundary, and there is no apparent anisotropy inside the LLSVP.

Data and Methods

In this study, we use shear diffracted phases from a deep event near the Fiji islands (~621 km, $M_w$ 6.2, 09/04/1997, Figure 2.8.1) towards stations in southern Africa at distances of > 120°. Diffracted phases at these distances become polarized along the SH component due to the coupling of the SV component with the outer core. To et al. (2005) first pointed out the anomalously strong SV arrivals, which result in elliptical particle motions (Figure 2.8.2). These arrivals result from the splitting of the SH component due to the presence of anisotropy.

We measure the shear-wave splitting with the rotation-correlation method in SplitLab (Wuestefeld et al. 2010). The stations at smaller azimuths show a mean fast axis of -46° (defined to be positive away from the T component towards the R component) and a mean splitting time of 1.0 second.

The splitting in Sdiff results from the presence of anisotropy in the upward leg of the path after the diffracted part of the path. We separately measure the splitting in the SKS and SKKS phases to exclude an origin of the splitting in the upper mantle. There is little and very scattered splitting in these phases for this event. Other studies of upper mantle anisotropy beneath the Kaapvaal array (e.g., Adam and Lebedev, 2012) show different trends than the shear-diffracted waveforms would suggest here.

We forward model full waveforms for anisotropic models in the D” using the ‘sandwiched’ Coupled Spectral Element Method (‘sandwiched’-CSEM, Capdeville et al. 2003). This method couples the spectral element solution for an anisotropic 3D velocity model in the lowermost 370 km of the mantle to a 1D normal mode solution in the rest of the mantle and the outer core. It is computationally advantageous to apply this method for different models in the lowermost mantle for a single event, as the normal mode computation only needs to be done once. The background model is SAW24B16 (Megnin and Romanowicz, 2000) saturated at +1% outside and -2.75% inside the LLSVP.
The saturated model captures the delay in travel time with increasing azimuth (which is apparent in the change in color in particle motions in the second panel of Figure 2.8.2). We define the anisotropy to be in the plane orthogonal to the direction of propagation, as this relates to the apparent anisotropy seen in the waveforms, but we acknowledge that this only represents part of the actual anisotropic elastic tensor. With full waveform modeling we test the sensitivity to fast direction, strength of anisotropy and radial and lateral extent of the anisotropy (Cottaar and Romanowicz, 2013). Here we only present the best model.

Results

The preferred model has a fast axis direction as measured in the data, and 8% of velocity contrast between the fast and slow axis. The anisotropy is constrained to the lowermost 150 km, although there is a strong trade-off between the vertical extent and the strength of anisotropy. Laterally, the anisotropy is constrained to the fast region (with isotropic velocity perturbations over 0.5%). The synthetic waveforms for this model are shown in Figure 2.8.2.

The synthetic waveforms capture the ellipticity of the particle motions at smaller azimuths. They do not capture the increase in amplitude at these azimuths. The amplitudes of the waveforms are higher than predictions for PREM. The synthetics show a decrease in amplitude and a postcursor due to multi-pathing around the LLSVP boundary. The postcursor in the synthetics is less delayed than in the observations (To et al., 2005), resulting in elliptical particle motions. The amplitudes within the LLSVP, at the higher azimuths, are larger due to the slow velocities. The S(H)diff arrivals are rotated slightly out-of-plane due to refractions at the LLSVP boundary. The rotations are opposite for the synthetics and observations, though. Capturing the exact multi-pathing and refraction behavior requires corrections to the boundary shape, which is beyond the scope of this study.

Conclusion

We found evidence for the presence of strong anisotropy to the south of the African LLSVP margin by using shear diffracted phases at large distances. We can constrain the part of the elastic tensor that causes the splitting in the waveforms, i.e. in the plane orthogonal to the direction of propagation. Most strikingly, the anisotropy weakens towards the LLSVP boundary, and appears absent within.

This study adds an additional location where the presence of strong complex anisotropy appears to correlate with fast velocities and possibly with the presence of slab remnants. Additionally, the presence of textured postperovskite could explain strong anisotropy, as its single crystals have stronger azimuthal anisotropy than in perovskite. The LLSVP margin might be acting as a mechanical boundary that rotates the present fabric (Figure 2.8.3). Within the LLSVP, convection is either too weak or small-scaled, or the material’s intrinsic anisotropy is too weak to observe using diffracted waves.

Acknowledgements

The data for this project came from IRIS (www.iris.edu). We thank Yann Capdeville for providing the CSEM code which produced the synthetic data in this study. Shear wave measurements are done with help of the SplitLab Matlab package (www.gm.univ-montp2.fr/splitting/). This work was supported by NSF/CSEDI grant 1067513 and ERC grant ‘WAVETOMO’.

References


