30 Azimuthal anisotropy in the Pacific upper mantle

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30.1 Anisotropic Layering in North America

We recently developed a new three dimensional radially and azimuthally anisotropic model of the upper mantle in north America, using a combination of long-period 3-component surface and overtone waveforms, and SKS splitting measurements (Yuan and Romanowicz, 2010). We showed that: 1. azimuthal anisotropy is a powerful tool to detect layering in the upper mantle, revealing two domains in the cratonic lithosphere, separated by a sharp laterally varying boundary in the depth range 100-150 km, which seems to coincide with the mid-lithospheric boundary (MLD) found in receiver function studies; 2. contrary to receiver functions, azimuthal anisotropy also detects the lithosphere-asthenosphere boundary (LAB) as manifested by a change in the fast axis direction, which becomes quasi-parallel to the absolute plate motion below ~ 250 km depth; and 3. a zone of stronger azimuthal anisotropy is found below the LAB both in the western US (peaking at depths of 100-150km) and in the craton (peaking at a depth of about 300 km).

30.2 Going to the global inversion

Here we show preliminary attempts at expanding our approach to the global scale with the goal, in particular, of determining whether our results can be generalized to other continents and oceans. We started with our most recent global upper mantle radially anisotropic shear velocity model, determined using the Spectral Element Method (French et al., in prep) and augmenting the corresponding global dataset of initially 200 events and 10,000 long period waveforms, in order to ensure optimal azimuthal coverage of the globe. Depth parameterization is chosen so as to resolve the kind of layering seen in North America. Our preliminary results, which do not yet incorporate SKS splitting measurements (see discussion below), look promising as they confirm the layering found in North America, using a different, global dataset and starting model (Fig. 2.59).

30.3 Robust SKS measurements

In Romanowicz and Yuan (2012), we show that back-azimuthally averaged splitting does not depend on the order of layers in the model and is correctly predicted by the formalism of Montagner et al. (2000), which forms the basis of our joint inversion of surface waveforms and SKS splitting data. Robust station average measurements is contingent upon a wide back-azimuthal coverage of the

Figure 2.59: Two layered lithosphere in the North American craton shown by both the regional (top) and global (bottom) inversions. Color coded are anisotropy direction differences with respect to the HS3 NUVEL-1A absolute plate motion (APM; Gripp and Gordon, 2002). A promising three-layer anisotropy domain is observed, confirming the layering found in North America.

SKS events. A systematic evaluation of the global SKS datasets to obtain robust station averaged measurements is currently being performed, which is essential in recovering the deep azimuthal anisotropy at deep depth (Yuan and Romanowicz, 2010).

We therefore focus only the upper most mantle (< 250 km) of the Pacific region, where earthquakes from the Pacific ring of fire have given the region an optimal azimuthal coverage. The available SKS measurements are sparse in the region (e.g., Becker et al., 2012), which as we showed in our previous study in North America are needed in continents where the lithosphere is thick (~200-250 km). For the Pacific region, however, the oceanic lithosphere is relatively thin (e.g., Rychert and Shearer, 2011; Schmerr, 2012), thus the natural depth resolution of the surface waveforms allows us to look into both the lithosphere and asthenosphere and their interactions.

30.4 Pacific Layering

Anisotropy stratification of the Pacific upper mantle was reported in early azimuthal anisotropy studies (e.g., Montagner, 2002; Smith et al., 2004; Maggi et al., 2006). Our initial results (Fig. 2.60) show at shallow depths (70-100km) a domain of anisotropy with a general northward fast axis direction beneath the old (e.g. west of Hawaii > 80Ma, Muller et al. 2008) portion of the plate. The direction is consistent with the paleo-pacific plate motion (e.g., Muller et al., 2008). Within this shallow domain an east-west direction, which seems to follow the fracture zones (e.g., Smith et al., 2004), is observed where the
Clearly the paleo- or current APM parallel direction is also follows the age progressive pattern at similar depths. Domains, corresponding to those discussed in (Fig. 2.60, 2.61). Remarkably the boundary of the two anisotropy domains, is observed near the Hawaii hotspot and the Pacific/Eurasia subduction region.

Figure 2.60: Two anisotropic domains in the Pacific Ocean. Azimuthal anisotropy direction and strength (shown as the black sticks) at 70- (left) and 150-km (right), respectively. The APM in HS3-NUVEL 1A model is illustrated in small red arrows. Ridges and hotspots are indicated.

Figure 2.61: Depth cross-sections of isotropic Vs (top), azimuthal anisotropy strength G (middle) and fast axis directions (bottom). The location of the cross-section is shown in (Fig. 2.60). Black broken line indicates the bottom of the oceanic lithosphere inferred from Vs and G. Vertical dashed lines show the location of the Hawaii hotspot and the East Pacific Rise. The APM directions are in general NWW (light purple) in the Pacific.

The Vs depth cross-section from our group’s most recent global model (~300-km horizontal resolution: French et al. in prep.) shows age-progressive thickening of the high velocities away from the ridge (Fig. 2.61). Remarkably the boundary of the two anisotropy domains, corresponding to those discussed in (Fig. 2.60), also follows the age progressive pattern at similar depths. Clearly the paleo- or current APM parallel direction is associated with each domain, respectively, a strong indication that the past and present time plate motions have been preserved in the upper mantle.

30.5 Summary

We expand our regional azimuthal anisotropy inversion to the global scale. With the current low data-fold waveforms, we are able to re-produce the layered lithospheric anisotropy pattern found in our previous studies. While robust SKS data are yet to be incorporated to address deep anisotropy in the cratonic upper mantle worldwide, promising results indicate that that the Pacific ocean upper mantle is also anisotropically layered, with depth dependent domains that record past and current plate motions.

30.6 Acknowledgements

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30.7 References


