A seismological constraint on the asthenosphere: mapping radial anisotropy with multi-mode surface waves

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Lateral heterogeneity and anisotropy in the upper mantle can be well constrained by seismic surface waves that have been widely used in the construction of 3-D shear wave models on global and regional scales. It is well known that there are significant differences in the typical thickness of the lithosphere between oceans and continents. In oceanic areas with typical lithospheric thickness of about 80-100 km, seismic structure in the lithosphere and asthenosphere can be constrained by the fundamental-mode surface waves. Recent surface wave models have revealed anomalous radial anisotropy under the lithosphere beneath Pacific Ocean (e.g., Nettles & Dziewonski, 2008, JGR). To the contrary, in continental areas, particularly under cratons, the thickness of the lithosphere reaches much deeper (~ 200 km), at which the fundamental modes lose their sensitivities. Therefore, higher-mode information is inevitable to map the seismological structure in the lithosphere and asthenosphere beneath continental regions. A recent high-resolution 3-D model in Australian continent using multi-mode surface waves (e.g., Yoshizawa, 2014, PEPI; Yoshizawa & Kennett, 2015, GRL) have revealed the existence of anomalous radial anisotropy (SH > SV) in the asthenosphere, which may manifest the effects of strong shear under the fast-drifting continent.

One of the advantages of using multi-mode surface waves for constraining shear wave models in the upper mantle is that we can map the spatial distribution of the lithosphere-asthenosphere transition and anisotropic properties in the upper mantle by using Rayleigh and Love waves simultaneously. We have investigated the resolving power of multi-mode surface waves for the lithosphere-asthenosphere system and radial anisotropy through a variety of synthetic experiments as well as practical applications to the observed data in continental and oceanic regions, focusing particularly on the Australian continent.

The spatial distribution of the lithosphere-asthenosphere transition (LAT) can be well constrained by multi-mode surface waves, although they are inherently less sensitive to the sharpness of the boundary or interface, unlike body waves/receiver functions at shorter periods. LAT can be estimated from the depth of either the negative peak of vertical velocity gradient and/or the slowest shear wave speed beneath the lithosphere, which provides a plausible depth range of the transition from the lithosphere to asthenosphere.

Seismic models of radial anisotropy (difference in shear wave speeds between SH and SV waves) derived from simultaneous inversions using both Rayleigh and Love waves tends to be affected by the choice of independent parameters for inversions. Theoretically, we may use either set of model parameters for the representation of radially anisotropic shear wave speeds; i.e., (A) Vsv and Vsh, or (B) Vsv and Xi [=(Vsh/Vsv)^2], but in the practical applications, they cause non-negligible influences on the resultant radial anisotropy models, mainly due to the intrinsic differences in the Love-wave sensitivity kernels to these independent parameters. Our synthetic experiments suggest the former parameterization with [Vsv, Vsh] would be preferable particularly when the radial anisotropy with SH>SV is caused by anomalously slow SV wave speeds, like those found under the fast drifting plates such as the Pacific and Australian plates.

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