Seismic anisotropy below Mexico and its implications for mantle dynamics

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Abstract

The Mexico subduction zone is characterized by both steep and flat subduction, a volcanic arc that appears to be oblique to the trench, and an excellent data coverage due to the 2006-2007 Middle America Subduction Experiment (MASE).

First, we develop a 3-D model of shear wave velocity and anisotropy in the region with Rayleigh wave phase velocity dispersion measurements. This model results are consistent with the presence of flat and steep subduction as well as variations in azimuthal anisotropy that suggest a tear between the flat and steep portions of the slab.

Next, we conduct a shear wave splitting analysis that results in delay times of 1-2 s and the fast direction that coincides with the APM for the MASE stations as well as east of it but differs from the surface wave anisotropic direction.

Finally, we determine phase velocities of higher modes (HM) of Rayleigh waves and constrain the depth of the anisotropy revealed by the shear wave splitting to a likely 200-400 km layer.

Data selection

Surface wave, 116 events, M6.0, D=250 km. Z = 1, 2 s filtered at 16-110 sec. Iso-depth for the dispersion of the wave. SK(S)S 32 (53) events, M6.0, 0°<θ<135°. E and N @ 20 sps filtered at 7-50 sec. Higher mode 54 events, M6.0, D=300 km. Z = 1, 2 s filtered at 25-125 sec.

Anisotropy calculation based on spheroidal modes, depth constraints

We choose data that maximize HM from deep (>100 km) and strong (> M 6.0) events. Then we group events and stack (concatenate) all relevant data for each direction.

Determine phase velocities for different HM, periods, and directions as PA parallel, PS and DS perpendicular to the fast SKS direction. Interpret the results in terms of anisotropy with and calculate the interstation phase velocities to eliminate the path effects.

Synthetic waveforms for n = 0 to 5 are computed with MOVEOUTUSING PREM. Sum of the synthetic waveforms is similar to data but shifted in time. Shifting waveforms before summing them improves in the fit. Phase velocities of wavelets are determined from the PSKs phase. We find phase velocity of each extrapolation that maximizes the fit using nonlinear least squares.

Energy of the synthetic data is computed using wavelets.

3-D S-wave velocity and anisotropy model based on the inversion of the Rayleigh wave phase velocity map. A-C2 Shear wave velocities (color) and fast directions averaged over each of the three layers of the model (D). Layers 1 and 2 have variable depth to account for lateral changes in crustal thickness. The velocity variations in the mantle lithosphere (layer 2) show high velocities in the subduction zone near the coast, extending inland beneath the southern part of the MASE array. These higher velocities are likely associated with the flat slab. Anisotropic directions (C) have low values beneath the TMVB, probably due to altered mantle from slab dehydration. The high velocities correspond to the steep slab.

Results

Stacking the SK/SKKS phases from multiple events

The radial (R) initial polarization of the SK/SKKS phases, as they leave the CMB, becomes partially polarized in the transition (T) direction at the receiver. The shear wave splits into the fast and slow component that arrive & s seconds apart with the fast axis polarized with an angle of. The T component of the SKKS phase resembles the time derivative of a given waveform on the R component. Without the splitting, the SK/SK phase would only appear on the R.

Table: Depth resolutions: Surface, 0-200 km; SKKS, 0-250 km; HM (1st and 2nd) 200-650 km

Surface wave, shear wave splitting, HM predicted, and calculated results along with the absolute plate motion (APM) vectors for North America (after Kreemer, 2010).

APM indicates the motion of lithosphere relative to the deep (assumed stable) mantle. The SKKS fast polarization directions are mostly consistent with the APM which may mean that the SKS anisotropic sources lie deeper than the surface wave Rayleigh waves. The results are not consistent with the fast anisotropic directions discrepancies calculated by the shear-wave splitting and the Rayleigh-wave analysis.

Higher mode results support the fast shear-wave splitting direction

Which depths makes PA fast for n=2, T = 40-60 s of n=2, T = 10-20 s, D = 27 s. Depths above 200 km do not work based on surface wave analysis. These depth are also likely to affect n = 1 and n = 2 similarly. n = 1 is not sensitive to depths below ~500 km for shorter periods.

Likely candidate: Depths between 200 and 400 km. Sensitivity kernels have a pronounced peak (red line for n = 2) and T = 70-90 s, explaining why PA is not fast for those periods.

The 200-400 km layer 1 corresponds to the bottom of the asthenosphere, likely to be affected by plate motion and its deep roots and/or mantle convection cell, explaining why the fast direction is aligned with the plate motion.