Annual Report for 2007 SCEC Grant

07041 and 07118: Constraining the evolving architecture of the Plate Boundary Zone through 3D Seismic Velocity and Anisotropy Mapping

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Technical Description

1.Summary

It has been noted that two main data sources for anisotropy, i.e., the SKS splitting data and the surface wave data, often show inconsistent patterns. This seems to be supported by data in Southern California based on individual SKS and surface wave studies. The primary goal of this project is to understand the source of this discrepancy and to obtain a seismic structure that satisfies both sets of data. The key must be in the depth variations in anisotropy, as the two types of data have different depth sensitivities. In 2007, we formulated a scheme to invert surface waves and obtained S-wave velocity anisotropy maps.We also started to reexamine SKS splitting data in Southern California and are setting up the inversion procedure for joint inversion.

Below, we summarize our progress in each type of data.

2. Progress in 2007

(2.1) Surface wave inversion

Rayleigh wave phase velocity maps indicate that fast velocity axes tend to rotate as a function of frequency in Southern California (Prindle, 2006; Figure 1). This gives us some clues as to depth variations of anisotropy. We first inverted this set of data for depth variations of anisotropy, making a simplifying assumption on the form of anisotropy; we assumed that the symmetry axes of P- and S-wave velocity align in the horizontal plane and the medium has hexagonal symmetry. Under these assumptions, the formulation becomes

$$\frac{\delta c}{c} = \int \{K_S \frac{\Delta Vs}{Vs} + K_P \frac{\Delta Vp}{Vp}\} \cos\{2(\theta - \psi)\} dr$$

where $\Delta Vs/Vs$ and $\Delta Vp/Vp$ are (fractional) anisotropy for S-waves and P-waves, K_S and K_P are the kernels we derived as functions of eigenfunctions, θ is azimuth and ψ is the azimuth of fast velocity direction.

Figure 2 shows results of this inversion for the 2θ type variations. We inverted for four layers, the upper crust (0-15 km), the lower crust (15-33 km), the lithospheric upper mantle (33-100 km) and the asthenospheric upper mantle (100-150km). Results indicate that the data require strong anisotropy in the upper mantle 33-100 km and a somewhat weaker anisotropy in the lower crust, whereas contributions from other layers and P-waves are relatively small.

One of the features that stands out in Figure 2 is that the anisotropy is strong in the transverse ranges. It also hints that anisotropy is stronger on the Pacific plate side of the San Andreas Fault. Anisotropy in the uppermost mantle, just below Moho, is stronger than anisotropy in the lower crust, indicating the need for mantle anisotropy for surface wave results. However, its depth range may be shallow, confined within the range from Moho to 60-70 km in depth.

(2.2) SKS splitting

For the model derived in Figure 1, we computed predicted SKS splitting times. Figure 2 shows the results. The top panel shows the variations along the line in the bottom panel, stressing the fact that predicted splitting time reaches a peak near the fault on the Pacific plate side. The bottom panel shows predicted SKS times and fast axes directions for the whole field.

There are obviously a few features that are different from previously reported SKS results (Polet and Kanamori, 1997; Silver and Holt, 2002; Davis, 2003; Becker et al., 2006). Figure 3 shows a compilation of SKS splitting results for Southern California from various sources (Polet and Kanamori, 1997; The Arizona Splitting Data Base; and Davis, 2003). First of all, the maximum time predicted by the model is 0.4 seconds at most, and is smaller than (about) 1 second reported for SKS splitting in this region. The fast axes directions are also different in that our results are mostly parallel to the relative plate motion direction. Larger variations closer to the major faults also seem to be a new observation.

Anisotropic structure derived from surface waves clearly cannot explain SKS splitting data. South of the San Andreas fault SKS splitting is oriented east-west with over 1 sec delay. The surface waves have split times of 0.4 secs and are oriented WNW. Since SKS waves are sensitive to deeper parts of upper mantle, probably down to 300-400 km (Becker et al., 2006), there is a strong possibility that the fast-axes patterns in SKS data are dominated by deeper anisotropic patterns that are not included in the surface wave results. We aim to resolve this question in 2008.

In order to test the effects of a mantle lithosphere layer on SKS splitting we analyzed 59 stacked seismograms (using the method described in Davis, 2003) from station PAS by first removing splitting determined by the surface waves, and solving for deeper splitting parameters, presumably located in the asthenosphere. The net effect, as might be expected, is to rotate the single layer fast direction anticlockwise (from phi=79.2^o to 69.3^o) and reduce the splitting time (from *dt*=1.2 s to 0.94 s). In this area the surface wave results gave phi=105^o, *dt*=0.2s. So if this analysis is correct, the deeper splitting rotates further away from the San Andreas Fault suggesting a deep mantle flow, but in the lithosphere, where the deformation is most extreme, the effects of plate margin strain on anisotropy can be recognized. This analysis was based on ray theory but needs to be checked against finite-frequency wave formulations.

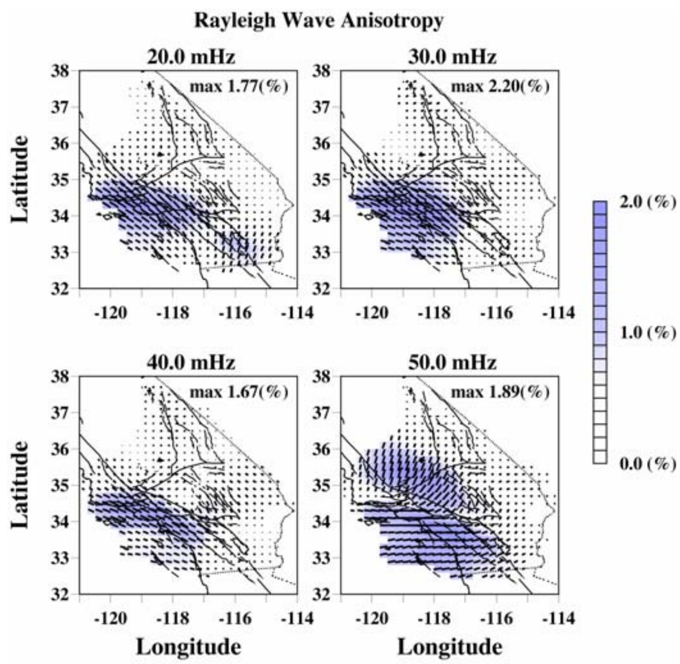

Figure 1: Rayleigh wave azimuthal anisotropy maps from 20 to 50 mHz. (20-50 seconds) Fast axes directions vary with frequency.

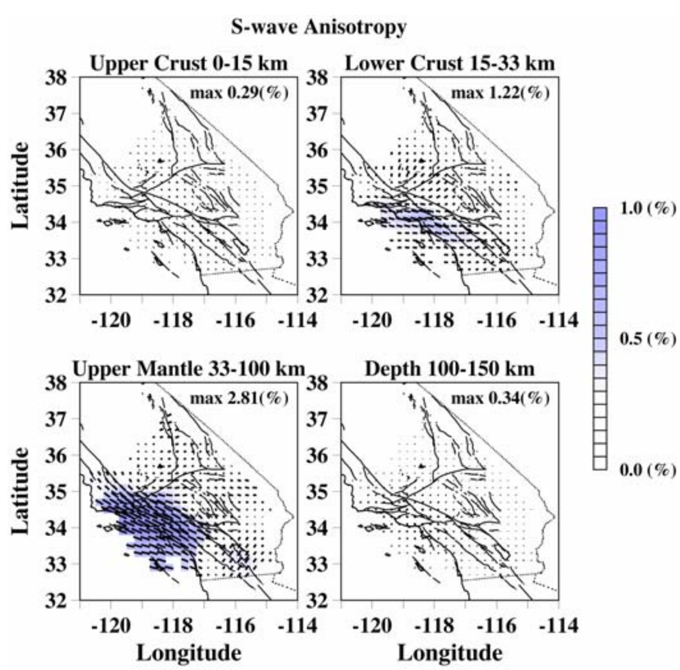

Figure 2: S-wave anisotropy derived from Rayleigh wave azimuthal anisotropy. The data require large anisotropy in the lithospheric upper mantle (33-100 km) and smaller anisotropy in the lower crust (15-33 km).

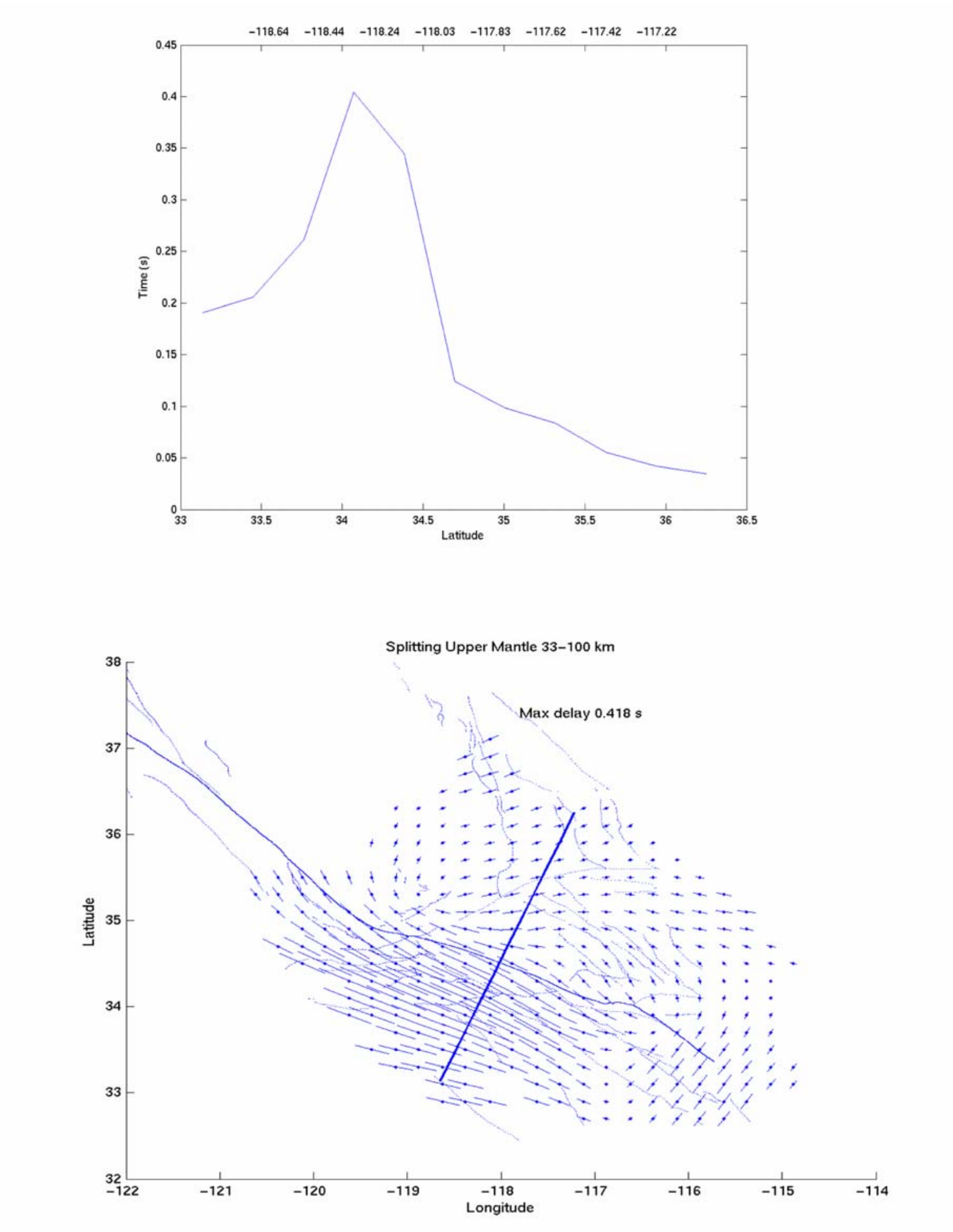

Figure 2: Theoretical predictions for SKS splitting by the model in Figure 1. The top panel shows variations along a solid line in the bottom panel. Anisotropy is stronger on

the Pacific plate side and close to the San Andreas Fault. The features do not match with previously observed patterns of SKS splitting data.

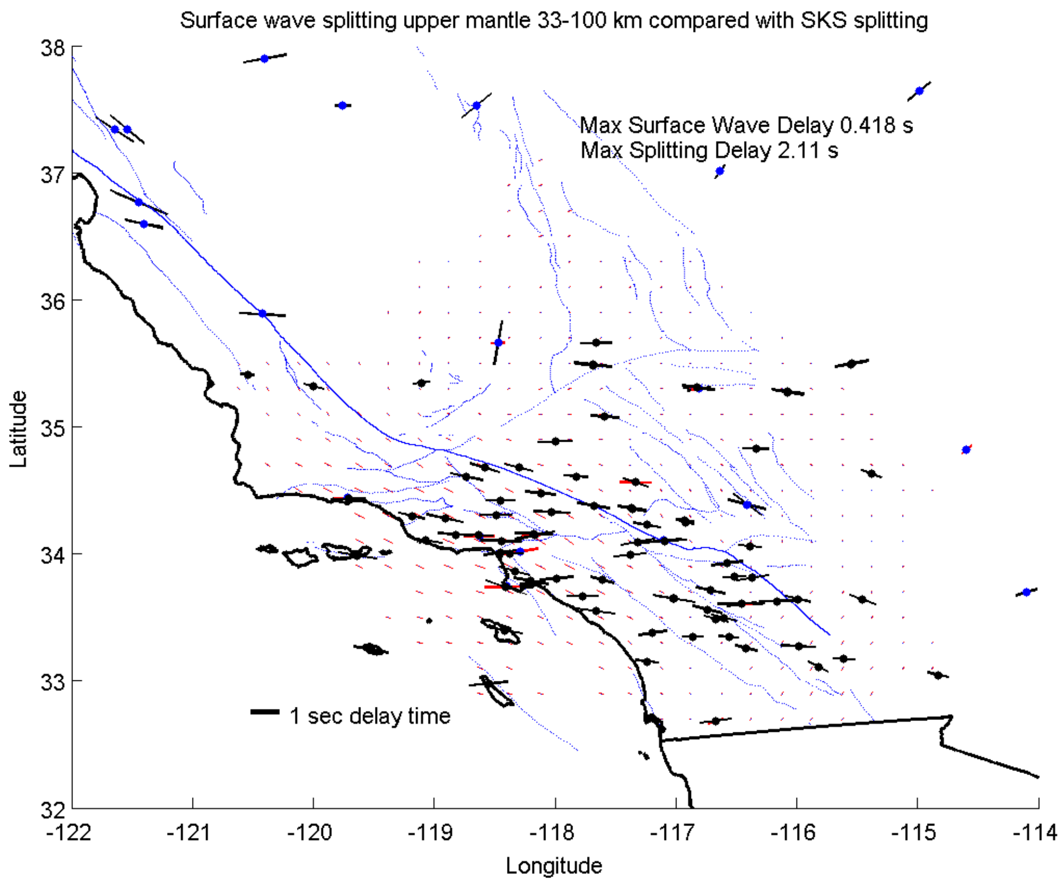

Figure 3: Observed SKS splitting (Polet and Kanamori, 2002; Davis, 2003; Arizona Data Base) compared with values predicted by surface wave analysis (red lines). SKS splitting fast axes tend to align in the east-west direction and no evidence of larger anisotropy near the fault is found. We suspect that these patterns reflect deeper, large-scale flow patterns in the upper mantle, below 100 km.

5. References

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