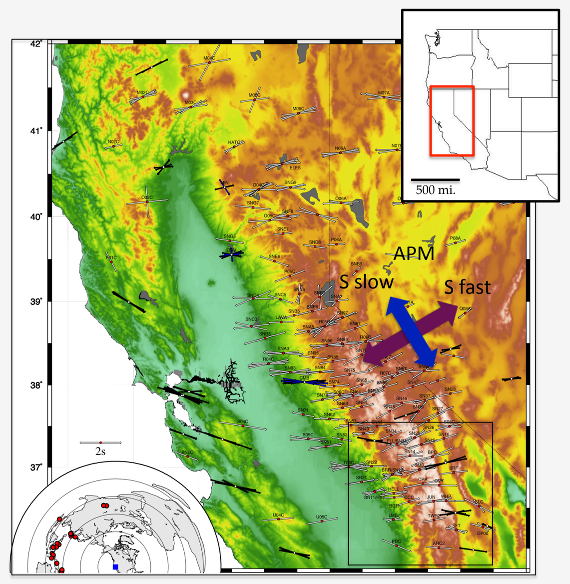
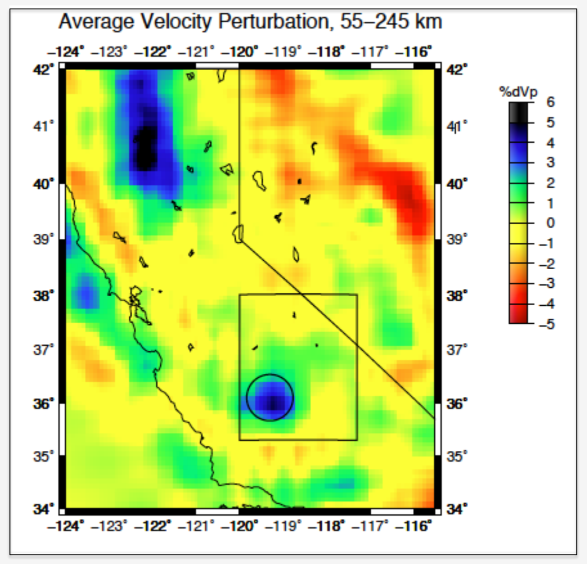
S (fast)/S (slow) Wave Tomography of the Sierra Nevada, California and the Implications of Seismic Anisotropy for Continental Crust Evolution

Gina Oliver, William Levandowski
Department of Geological Sciences, California State University, Long Beach, Department of Geological Sciences, Colorado University

Introduction

- Previous work has supported that the Sierra Nevada batholith has experienced crustal thinning by removal of the dense underlying root.
- Felsic crust, elevation reinforcement, and the connection of the missing root with the high wave speed Isabella Anomaly are controversial.
- Absolute plate motion (APM) is thought to be the cause of anisotropy
- Depth of anisotropy under the southern Sierra Nevada is unknown from previous SKS data (Bastow et al., 2007).
- Suggested removal processes in the Sierra Nevada provides constraints on continental crust formation (Boyd et at., 2004).

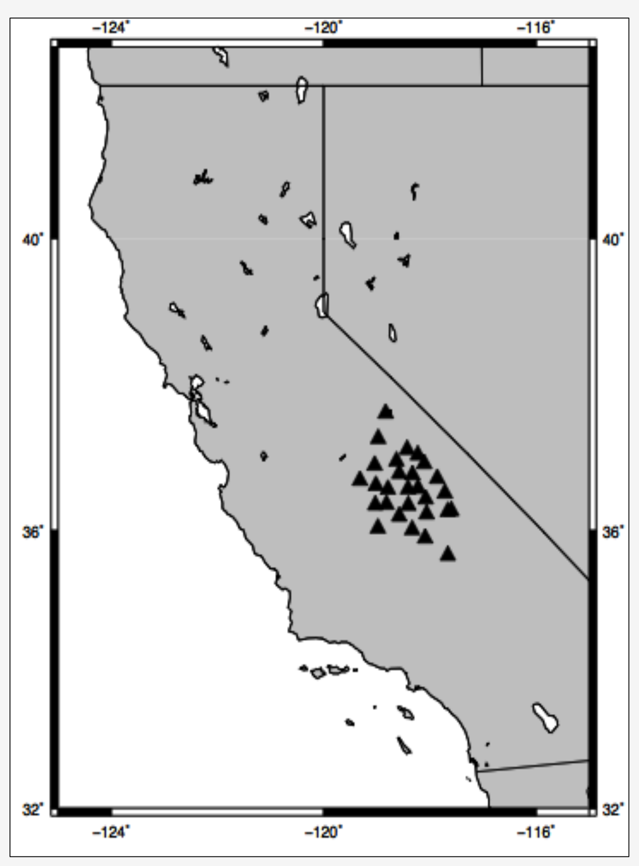


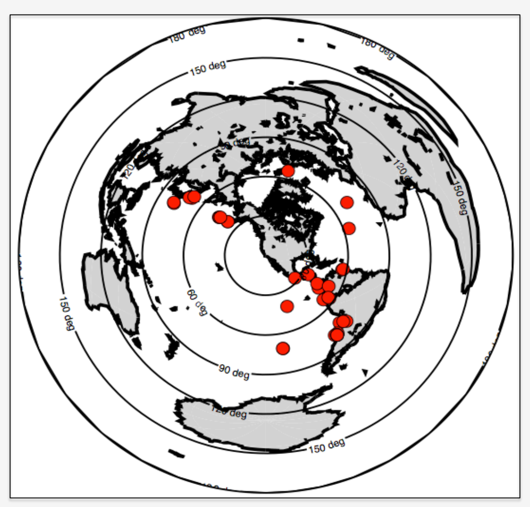


- Left: Arrows indicating SKS fast direction (Bastow et al., 2007)
- Right: Average upper mantle velocity (Jones et al., submitted). Blue area within the box is the Isabella Anomaly

Methods

- Cross-correlation of split teleseismic shear waves with varying back azimuth and station-event distance.
- Known fast and slow planes from previous SKS analysis (Bastow et al., 2007), seismic data are rotated to N75E/N15W
- Cross-correlations done with Seismic Analysis Code (SAC).
- "Pauper's Tomography"(Jones et al., 1994) to back project down the ray path to find depth

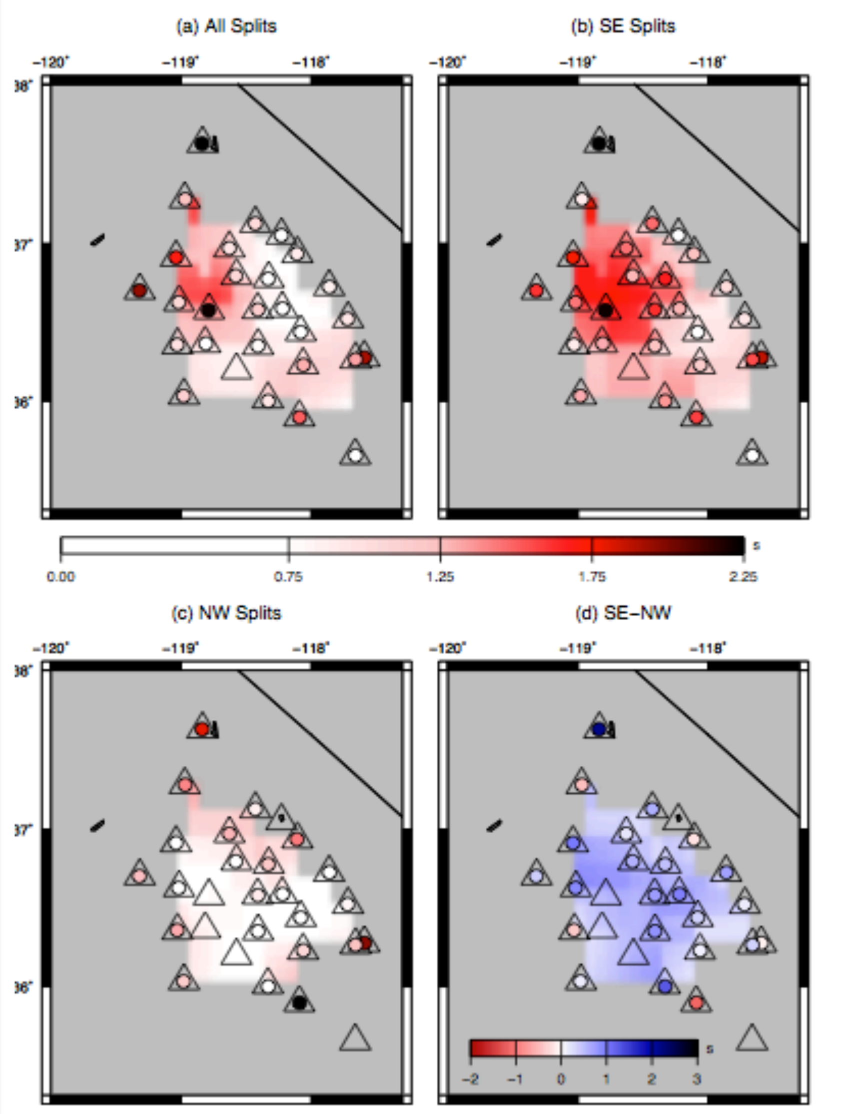


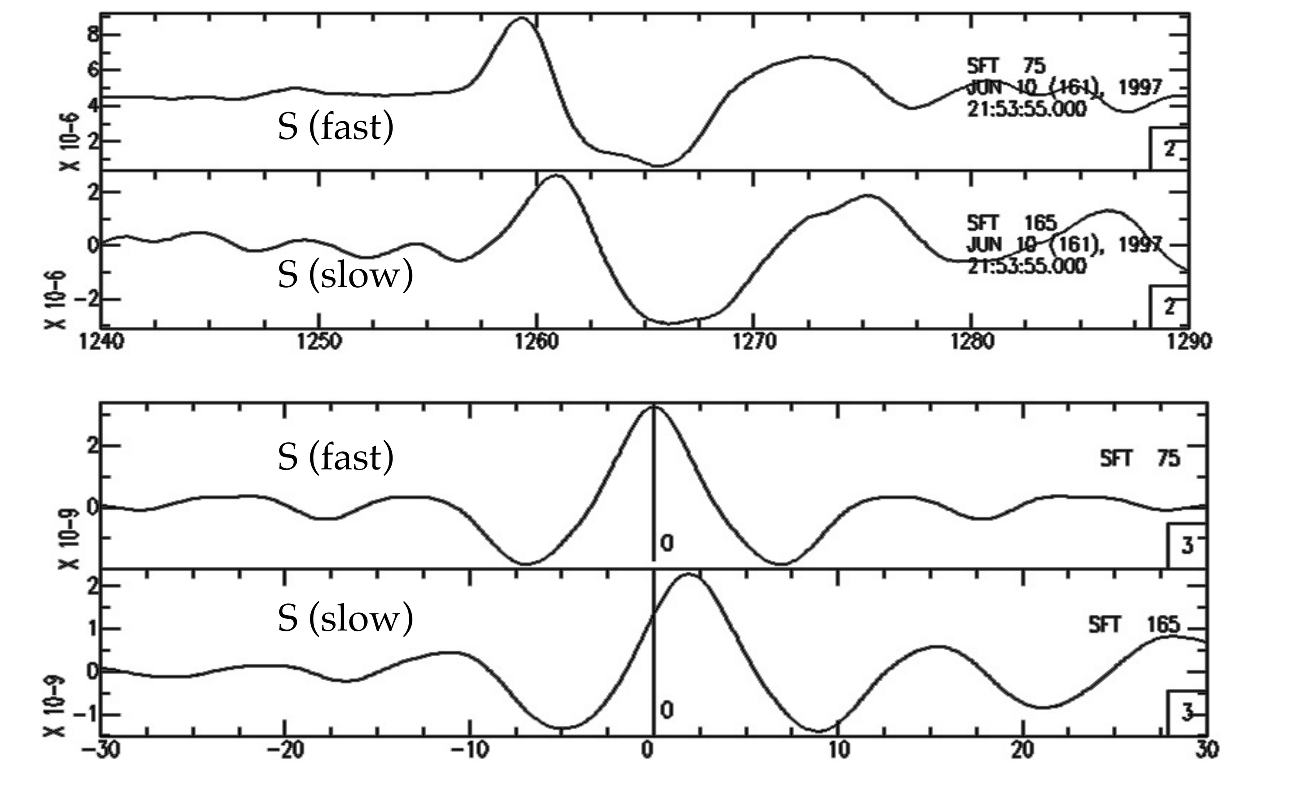


- Left: Seismic Stations from Sierra Nevada EarthScope Project (SNEP) and Sierran Project Experiment (SPE)
- Above: Global plot showing earthquake event locations

Results

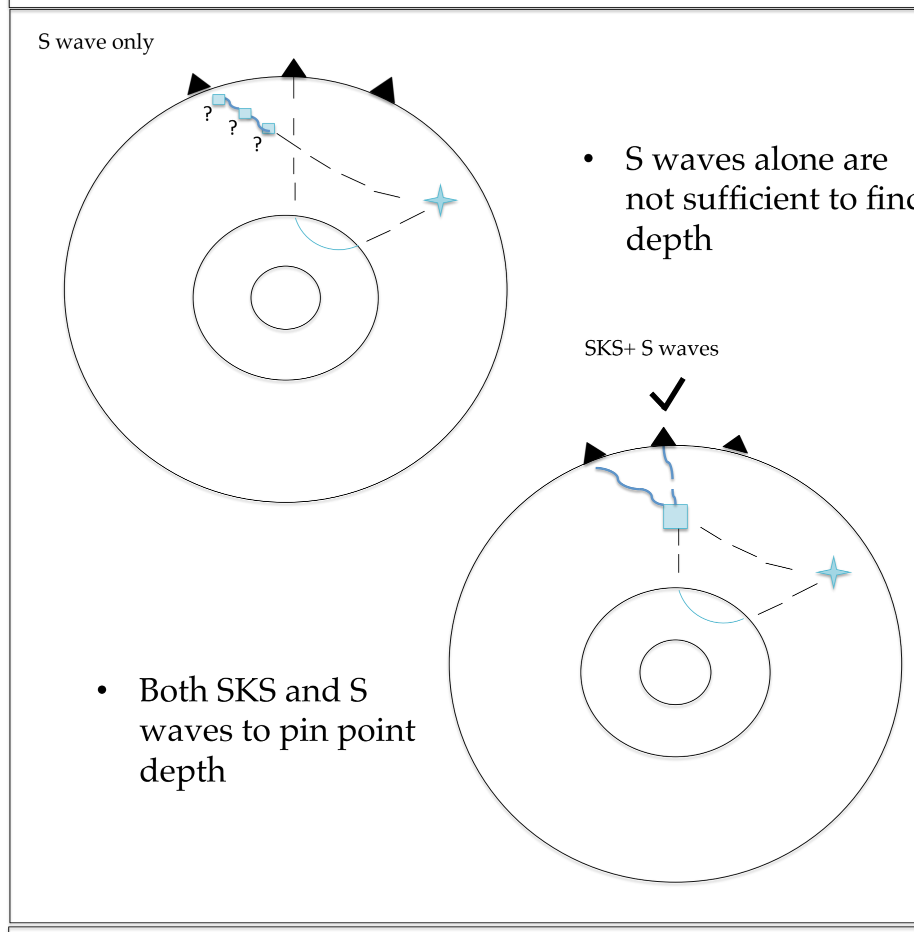
- Picks of S-fast/S-slow lag times for 260 split waveforms from 15 events recorded at 27 seismic stations.
- The lag times (up to 3.25 s) from the fast (N75E polarized) and slow waves are recorded for each waveform pick.
- Null (52 less than 0.5 s) and negative (16) splits were allowed, but the coordinate system was fixed.
- Anisotropy depth 150-200km





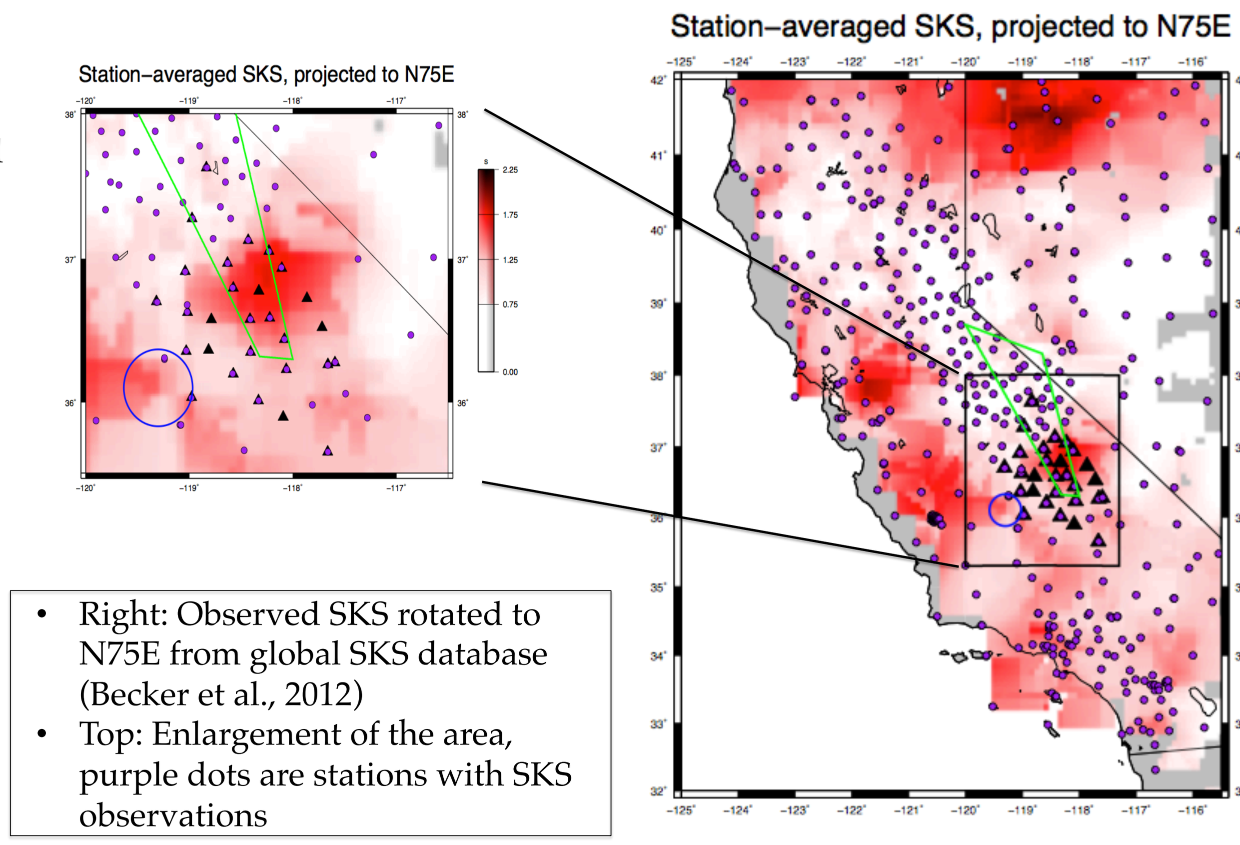
- Left: SKS and S waves coming from different back azimuths showing a directional dependence.
- (d): The difference between SE and NW back azimuth

- Top: SPE raw waveform, S(fast) and S (slow) polarized in two different planes but propagating in the same direction
- Bottom: Correlation of the same raw waveform in SAC

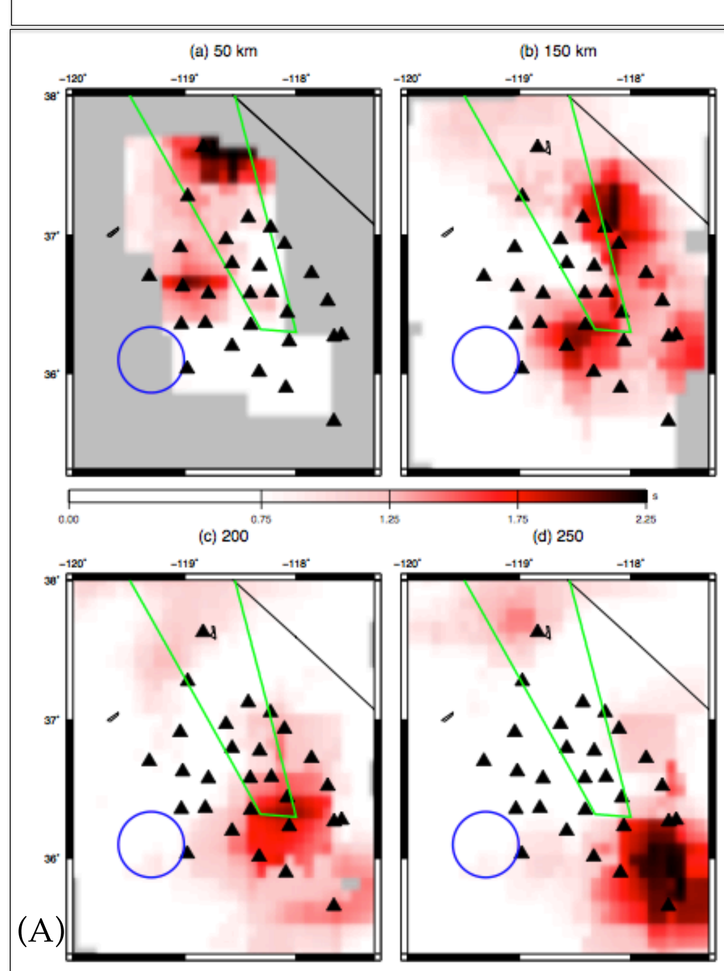


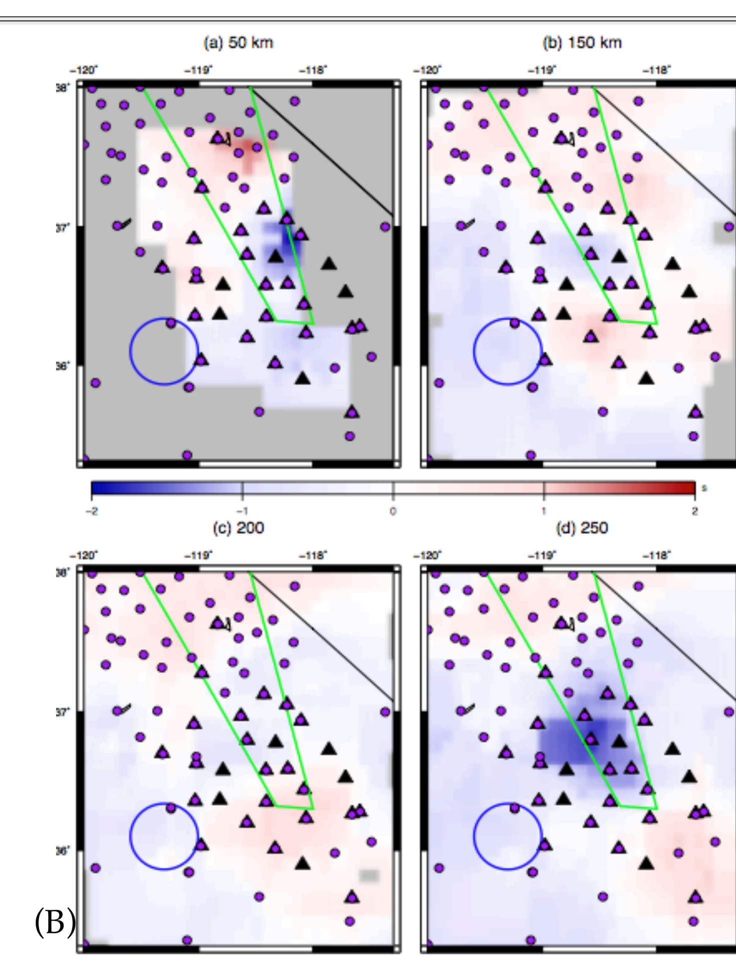
- S waves alone are not sufficient to find depth

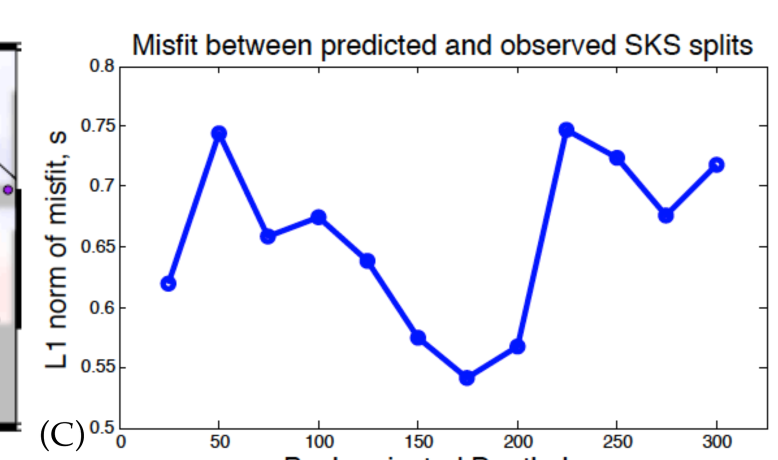
- Both SKS and S waves to pin point depth



- Right: Observed SKS rotated to N75E from global SKS database (Becker et al., 2012)
- Top: Enlargement of the area, purple dots are stations with SKS observations



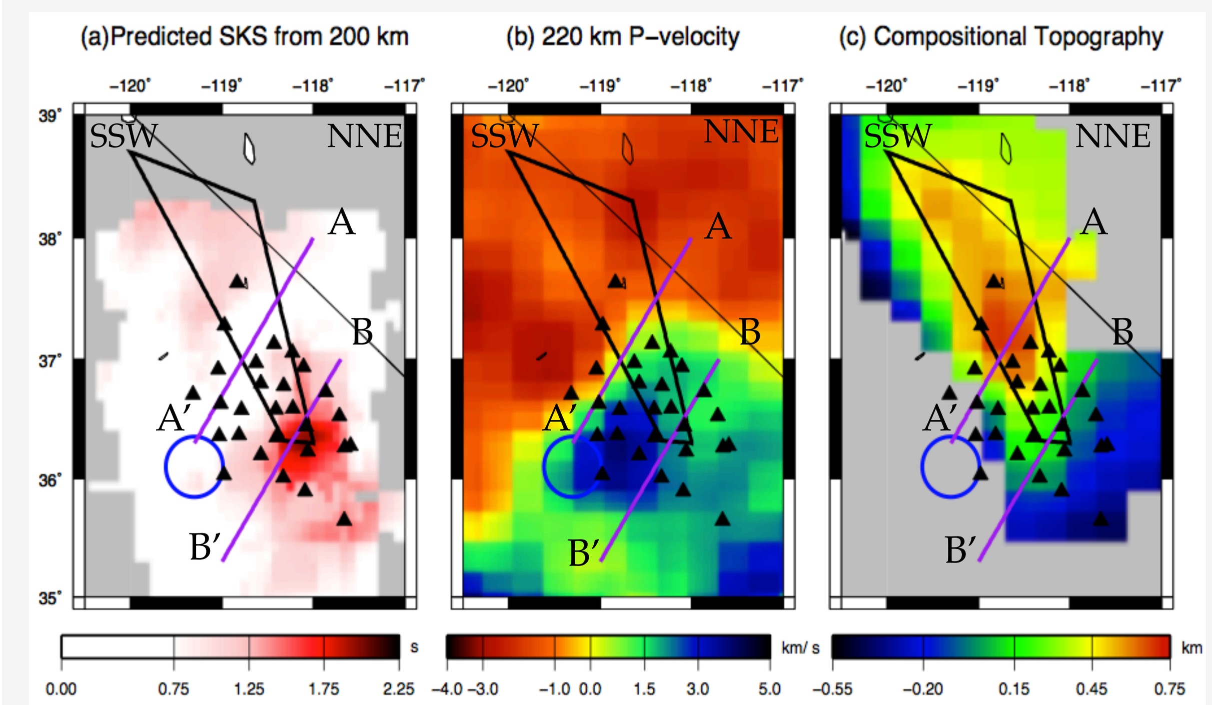


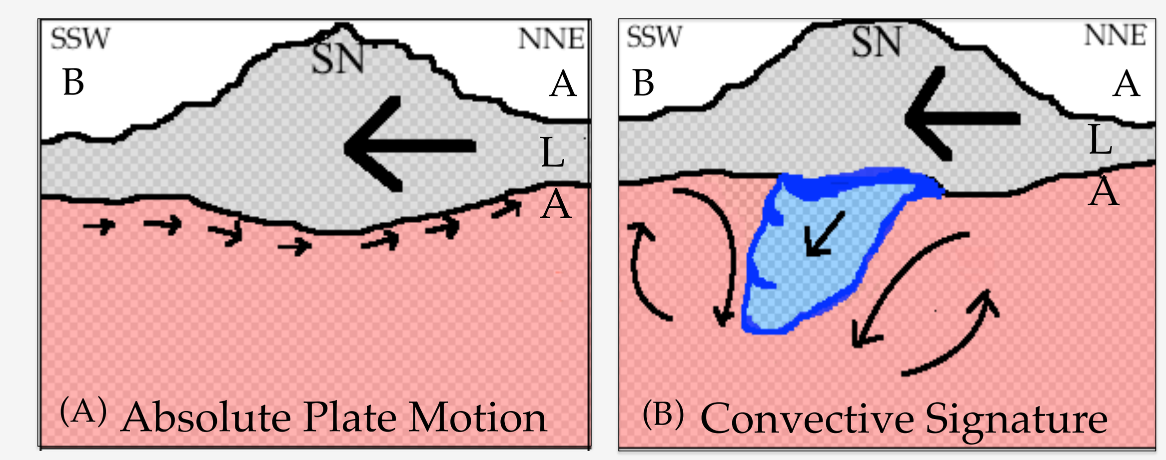


- Velocities used: 3.5 km/s in upper 40km, 4.5 km/s below 40km
- (A): Predicted SKS at multiple depths by back projection method
- (B): Graph of misfit from the predicted and observed SKS
- (C): Plot of misfit, closest to zero between 150-200km

Discussion

- S(fast)/S(slow) wave tomography and cross-correlation methods effectively imaged depth of anisotropy under the Sierra Nevada.
- Anisotropy depth (asthenospheric) supports two hypotheses
  1) Regional anisotropy dominated by APM
  2) Sinking of dense, mafic root from south-central Sierra toward Isabella Anomaly.





- Top: Comparisons among the SKS data, P-wave velocity and compositional topography (Levandowski et al., 2013)
- Bottom: Cross sections of two interpretations. (A) Anisotropy caused by absolute plate motion (APM) (B) Anisotropy caused by sinking of dense root

Conclusion

- APM (~WSW-ENE) dominated flow disrupted by a ~100 km wavelength NNE-SSW trending zone from south-central Sierra to Isabella Anomaly
- Suggests that Isabella Anomaly is dense lower crust and mantle lithosphere removed from beneath Sierra Nevada
- Remaining felsic crust may be a microcosmic explanation for global continental-oceanic crustal composition dichotomy

Literature Cited

- Bastow, I., Owens, T., Badger, N., Zandt, G., Jones, C., Gilbert, H. (2007). S33B-1956: Shear wave Anisotropy Beneath the Sierra Nevada; Implications for Lithospheric foundering and Upper Mantle flow. *American Geophysical Union*.
- Becker, T.W., Lebedev, S., Long, M.D., (2012), On the Relationship between Azimuthal Anisotropy from Shear Wave Splitting and Surface Wave Tomography. *Journal of Geophysical Research*, 117
- Boyd, Oliver S., Jones, C., Sheehan A. F., (2004), Foundering Lithosphere Imaged Beneath the Southern Sierra Nevada, California, USA. *Science*, 305, 660
- Jones, C.H. et al., 2013, submitted to *Geosphere*
- Toomey, D. R. (1998). Mantle Seismic Structure Beneath the MELT Region of the East Pacific Rise from P and S Wave Tomography. *Science*, *280*(5367), 1224–1227. doi:10.1126/science.280.5367.1224
- Levandowski, W. et al., (2013) Seismological Estimates of Means of Isostatic Support of the Sierra Nevada, submitted to *Geosphere*

Acknowledgements

Many thanks to:
- UNAVCO RESESS and NSF
- Dan Zietlow, Justin Ball, and Dr. Anne Sheehan
- Hannah Grist, Peter Shellito and Rolf Norgaard