Shear-Wave Splitting in the Great Basin

John D. West and Matthew J. Fouch

School of Earth and Space Exploration, Arizona State University, Tempe, AZ

SCHOOL OF EARTH & SPACE EXPLORATION
ARIZONA STATE UNIVERSITY

earthscope

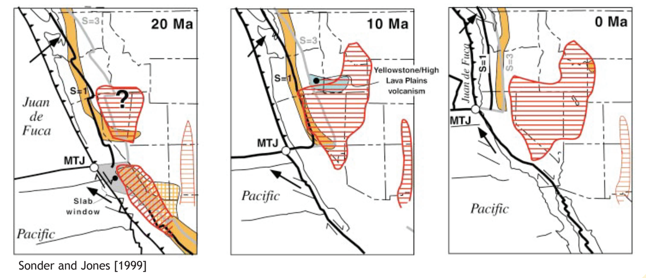
Introduction:

One of the goals of the EarthScope program is to investigate the processes and mechanisms responsible for continental tectonics. Within that framework, we are investigating the role that mantle forces play in wide-spread crustal extension in the Great Basin region of western North America. Shear-wave splitting analysis to measure seismic anisotropy is widely used to infer strain conditions and recent history in the upper mantle, and is an important method in our research. We are analyzing shear-wave splitting in SKS-phase seismic data from EarthScope/USArray stations in the Great Basin with the goal of better understanding the underlying forces, the structure of the crust and upper mantle, and the causes of extension in the region.

The Great Basin is a region of wide-spread crustal extension andcontains a large number of relatively small mountain ranges, oriented roughly north-south and separated by sediment-filled basins. The ranges were formed by normal faulting during the extension process.

http://www.tu-berlin.de/~kehl/project/lv-twk/images/jpgs/241-great-basin-nbii-factsheet.jpg

Much of the extension in the Great Basin has occurred over the past 20 My. The figures to the right show estimated extension and boundaries of the Great Basin over the last 20 million years.



Sonder and Jones [1999]

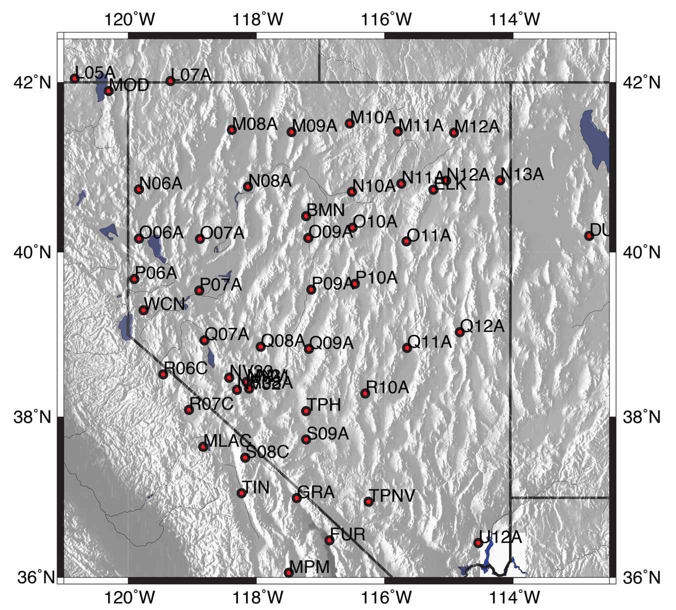
Data:

We analyzed broadband seismic data covering a time span of nearly three years, from January 1, 2004 through December 11, 2006. We selected events occurring within an epicentral distance range of 85-130 degrees, and with a body wave magnitude of 5.8 or larger.

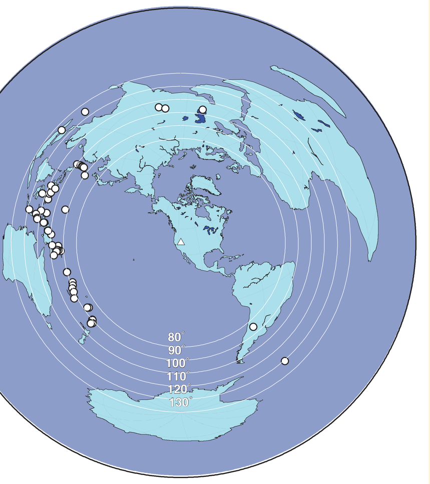
We used data from 113 seismic stations; a combination of EarthScope/Transportable Array stations and existing permanent stations. A map of station locations is shown to the right.

With these critera, we gathered 9981 discrete event/station pairs, and processed each for shear-wave splitting. We reduced the data to 79 event/station pairs exhibiting good quality shear-wave splitting measurements, and 92 event/station pair exhibiting well-constrained null measurements.

Great Basin Seismic Station Locations



Events Used in this Study



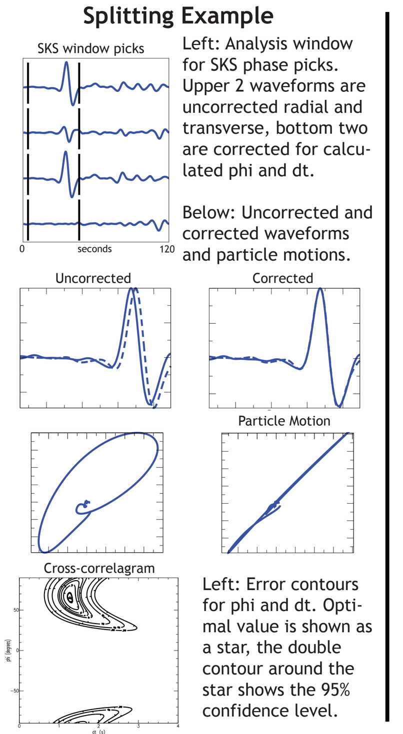
Distribution of events used in this study. As expected, the majority of the events occur along the margins of the Pacific plate.

Methodology:

When a shear wave passes through an anisotropic material, it is split into two orthogonal components which travel at different velocities. We used the method of Silver and Chan [1988, 1991] to analyze the waveform data for analysis of shear-wave splitting. This method uses a grid analysis to evaluate the energy in the slower component over a range of values in fast polarization direction (phi) and splitting time (dt). In the presence of anisotropy, particle motions will be elliptical. We therefore determine the best-fitting splitting parameters which yield the most nearly linear particle motion .

If the shear wave arrives parallel to either the fast or slow directions of the anisotropic material, no orthogonal component can be generated and the result is known as a null. A null can also be recorded if there is no detectable anisotropy, or if the collection of anisotropic layers is so complex that no fast or slow component can be identified.

Splitting Example

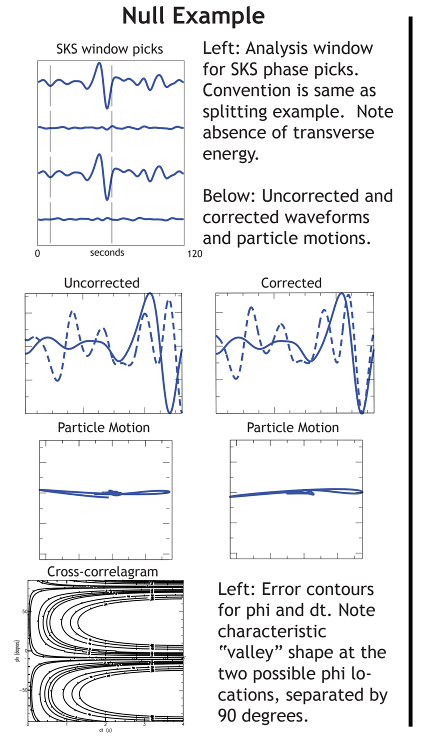


Left: Analysis window for SKS phase picks. Upper 2 waveforms are uncorrected radial and transverse, bottom two are corrected for calculated phi and dt.

Below: Uncorrected and corrected waveforms and particle motions.

Left: Error contours for phi and dt. Optimal value is shown as a star, the double contour around the star shows the 95% confidence level.

Null Example



Left: Analysis window for SKS phase picks. Convention is same as splitting example. Note absence of transverse energy.

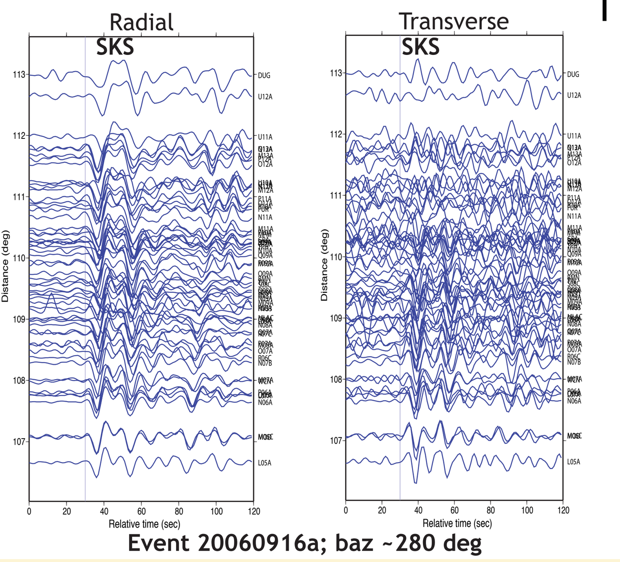
Below: Uncorrected and corrected waveforms and particle motions.

Left: Error contours for phi and dt. Note characteristic "valley" shape at the two possible phi locations, separated by 90 degrees.

Record Section Example: Splits and Nulls

Below left is a record section of the radial component for an event exhibiting both splits and nulls. Note the well-defined SKS arrivals on most waveforms.

On the right is a record section of the transverse component for the same event. Here some waveforms show well-defined SKS arrivals (splits), and others do not

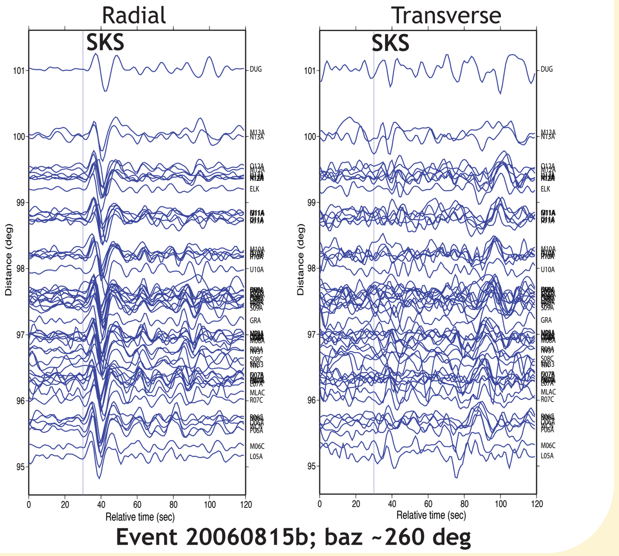


Event 20060916a; baz ~280 deg

Record Section Example: Nulls Only

Below left is a record section of the radial component for an event exhibiting mostly nulls. Note the well-defined SKS arrivals on most waveforms.

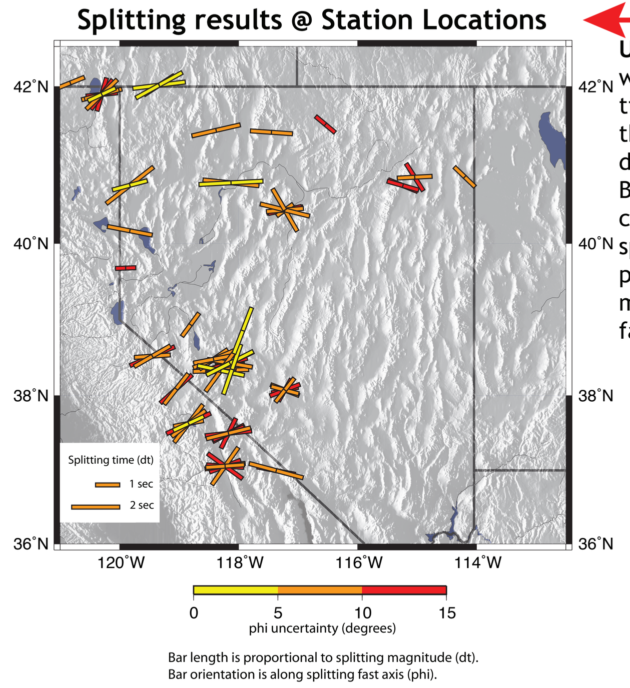
On the right is a record section of the transverse component for the same event. The SKS arrivals are much less coherent than those for signals exhibiting splitting.



Event 20060815b; baz ~260 deg

Shear Wave Splitting Observations Across the Great Basin

Splitting results @ Station Locations

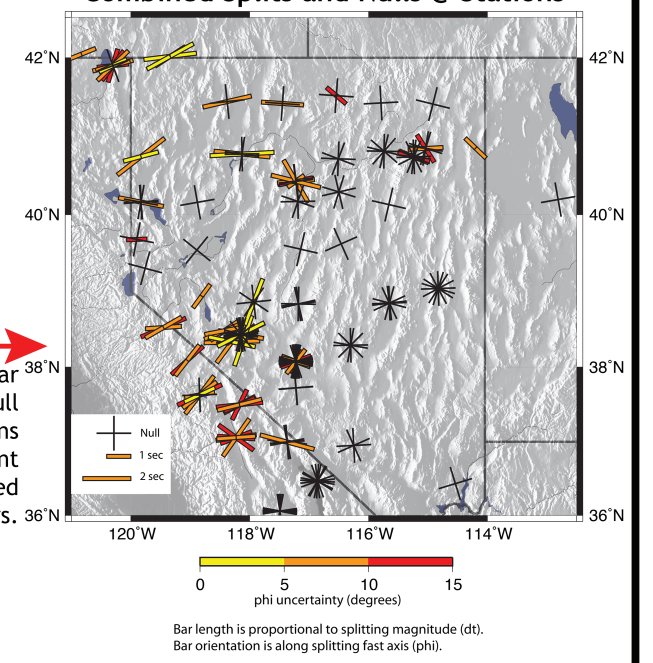


Bar length is proportional to splitting magnitude (dt).
Bar orientation is along splitting fast axis (phi).

Upper left: Shear-wave splitting results with vectors centered on the station locations. The vector length is proportional to the splitting time, and vector azimuth indicates the fast polarization direction. Bars are color coded to indicate the uncertainty in fast direction. Note that the splitting directions present a very complex picture -- several stations have split measurements exibiting widely differing fast directions.

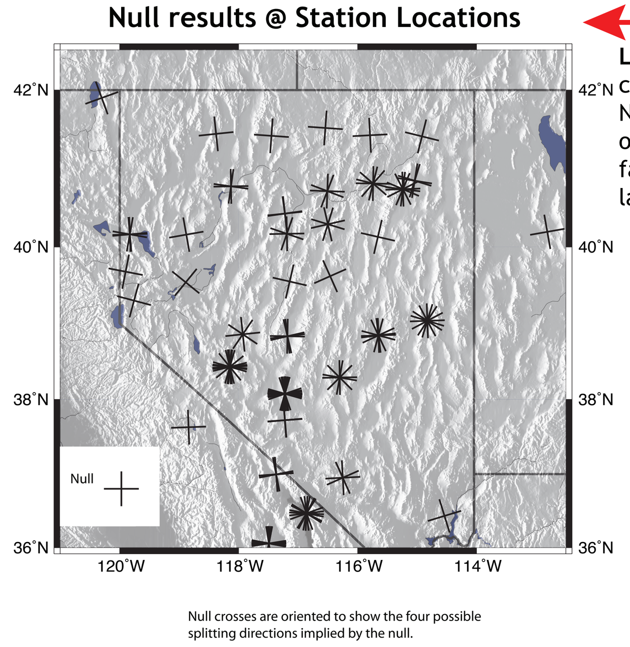
Upper right: Shear wave splitting and null results. Most stations exhibit significant complexity in inferred splitting parameters.

Combined Splits and Nulls @ Stations



Bar length is proportional to splitting magnitude (dt).
Bar orientation is along splitting fast axis (phi).

Null results @ Station Locations

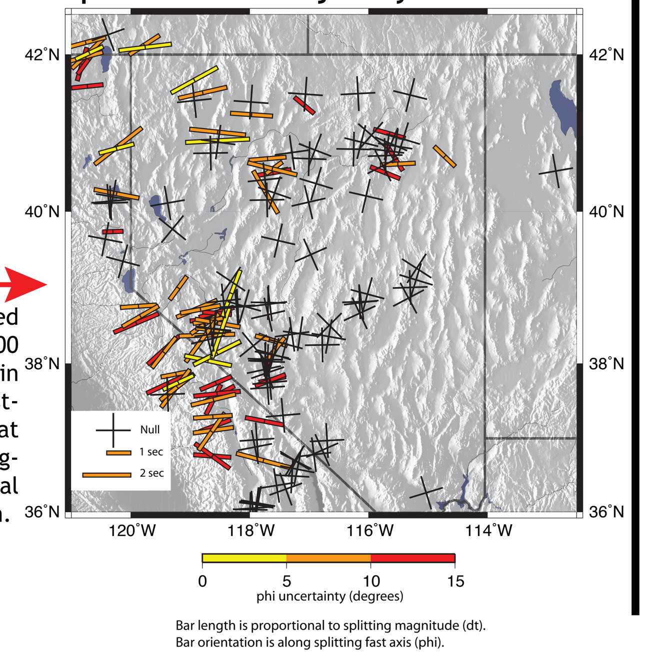


Null crosses are oriented to show the four possible splitting directions implied by the null.

Lower left: Null measurements with crosses centered on the station location. Nulls are plotted as crosses with the arms of each cross aligned with the possible fast directions based on both incoming polarization and resulting cross-correlagram.

Upper left: Splits and nulls projected along individual backazimuths at the 200 km piercing points. Regional variations in splitting parameters are evident, suggesting complexity in anisotropy recorded at most stations. Regional correlations suggest variations in anisotropy at lateral length scales of perhaps 100 km.

Splits and Nulls Project by Backazimuth

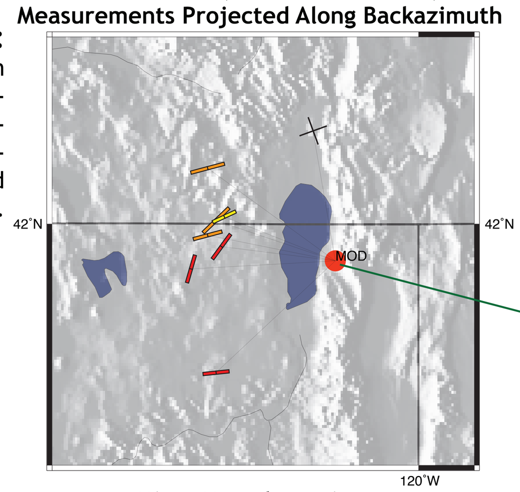


Bar length is proportional to splitting magnitude (dt).
Bar orientation is along splitting fast axis (phi).

Station MOD:

Expanded view of events recorded at station MOD in the north-eastern corner of California. These variations in splitting parameters are somewhat less pronounced than at other stations presented in this section. Note that station MOD is on the very edge (and possibly outside) the bounds of the Great Basin.

Station MOD (Modoc Plateau, CA)
Measurements Projected Along Backazimuth

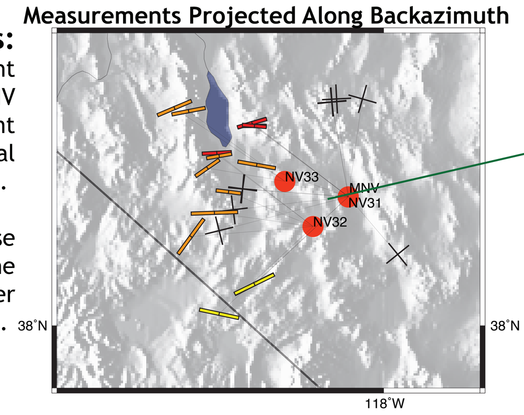


Mina, NV Stations:

Expanded the plot of events recorded at the tight grouping of stations NV31, NV32, NV33, and MNV. MNV and NV31 are co-located. Here the nulls are consistent with back azimuth, and the splits and nulls in general seem to be separated into sectors by back azimuth.

As in the case of station TPH below, we interpret these variations as having a significant contribution from the crust or upper mantle due to the small distances over which the variations are observed.

Mina, Nevada stations
Measurements Projected Along Backazimuth

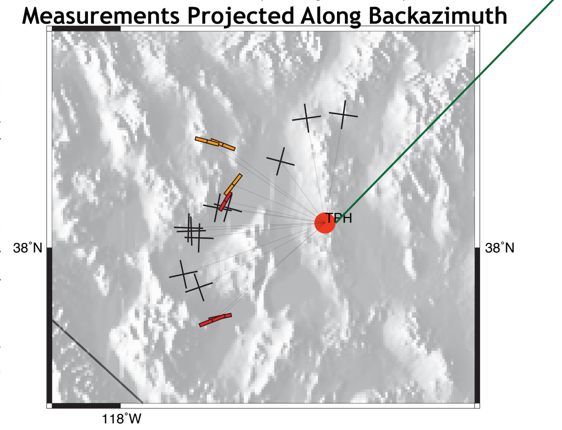


Station TPH:

Station TPH shows significant variation in fast direction with back azimuth, with separate segments of splits and nulls. Most of the nulls are aligned consistent with back azimuth, but the splits show significant variations over small angular and spatial separations.

We interpret these variations as likely being due to fabric of the crust or uppermost mantle, as deeper structures would not be visible to stations so closely spaced. The angular variations cannot be ascribed to a single horizontal layer of anisotropy, but instead must be due to crustal variations, multiple anisotropy layers with different orientations, and/or dipping layers.

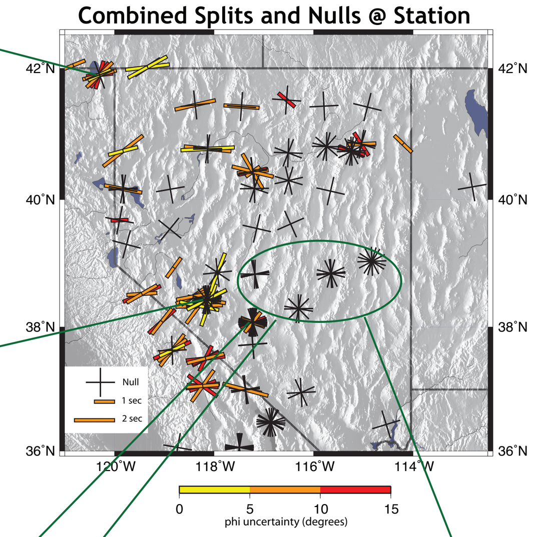
Station TPH (Tonopah, NV)
Measurements Projected Along Backazimuth



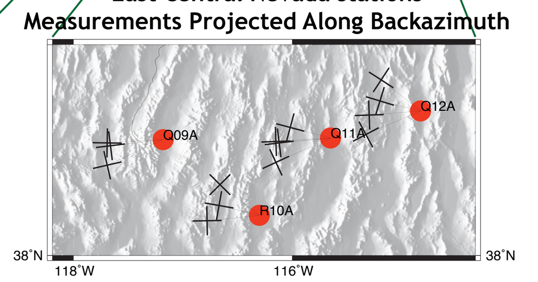
Expanded Views of Selected Stations:

Here we have expanded two individual stations and two groups of stations to show the local complexity of results. Events are plotted offset along the back azimuth for a 200 km piercing depth, and light lines have been drawn connecting the station to the splitting or null symbol.

Combined Splits and Nulls @ Station



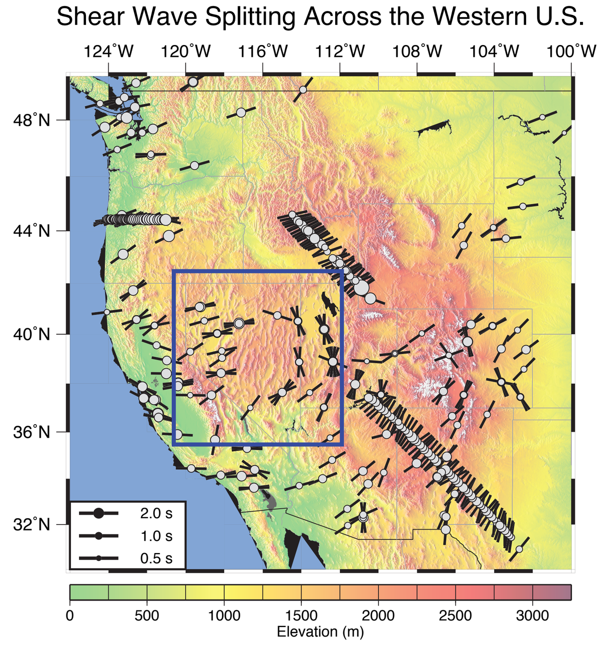
East-central Nevada stations
Measurements Projected Along Backazimuth



Stations Q09A - Q12A and R10A:

This group exhibits null measurements only which appear to be consistent with back azimuth. This can mean either that there is no discernable anisotropy in this region, or that the multiple layers of anisotropy are complex. We note, however, that this group of stations has only recently been installed, so available data for them is very sparse at present. Because the existing data cover only a limited range of backazimuths, it is possible that splitting will be observed for events from other backazimuths.

Shear Wave Splitting Across the Western U.S.



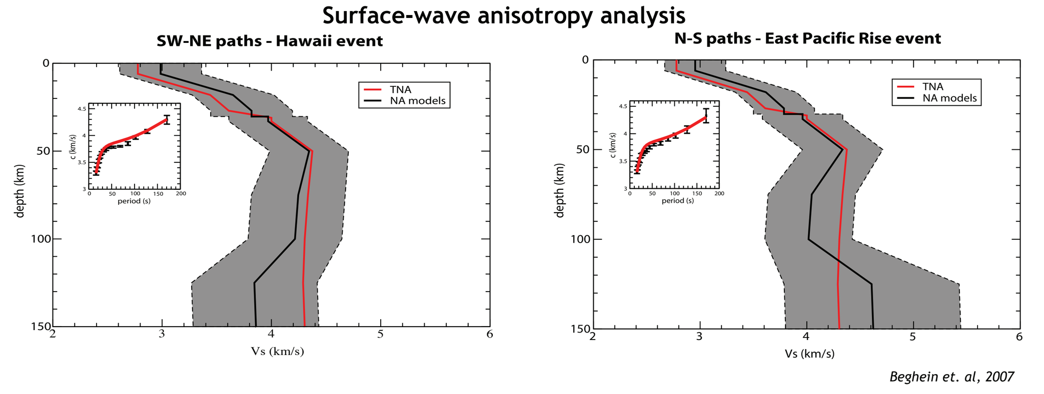
Comparison to Regional Shear Wave Splitting:

Map on left shows published shear wave splitting values from ASU's shear wave splitting database (http://geophysics.asu.edu/anisotropy/upper). The Great Basin exhibits a wide range of splitting parameters that change over lateral scales of ~100 km or more. These results have been used to proposed a host of possible mechanisms primarily controlled by mantle flow. We note that the complexity found in our study suggests that local structural effects must be better documented to provide a more complete picture of the role of the crust and mantle in shear wave splitting observations.

Comparison to Regional Surface Wave Structure:

Several other studies have doucmented complexity in regional anisotropic structure across the region, but depth constraints on anisotropic structure remain poorly known. An independent study of surface wave velocity and anisotropic structure are beginning to document possible sources of some of the anisotropy. The figures below are from an analysis of surface-wave travel times across the Great Basin region (Beghein et al., 2007). Thefigure on the right from a N-S path across the Great Basin shows significantly slower velocities in the 50-100 km depth range than those from a SW-NE path shown on the left. This may be interpreted as evidence for generalized E-W fast directions across the region over a narrow region of the asthenosphere.

Surface-wave anisotropy analysis



Beghein et. al, 2007

Conclusions:

1. Shear-wave splitting in the Great Basin is generally complex, varying over small azimuthal and lateral distances, consistent with the findings of some previous regional studies.

2. Local fabric in the crust is likely the cause of at least a portion of the anisotropic complexity in this region. Caution should therefore be applied when interpreting regional shear wave splitting variations as caused solely by mantle flow.

3. Simple regional asthenospheric flow is not consistent with our results, and suggests a more complex flow field. This result, combined with the result that local splitting is complex, demonstrates the necessity that we continue to develop better constraints regarding the role of local anisotropic structure to tease out the nature of crust and mantle deformation across the region.

References:

Beghein, C, MJ Fouch, and JA Snoke, et. al., 2007, Upper mantle seismic velocity structure in the Great Basin, EarthScope National Meeting.

Silver, PG and Chan, WW, 1988, Implications for Continental Structure and Evolution from Seismic Anisotropy. Nature 335 (6185): 34-39

Silver, PG and Chan, WW, 1991, Shear-Wave Splitting and Subcontinental Mantle Deformation J Geophys Res-Sol Ea 96 (B10): 16429-16454

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Acknowledgements:

Partial support for this project came from National Science Foundation grants EAR-0548288 (EarthScope CAREER grant) and EAR-0507248 (Continental Dynamics High Lava Plains grant).