Shear-Wave Splitting in the Great Basin

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Introduction

The Great Basin (**Figure 1**) is a tectonically-active area of widespread crustal extension in the western United States. The region is characterized by numerous north-south oriented mountain ranges formed as normal faults during extension, which are separated by sediment-filled valleys. Crustal extension in the Great Basin can be as much as 200%, is oriented predominantly east-west, and is generally thought to have occurred over the past 20 My (**Figure 2**).

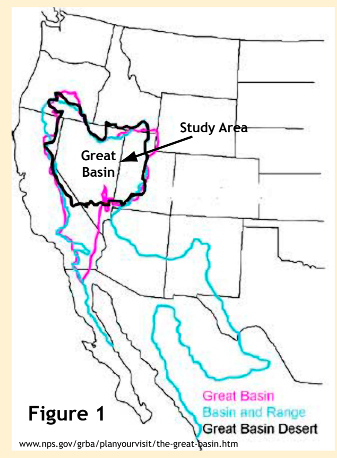
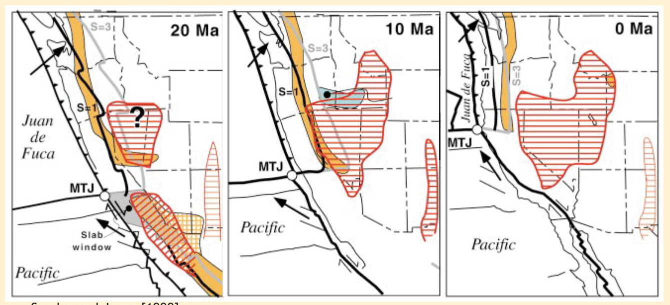


Figure 1

Our goal is to understand the causes of extension in the Great Basin and the extent to which mantle dynamics has contributed to this extention. Seismic anisotropy is widely used to infer strain conditions and recent history in the upper mantle. In this study we therefore examine seismic anisotropy via shear-wave splitting analysis to evaluate mantle flow and other forces acting on this region.



Sonder and Jones [1999]

Figure 2

Data

The Great Basin is home to eight long-term broadband seismic stations (BMN, ELK, MNV, NV31, NV32, NV33, TPH, and TPNV), and is also temporarily occupied by 74 stations of the EarthScope/USArray Transportable Array (TA) (**Figure 3**). We analyzed two data sets, one with approximately 14 years of data for the eight long-term stations, and the other with approximately 2 years of data for the TA. Because of the roll-out schedule for the TA, some of the stations in this region have been in operation for less than a year.

Great Basin Seismic Station Locations

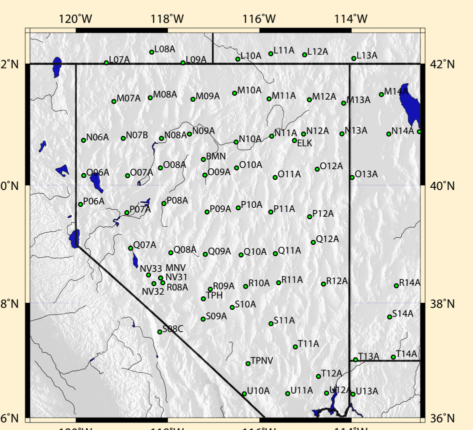


Figure 3

For our shear-wave splitting analysis, we selected events with $m_b > 5.8$ and epicentral distances between 85 and 130 degrees. We began the analysis effort with 14,476 total event/station pairs. Following elimination of unsuitable samples we present results for 1326 well-constrained measurements, of which 633 are nulls and 693 are splits.

Figure 4 shows the locations of seismic events used in this study. As expected given the study location and global seismicity distribution, the majority of the events included in this dataset originated from the westward margins of the Pacific plate.

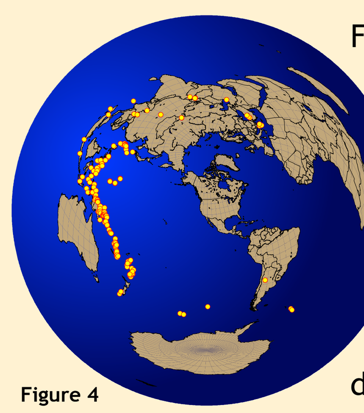


Figure 4

Methods

When a seismic shear wave passes through an anisotropic material, its energy is split into two orthogonal components which travel at differing velocities. Using the method of Silver and Chan (1991) and the SplitLab analysis tool set (Wüstefeld, et. al 2007), we determined the splitting delay time (dt) and the direction of the fast axis of transmission (phi) for each event/station pair.

We show a splitting example (**Figure 5**) and a record section of the same event recorded at multiple stations (**Figure 6**).

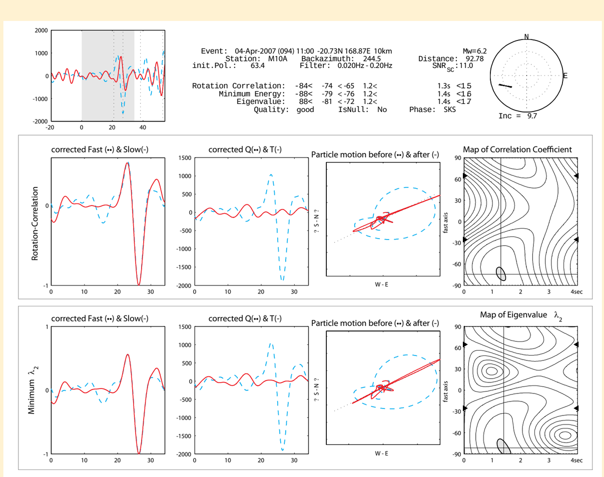


Figure 5

Event 2007.094.11.00.27

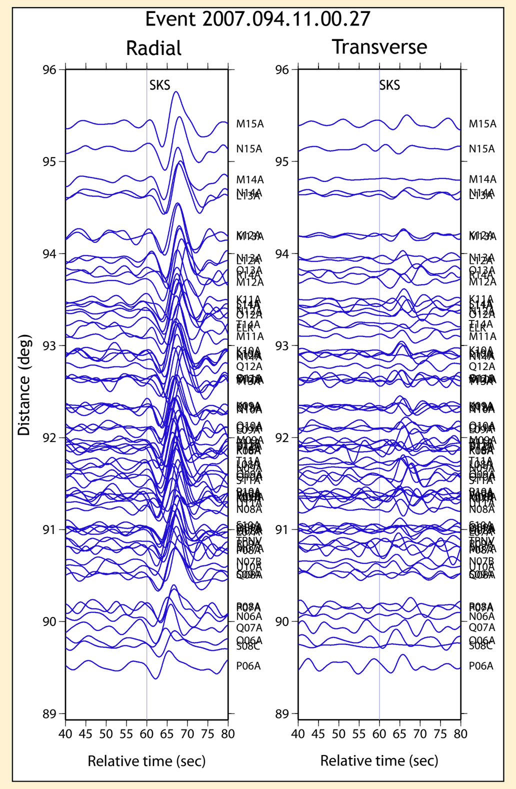


Figure 6

Results

Our splitting measurements show several notable features (**Figure 7**):

- In the northern portion of the Great Basin, splitting times are generally large (near 2 seconds) and oriented in a nearly east-west direction. These results are consistent with findings by Fouch (2007) and Klaus et. al. (2007) for separate studies in the Pacific Northwest, north of our study region.
- Southward toward the central Great Basin, splitting times generally become shorter, and fast directions exhibit a noticeable "swirl" pattern. This pattern was originally shown by Savage and Sheehan (2000) for a relatively limited dataset.
- In the central Great Basin, the "swirl" pattern becomes more apparent and splitting times become quite small, except along the western edge of the Great Basin.
- In the southern and eastern Great Basin the "swirl" pattern is less evident, likely due to the limited data availability for this region.

Great Basin Splitting Results
Plotted at Station Location

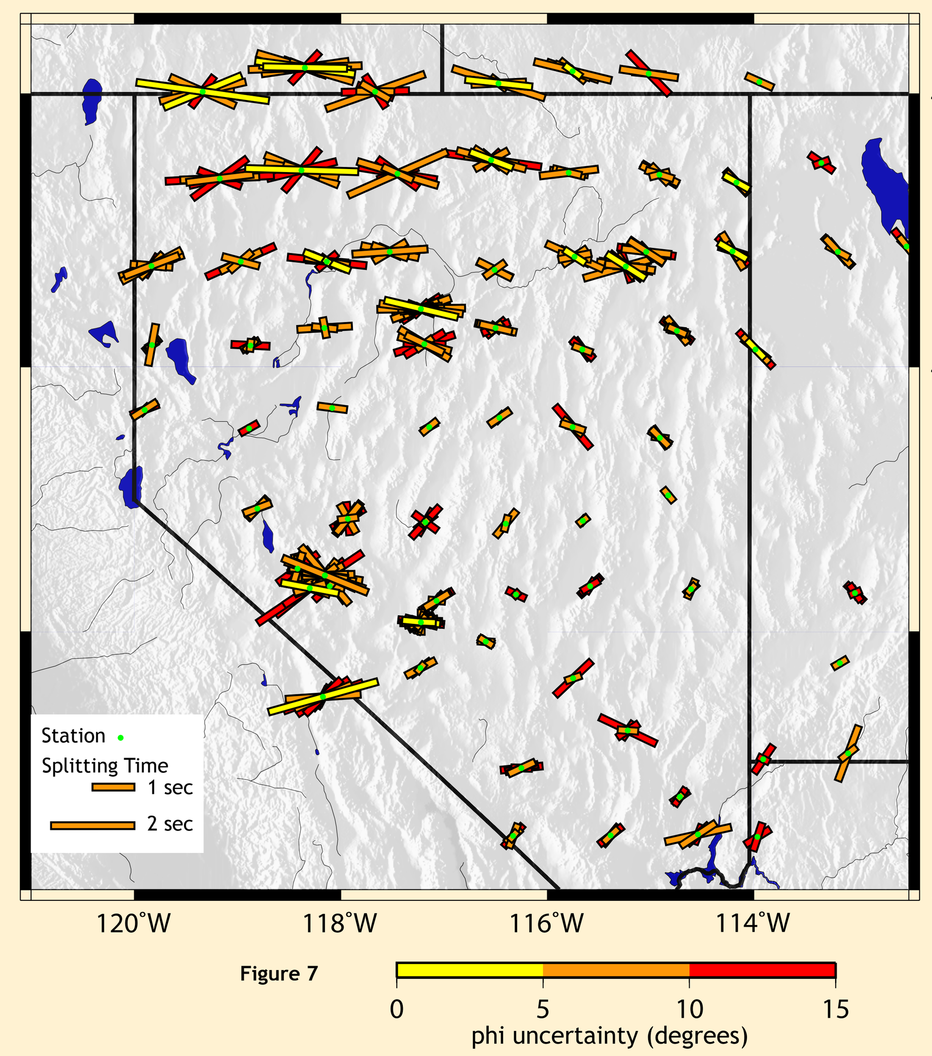


Figure 7

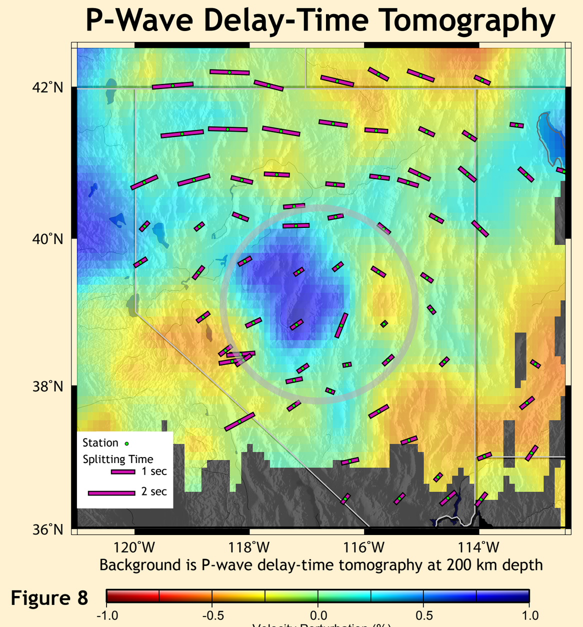
Discussion

Station-averaged splitting results plotted with P-wave delay-time tomography at 200 km depth (Roth and Fouch, 2007)(**Figure 8**), and Two Plane-Wave Tomography (TPWT) results of Yang and Ritzwoller (2007)(**Figure 9**) both clearly show a high-velocity mantle anomaly near the center of the "swirl". To develop further constraints on the cause of the "swirl", we compare the splitting variations to Complete Bouguer Gravity Anomaly (**Figure 10**), and heat flow (**Figure 11**) datasets. (http://paces.geo.utep.edu/research/gravmag/gravmag.shtml and http://www.smu.edu/geothermal/heatflow/heatflow.htm.)

The presence of the "swirl" pattern of anisotropy implies that the anomaly is somehow anchored in such a way that there is (or was) asthenospheric flow around the anomaly. The weak splitting in the anomaly could be due to:

- Vertical flow (implies vertical fast axis)
- Recent reorganization of the local mantle flow field
- High level of complexity, or little/no anisotropy

P-Wave Delay-Time Tomography



Background is P-wave delay-time tomography at 200 km depth

Figure 8

TPWT Phase Velocity Anomaly Tomography

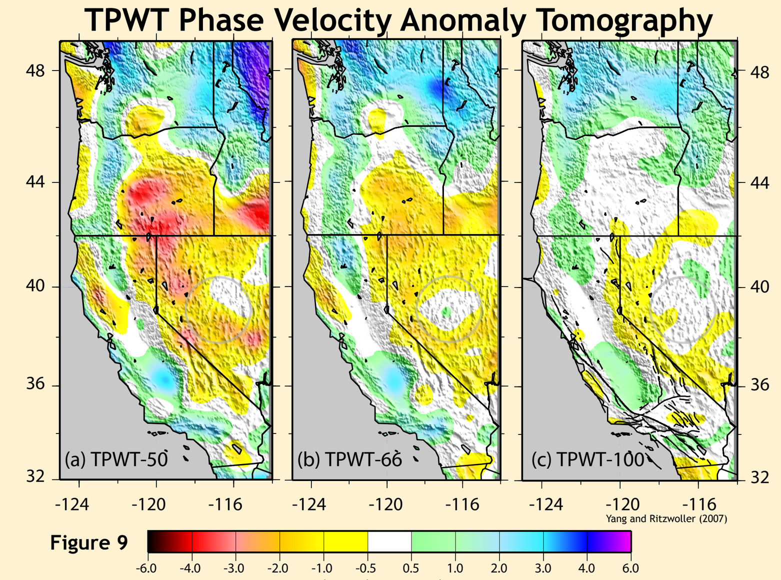


Figure 9

Complete Bouguer Gravity

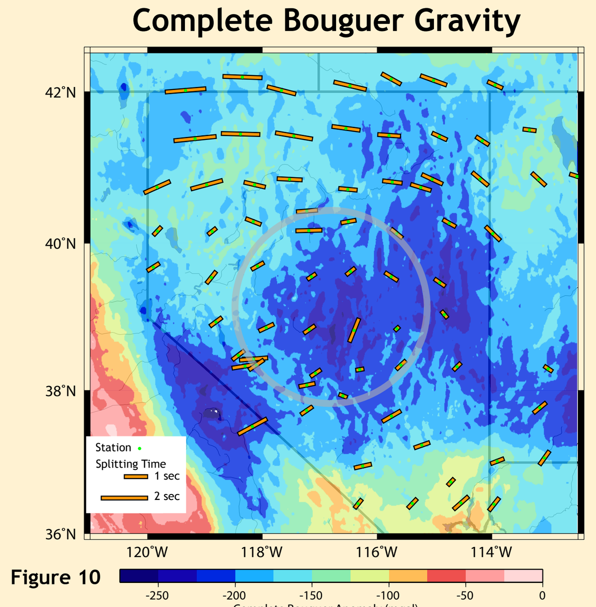


Figure 10

Heat Flow

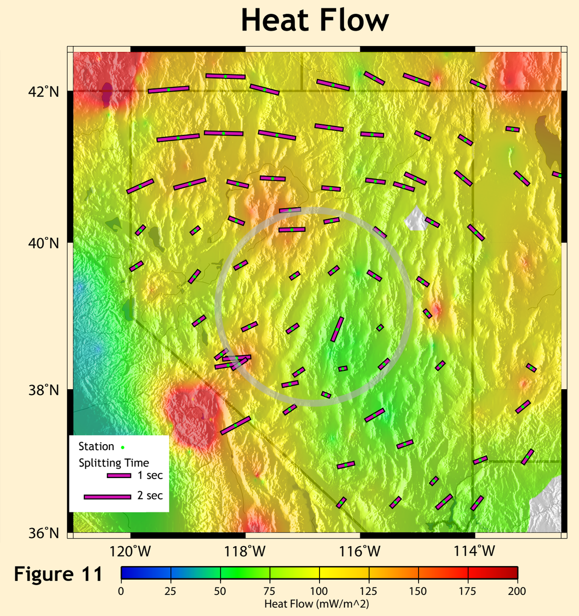


Figure 11

Possible Causes of the "Swirl" in SWS Beneath the Great Basin

Various researchers have proposed models to account for extension in the region and/or the "swirl" pattern observed in central Great Basin shear-wave splitting. Here we briefly describe each primary model and its fit to the regional geophysical data.

1. **Extension caused by tectonic processes** due to Gravitational Potential Energy (GPE) collapse, (Sonder and Jones 1999, Flesch 2007) or far-field effects (Humphreys and Coblentz 2007). These studies examine Great Basin extension, but do not address the "swirl" pattern, gravity low, low heat flow, or the localized tomographic high velocity anomaly.

2. **Plume flow + asthenospheric flow** (Savage and Sheehan 2000)
- Can explain "swirl" pattern in fast directions.
- Plume warming could explain small splitting times.
- Missing signatures of a plume – center is a cold spot, not a hot spot.
- Should be imaged by P-wave tomographic as a lower velocity region (higher velocity anomaly)

3. **Toroidal flow at edge of subducting plate** (Zandt and Humphreys 2007)
- Can explain "swirl" pattern in fast directions.
- Recent reorganization of LPO could account for small splitting times.
- Not consistent with simple splitting patterns in High Lava Plains and surrounding regions.
- Does not explain low gravity or low heat flow.
- Does not explain local P-wave tomographic high-velocity anomaly.

4. Asthenospheric flow around slab remnant Upward-protruding feature of subducting Juan de Fuca slab beneath central Nevada (Roth and Fouch, 2007)(**Figure 12**)
- Can explain "swirl" pattern in fast directions.
- Recent reorganization of LPO from east-west to "swirl" pattern might cause small splitting times.
- Can explain low heat flow.
- Incorporates tomographic localized high-velocity anomaly (Roth and Fouch, 2007).

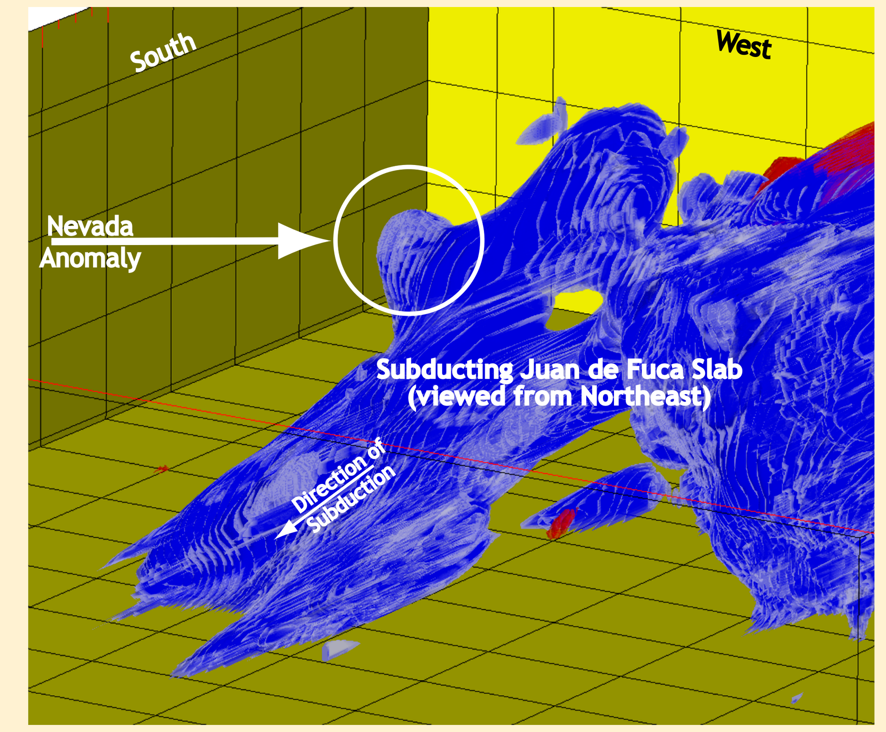


Figure 12: 3-dimensional model of the subducting Juan de Fuca slab (Roth 2007) from P-wave delay-time tomography shows the upwardly protruding feature labeled as the "Nevada Anomaly". This feature is located at approximately 117ºW 39ºN, near the center of the "swirl" pattern in shear-wave splitting anisotropy, the area of low heat flow, and the complete Bouguer Gravity low. View is from above and northeast; the "Nevada Anomaly" is on the southern edge of the slab and the slab is subducting eastward toward the bottom left corner of the figure.

Conclusions

- The northern Great Basin comprises a transition zone between the northern Basin and Range near the Pacific Northwest, which is characterized by large (~2 sec) splitting times and sub-east/west fast axis directions, and the central Great Basin, which is characterized by small splitting times (<1 sec) and a circular "swirl" pattern centered in central Nevada.
- The "swirl" pattern is not easily explainable by traditional tectonic or mantle flow processes, or driven by lithospheric extension.
- The center of the "swirl" pattern coincides with an area of relatively low heat flow, low Complete Bouguer Gravity anomaly, and high P-wave velocity. In tomographic images, the P-wave velocity anomaly is most pronounced around 200 km depth.
- The western edge of the Great Basin (Mina, NV and points southwest) exhibits large splitting times and clear evidence for back-azimuthal variations. This appears to be the transition to a different structural regime likely related to Sierra Nevada dynamics.

Plans for Future Study

- Receiver function study to add depth constraints to extent of anisotropy
- Addition of Utah Great Basin TA station results as TA rollout continues
- Rayleigh/Love wave analysis to look for vertically-oriented fast direction of anisotropy (currently in-process by C. Beghein)
- Modeling to look for multiple layers and/or dipping layers of anisotropy

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