SKS anisotropy on a dense broadband array over the Ruby Mountains Metamorphic Core Complex, Nevada

Eva M. Golos[1,2], Mairi Litherland[1], Simon L. Klemperer[1]

[1] Department of Geophysics, Stanford University, Stanford, CA 94305
[2] Also at Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY 14853

T43C-2691

Introduction

- The Ruby Mountain Metamorphic Core Complex (RMCC), located in northeastern Nevada, is part of the Basin and Range province
- Cenozoic extension and exhumation followed Mesozoic shortening
- Various mechanisms have been suggested for RMCC formation:
  1) Low-angle normal faulting
  2) Lateral crustal flow
  3) Vertical diapirism
- The Ruby Mountains Seismic Experiment (RMSE) was deployed to evaluate the formation and structure of the RMCC

Figure 1: Map of Nevada, showing the location of the Ruby Mountains in red.

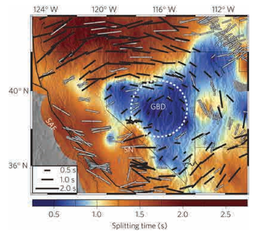

Figure 2: West et al. (2009)'s map of anisotropy directions in the western United States

Objectives

- We hoped to detect and determine the structure of separate crustal and mantle anisotropy layers
- Specifically, we examined variations in fast-axis direction, delay time between components of a split shear wave on SKS phase
- Anisotropy is influenced by composition and by deformation
- Multiple layers would indicate discrete strain fabrics and thus differential crustal and mantle flows
  - Crustal signal dominated by East-West extension; mantle, by the "lithospheric cylindrical drip" of West et al., 2009 (figure 2)
- For example, horizontal strain patterns (vertical anisotropy variation) would indicate that lateral flow dominates, while vertical patterns would suggest diapiric activity (horizontal variation)

Methods and Data

- We used an array of 50 broadband passive seismic stations supplied by IRIS/PASSCAL, active from June 2010 through June 2012
- We also included events from the US Transportable Array stations N11A and N12A
- Events of magnitude ≥ 5.5, at a distance of 90° to 130°, showed a pronounced SKS phase signal
- Calculations were performed in SplitLab, MATLAB-based program (Wüstefeld et al., 2008)
  - 3 methods are used; we chose the Minimum Energy (SC) method but considered the Rotation-Correlation (RC) method as a data quality check
- The user selected a time window with the SKS phase arrival, from which the program calculated fast-axis azimuthal direction, Φ, time delay, ∂t, and a series of graphs for determining usability and quality of data (figure 3)
- Average Φ and ∂t were calculated for the 36 stations examined using a stacking method (figure 4)
- Forward modelling was used to fit the distribution of parameters to a layer structure (figure 5)

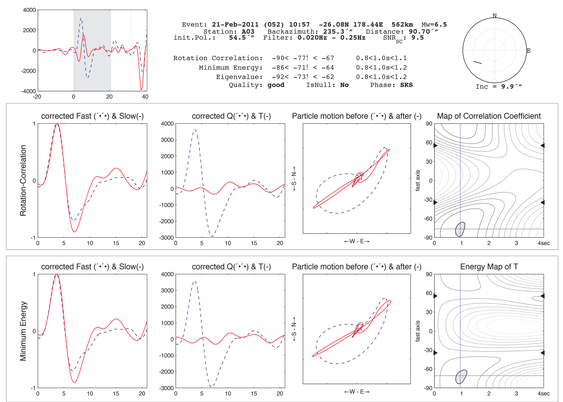

Figure 3: SplitLab results of a single, good-quality, event from station A03. The filtered waveform is visible in the upper left-hand corner. The upper right-hand image portrays the backazimuthal location of the event from the station as location around and distance from the center of the circle; angle of the line indicates fast-axis azimuthal direction, and length of line indicates magnitude of time delay. The four graphs, in two rows, are used to determine the usability of the event and the quality of result for the RC method (above) and SC method (below):

1) Motion along fast (red) and slow (blue) axes, corrected for time delay. For good-quality result, the two curves match.
2) Transverse component before (blue) and after (red) time correction; ideally blue curve has peaks and red curve is flat.
3) Particle motion before (blue) and after (red) correction; ideally the blue curve spirals around a flat red line.
4) Map showing solution on coordinates of fast axis direction vs. time delay. Good-quality solution region approaches a single point.

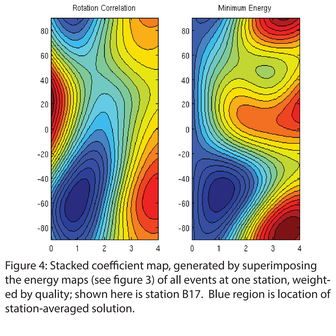

Figure 4: Stacked coefficient map, generated by superimposing the energy maps (see figure 3) of all events at one station, weighted by quality; shown here is station B17. Blue region is location of station-averaged solution.

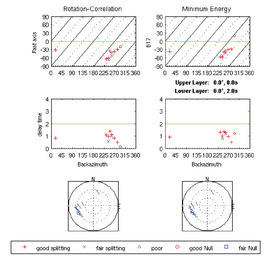

Figure 5: SplitLab results for an entire station; in this example station B17 is used due to the clarity demonstrated by its longer delay times. Here the non-uniform distribution of backazimuthal directions of useable events is apparent.

SKS Splitting Observations

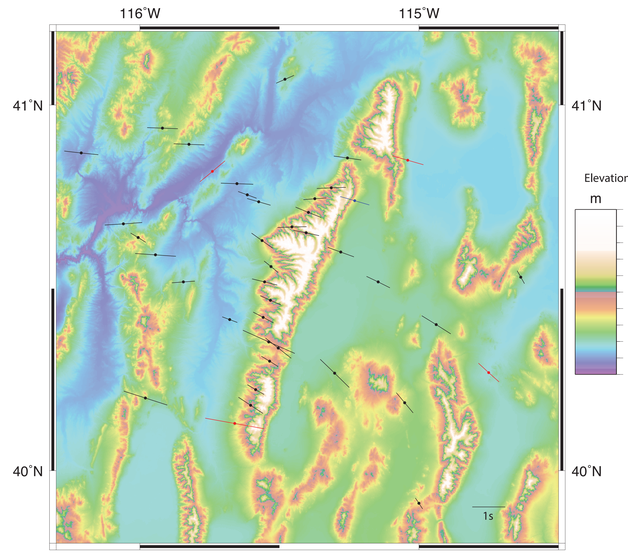

Figure 6: Map of the used stations. The direction of each associated line reflects Ø, in azimuthal degrees from North, while the length of the line corresponds to ∂t. The YX stations of our deployment are black; red stations are part of the Transportable Array campaign (2006-2008); and blue is the USGS ELK station, using data determined in West et al.,

Results and Discussion

- 494 data points, representing 105 events at 36 RMSE stations + 2 TA stations, were used.
- Mean fast-axis direction was -70°, with a standard deviation of 18.9°.
- Mean time delay was 0.84 s, with a standard deviation of 0.28 s.
- 94.3% of used points had backazimuth between 180° and 360° (Indonesia/Tonga region)
  - Incomplete sampling complicates resolving variation of Φ with backazimuth; a uniform global distribution is desired

- We found no evidence of two-layer anisotropy. Several possible explanations:
  1) Lack of significant crustal strain
  2) Strain direction is similar to direction of regional mantle flow
  3) Data quality is insufficient to resolve crustal from mantle anisotropy signatures
- Explanation (1) is reasonable when the nonuniform backazimuth distribution of useable events is considered
  - If so, we cannot rule out the possibility of slight differences in mantle and crustal anisotropy
- Explanation (2) is also plausible, because the Basin-and-Range crustal extension and the proposed "lithospheric drip" beneath the western U.S. both act roughly East-West

- We saw a systematic counterclockwise rotation of fast axis directions westward across our region of coverage. This agrees with West et al., 2009, which proposes a "lithospheric drip," centered beneath the Great Basin, indicated by a circular trend in fast-axis directions. We compared a circular anisotropy model, centered at 39.5°N and -117°W, to the calculated Φ at each station, yielding an average difference of 23.1°.

Determination of Quality

- Quality was assigned by user as "good," "fair," or "poor," based on Wüstefeld and Bokelmann, 2007:
  - good: $0.8 \le \rho \le 1.1$ and $\Delta\Phi \le 8°$
  - fair: $0.7 \le \rho \le 1.2$ and $\Delta\Phi \le 15°$
  - poor: any other values; these events were not used.
  - where $\rho = |\Phi_{SC} - \Phi_{RC}|$ and $\Delta\Phi = |\Phi_{SC} - \Phi_{RC}|$

- Null measurements occurred when fast-axis direction aligned with backazimuthal direction
  - Such points were less useful: ∂t cannot be constrained
  - Only good-quality null measurements were used; $0 \le \rho \le 0.2$ and $27° \le \Delta\Phi \le 53°$

- Signal-to-noise ratio (SNR) ≥ 8 was desired (Restivo and Helffrich, 1999); SNR = 4 acceptable if backazimuth and Φ differ by > 20°
  - The stacking method lessened the influence of noisy data

References

Restivo, A., Helffrich, G., Teleseismic shear-wave splitting measurements in noisy environments. *Geophys. J. Int.* **137** 821-830.
Silver, P. G., Savage, M. K., The interpretation of shear-wave splitting parameters in the presence of two anisotropic layers. *Geophys. J. Int.* **119** 949-963 (1994).
West, J. D., Fouch, M. J., Roth, J. B., Elkins-Tanton, L. T., Vertical mantle flow associated with a lithospheric drip beneath the Great Basin. *Nat. Geos.* **2** 439-444 (2009).
Wüstefeld, A., Bokelmann, G., Null detection in shear-wave splitting measurements. *Bulletin of SSA.* **97** 1204-1211 (2007).
Wüstefeld, A., Bokelmann, G., Zaroli, C., Barruol, G. SplitLab: a shear-wave splitting environment in Matlab. *Comp. & Geos.* **34** 515-528 (2008).

Acknowledgements

EG was supported by the Incorporated Research Institutions in Seismology (IRIS) Summer Internship Program.
Major funding for the RMSE was provided by NSF as part of the Earthscope Flexible Array; seismic equipment was provided by IRIS/PASSCAL.
The SplitLab program was developed by Wüstefeld et al.
The stacking method to generate station-wide averages of parameters was developed by Shahar Barak and Alex Kinsella, Stanford University.