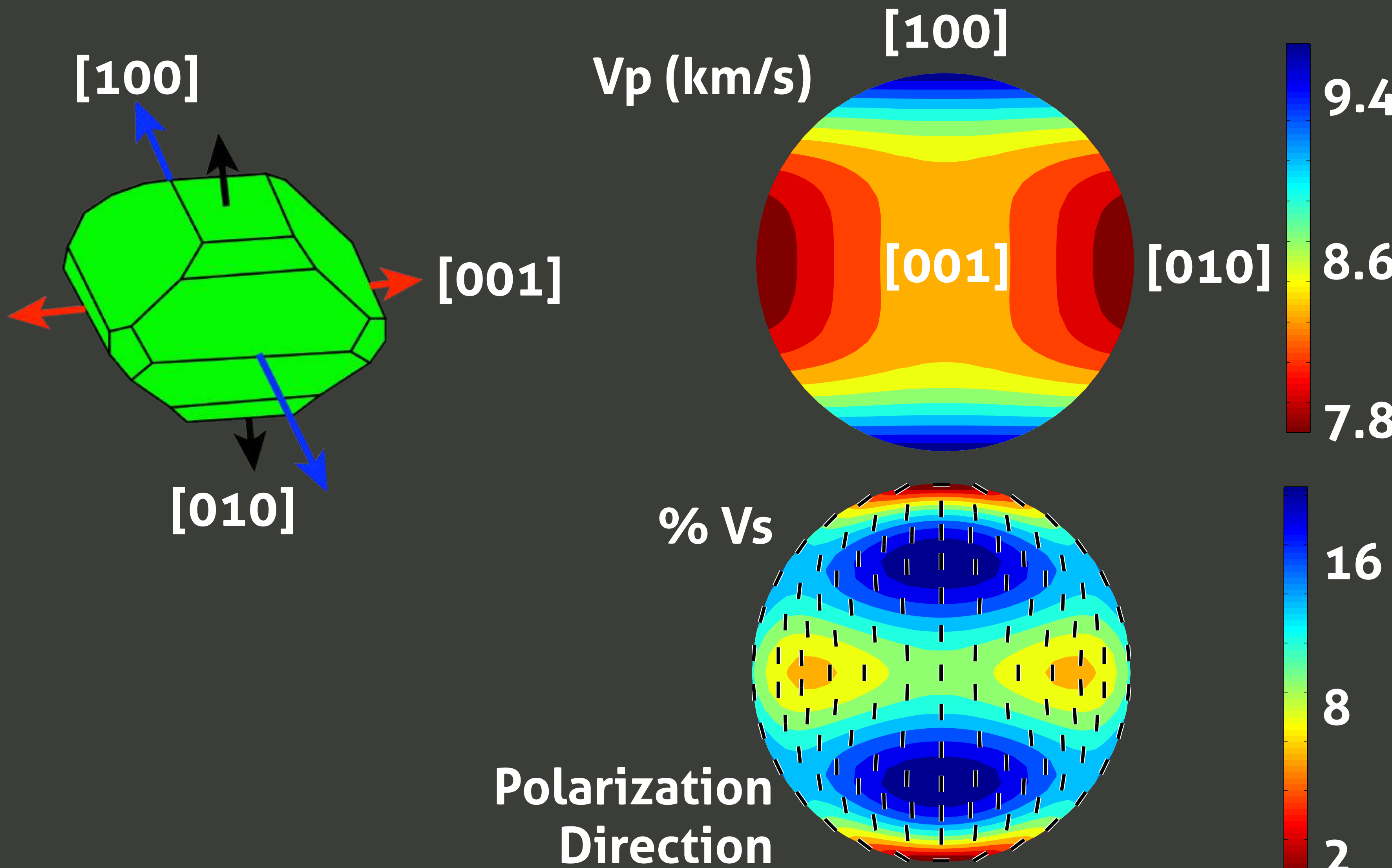
Rheological constraints from seismic anisotropy

Heather Ford, UC-Riverside
June 8, 2016

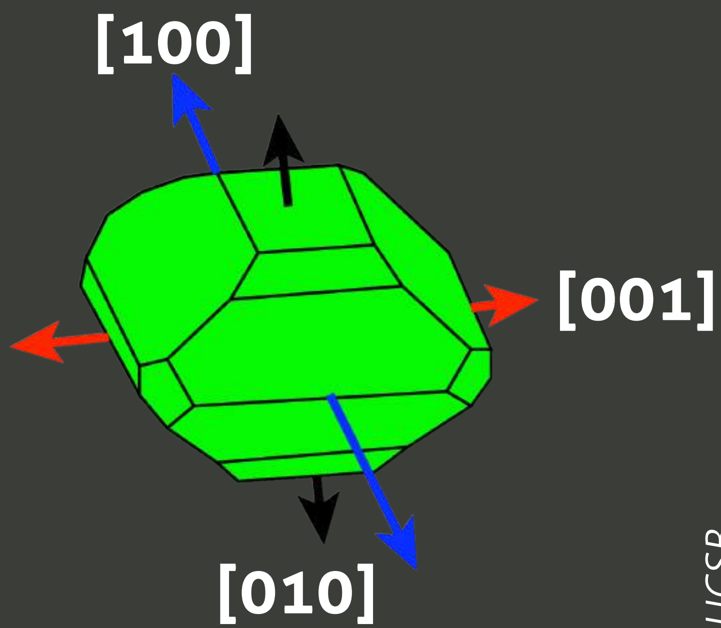
What is seismic anisotropy?

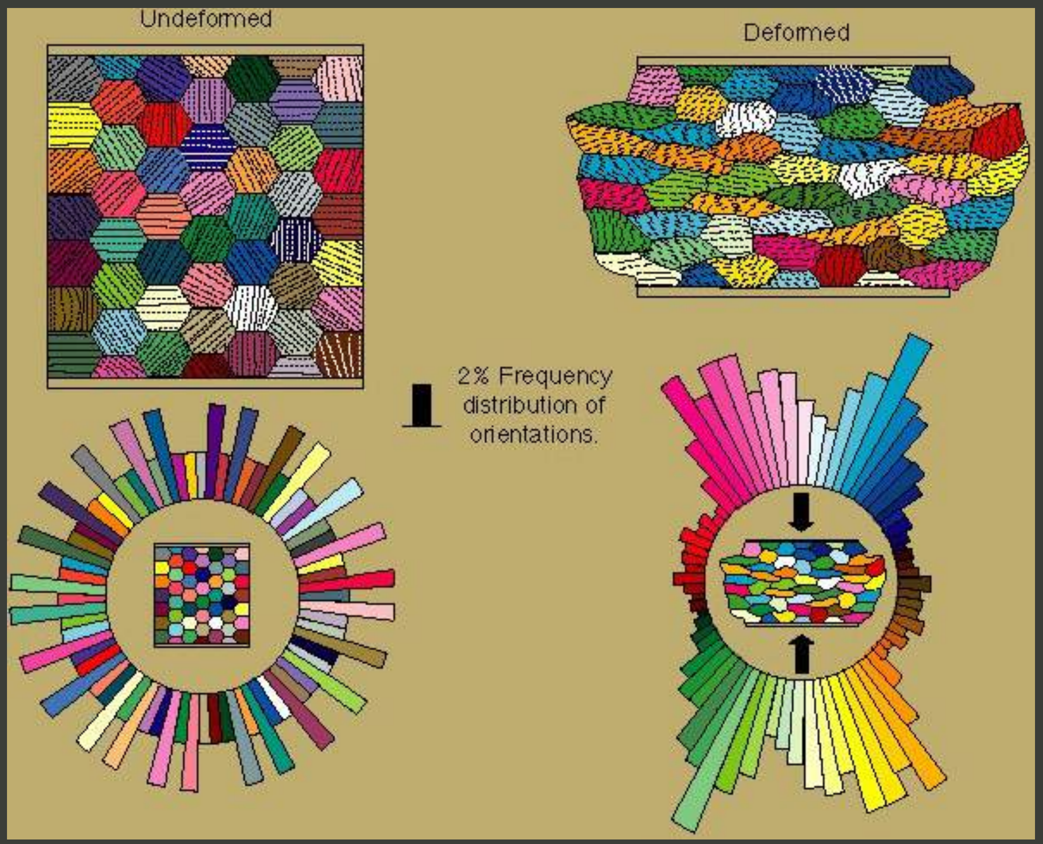
Directional dependence of seismic wave velocity



What causes seismic anisotropy? (Polycrystalline)

Lattice Preferred Orientation (LPO) is one possibility





B. Hacker, UCSB

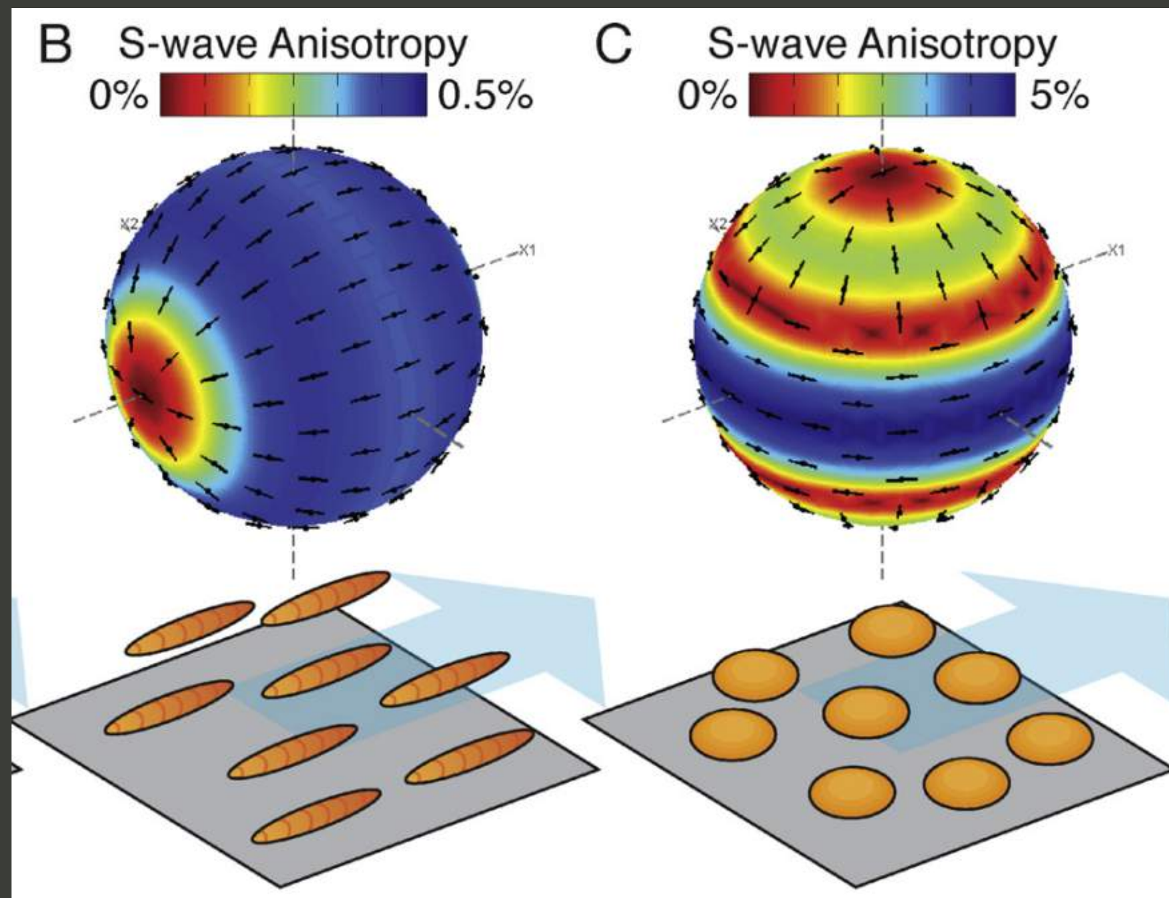
Commonly invoked in upper mantle
Often thought of as a proxy for mantle flow

What causes seismic anisotropy? (Polycrystalline)

Shape Preferred Orientation (SPO) is another possibility

Sub-wavelength layering or ordering of materials with varying seismic velocities

Possibilities:
Layering of distinct materials
Alignment of melt, cracks



Nowacki et al., 2011

Seismic anisotropy overview

Deformation environment

Rheology*

seismic anisotropy

Anisotropy affected by:

Stress, temperature, pressure, volatile content

Function of accumulated strain

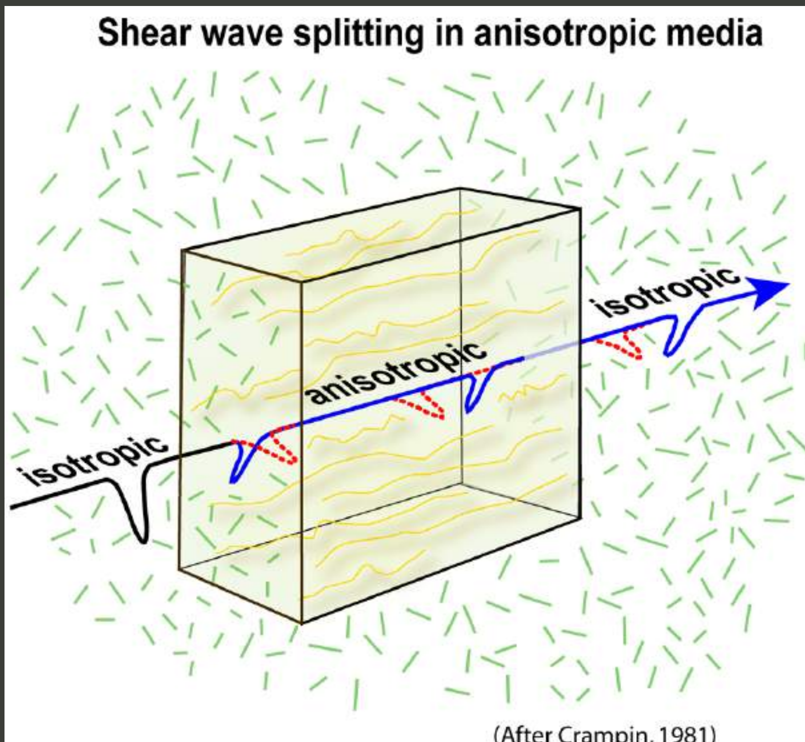
Methods used to characterize anisotropy:

Shear wave splitting

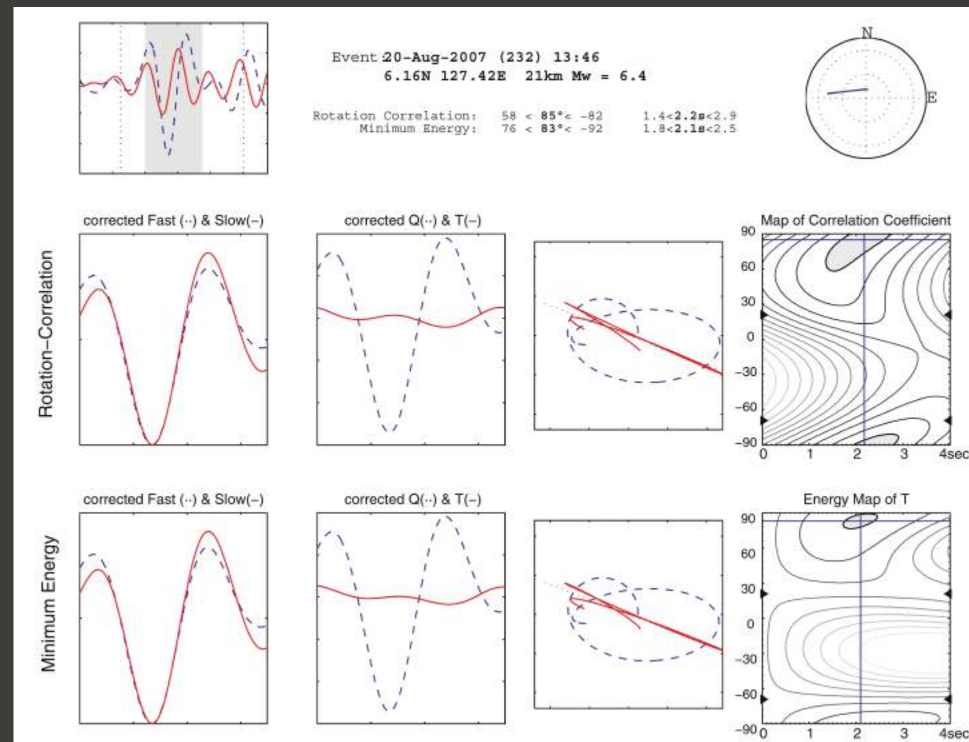
Tomography (several varieties)

Receiver function analysis

Measuring Anisotropy: Shear Wave Splitting



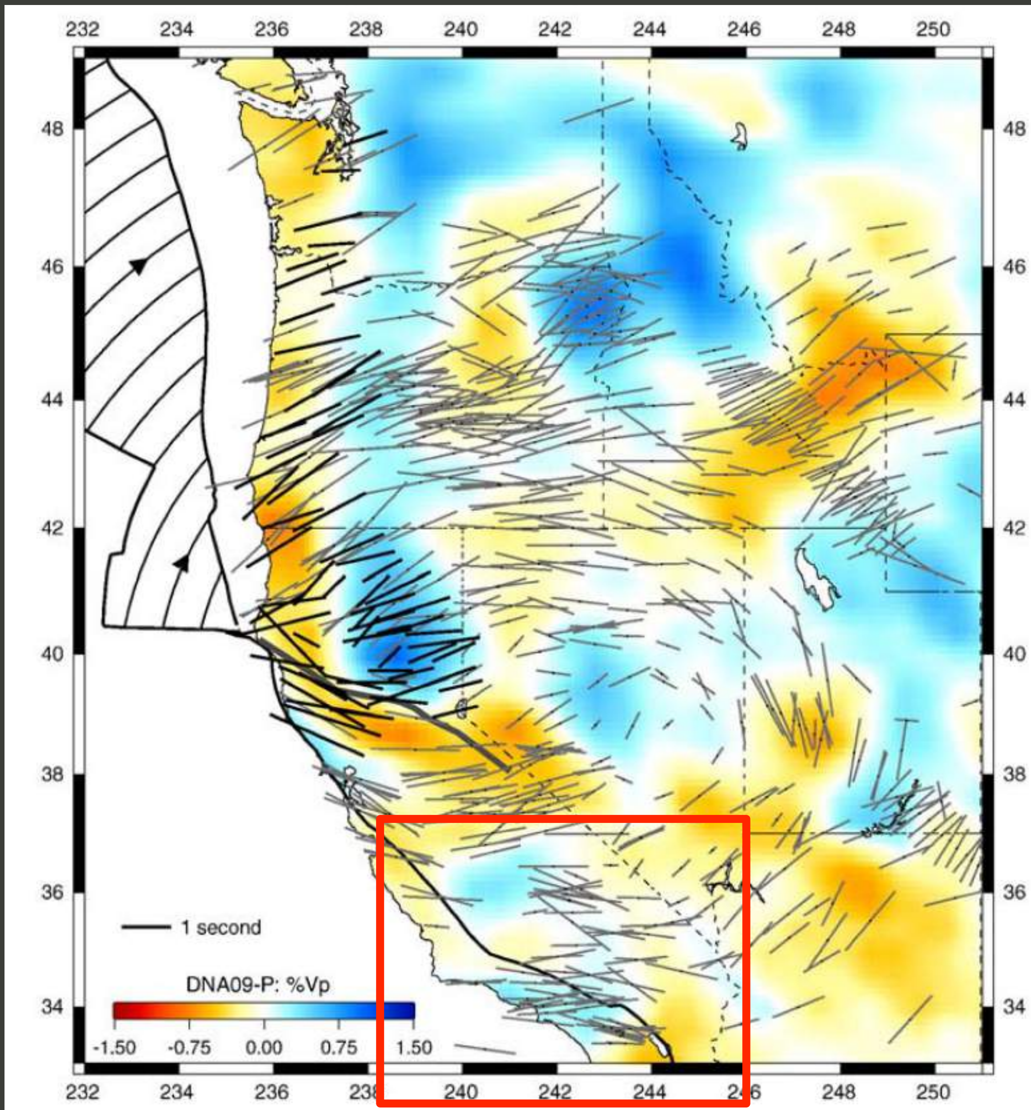
E. Garnero, ASU



Long and Silver, 2009

<u>Very</u> commonly used tool
Integrates across layers, if present
Need to account for anisotropy along ray path

Measuring Anisotropy: Shear Wave Splitting



Eakin et al., 2010

Well-established pattern of splitting in SoCal- oriented roughly E-W

Numerous origins/models investigated:

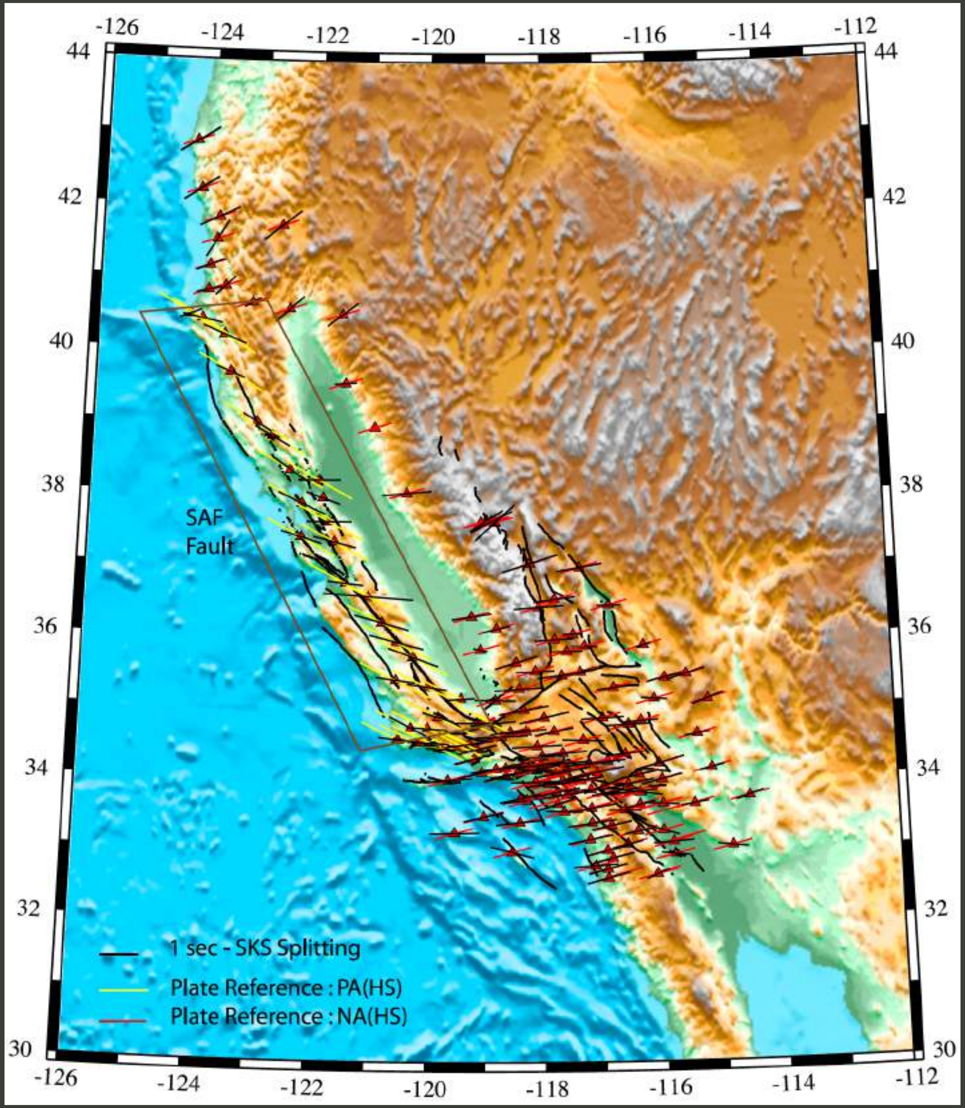
- Plate motion
- Regional dynamic models
- Frozen-in anisotropy
- Single vs. layered anisotropy
- Distributed vs. localized deformation

Measuring Anisotropy: Shear Wave Splitting

Direction of fast-axis consistent across plate boundary in southern California → asthenospheric origin

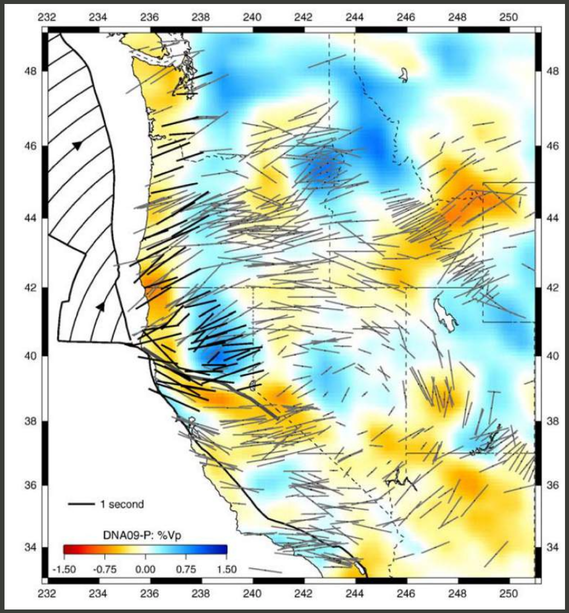
Overall good agreement between splitting direction and plate motion

Exception- Portion of southern California west of the plate boundary

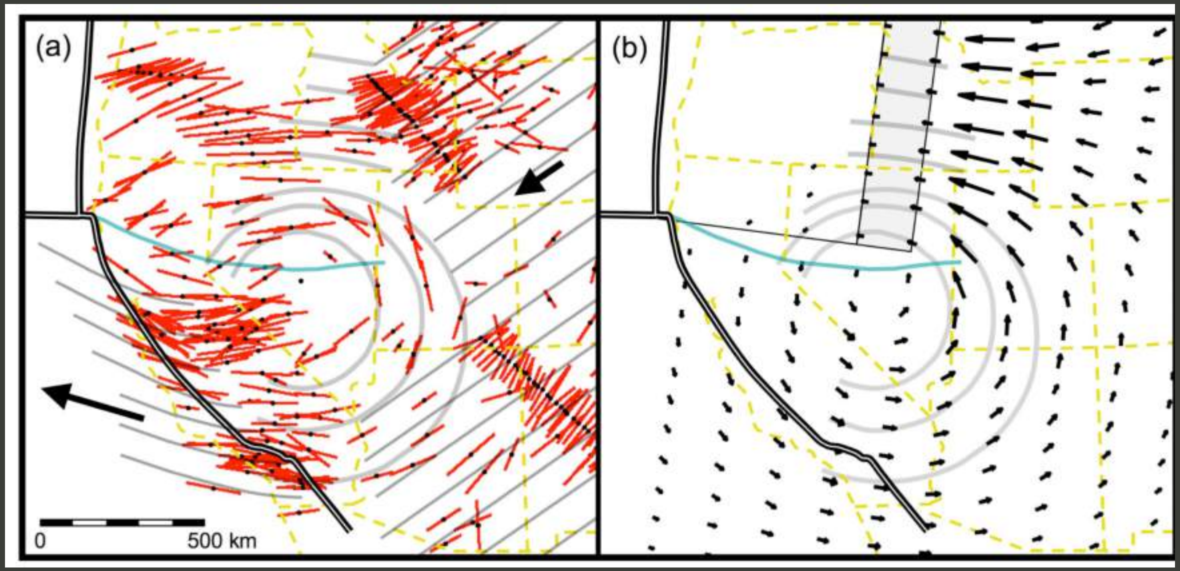


Kosarian et al., 2011

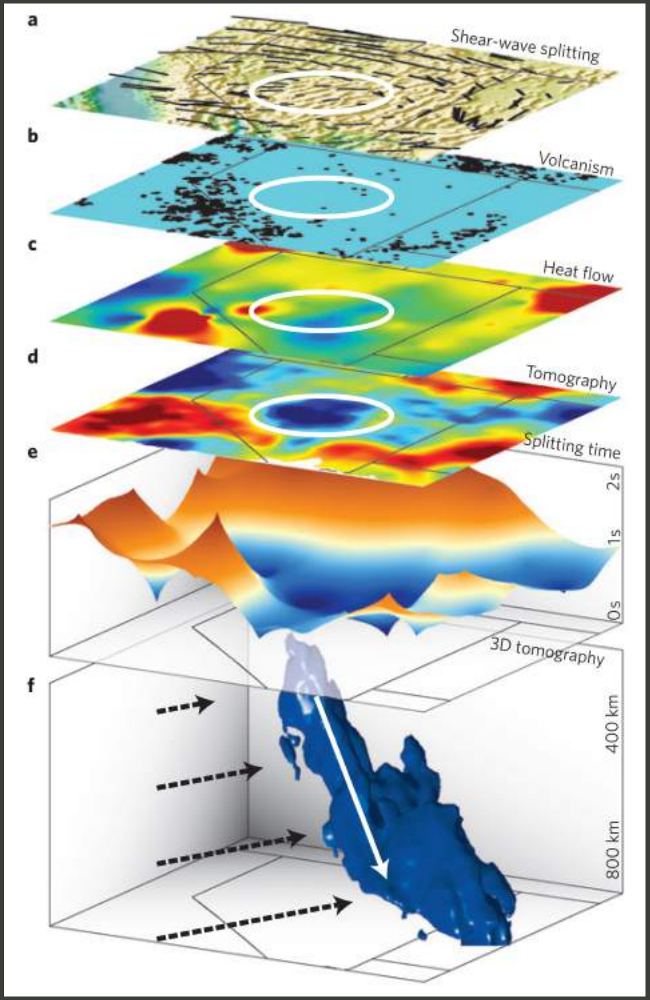
Measuring Anisotropy: Shear Wave Splitting



Alternative dynamic processes – toroidal flow or lithospheric dips



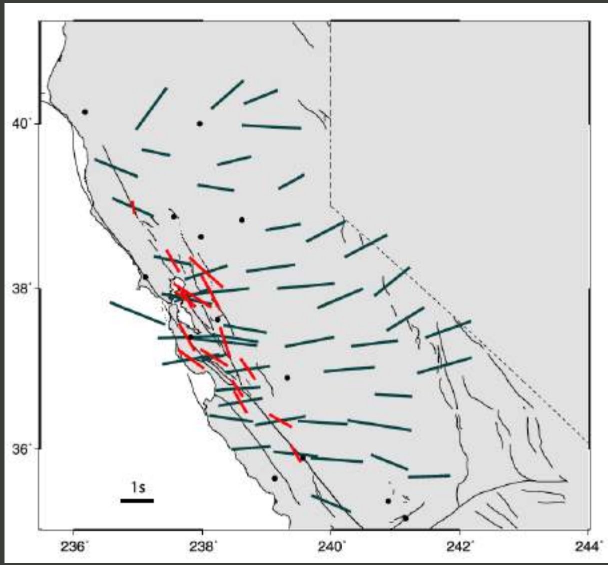
Zandt and Humphreys, 2008

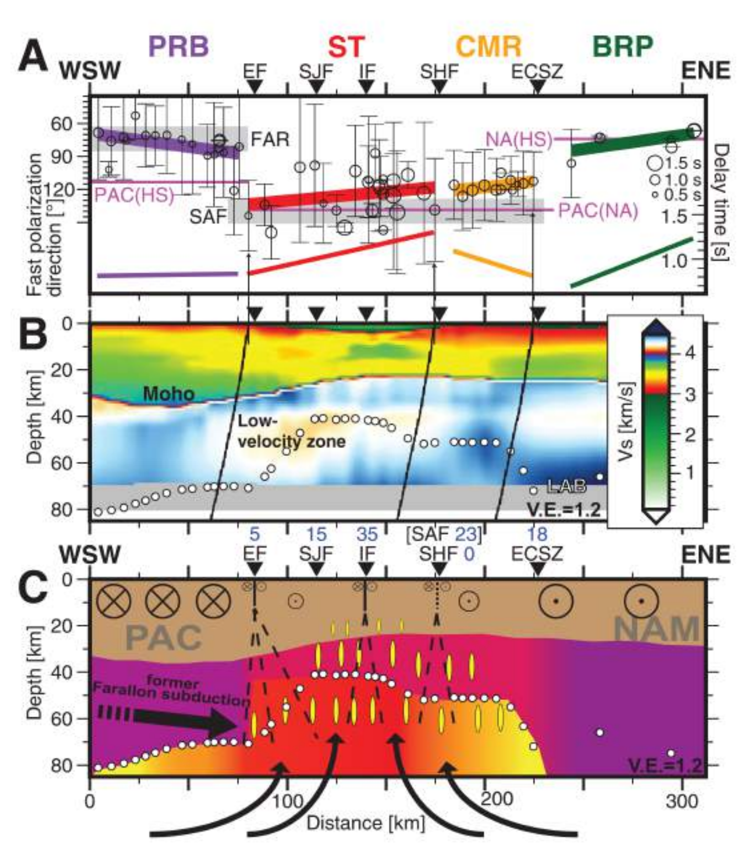


West et al., 2009

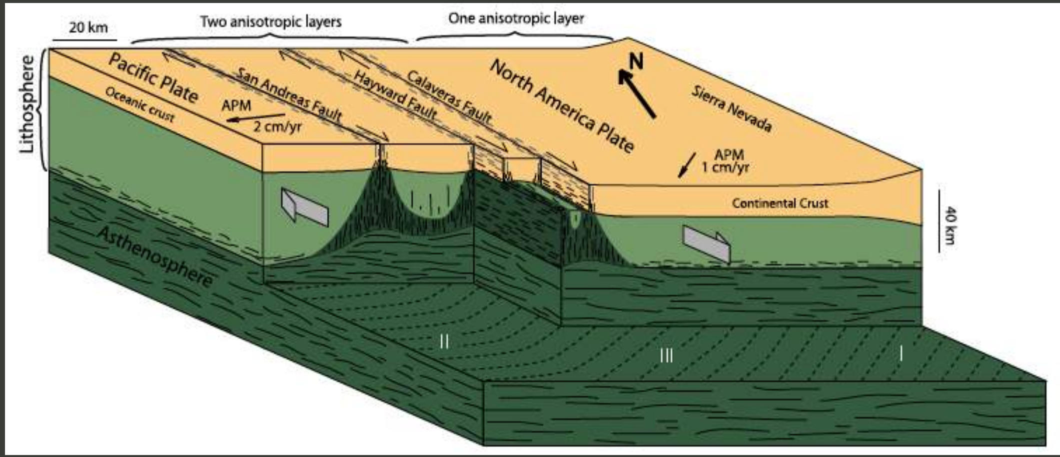
Measuring Anisotropy: Shear Wave Splitting

Contributions from lithospheric sources, fault-related mechanics and strain localization



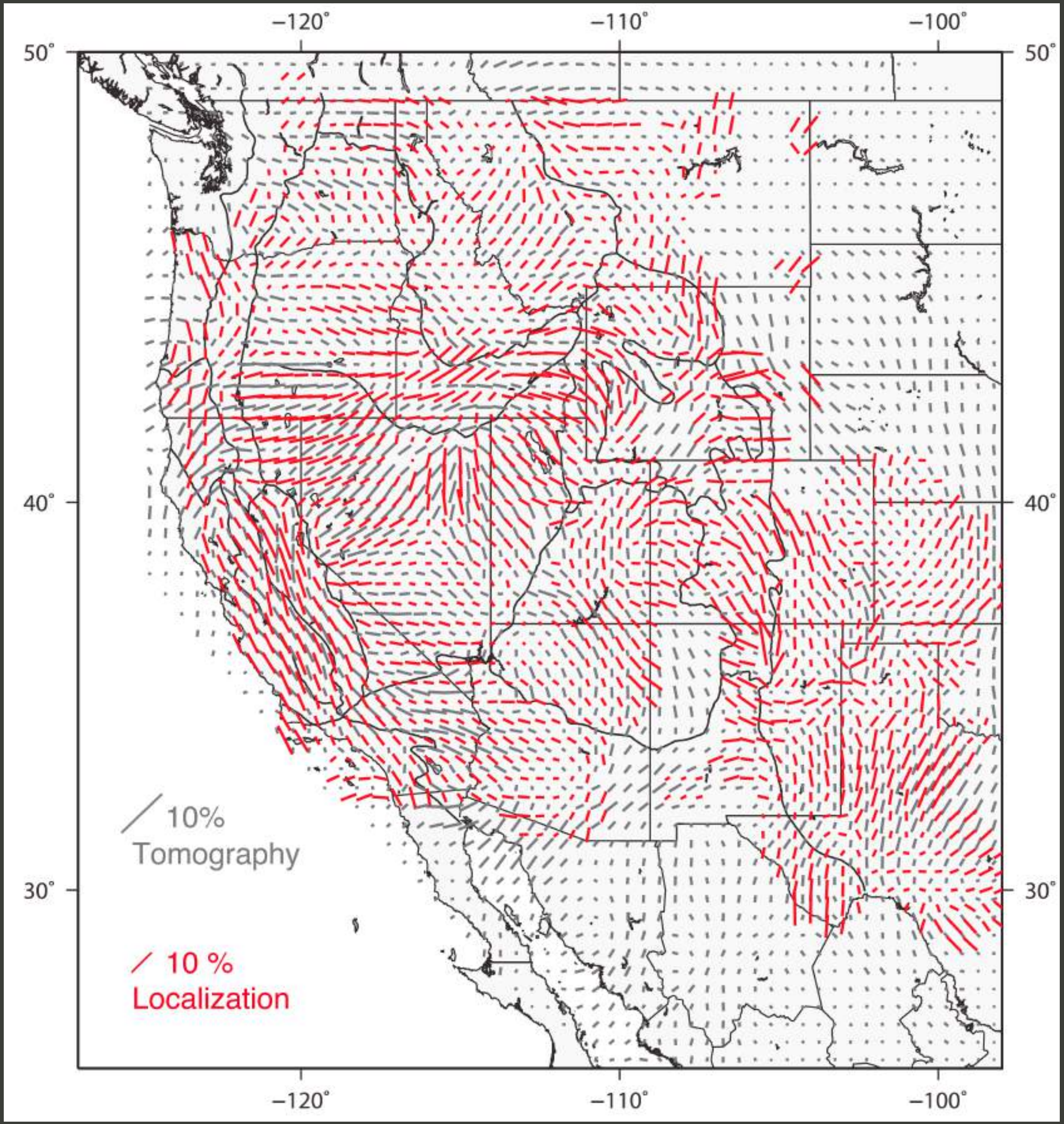


Barak and Klemperer, 2016

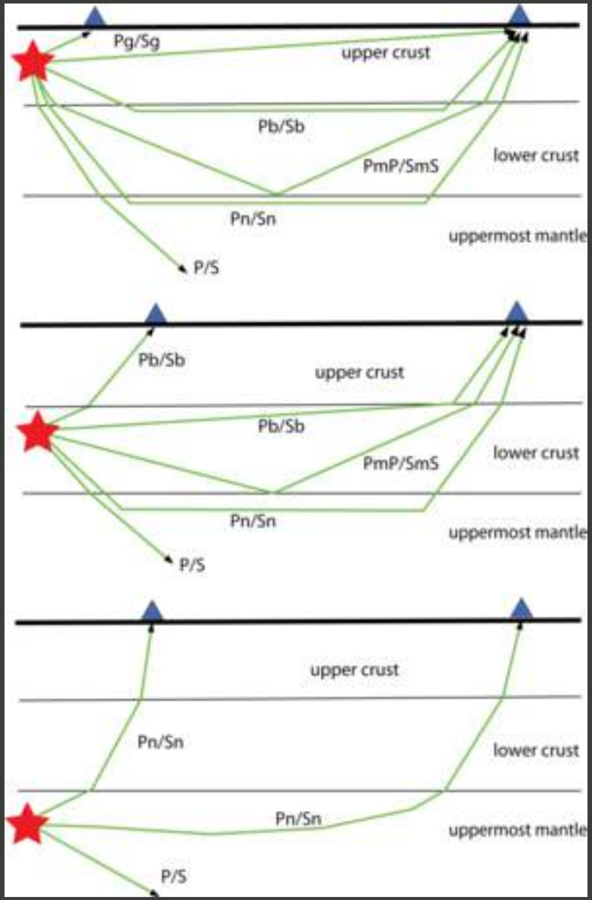


Bonnin et al., 2010

Measuring Anisotropy: Pn Tomography



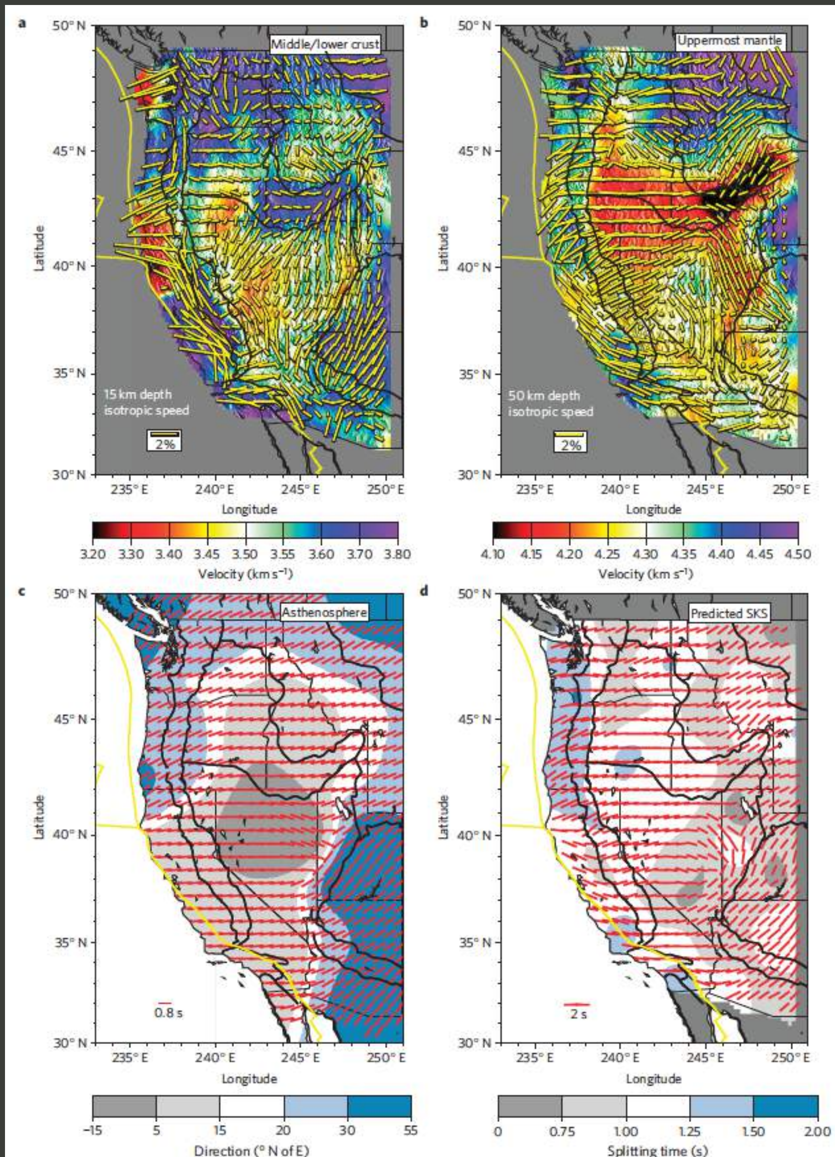
Pn tomography results focus on uppermost lithospheric mantle

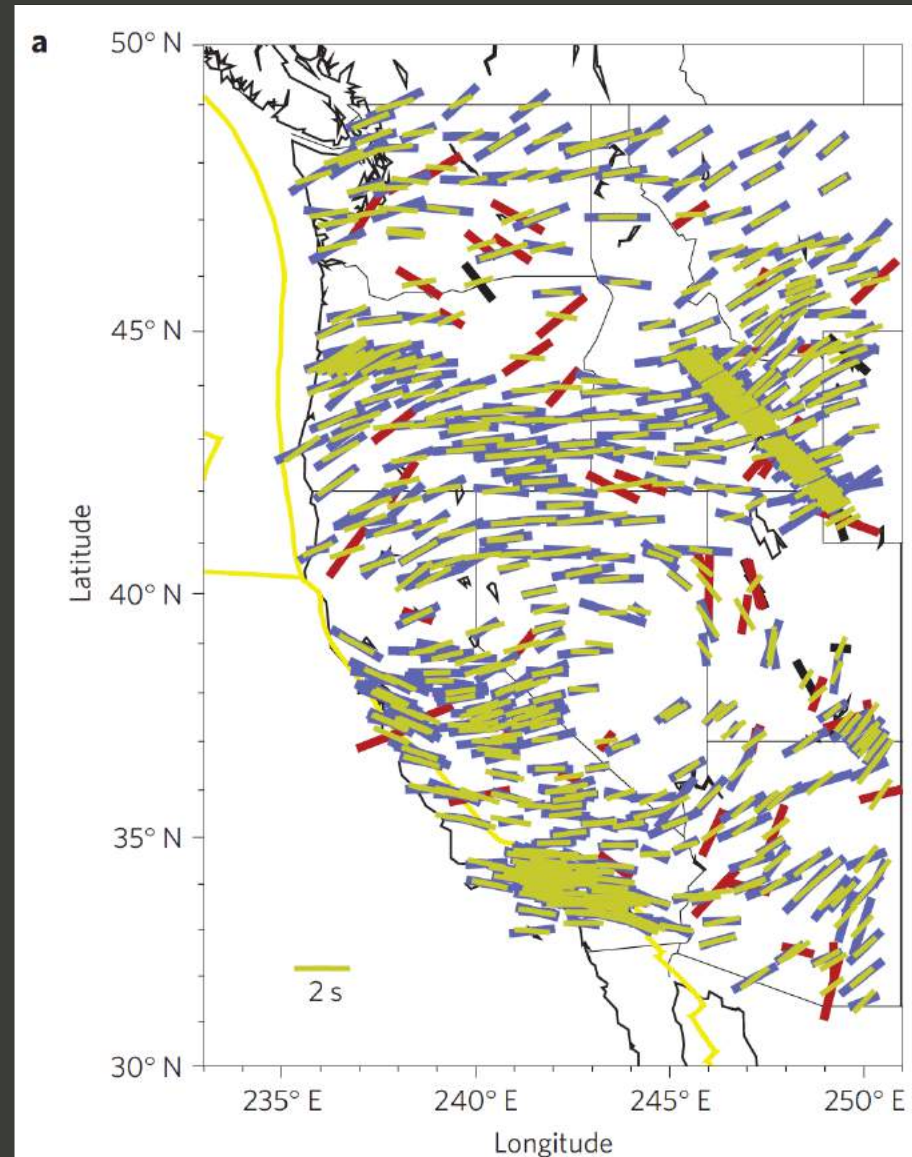


Buehler and Shearer, 2012

Courtesy of ISC

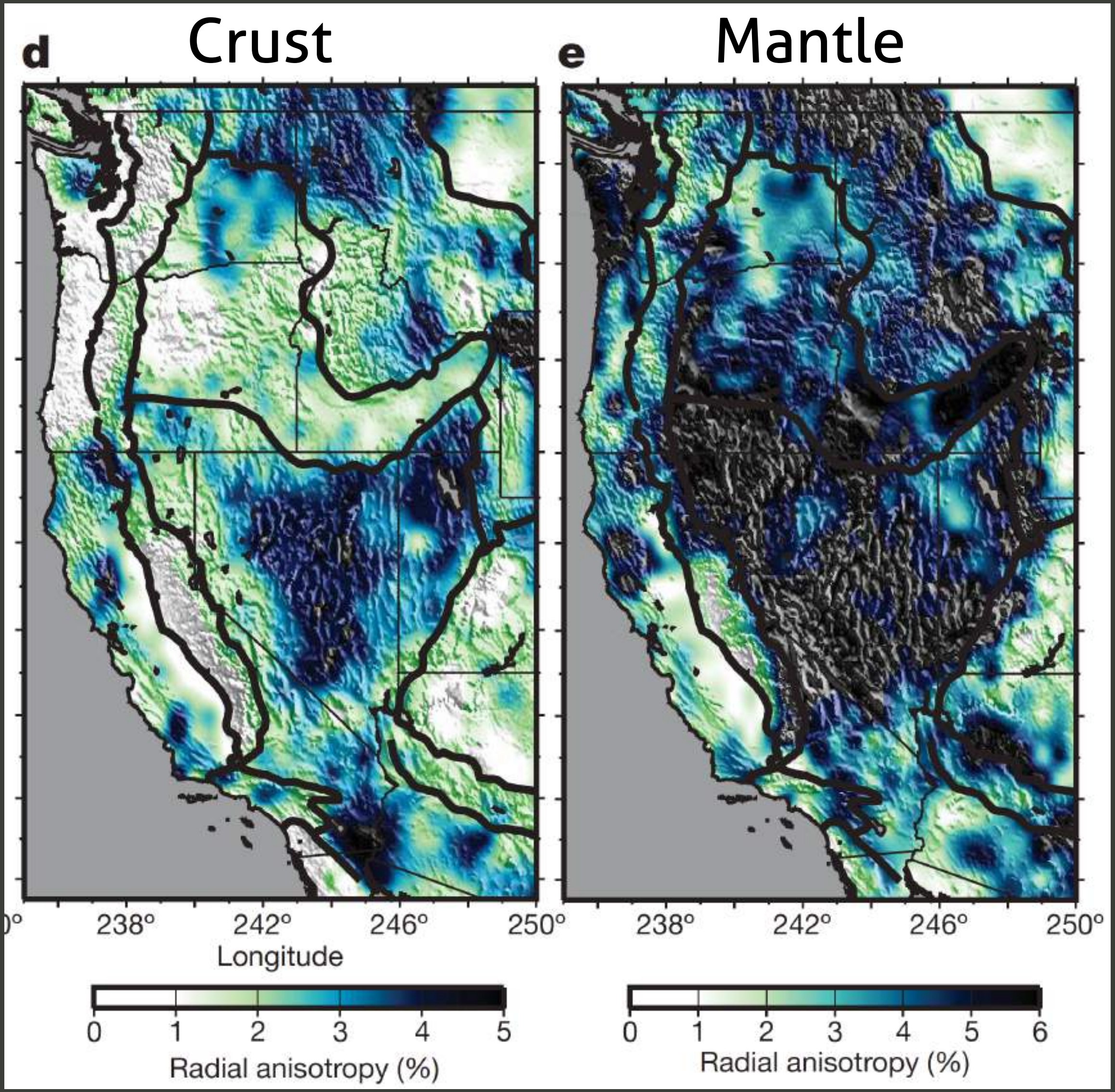
Measuring Anisotropy: Ambient noise tomography





Lin et al., 2011

Measuring Anisotropy: Ambient noise tomography



Also need to consider the impact of deformation on radial anisotropy

Correlation between regions of extension and strong radial anisotropy ($V_{SH}>V_{SV}$)

Possibly due to LPO of lower crust minerals

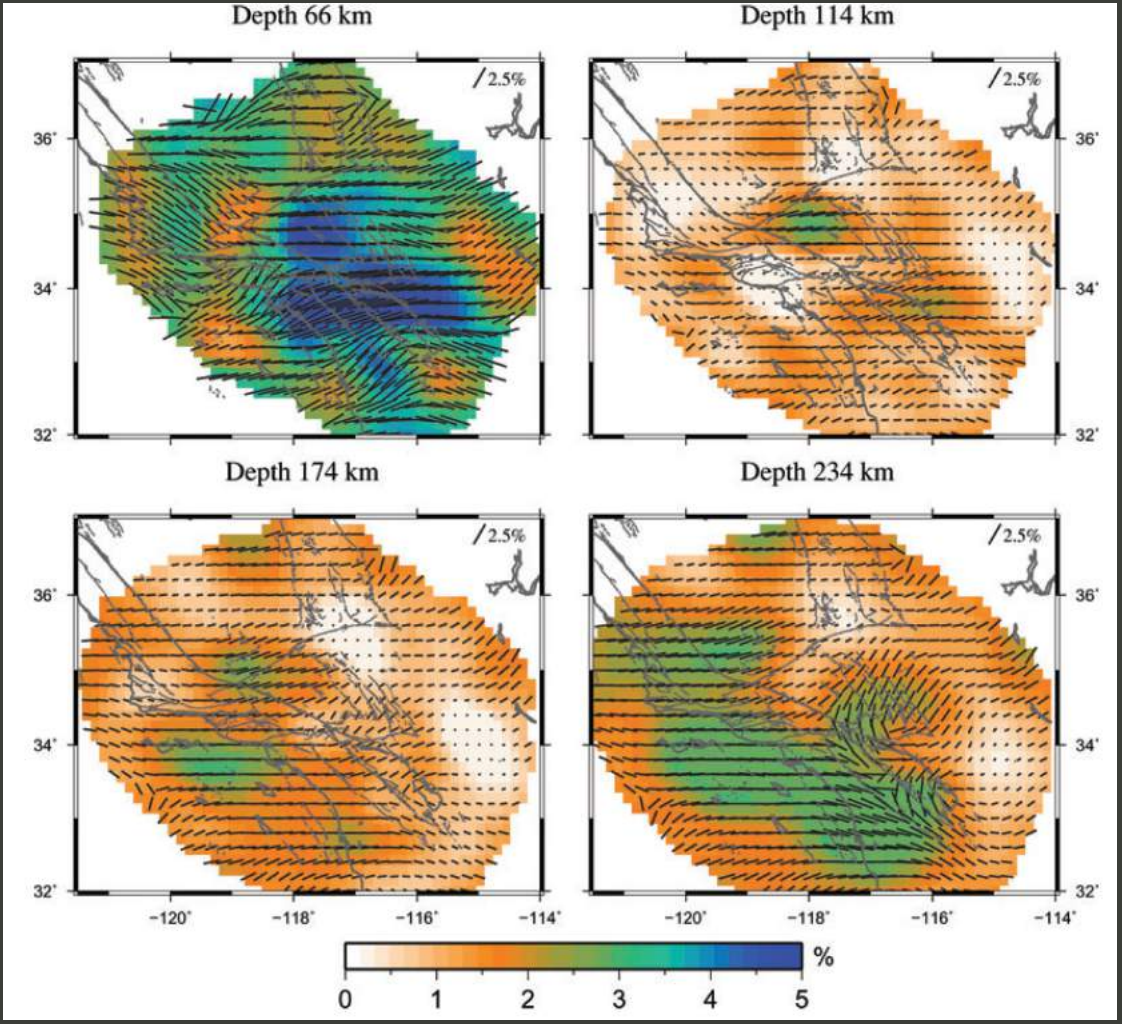
Moschetti et al., 2010

Measuring Anisotropy: SWS Tomography

Argue for no evidence of localized lithospheric shear deformation beneath the San Andreas Fault.

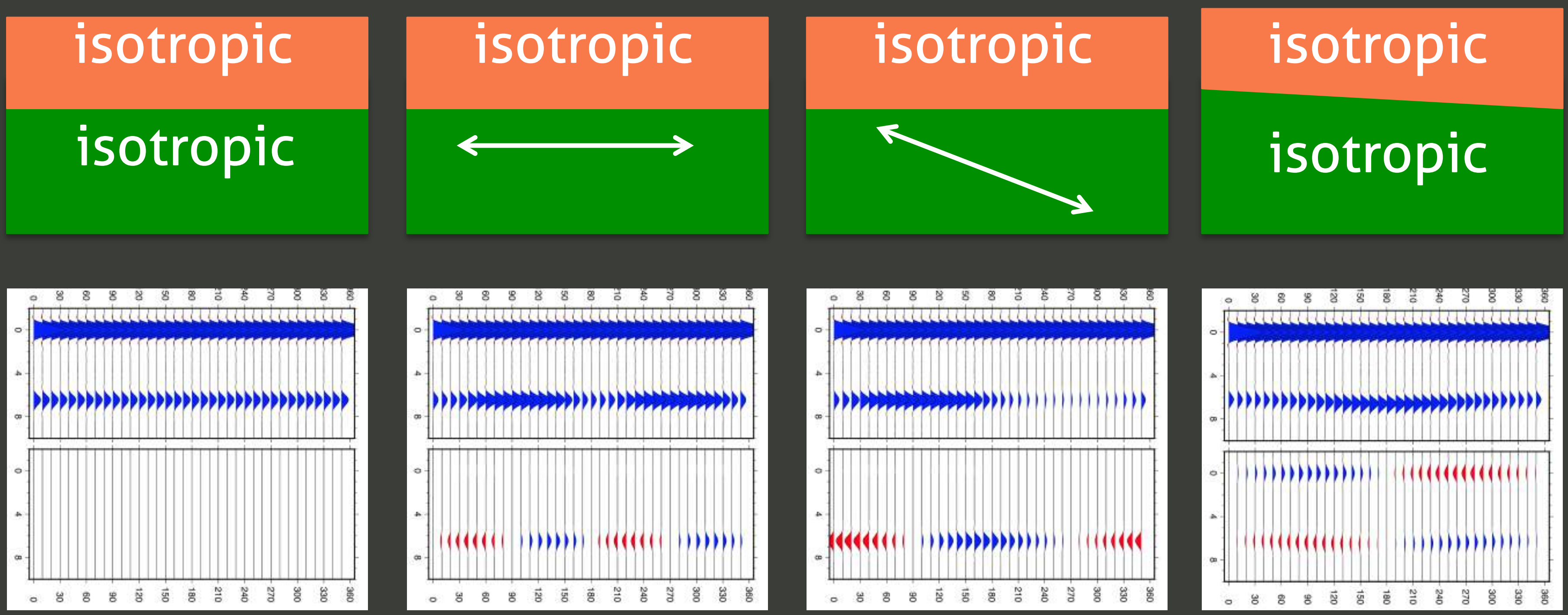
Plate boundary is localized in a broad shear zone beneath ECSZ

Weak anisotropy in the asthenosphere → little coupling with lithosphere.

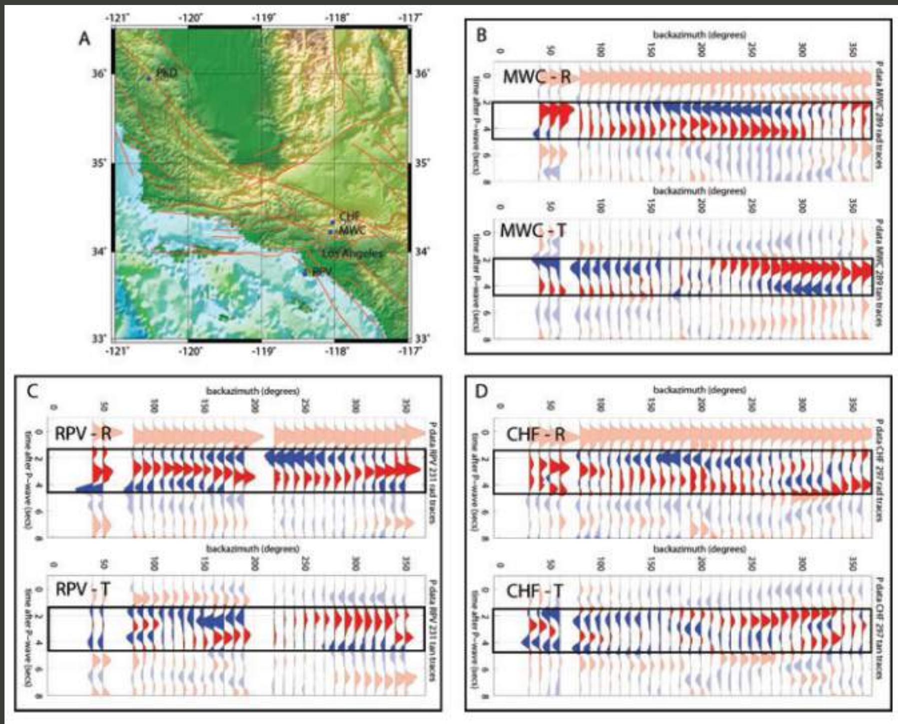


Monteiller and Chevrot, 2011

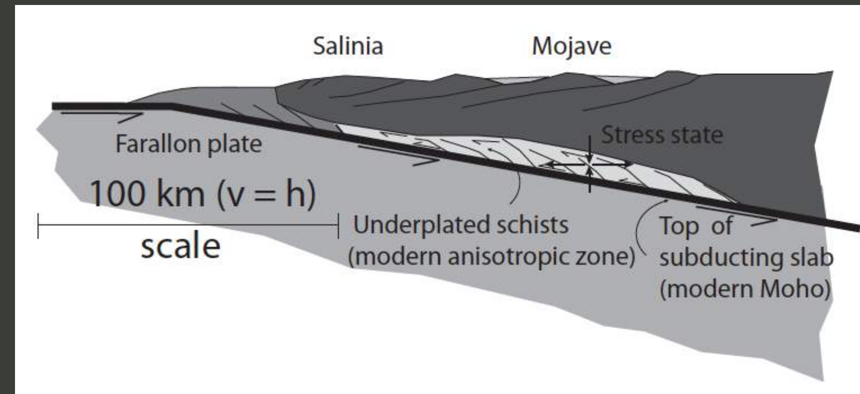
Measuring Anisotropy: Ps receiver function anisotropy

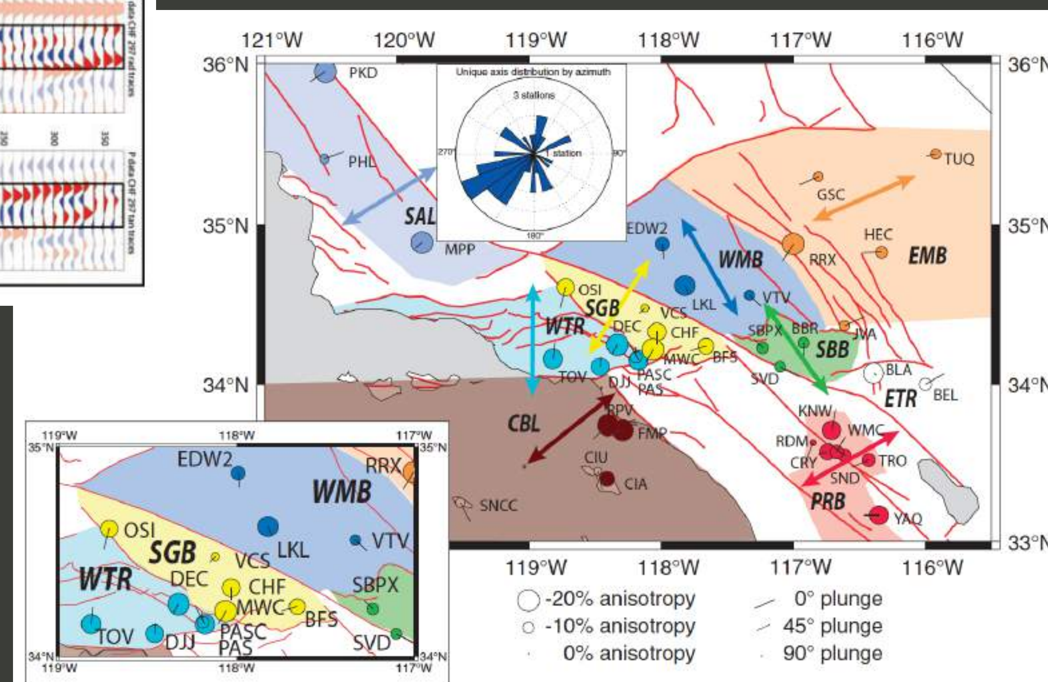


Measuring Anisotropy: Ps receiver function anisotropy



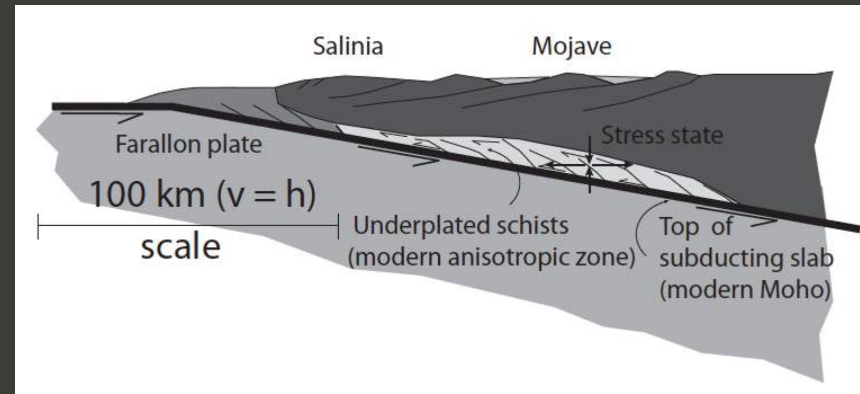
Ozacar and Zandt, 2009

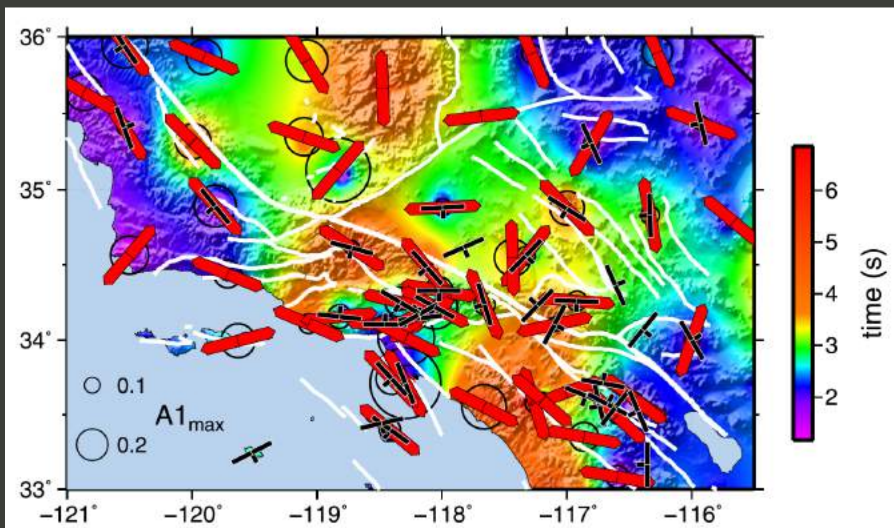




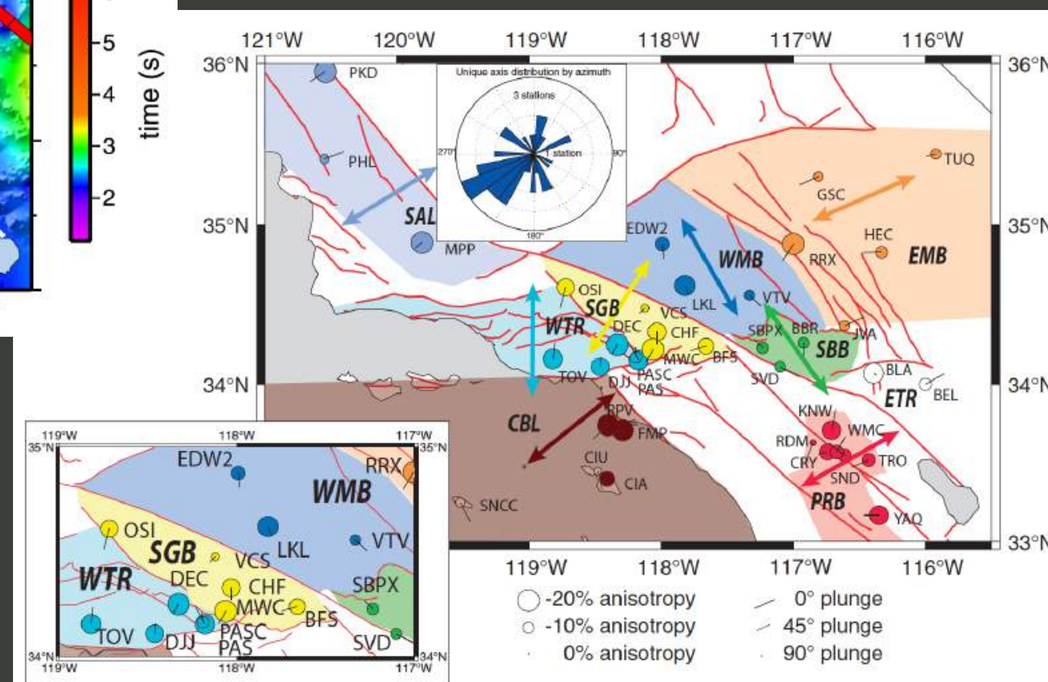
Porter et al., 2011

Measuring Anisotropy: Ps receiver function anisotropy





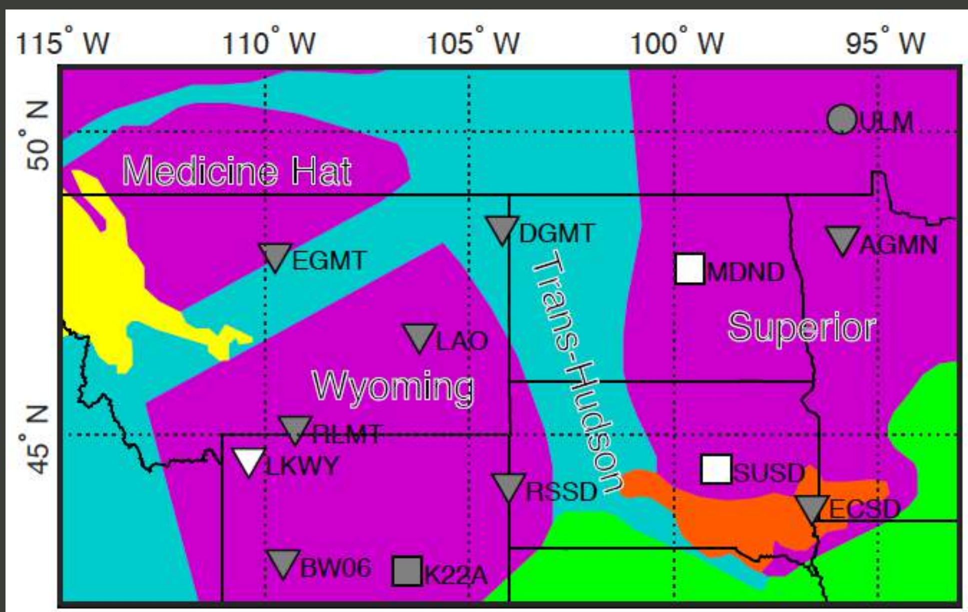
Schulte-Pelkum and Mehan, 2014

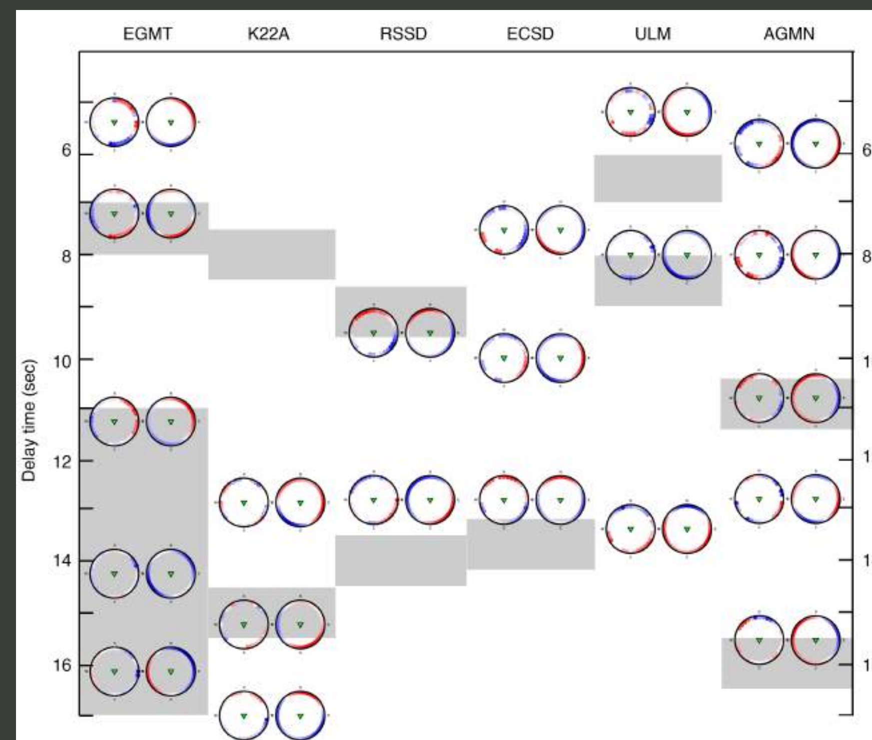


Porter et al., 2011

Measuring Anisotropy: Ps receiver function anisotropy

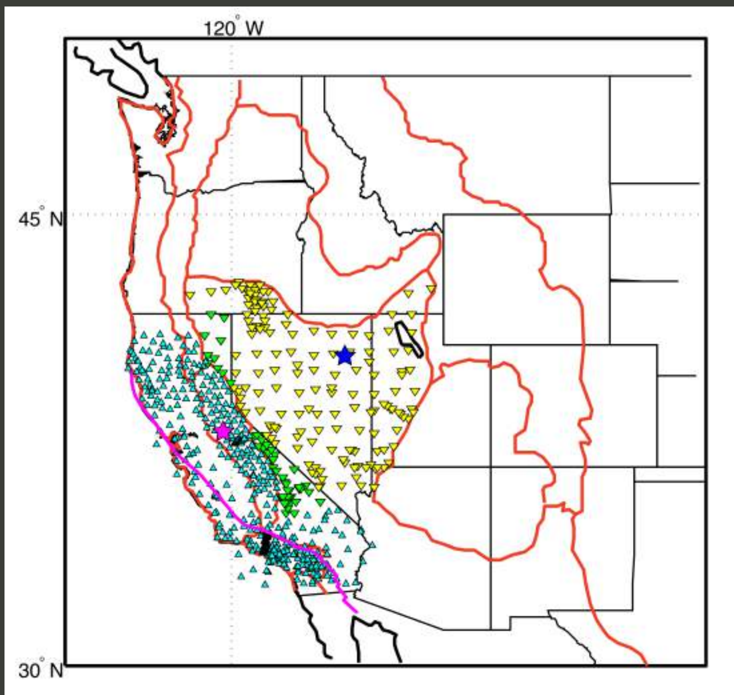
Ps receiver function results indicates anisotropy present at mid-lithospheric depths within the continental interior



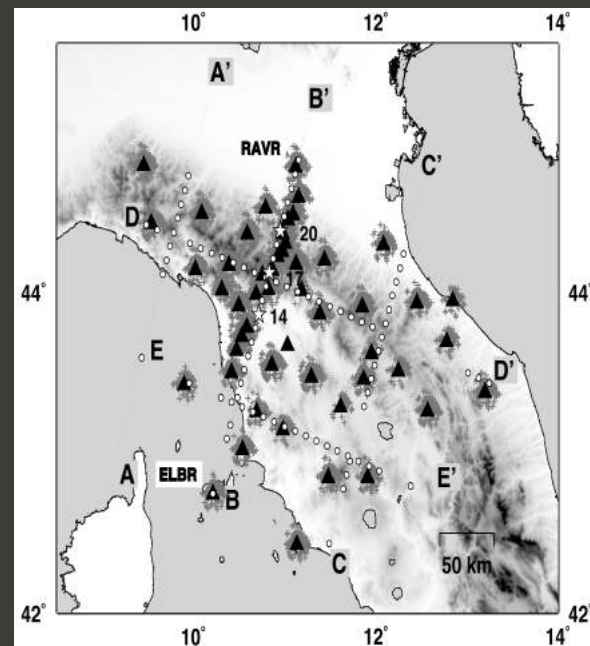


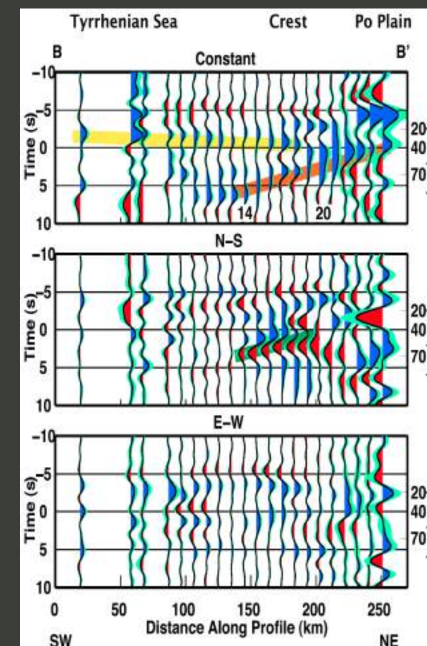
Ford et al., in revision

Measuring Anisotropy: Ps receiver function anisotropy



Using Transportable Array & Harmonic stacking to produce 3D images of anisotropic structure





Bianchi et al. (2010)

Building a community model

Room for improvement:

Outside the scope of this workshop/ SCEC5?

Continued methodological advances
Improve data coverage

Opportunity to better utilize results

Synthesis of prior results

Test models of rheology

Considerations:

- Variations between crust & mantle
- Radial vs. azimuthal anisotropy
- Differences within methodology

Building a community model

One possible approach:

Thermomechanical* + VPSC modeling of LPO (olivine + pyroxene)

Calculation of elasticity tensors

Forward modeling of seismic wave propagation (ray theoretical, finite-frequency, full waveform)

Compute synthetic results + compare

Bonnin et al. (2012)