Castellanos et al. (2020)

Seismic anisotropy reveals crustal flow driven by mantle vertical loading in the Pacific NW [Northwest]

A Sacred Reading with
Kitri Spencer

Sacred Reading

Trust · Rigor · Community

1

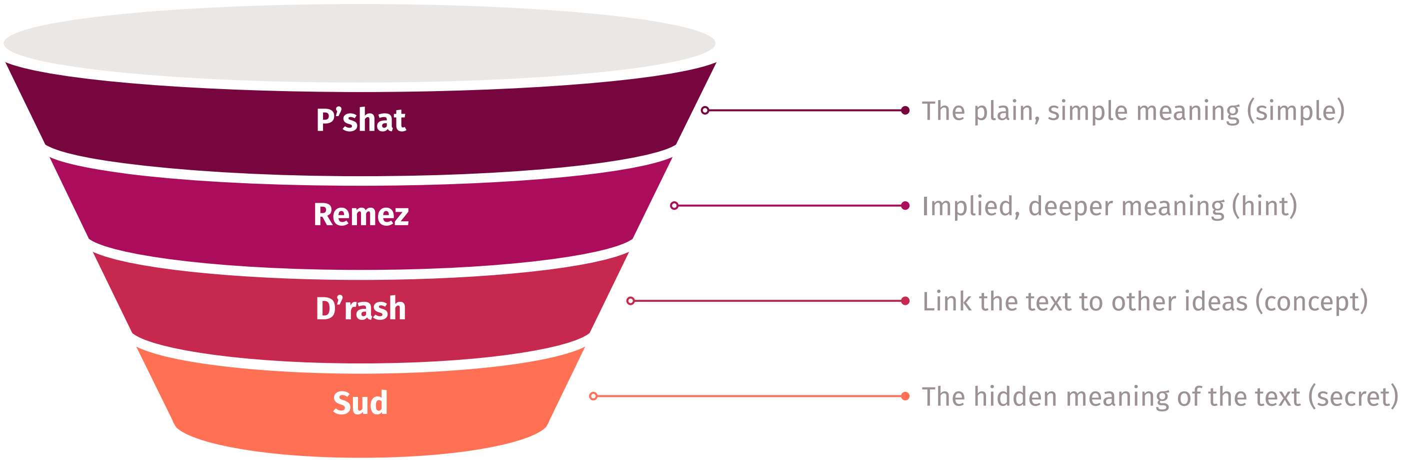
“

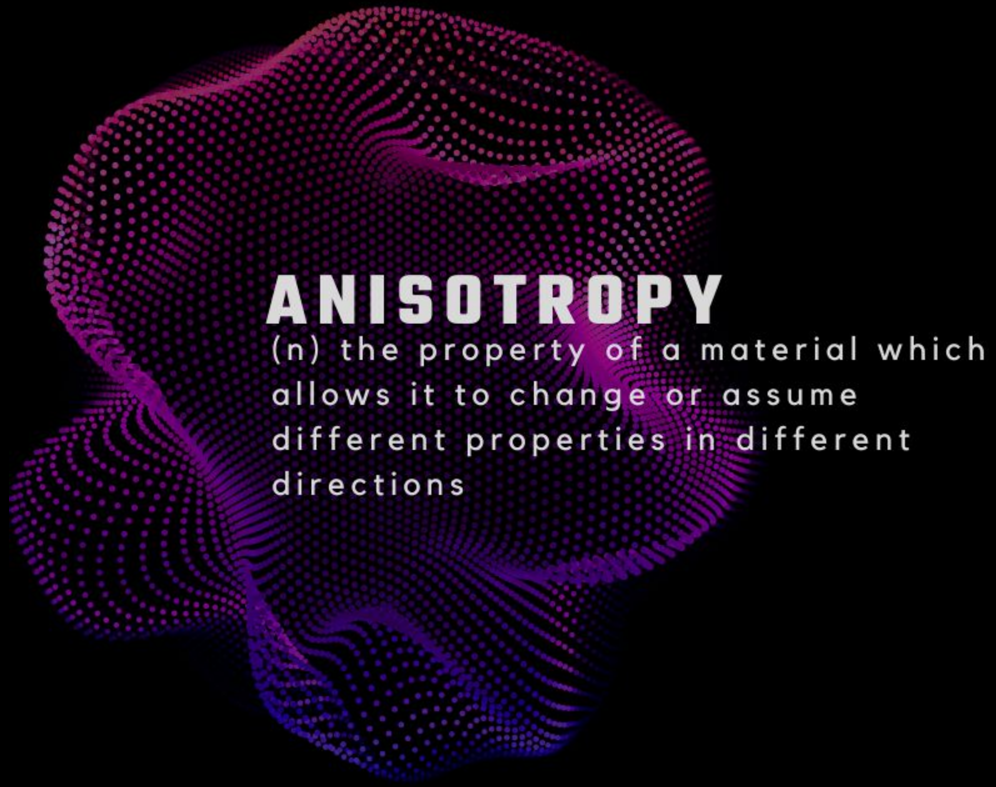
. . .Everything is opaque until you break beneath the surface to understand it.

-Rabbi Scott Perlo

PaRDeS

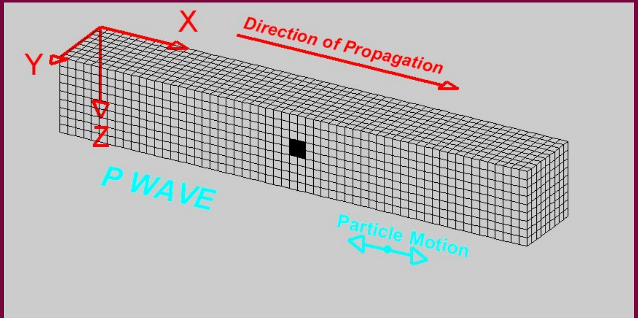
Orchard: Pluck any sentence (figure) from the text, bite into it and be nourished

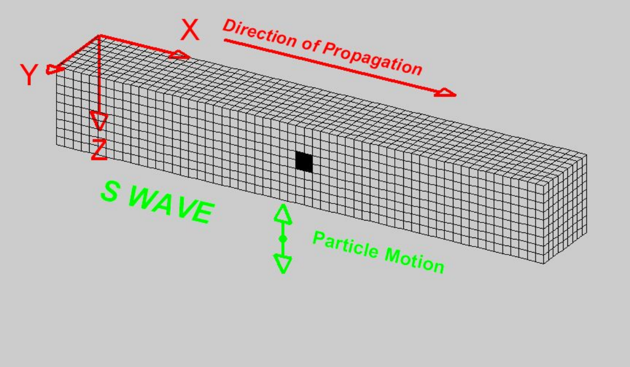


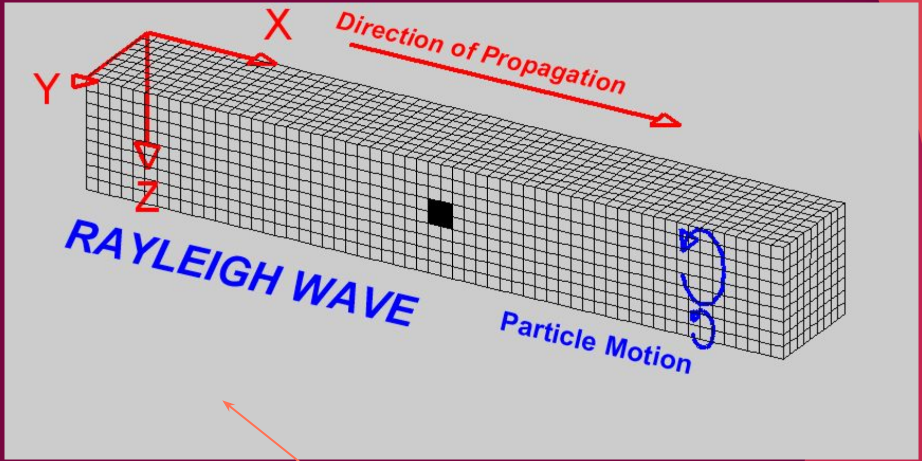


Seismic anisotropy- the directional dependence of seismic wave speeds and particle motion polarizations, as well as the splitting of normal modes, as caused by the elastic properties of rocks

Wave Review



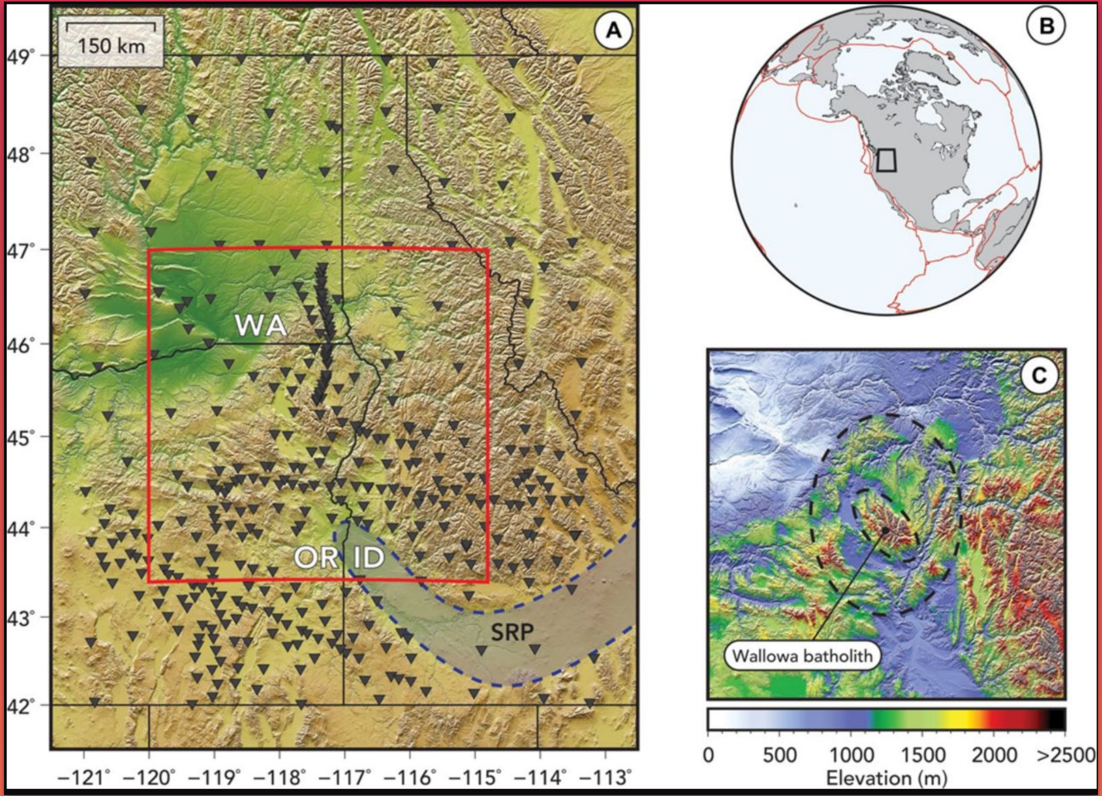




Dataset used in this study consisted of these waves from 350 broadband seismic stations!

Fig. 1: Regional and Location Maps

A) Regional map showing the broadband seismic stations used in this study. Dashed blue line depicts the Snake River Plane



B) Global map centered on NE Oregon

C) Elevation map of the topographic bullseye region (red in A). The Dashed larger ellipse is the outer limit of the bullseye, whereas the inner ellipse locates the Wallowa Mountains

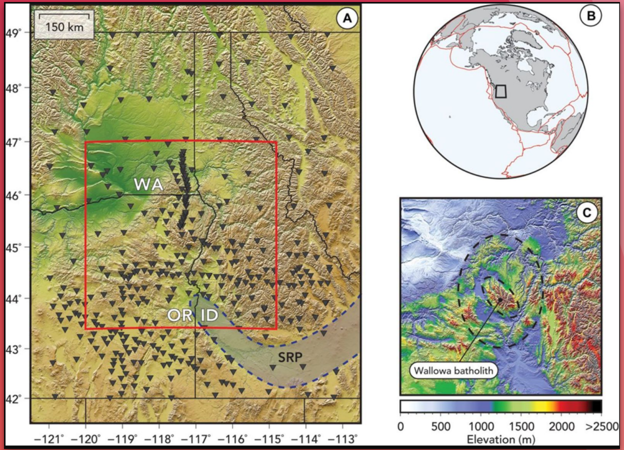
Fig. 1: Regional and Location Maps

P'shat: There are many stations at the 706 boundary. This represents the docking of the Siletzia slab during the Eocene.

Remez: Lots of stations means lots of data! Having this many stations is beneficial for resolving seismic signal. The 706 line represents the docking of the Siletzia slab during the Eocene. Farallon slab subduction, however, is ongoing.

D'rash: There may be connections between Castellano's thermal model to the uplift of the Colorado Plateau as well as the timing of the Wallowa uplift. Could there be a thermal connection to the Liberty Gold or the Yellowstone Hotspot? There are also connections to volatile movement and geochemistry.

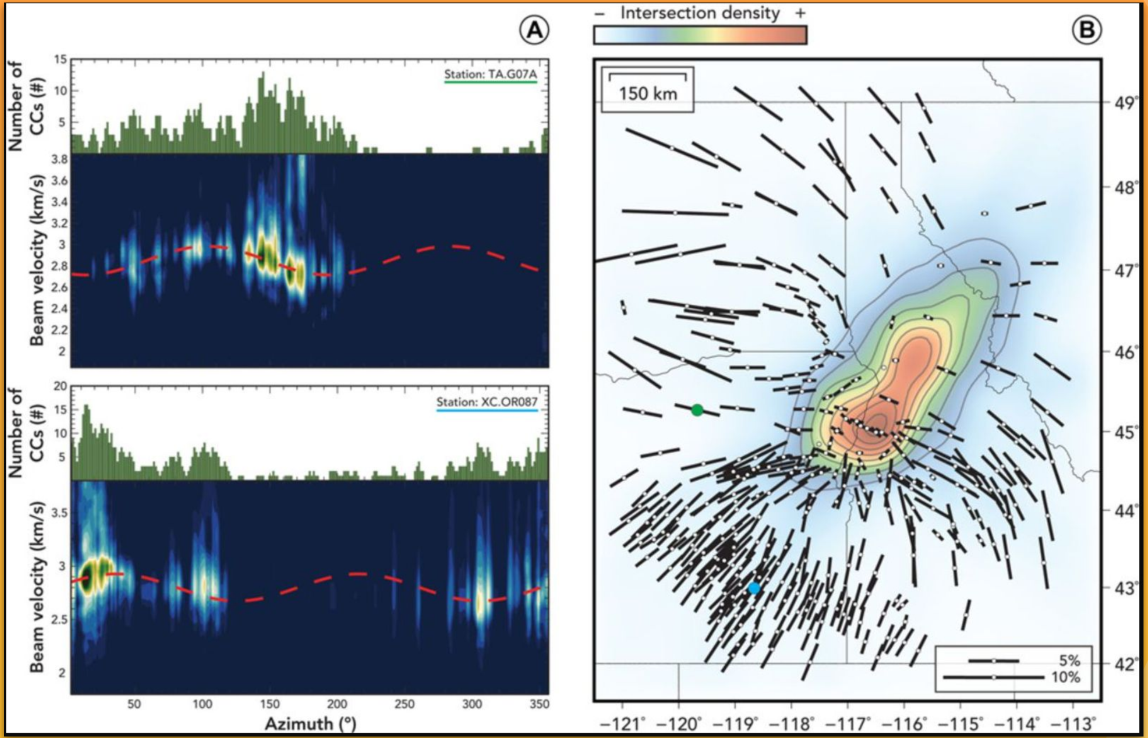
Sud: Could thermal perturbations and volatiles have implications for plate subduction timing?



A technique that focuses a wireless signal towards a specific receiving device, rather than have the signal spread in all directions

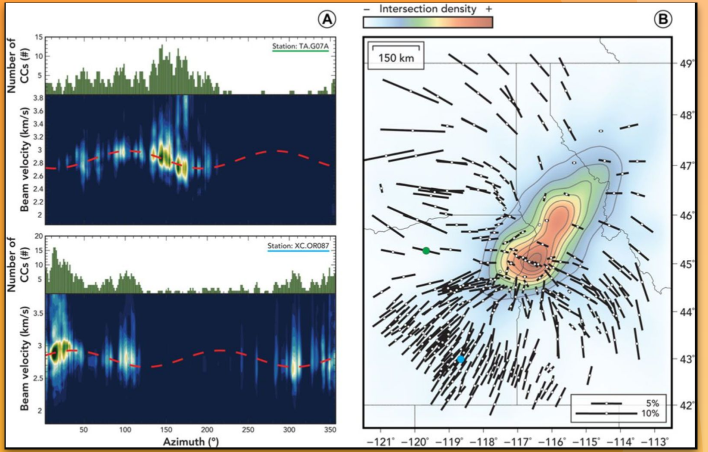
Fig. 2: Example of beamformer outputs and final azimuthal anisotropy model

A) 2D histograms over the azimuth-velocity space with the best-fitting anisotropy model (red lines). Green bars indicate the number of noise cross-correlations available



B) Azimuthal anisotropy model for crust of Pacific NW. Bars give the fast direction of azimuthal anisotropy and anisotropy amplitude. Colors represent intersection density of the anisotropy vectors and dots indicate stations

Fig. 2: Example of beamformer outputs and final azimuthal anisotropy model



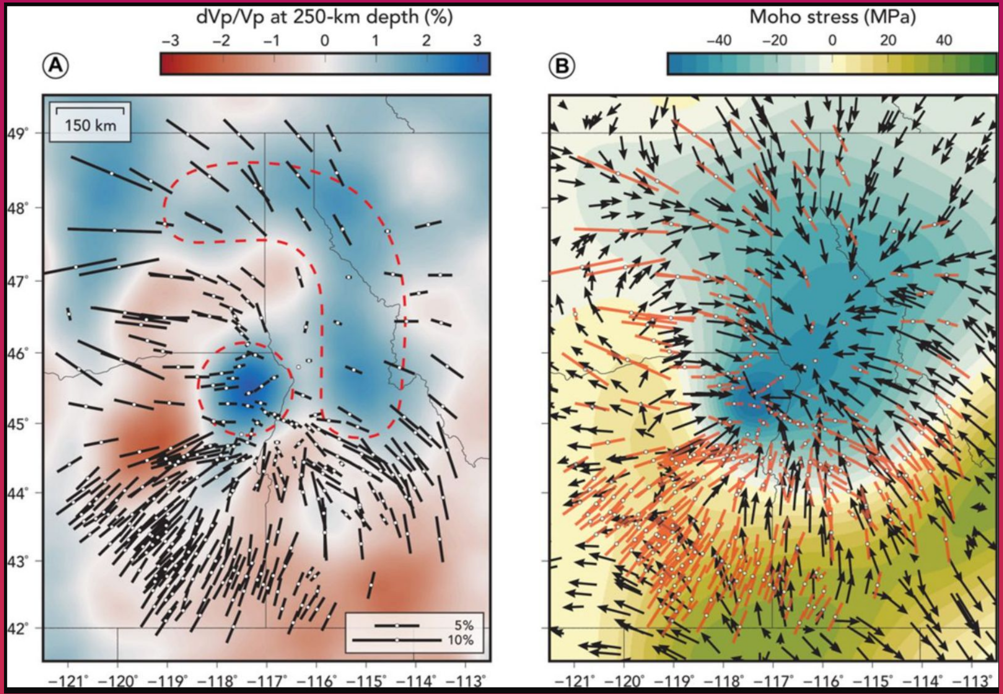
P'shat: We talked about the number of seismic stations, how they are semi-permanently placed and detect ambient seismic noise (Rayleigh waves). Seismic noise at these stations varies, so we can compare different stations from day-to-day (cross-correlation). The Moho is the boundary between the earth's crust and the mantle, a compositional boundary that can be seen in seismic wave imaging.

Remez: Seismic wave velocity is a function of the sign of the Azimuth, different velocities in different directions and on different days. What could this say about densities and buoyancy near the Wallowa anomaly?

D'rash: The best fit anisotropy models both have a sinusoidal distribution, which seems to be a common pattern in this class (waves, heat distribution, etc.). Where do densities intersect, do they really align with the features the authors said they did?

Sud: How well do the best fit models actually fit? Is there uncertainty, why?

Fig. 3: Comparison of seismic and geodynamic results with crustal anisotropy



A) Azimuthal anisotropy model over a depth slice through the Vp tomography model at 250 km. Red dashed lines depict the wallowa anomaly and the Siletzia slab curtain

B) Modeled Moho stress and mid-lower crustal flow velocity. Colored contours represent vertical stress at the Moho based on a global geodynamic model driven by density anomalies derived from P-wave velocity structure. Black arrows denote predicted mid-lower crustal flow velocity that results from the applied modeled Moho stress to a viscously heterogeneous crust. Red bars represent anisotropy measurements

Fig. 3: Comparison of seismic and geodynamic results with crustal anisotropy

P'shat: Here, the modeled anisotropies are compared with actual observations along with seismic wave velocities and stress on the Moho.

Remez: The paper proposes a density anomaly at depth which is exhibited at the surface. The stress is associated with the buoyancy anomaly.

D'rash: The boundary stress is related to the flow in the mantle (as in Figure 5)! This relates the normal stress in the mantle to anisotropy in the crust.

Sud: Figure 3B really represents the core kernel of observations from this study. Amanda said that there are a lot of assumptions here. Does this model really capture the trend investigated? Could it be better?

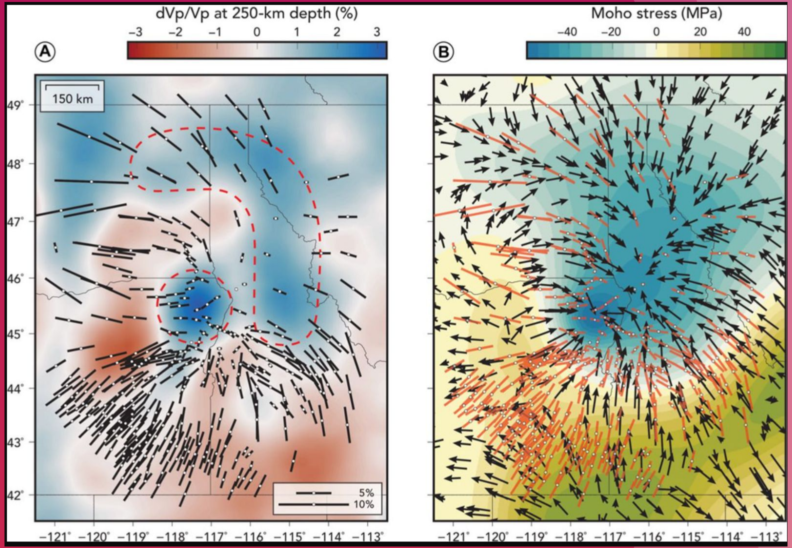
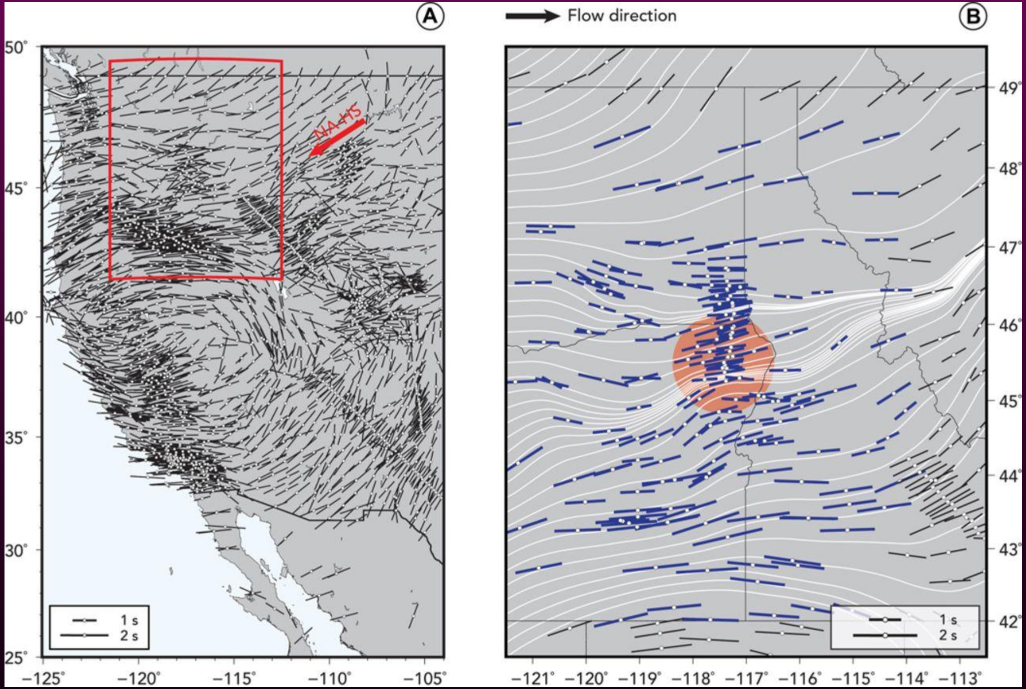


Fig. 4: Station averaged shear wave splitting measurements for the Pacific NW

A) SKS splitting measurements for the Western US. Red arrow depicts relative motion between NA plate and hot spot.



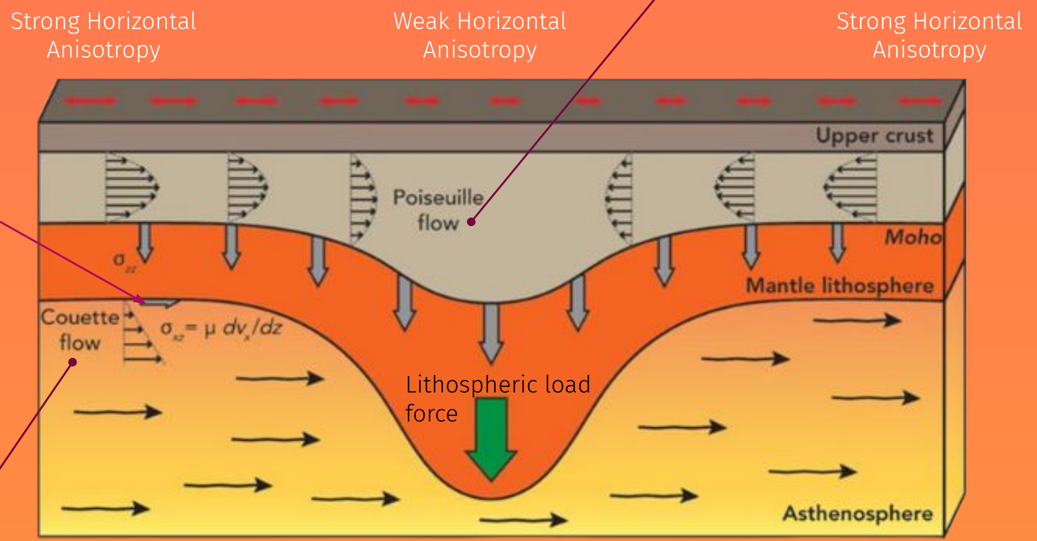
A) SKS splitting measurements for study region. Blue vectors depict Niday & Humphreys' measurements and black vectors are from Becker et al. database.

Orientation of vectors gives the angle of fast polarization and length is proportional to magnitude of shear wave splitting

Fig. 5: Upside-down waterbed model

Pressure-induced flow in a long duct (pipe). Laminar flow induced by pressure difference in the pipe

Stress contribution from flowing asthenosphere

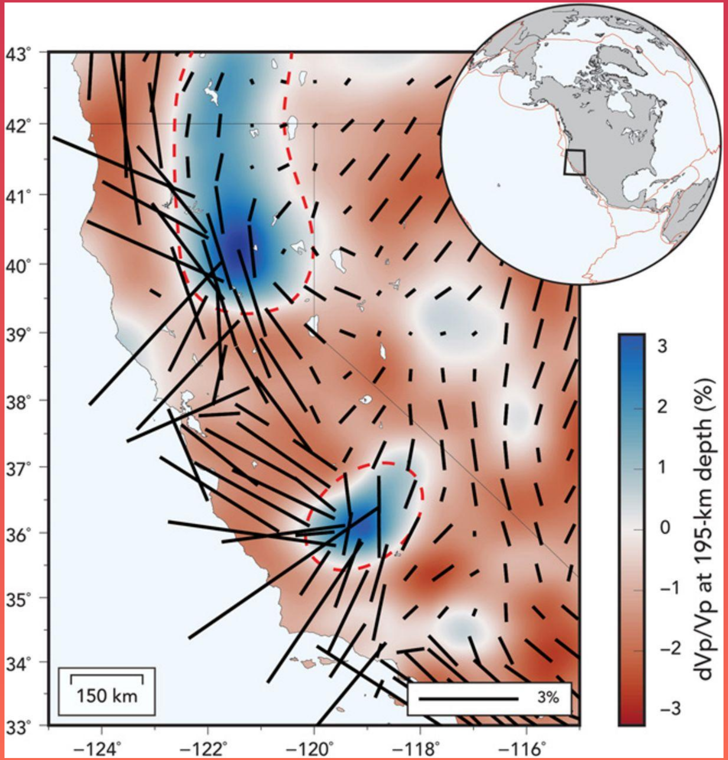


Drag-induced flow of viscous fluid in space between two surfaces; Motion of surfaces imposes shear stress on the fluid and induces flow

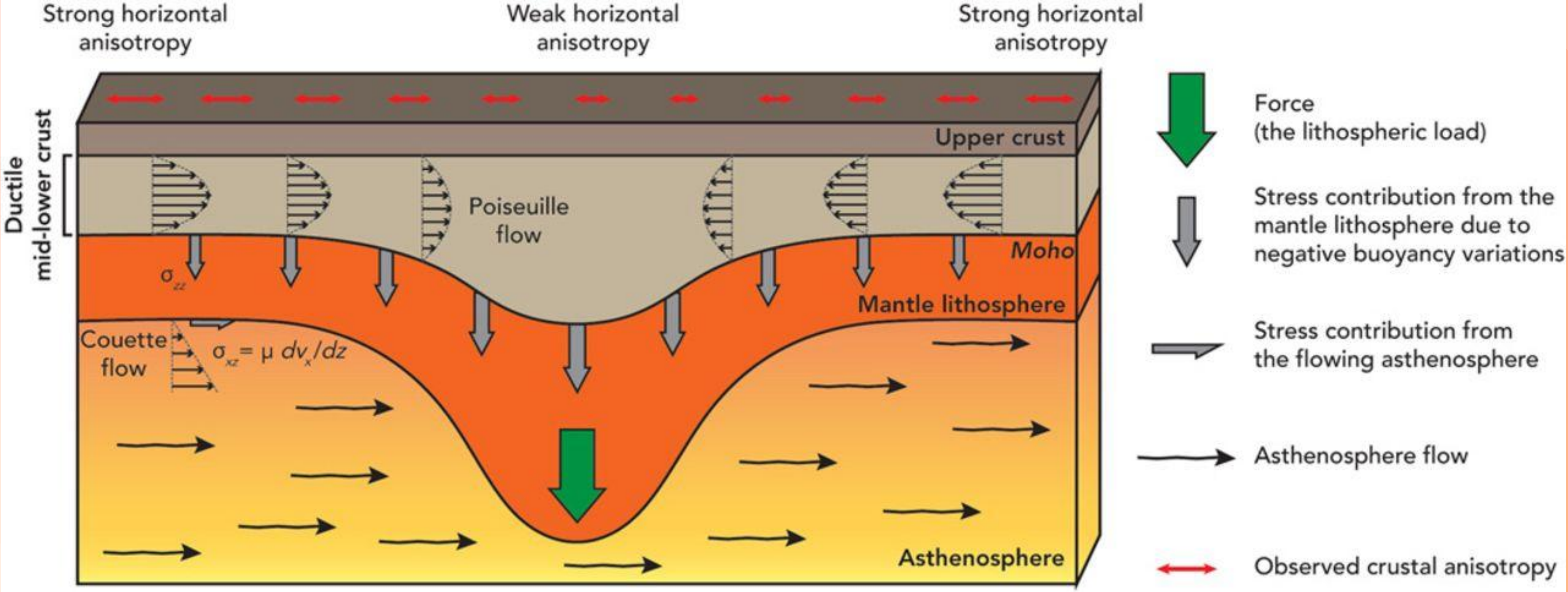
Load of the mantle lithosphere is a force creating vertical stresses on the Moho. Lithospheric load pulls down on the crust, creating a lateral pressure gradient that drives poiseuille flow. Asthenosphere flow independently creating local Couette flow decoupled from the mid-lower crust by mantle lithosphere

Fig. 6: Crustal anisotropy and upper mantle velocity structure of California

Black vectors depict Lin et al.'s surface wave anisotropy measurements for the 12-s period. Bar orientation gives the fast direction of azimuthal anisotropy and bar length is proportional to anisotropy amplitude.



Background color corresponds to a depth slice through the Vp tomography model at 195 km. Red dashed lines denote two seismically fast and likely dense mantle anomalies



Strong horizontal anisotropy
Weak horizontal anisotropy
Strong horizontal anisotropy
Ductile mid-lower crust
Upper crust
Poiseuille flow
Moho
σ_{zz}
Mantle lithosphere
Couette flow
$\sigma_{xz} = \mu\, dv_x/dz$
Asthenosphere
Force (the lithospheric load)
Stress contribution from the mantle lithosphere due to negative buoyancy variations
Stress contribution from the flowing asthenosphere
Asthenosphere flow
Observed crustal anisotropy

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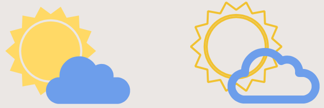

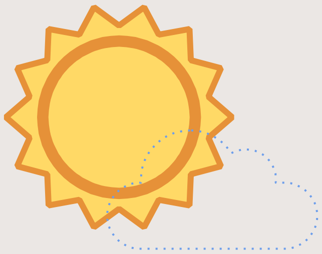

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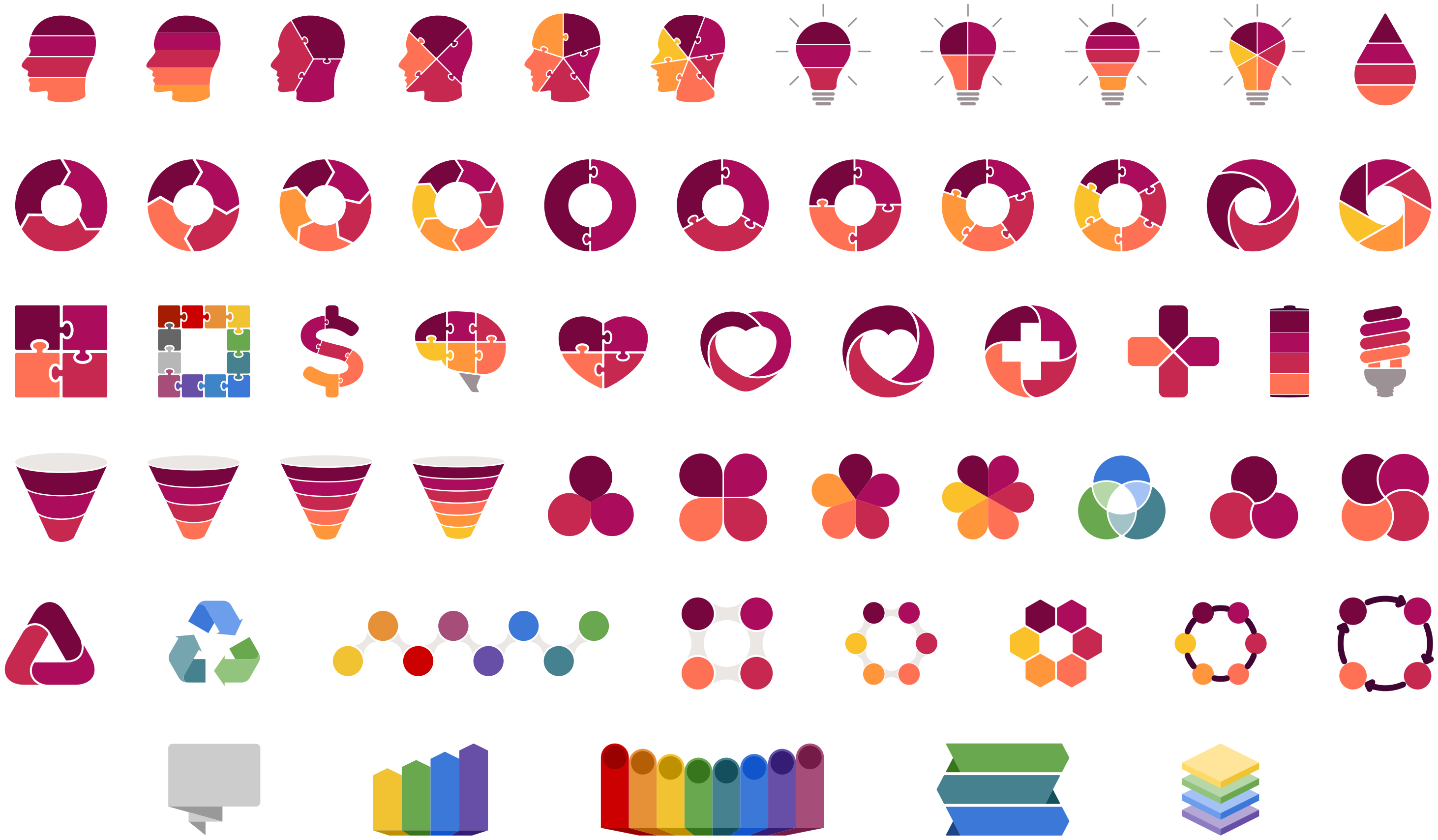

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