Inferring Mantle Flow Patterns Beneath Iceland from the Phase Velocity of Rayleigh and Love Waves

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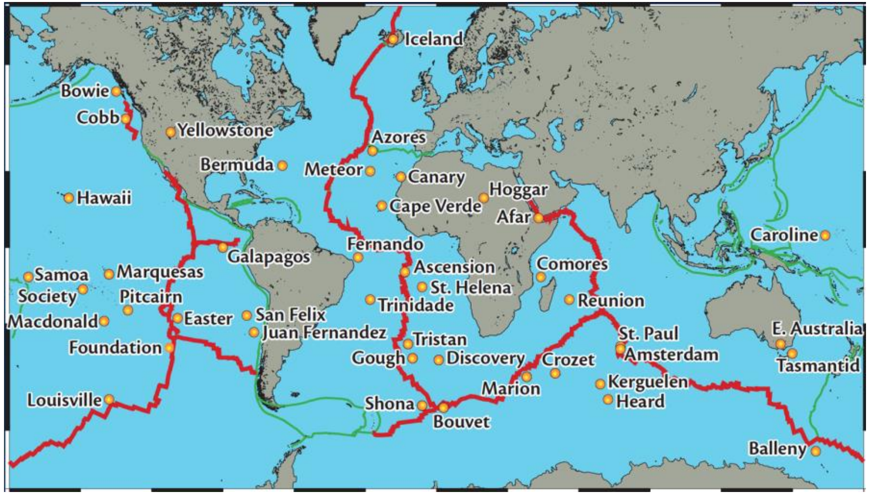
Background

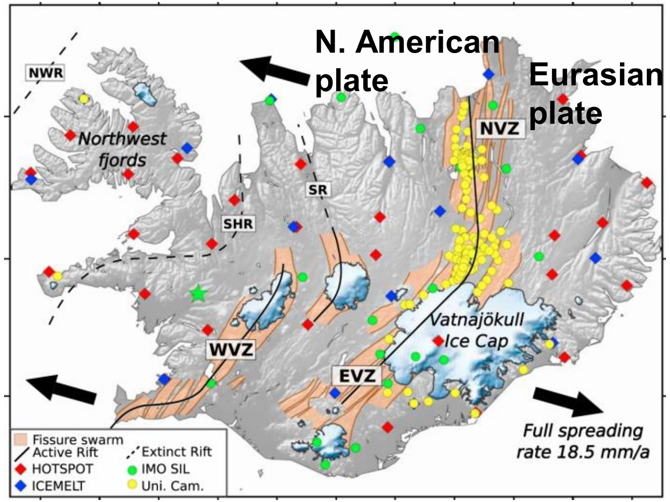
- Spreading ridge and mantle plume
- Three volcanic zones
    - Northern, Eastern, Western

Mid-Ocean Ridges & Volcanic Hotspots



Dyment et al. (2007)

Iceland

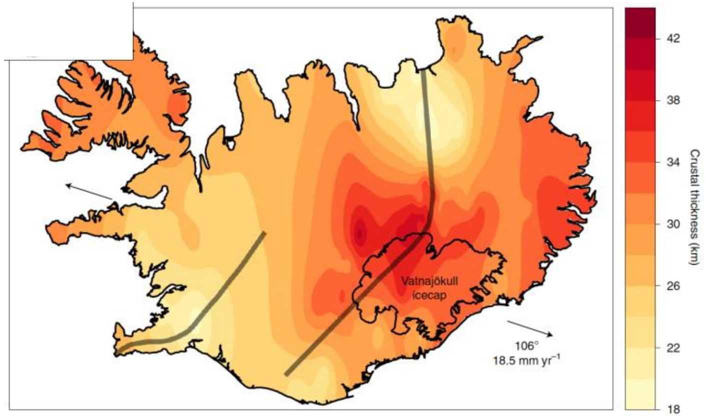


Jenkins et al. (2018)

Motivation

- Crustal thickness relates to wave velocity
- Iceland has a relatively thick crust

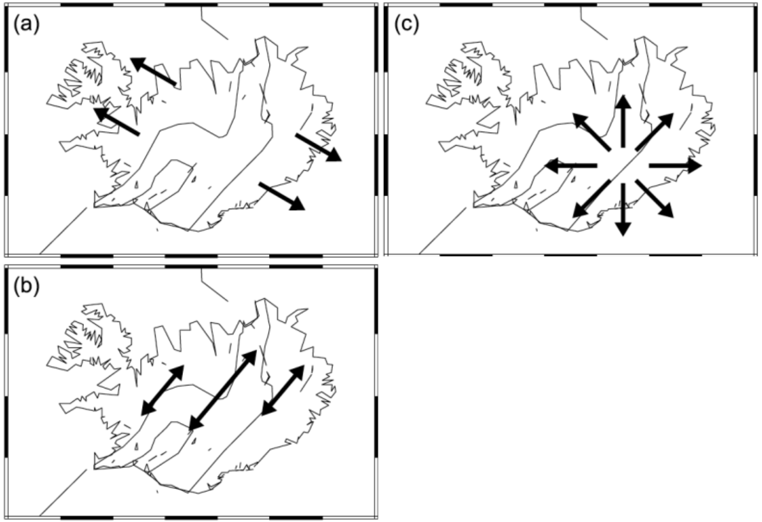
Crustal Thickness



Jenkins et al. (2018)

- Different mantle flow patterns depending on source

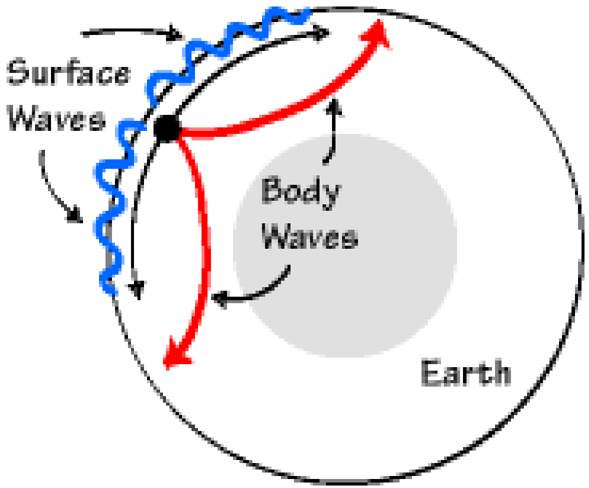
Mantle Flow: Possible Scenarios



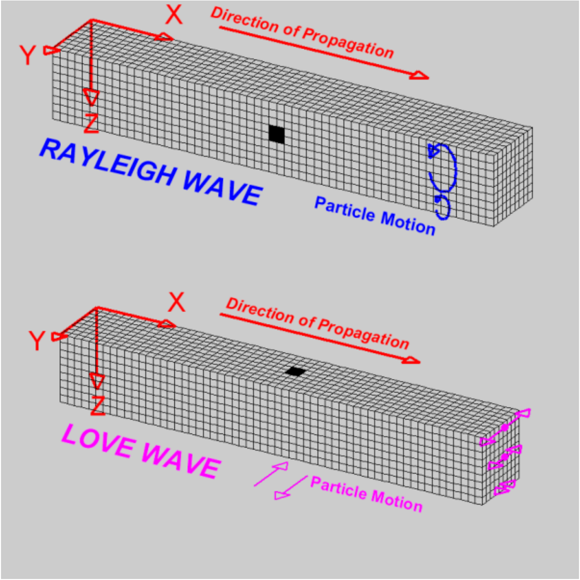
Li & Detrick (2003)

Surface Waves

- Surface waves travel parallel to the Earth's surface through the crust and upper mantle
- Two types of surface waves: Rayleigh and Love waves
- Longer periods sample greater depths
  - ❑ periods < 30 sec sample the crust



http://eqseis.geosc.psu.edu/cammon/HTML/Classes/IntroQuakes/Notes/waves_and_interior.html

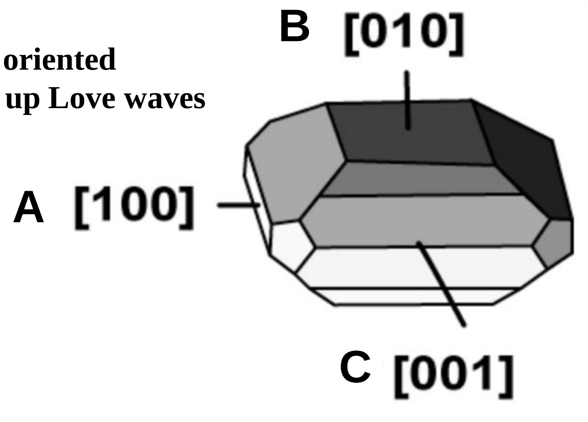


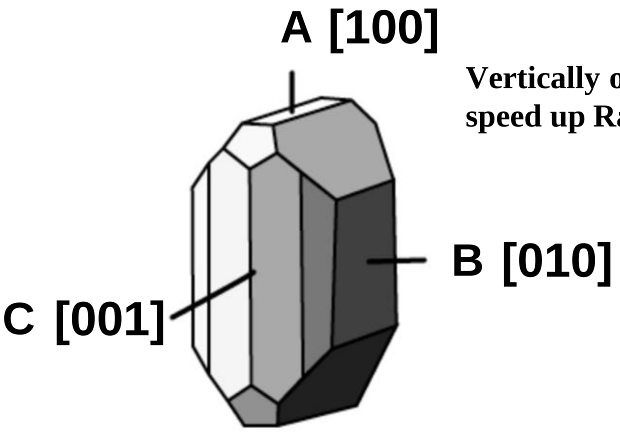
https://www.mtu.edu/geo/community/seismology/learn/seismology-study/surface-wave/

Anisotropy and Olivine Orientation

- Olivine grains orient in the direction of mantle flow
- The alignment causes significant anisotropy

Horizontally oriented olivine speed up Love waves





Vertically oriented olivine speed up Rayleigh waves

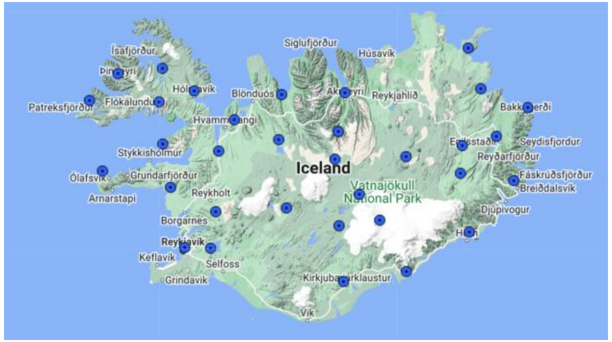
https://indico.ictp.it/event/a08171/session/36/contribution/25/material/0/0.pdf

1. What is the direction of mantle flow beneath Iceland?

2. How does crustal thickness vary across Iceland?

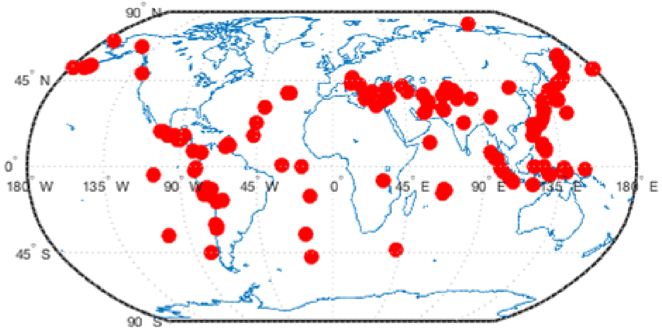
Methods: Data Collection

- We collect data from 33 stations across iceland, all of which are a part of the XD network
- Use earthquakes with magnitude (M_W) >5.5

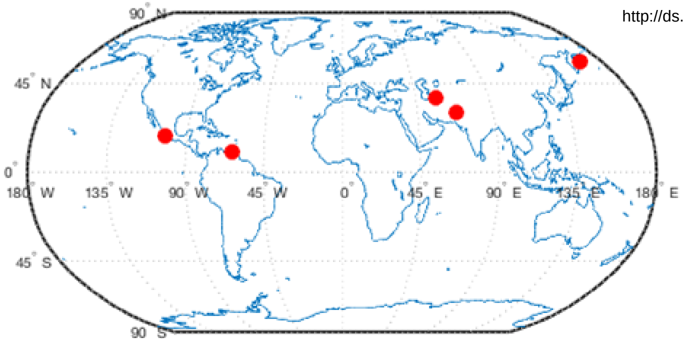


http://ds.iris.edu/gmap/#network=*&planet=earth

162 events for Rayleigh waves



5 events for Love waves



Methods: Measurements and Calculations

Measuring Travel Time

- We use a method developed by Jin and Gaherty (2015) to measure wave travel times
- Reduce overtone interference in Love Waves using method from Hariharan and Dalton (2022)

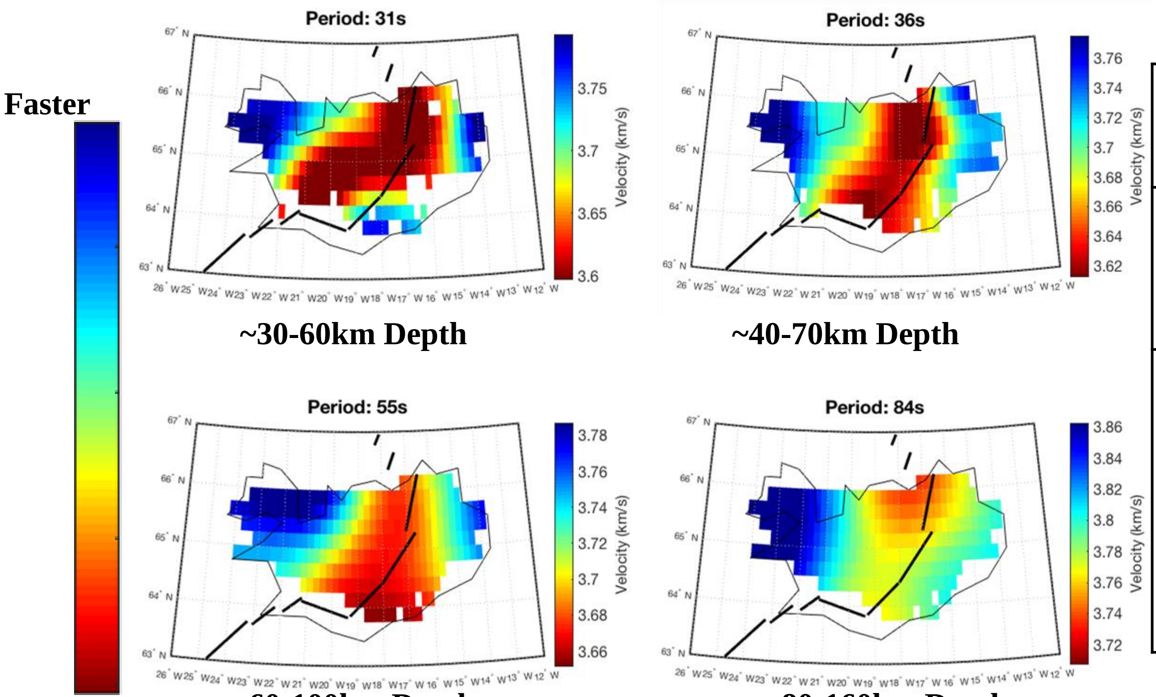
Computing Phase Velocity

- Solve for the phase velocity ($c'(\vec{r})$) using the inter-station travel times ($\tau(\vec{r})$)
- The phase velocity is defined by the Eikonal equation:

$$\boxed{\frac{1}{c'(\vec{r})} = |\nabla\tau(\vec{r})|}$$

Results: Rayleigh Wave Maps

- Slow velocities along the ridge and at a range of depths



~30-60km Depth

~40-70km Depth

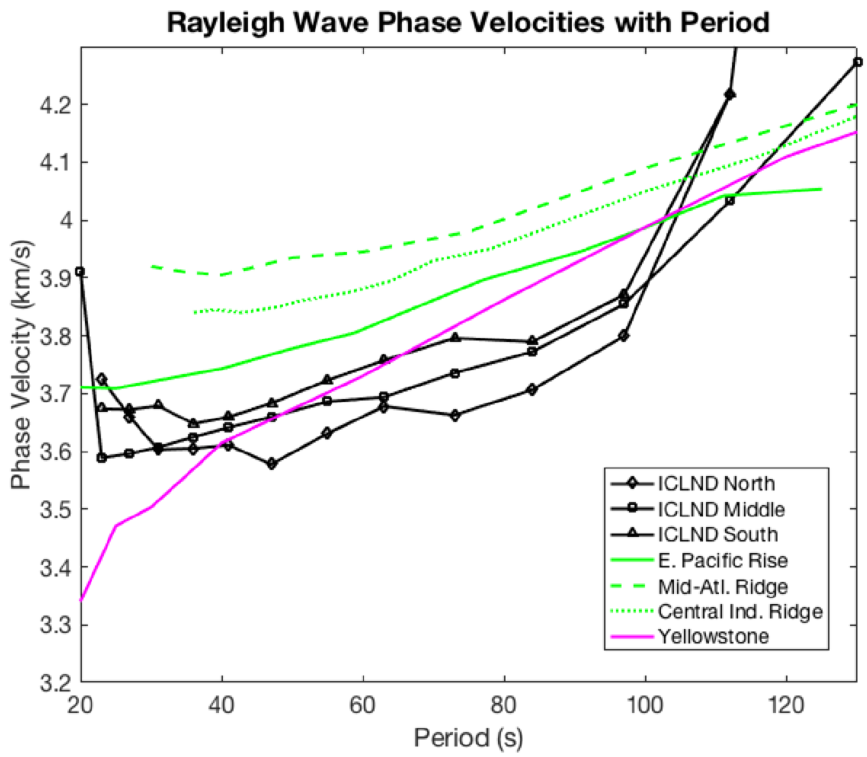
~60-100km Depth

~80-160km Depth

	slow phase velocity	fast phase velocity
Short periods (<30 seconds)	thick crust	thin crust
Long periods (>30 seconds)	hot mantle, maybe partially molten	cold, melt-free mantle

Results: Rayleigh Wave Speeds

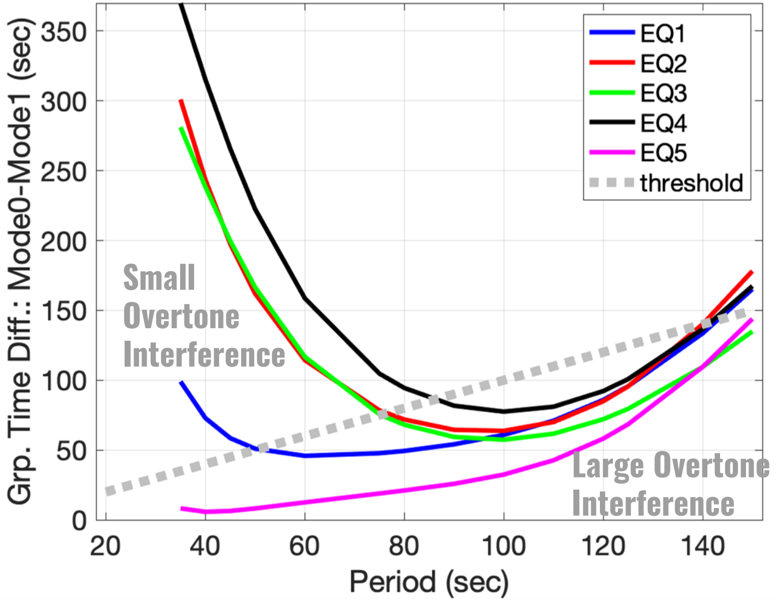
- Compare phase velocities at three locations along rift with global locations
- Slowest velocities under Iceland
- Comparable velocities to Yellowstone except at short periods



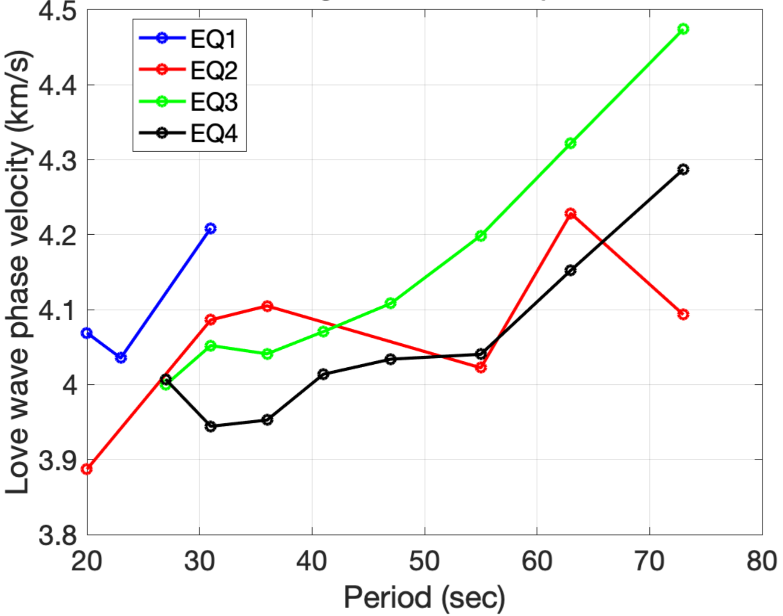
Love Wave Results

- Challenges with overtone interference and data availability
- Reasonably good consistency for events with low overtone interference

Events and periods above overtone threshold

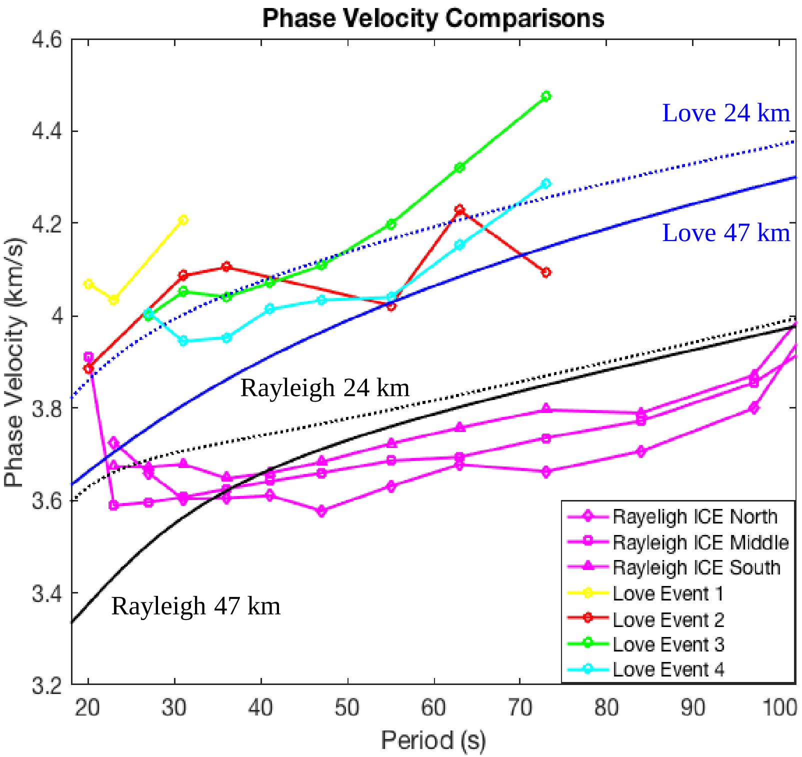


Average Phase Velocity

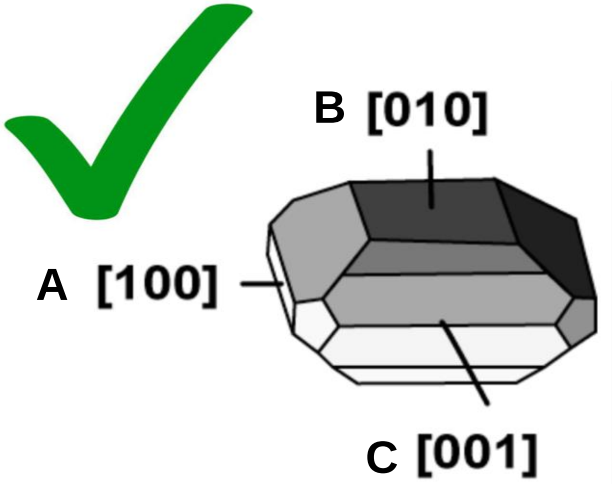


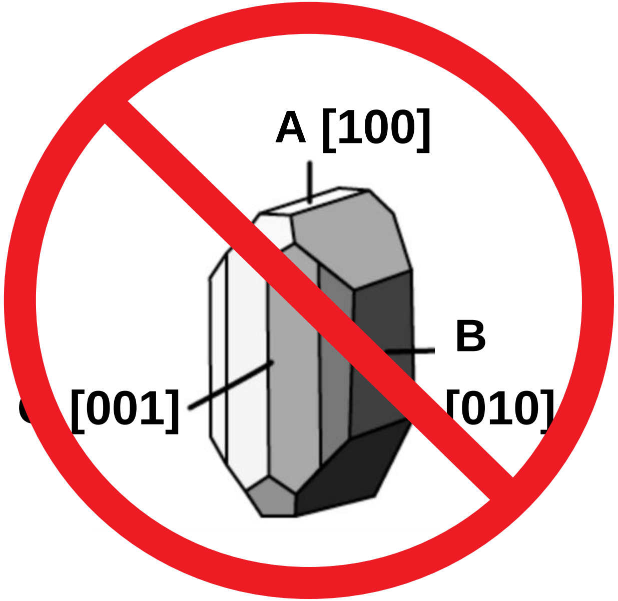
Preliminary Interpretations

- Predictions using Yellowstone model as reference
  - 47 km crust and 24 km crust
  - Isotropic velocities
- Short period data agreed better with thin crust
- Long period Love wave data agreed with predictions but Rayleigh wave data too slow
- Anisotropy is required to fit both data sets
- Suggests dominantly horizontal alignment of olivine a-axes



Preliminary Interpretations





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