Evaluating Drivers of Mantle Flow and Sources of Seismic Anisotropy in the Alaskan Subduction Zone: Observations from Offshore/Onshore Shear-Wave Splitting

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Abstract

Subduction zones are essential for mantle convection through the recycling of oceanic lithosphere, however, asthenospheric flow at convergent margins is not uniform. Deformation of the asthenosphere can be driven by subduction processes such as, viscous entrainment to plate motions, slab rollback-induced toroidal flow, and mantle wedge dynamics. These mechanisms are critical to understanding volcanism, margin evolution, and lithosphere-asthenosphere coupling. The easternmost Alaska subduction zone has been extensively studied showing evidence from seismic anisotropy for large-scale toroidal flow around the slab edge. Westward however, near the Shumagin Gap, few observations have been made. Along-strike changes in oceanic plate fabric, steepening slab dip, proximity to the slab edge, plate motion, and hydration of the mantle may all influence anisotropy and mantle flow in this region. Here, we evaluate models using independent offshore shear-wave splitting measurements acquired using data from the Alaska Amphibious Community Seismic Experiment (AACSE). We compare our splitting observations to forward models that consider the distribution of anisotropy and the backazimuthal dependence of observations. The models we test include viscously entrained flow due to oceanic plate motion (˜310° CW North), anisotropic fabric variations, anisotropy related to bending faults and mantle serpentinization, and changes in frozen anisotropy in the oceanic lithosphere. Onshore shear-wave splitting observations show fast-axis directions ˜55° CW North, inconsistent with 2D mantle wedge flow, assuming A-type olivine, but it is consistent with B-type fabric or trench-parallel flow as suggested by previous studies. Offshore splitting observations appear to vary along-strike. Here, two distinct oceanic plate fabrics exist, one developed from a northeast-spreading direction and the other from an east-spreading direction. Frozen anisotropy in the oceanic lithosphere may play a significant role in the splitting signal produced offshore and may be an important contributor to the distribution of seismic anisotropy. By synthesizing onshore and offshore observations here with our understanding of flow at the eastern slab edge, we can build a more complete model of mantle dynamics for the Alaskan subduction zone.

Evaluating drivers of mantle flow and sources of seismic anisotropy in the Alaskan subduction zone: Observations from offshore/onshore shear wave splitting

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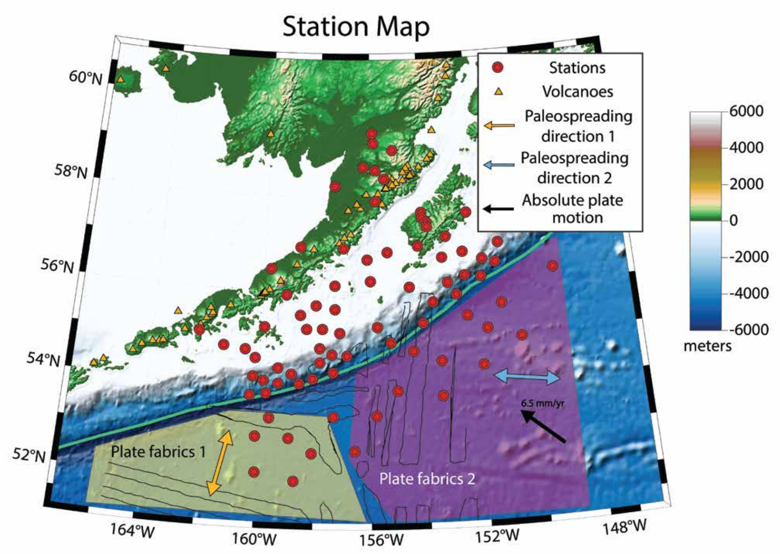
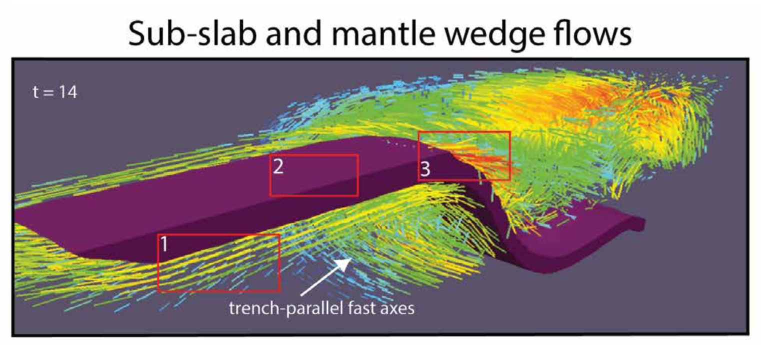
Introduction

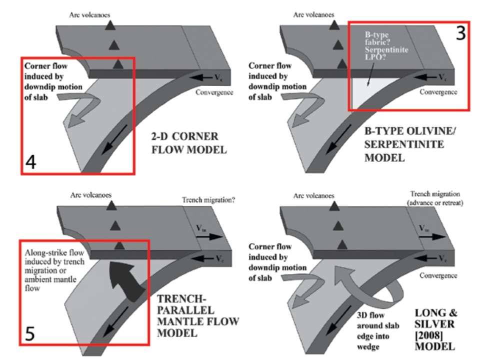
- What are the main drivers of mantle flow in complex subduction zones?
- How is the deformation in specific regions of subduction zones interrelated?
- How is anisotropy distributed offshore between the mantle lithosphere and the asthenosphere?
- How is anisotropy distributed in specific regions of the subduction zone?





Modified from Faccenda & Capitanio (2013). Time is in Ma. Numbers in red boxes refer to hypotheses tested.

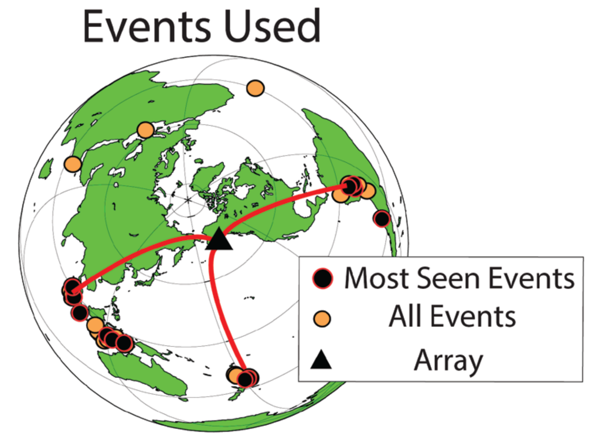
- The Alaska subduction zone presents along-strike variations in plate fabrics[1], hydration[12], slab dip[15], and seismicity[8] making it the ideal candidate for our study.
- Hypotheses:
  - Offshore:
    - (1) Plate-motion driven flow[5] dominates.
    - (2) Frozen anisotropy in the lithosphere is significant and changes along-strike.
    - (3) Overprinting by serpentinization from bending faults[12].
  - Mantle wedge and sub-slab region:
    - (4) Trench-perpendicular flow driven by the descending slab[11,12]:
      - A- or B-type olivine.
    - (5) Trench-parallel flow driven by slab-rollback[11,12] or slab dip[15].



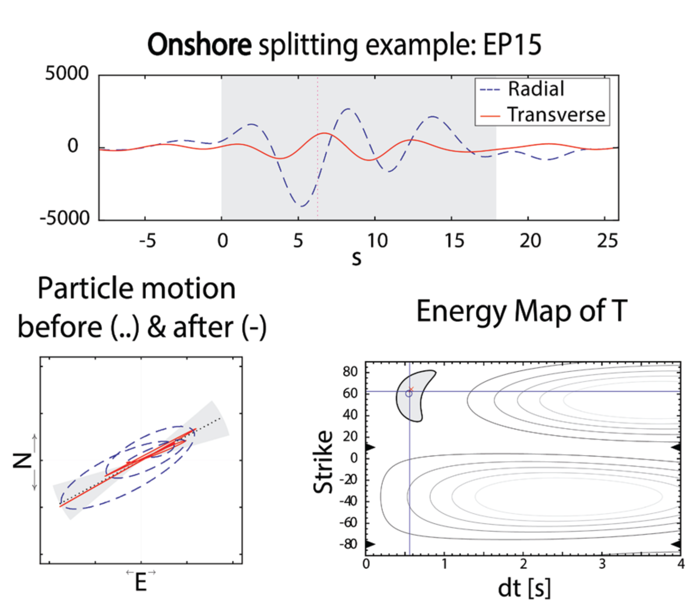
From Long & Wirth (2013). Four different possible models that would explain seismic anisotropy in the mantle wedge. Numbers in red boxes refer to hypotheses tested.

Data

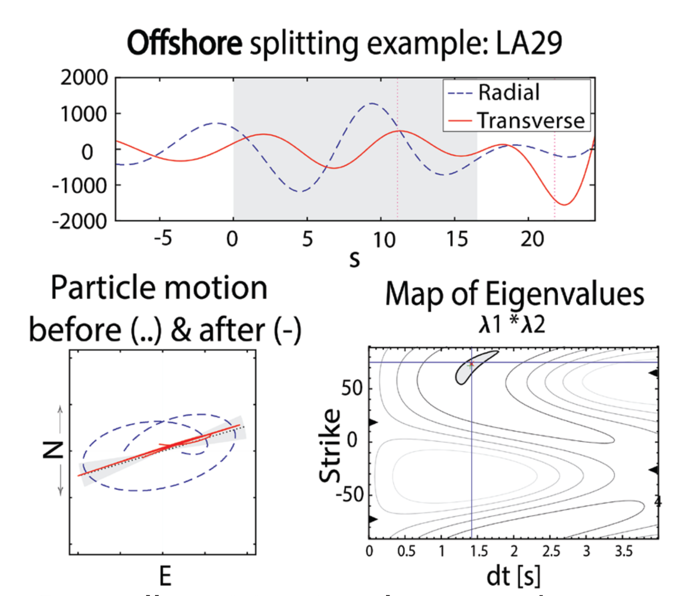
- Alaska Amphibious Community Seismic Experiment (AACSE)[2,3]
- Teleseismic events of $M_w > 5.0$
- 3 main backazimuths: 100, 200, and 265 degrees
- 29 events, 12 included in Most Seen Events



EXAMPLES:

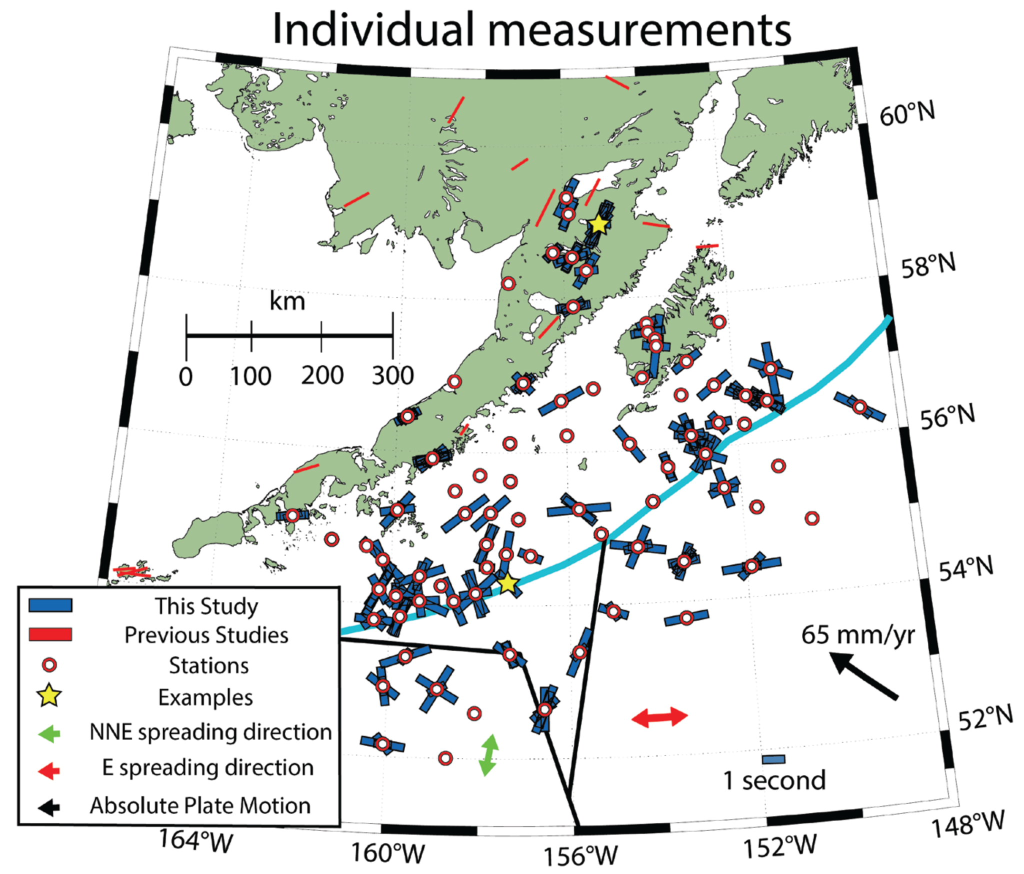


- Generally clear signals
- 79 SK(K)S measurements, 19 stations used
- All events considered

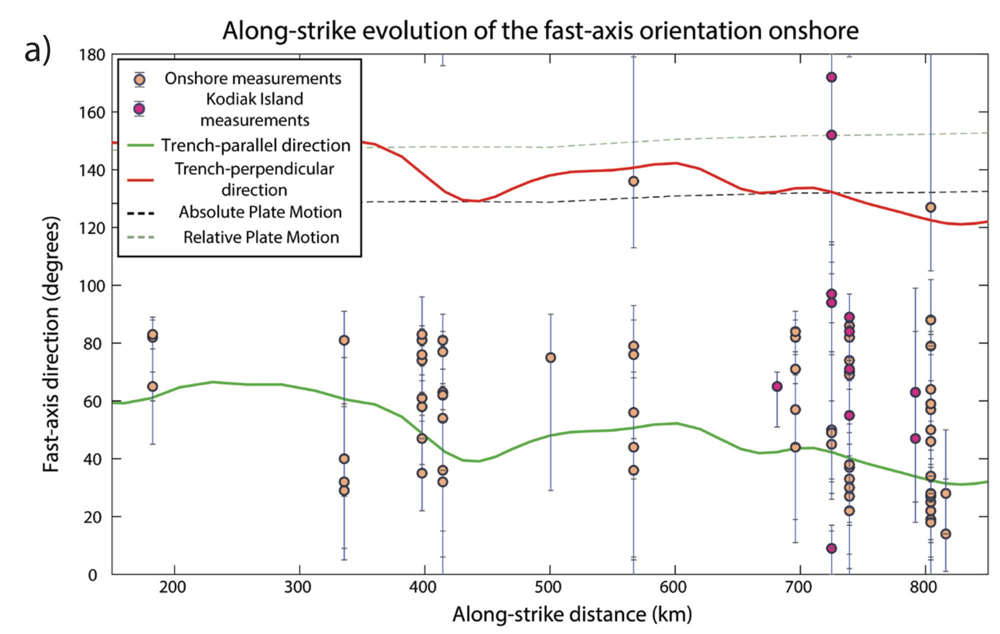


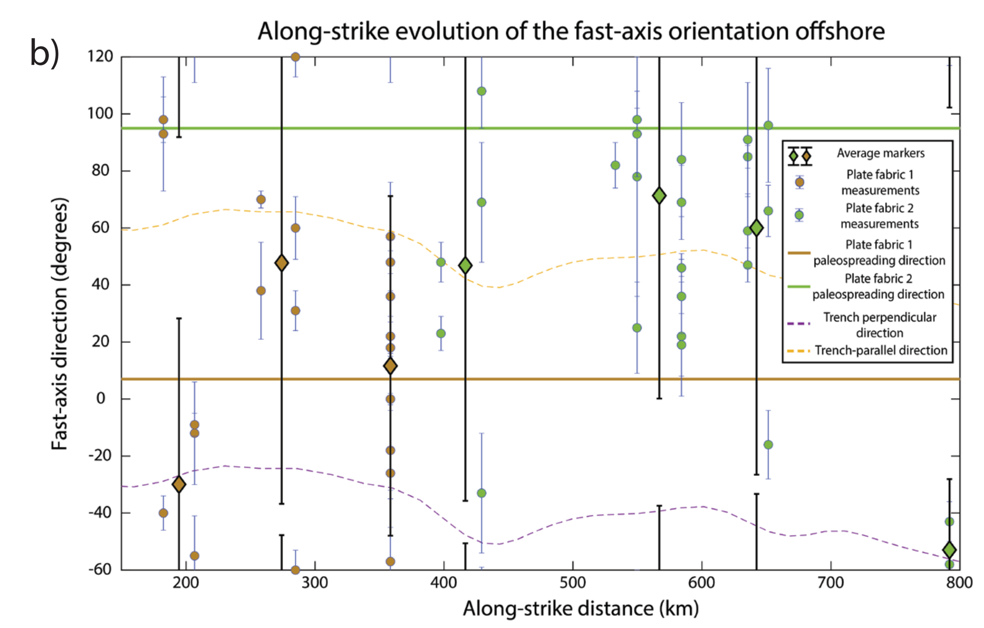
- Generally noisier signal w.r.t. onshore
- 105 SK(K)S measurements, 62 stations used, 1/3 of the stations no splitting information
- Only most seen events considered

Results



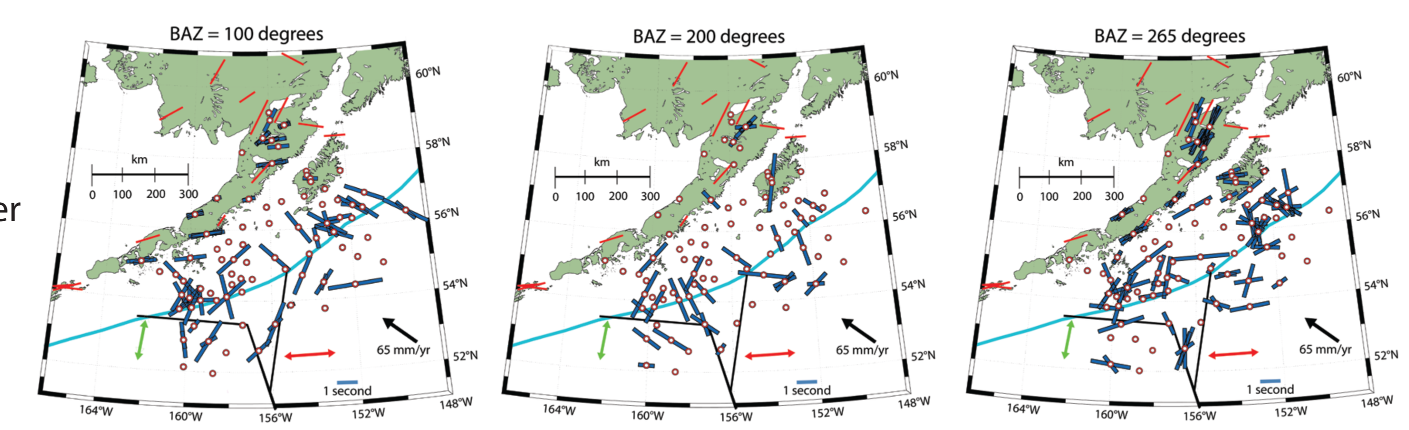
- Onshore:
  - Trench-subparallel fast-axis directions. (Plot a)
  - Average delay time of 1.10 s indicating sampling of the asthenosphere without significant contribution from the crust[10].
  - Knowing that the slab depth at the onshore stations is ~100 km[7] and assuming that the mantle wedge is the only contributor to the anisotropy signature, it would require ~5% of anisotropy in the mantle wedge[13].
- Offshore:
  - Average delay time = 1.70 s.
  - Assuming a single horizontal anisotropic layer with 4% anisotropy, it would be about 200 km thick[14].
  - Seaward of the trench :
    - Along-strike change in fast-axes transitioning with plate fabrics. (Plot b)
  - Shelf:
    - Trench-subperpendicular to the east.
    - Complex distribution to the west.





Backazimuthal variations:

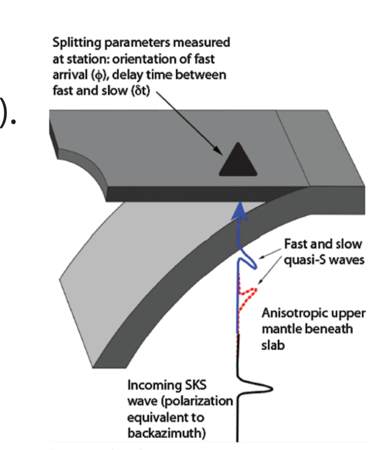
- ~90 degrees of difference in measurements to the west between BAZ ~100 degrees and the two other BAZ.
- Relatively consistent fast-axis directions onshore and to the east.



Methods

Shear wave splitting:

- Fast-axis direction (Φ) and delay time (δt) are measured for SKS and SKKS phases.
- Minimum transverse energy method[14].
- Null measurements are ignored (high SNR).
- Onshore: semi-automated grid search of splitting parameters (SplitRacer)[13].
- Offshore: grid search of the splitting parameters, user-defined filter and window (Splitlab)[17].



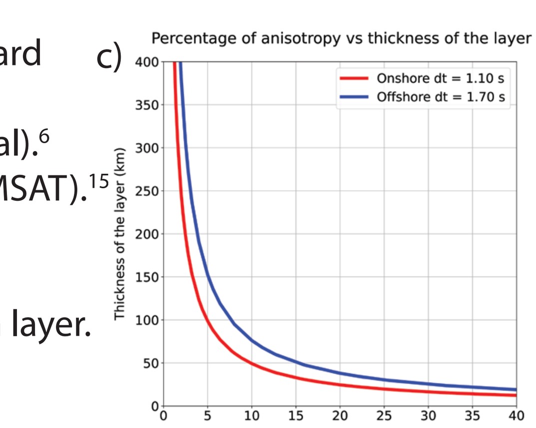
From Long (2016)

Filtering:

- Onshore: 4 - 33 s
- Offshore: 6 - 25 s (user-adjusted case-by-case)
- Orientations offshore (OBSIC): Rayleigh-wave polarization method[4].

Forward modeling:

- Multi-layer anisotropy based on (1) - (5).
- 4 regions: onshore, shelf, Eastward spreading center, North-Northeastward spreading center.
- Simplified elasticity tensor (hexagonal).[6]
- Solving of the Christoffel equation (MSAT).[15]

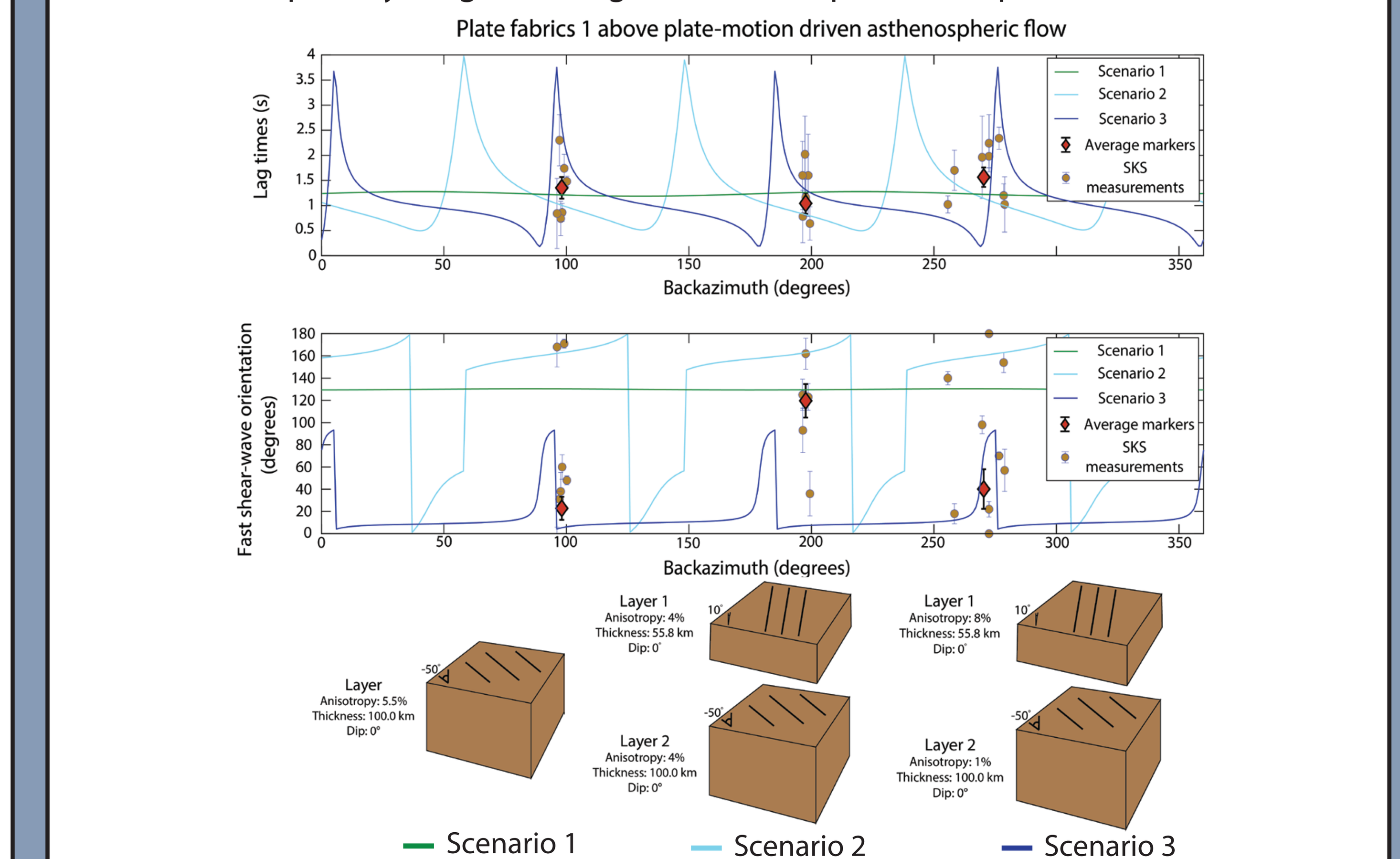


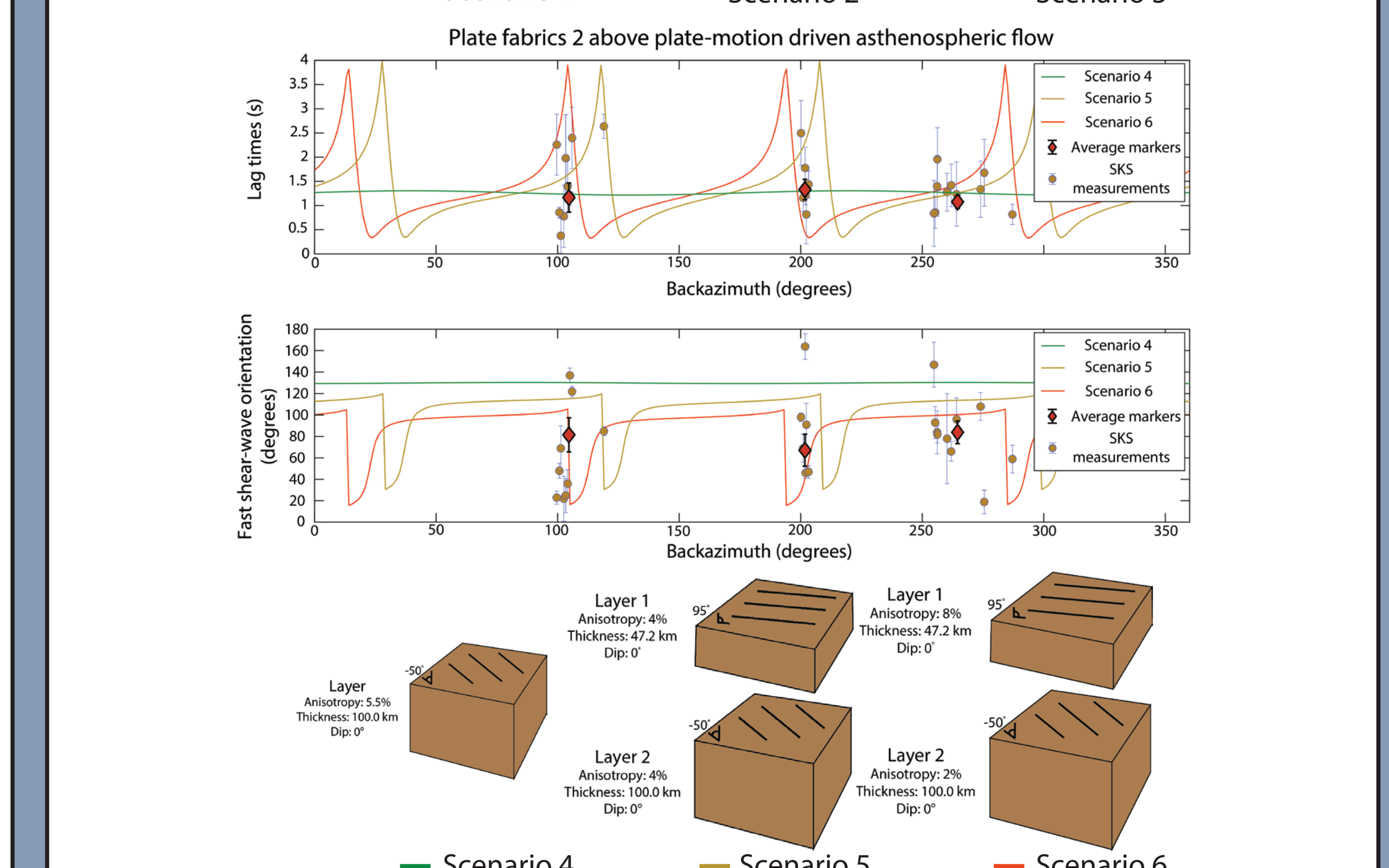
Assumptions:

- Uniform anisotropy throughout each layer.
- Anisotropy is allowed to dip.
- Mantle anisotropy.
- Percentage of anisotropy and thickness from c) when no external constraints.

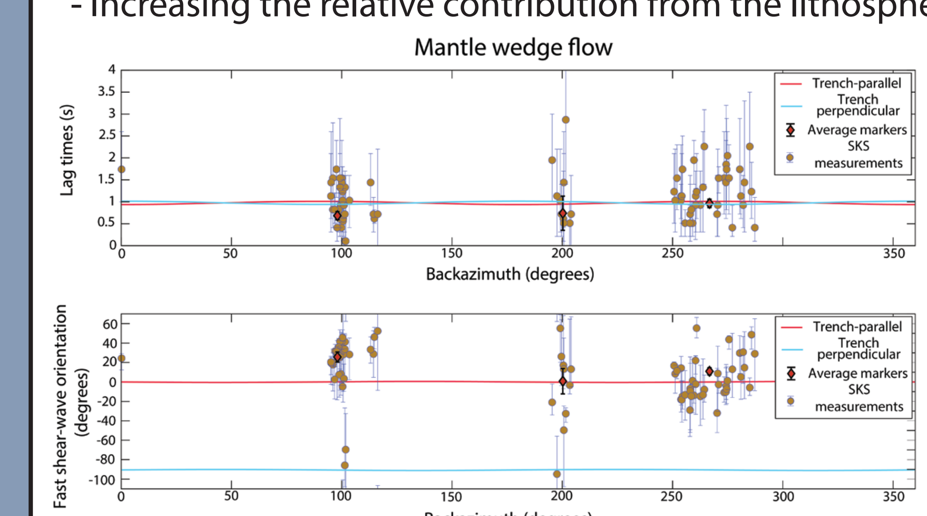
Discussion and Conclusions

Observations suggest multiple distinct anisotropic regions within the subduction zone and complex layering with a significant lithospheric component offshore.





- Increasing the relative contribution from the lithosphere increases the fit to the data.



- Anisotropy: 6.5%
- Thickness: 65 km
- Angles normalized to trench-parallel direction (i.e., trench-parallel = 0 degrees, trench-perpendicular = 90 degrees)

INTERPRETATIONS:

- The relative contribution of the oceanic lithosphere offshore has been underestimated. The lithosphere contributes to ~83% of the signal for plate fabrics 1 and the contribution of the lithosphere for plate fabrics 2 is ~66% of the signal.
- 2D corner flow only satisfies the observations if B-type olivine is considered.

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