V_P/V_S Structure of the Juan de Fuca Plate from Converted-Phase Tomography of the Ridge-to-Trench Dataset

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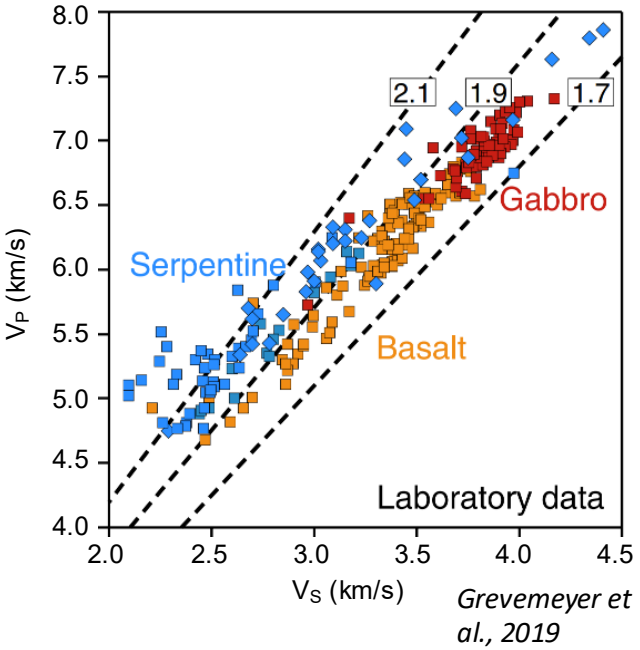
1 Why V_P/V_S ?

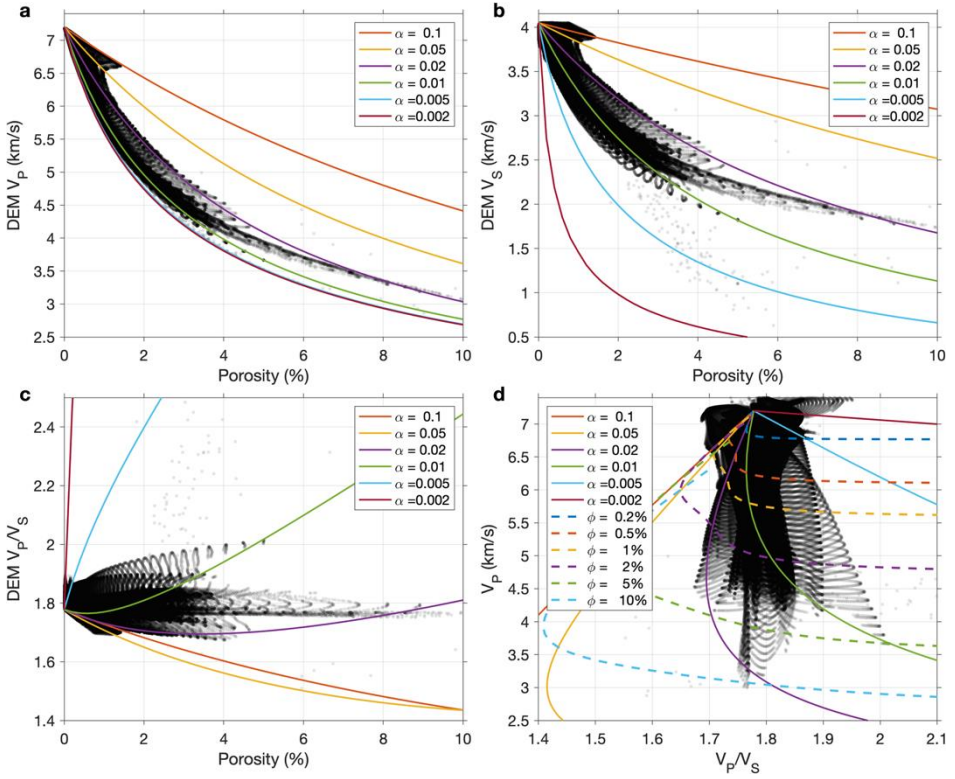
Using two modes of seismic velocities can help alleviate non-uniqueness in seismic interpretation!

Effect of lithology on seismic properties – overlapping of velocities from different lithologies if using a single mode of seismic wave

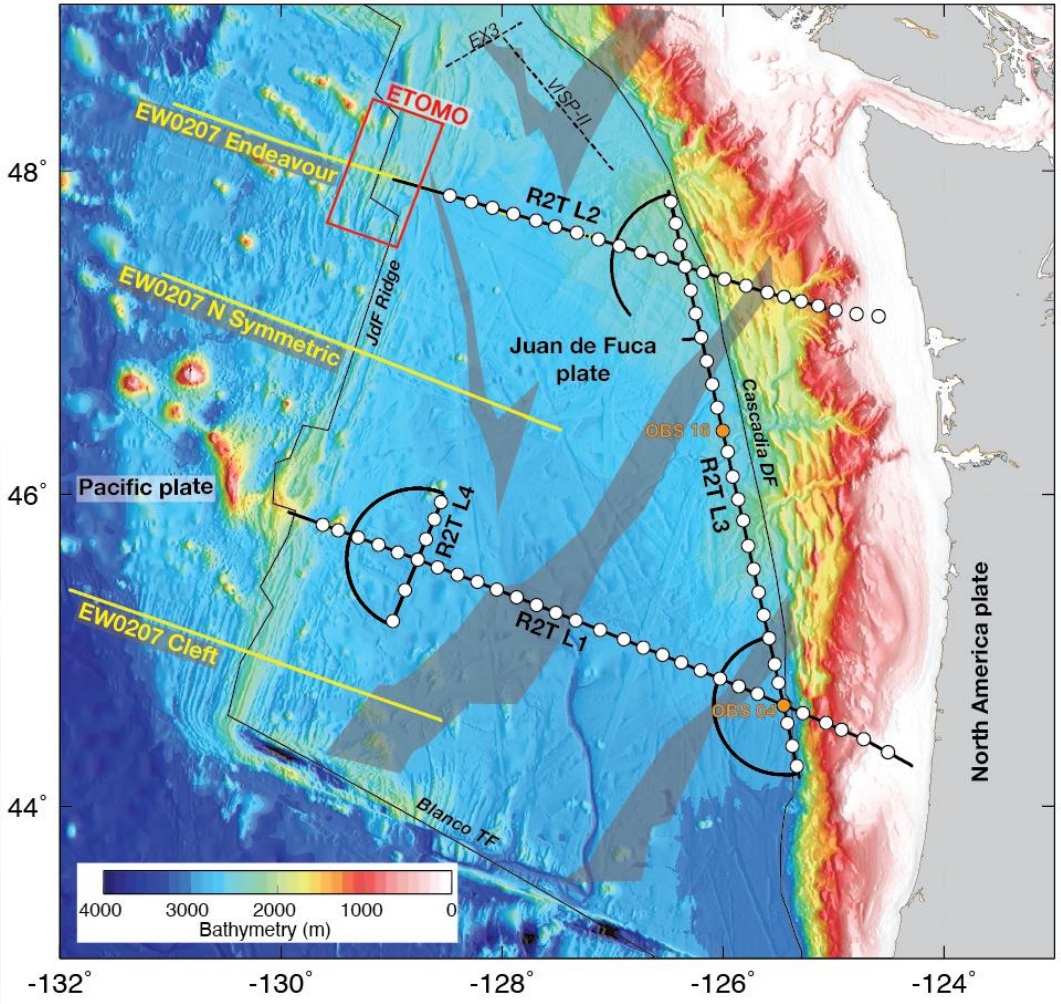


Grevemeyer et al., 2019

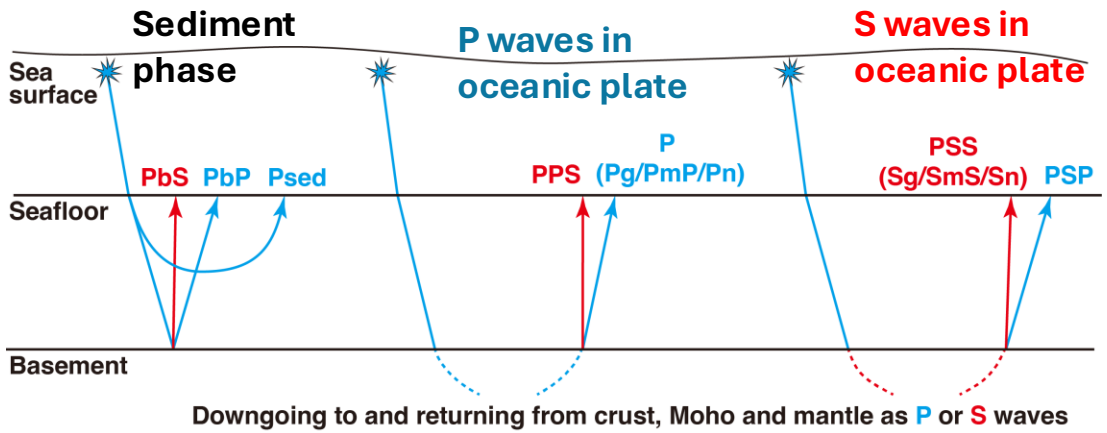
Effect of cracks on seismic properties – tradeoff between porosity and crack geometry



2 R2T data & converted phases



- Wave mode conversion occurs across basement.
- For crustal and mantle phases, P and PSS are used in the tomography, whereas PPS and PSP are excluded due to the redundance of information.



Phase group	P	PPS	PSS	PSP
Sediment refraction	**Psed**	N/A	N/A	N/A
Basement reflection	**PbP**	**PbS**	**PbS**	**PbP**
Crustal refraction	**Pg**	PgS	**[P]Sg**	[P]SgP
Moho reflection	**PmP**	PmPS	**[P]SmS**	[P]SmSP
Mantle refraction	**Pn**	PnS	**[P]Sn**	[P]SnP

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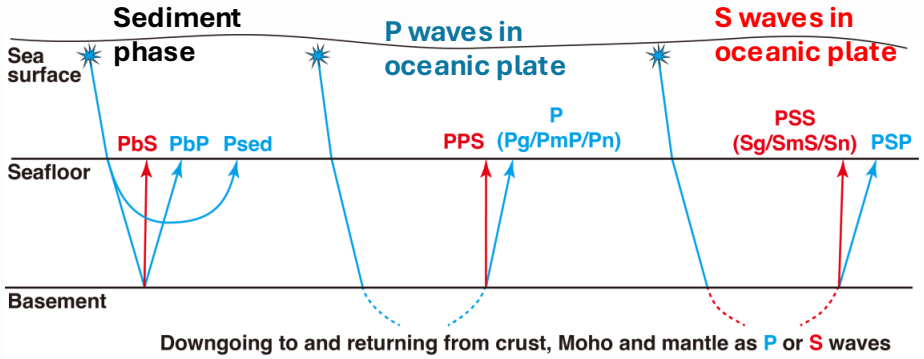

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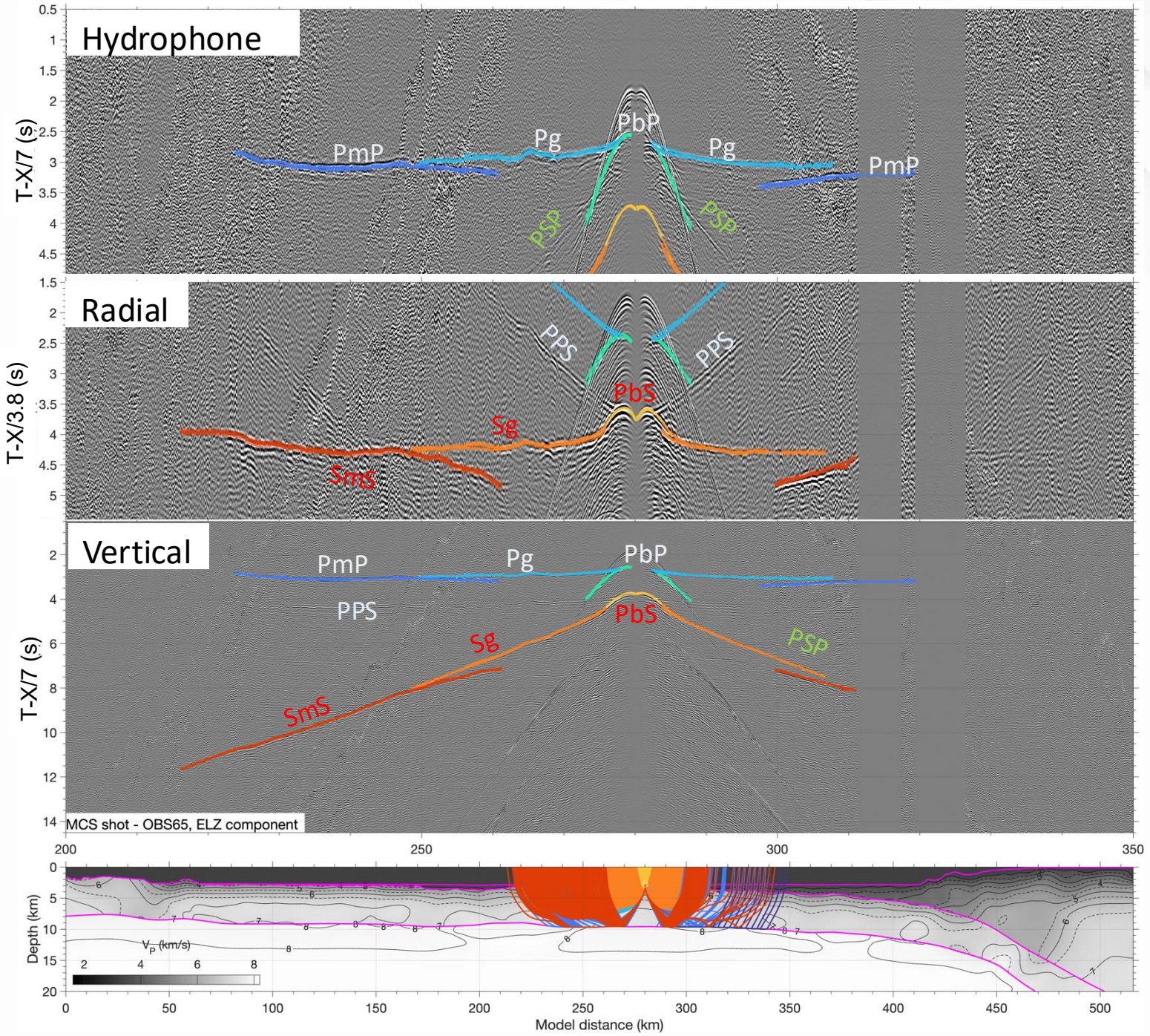
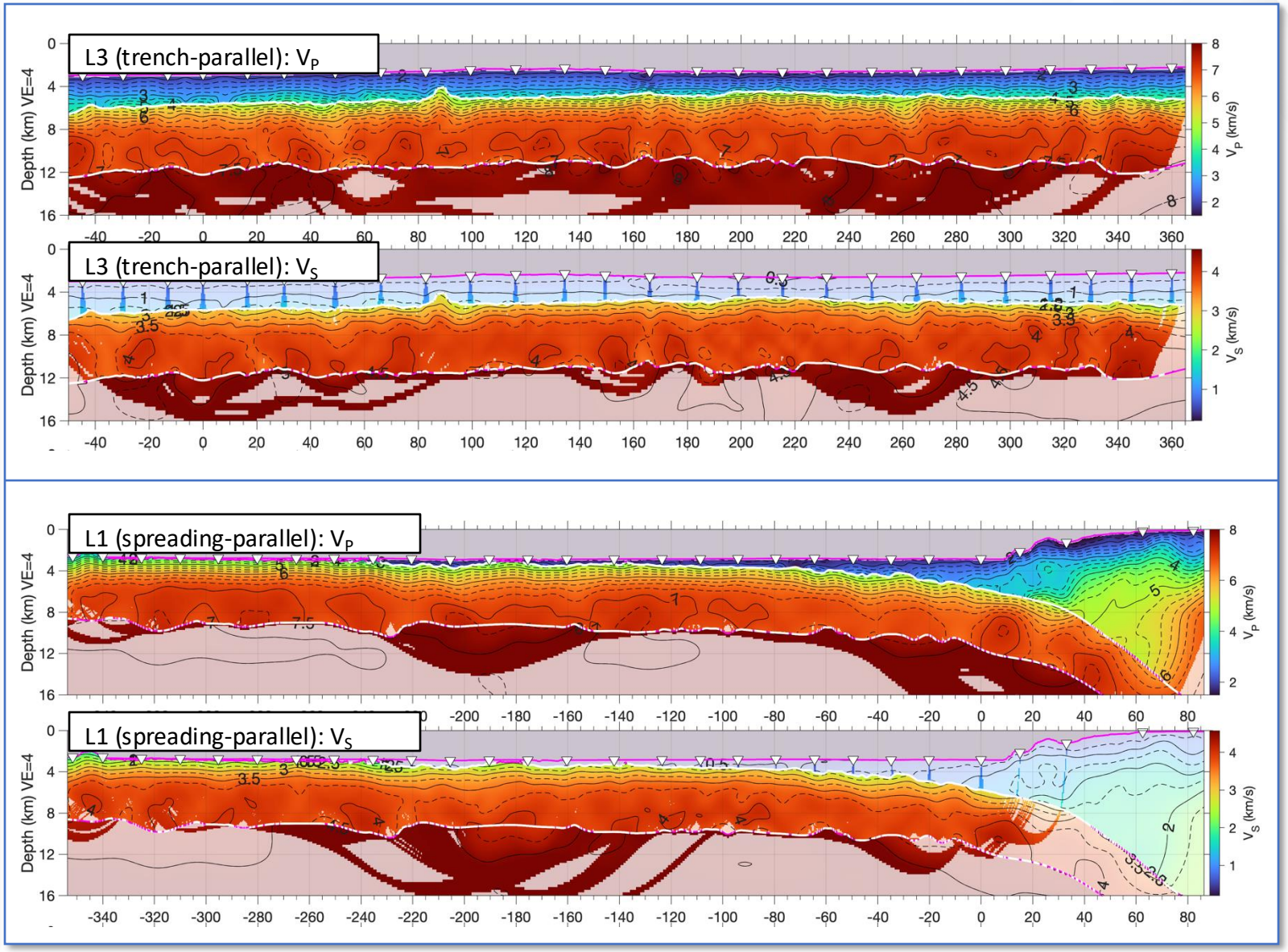


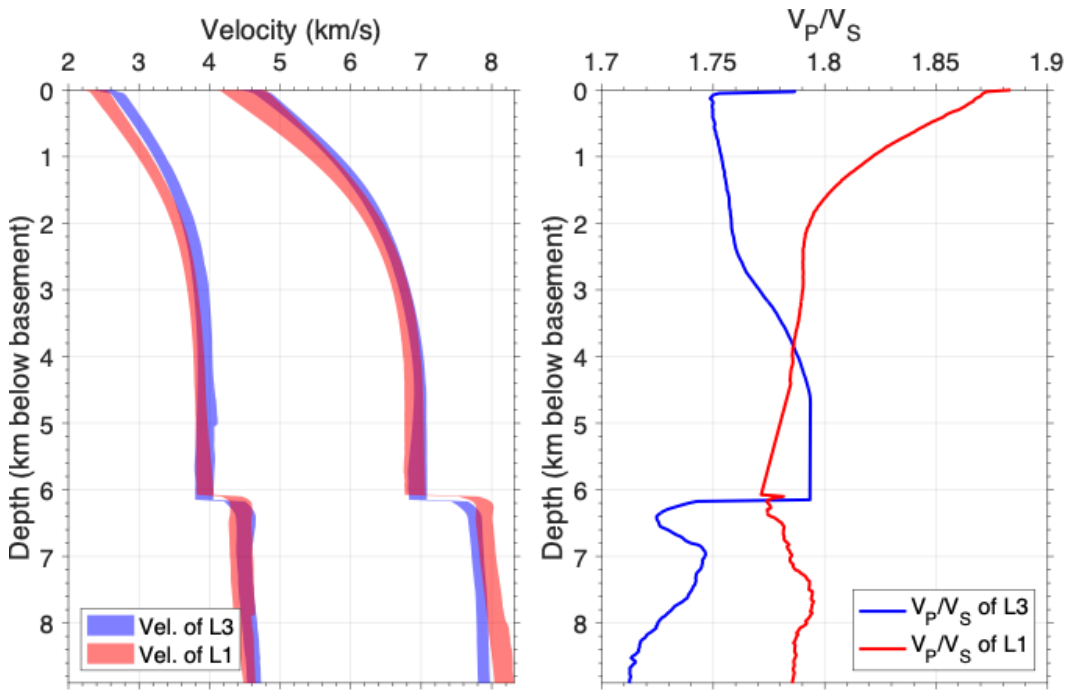
3 Joint V_P & V_S tomography

- Forward modeling: direct modeling of **all mode conversions through arbitrary interfaces** by extending the shortest path method (*Van Avendonk et al., 2004*).
  - In this case, it allows ray tracing through sediment as P and S waves in downgoing and upgoing branches.
- Inversion:
  - Simultaneous inversion of V_P, V_S and interface depth structure.
  - Optional regularization constraints on V_P and V_S structure coupling, such as damping and smoothing on V_P/V_S variations and cross-gradient coupling between V_P and V_S.
- V_S structure in sediment and upper plate is not well constrained due to lack of rays turning inside them!

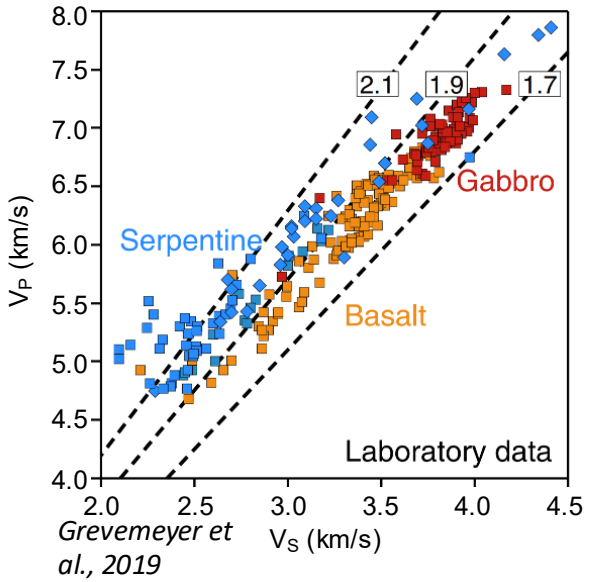


4 Results: average model & depth dependence

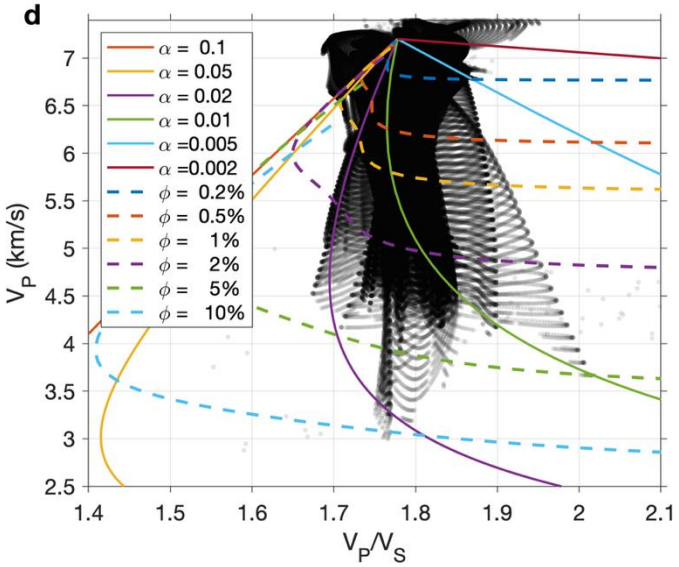
- Most V_P/V_S values are within 1.7 and 1.82.



- No significant serpentinization is required.
- Most variations can be explained by porosity variations.



Grevemeyer et al., 2019



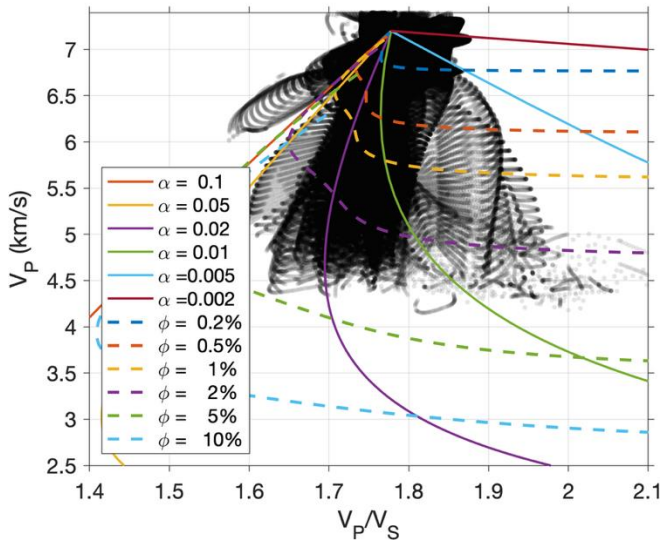
4 Results: crustal hydration along L3

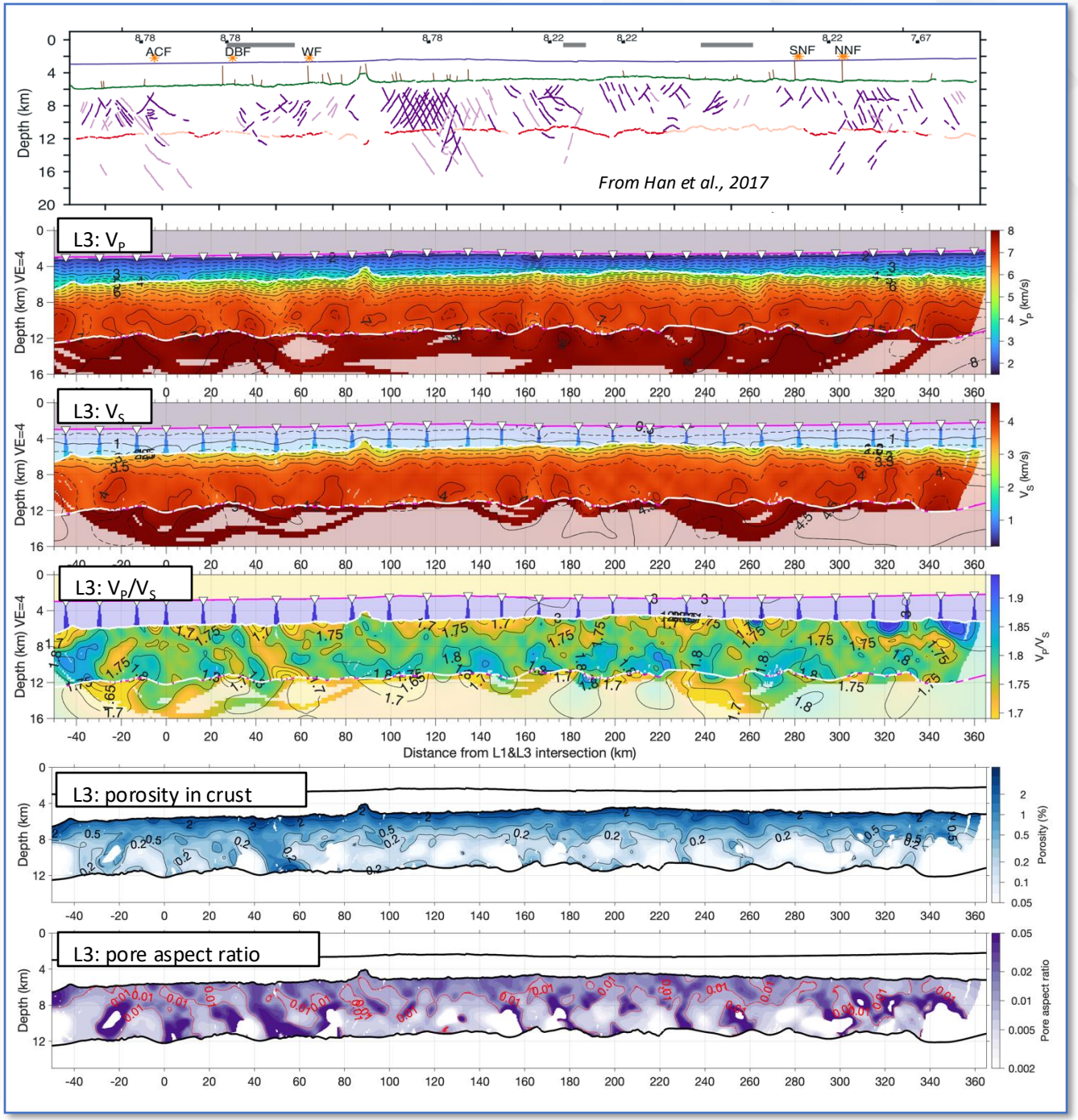
- Assumptions for the porosity calculation
  - No considerations of alteration products or structurally bound water.
  - Assuming only seawater-filled cracks, which can be represented by a single value of effective pore aspect ratio.

- Within the reasonable range of aspect ratio and **low porosities**:

1. Thin cracks cause increased V_P/V_S ratios.

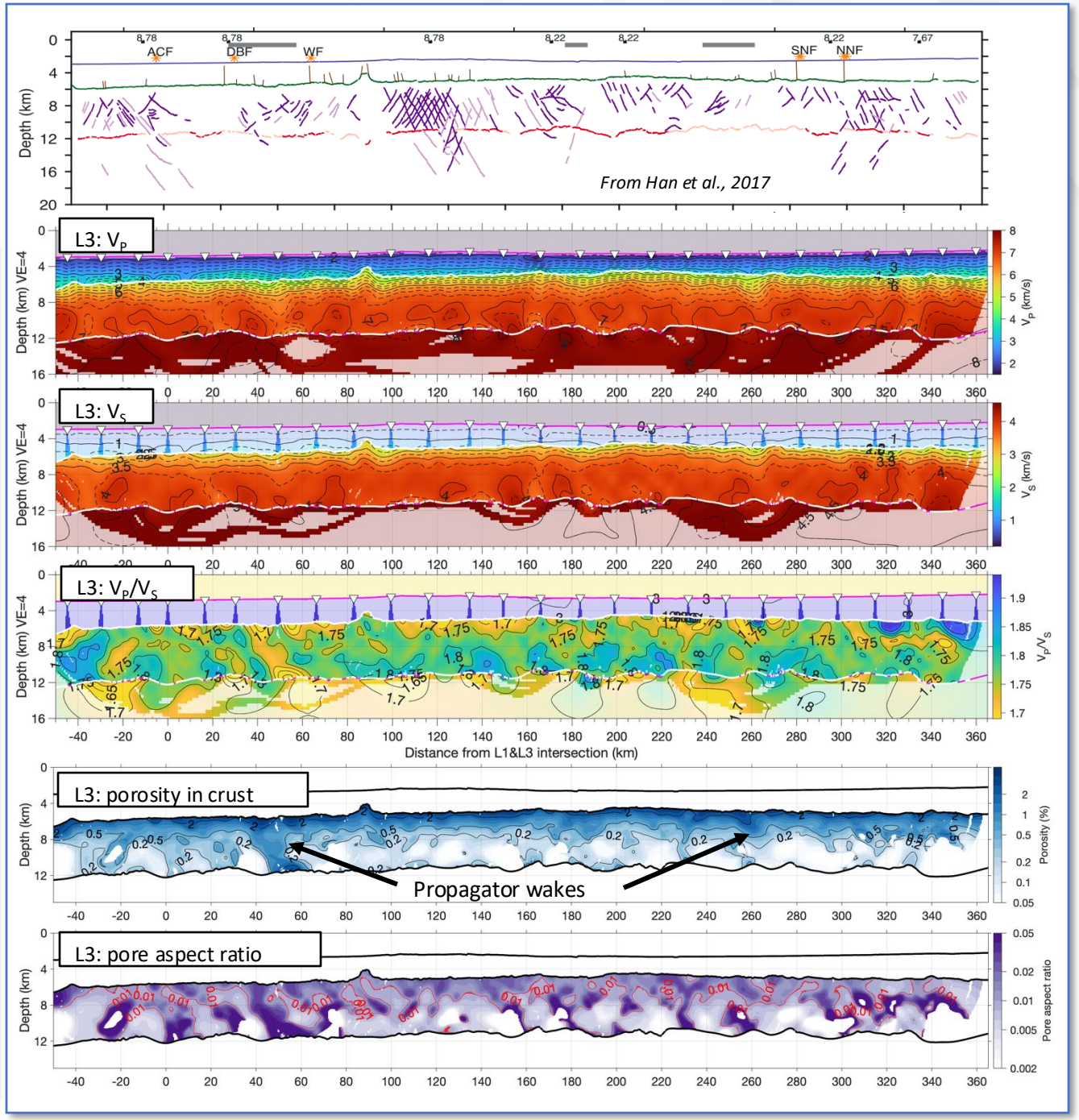
2. Thick cracks may cause decreased V_P/V_S ratios.





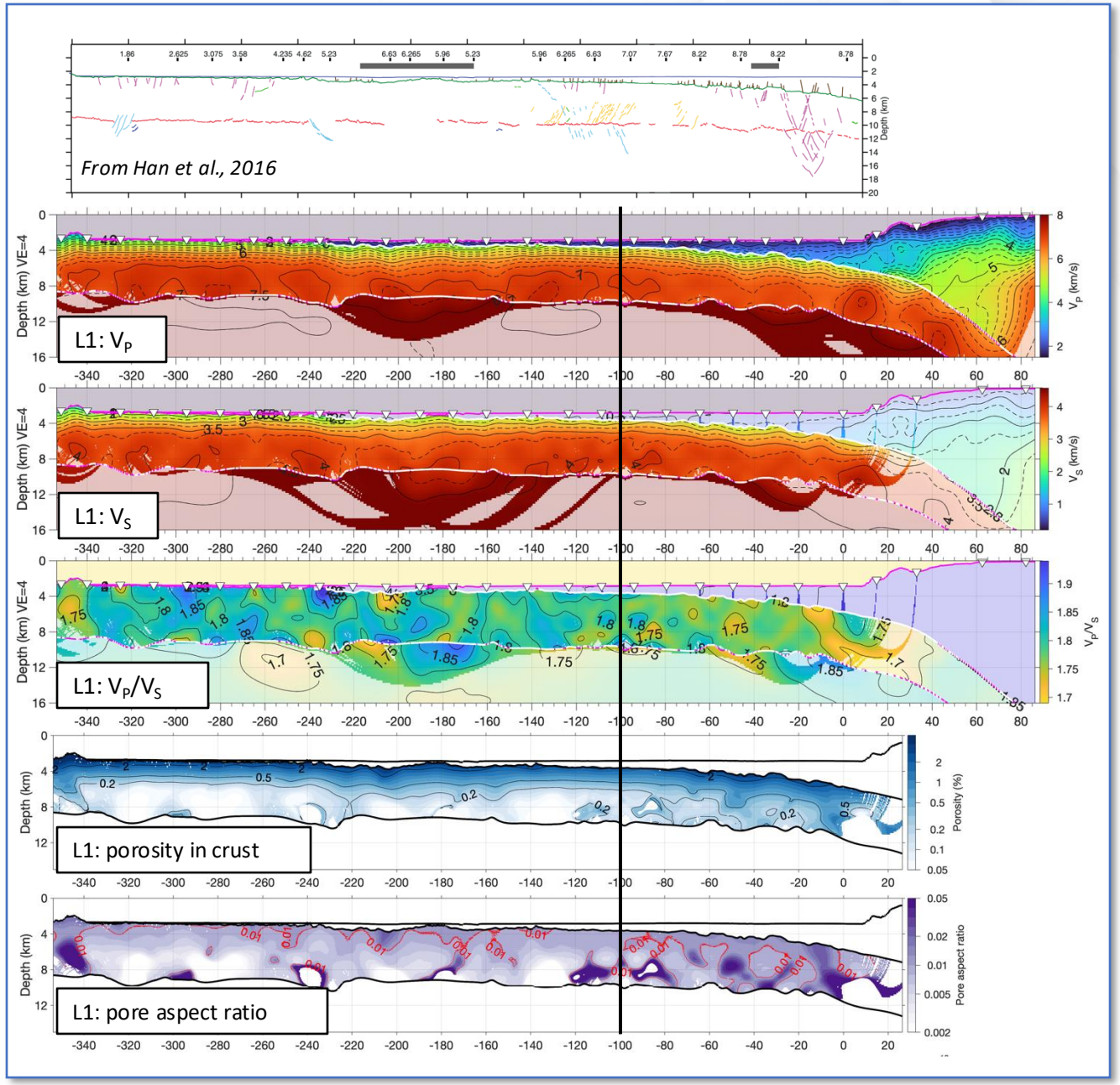
4 Results: crustal hydration along L3

- Crustal porosity is low: 0.2-2% in upper crust and <0.2% in lower crust.
- Both V_P and V_P/V_S values suggest the absence of serpentinization in mantle.
- Localized hydration anomalies are related to propagator wakes.
- Dry Juan de Fuca plate as indicated in earlier study using P-wave tomography results (*Canales et al., 2017*).



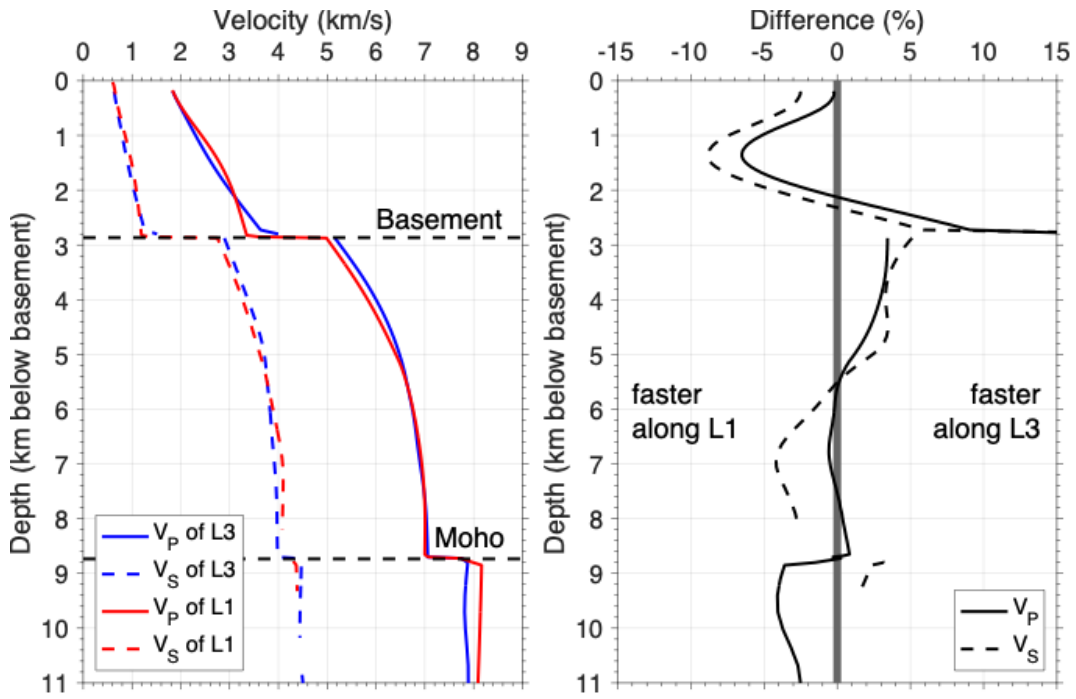
4 Results: evolution from ridge to trench along L1

- A large propagator wake caused localized hydration anomaly in both crust and uppermost mantle.
- At >100 km away from the deformation front, aging of oceanic crust dominates:
  - Velocities increase with age in upper crust
  - V_P/V_S and porosity decrease with age
  - Suggest filling of cracks by hydrothermal deposits.
- With 100 km from the deformation front, bend faulting may dominate:
  - Velocities decrease and porosity increases in whole crust as approaching the wedge.
  - Localized mantle serpentinization.
  - Decreasing V_P/V_S ratio and increasing pore aspect ratio may suggest thickening of subvertical crustal cracks under horizontal tensional stress.

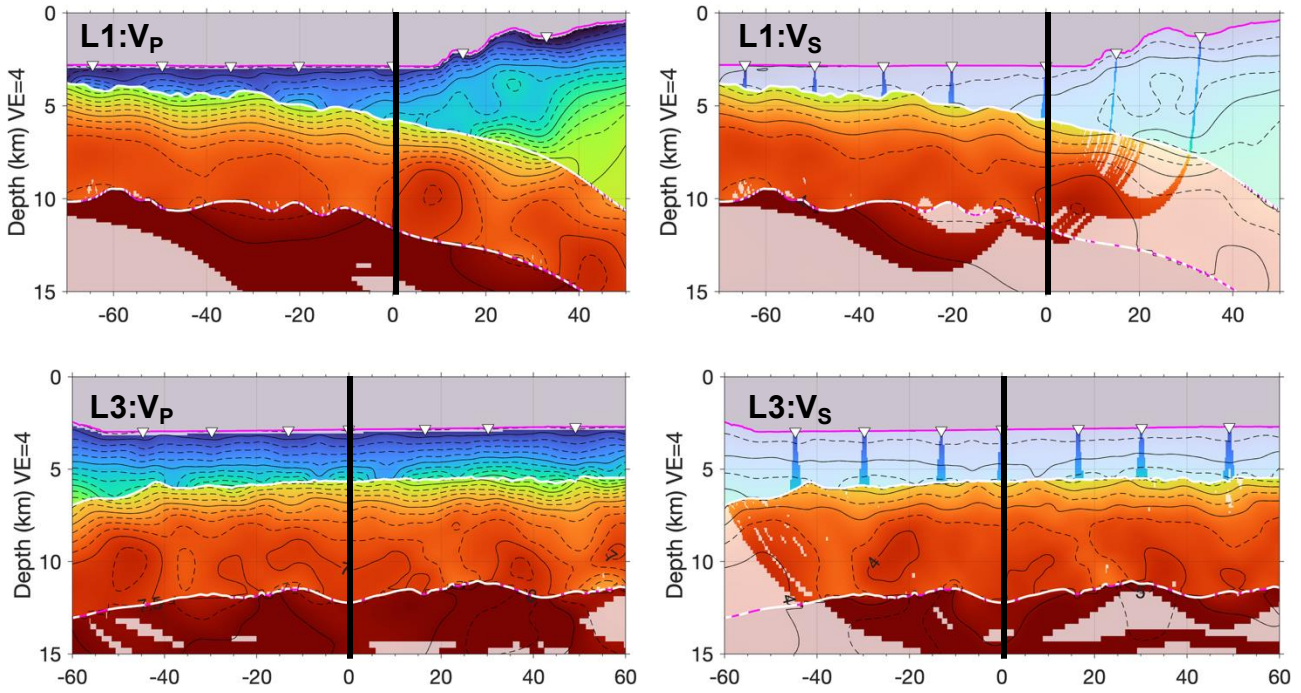


4 Results: anisotropy at intersection of L1 & L3

- Upper crustal anisotropy is consistent with the effect of ridge-parallel fractures.



- Lower crust is locally too heterogeneous along L1.



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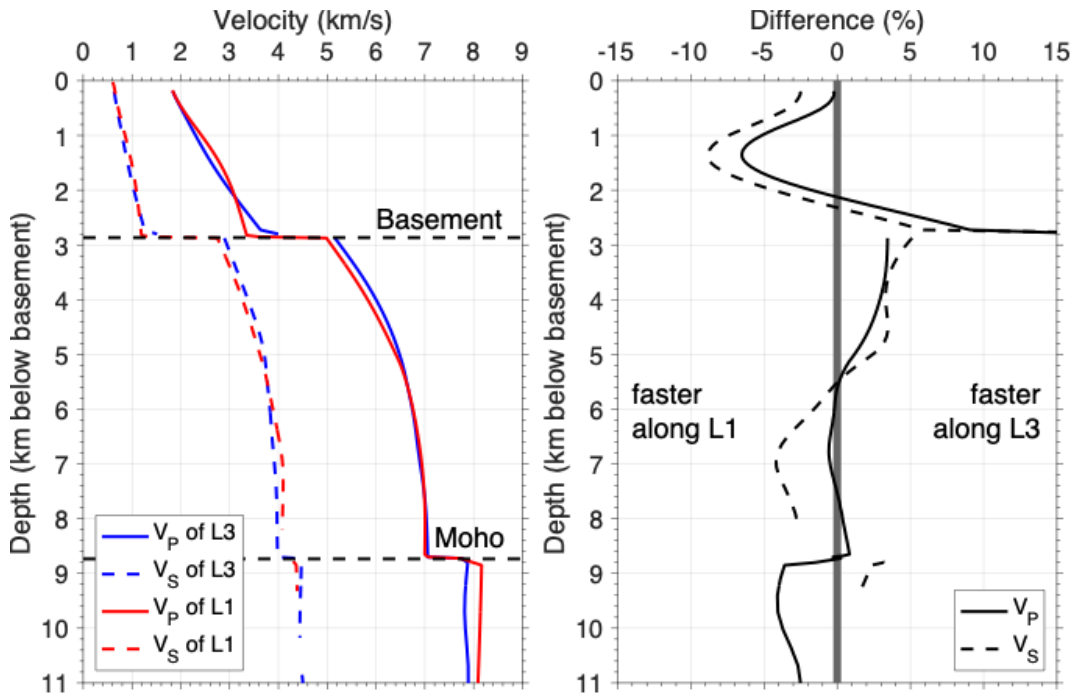
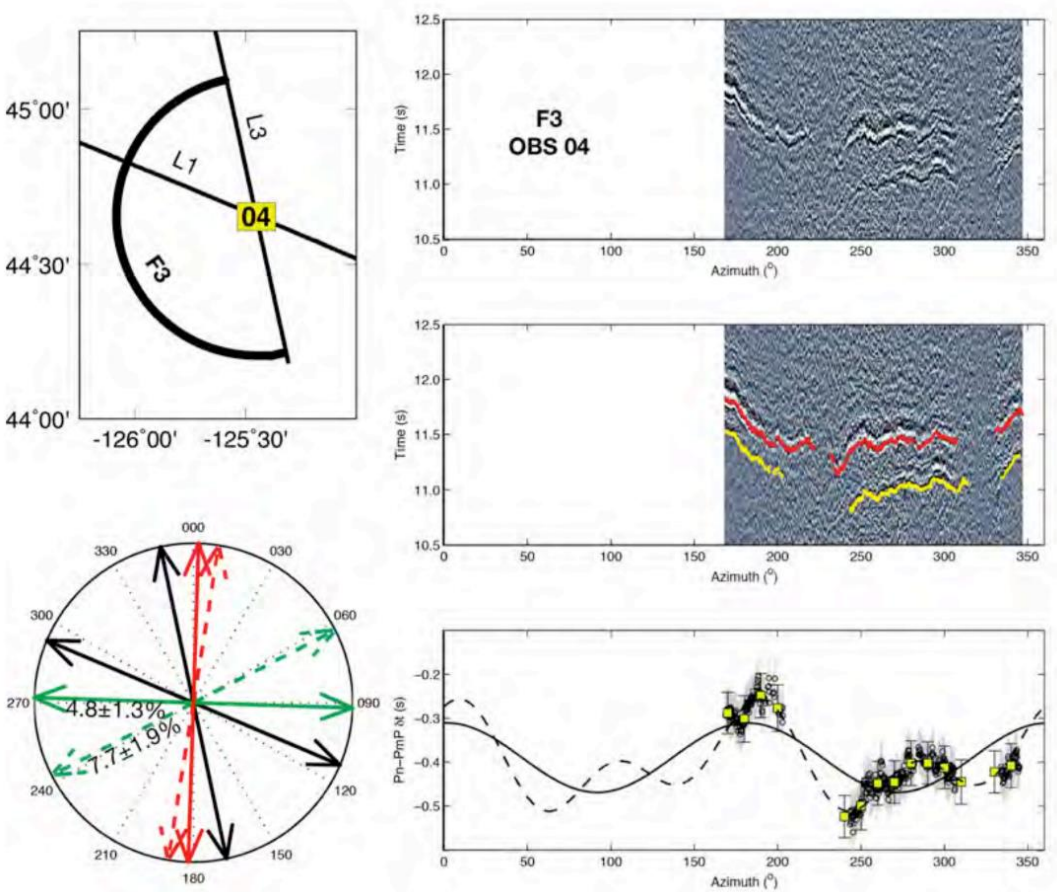
- Upper mantle V_P is faster along L1 by ~4%, consistent with Pn wave analysis.
- Upper mantle V_S is less constrained by our model.



- Pn wave anisotropy (*Canales et al., 2017*)



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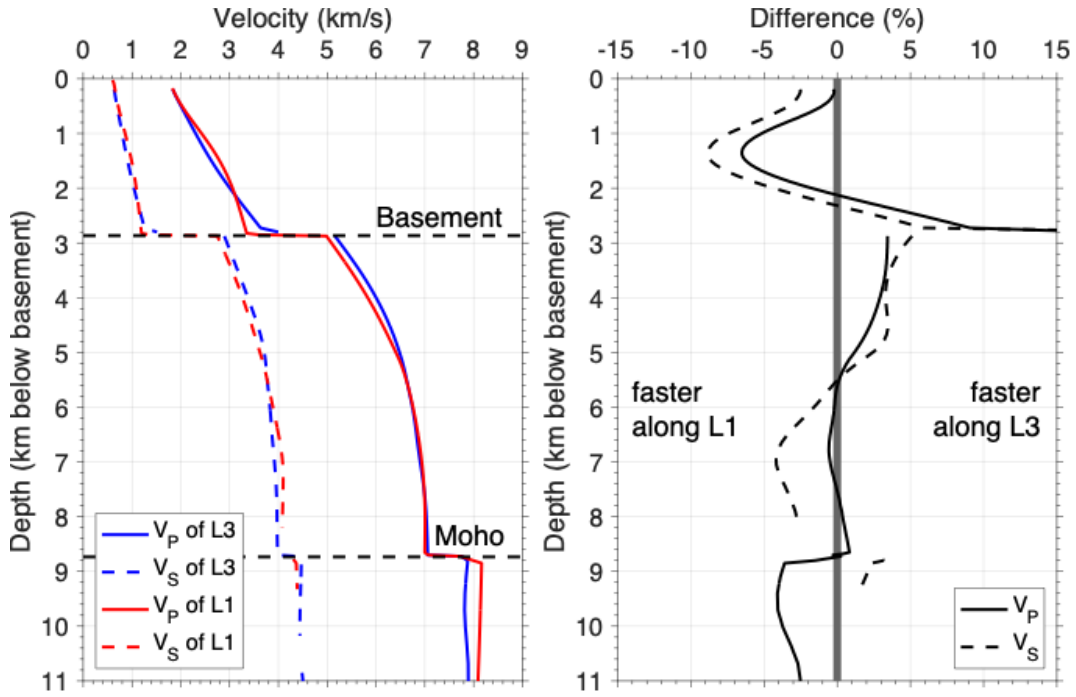
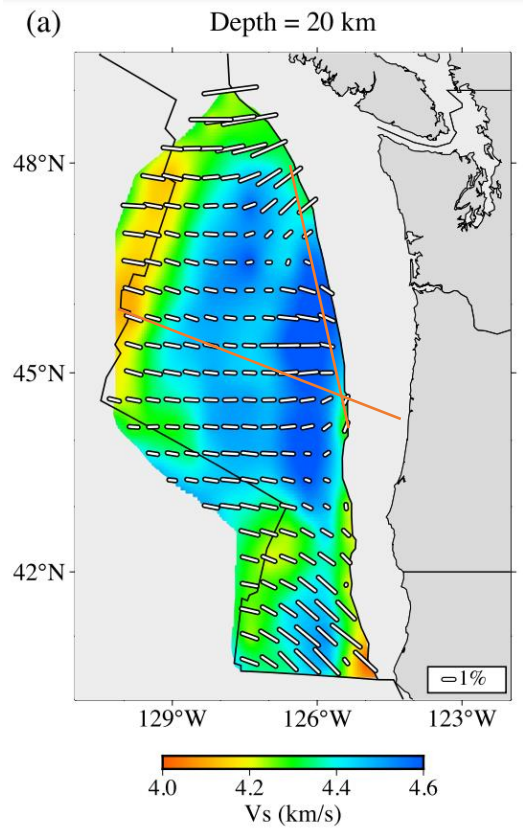
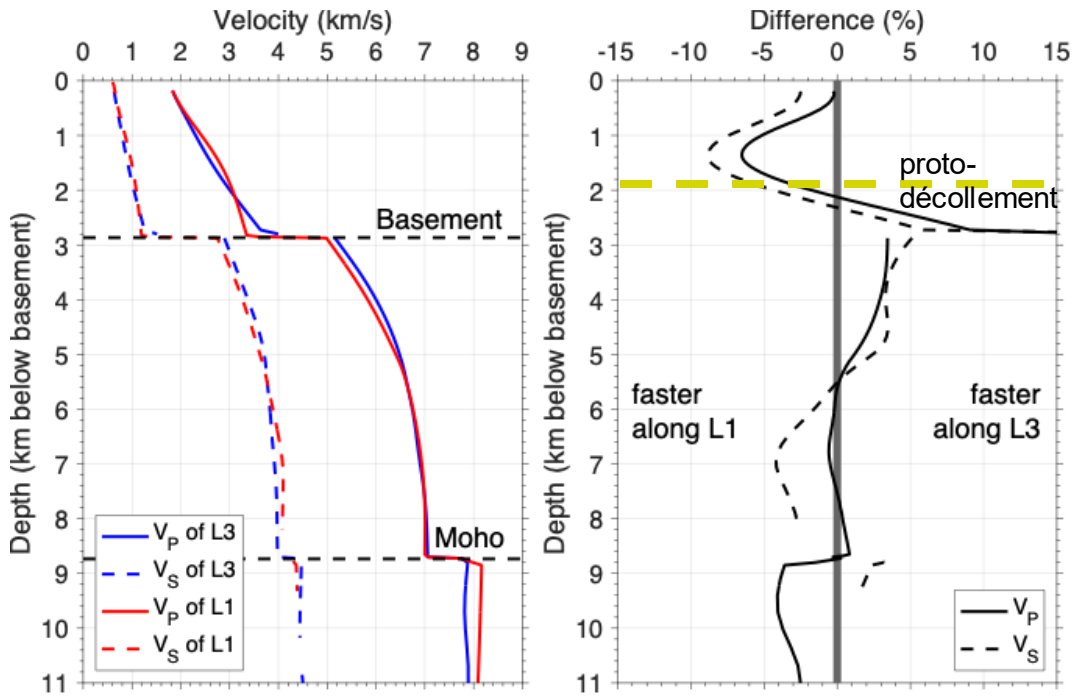


- S wave anisotropy in upper 20 km of lithosphere from surface wave tomography (*Liu et al., 2014)*

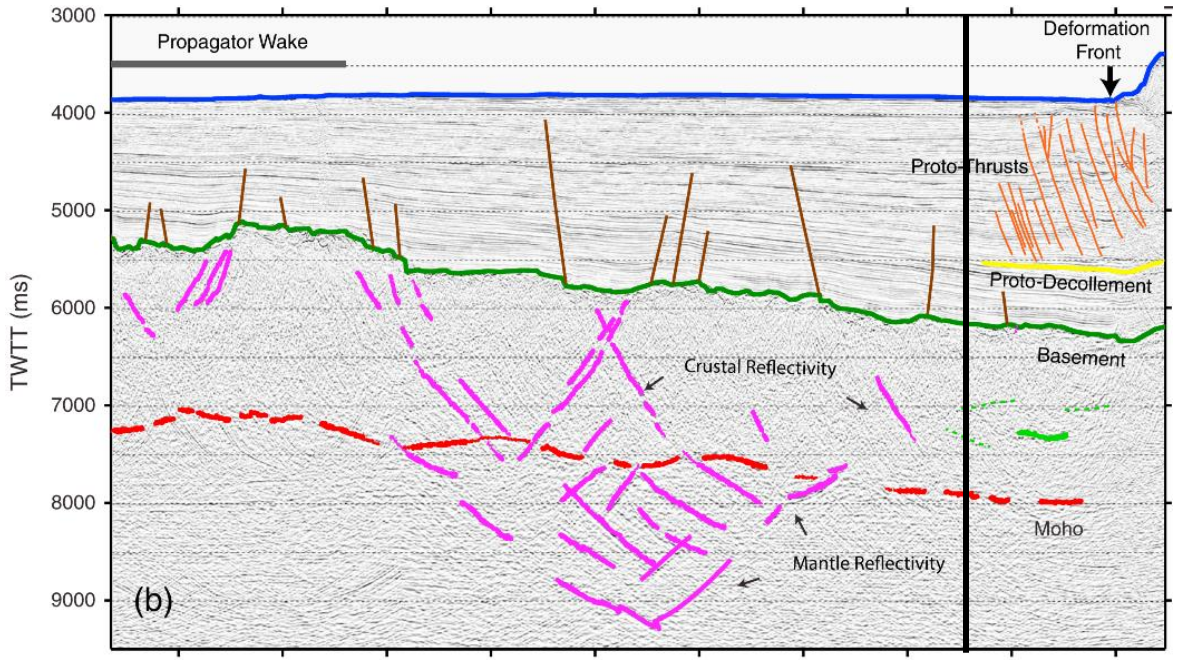


4 Results: anisotropy at intersection of L1 & L3

- Different faster direction across the proto-décollement.



- PSDM image and interpretations (*Han et al., 2017*)



5 Summary

- We extended a tomography code for joint V_P and V_S tomography, which can model arbitrary mode conversions and simultaneously invert for velocity and depth model parameters.
- Juan de Fuca plate is dry!
- Aging of oceanic crust dominates at >100 km away from the deformation front, causing increase in velocities and decrease in porosities and V_P/V_S ratios with age, which are the effect of crack filling by hydrothermal deposits.
- Within 100 km from the deformation front, bend faulting dominates, causing decrease in velocities and increase in porosities, but further decreasing V_P/V_S ratios, which may indicate crack opening under tensional stress.

Acknowledgement:

We gratefully acknowledge the support of the NSF grant.

Thank you for your attention!

Any questions or thoughts?

Feel free to contact us:

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3 Advantage of modeling arbitrary mode conversions

Methods by modeling all sediment wave propagation as P waves and applying correction to approximate upgoing S wave propagation through sediment have been applied. This method may introduce inaccuracies:

- The error (10s of ms) is acceptable when basement relief is small, and sediment is relatively thin and low-velocity beneath both shot and receivers.
- Otherwise, the error is significant (100s of ms).
- Direct ray tracing of phase conversions is essential for high-resolution tomography around subduction zones.