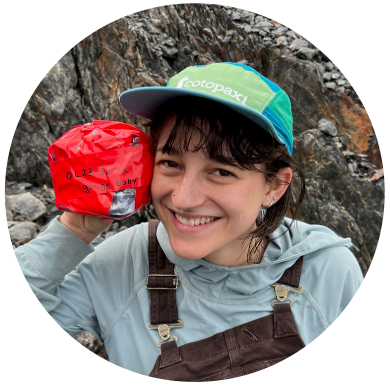
New observations and shifting paradigms for Cascadia megathrust and splay faults



Anna Ledeczi

Harold Tobin
University of Washington

with
Suzanne Carbotte (LDEO), Anna Ledeczi (UW), Madeleine Lucas (UW), Janet Watt (USGS), and others

Madeleine Lucas

Fault Structure Stress & Tectonics at UW

FaSST

Cascadia CoPes Hub
THE CASCADIA COASTLINES AND PEOPLES HAZARDS RESEARCH HUB

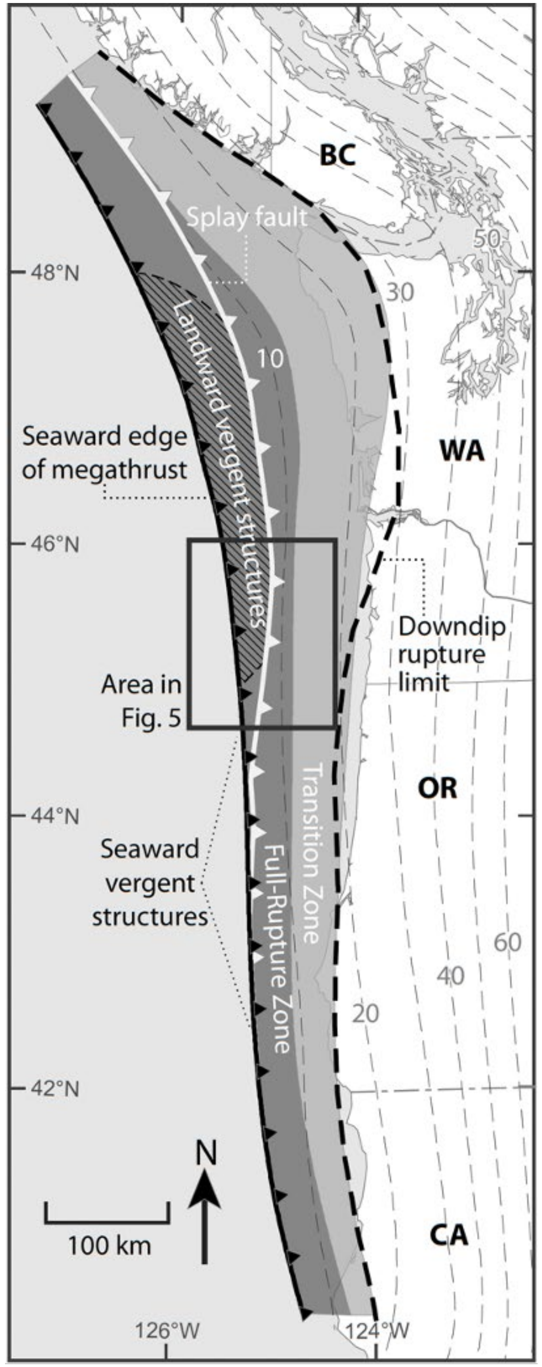
CRESCENT
CASCADIA REGION EARTHQUAKE SCIENCE CENTER

USGS
science for a changing world

NSF

Cascadia tsunami source models should be informed by geologic knowledge

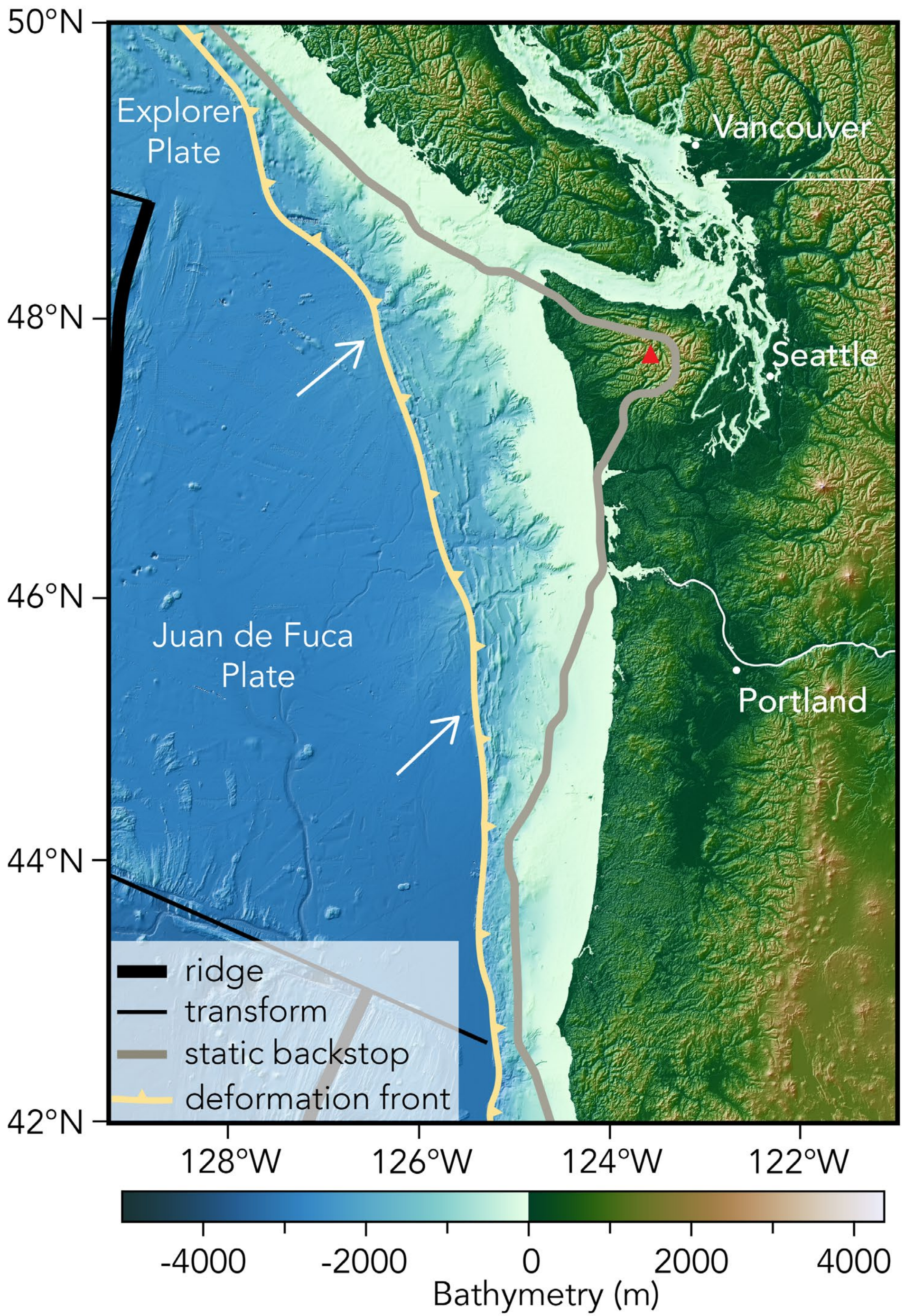
- Using geophysical observations at multiple scales, we map strain accumulation & fault zone structure, and infer fault properties
- Probabilistic approaches to tsunami source models require logic trees and weighting factors – *what is more or less likely to occur?*

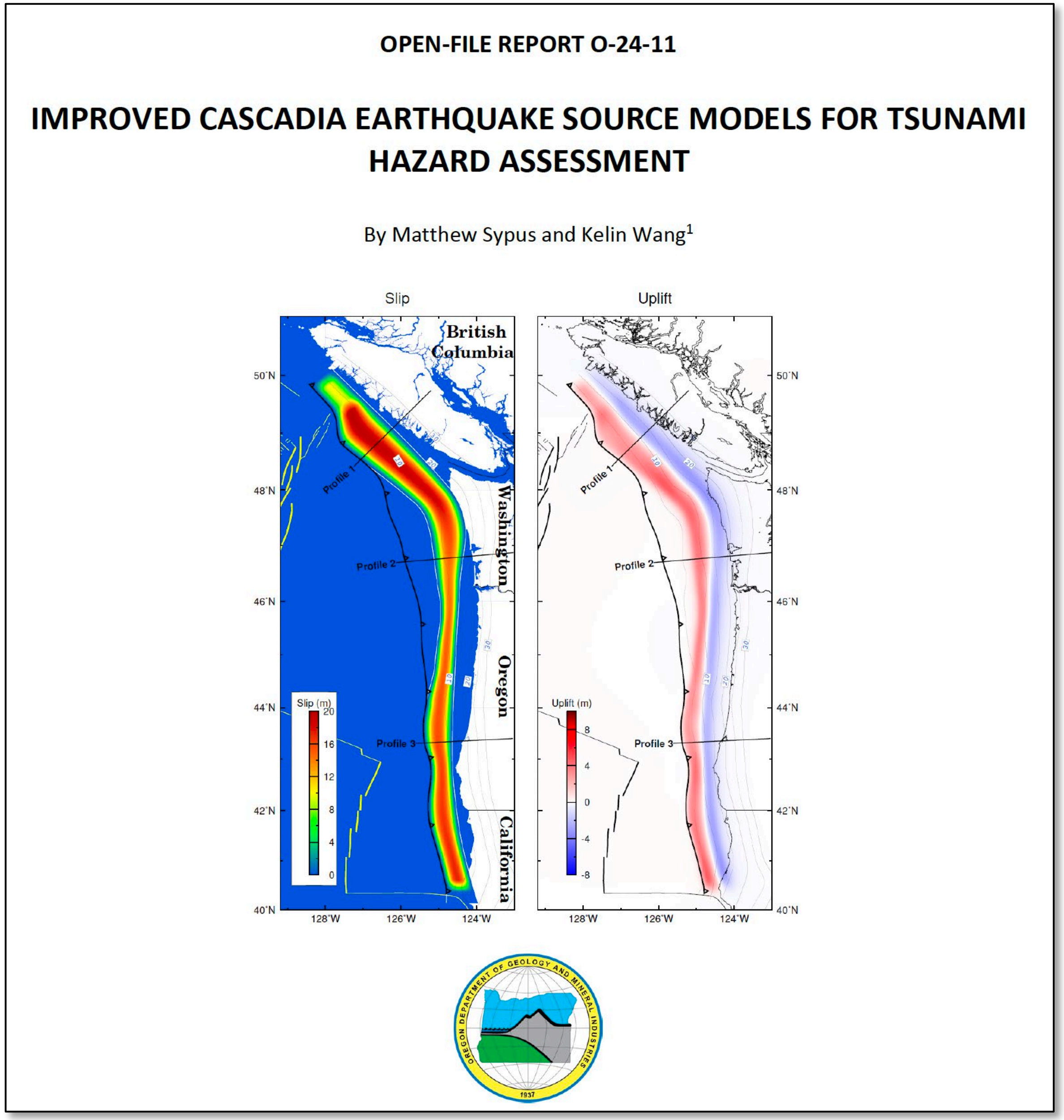


Witter et al. (2013)

3 key topics today:

- Geometry and nature of the plate interface fault in the zone of locking and likely coseismic rupture
- Evidence against a throughgoing mega-splay fault system
- Evidence for recent slip to the surface on numerous active shallow splay faults

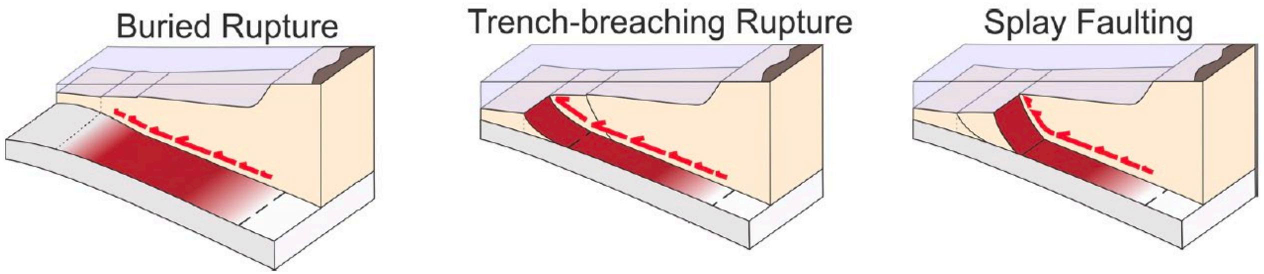



OPEN-FILE REPORT O-24-11

IMPROVED CASCADIA EARTHQUAKE SOURCE MODELS FOR TSUNAMI HAZARD ASSESSMENT

By Matthew Sypus and Kelin Wang[1]

New source models for PTHA
October, 2024

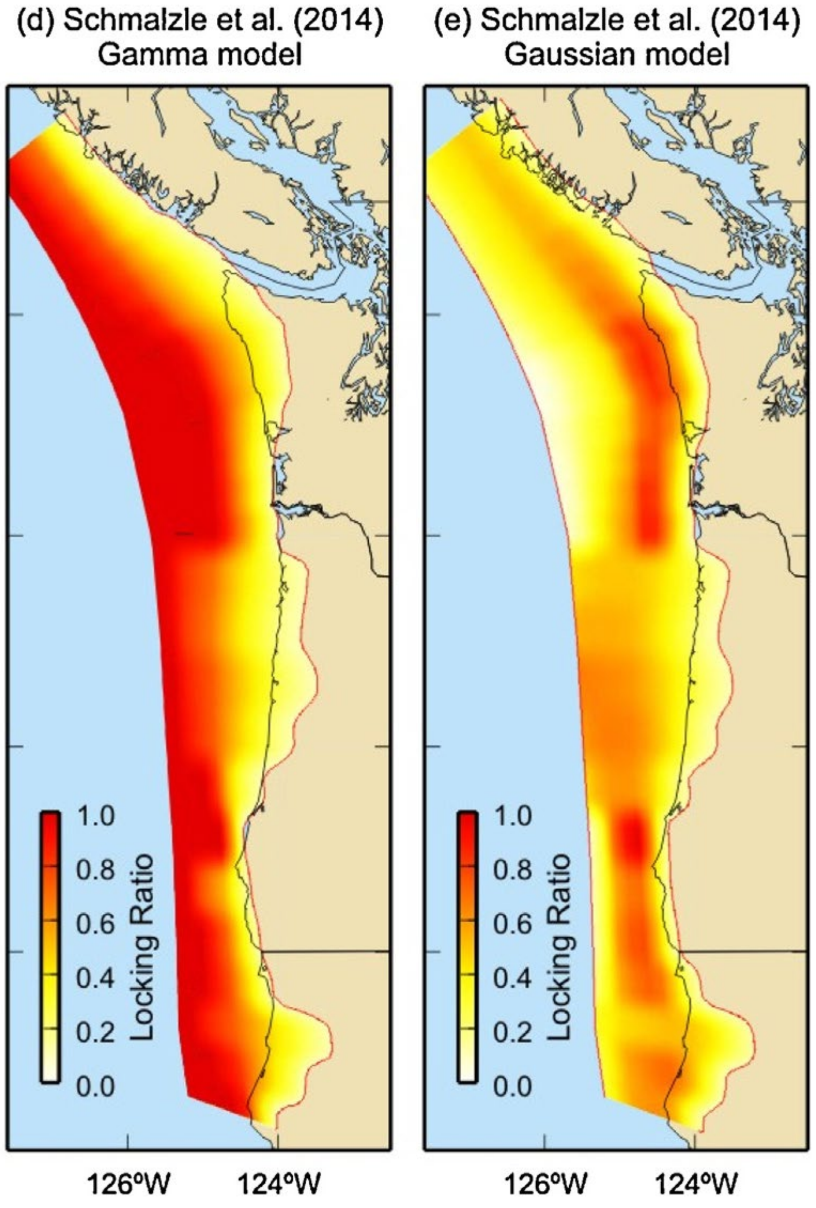


New work presented here was used as input to these source model geometries and to the logic tree weighting

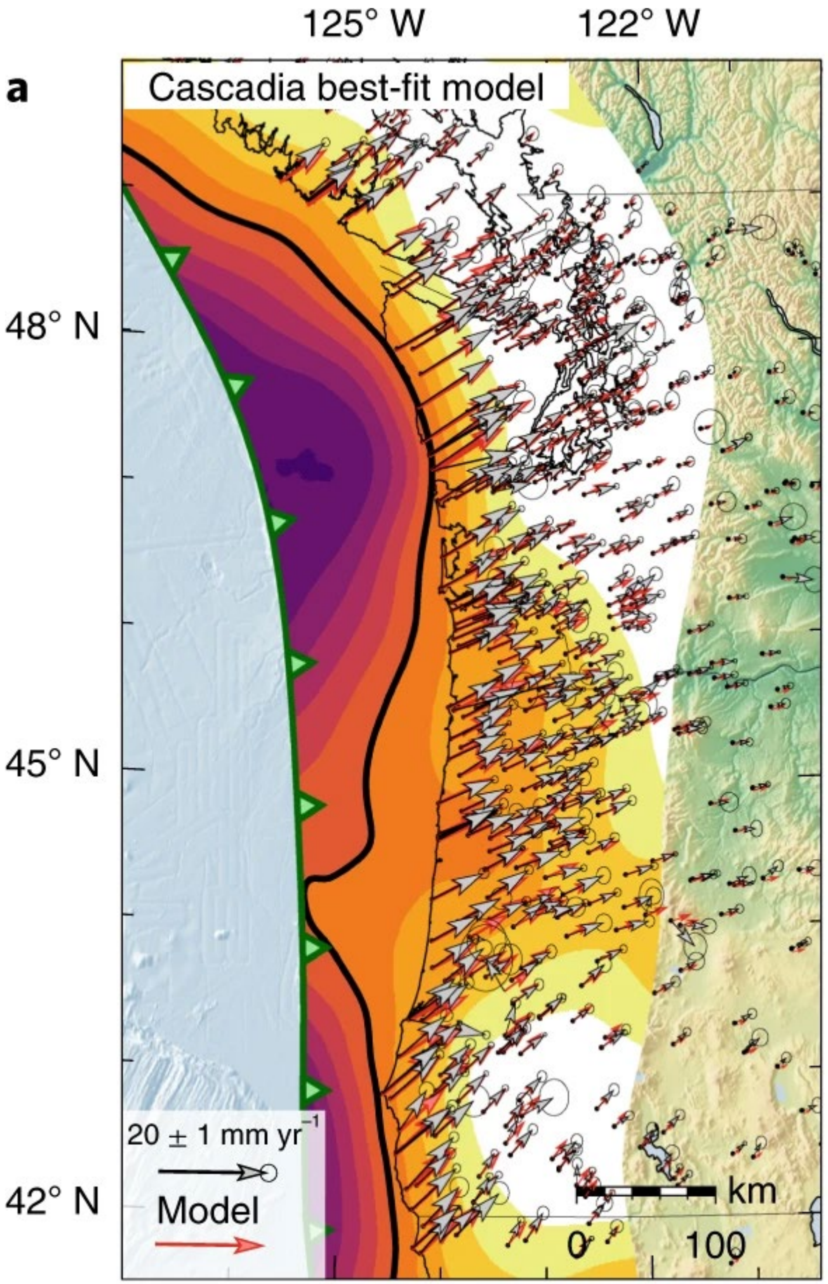
Cascadia Sources Working Group (CSWG)

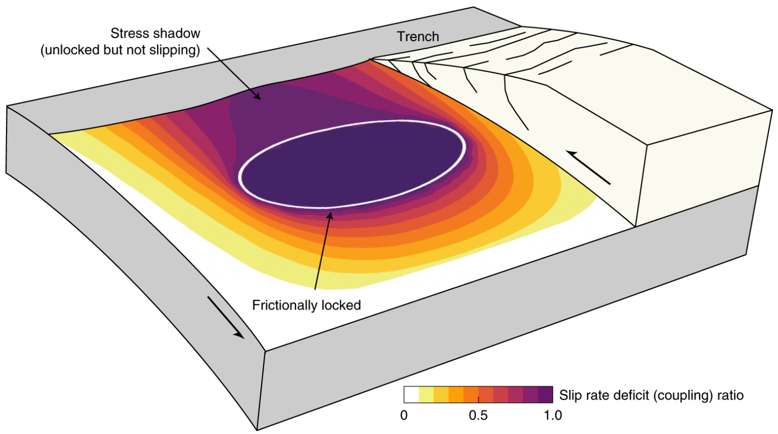
CASIE21 Team

First step: Geodetic strain accumulation at Cascadia



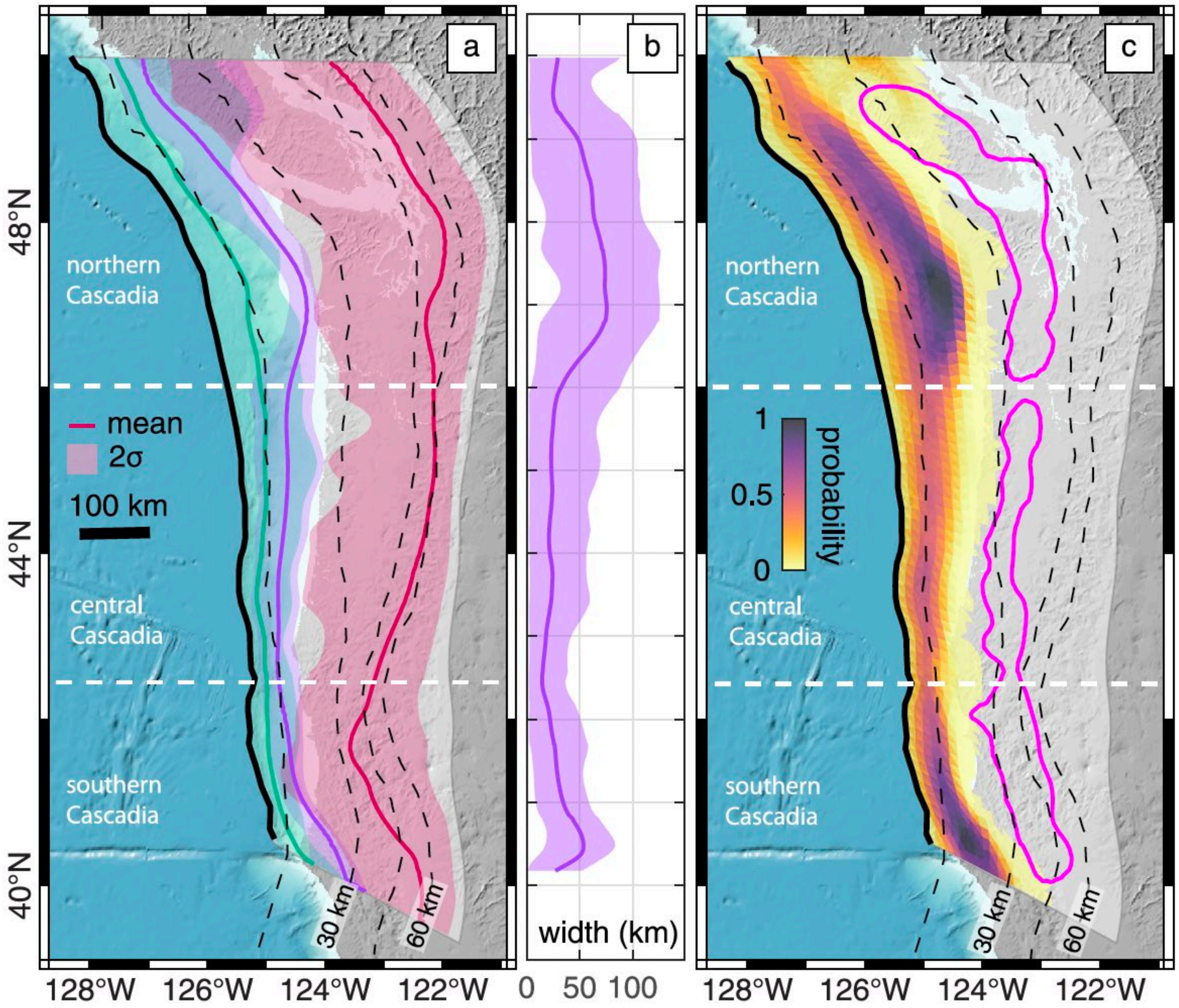
Schmalzle et al., 2014





- Widest, most-locked patch is off Washington
- Up-dip zone might be "effectively locked" … or just locked

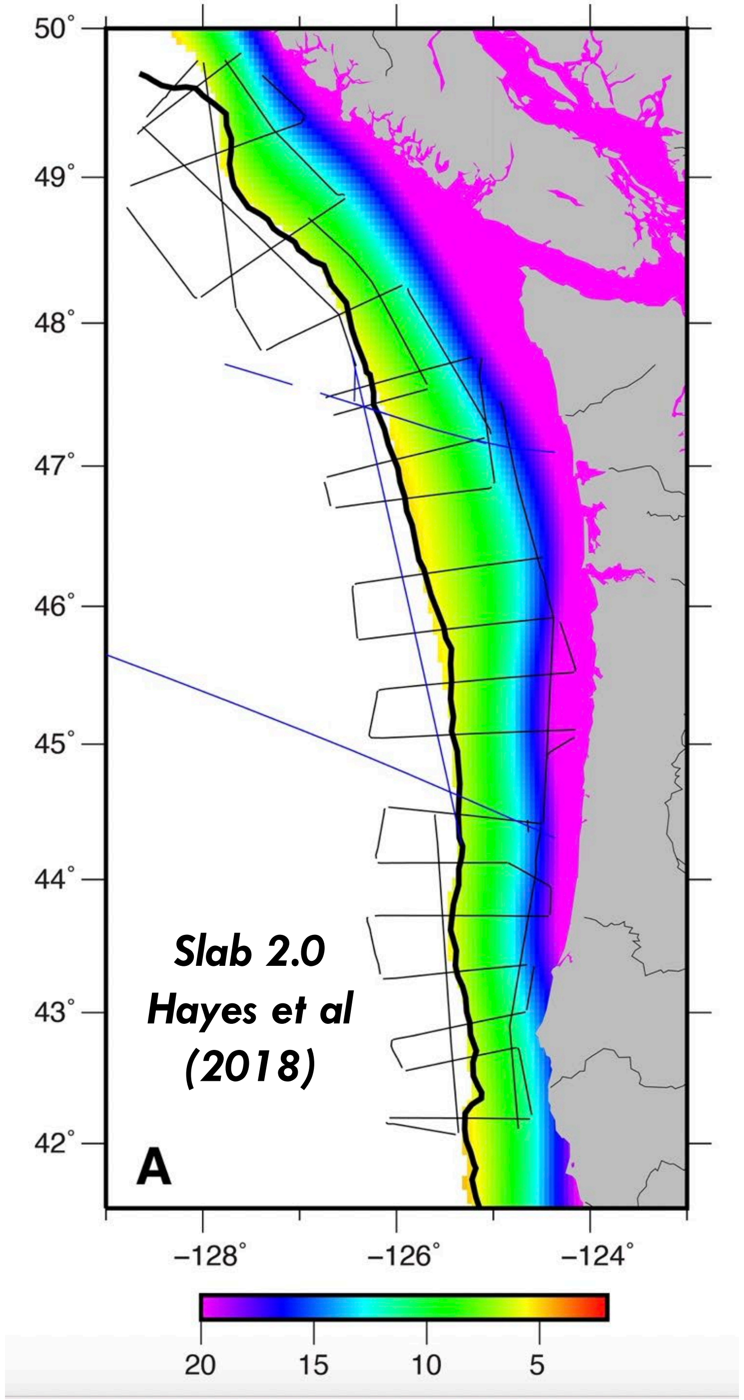
Lindsey et al., 2021



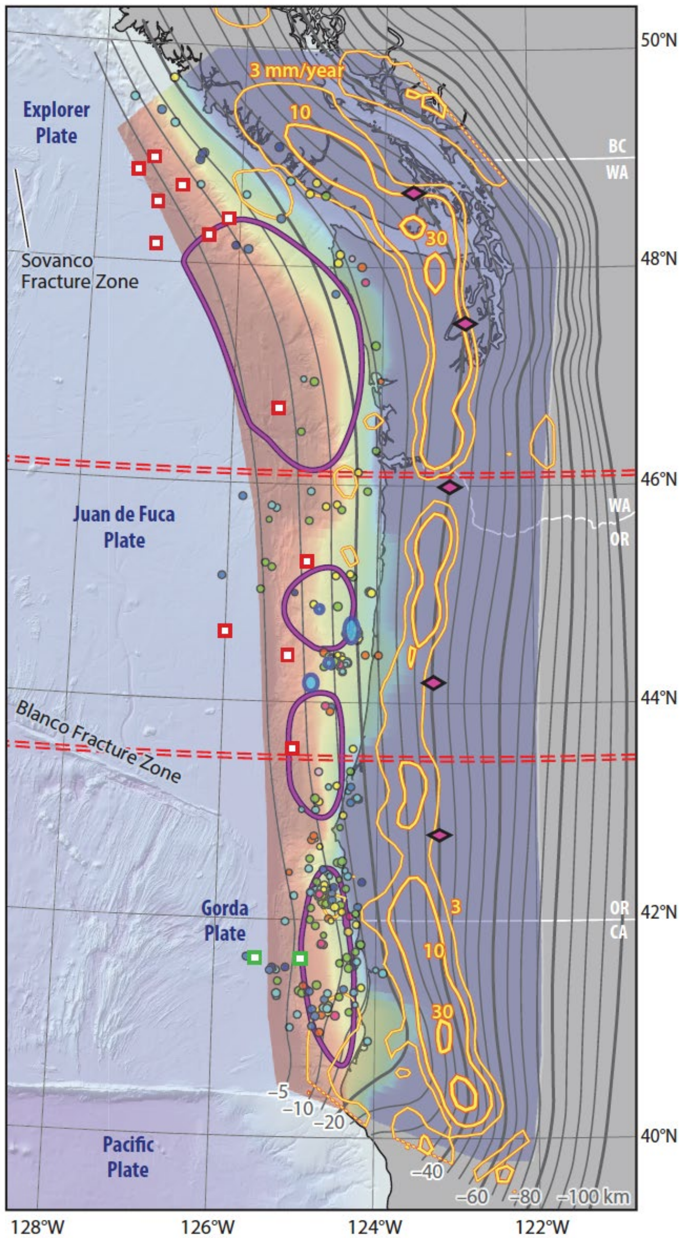
Recent on-land geodetic inversions affirm down-dip limits of substantial strain accumulation lie entirely offshore

- Gap between ETS zone and 0.2 locking contour persists
- Wide patch off Washington matches plate interface geometry and character

Sherrill et al., 2024



Slab 2.0
Hayes et al
(2018)



Walton et al., 2021

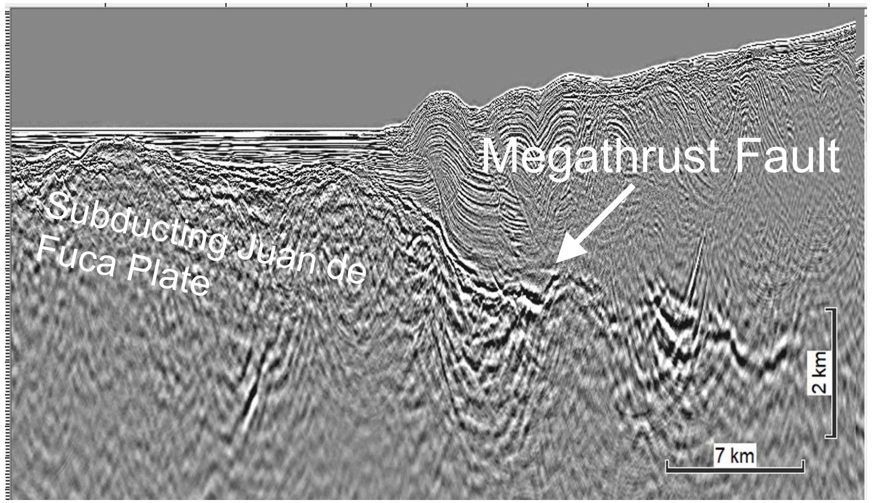
Most models of megathrust geometry use a smoothed and simplified surface, but we know there's plenty of real variability

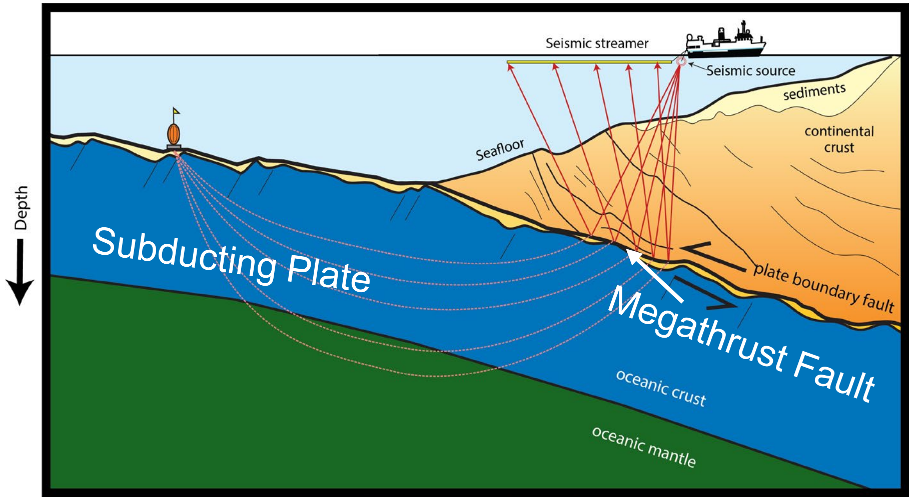
All of these vary in strike and/or dip:

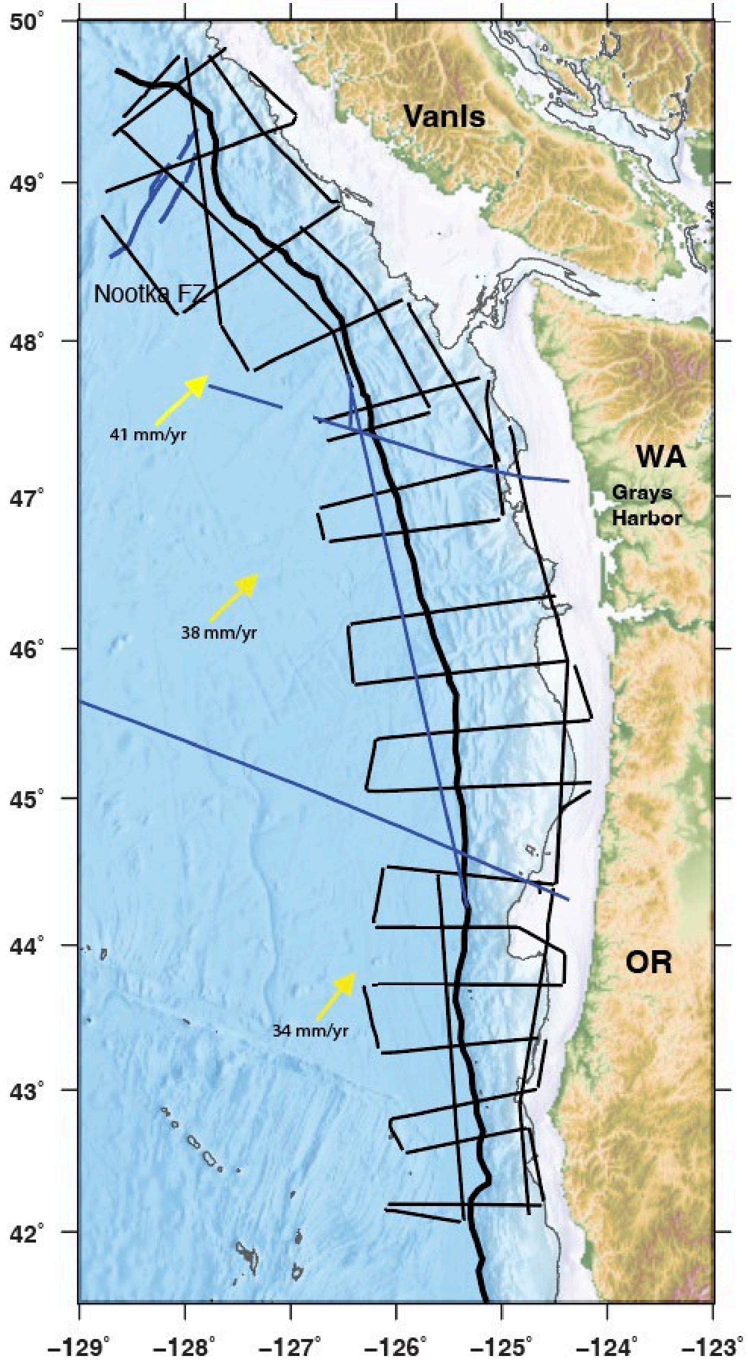
- Paleoseismic evidence
- Geodetic locking
- Structural geometries of wedge
- Input basement topography
- Convergence rate

New seismic reflection imaging: the CASIE21 experiment

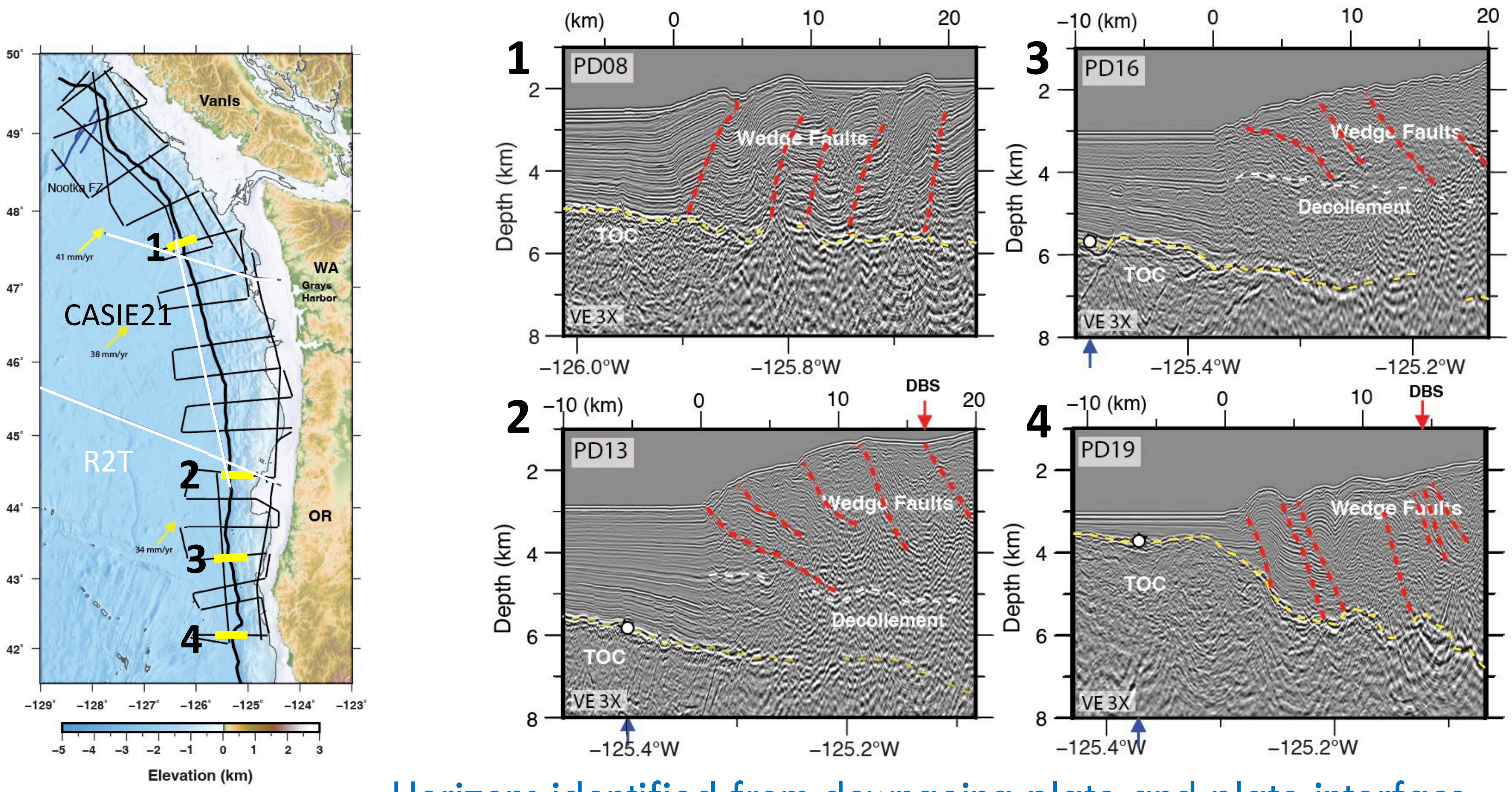
Carbotte et al., 2024 - and many other papers in review and in preparation







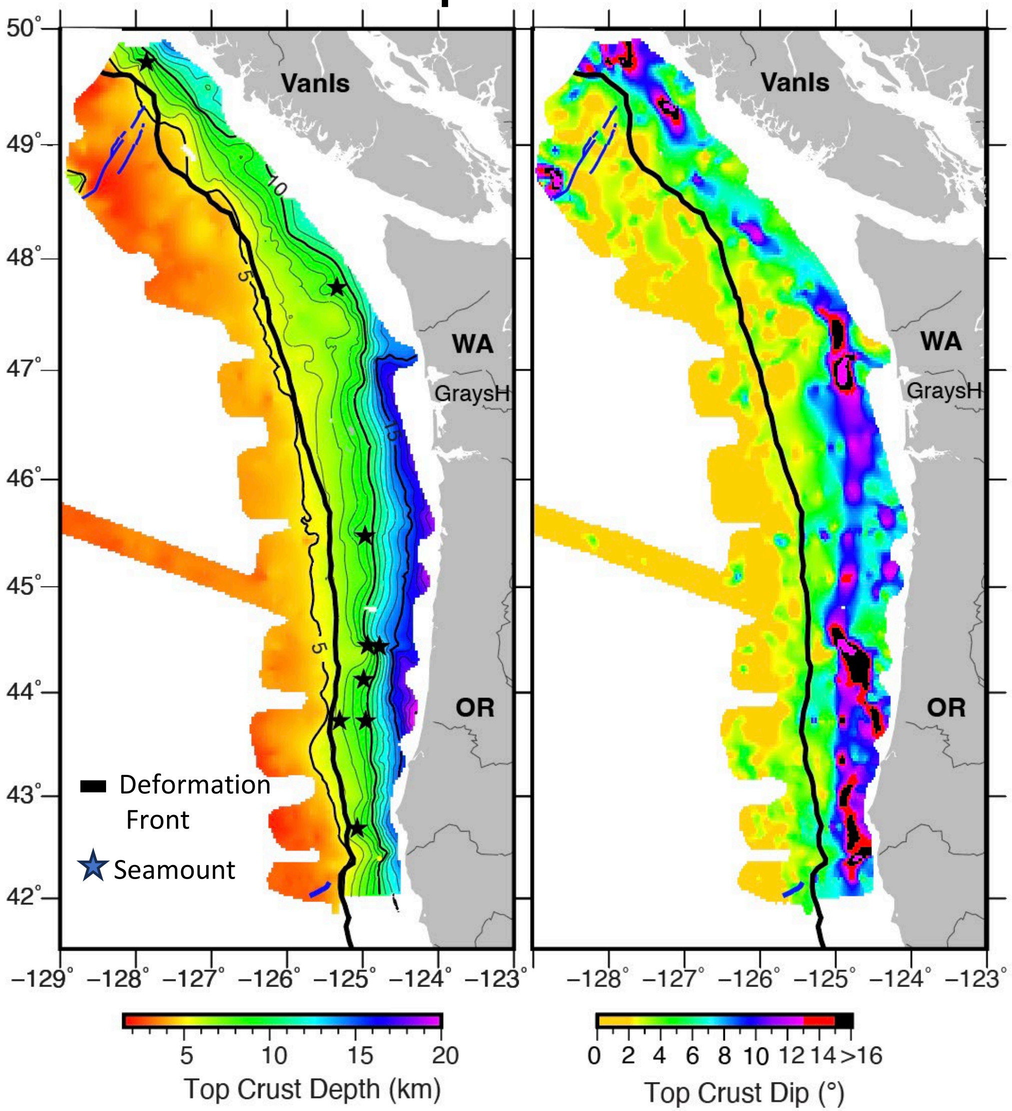
Comprehensive seismic reflection imaging of the offshore CSZ



Horizons identified from downgoing plate and plate interface

New maps of top of crust and plate boundary for seismogenic zone

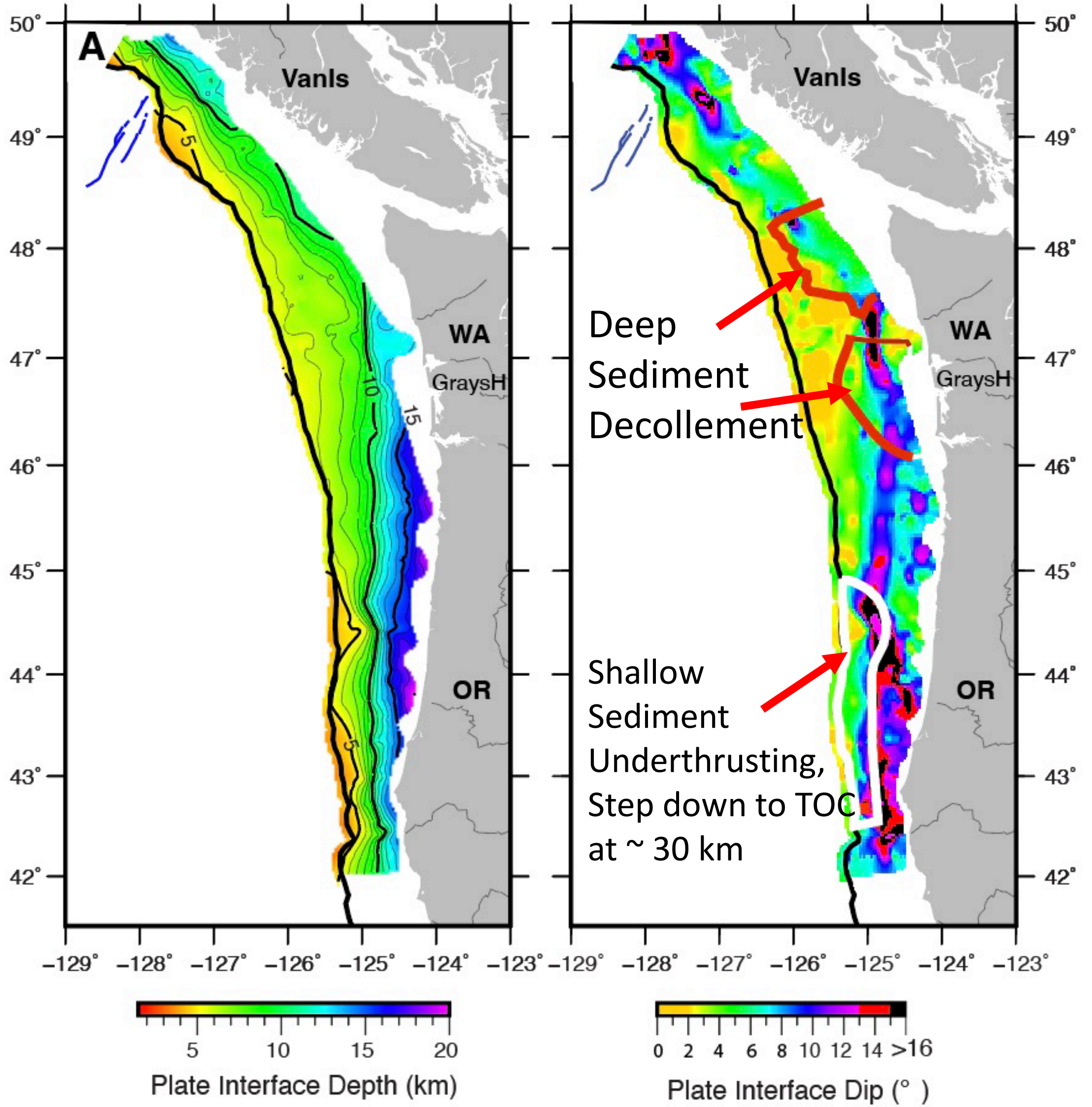
Top of Crust

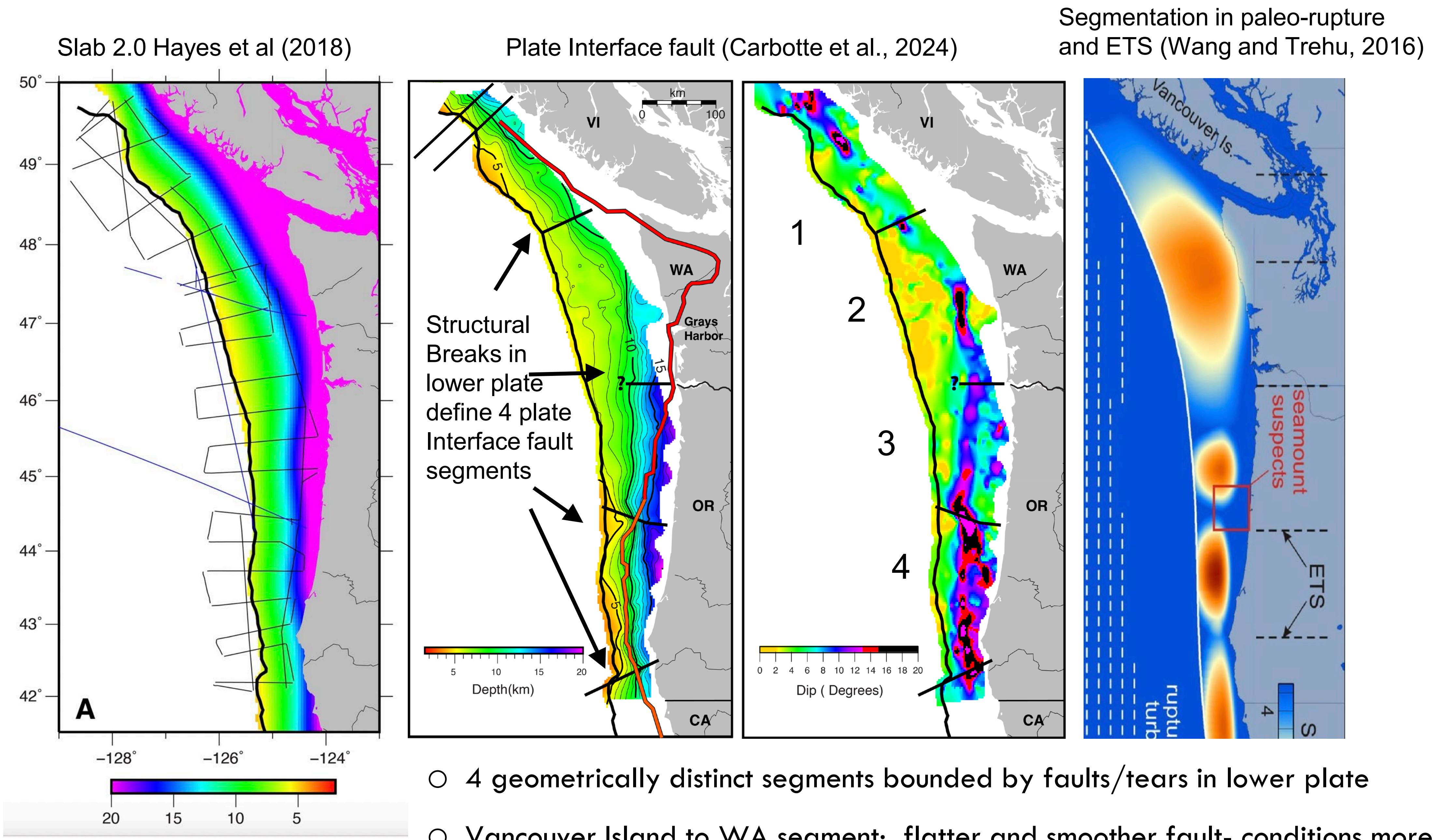


Depth uncertainties from Vp analysis:

+/- 100 m incoming plate
+/- 1 km under wedge

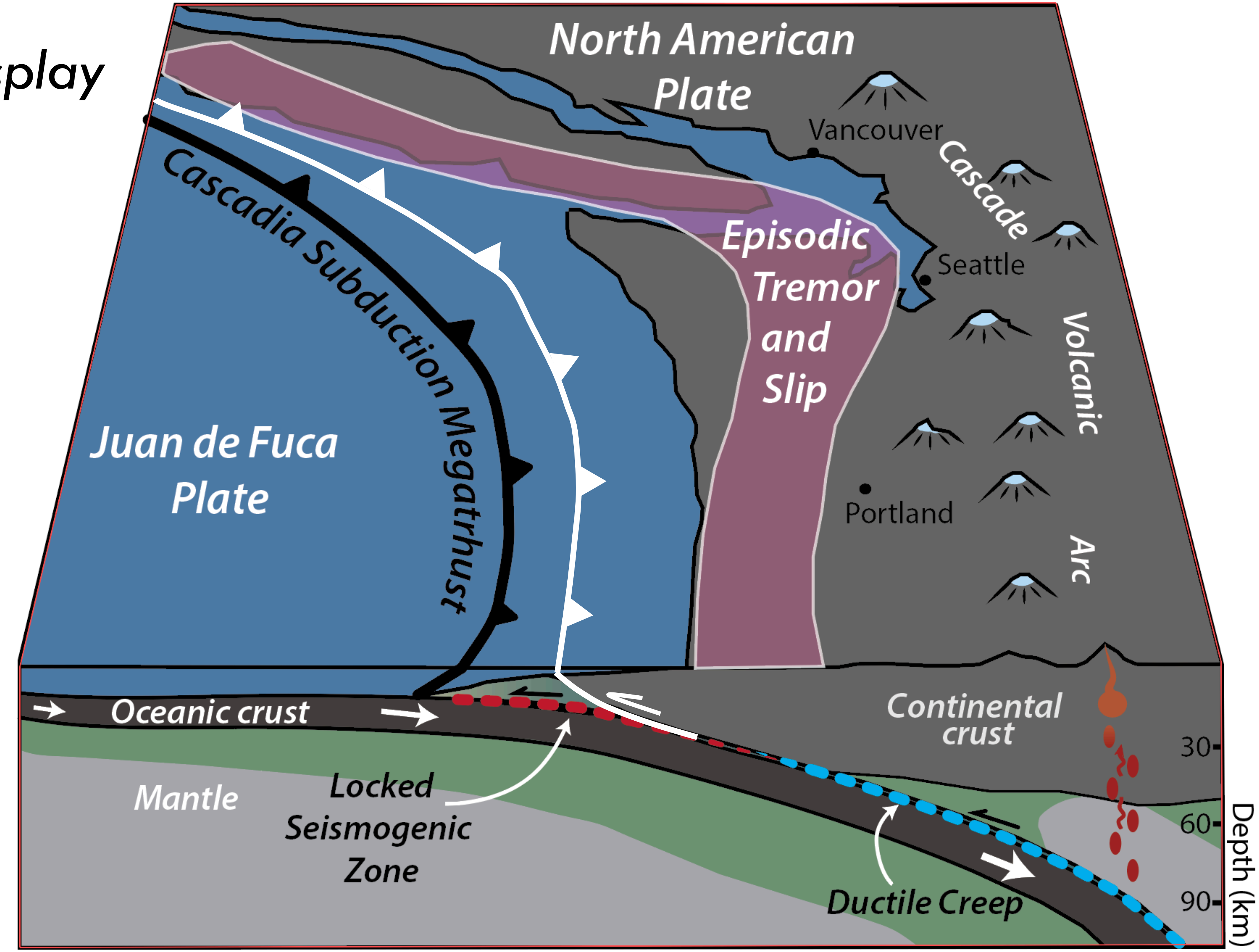
Plate Interface





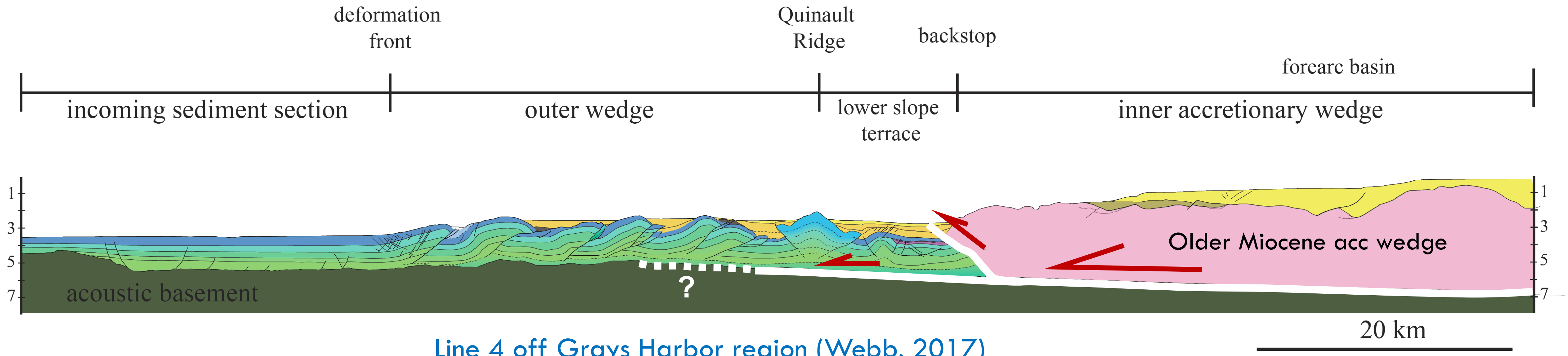
- 4 geometrically distinct segments bounded by faults/tears in lower plate
- Vancouver Island to WA segment: flatter and smoother fault- conditions more favorable for large EQ

What is the role of splay faults?



Graphic by Cailey Condit, UW

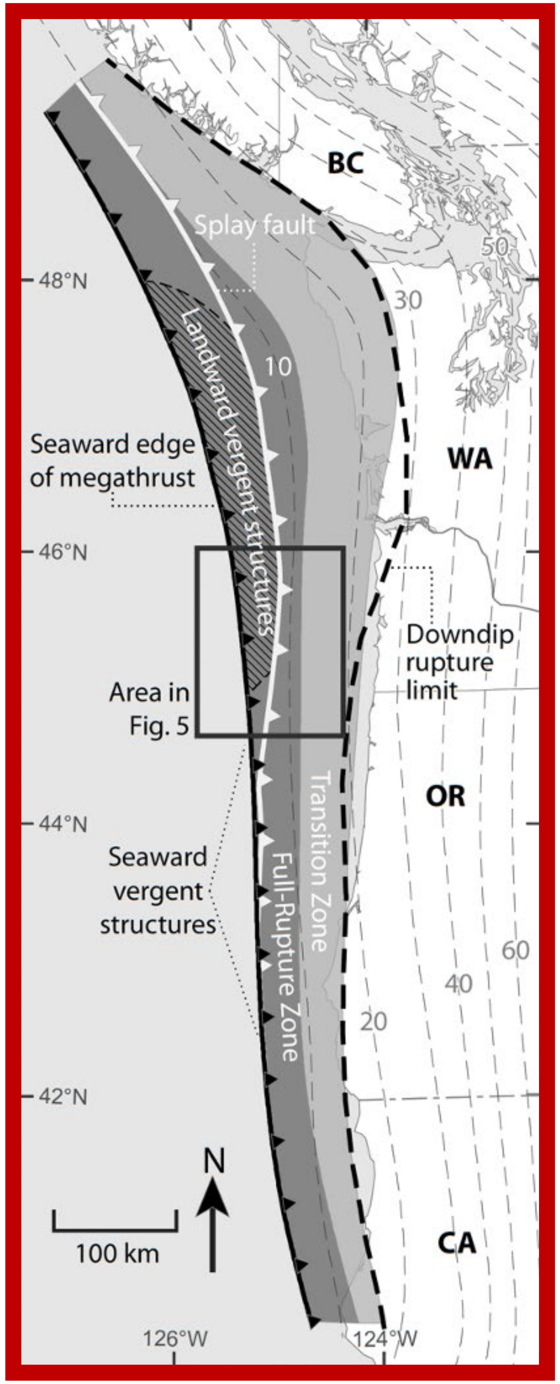
Where does the slip go in megathrust earthquakes? Which faults participate?



Line 4 off Grays Harbor region (Webb, 2017)

- *Is there actually a "mega-splay" fault?*
- *How far out to the deformation front does fast slip go?*
- *What about all the other splay faults?*

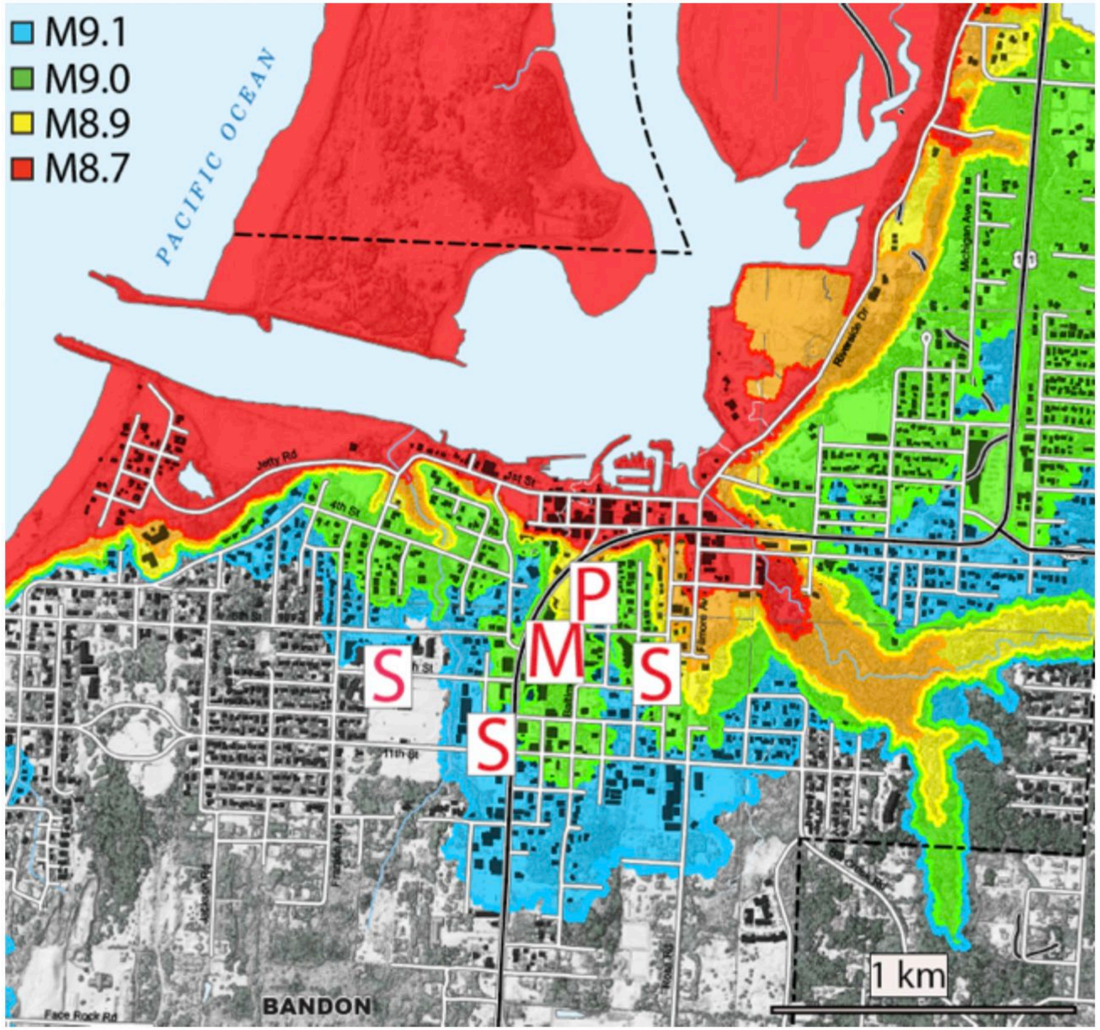
These unknowns have very real implications for policy in the Pacific Northwest: planning scenarios for tsunami hazards are based on available geoscience



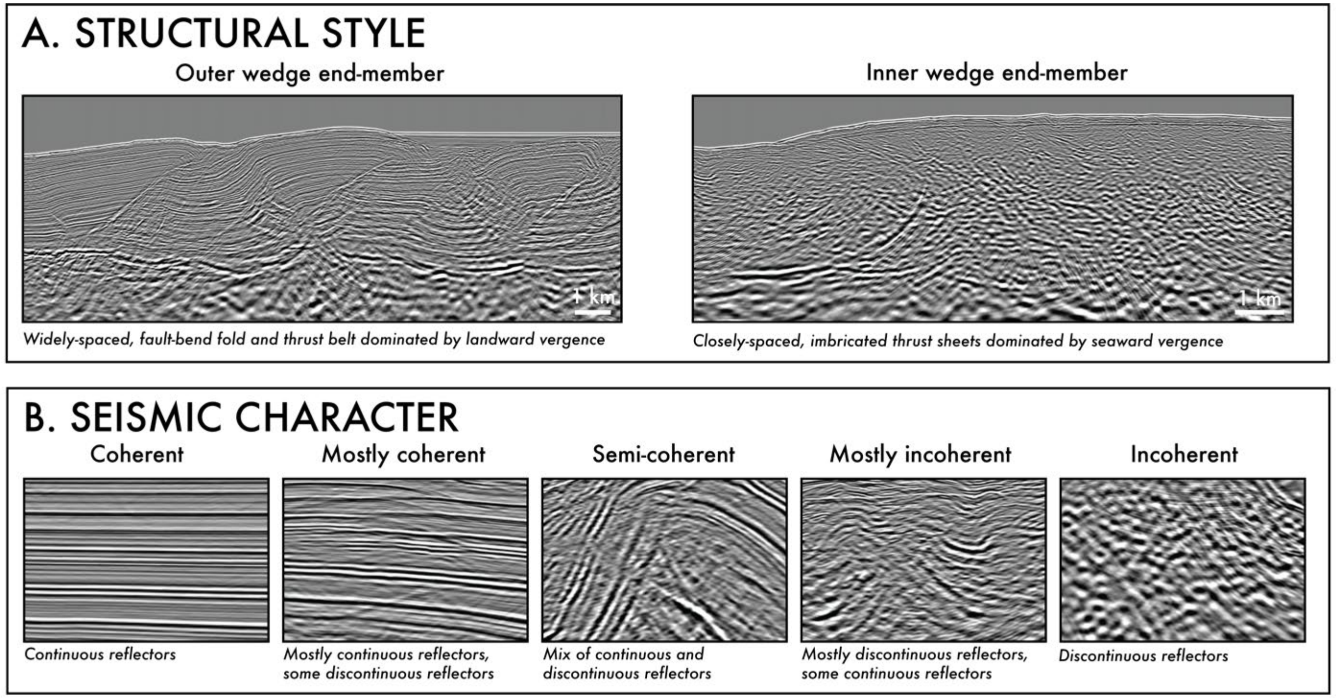
Witter et al. (2013)

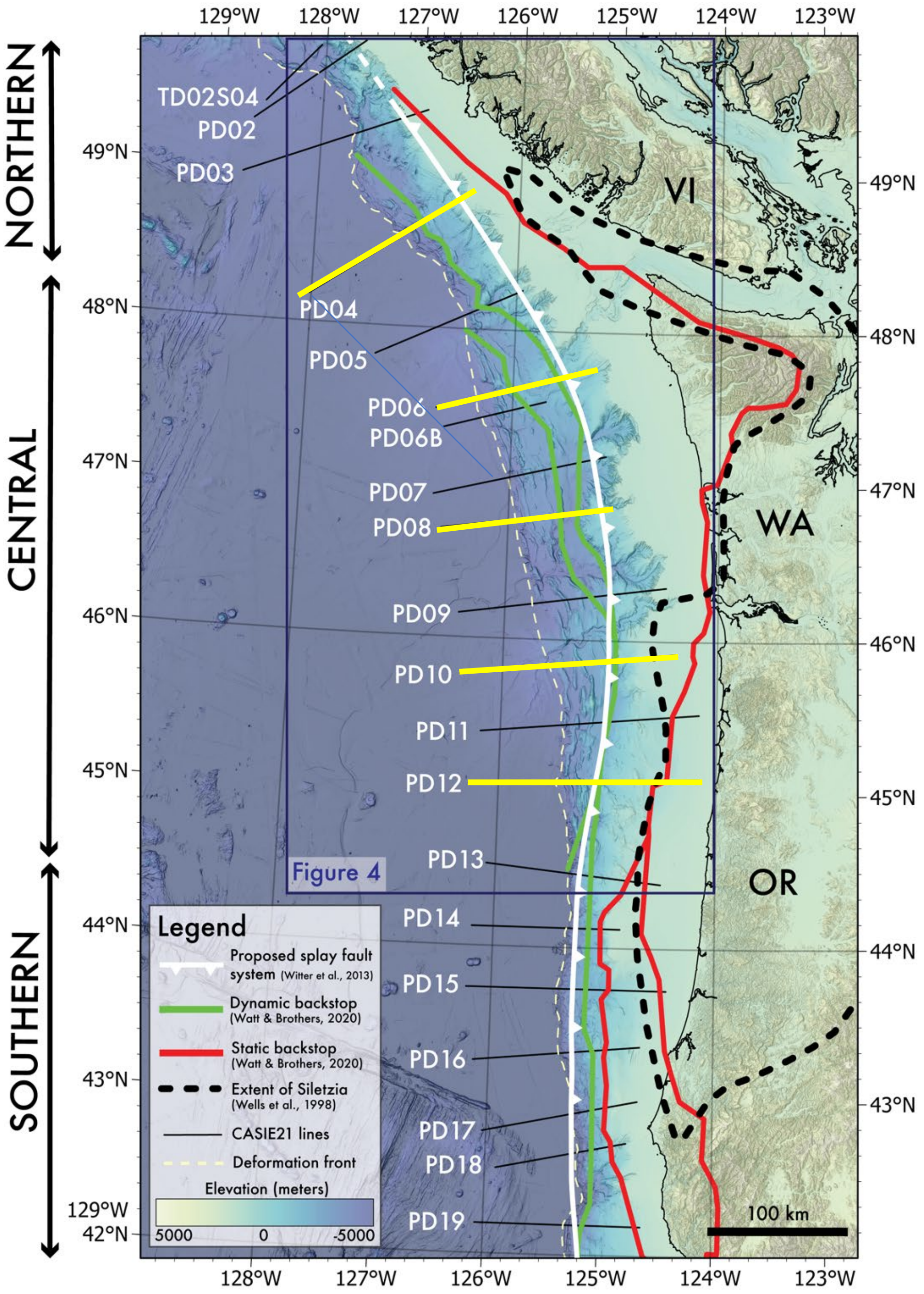
Emergency planners in Oregon and Washington use different selected scenarios from a set dubbed S, M, L, XL, XXL, with and without a megasplay fault

Tsunami inundation scenarios for Bandon, OR ranging from M8.7 – M9.1 models

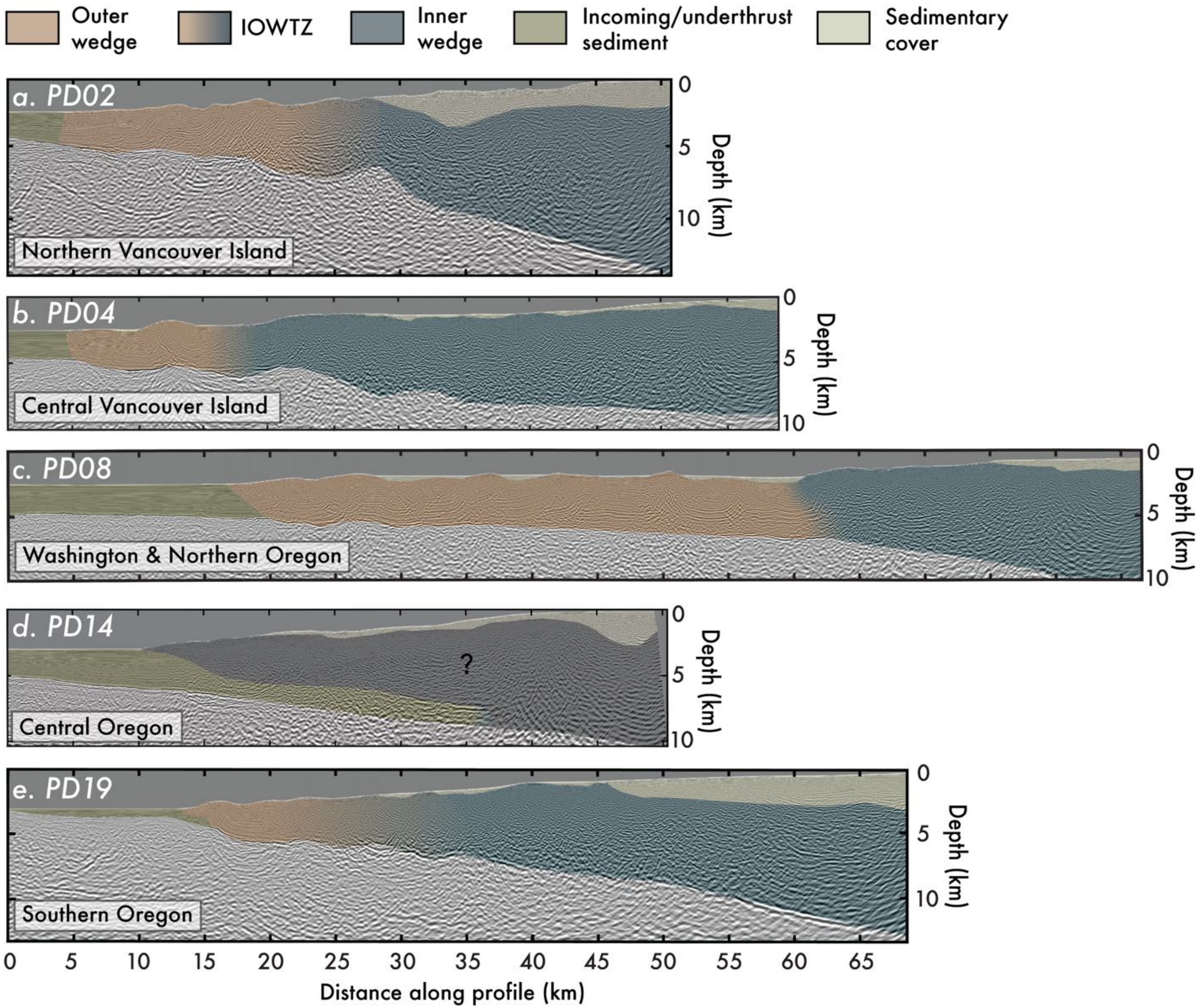


Is there a megasplay fault, as in many existing favored models?





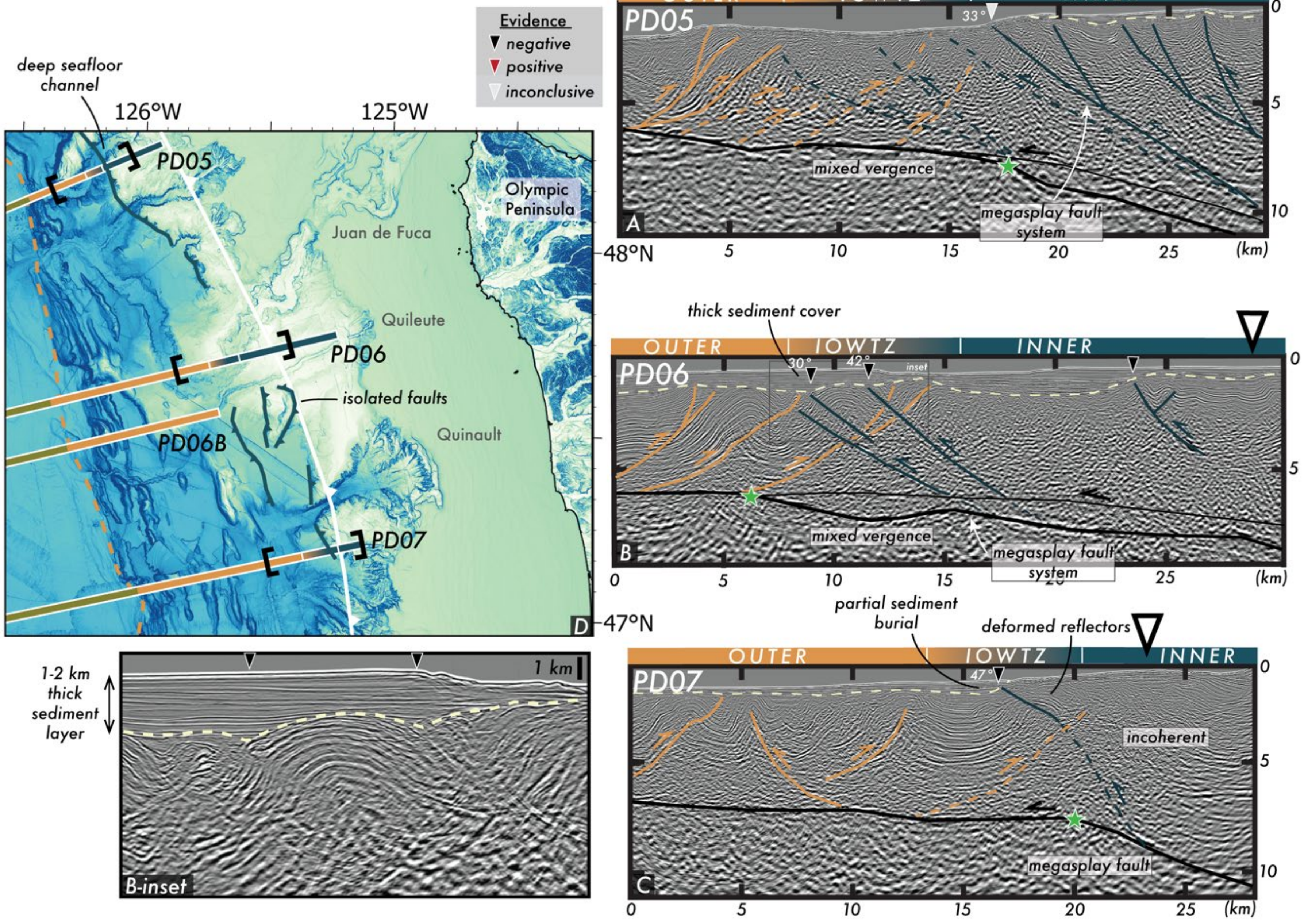
Lucas, Tobin et al., in review



Lucas et al., in review

Washington: megasplay faults are covered by undeformed sediments

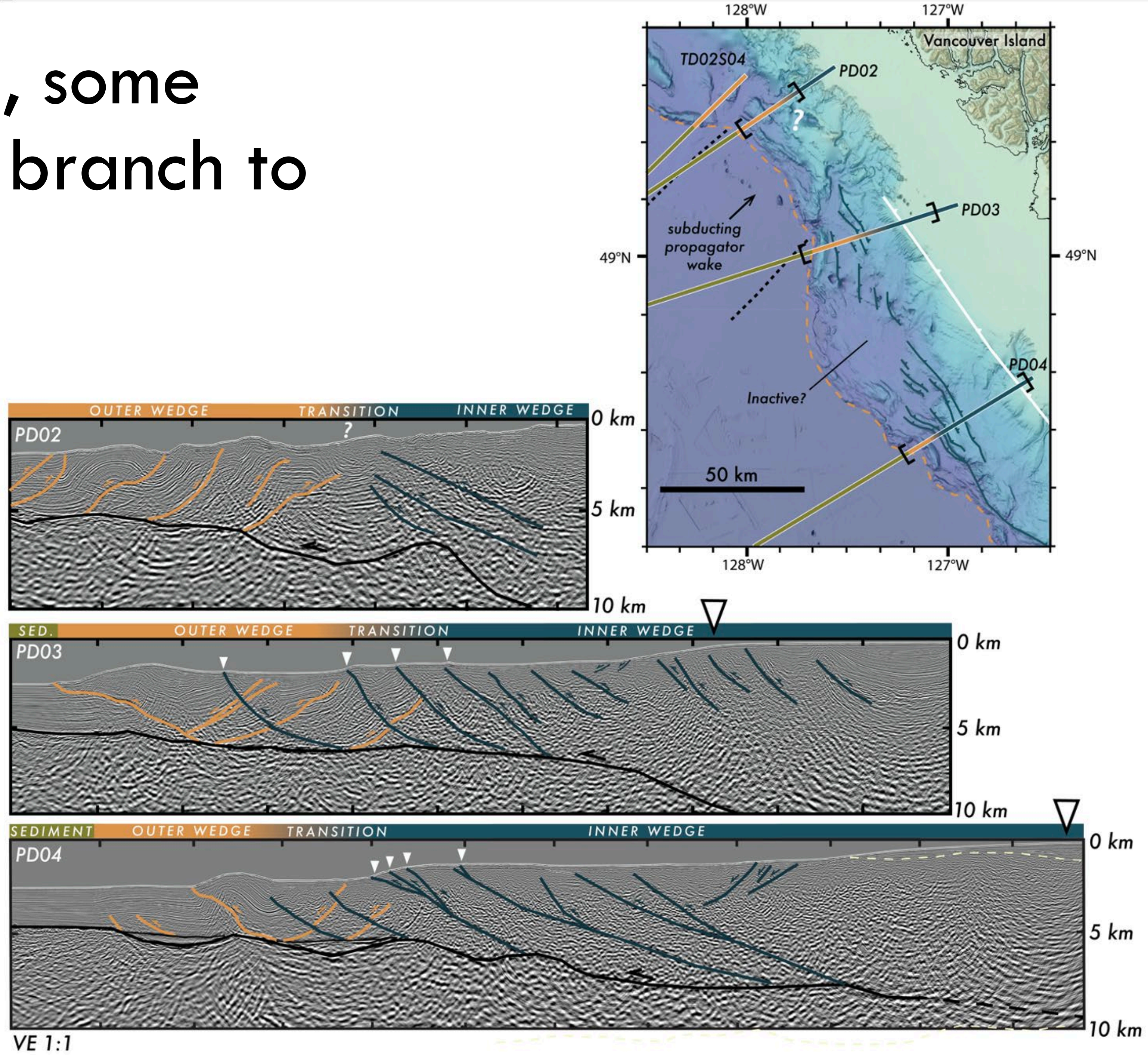
- Lines off Olympic peninsula, JdF Strait show faults *sealed* by younger sediments
- Transition northward to the Vancouver Island pattern, with plausible active megasplay fault



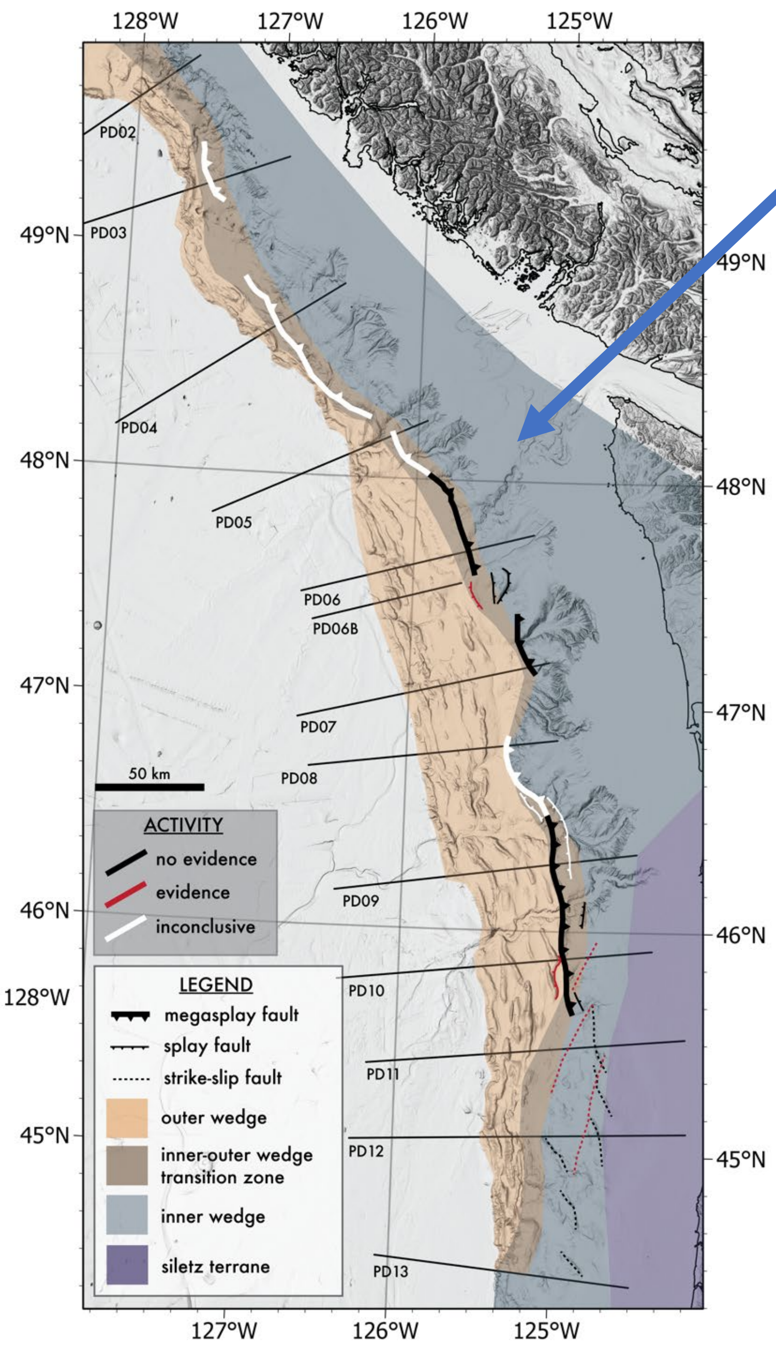
Lucas et al., in review

Off Vancouver Island, some large-scale faults do branch to surface

- Evidence of potential megasplay-style fault here, seaward of previously mapped-position
- Near-surface recent activity is difficult to evaluate because we don't have high-resolution complementary imaging



Lucas et al., in review



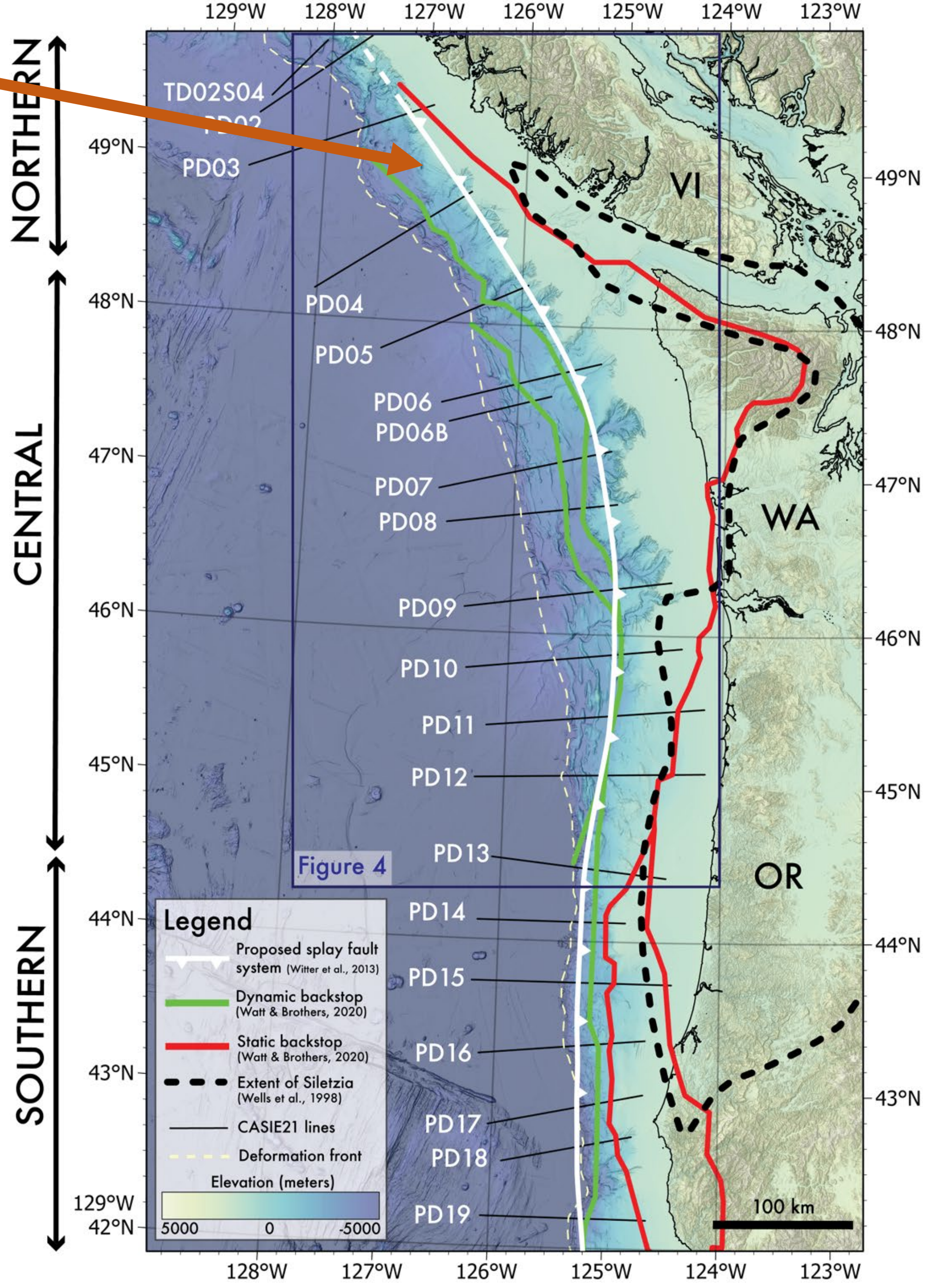
YES

NO

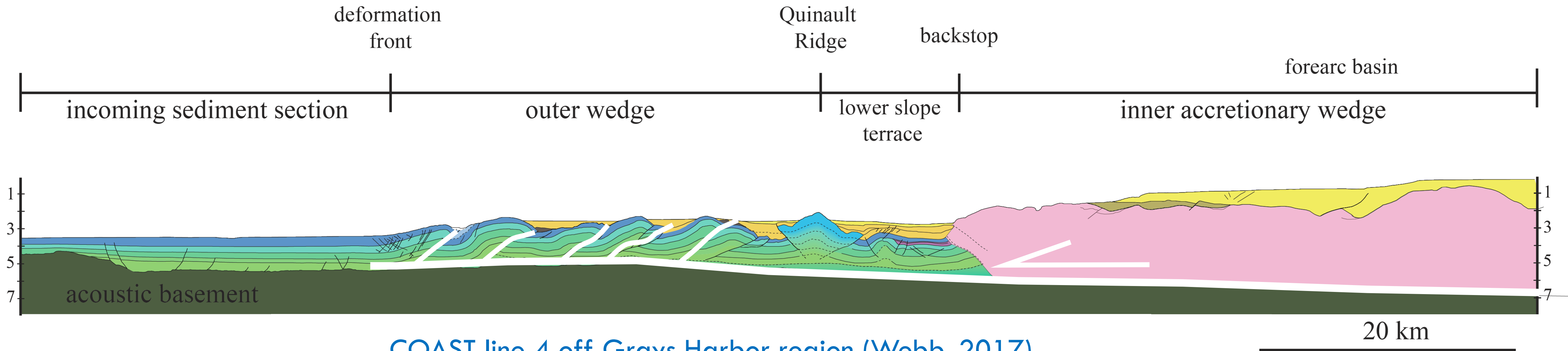
Bottom line:

Strong evidence that there is **no through-going megasplay fault** off Washington or Oregon

Lucas et al., in review



Do the other splay faults slip coseismically?

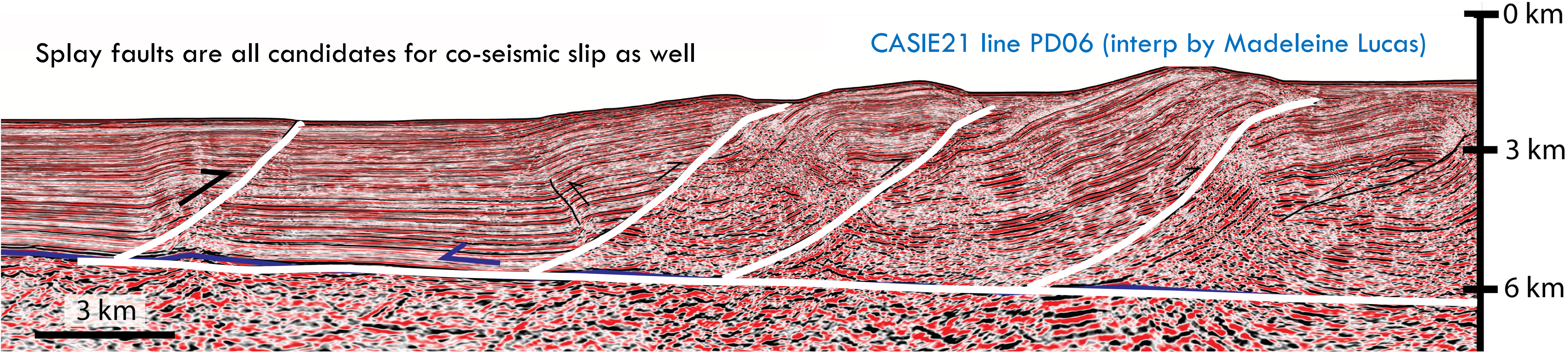


COAST line 4 off Grays Harbor region (Webb, 2017)

Decollement is the plate boundary, and lies **~3 km** below the surface right at the deformation front

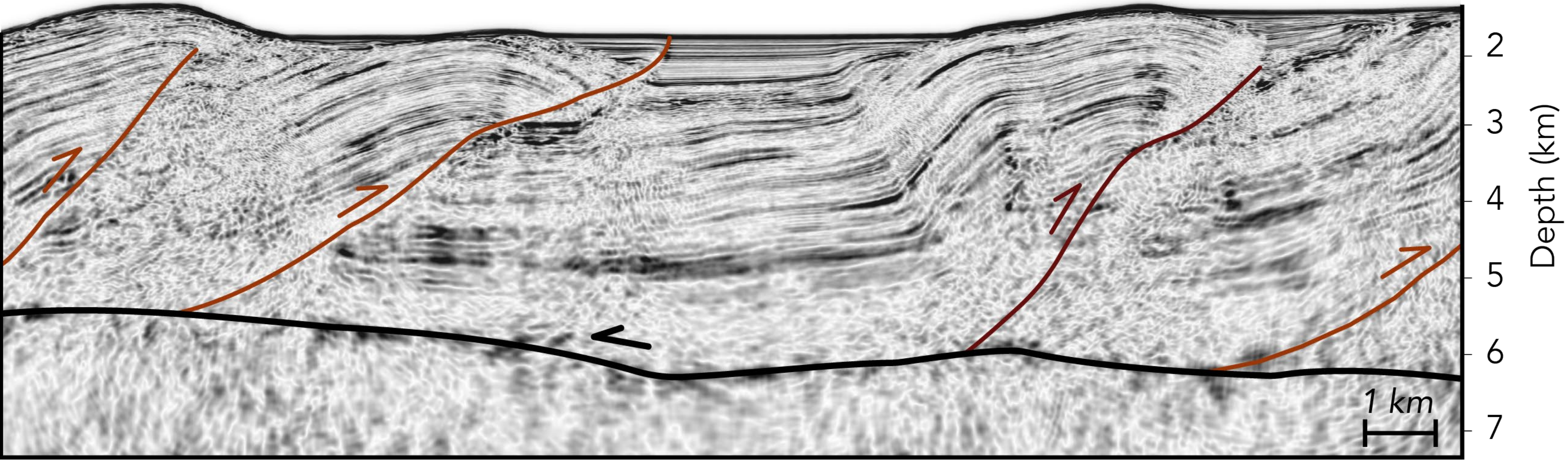
Splay faults are all candidates for co-seismic slip as well

CASIE21 line PD06 (interp by Madeleine Lucas)



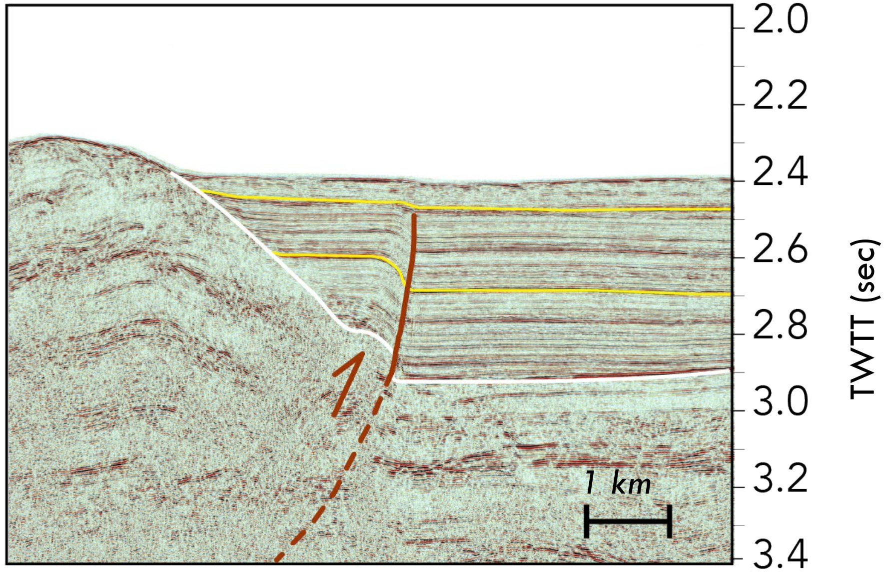
We conduct joint interpretation of near surface (<1 km) and deeper (<10 km) seismic reflection imaging

CASIE21 PD06B

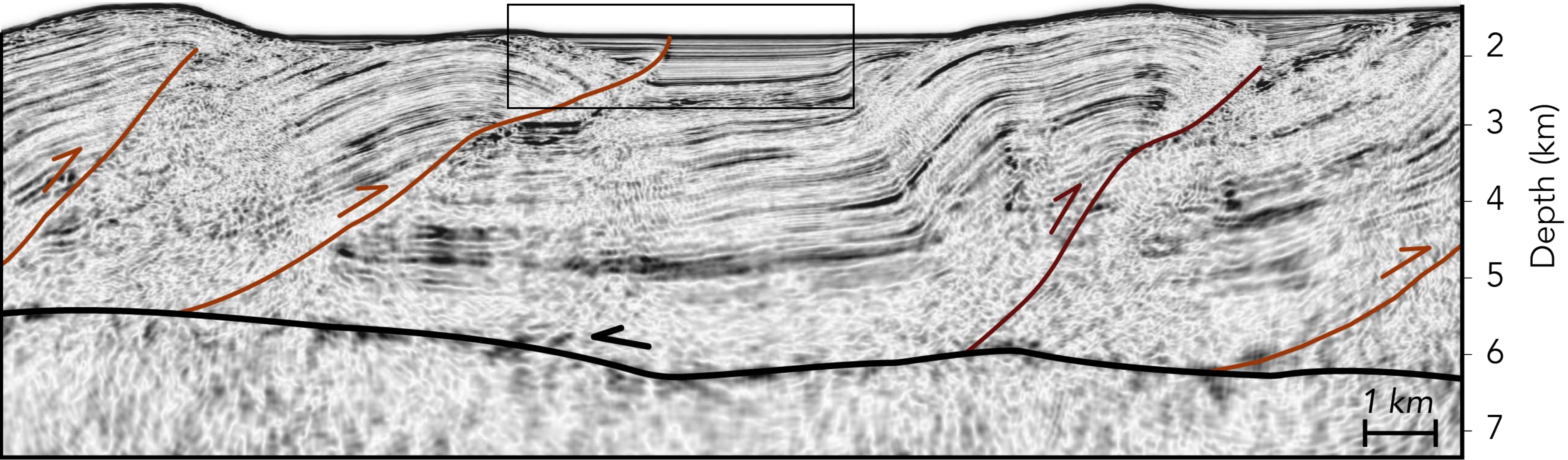


Ledeczi et al., 2024

We conduct joint interpretation of near surface (<1 km) and deeper (<10 km) seismic reflection imaging



Higher resolution sparker seismic data



Ledeczi et al., 2024

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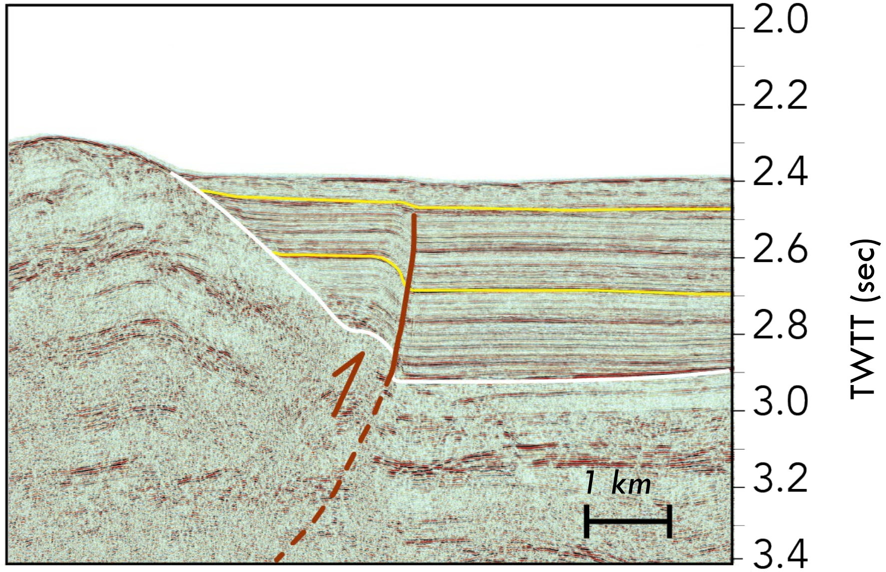
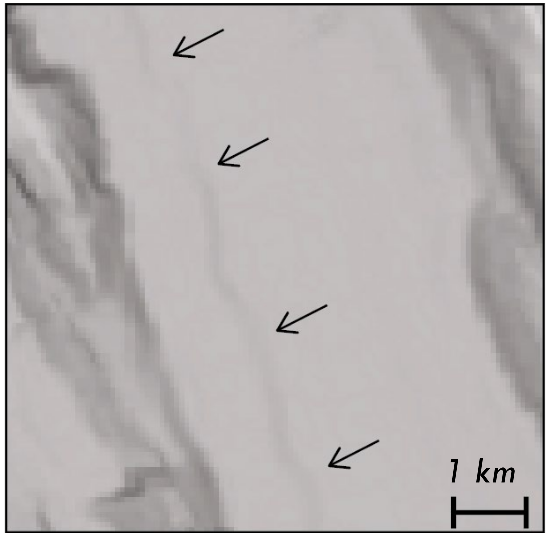
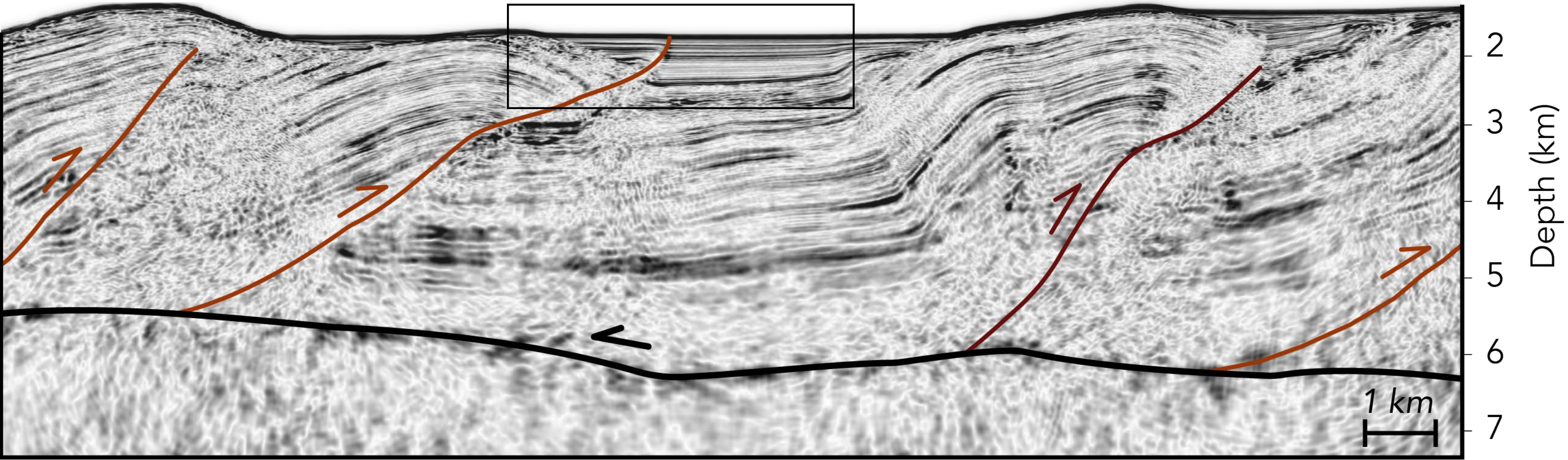


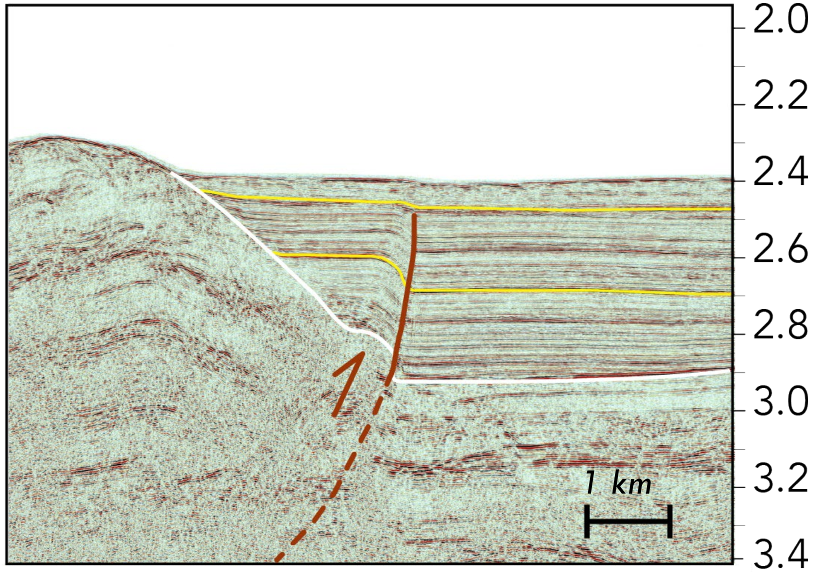


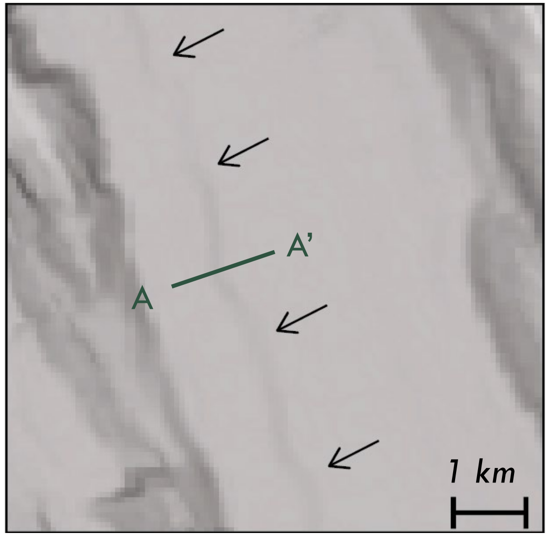
USGS 30-m bathymetry

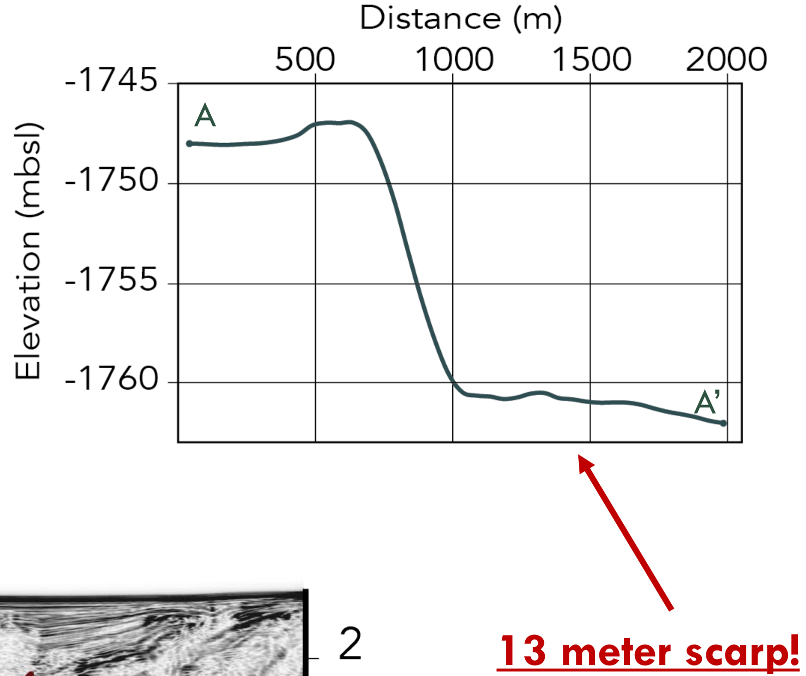


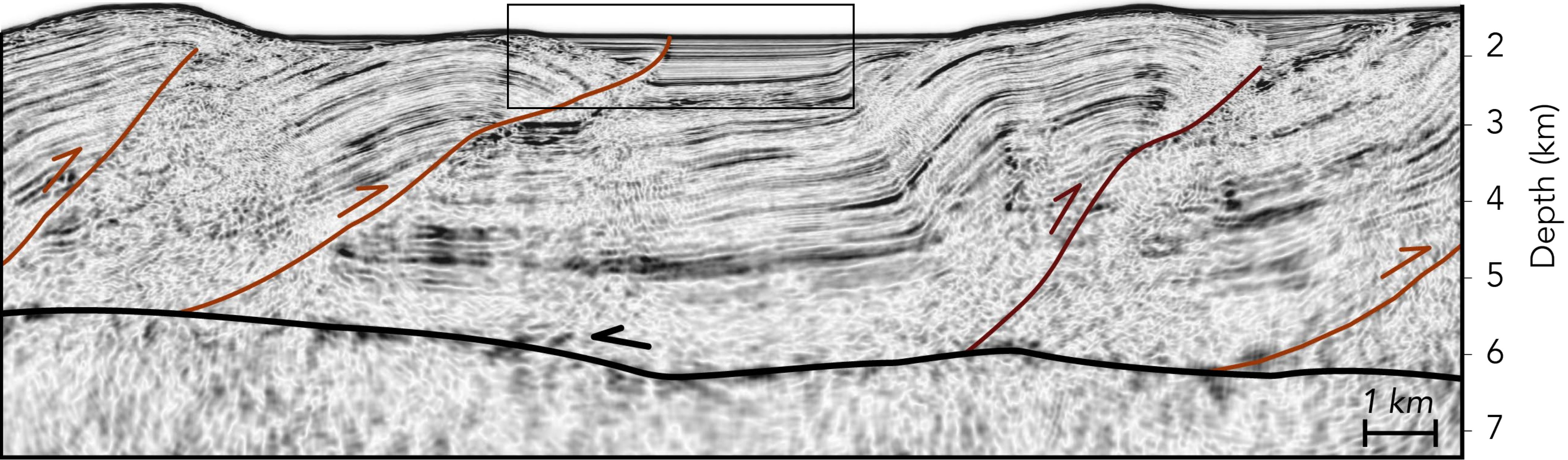
Ledeczi et al., 2024

We conduct joint interpretation of near surface (<1 km) and deeper (<10 km) seismic reflection imaging

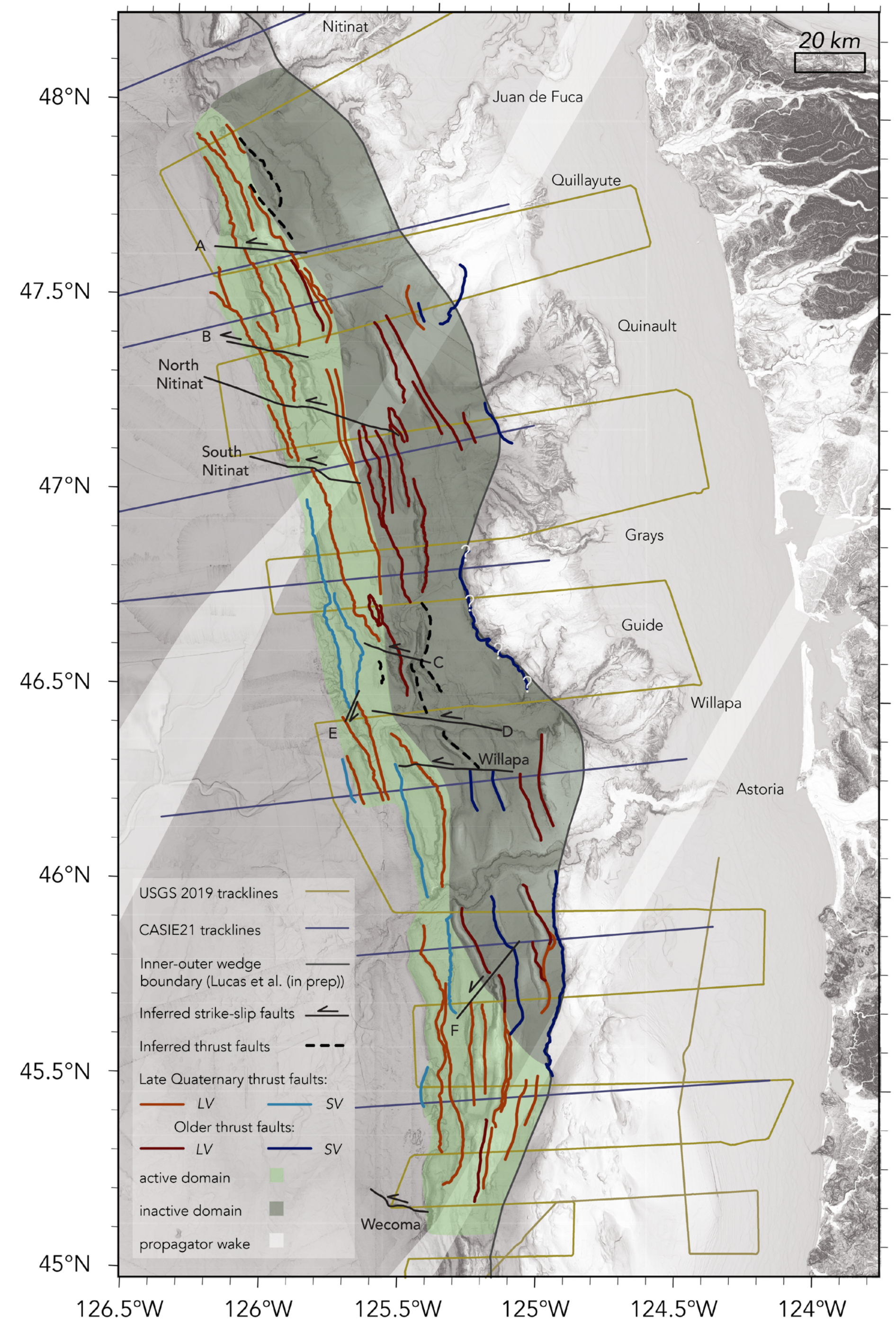








Ledeczi et al., 2024

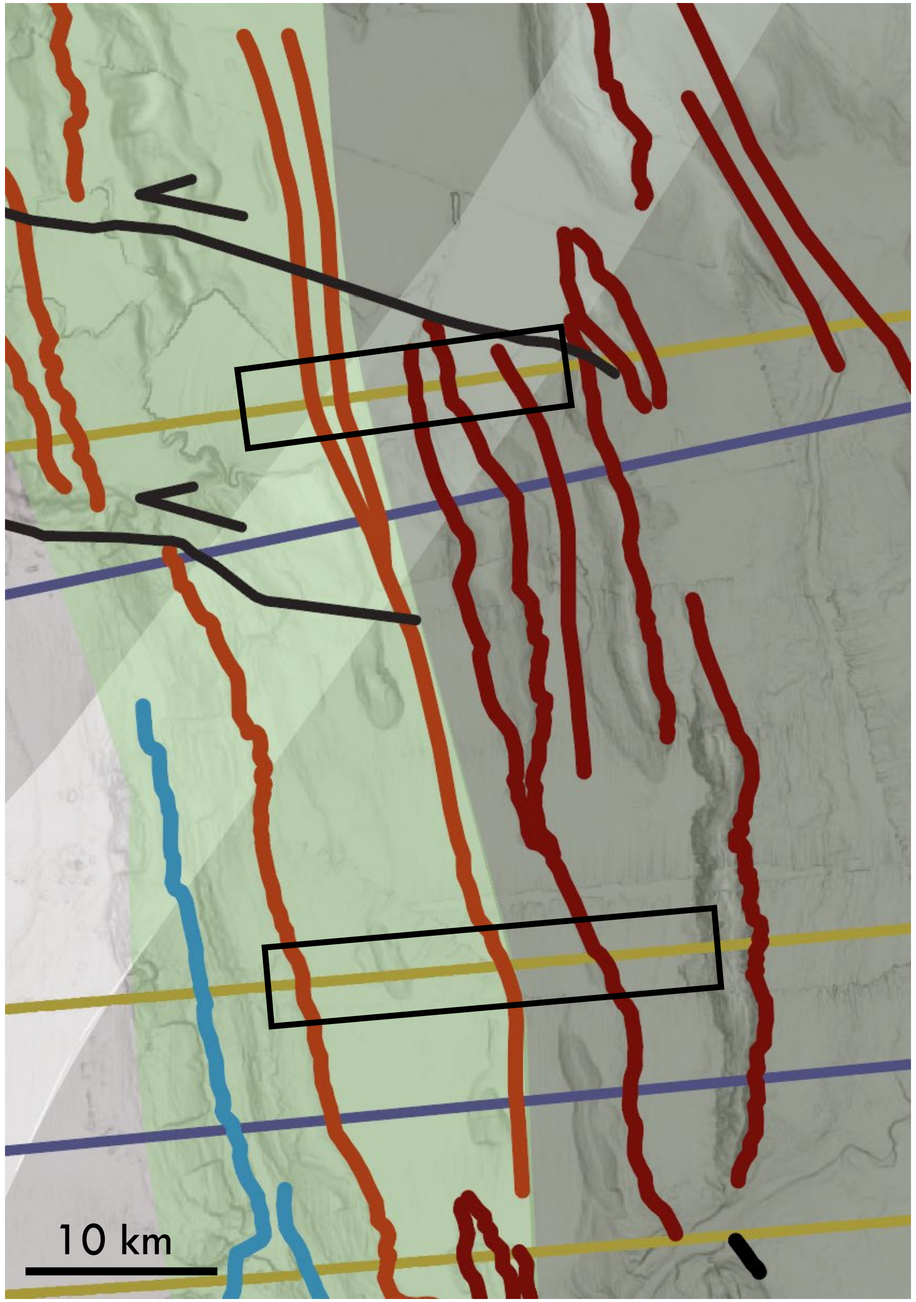


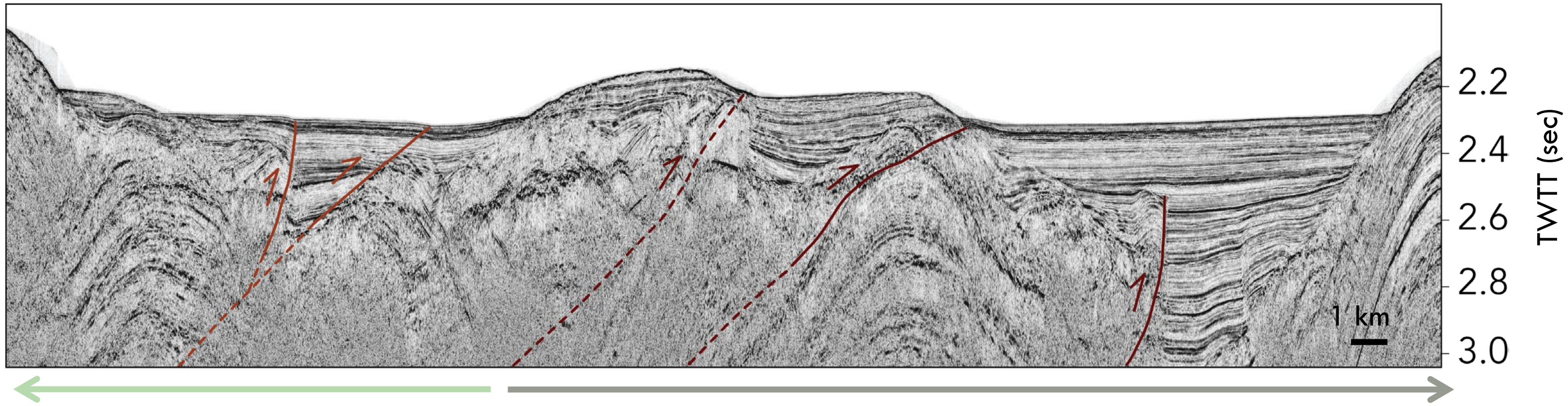
We document widespread recent activity of splay faults within ~30 km of the deformation front

- New data resolution allows to discriminate faults which are actually active
  - Previous work has identified similar faults, but all were called active
- Partitioning of recent activity into "active domain" and older activity into "inactive domain"
  - Active domain < 30 km wide
  - Inactive domain 10 to 40 km wide

Ledeczi et al., 2024

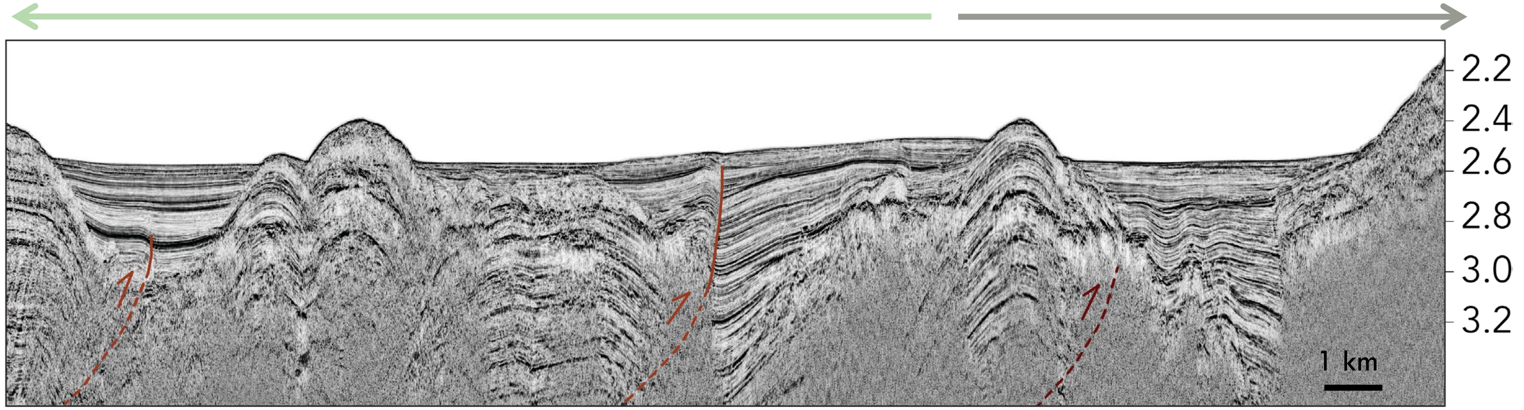
Sedimentary History



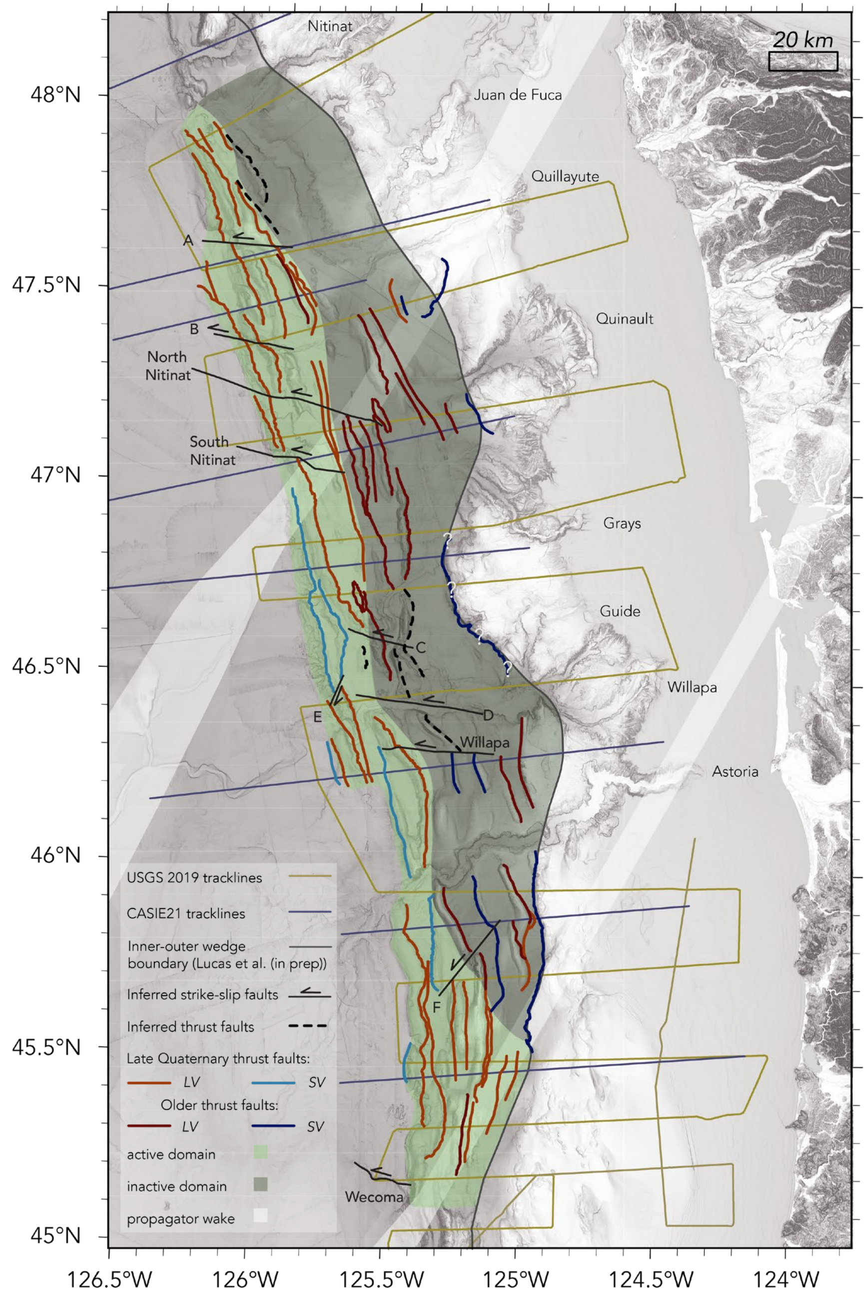


Active domain:
surface-breaking faults with syndeformational sediments

Inactive domain:
inactive faults buried by postdeformational sediments

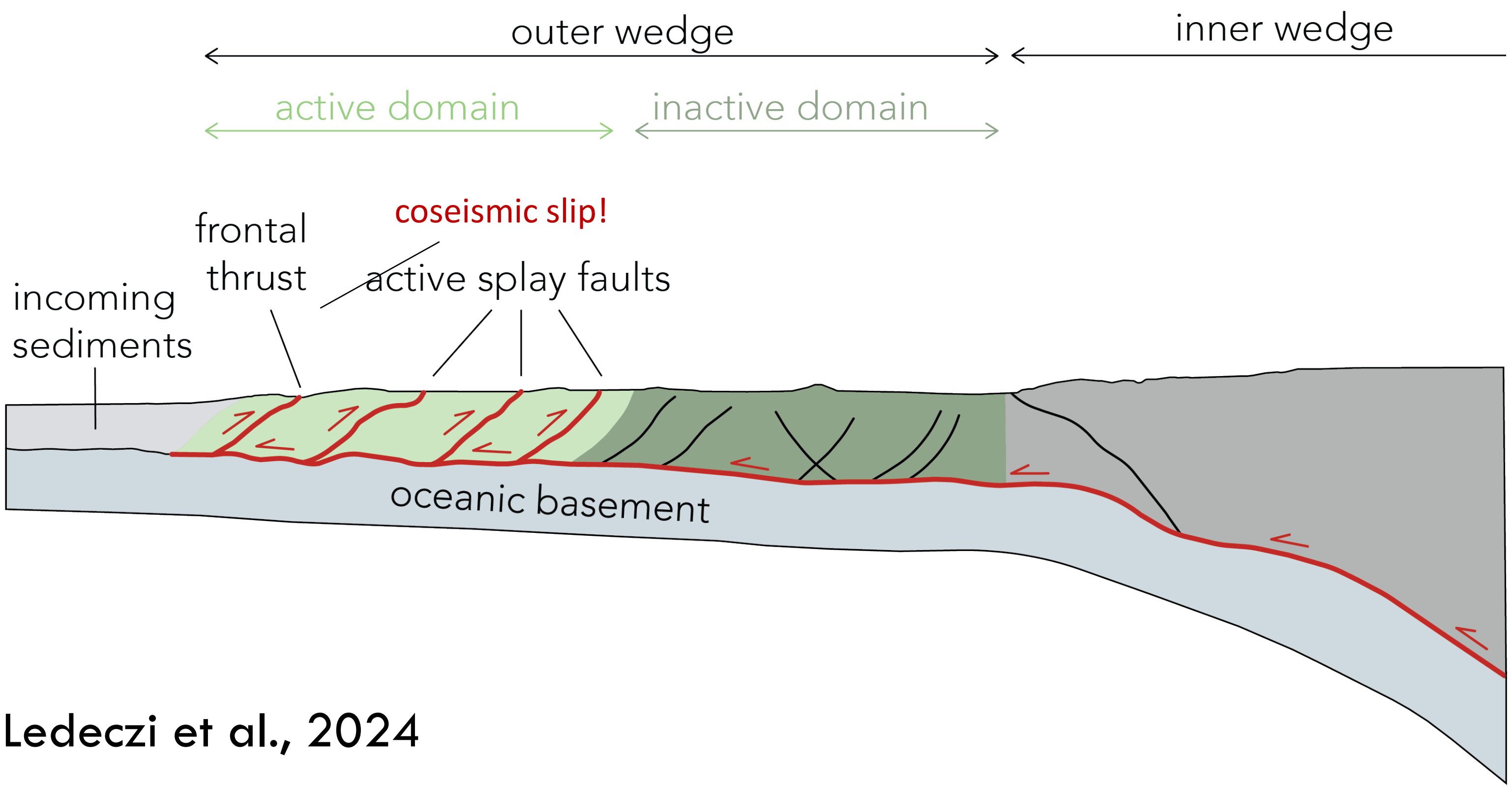


Faults in the active domain are candidates for recent (and therefore future) coseismic slip



- During megathrust events, shallow slip is likely distributed onto multiple landward-vergent splay faults within the active domain of the outer wedge

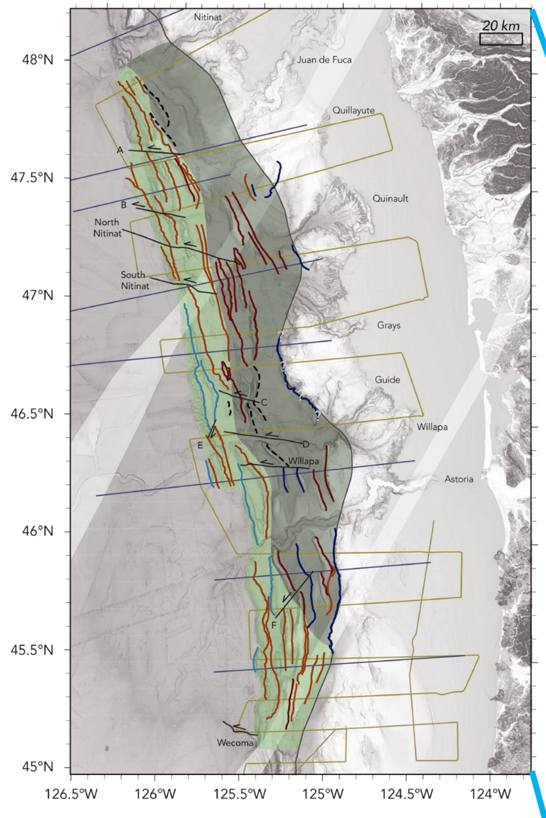
- ***The inner wedge and the inactive domain move as a rigid block***



Ledeczi et al., 2024

Proposed new paradigm for surface faulting offshore

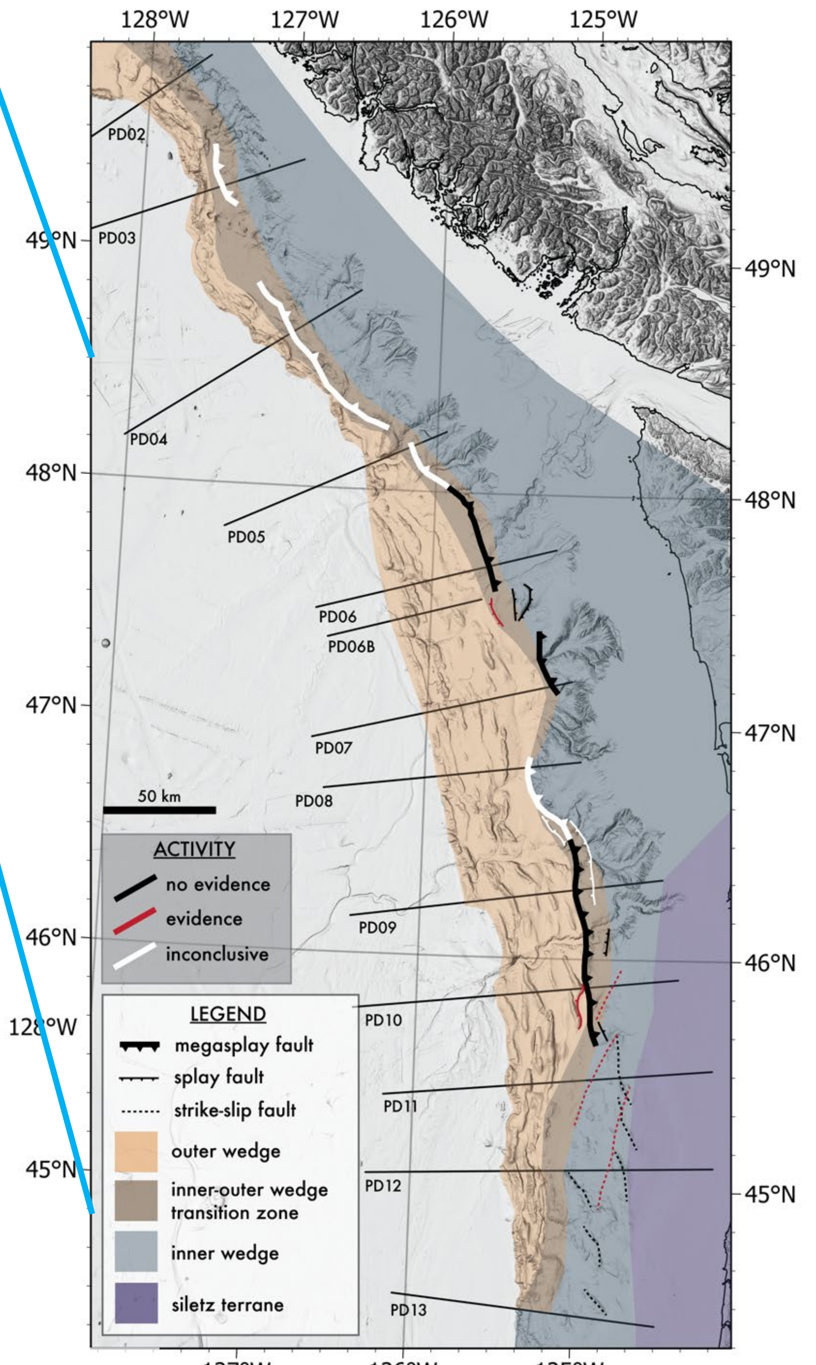
- There is only patchy evidence *at best* for a major megasplay fault – current tsunami scenarios need re-evaluation
- Slip ***is*** likely to occur on multiple shallow splay faults in the outermost ~ 30 km, which may add to seafloor displacement
- These results are being used by the earthquake and tsunami modeling groups in CoPes Hub and influenced ASCE model development



Ledeczi et al., 2024

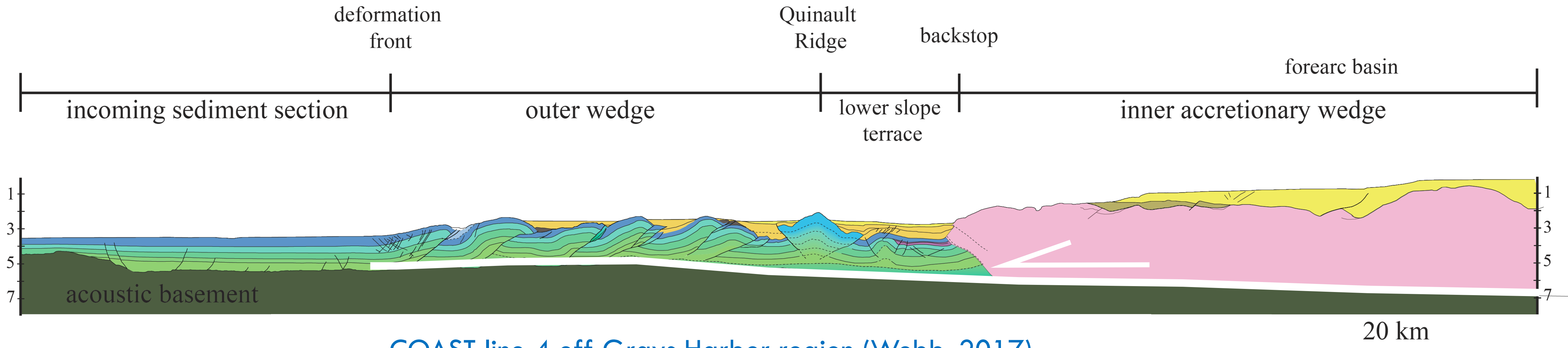
Many recently-active faults in outermost region (light green)

"Megasplay" fault is discontinuous and <u>mostly absent</u>



Lucas et al., in review

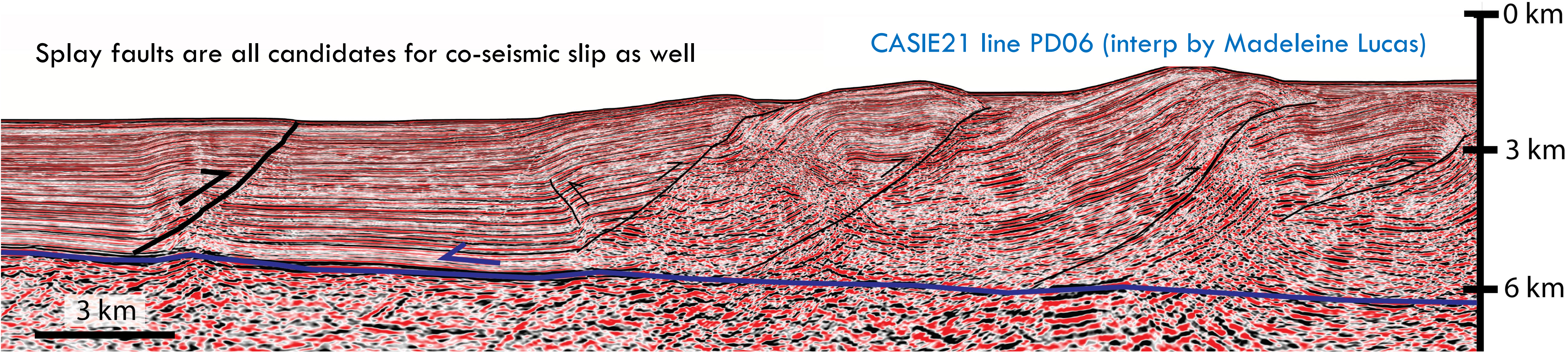
How likely is fast slip to the deformation front?



COAST line 4 off Grays Harbor region (Webb, 2017)

Decollement is the plate boundary, and lies **~3 km** below the surface <u>right at the deformation front</u>

Splay faults are all candidates for co-seismic slip as well

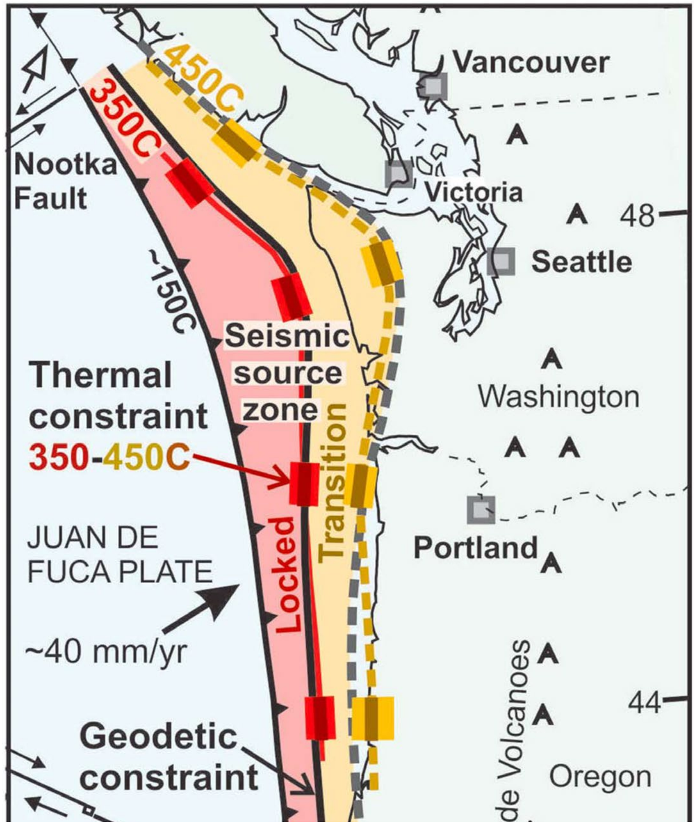


CASIE21 line PD06 (interp by Madeleine Lucas)

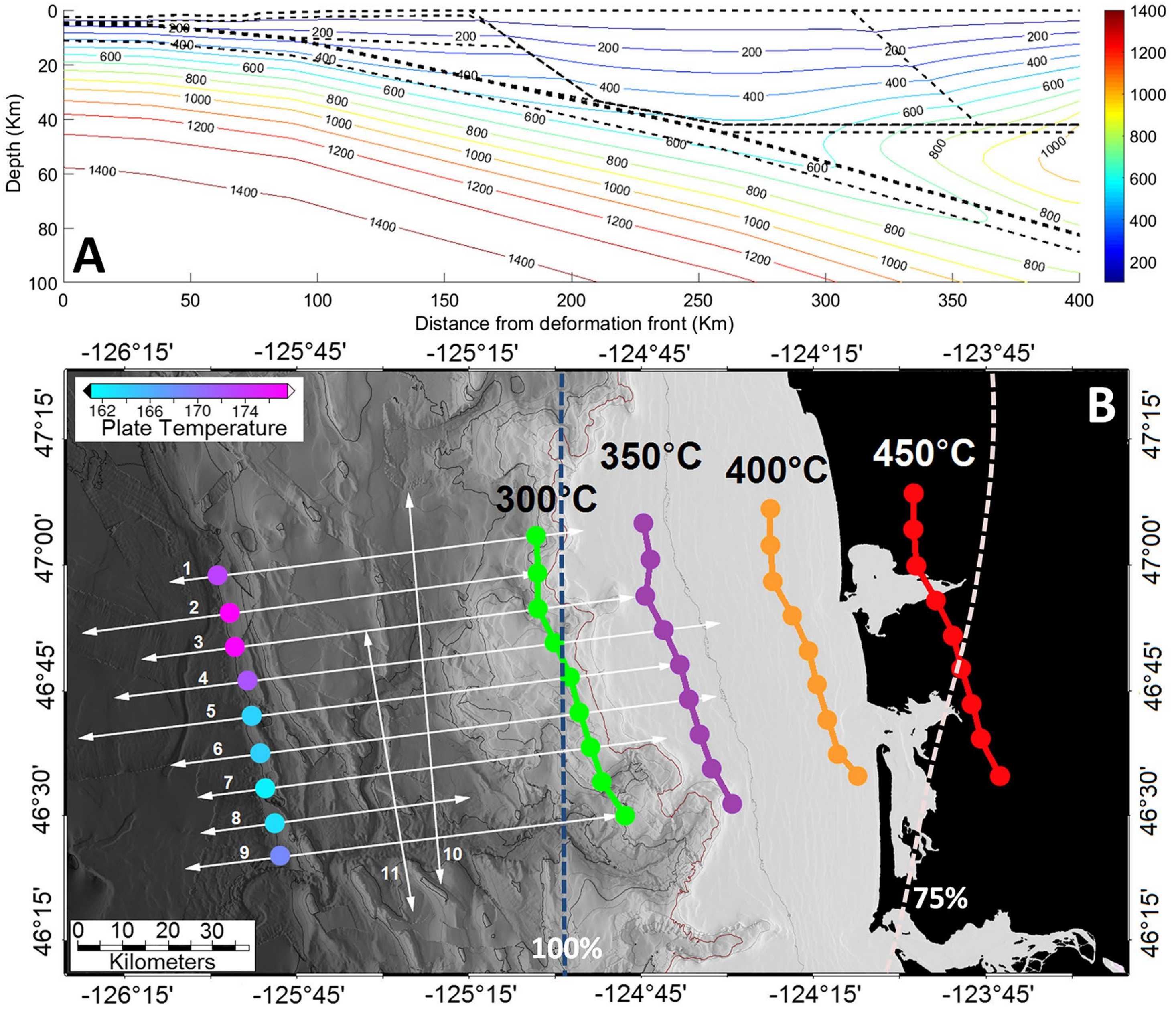
Cascadia thermal models agree that the temperature at the base of the sediment section at the deformation front exceeds ~150°C

→ At the DF, **T = ~170°C**

→ Heat flow = **110 mW/m²**



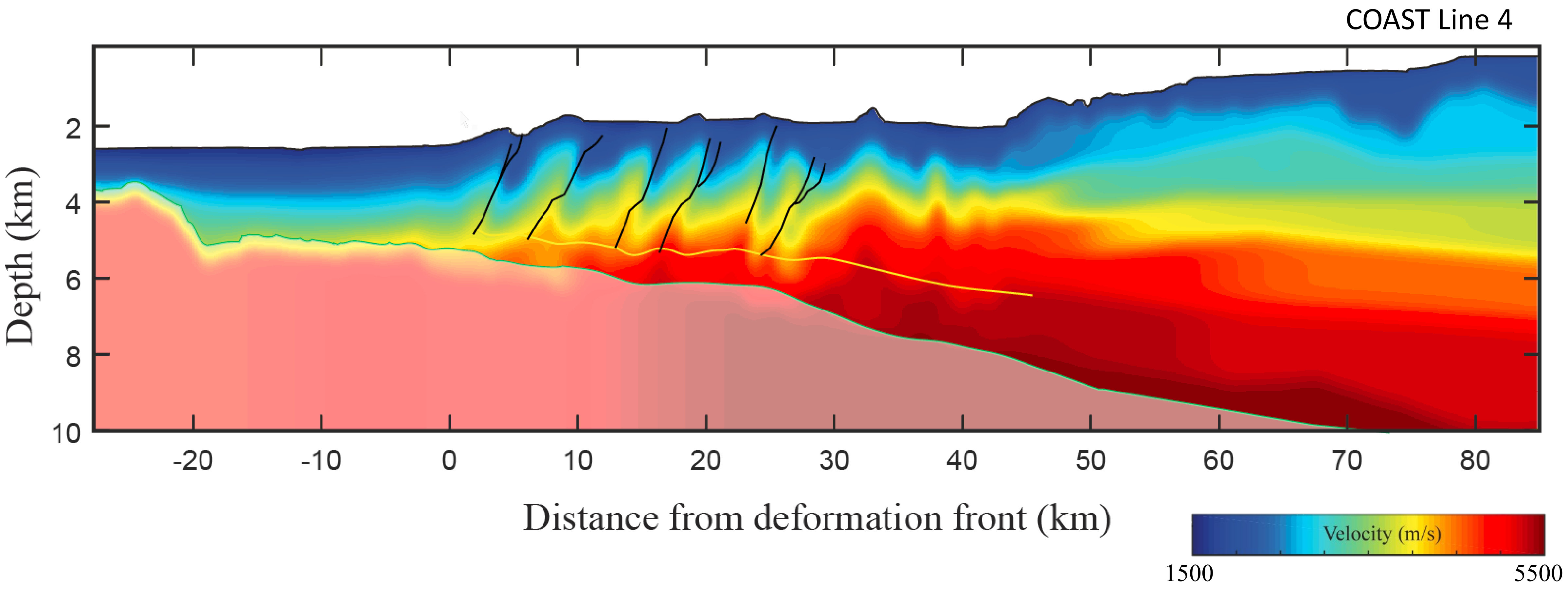
Hyndman et al., 1995, 2015



Salmi et al., 2017

Are the rocks lithified?

Seismic interval velocity from horizon-based tomography for Prestack Depth Migration

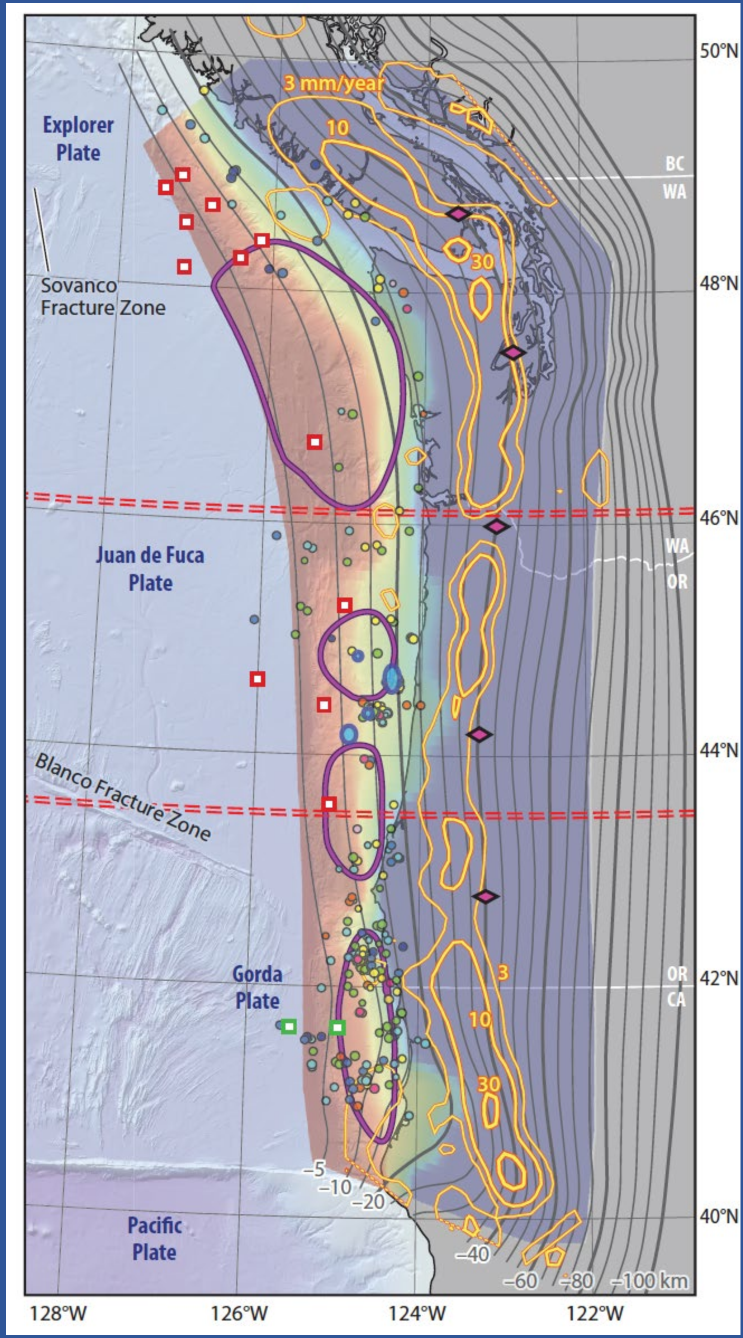


Decollement at the front is high Vp: $\geq 4000\ m/s$

PSDM by Susanna Webb, 2017

Is seismogenic slip to the deformation front likely? *YES*

- In the landward vergent zone at the deformation front, the megathrust is ~3 kilometers deep and at 160 - 180° C or more.
- There's little to no evidence for elevated pore pressure, seismic velocity is high, and porosity is low. It's <u>rock</u>, not sediment.
- For the quartz & feldspar (+clay) lithology along the fault, conditions are therefore met for likely frictional locking and rate-state instability.
- This is true of conditions on the splay faults at depth as well.
- **<u>Locking</u> to the "trench" is much more likely than not … and <u>slip</u> to the "trench" is extremely likely.**



Walton et al., 2021

Some Key Points

- Plate interface differs from Slab2 with more variable dip and along-strike steps suggesting segmentation of the megathrust
- North-central Cascadia is "locked and loaded" – most likely ***all the way to the trench***
- There is scant evidence for a major megasplay fault at the inner-outer wedge boundary – dominant tsunami scenarios need re-evaluation
- Slip *is*, however, likely to propagate up multiple splay faults in the outermost ~ 30 km, displacing the surface