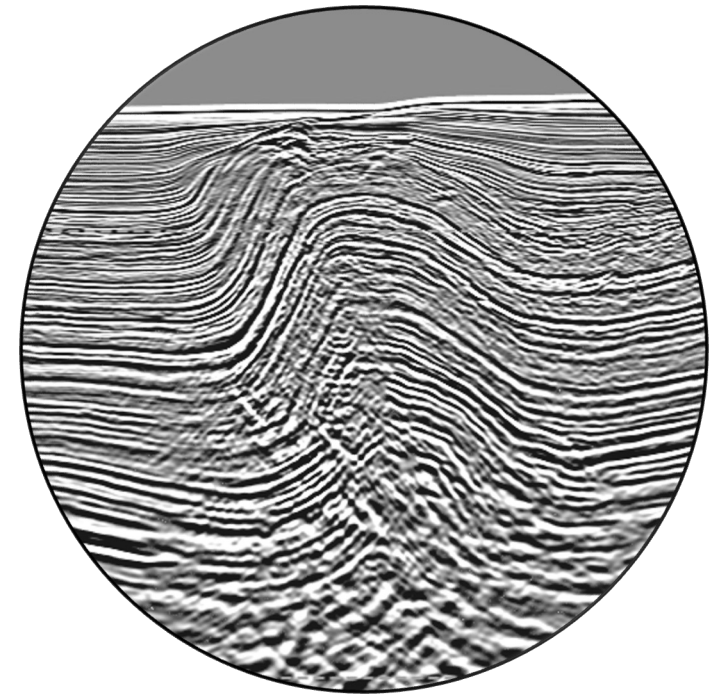


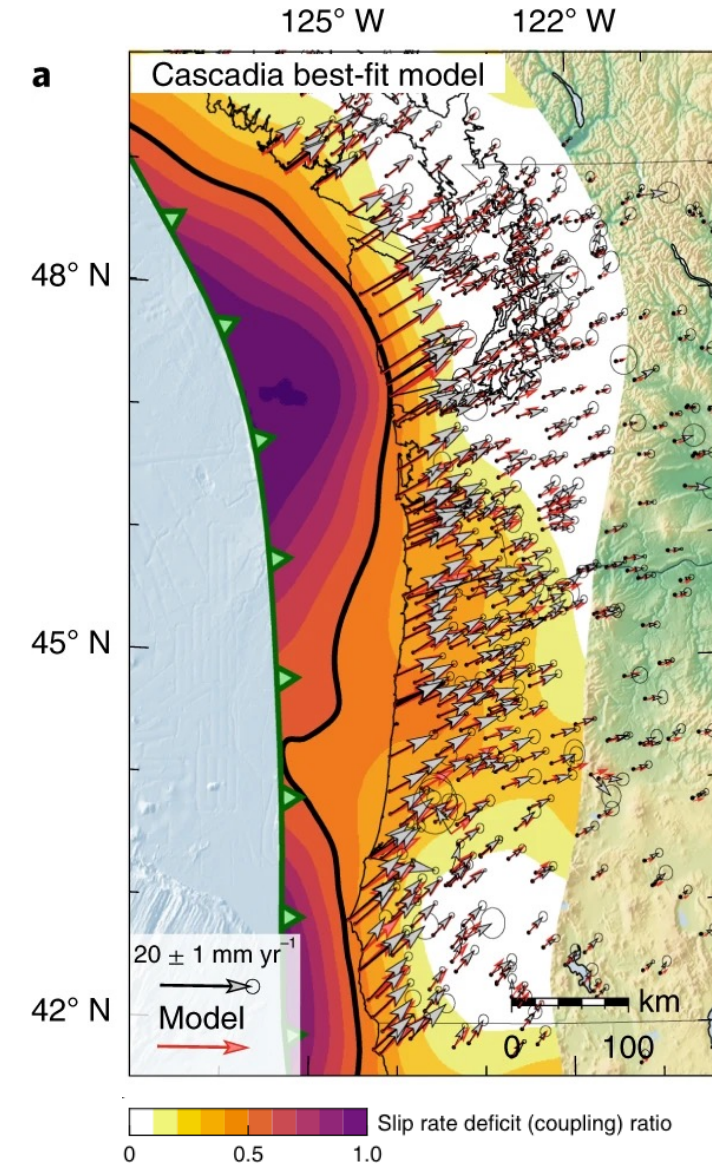
Evidence for active splay faulting and sediment subduction in Cascadia's accretionary wedge

Anna Ledeczi

*with Harold Tobin, Madeleine Lucas, Nathan Miller, Janet Watt,
and the CASIE21 Team*

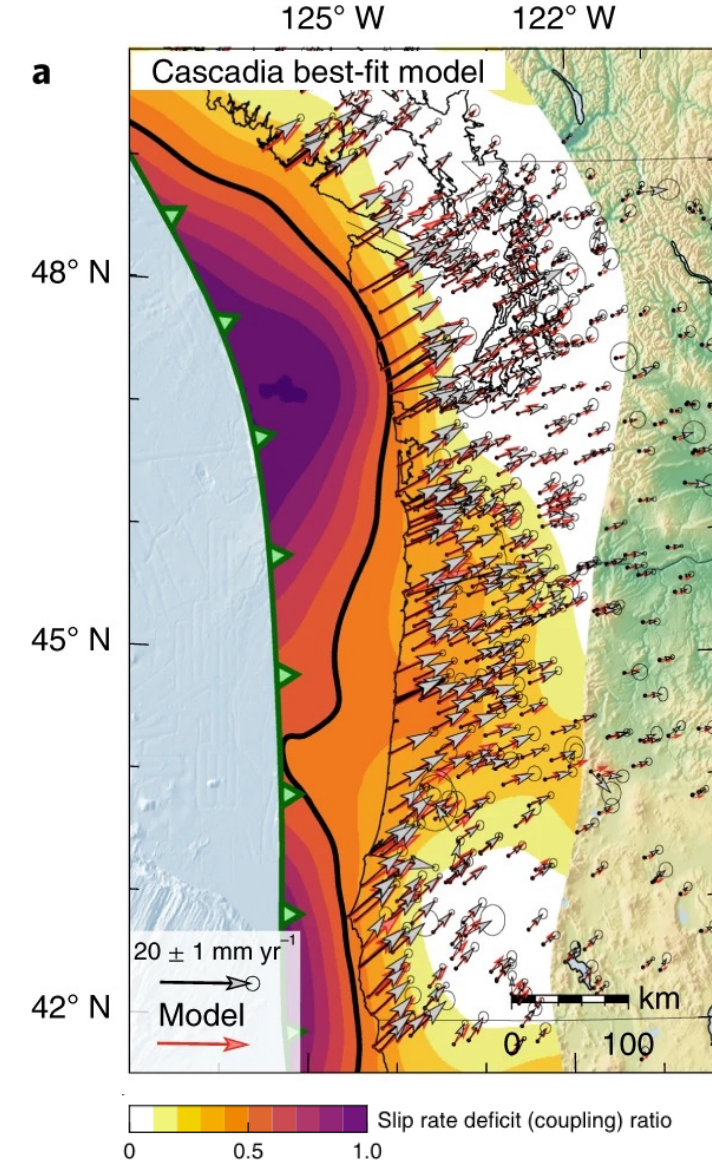


Central Cascadia is primed for slip to the trench



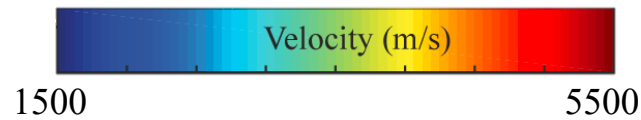
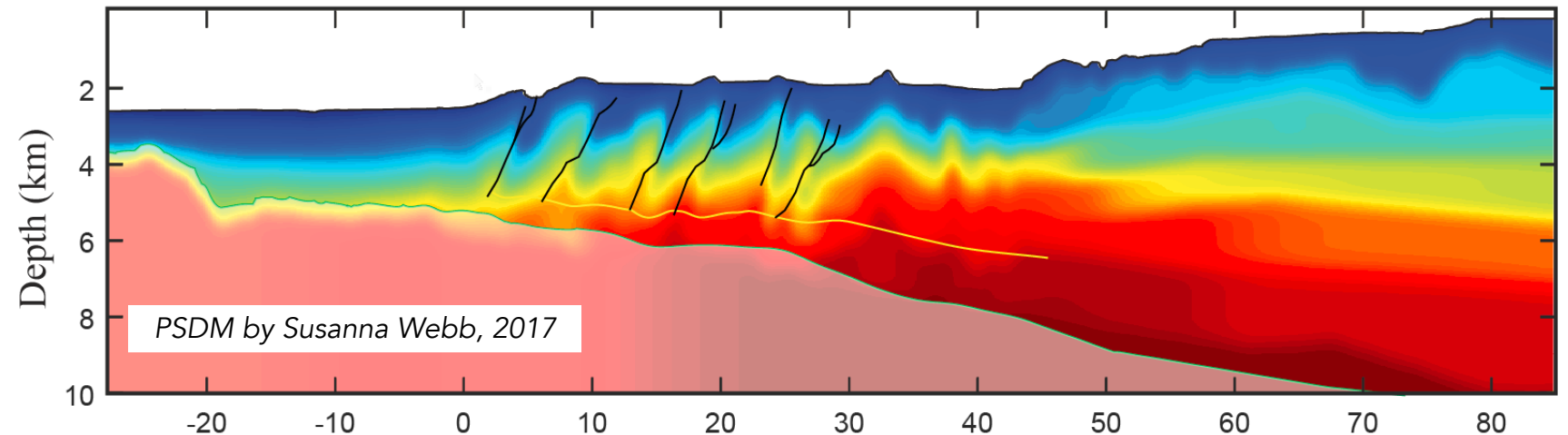
- Offshore WA: the largest highly-locked region of Cascadia
- Thick incoming plate sedimentary sequence, high wedge top sedimentation
- Temperature at the plate interface at the deformation front exceeds 150°C (seismogenic)

Central Cascadia is primed for slip to the trench



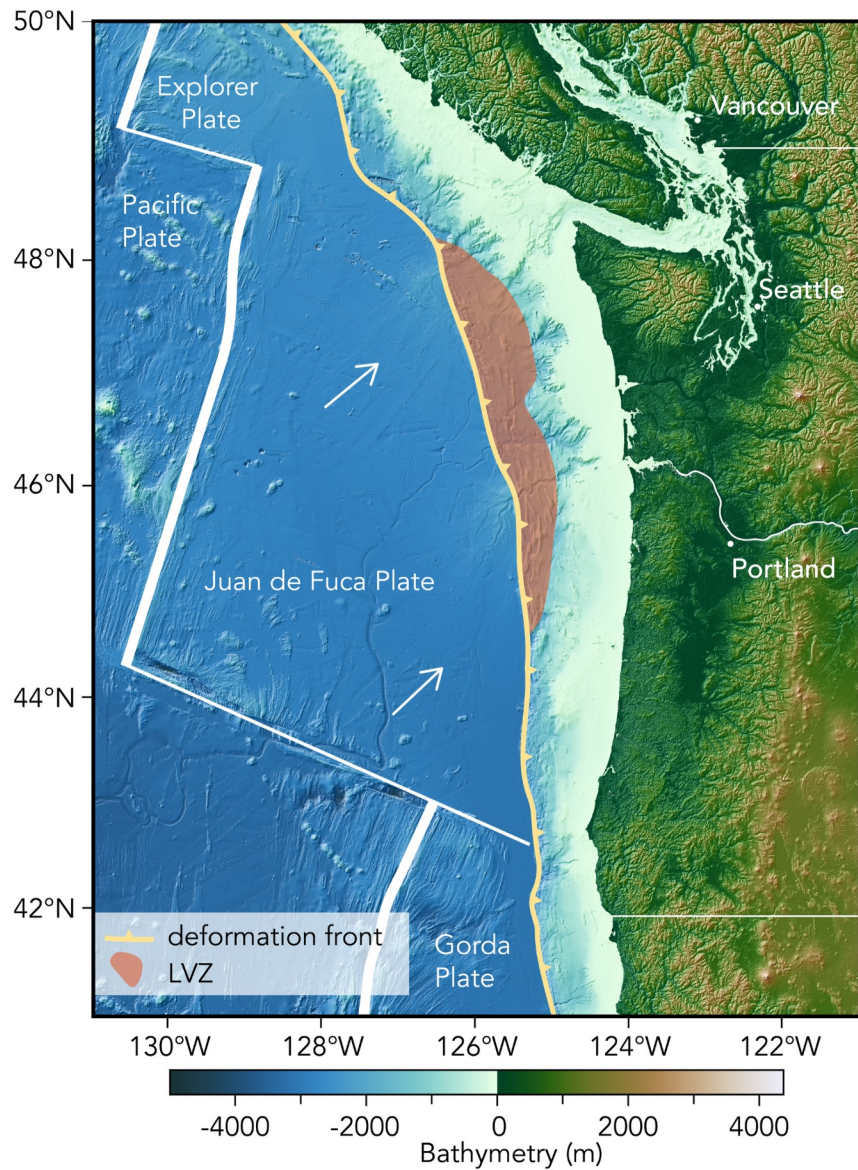
Lindsey et al., 2021

- Offshore WA: the largest highly-locked region of Cascadia
- Thick incoming plate sedimentary sequence, high wedge top sedimentation
- Temperature at the plate interface at the deformation front exceeds 150°C (seismogenic)
- Incoming sediments are well-lithified and strong
- All factors suggest slip to the trench is likely in this region

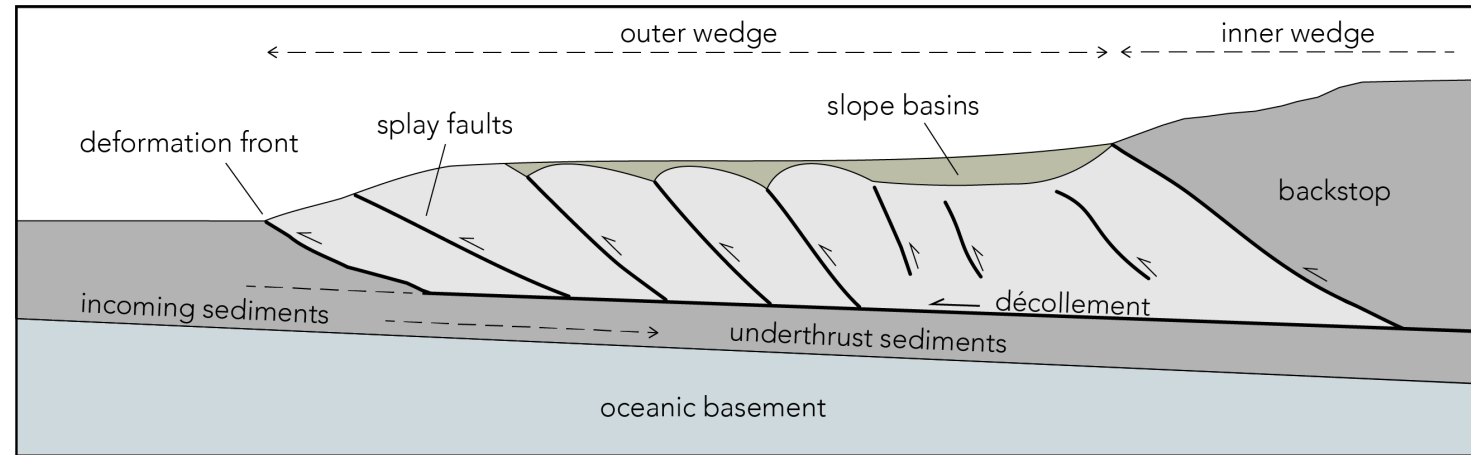


Distance from deformation front (km)

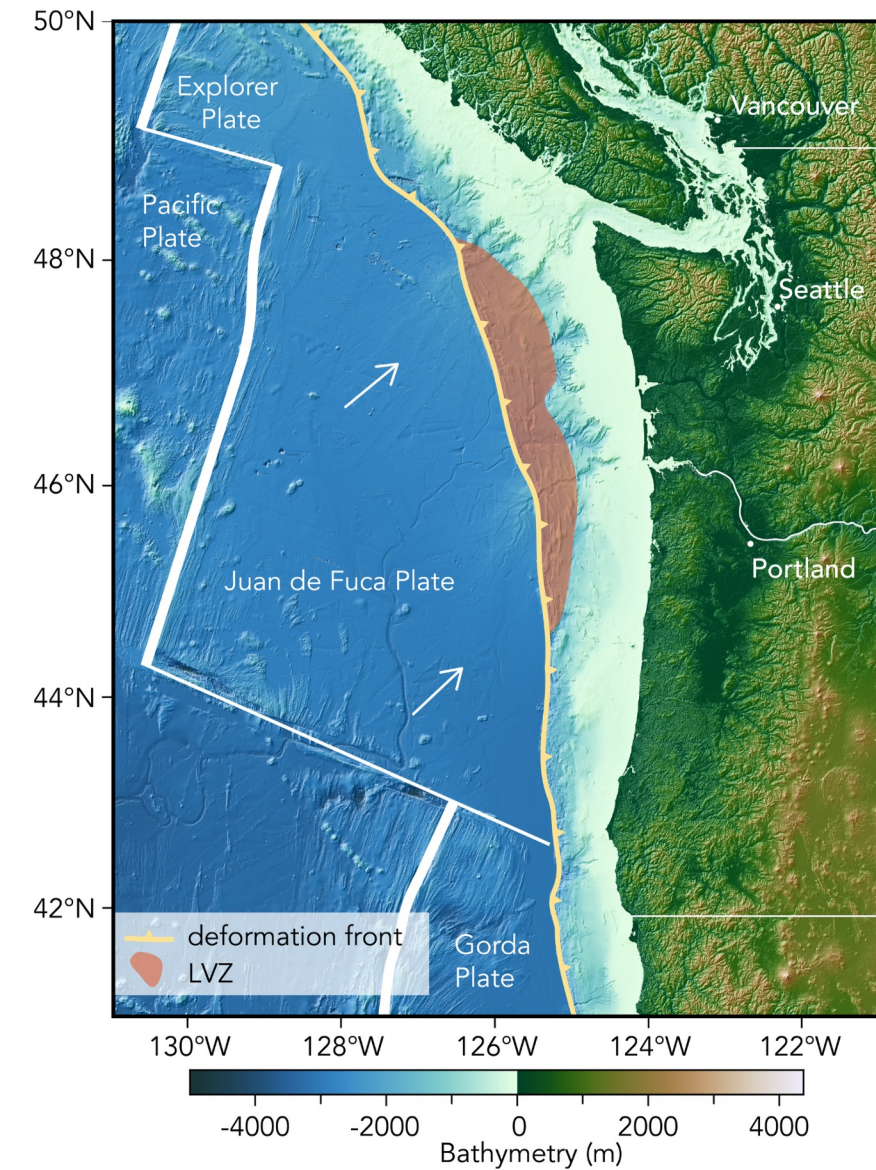
Cascadia's landward vergence zone



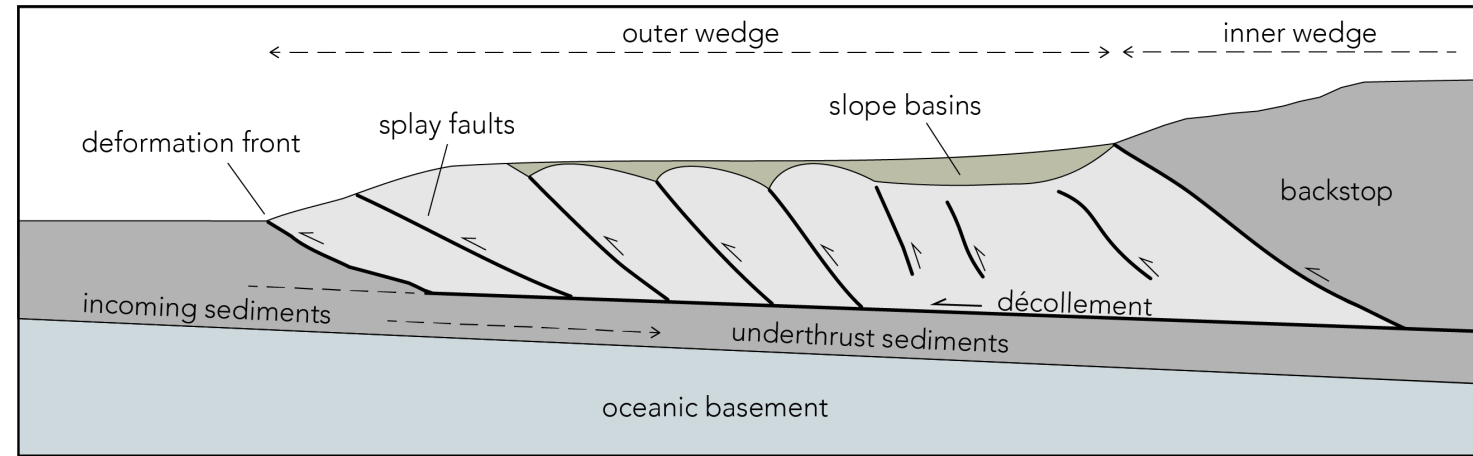
Seaward vergence:



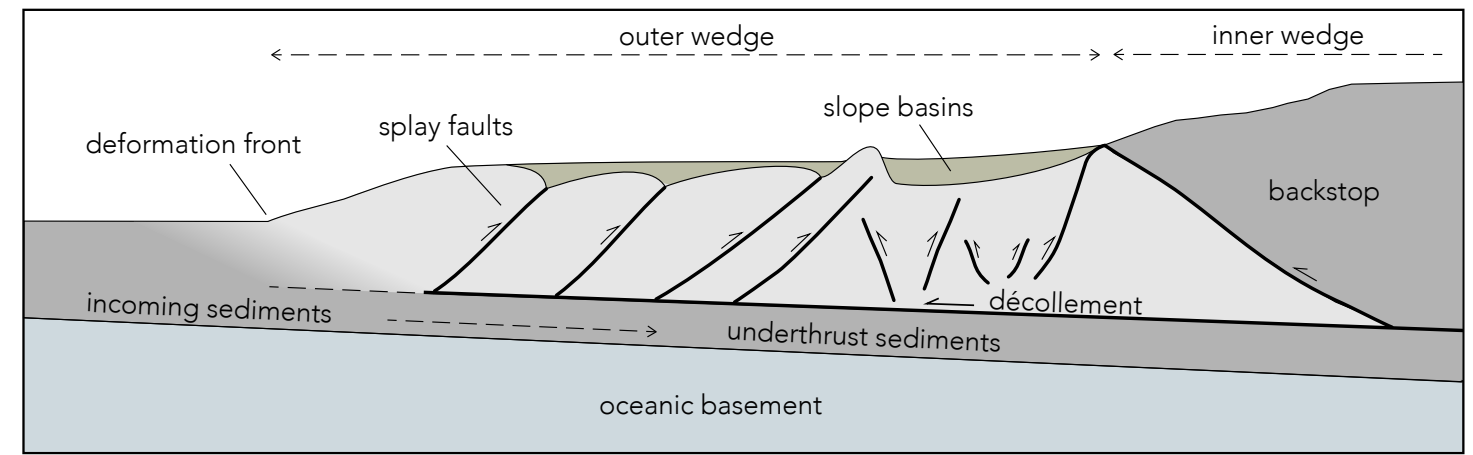
Cascadia's landward vergence zone



Seaward vergence:

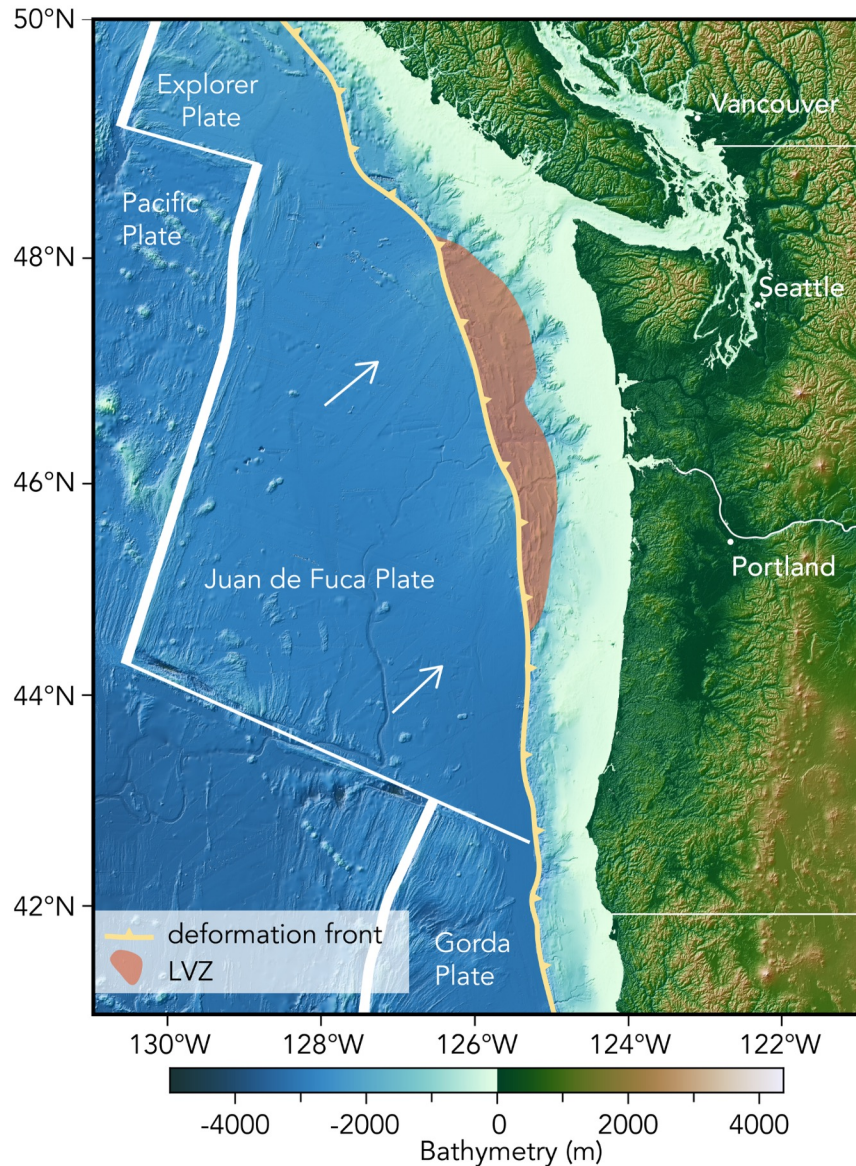


Landward vergence:

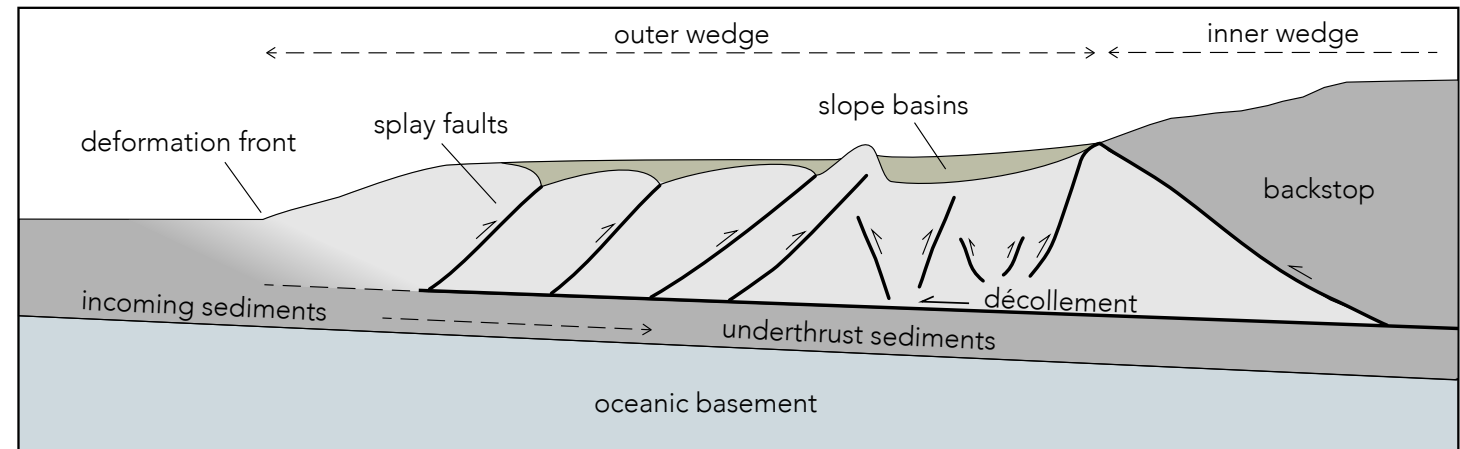


Cascadia's landward vergence zone

If we can better understand accretionary wedge structure and fault activity, we can better understand what to expect in future earthquakes and tsunamis.

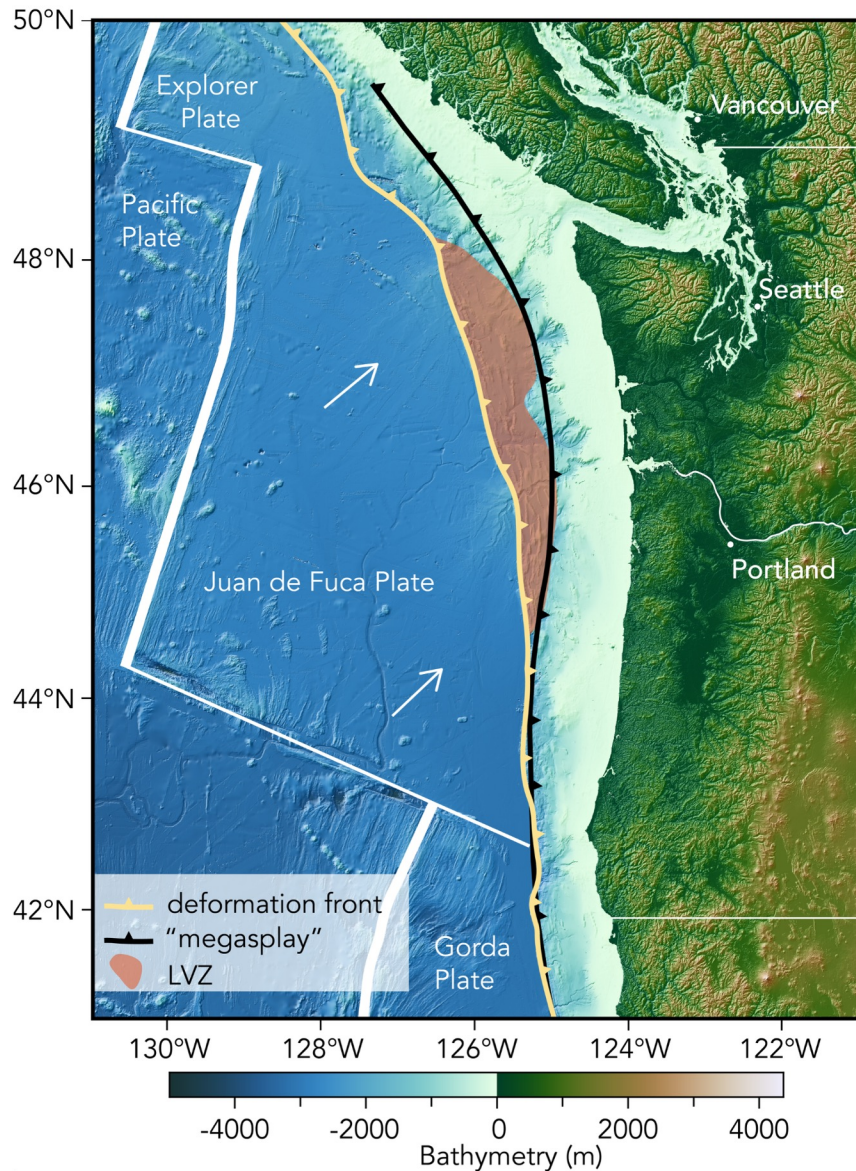


Landward vergence:

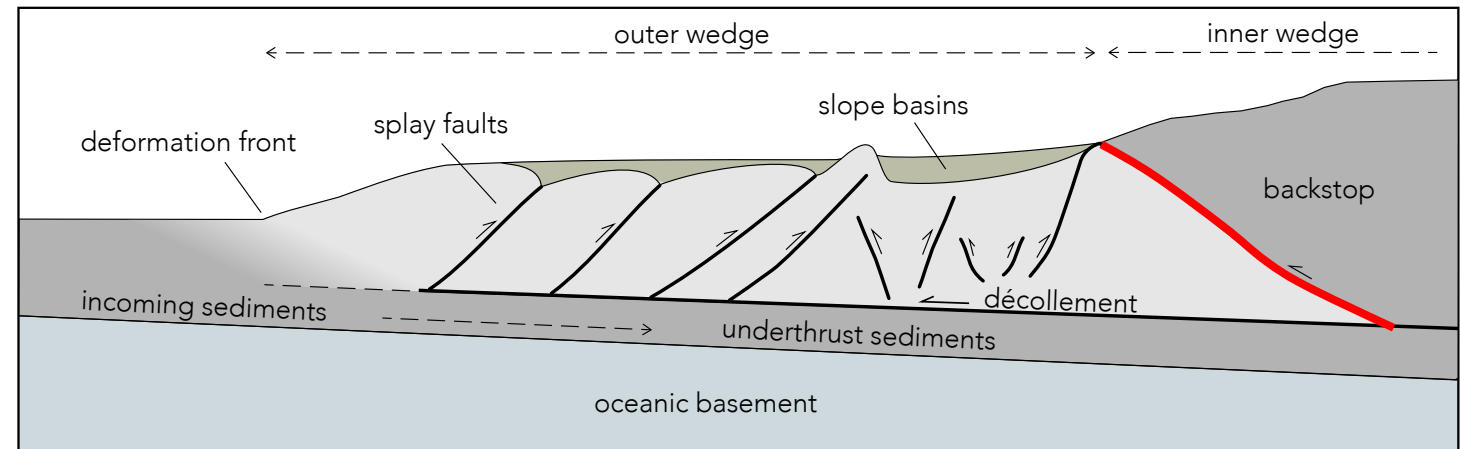


The megasplay model

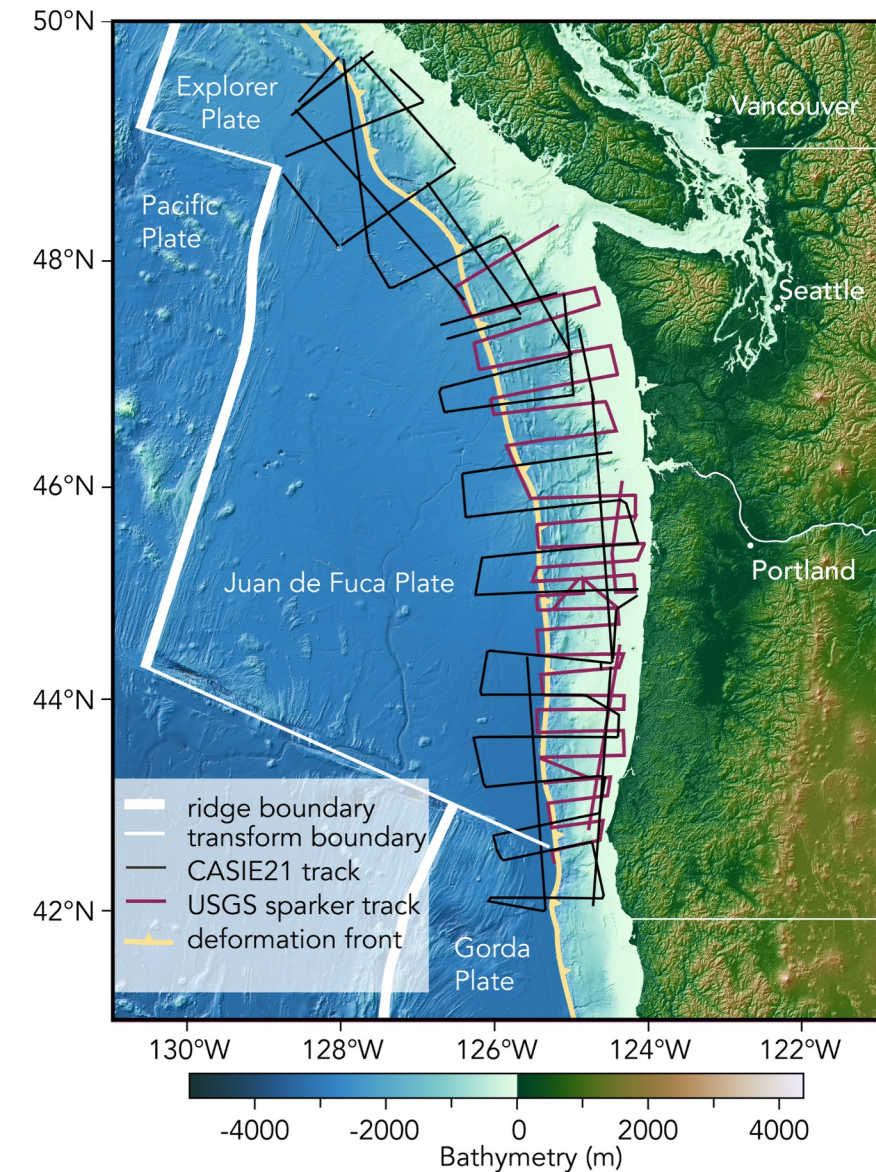
- Current tsunami models and coastal hazards assessments use a “megasplay”
- A large, continuous, and long-lived fault system located at a rheological contrast between wedge domains
- Based on old seismic imaging, simplification, and observations from other subduction zones



Landward vergence:



New seismic reflection data can answer these questions

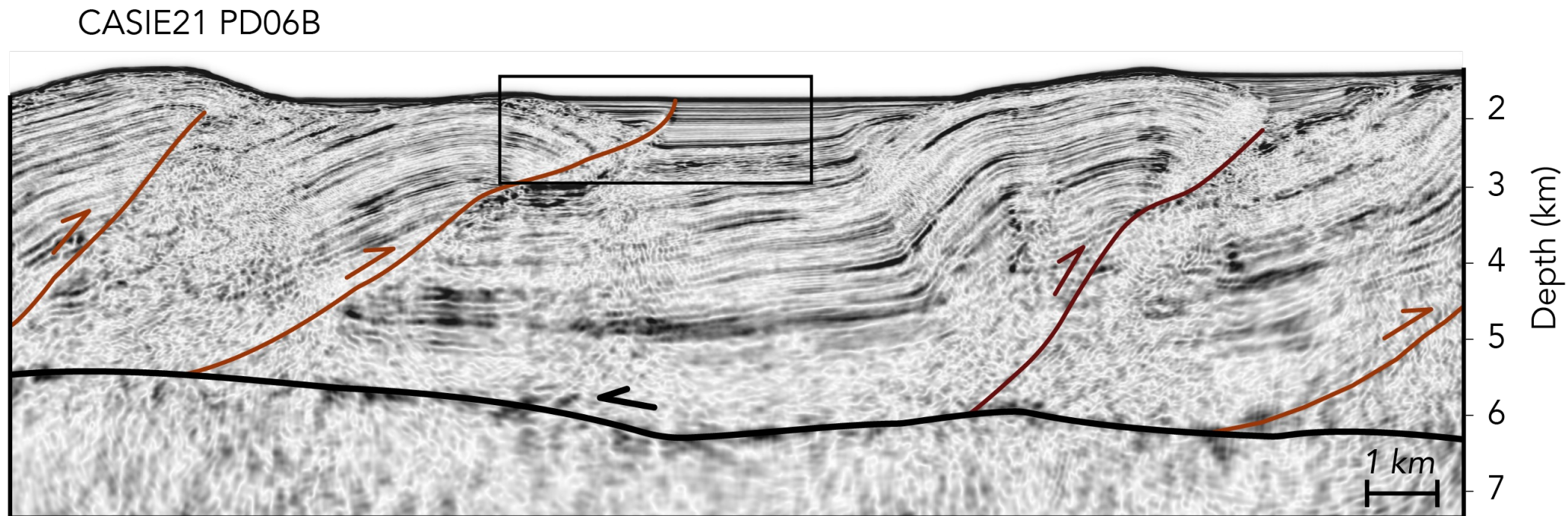


- CASIE21: first modern, regional 2D multi-channel seismic reflection experiment at Cascadia
 - Images >10 km depth
- USGS Sparker: high-resolution imaging
 - Images <1 km depth

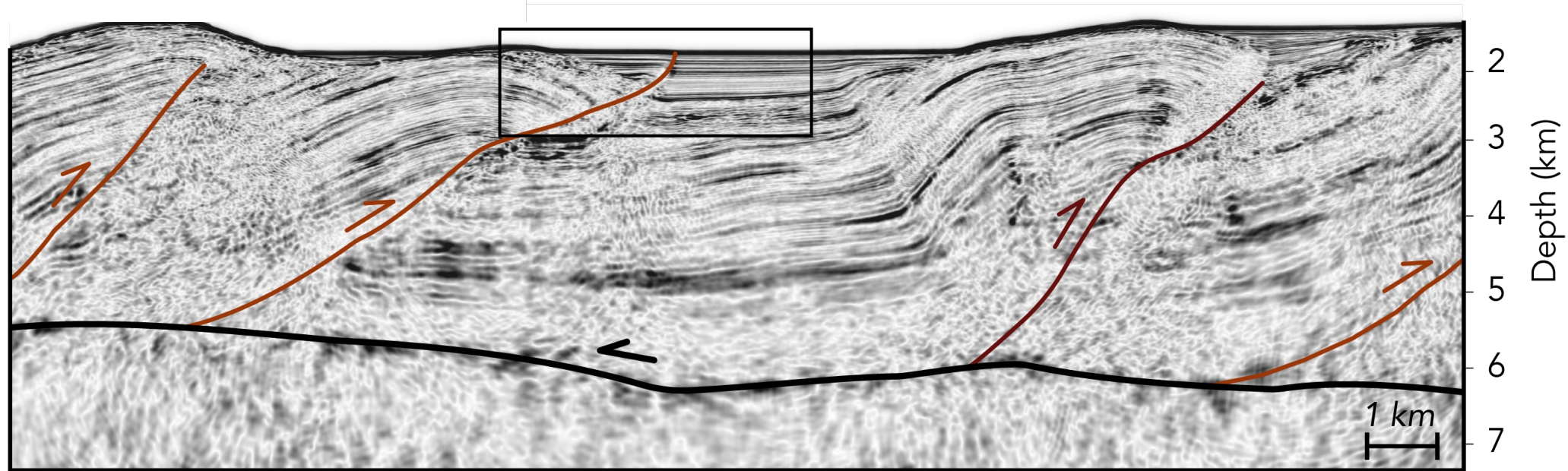
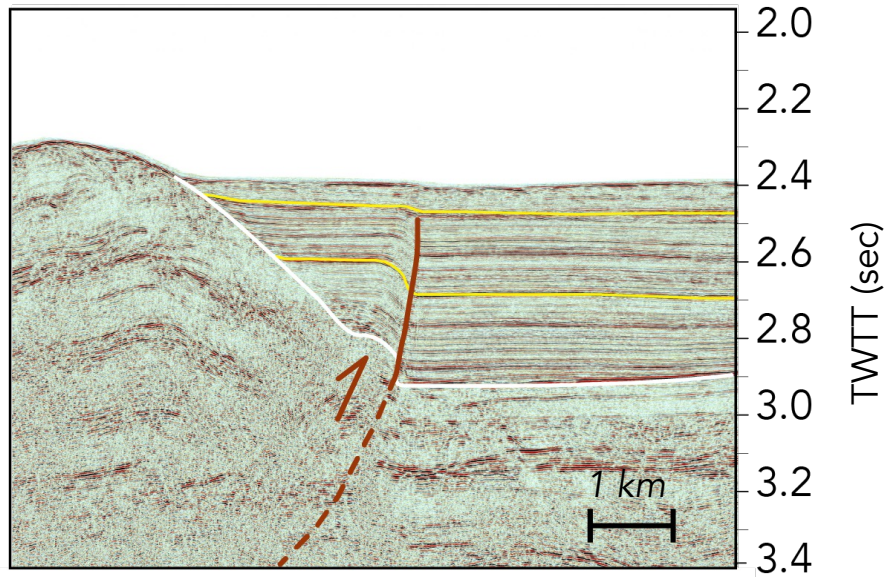
Joint interpretation of near-surface and crustal-scale seismic imaging

- Late Quaternary or “**active**”: since 100 kyr
- Older Quaternary or “**inactive**”: 100 kyr to 2.6 Ma

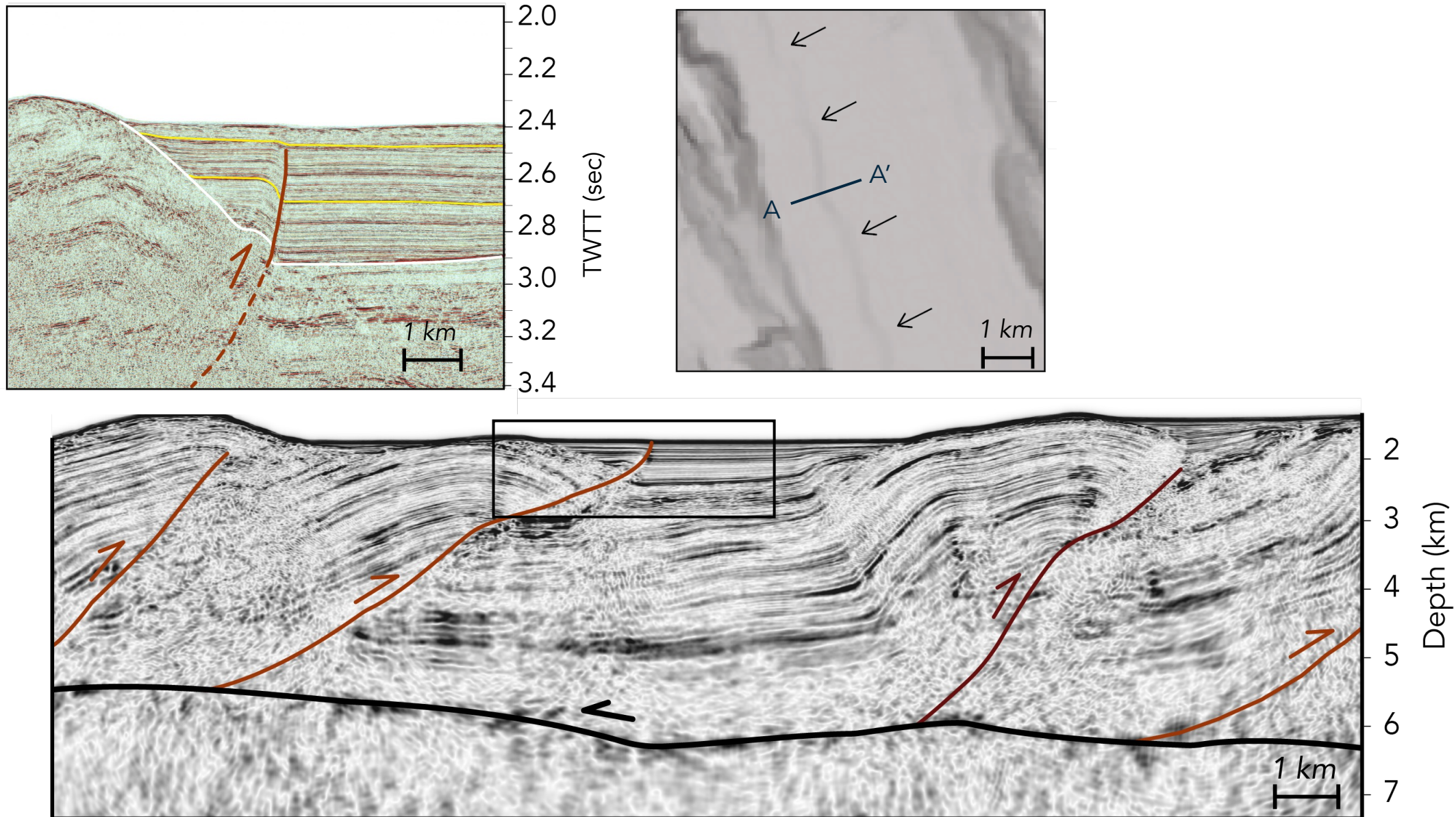
Joint interpretation of near-surface and crustal-scale seismic imaging



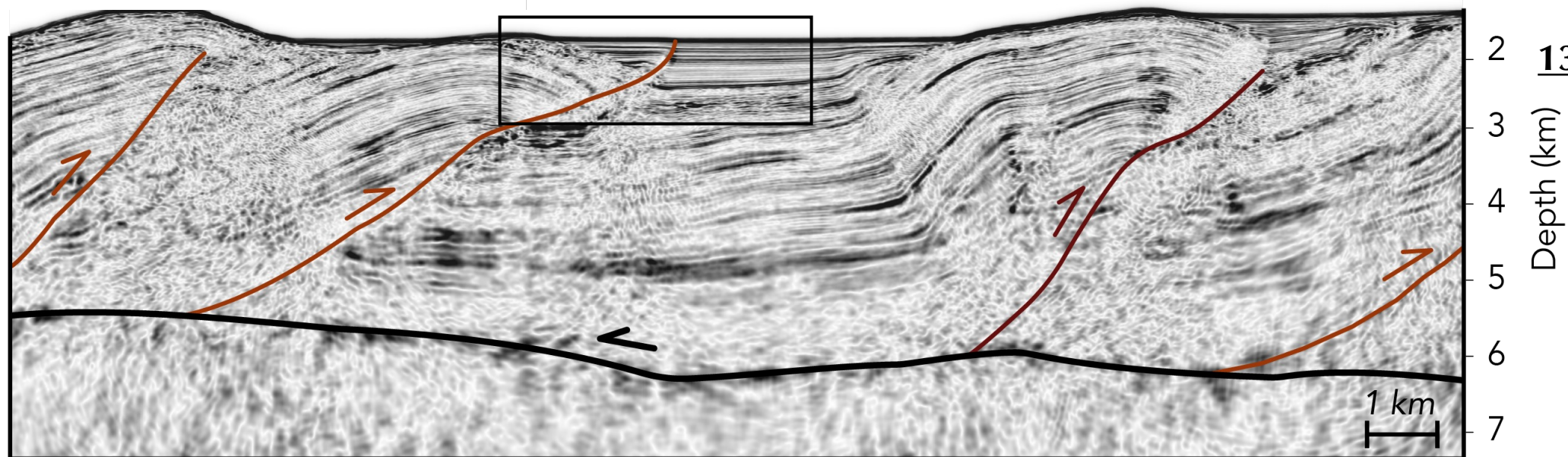
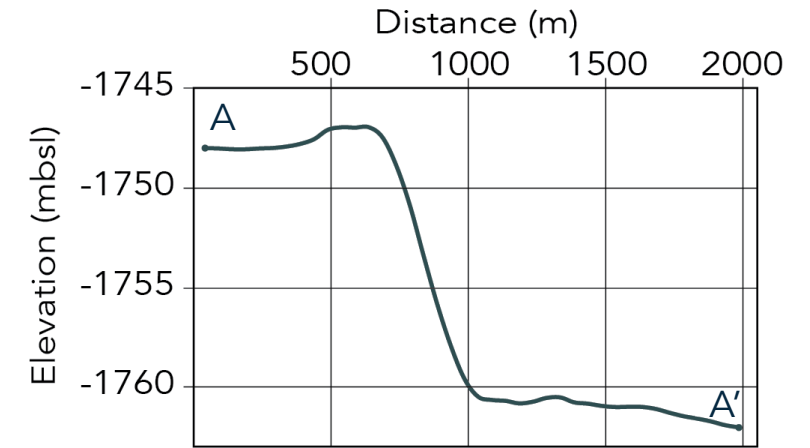
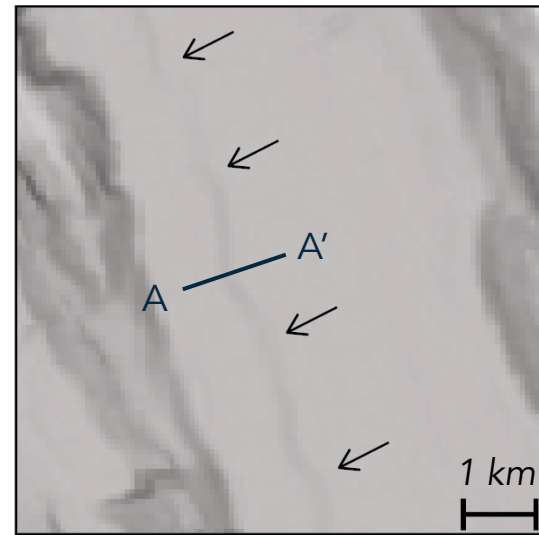
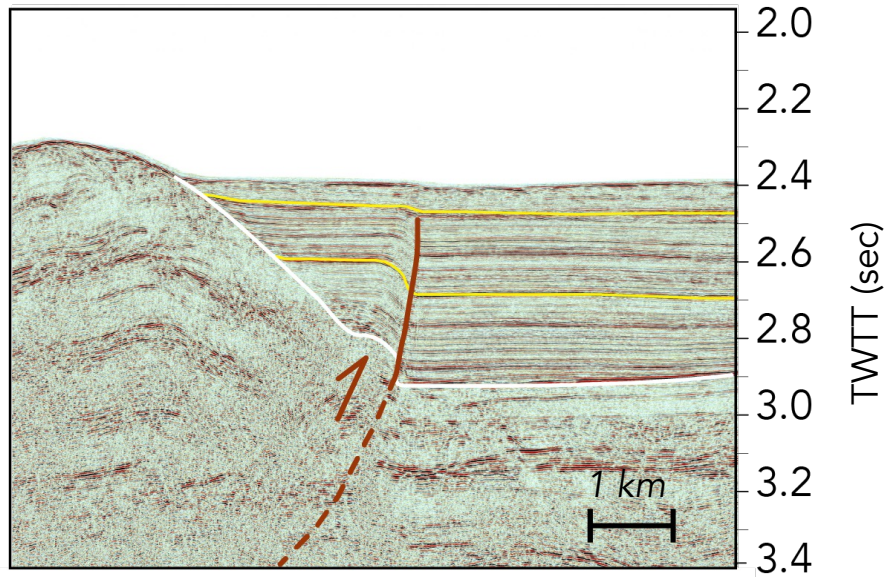
Joint interpretation of near-surface and crustal-scale seismic imaging



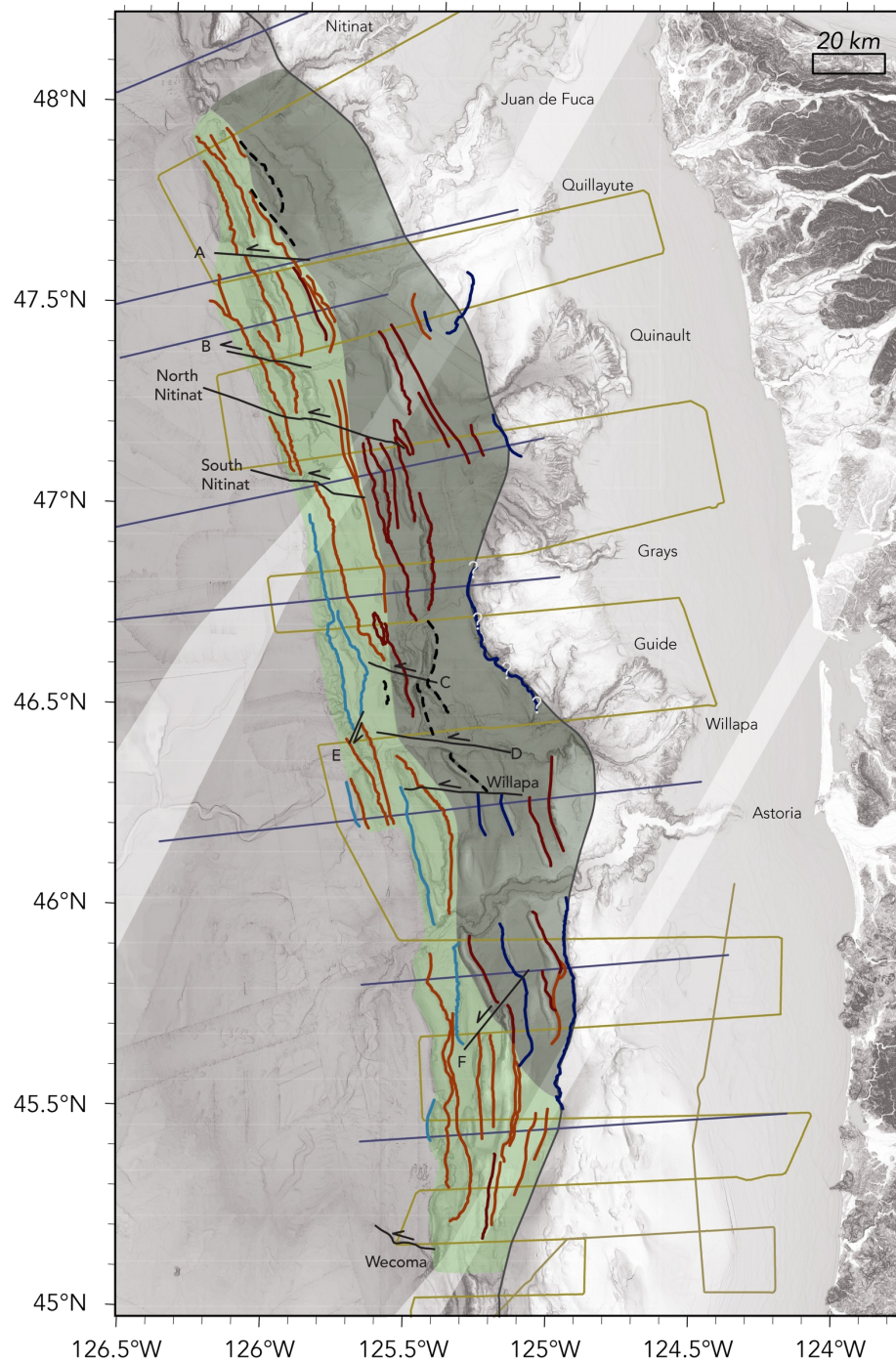
Joint interpretation of near-surface and crustal-scale seismic imaging



Joint interpretation of near-surface and crustal-scale seismic imaging




13 meter scarp!



USGS 2019 tracklines 

CASIE21 tracklines 

Inner-outer wedge boundary (Lucas et al. (in prep)) 

Inferred strike-slip faults 

Inferred thrust faults 

Late Quaternary thrust faults:

 LV  SV

Older thrust faults:

 LV  SV

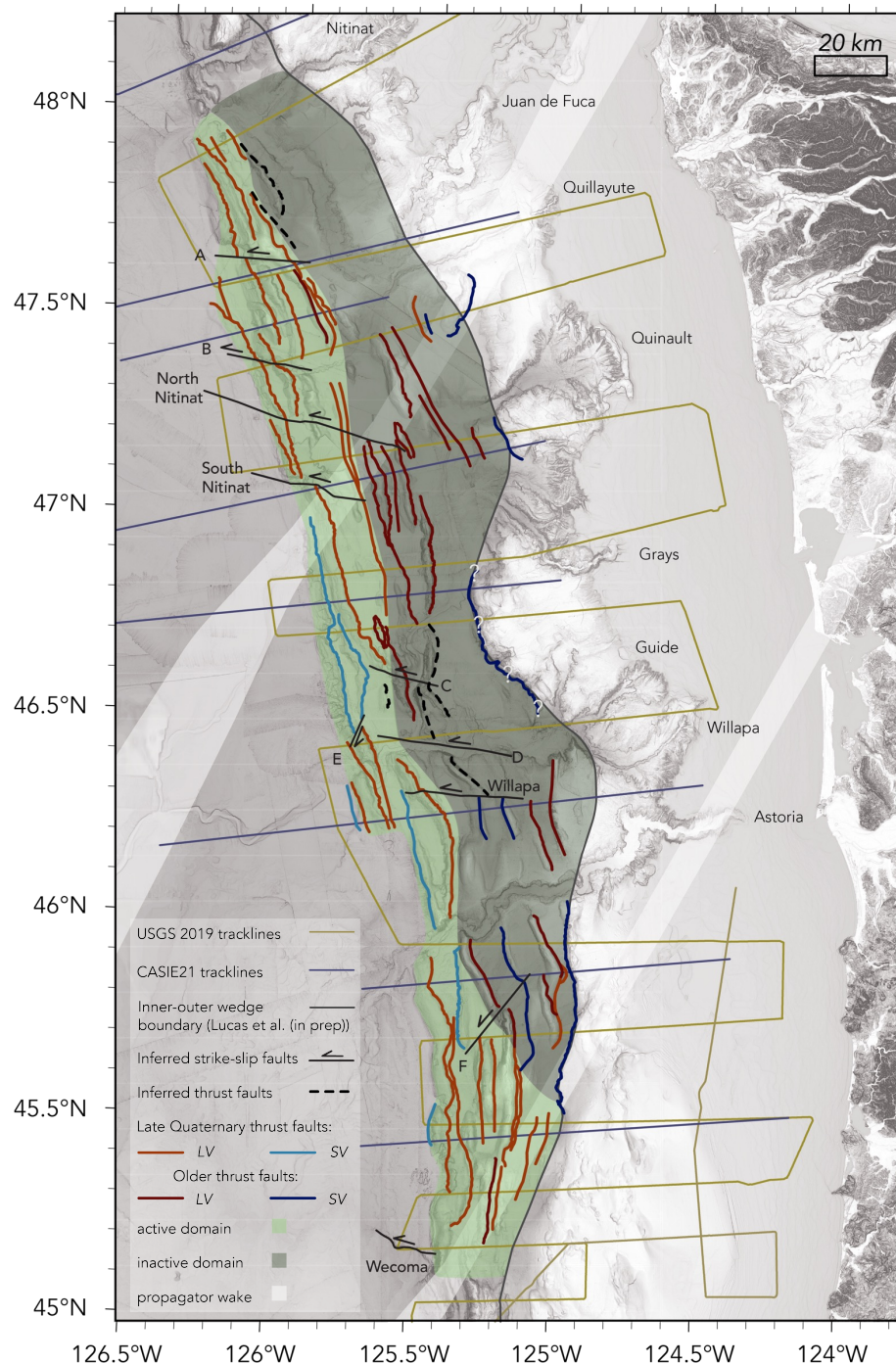
active domain 

inactive domain 

propagator wake

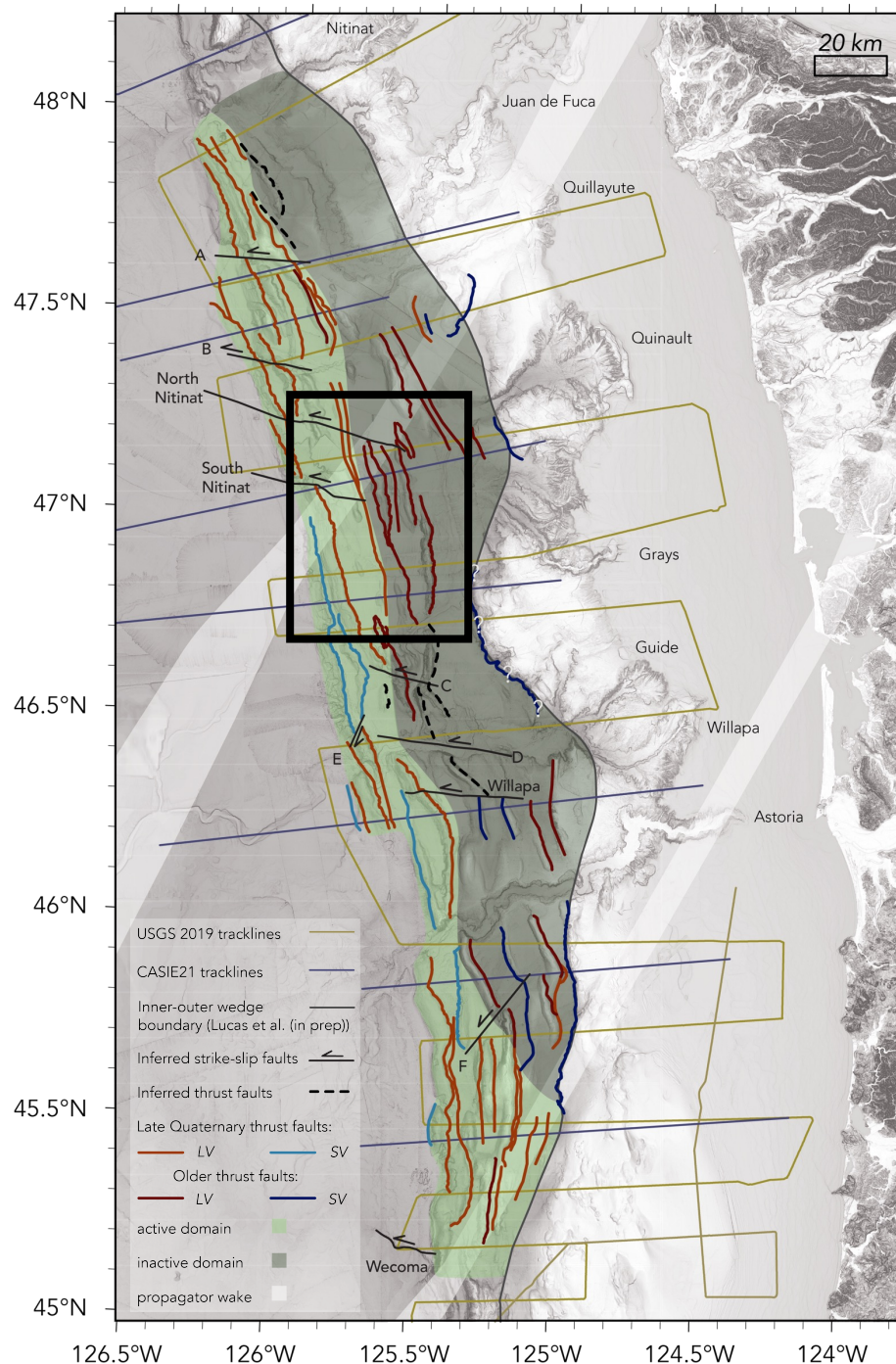
Widespread recent activity of splay faults within ~30 km of the deformation front

- 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
- New data resolution allows to discriminate faults which are actually active
 - Previous work has identified similar faults, but activity was unknown

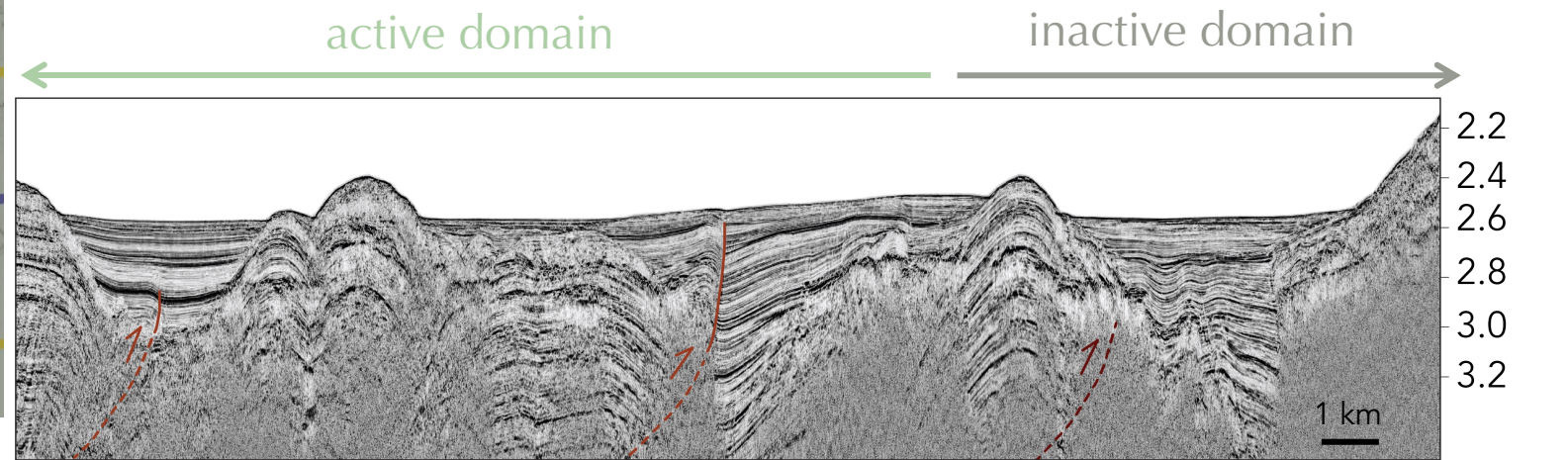
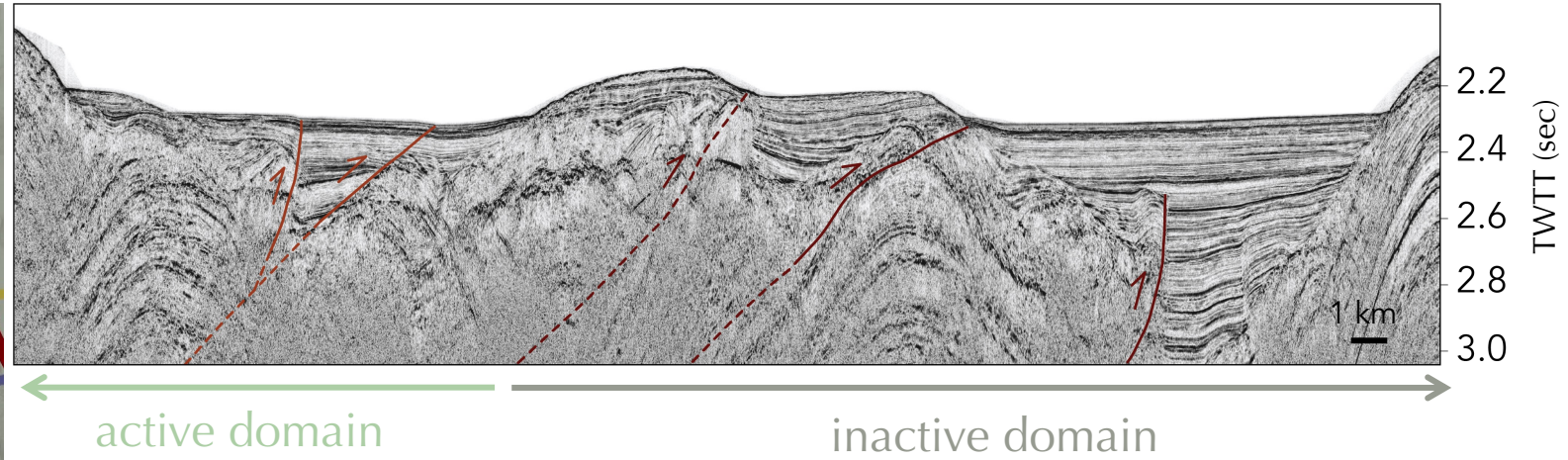


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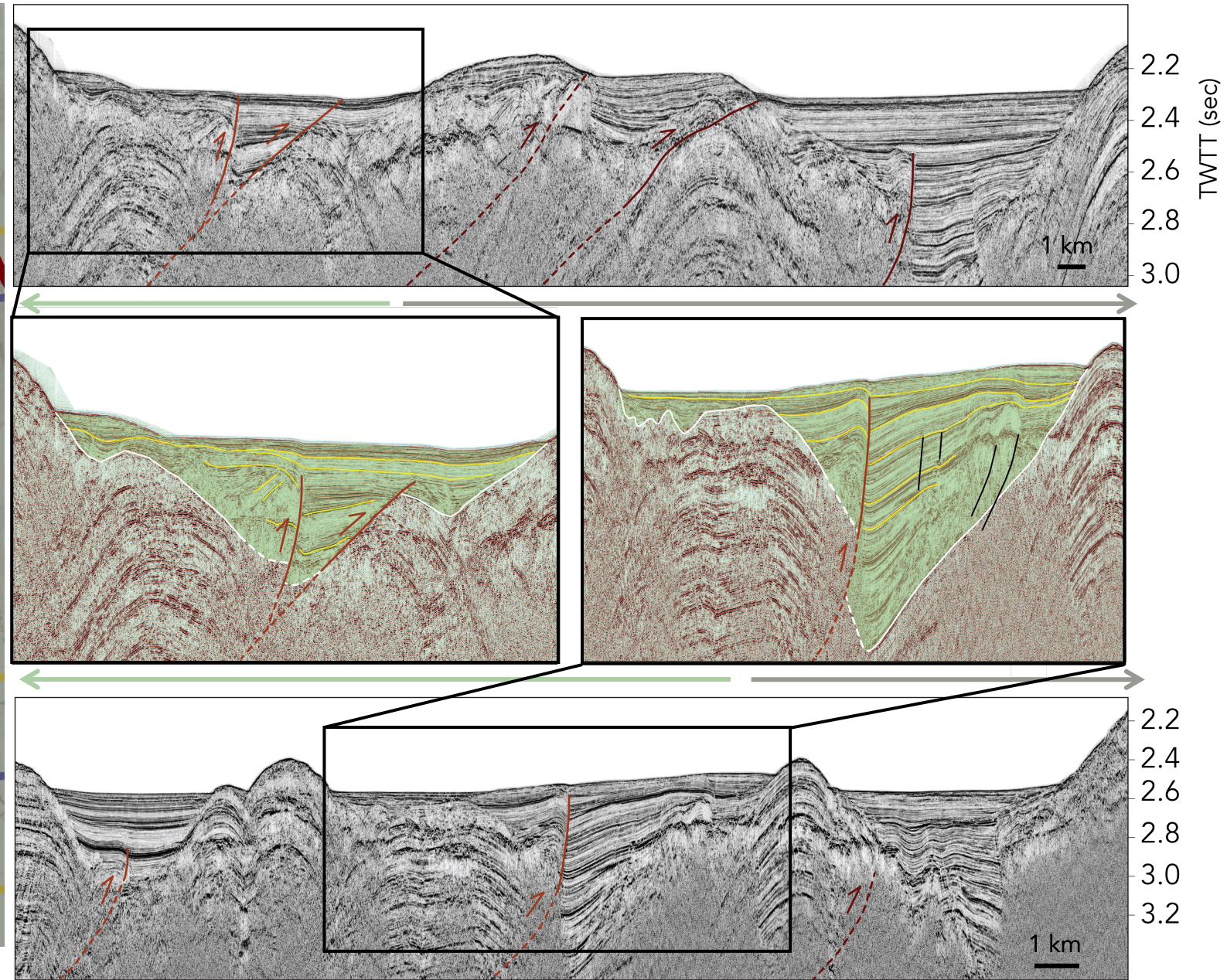


active faults: — LV inactive faults: — LV

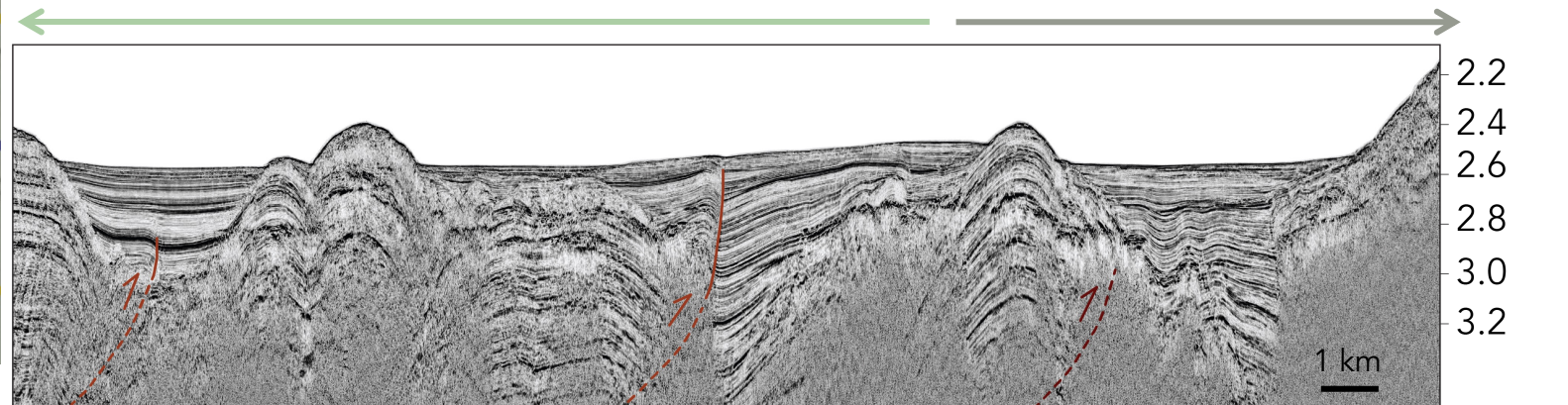
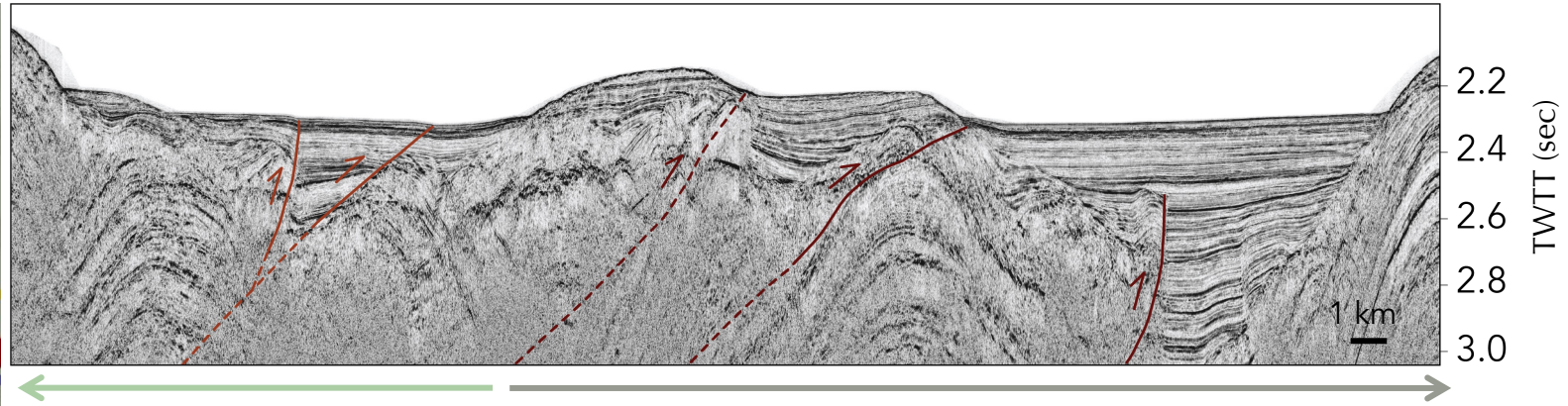


The active domain

■ syndeformational ■ postdeformational
active faults: — LV inactive faults: — LV

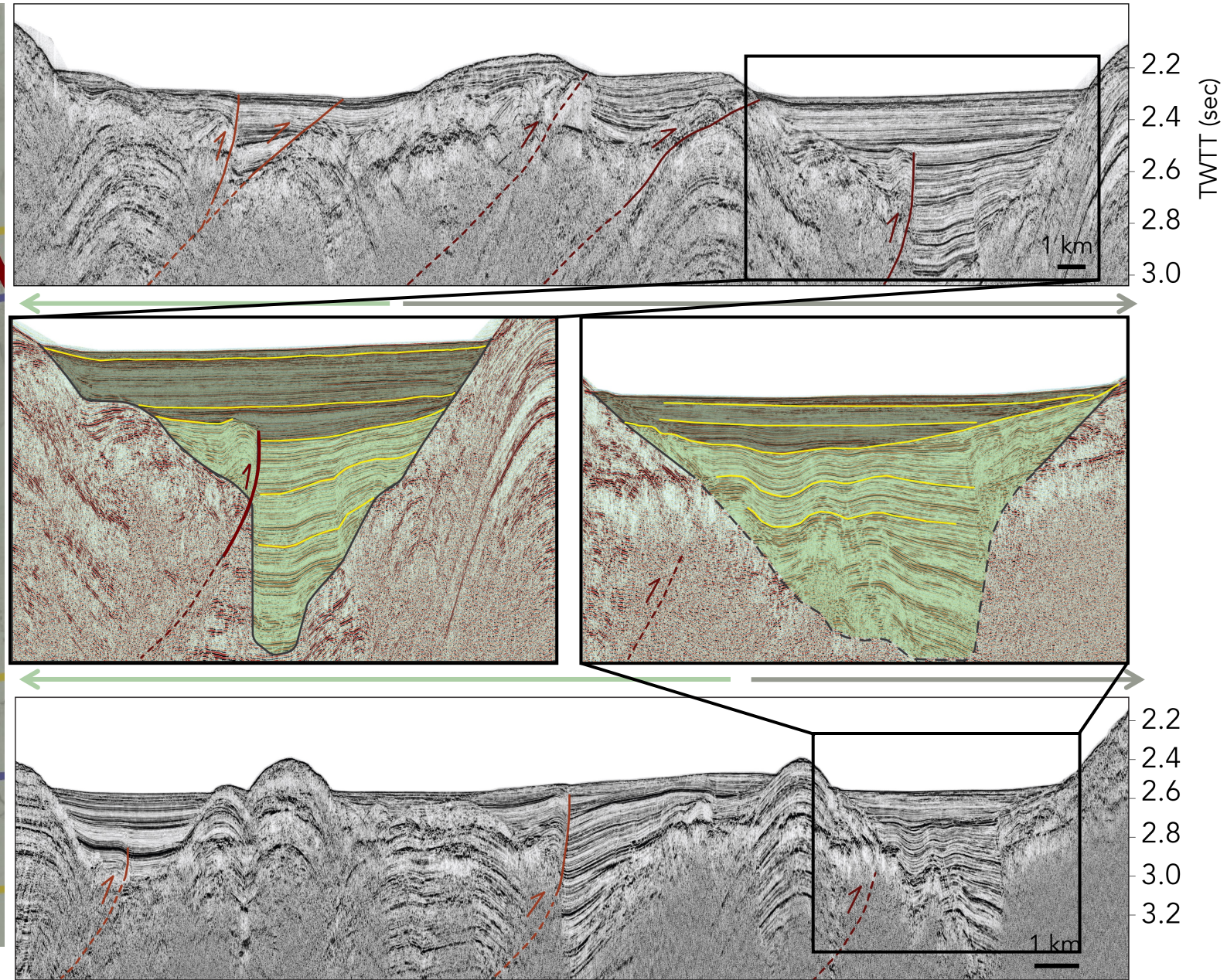
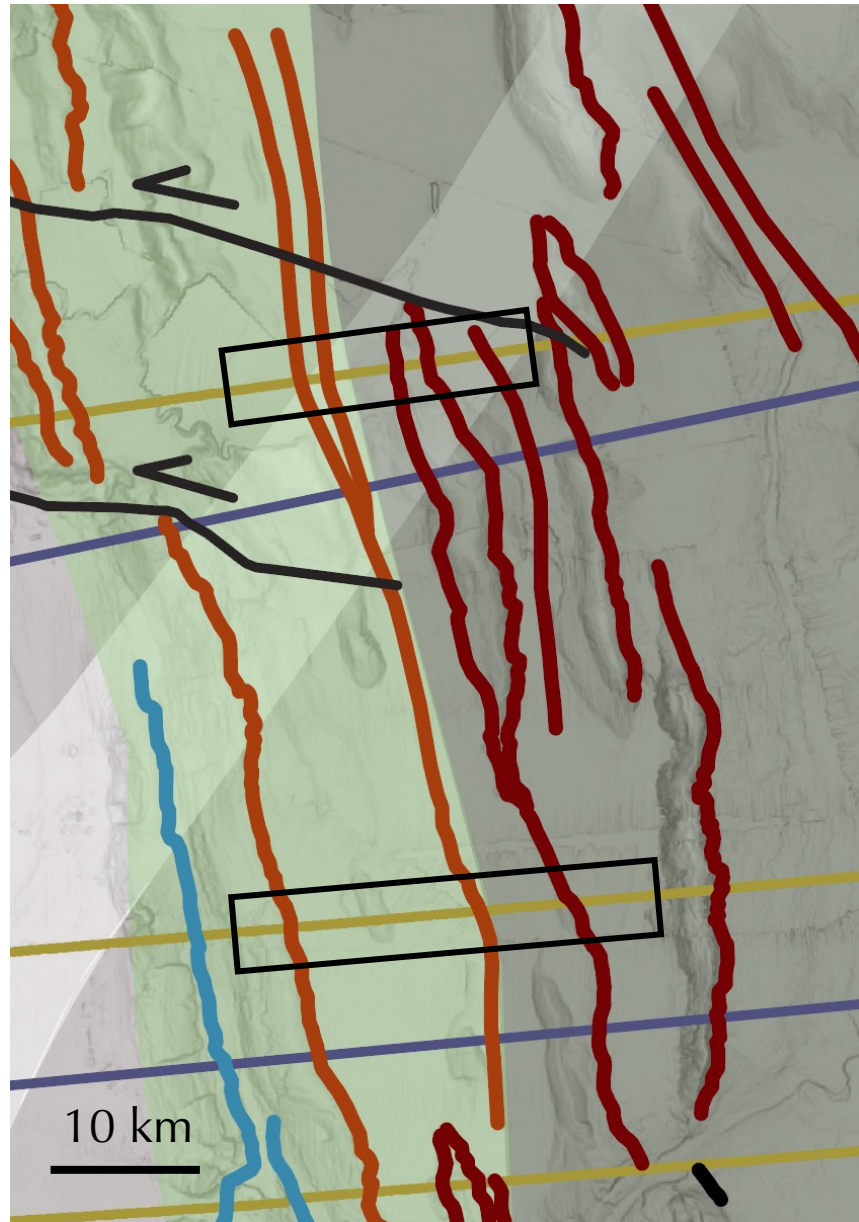


active faults: — LV inactive faults: — LV



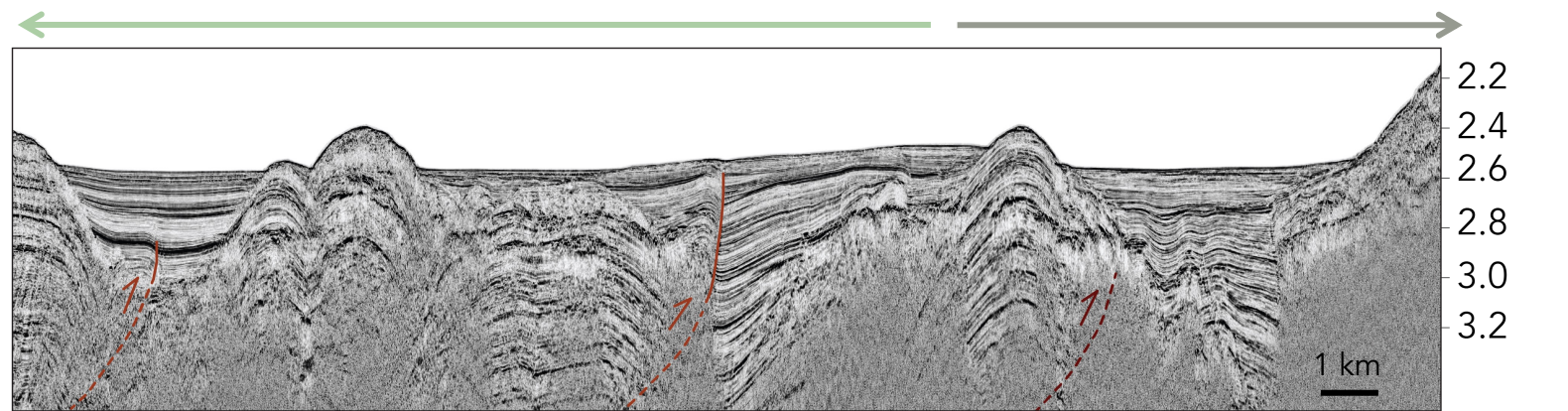
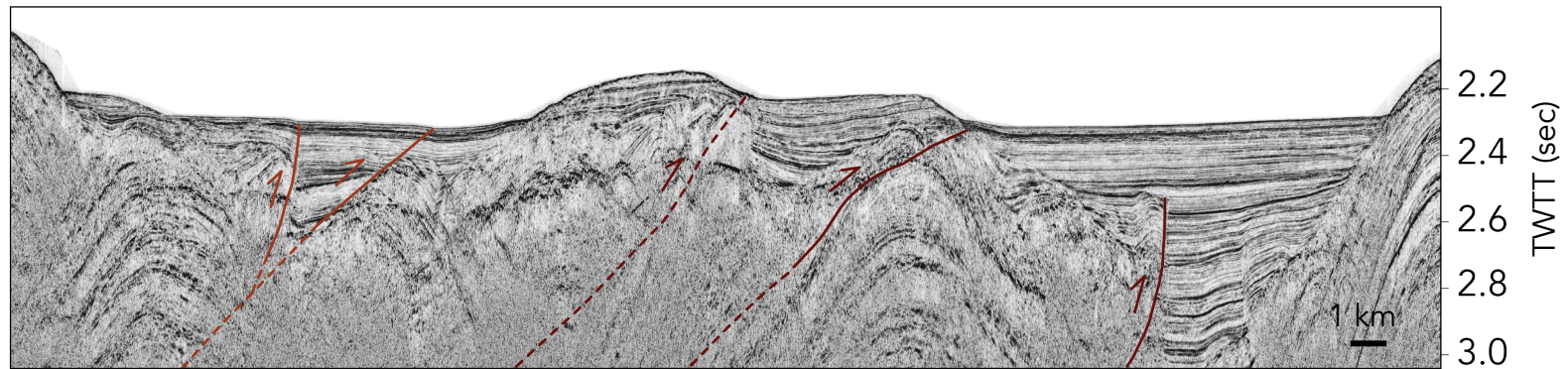
The inactive domain

■ syndeformational ■ postdeformational
active faults: — LV inactive faults: — LV



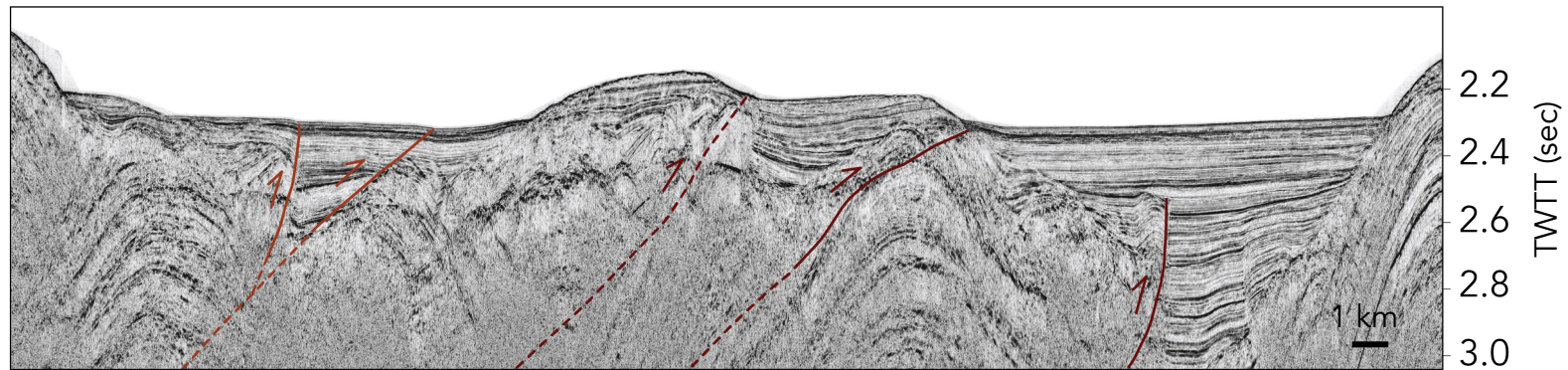


Ledeczi et al., 2024

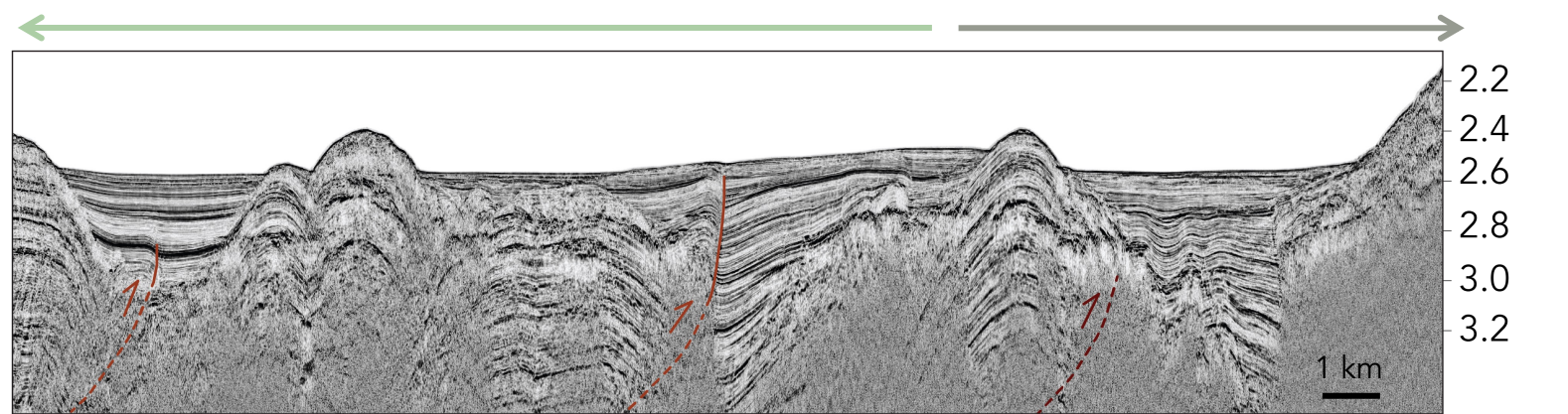




Ledeczi et al., 2024

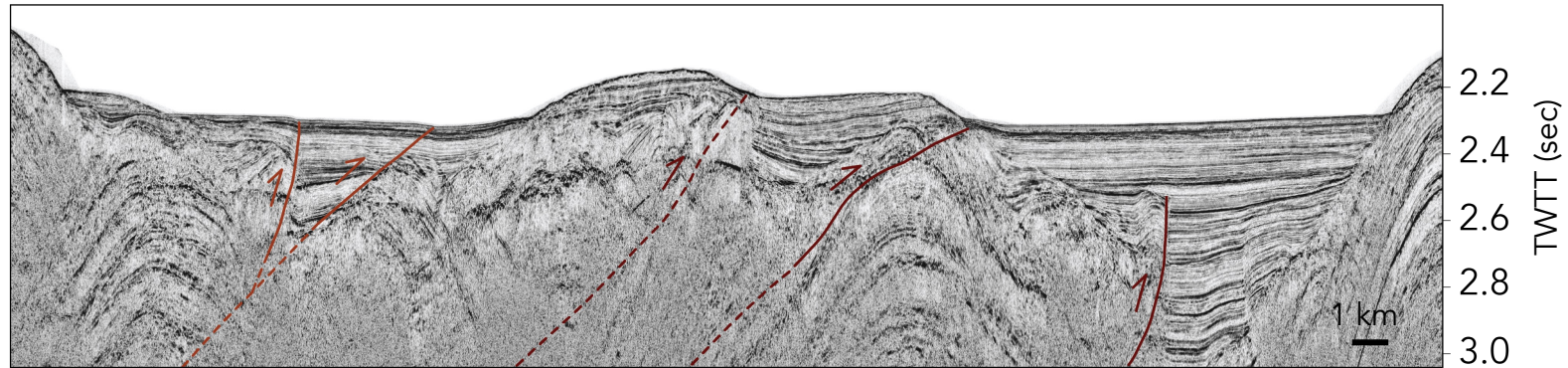


Active domain:
 surface-breaking
 faults with
 syndeformational
 sediments



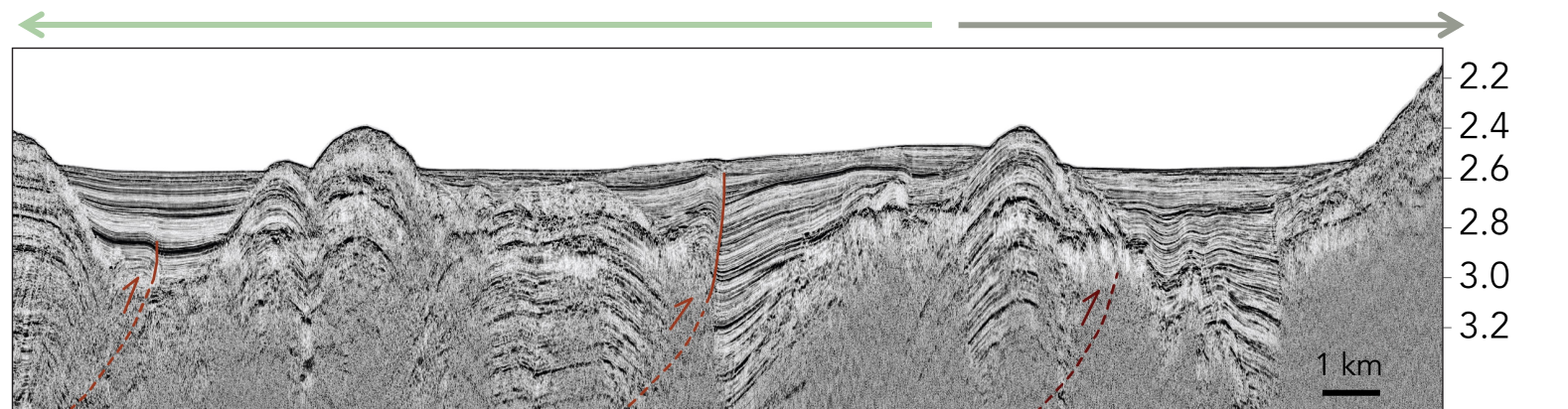


Ledeczi et al., 2024

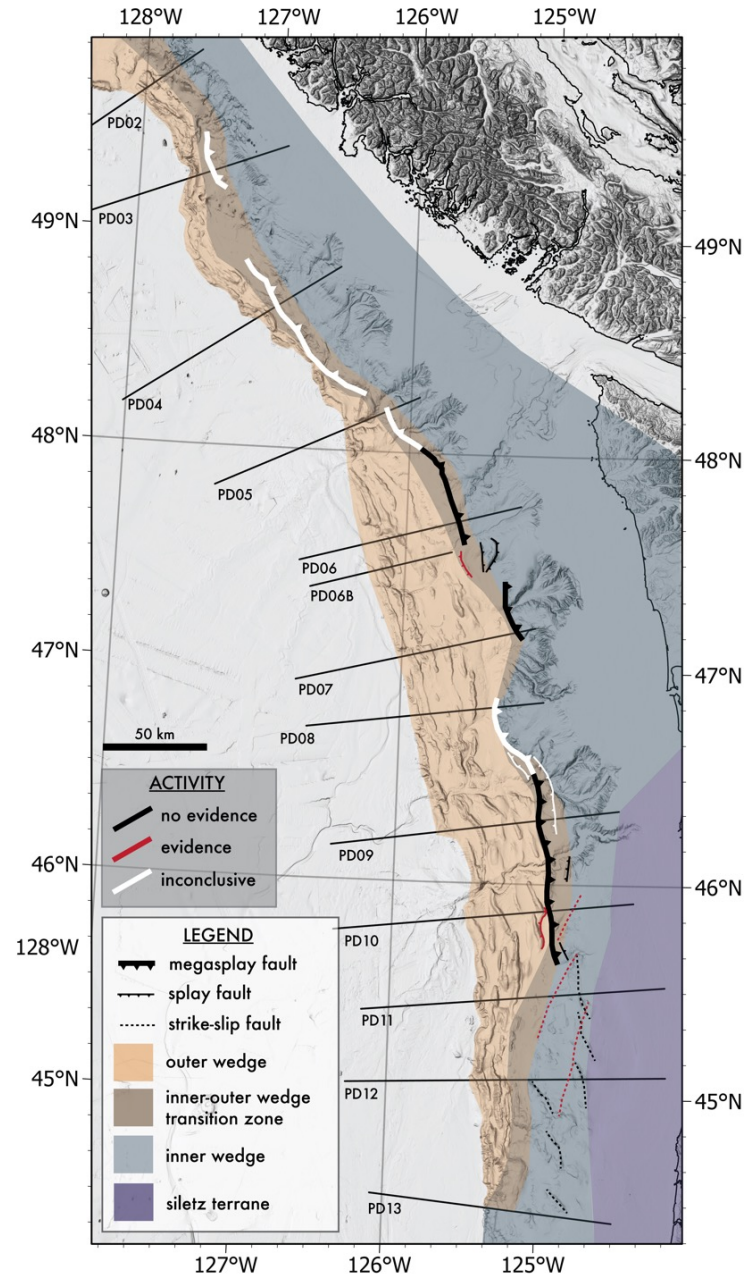
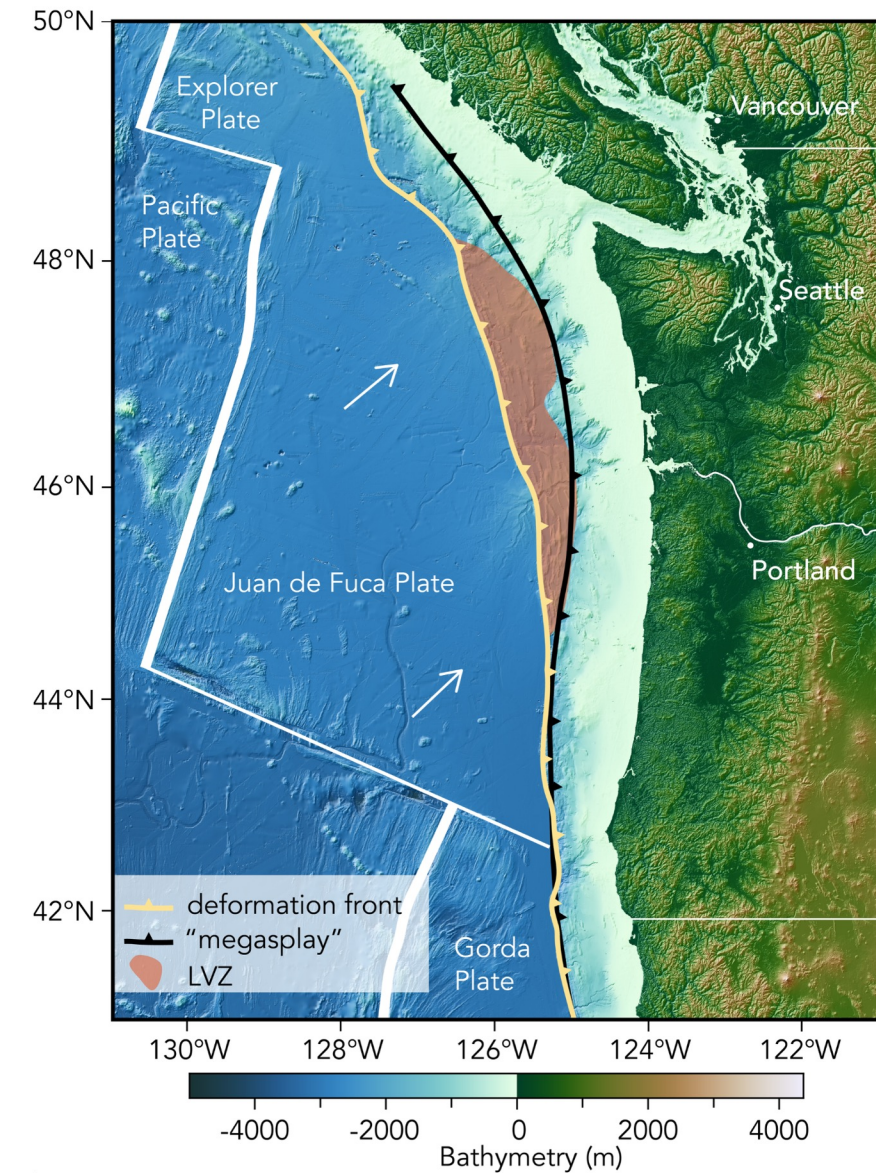


Active domain:
 surface-breaking
 faults with
 syndeformational
 sediments

Inactive domain:
 inactive faults buried
 by postdeformational
 sediments

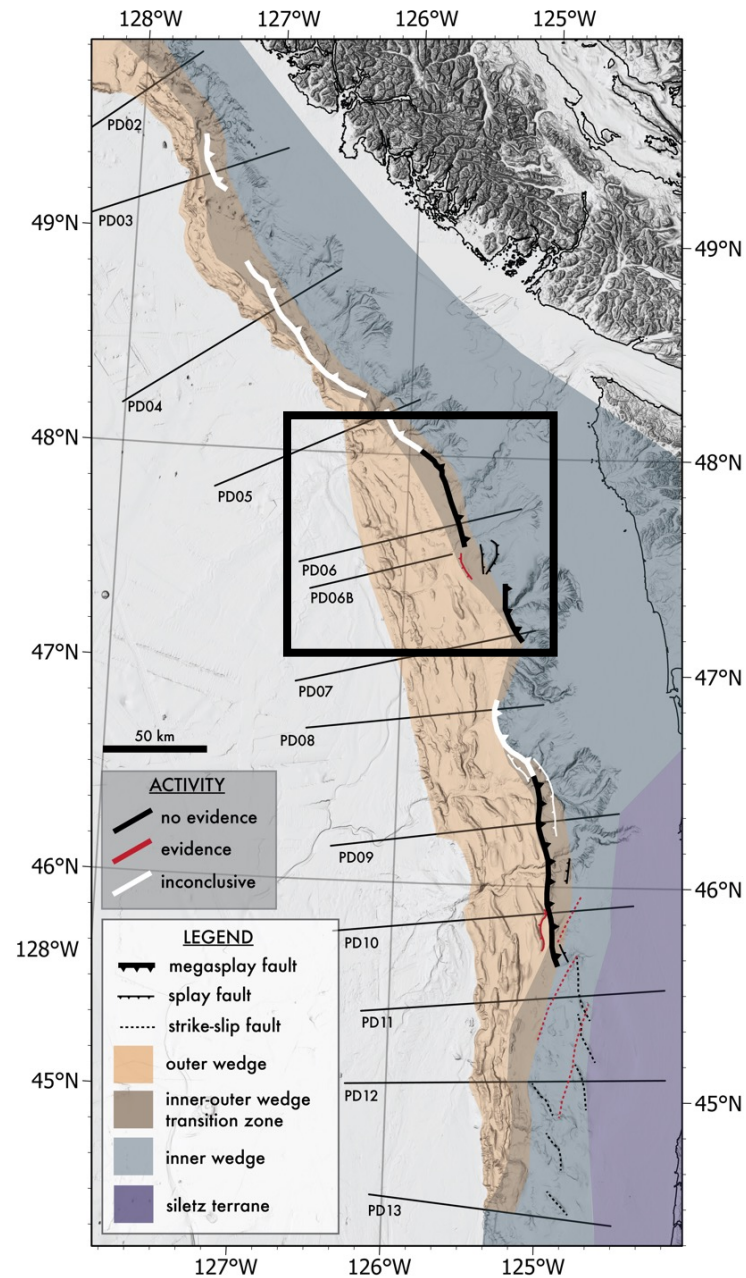
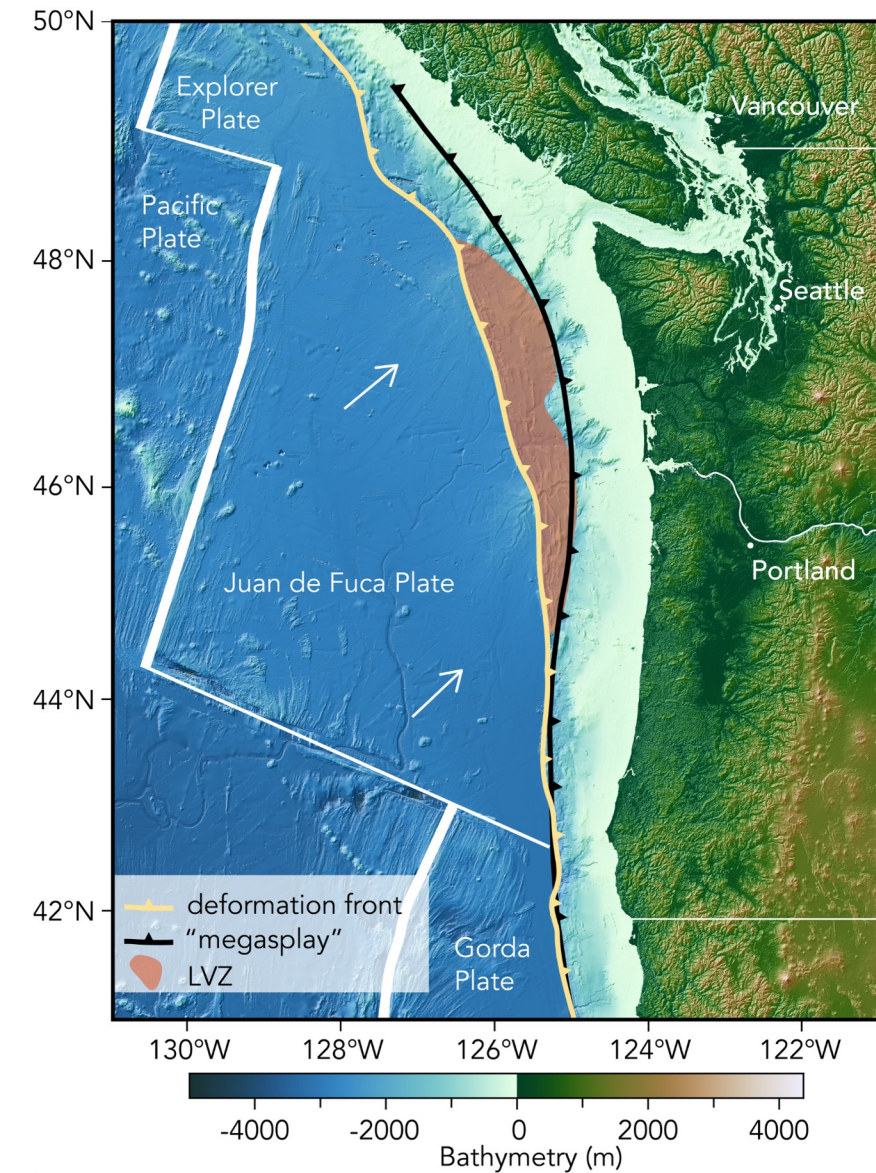


Is there a megasplay fault?



- Megasplay-style faults are largely absent to inactive along the margin

Is there a megasplay fault?



- Megasplay-style faults are largely absent to inactive along the margin

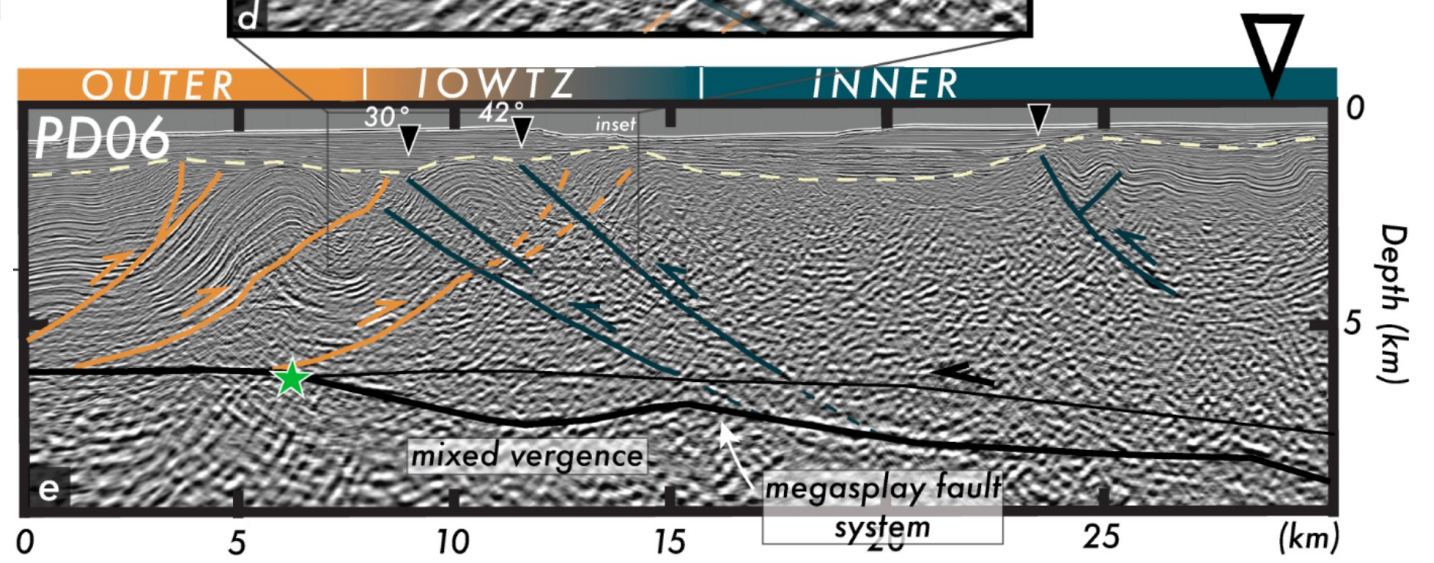
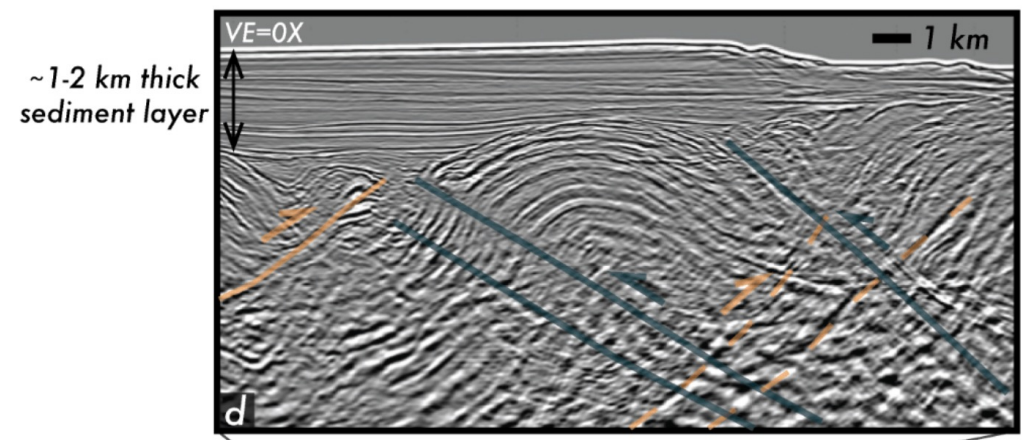
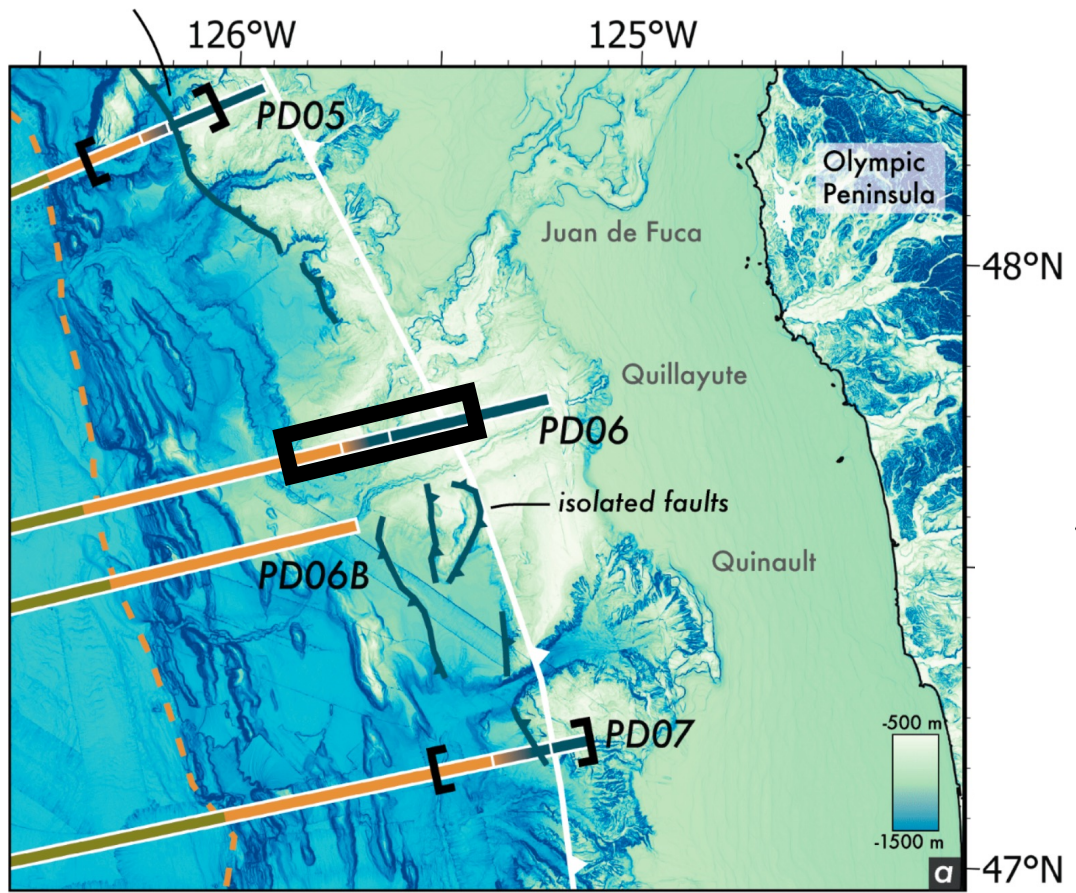
Megasplay-style faults are covered by undeformed sediments

- Lines off WA show faults sealed by kilometers of undeformed sediments, inactive for >100,000

▽ hypothesized megasplay fault location

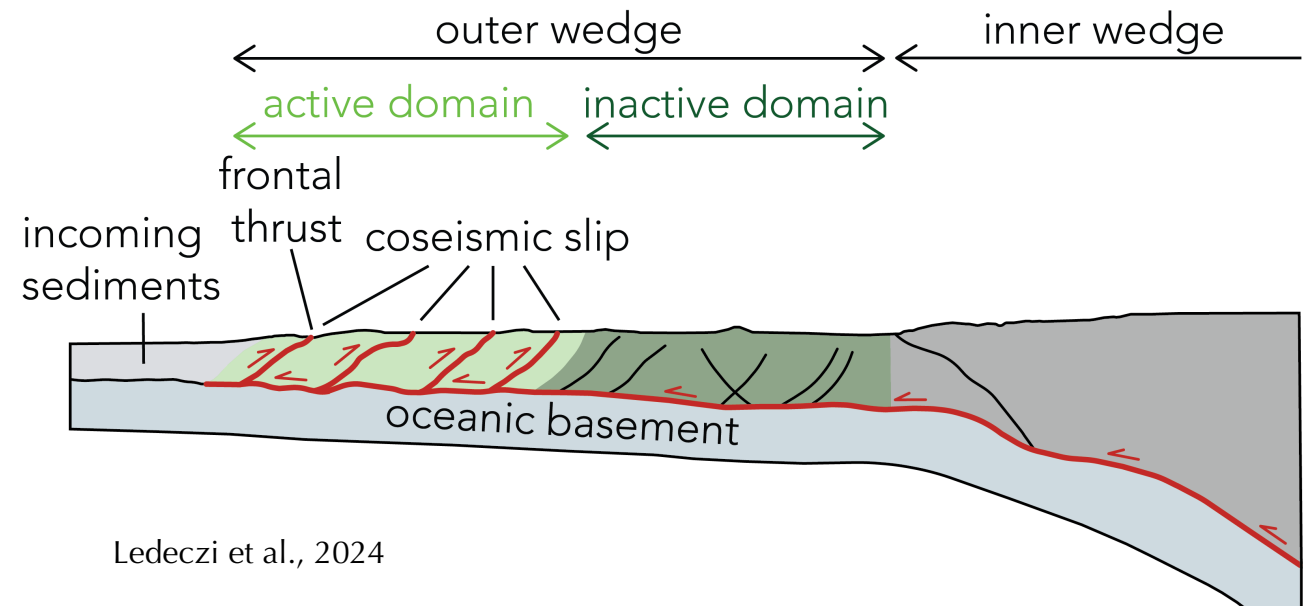
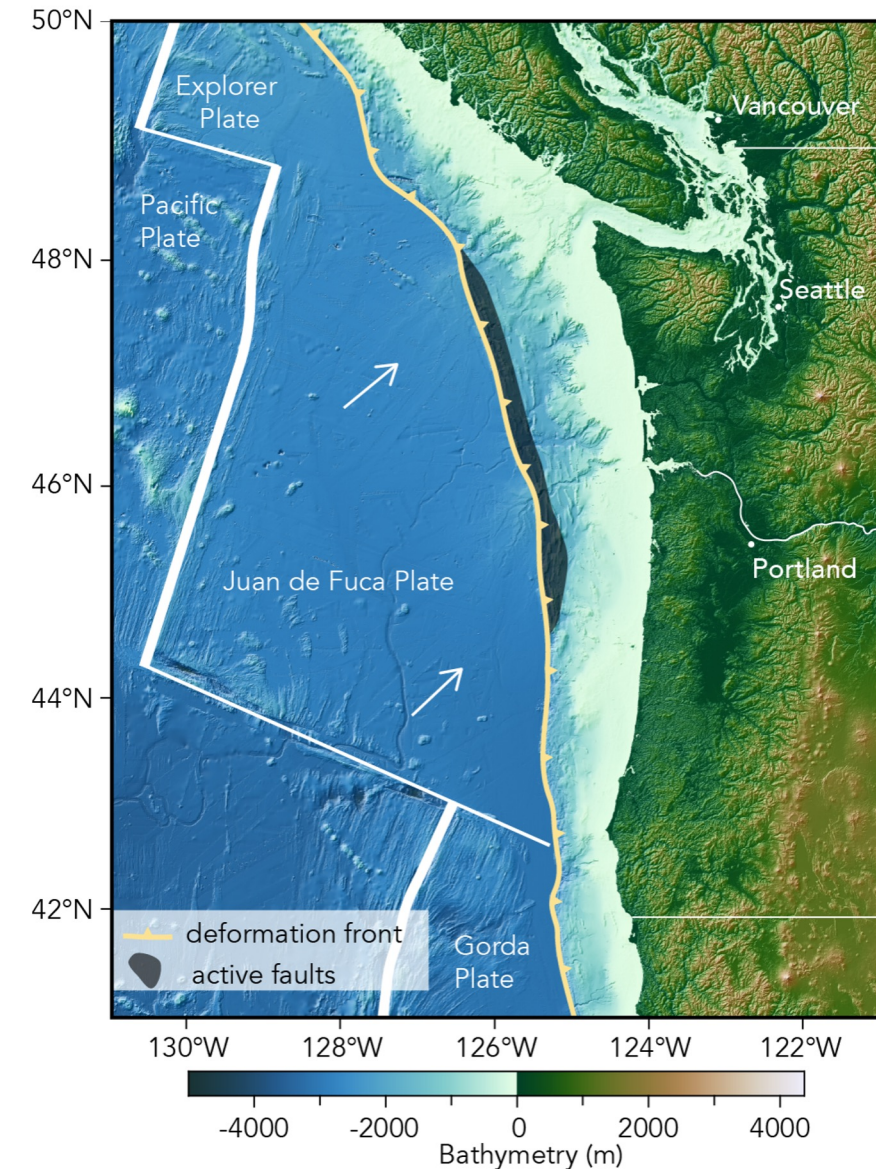
Evidence

- ▼ negative
- ▼ positive
- ▽ inconclusive



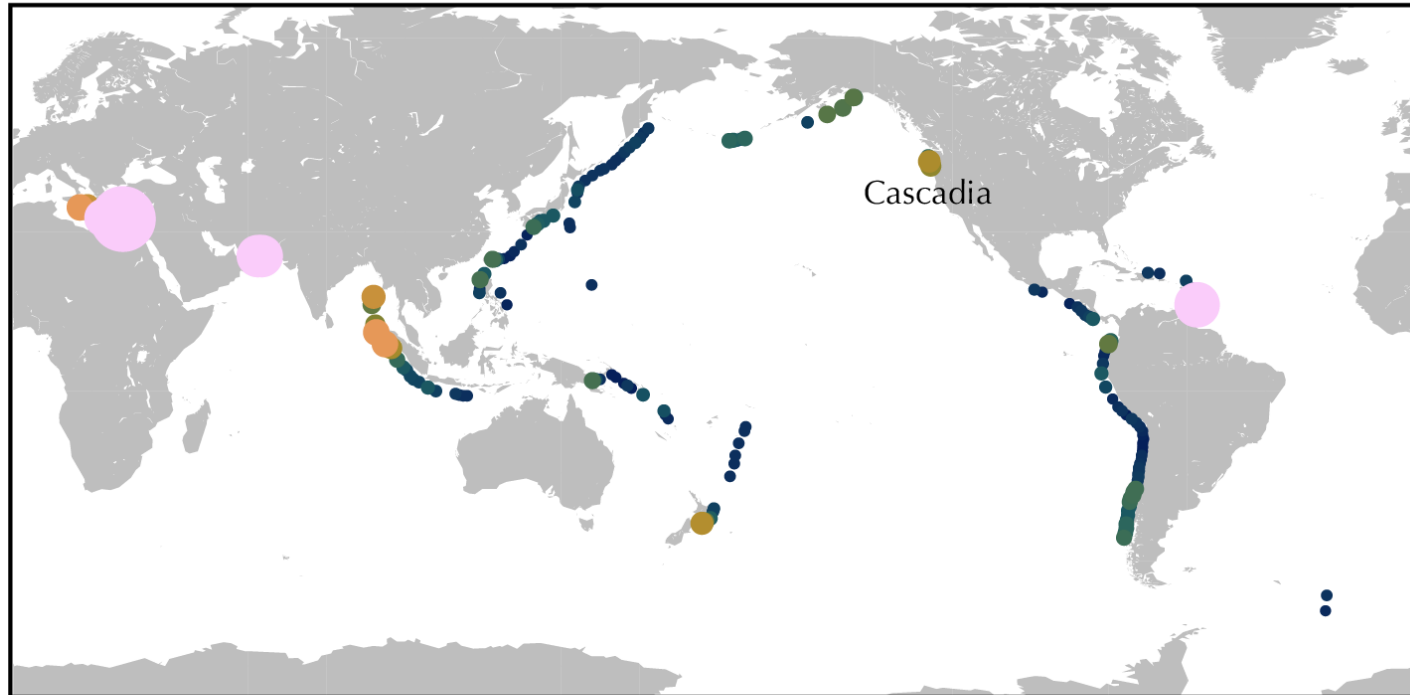
Faults in the active domain are candidates for coseismic displacement

- Cascadia will likely experience distributed shallow rupture on multiple landward-vergent splay faults located within ~30 km of the deformation front in a future megathrust event
- The inner wedge and the inactive domain move as a rigid block
- Produces a significant, previously unknown tsunami hazard



Cascadia has high sedimentation

incoming plate clastic sedimentary package

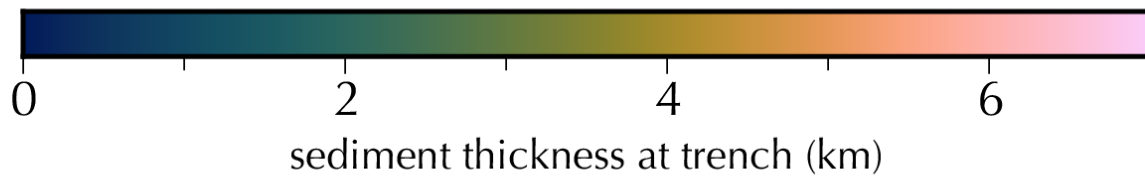
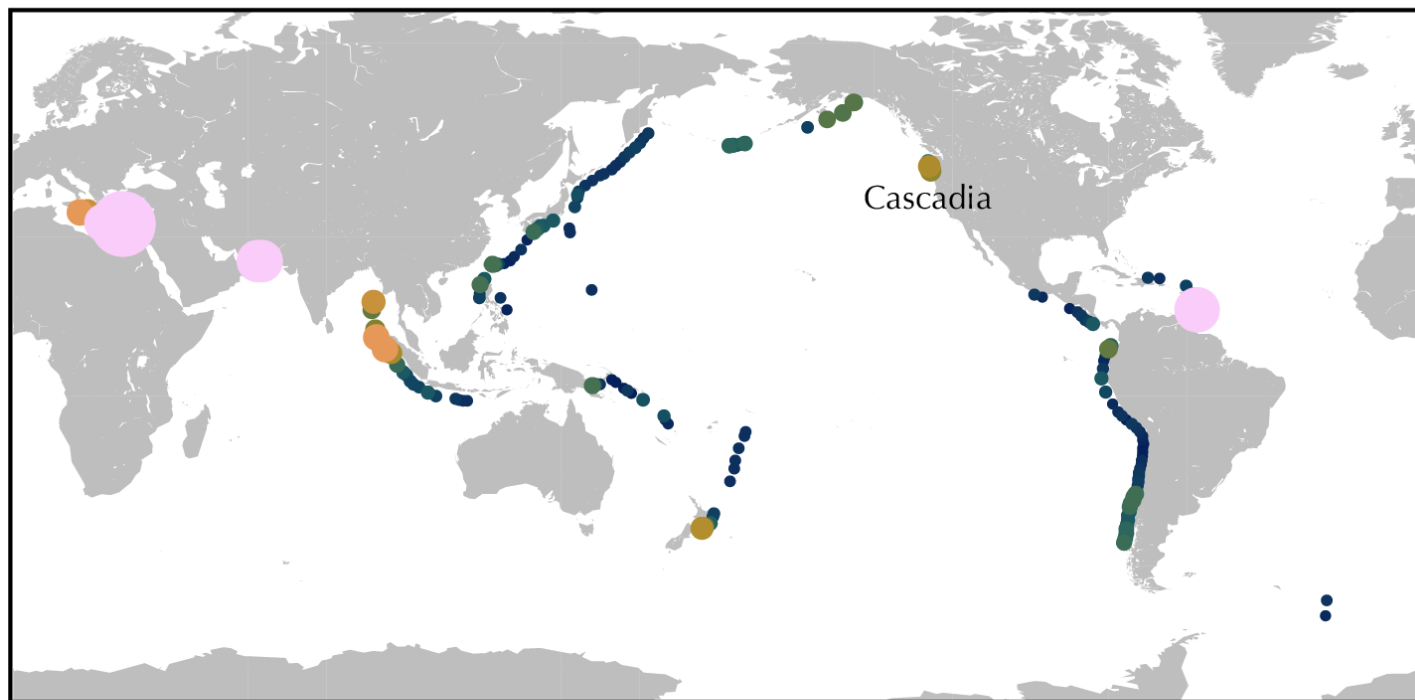


0 2 4 6

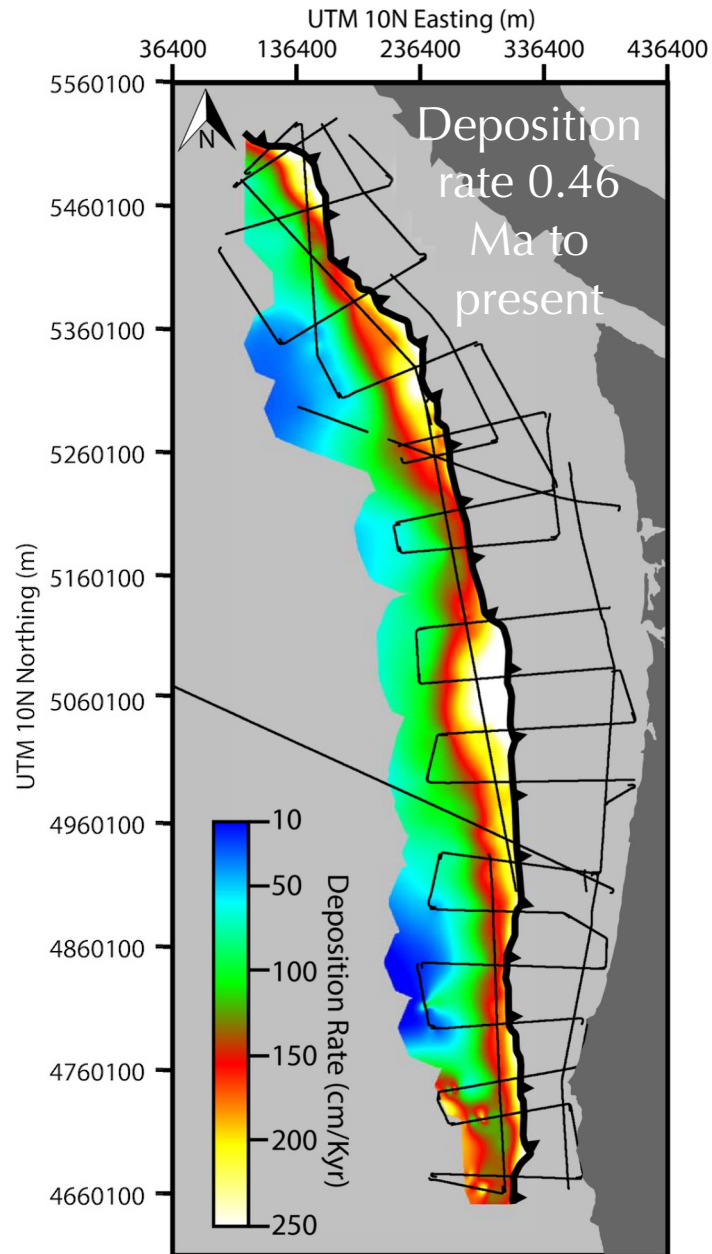
sediment thickness at trench (km)

Cascadia has high sedimentation

incoming plate clastic sedimentary package



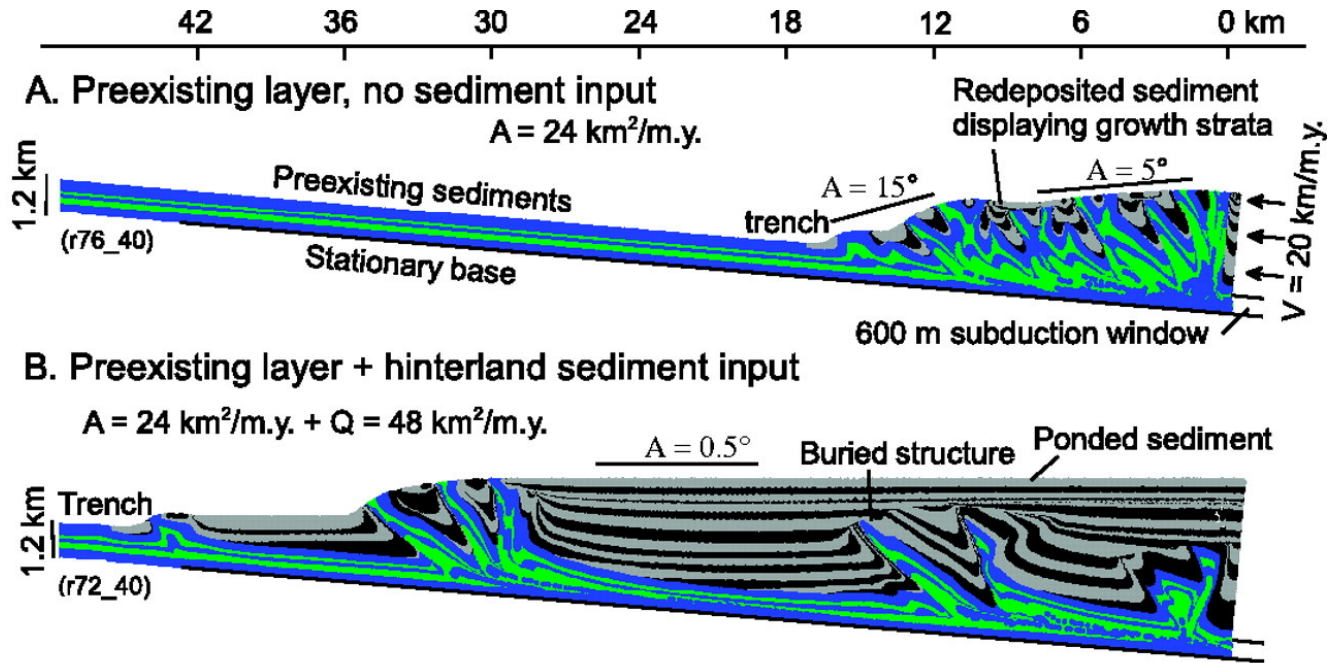
high Pleistocene sedimentation rate



Brandon Shuck

High sedimentation causes seaward migration of deformation

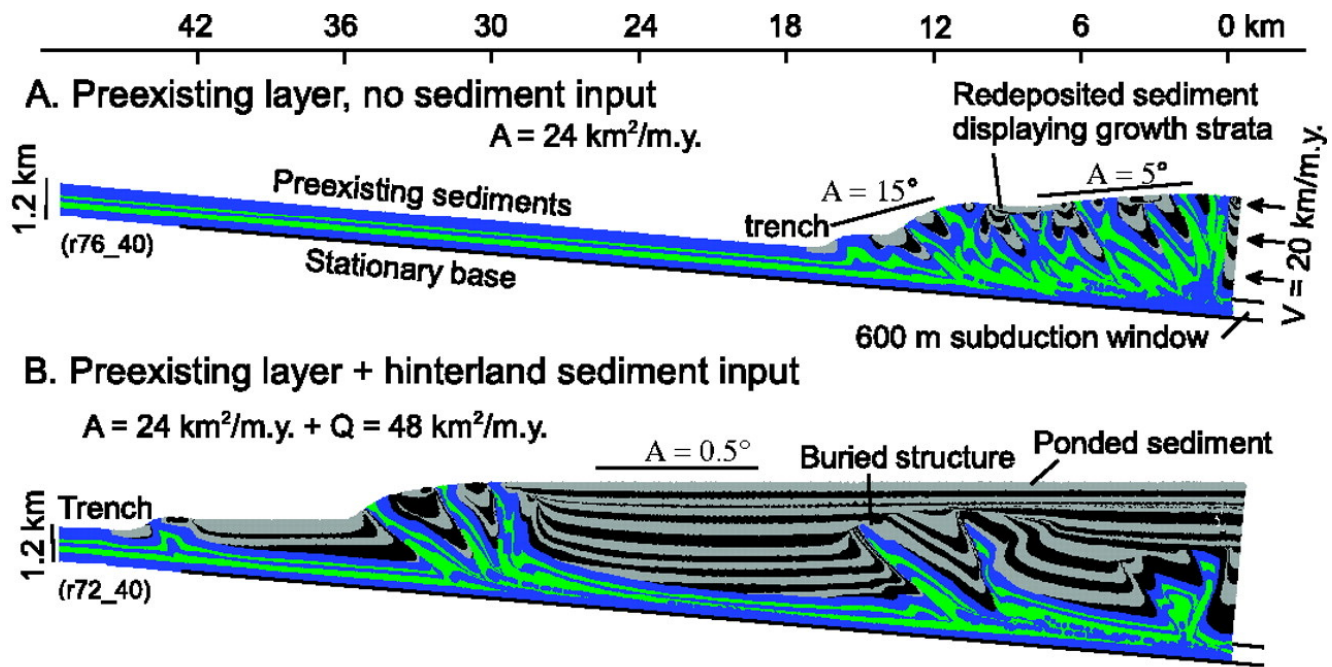
High hinterland sediment input produces widely-spaced thrust sheets with low surface slope



Simpson et al. (2010)

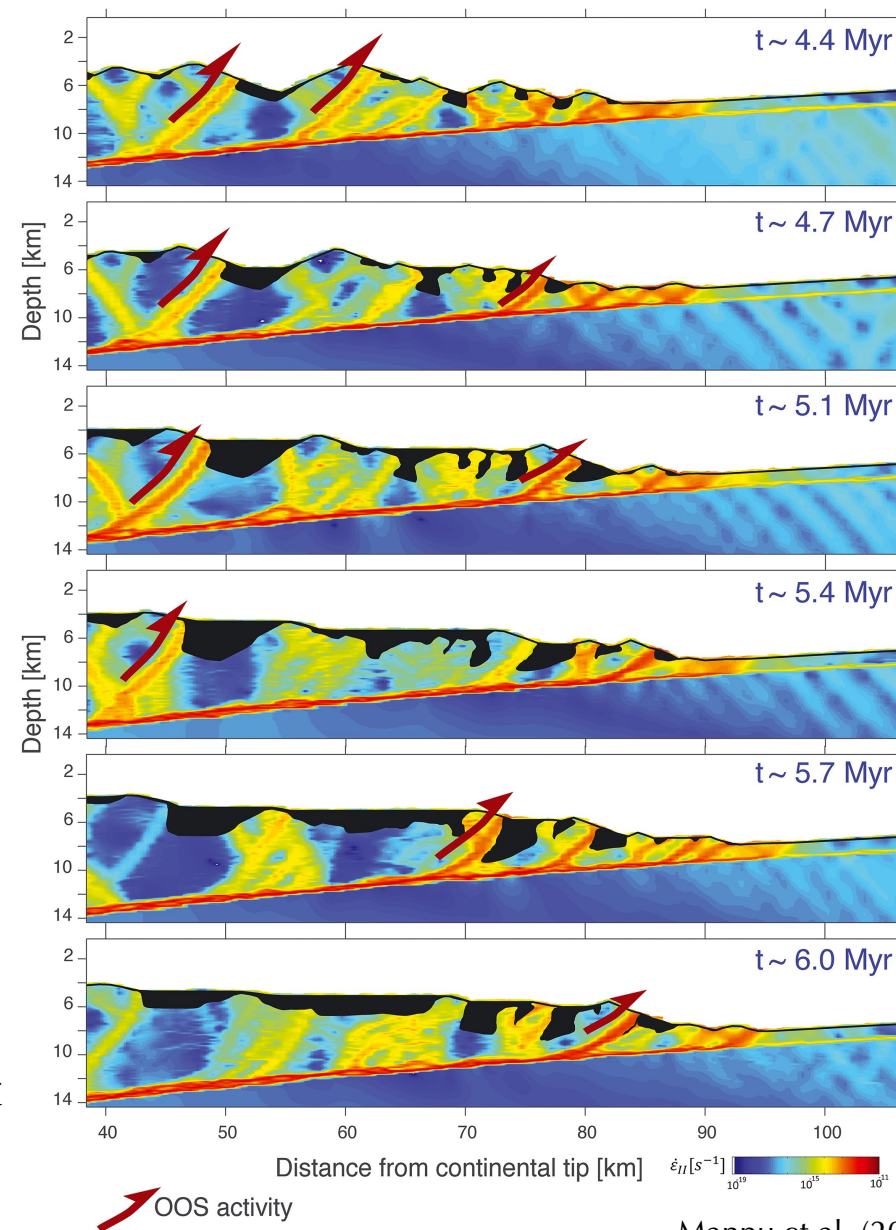
High sedimentation causes seaward migration of deformation

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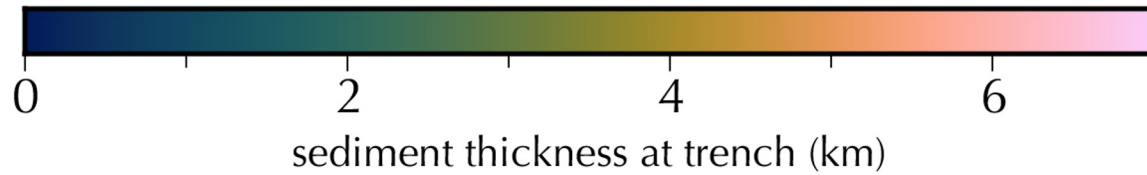
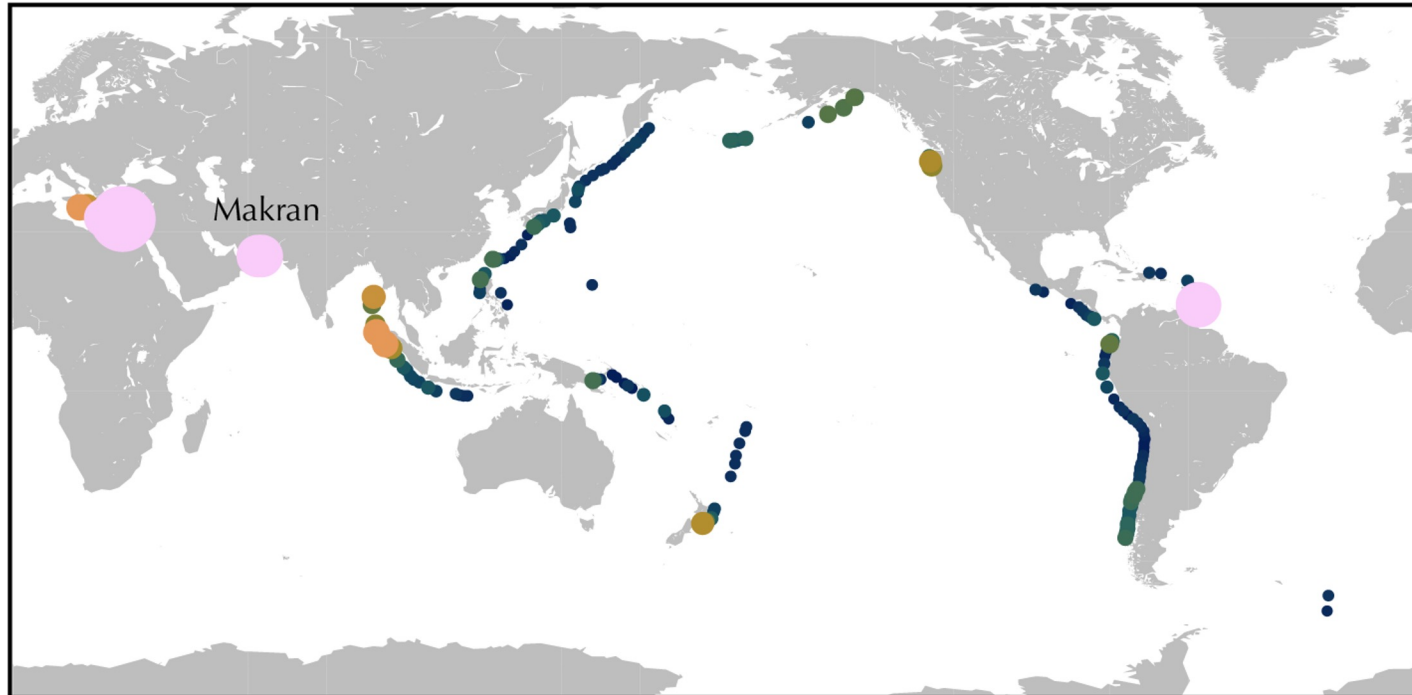
High slope basin sedimentation suppresses underlying fault activity & deformation migrates outside of the sedimentation zone



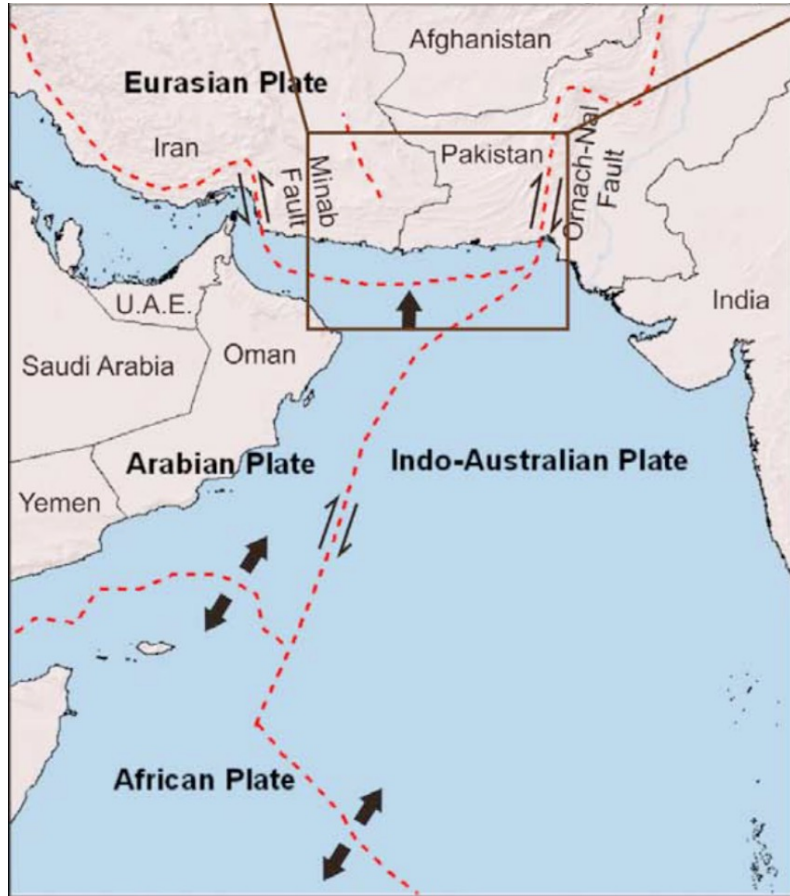
Mannu et al. (2016)

High sedimentation causes seaward migration of deformation

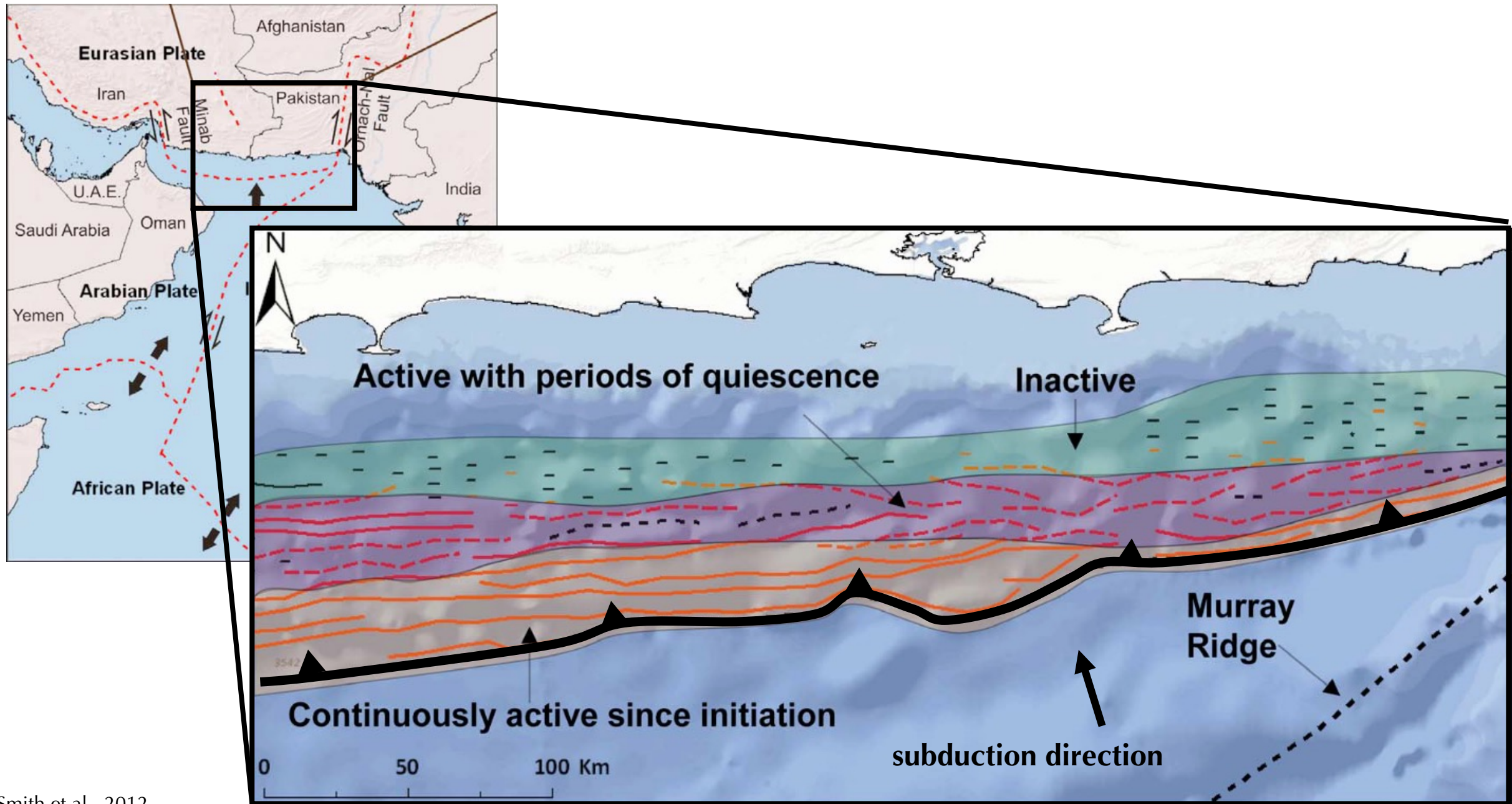
incoming plate clastic sedimentary package



Makran shows a similar pattern of fault activity



Makran shows a similar pattern of fault activity



Faults in the the paper are now available through the CFM

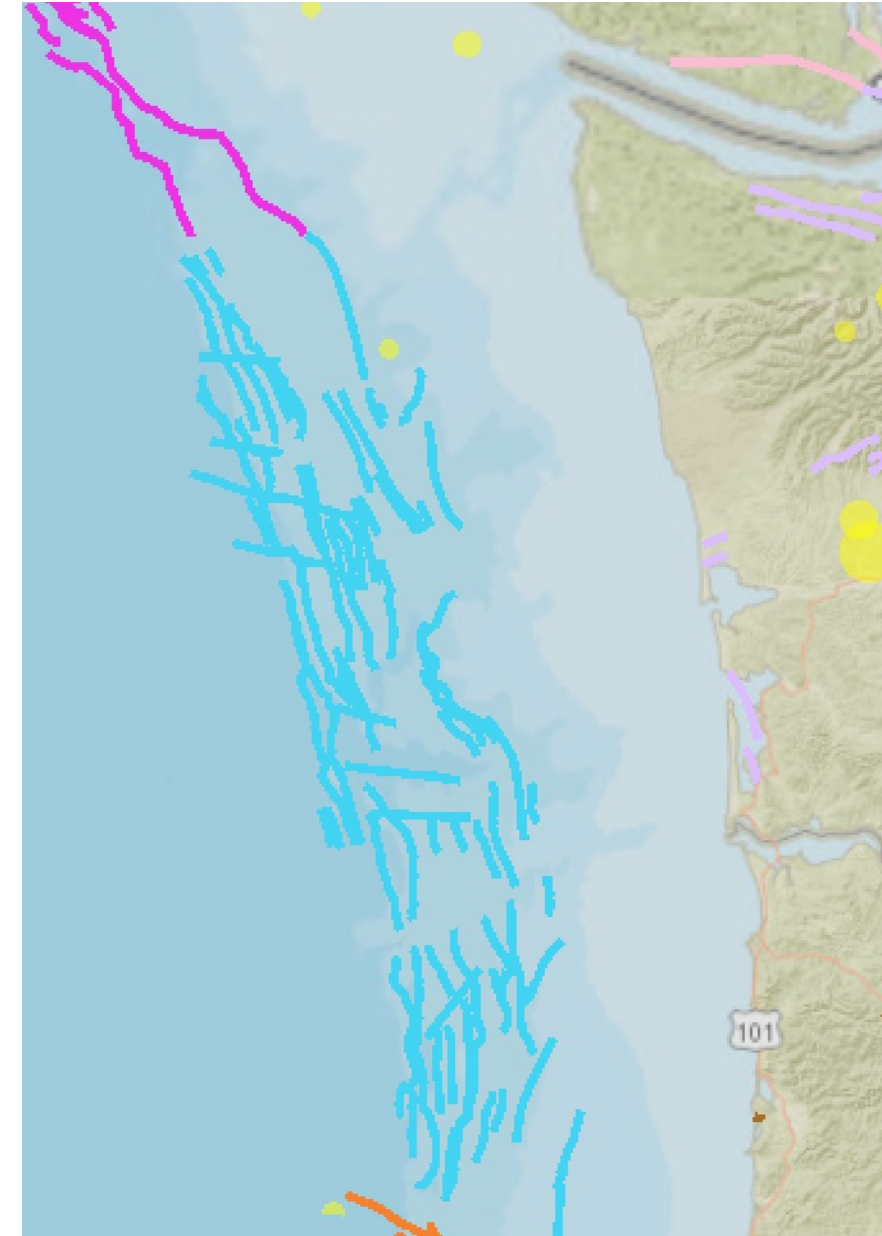
doi:10.26443/seismica.v2i4.1158

SEISMICA

Late Quaternary Surface Displacements on Accretionary Wedge Splay Faults in the Cascadia Subduction Zone: Implications for Megathrust Rupture

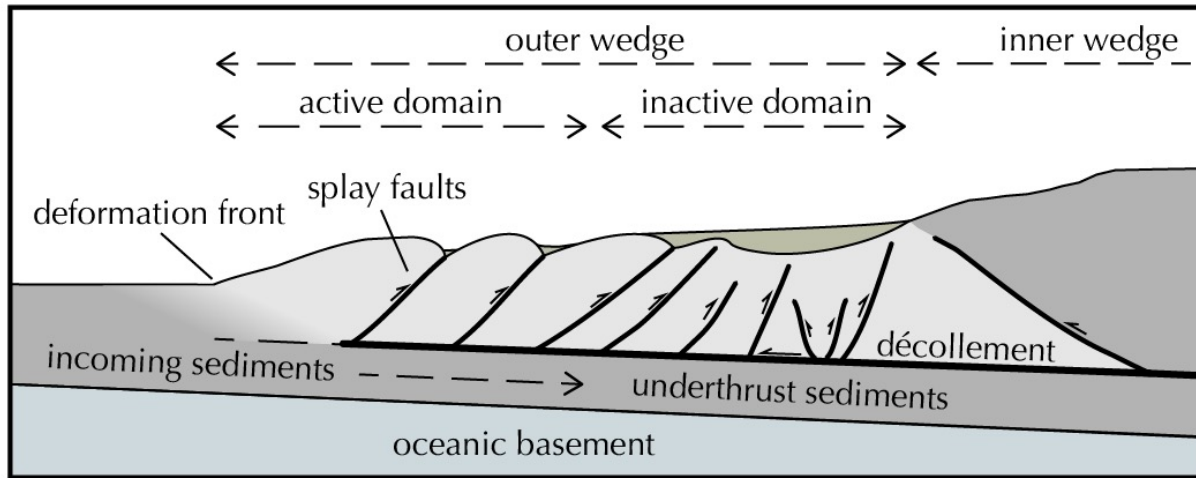
A.M. Ledeczi *¹, M.C. Lucas ¹, H.J. Tobin ¹, J.T. Watt ², N.C. Miller ³

¹Department of Earth & Space Sciences, University of Washington, Seattle, WA, ²U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA, ³U.S. Geological Survey, Woods Hole Coastal and Marine Science Center, Woods Hole, MA

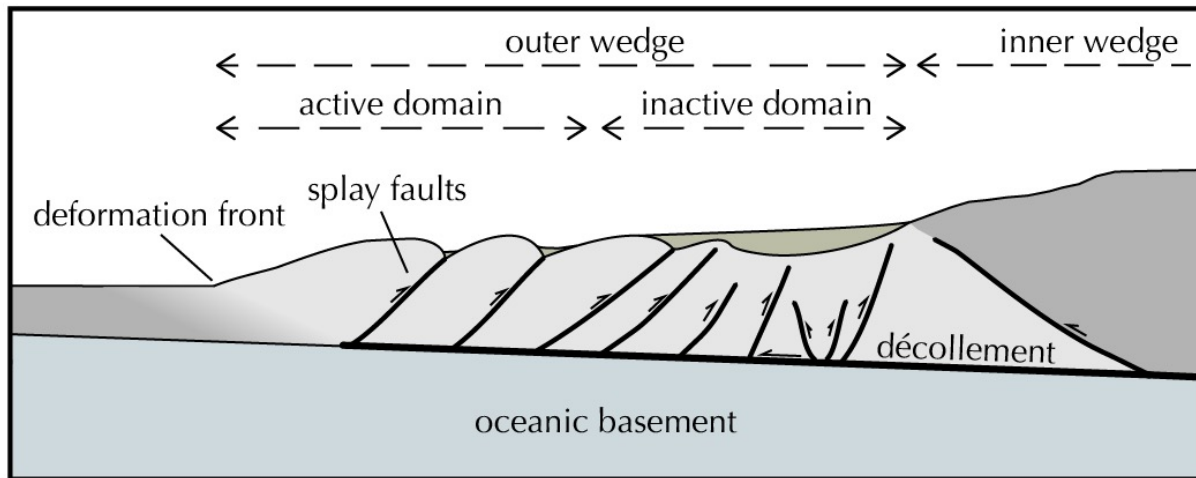


What is the structure of the megathrust fault in the LVZ?

Sediment subduction

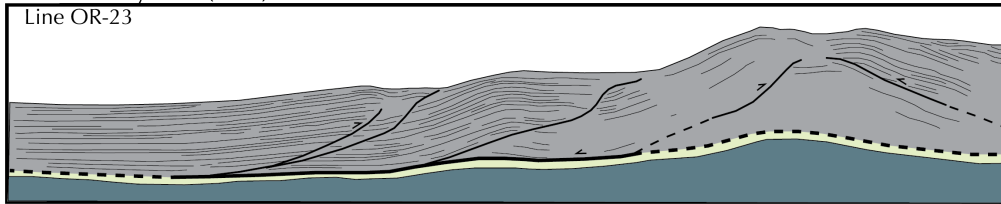


No sediment subduction

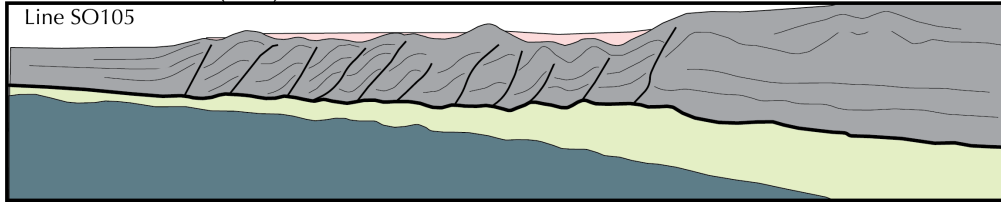


Previous interpretations of LVZ structure

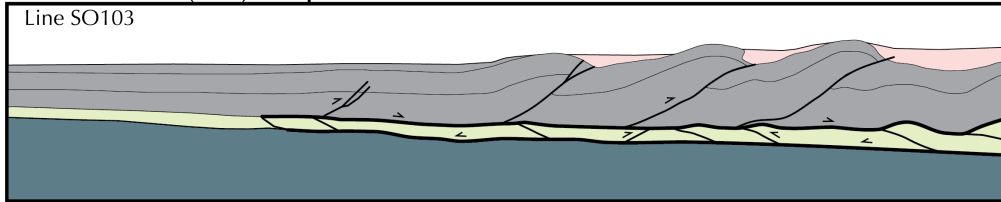
MacKay et al. (1992) Sediment-hosted décollement



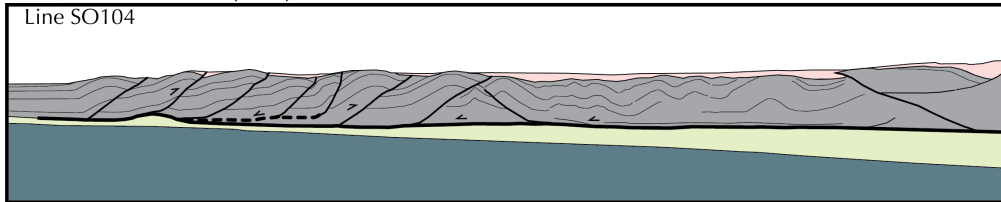
Gutscher et al. (2001) Sediment-hosted décollement



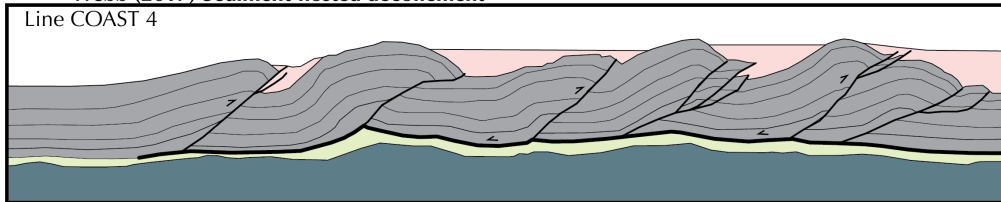
Adam et al. (2004) Multiple décollements



Booth-Rea et al. (2008) Sediment-hosted décollement



Webb (2017) Sediment-hosted décollement

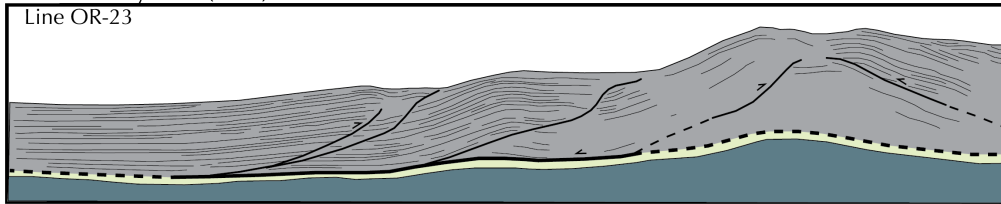


- All legacy seismic data interpretation in the LVZ identifies a décollement ~100s of meters above basement in the outermost wedge
- Underthrust sediment increases to the inner wedge due to the shallow décollement dip compared to the downgoing oceanic crust

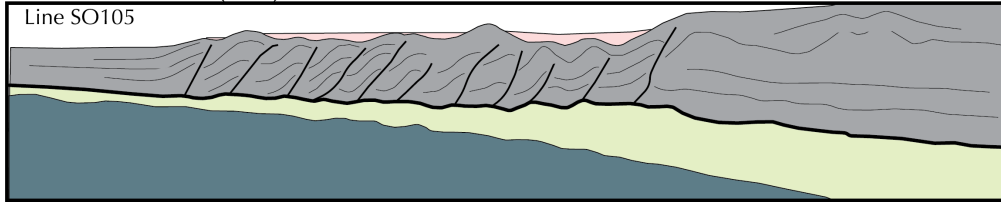


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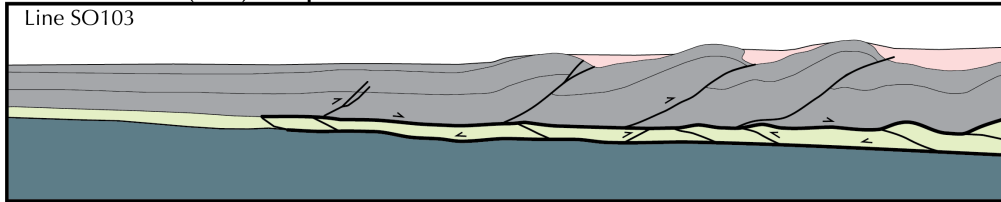
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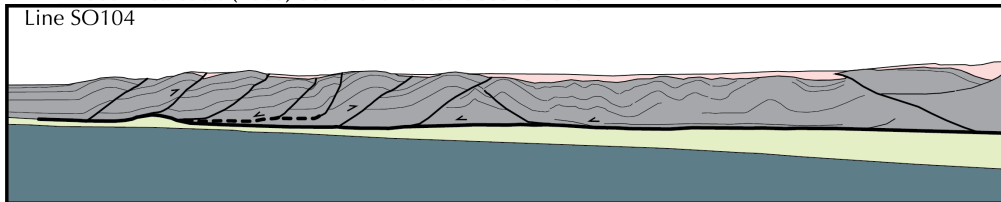
Gutscher et al. (2001) Sediment-hosted décollement



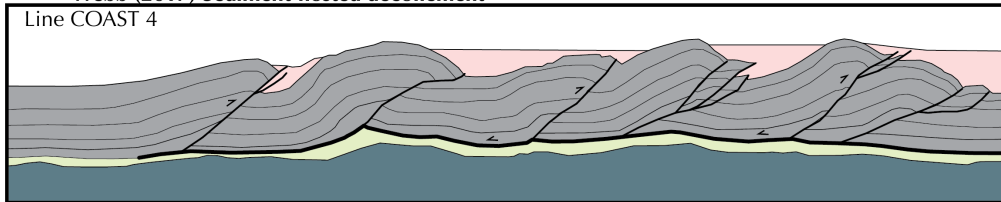
Adam et al. (2004) Multiple décollements



Booth-Rea et al. (2008) Sediment-hosted décollement

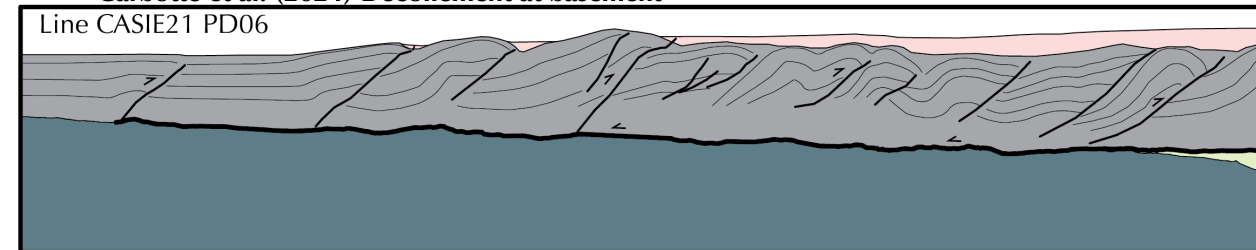


Webb (2017) Sediment-hosted décollement



- All legacy seismic data interpretation in the LVZ identifies a décollement ~100s of meters above basement in the outermost wedge
- Underthrust sediment increases to the inner wedge due to the shallow décollement dip compared to the downgoing oceanic crust
- New plate boundary from CASIE21 identifies décollement at basement in the LVZ

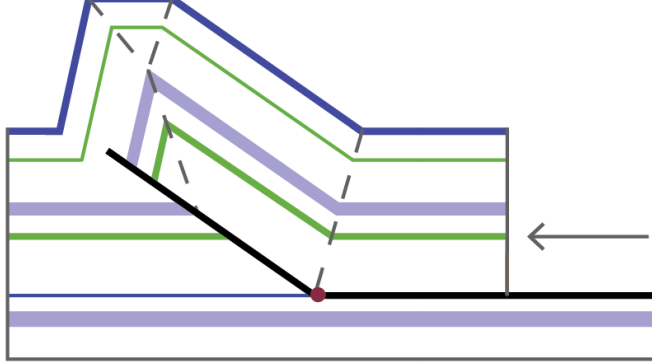
Carbotte et al. (2024) Décollement at basement



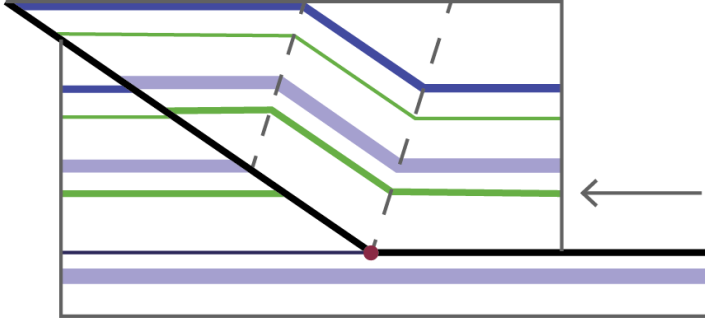
- megathrust fault
- - - upper-level décollement
- splay fault
- wedge-top sediment cover
- wedge
- underthrust sediments
- oceanic crust

Theoretical fault geometries

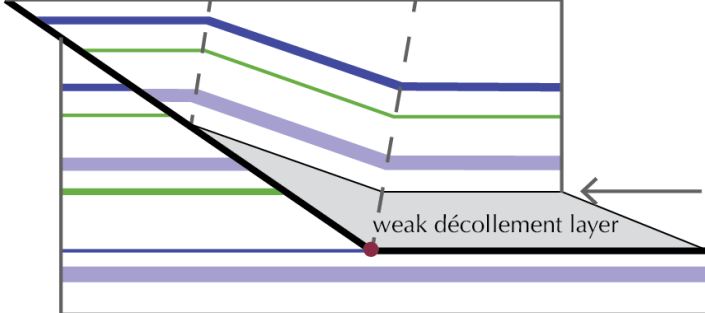
Fault-propagation fold



Fault-bend fold

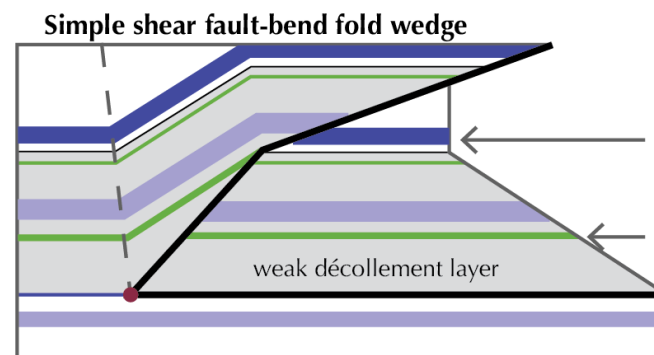
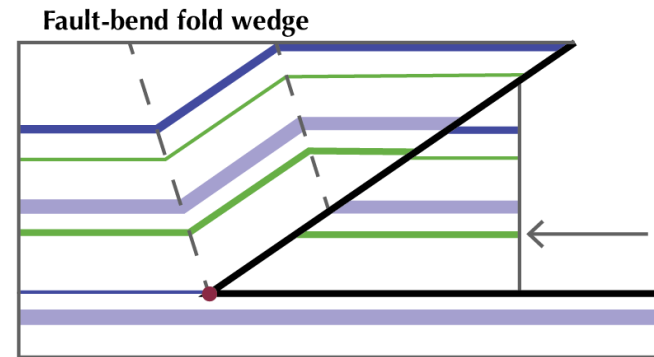
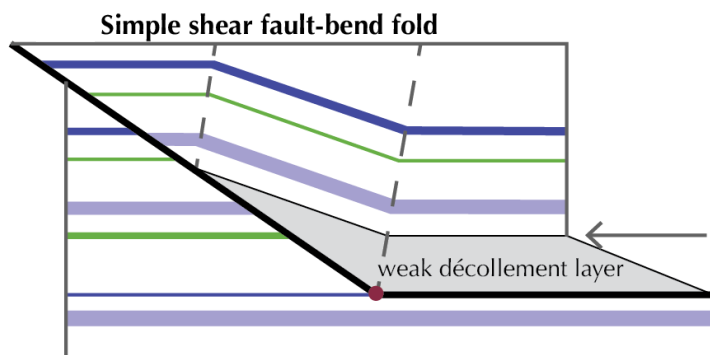
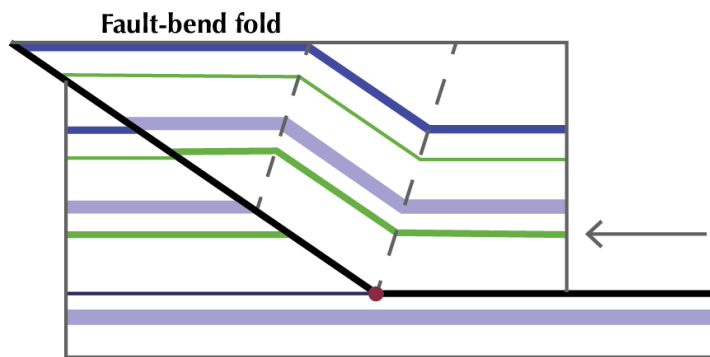
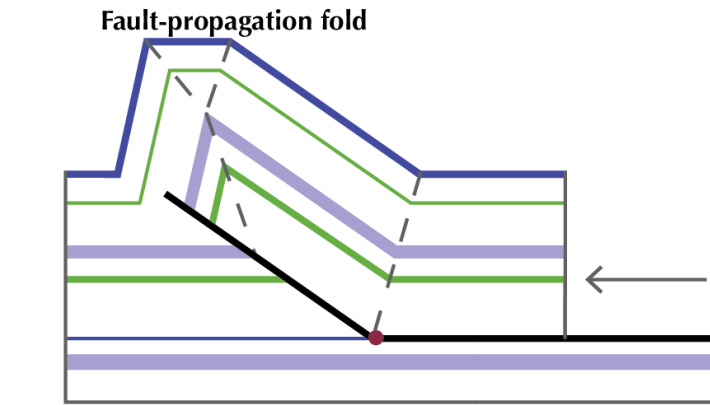


Simple shear fault-bend fold



- Theoretical fault geometries can be applied to real-world faults

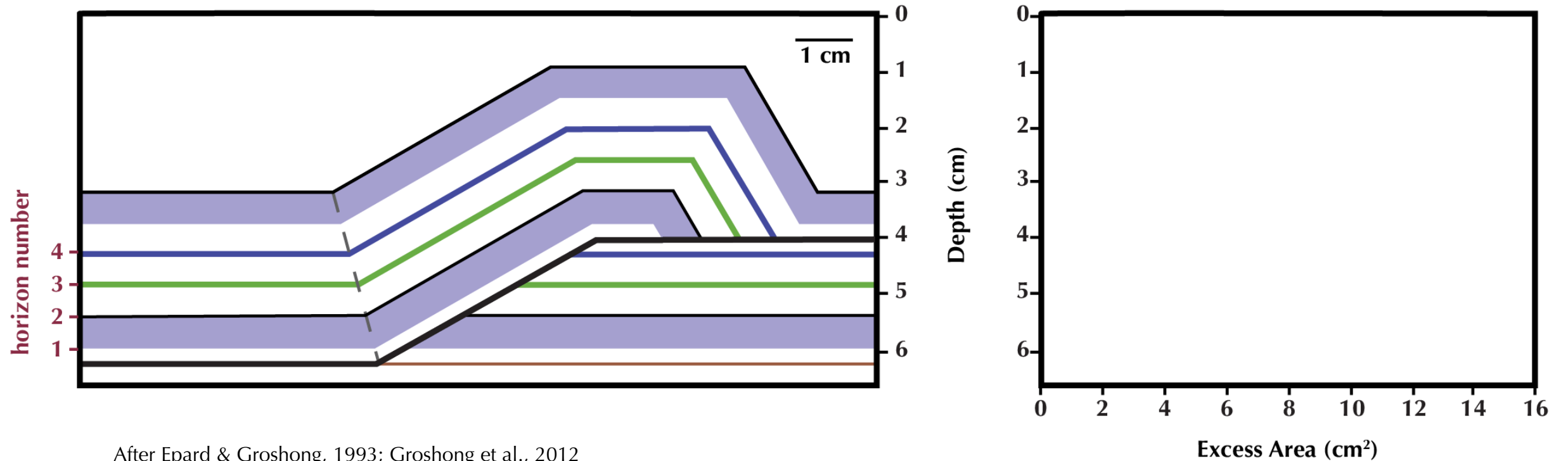
Theoretical fault geometries



- Theoretical fault geometries can be applied to real-world faults
- Wedge versions are more appropriate for landward vergence
- Syncline's axial surface always intersects with the fault at the point of the décollement

Area-depth theory

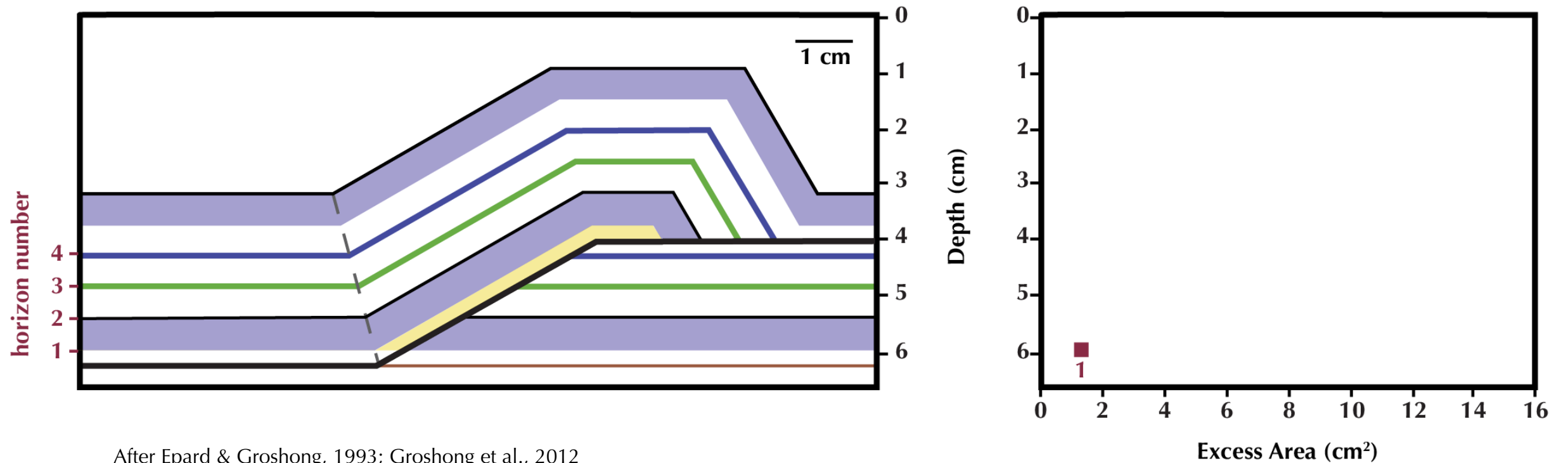
- A quantitative way to determine the depth of the décollement
- Independent of the structural style of the fault



After Epard & Groshong, 1993; Groshong et al., 2012

Area-depth theory

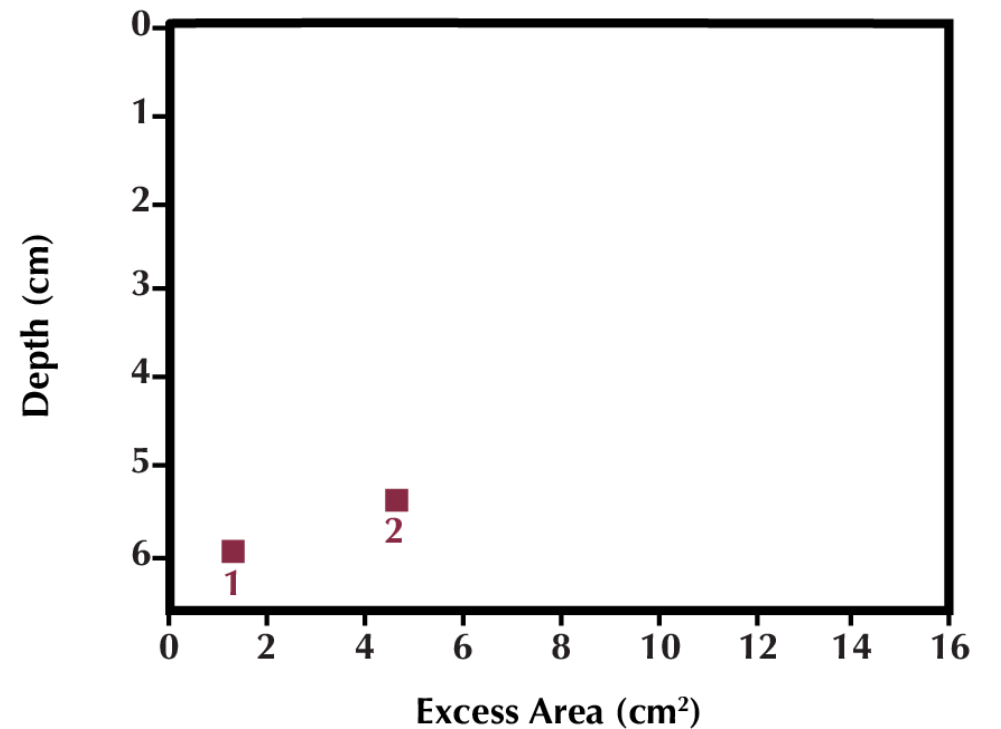
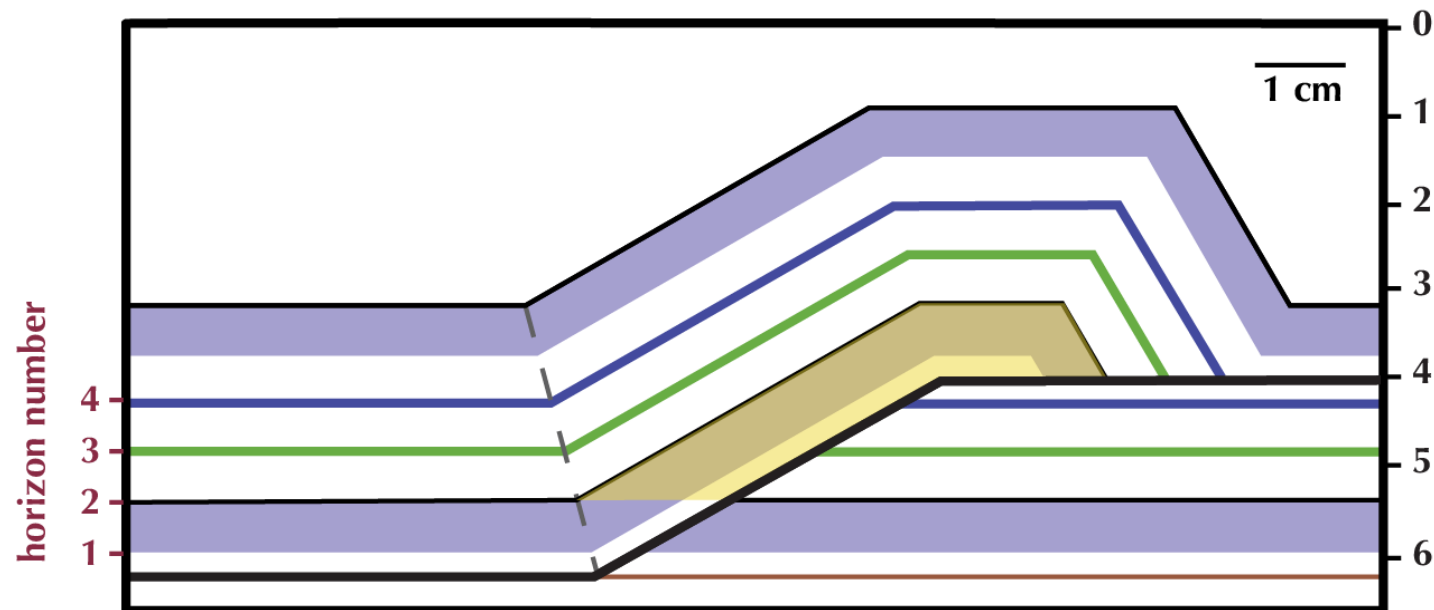
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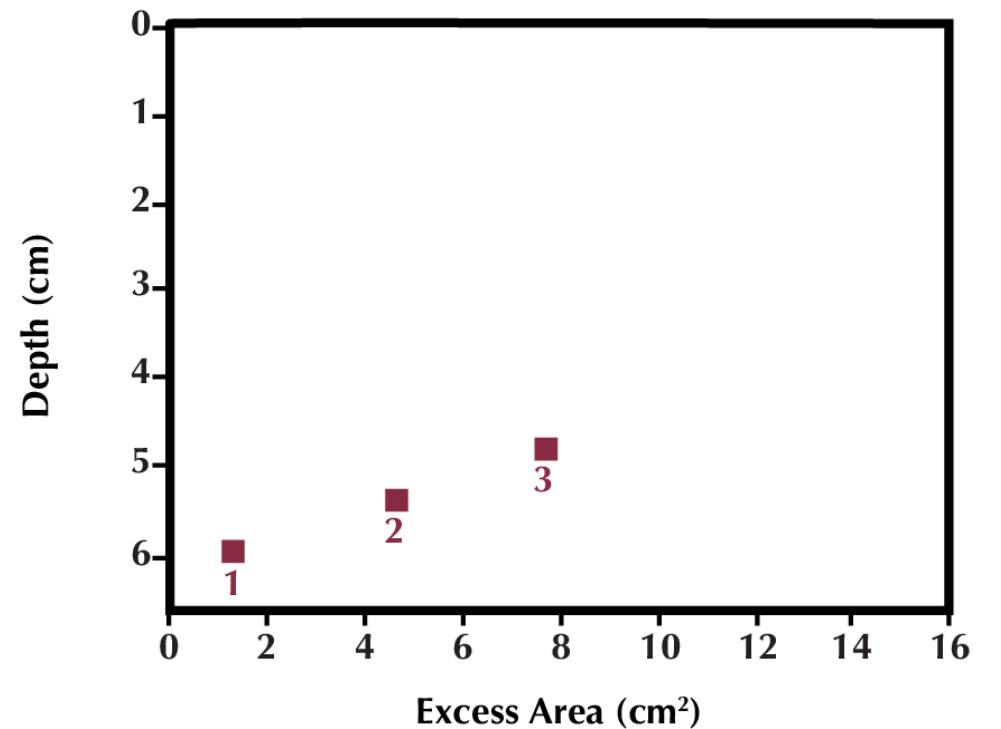
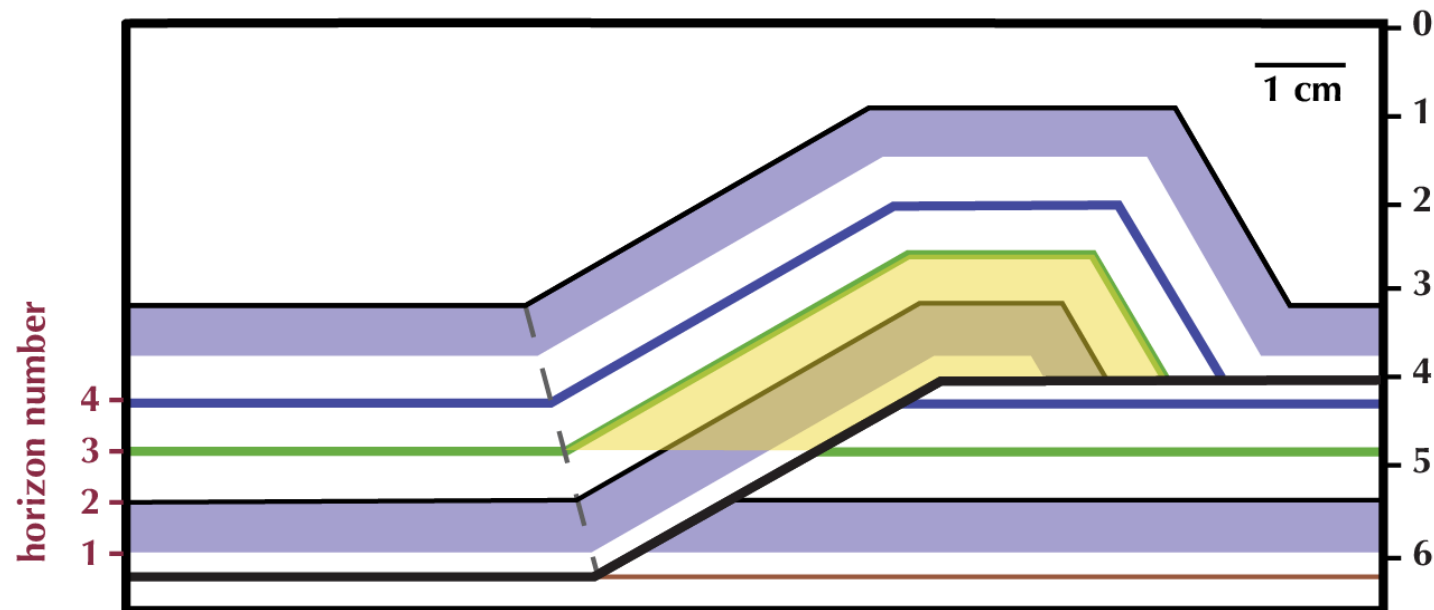
Area-depth theory

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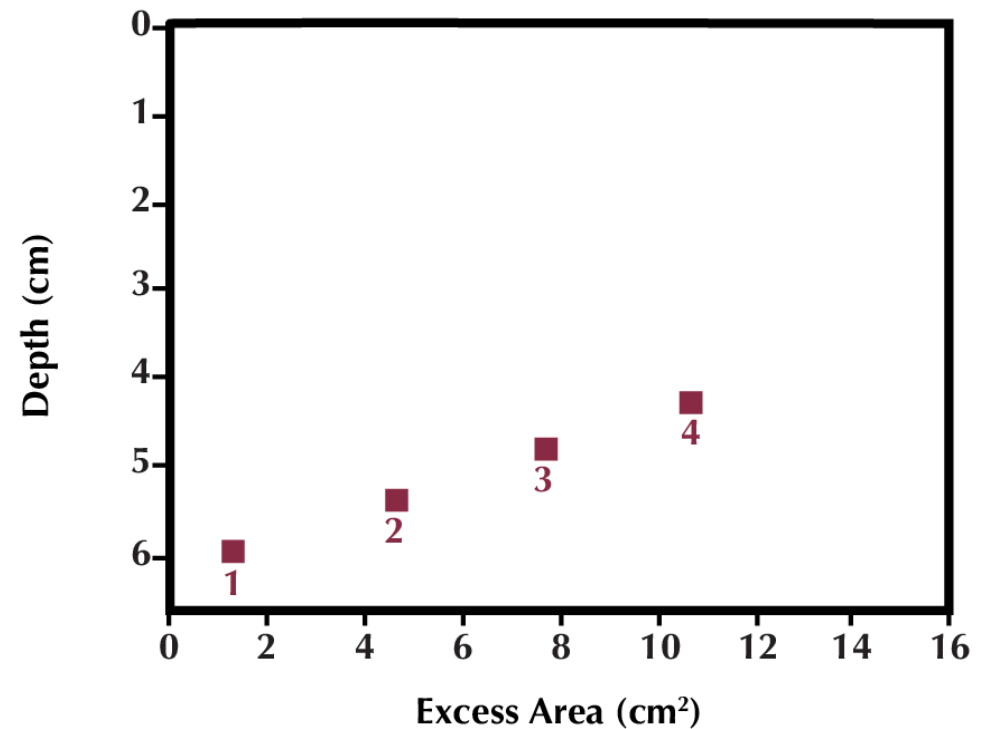
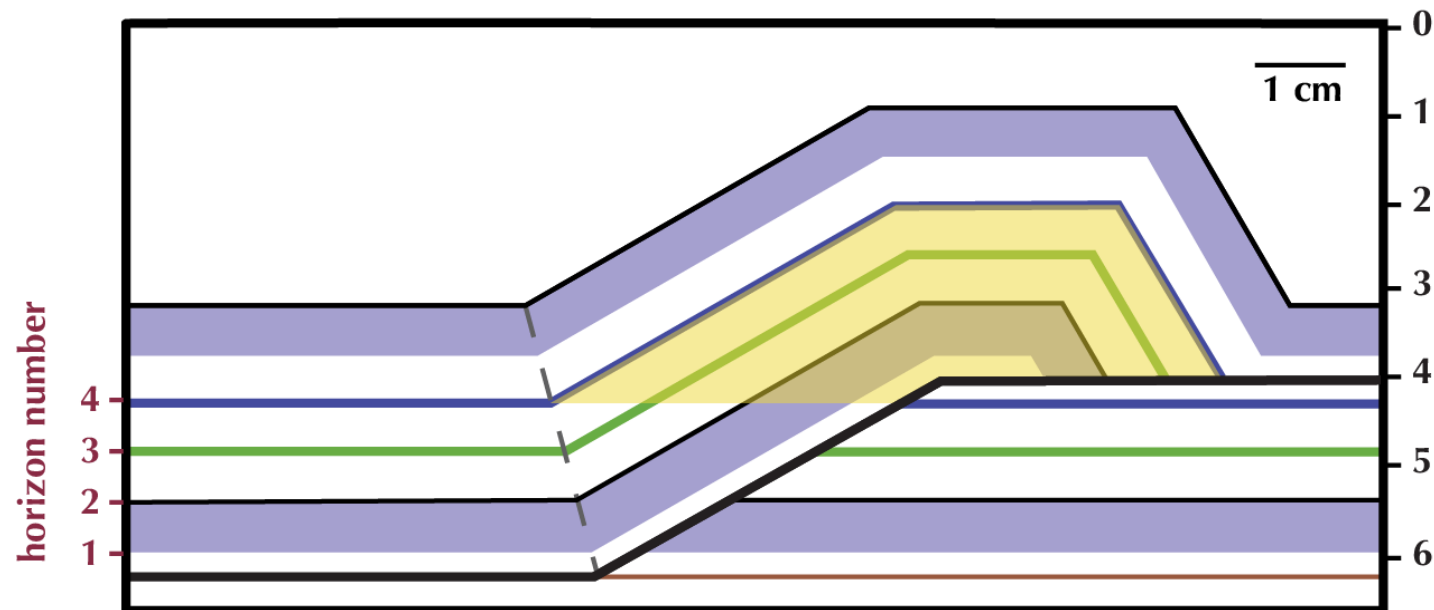
Area-depth theory

- A quantitative way to determine the depth of the décollement
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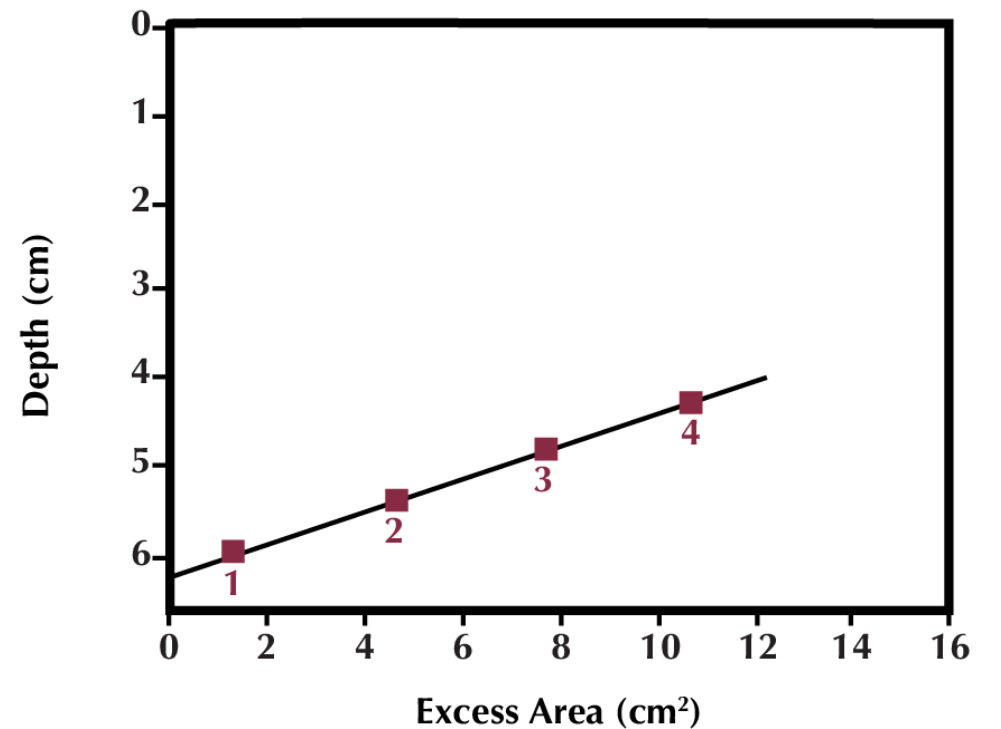
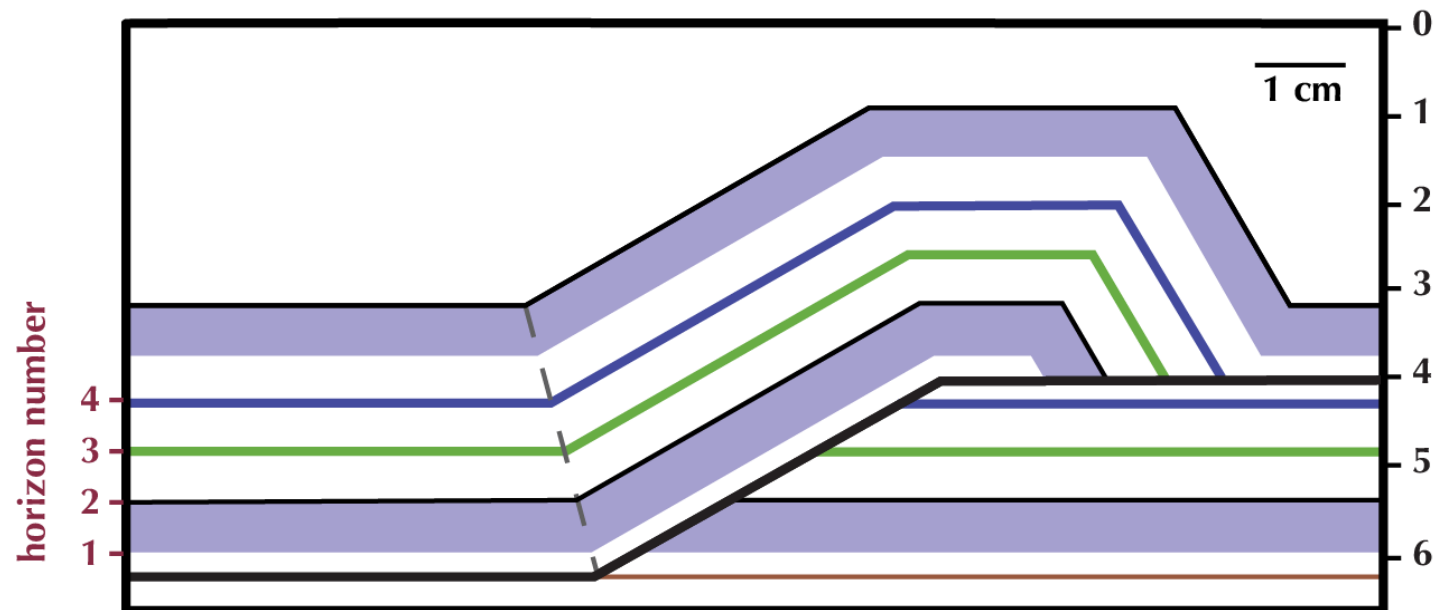
Area-depth theory

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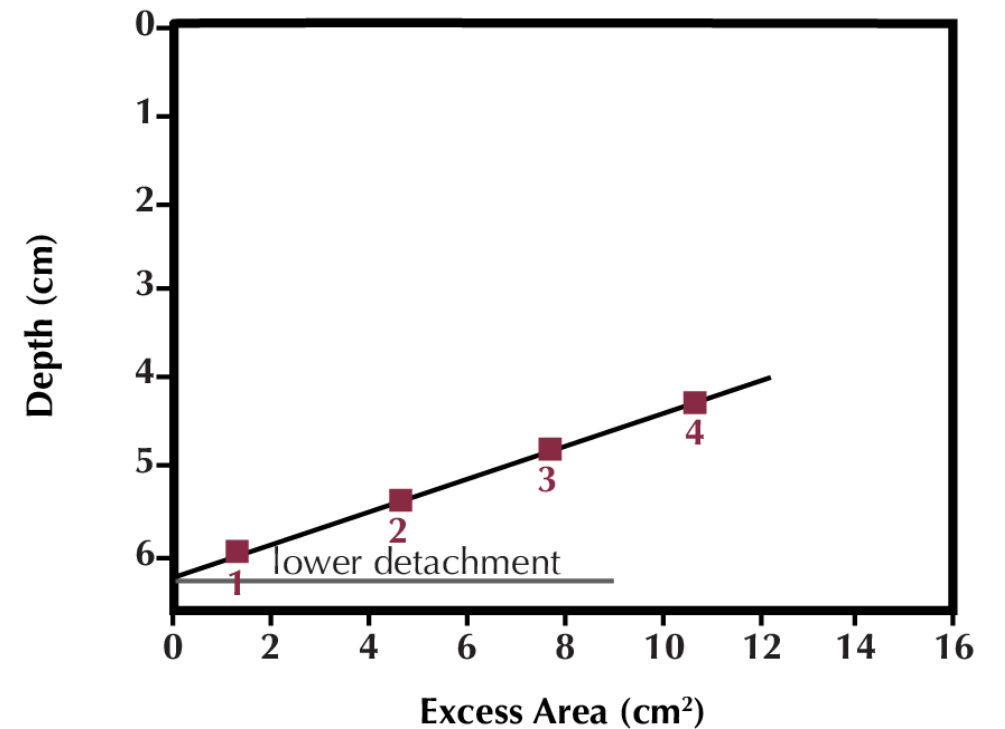
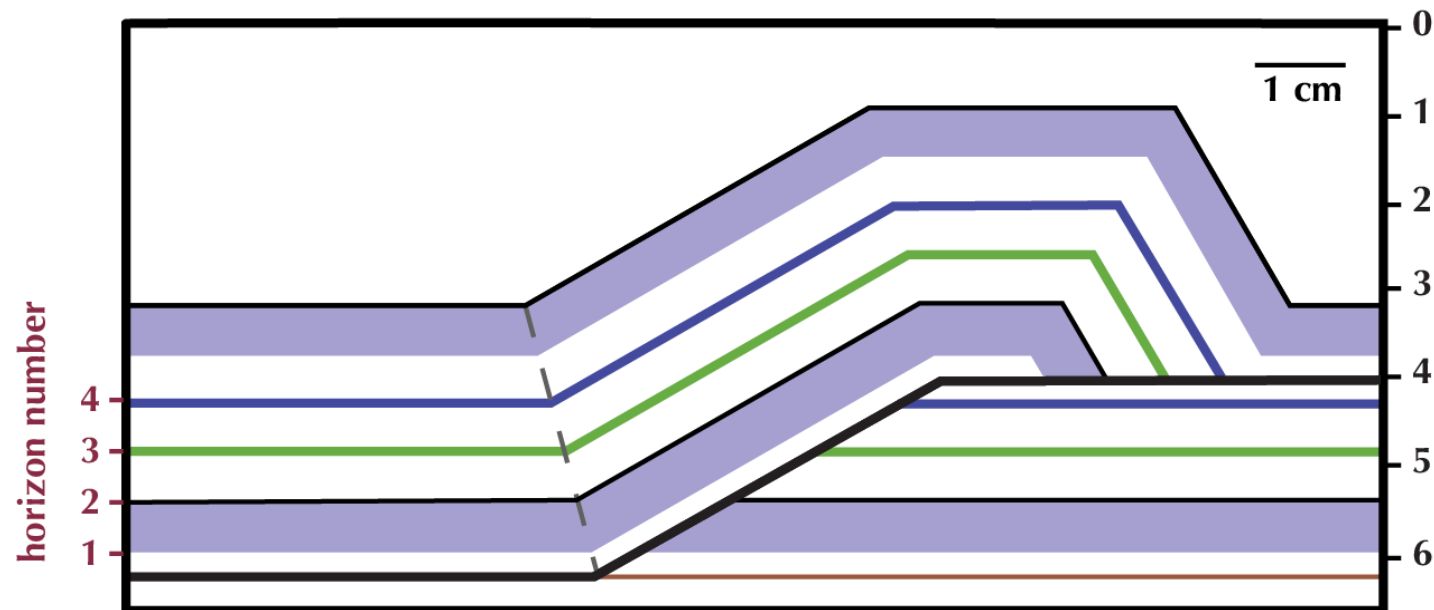
Area-depth theory

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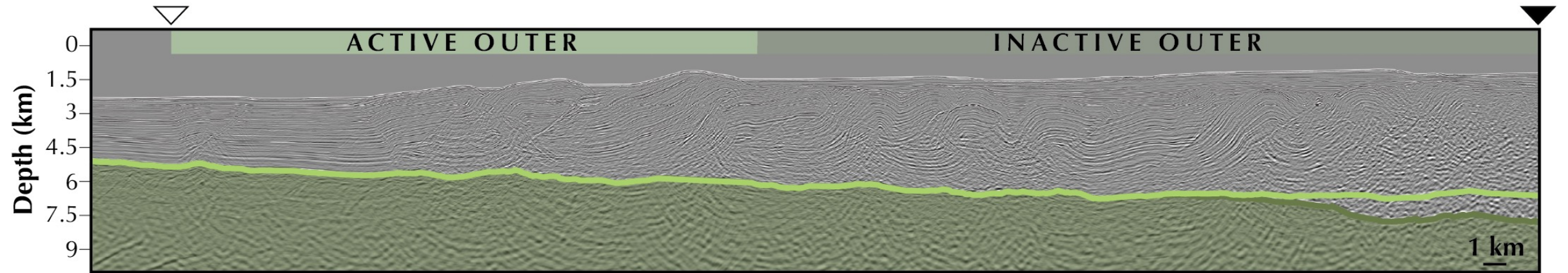
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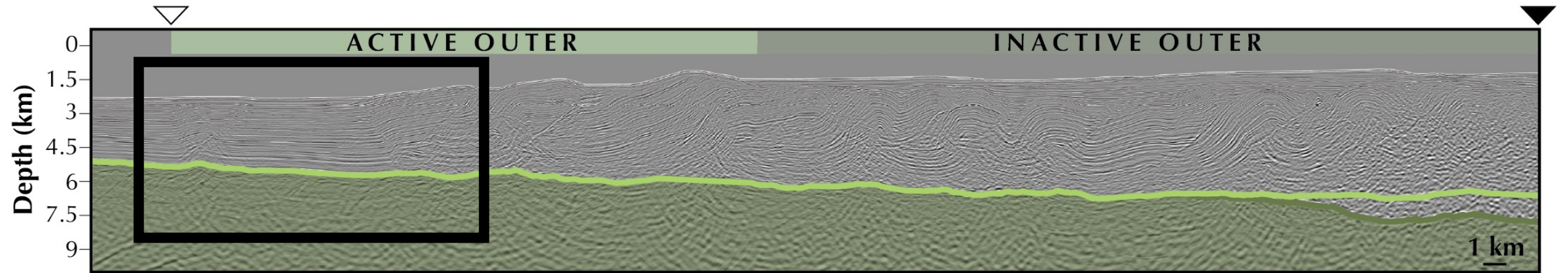
Fault geometry analysis reveals a shallower décollement

- Carbotte et al. (2024) décollement
- Carbotte et al. (2024) basement
- deformation front
- Inner-outer wedge boundary
- active fault
- inactive fault
- horizon



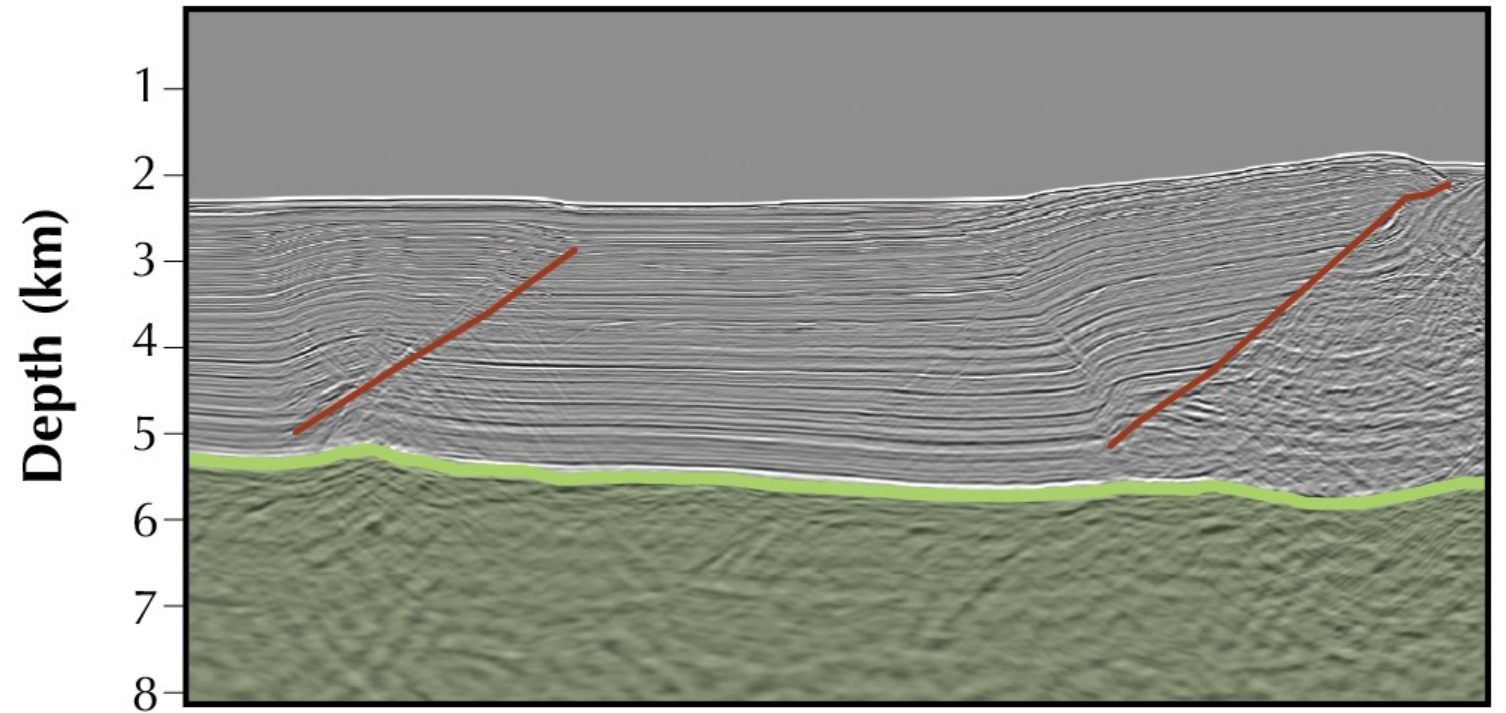
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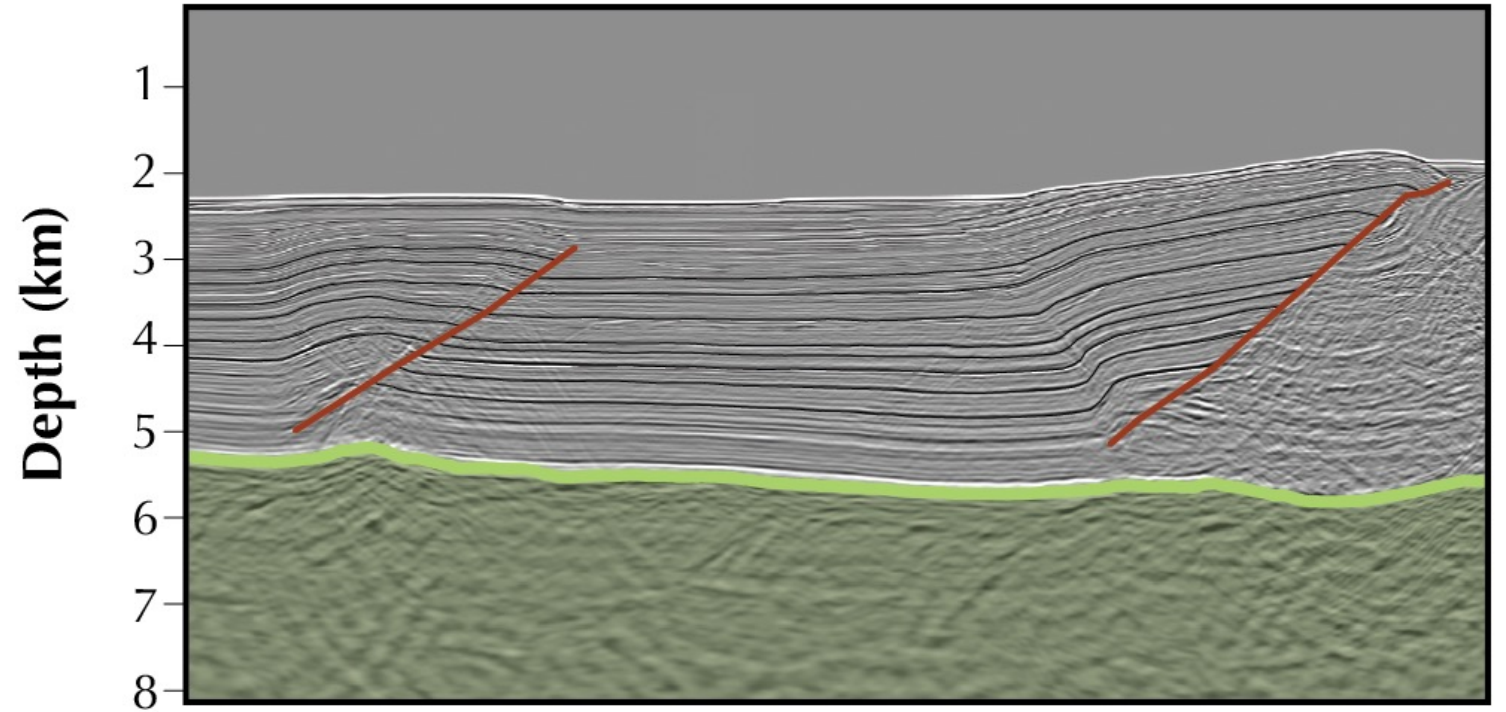
Fault geometry analysis reveals a shallower décollement

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- hinge



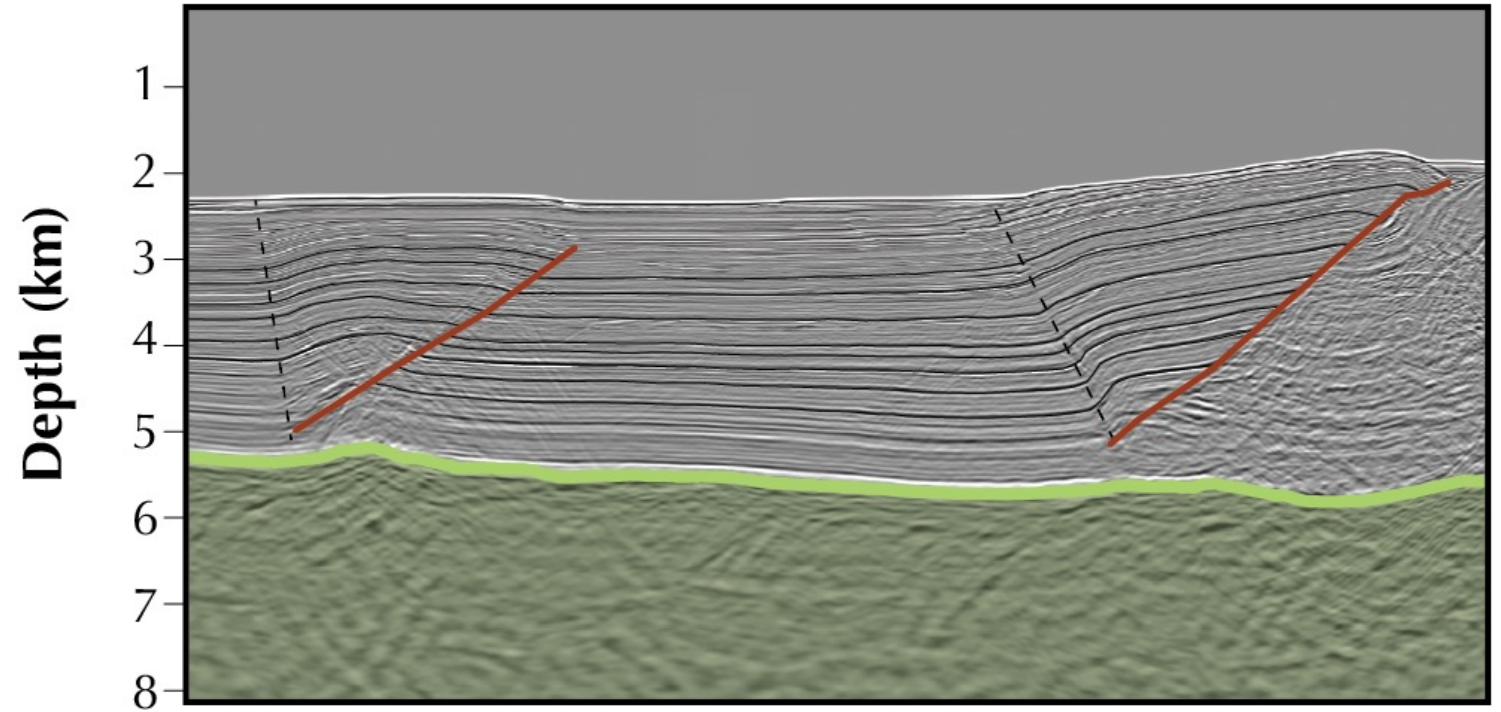
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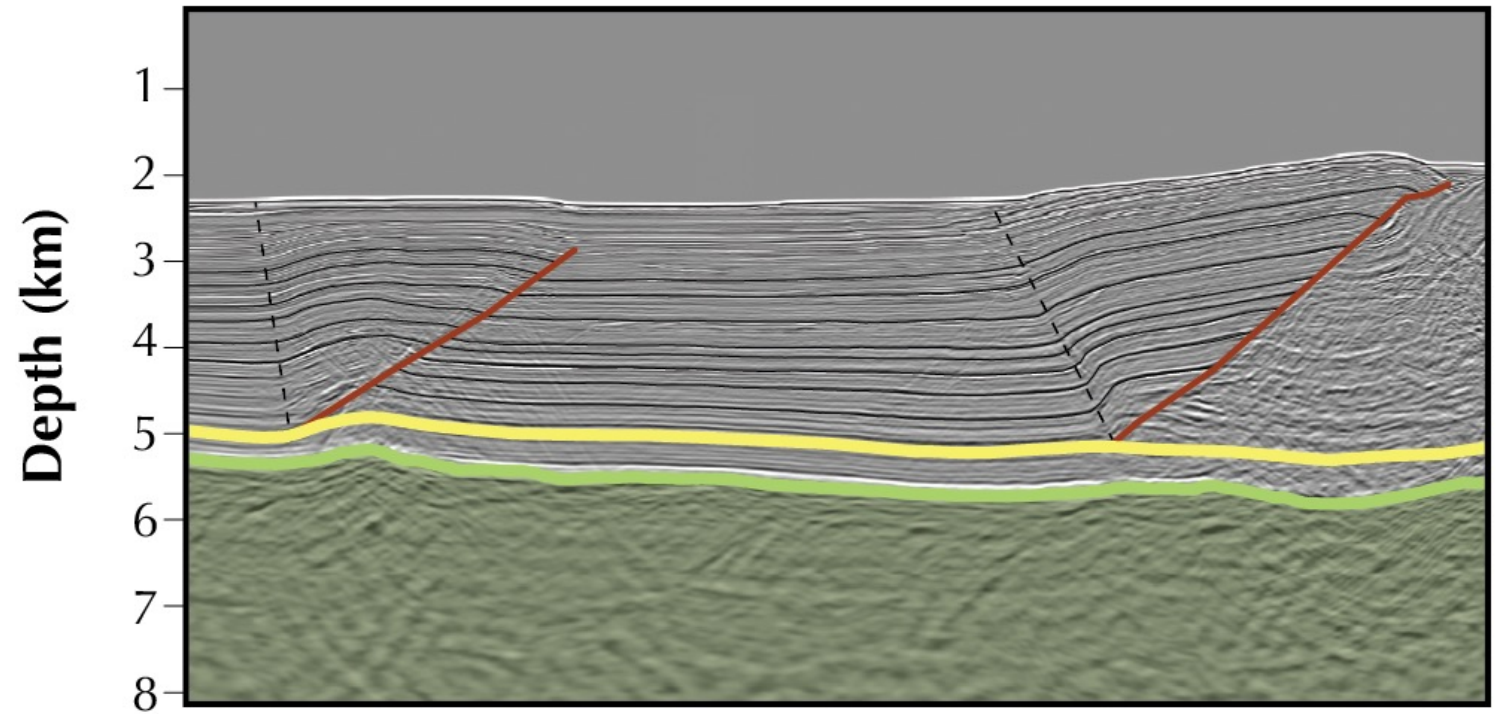
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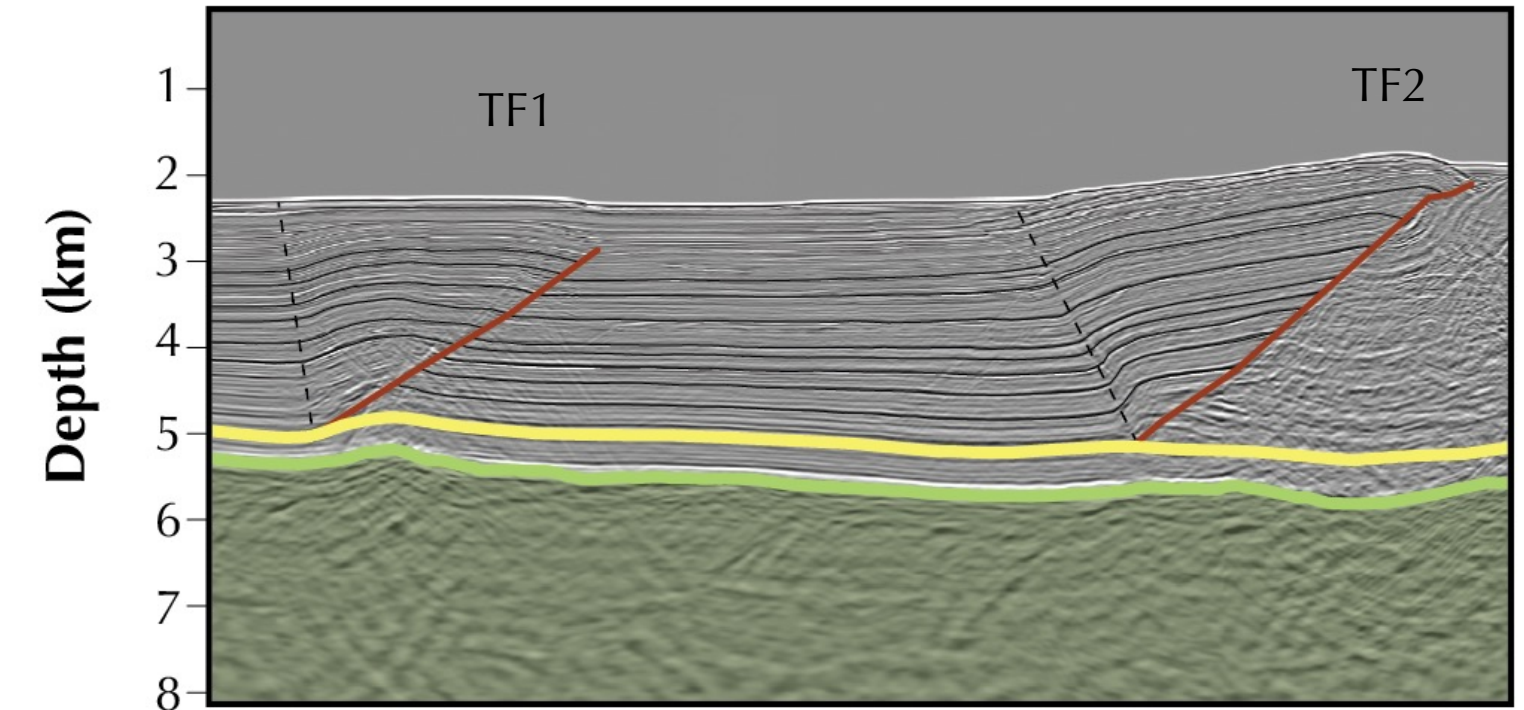
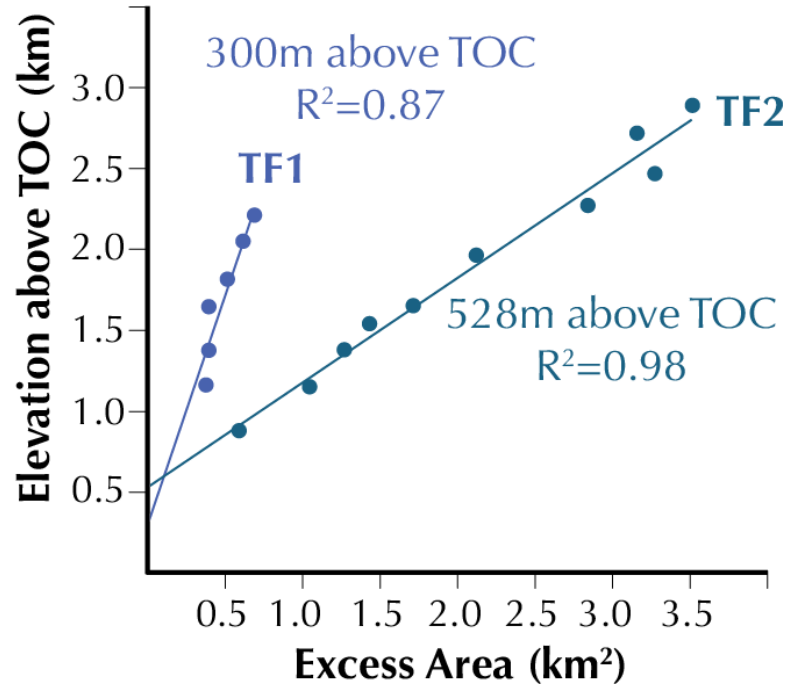
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Fault geometry analysis reveals a shallower décollement

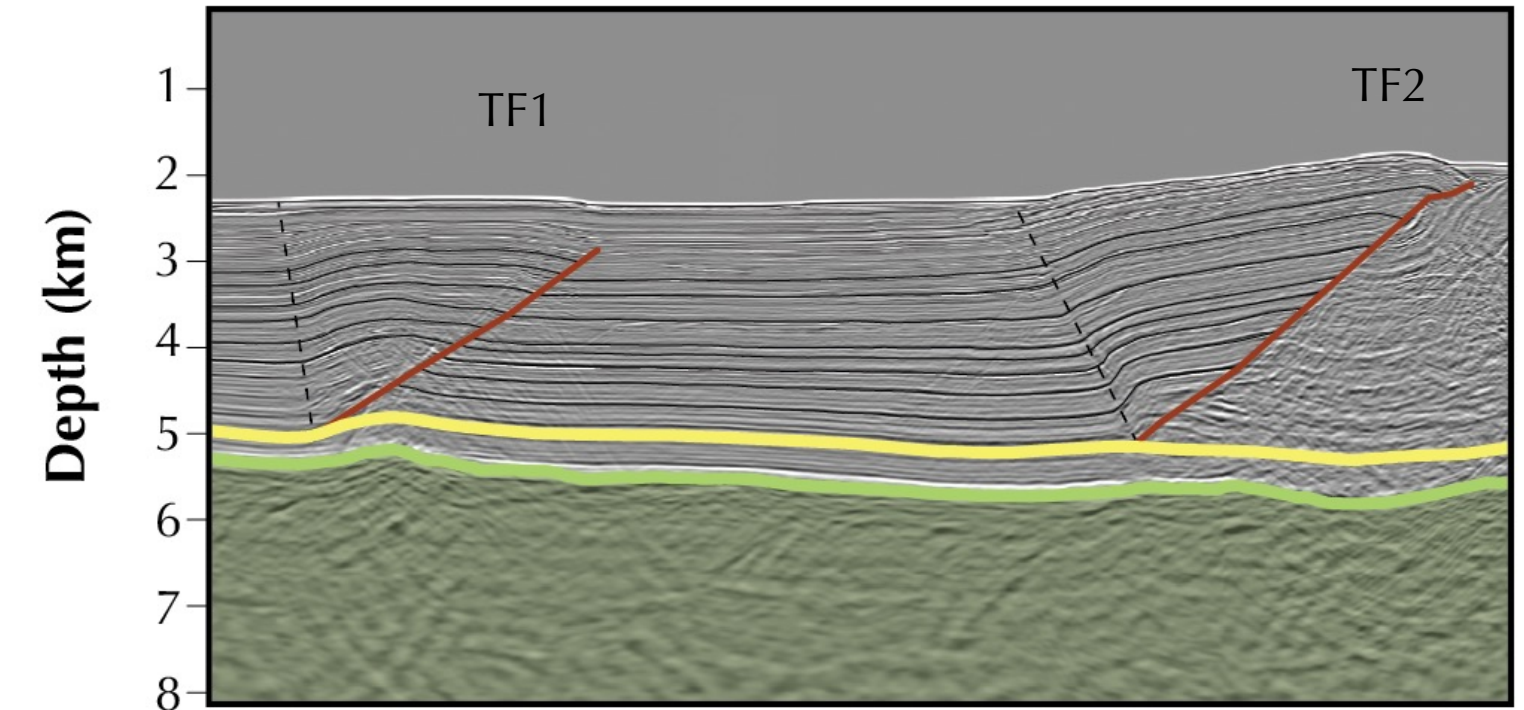
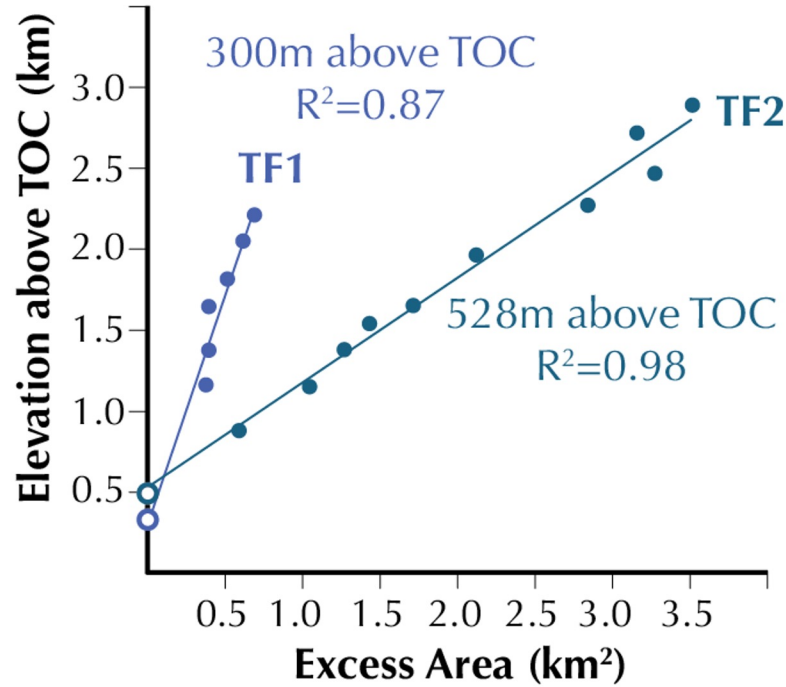
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• horizon









Fault geometry analysis reveals a shallower décollement

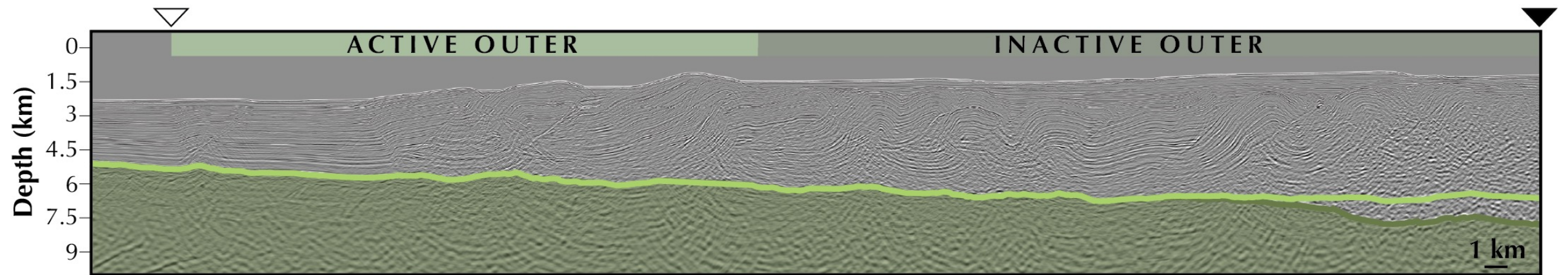
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







- horizon
- décollement interpreted here

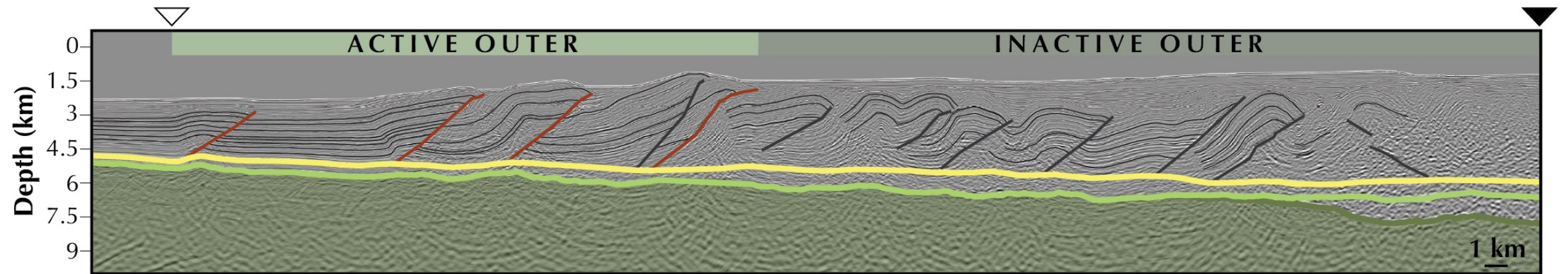
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









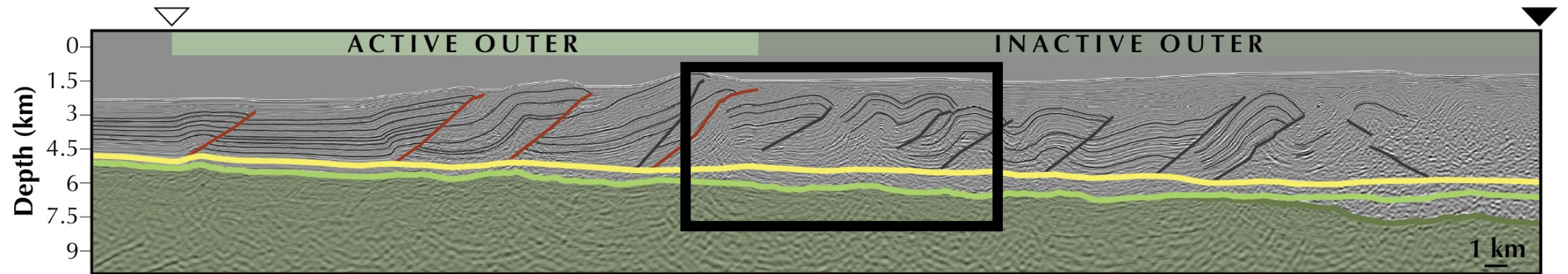
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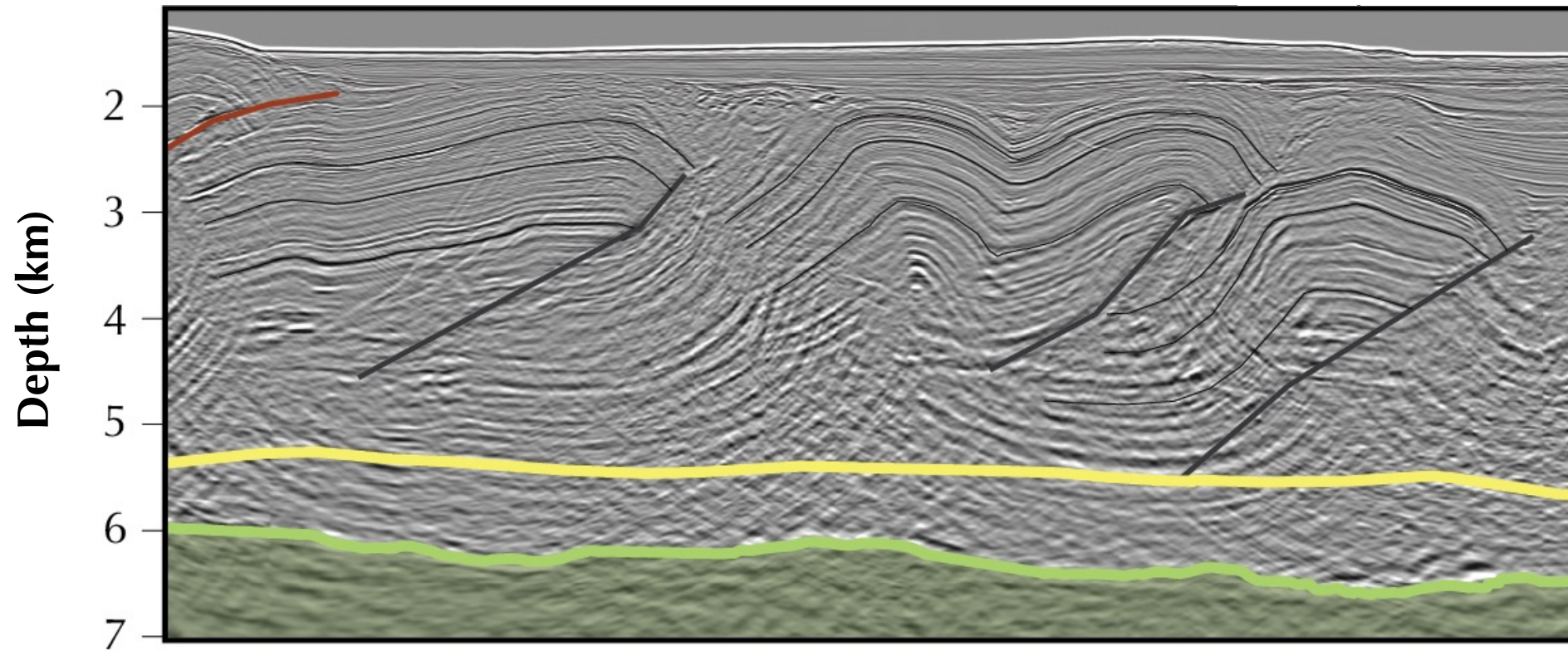
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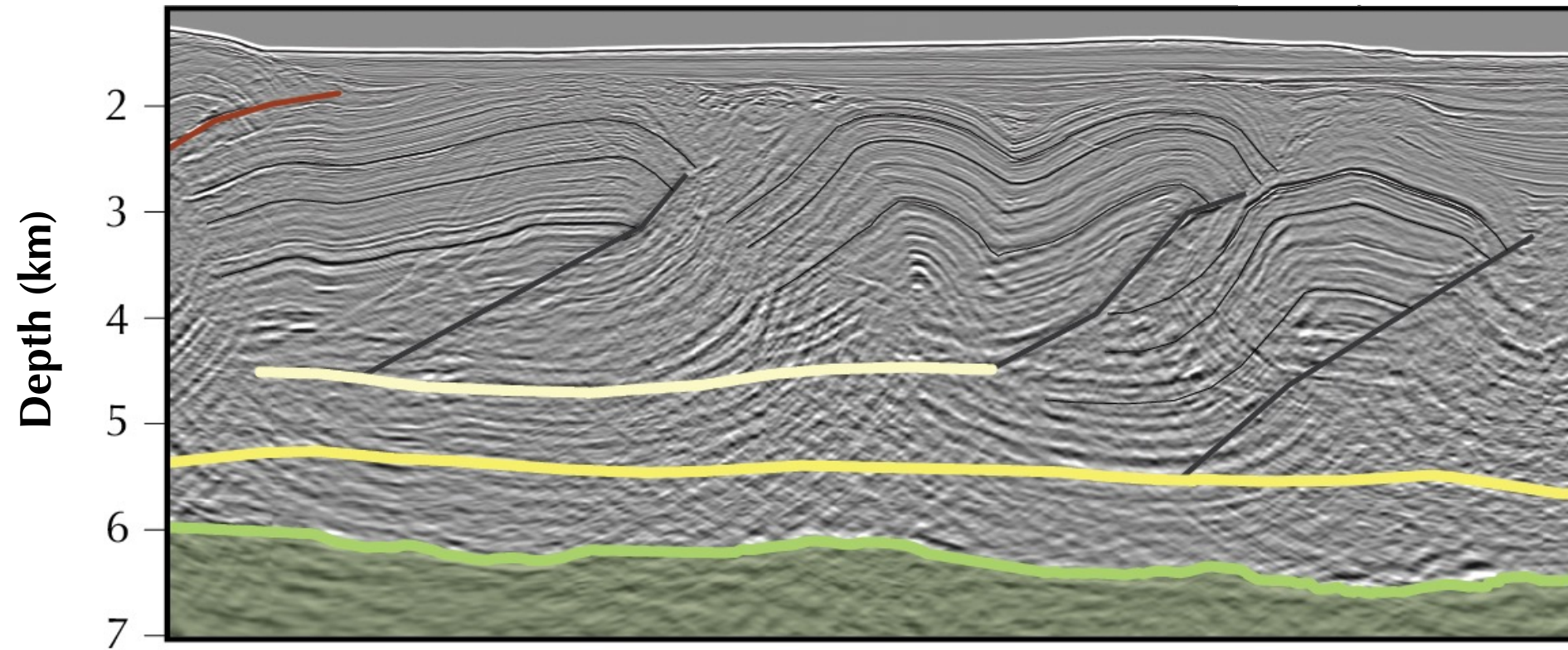
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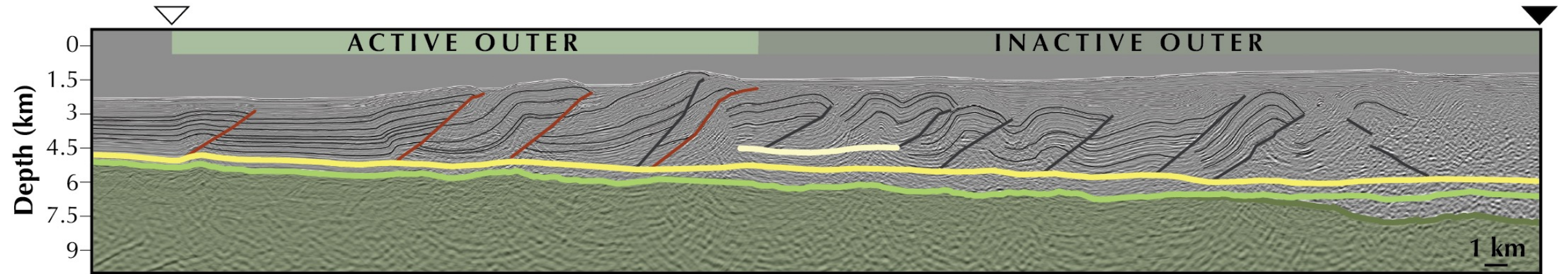
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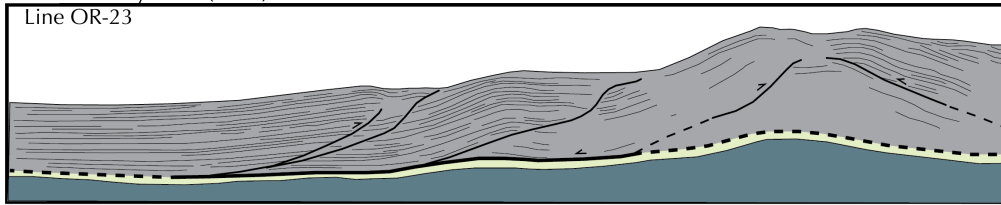
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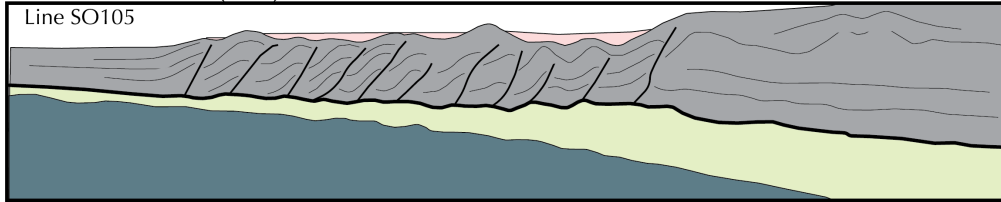


Previous interpretations of LVZ structure

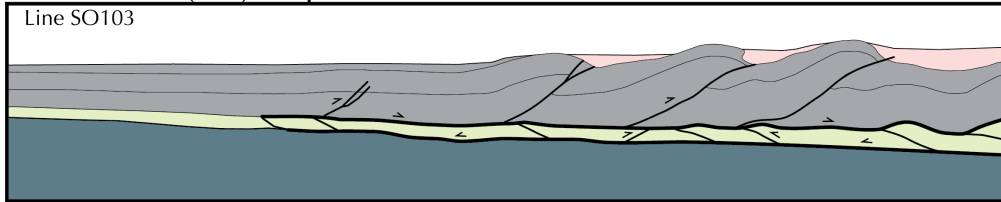
MacKay et al. (1992) Sediment-hosted décollement



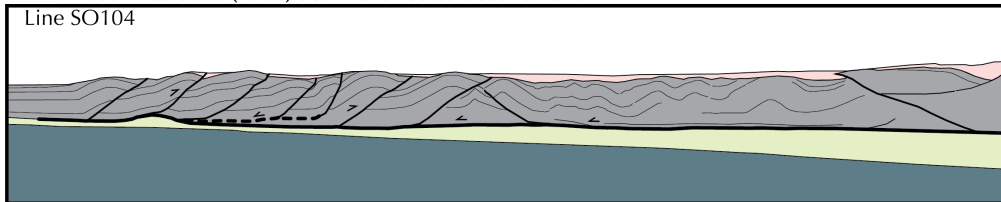
Gutscher et al. (2001) Sediment-hosted décollement



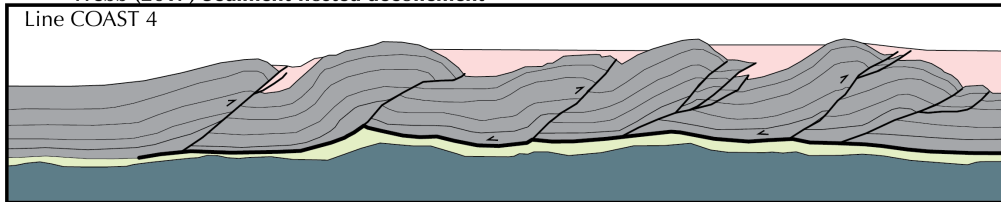
Adam et al. (2004) Multiple décollements



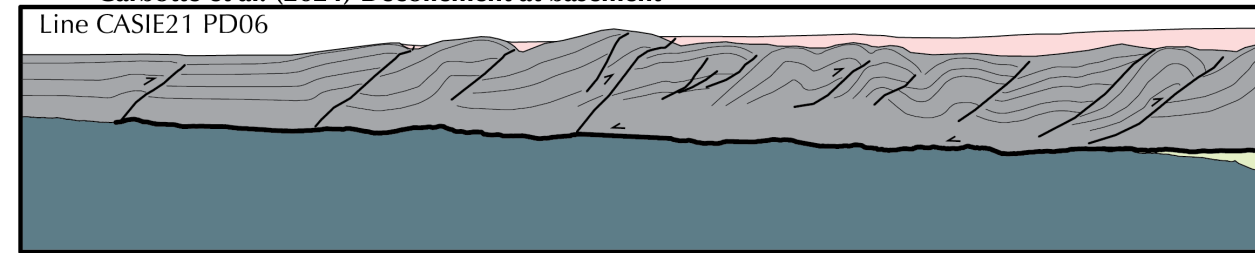
Booth-Rea et al. (2008) Sediment-hosted décollement



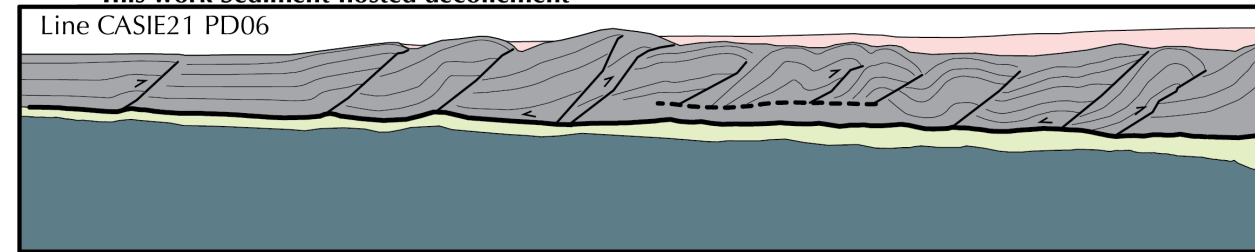
Webb (2017) Sediment-hosted décollement



Carbotte et al. (2024) Décollement at basement



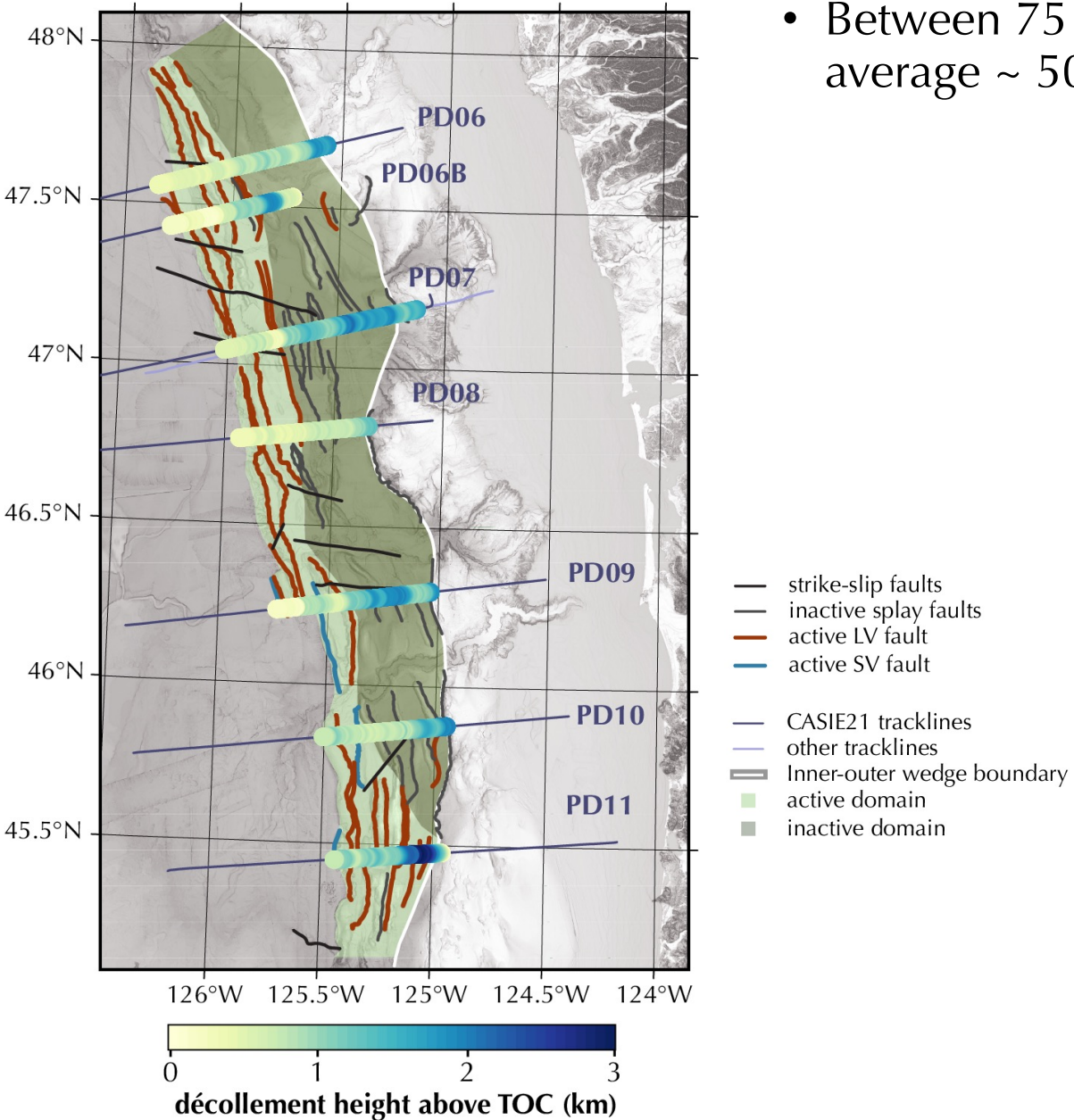
This work Sediment-hosted décollement



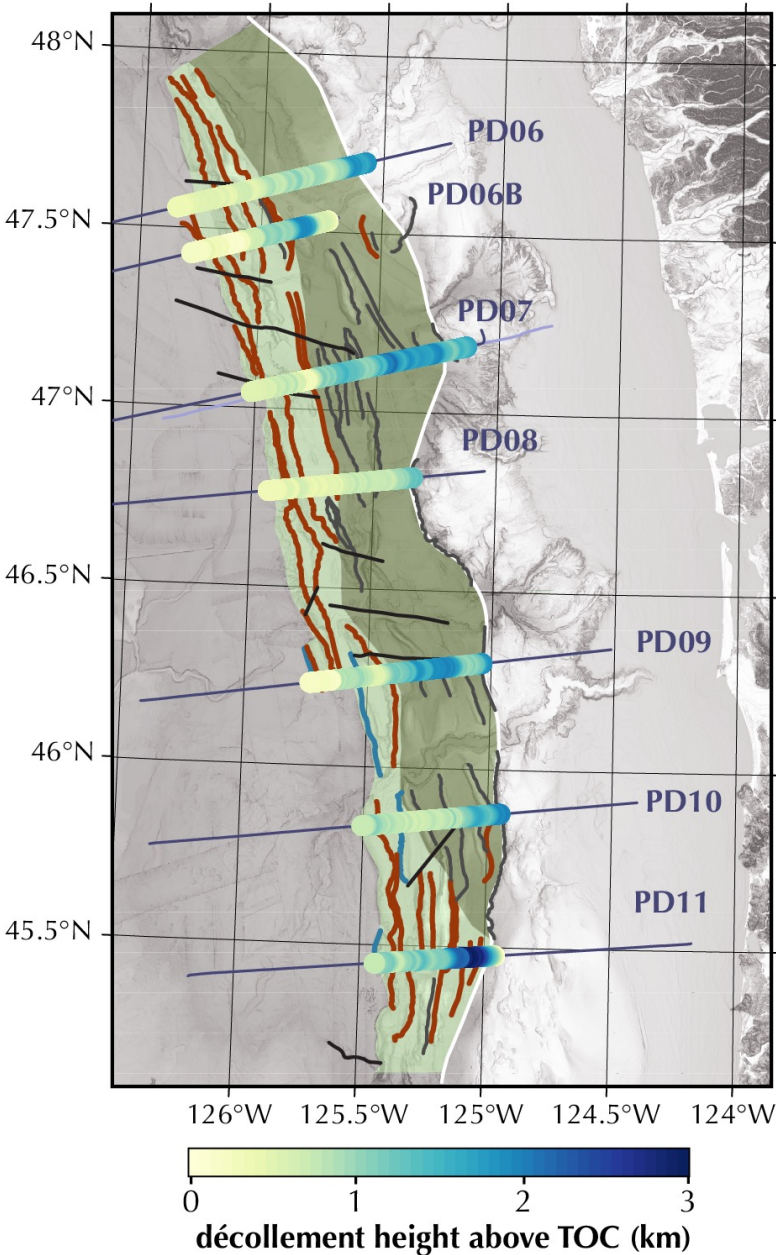
- megathrust fault
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- oceanic crust

Sediment subduction is widespread in the LVZ

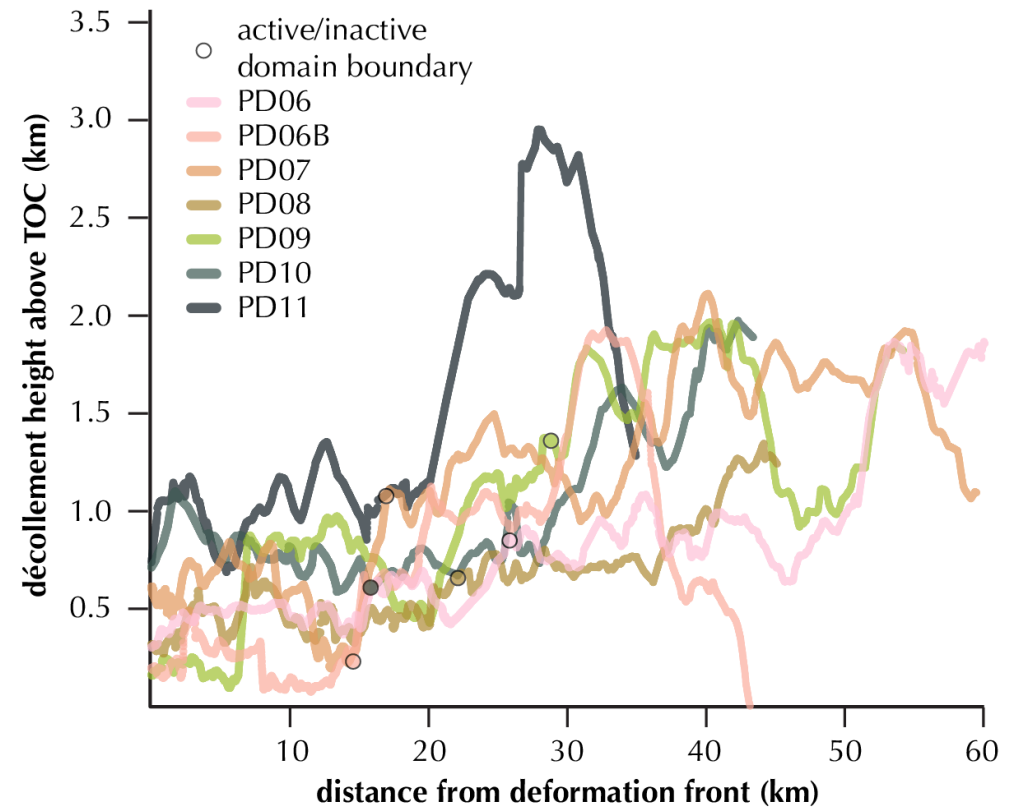
- Between 75 m and 3 km of underthrust sediment in the LVZ, on average ~ 500 m in the active outer wedge



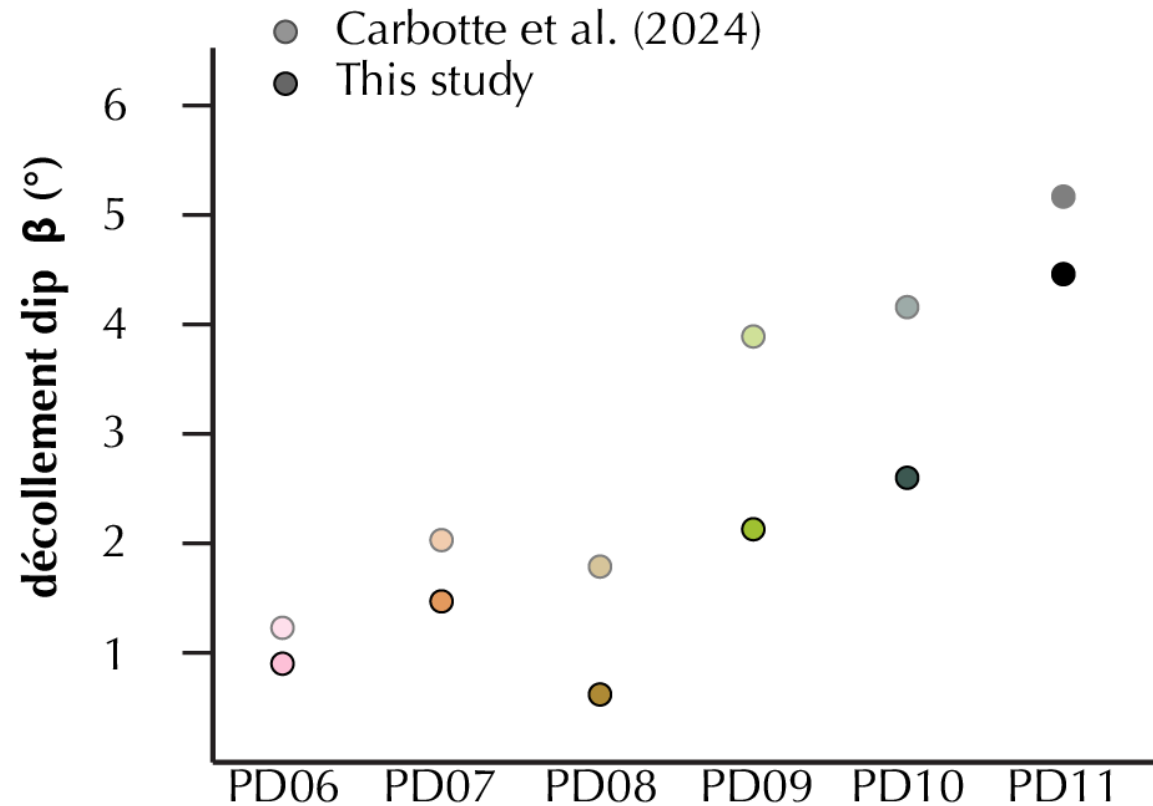
Sediment subduction is widespread in the LVZ



- Between 75 m and 3 km of underthrust sediment in the LVZ, on average ~ 500 m in the active outer wedge
- Sediment subduction increases from the deformation front to the inner-outer wedge transition
- Either due to basal erosion from the wedge or original differences in sediment thickness

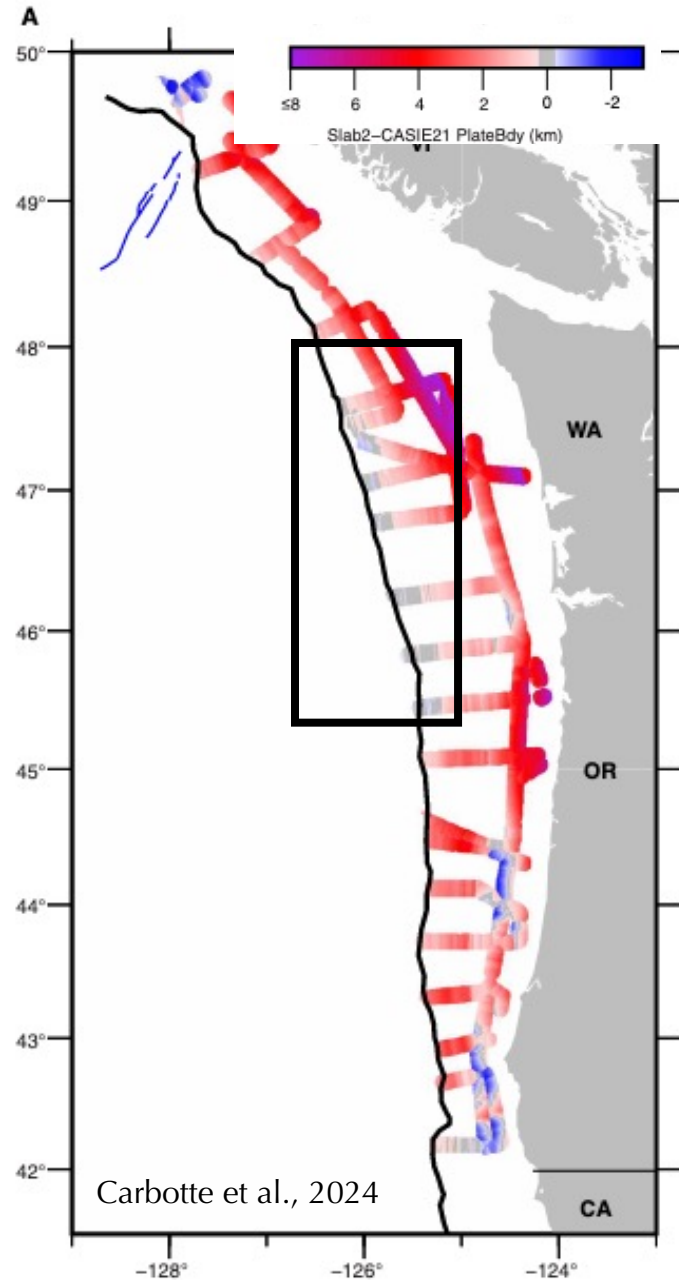
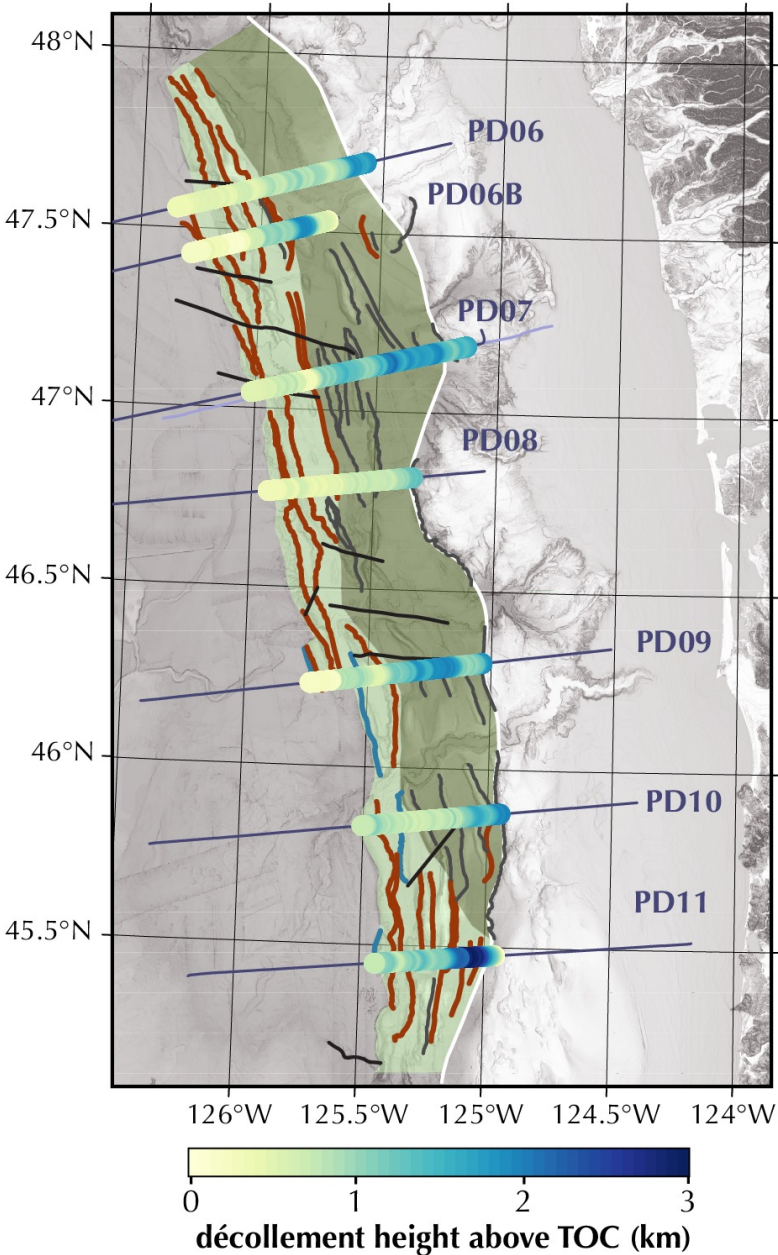


A low taper wedge



- This work suggests a lower décollement dip than in previous work
- A strong wedge over a weak megathrust fault, promoting slip to the trench style events
- Well-drained and consolidated wedge
- Consistent with geophysical evidence

The choice of a plate boundary model is important



- Carbotte et al. (2024) model already >8 km shallower than Slab2 in some areas
- When accounting for new interpretation here, differences are compounded

Hayes et al., 2018

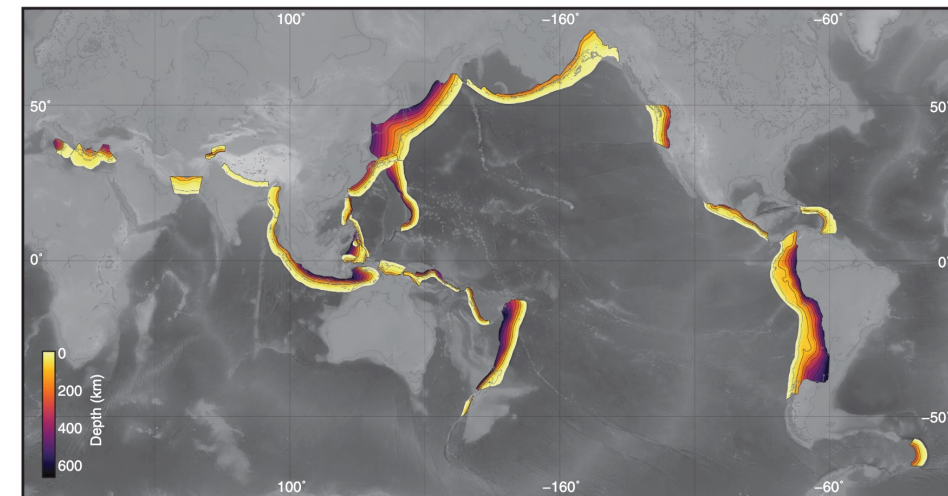
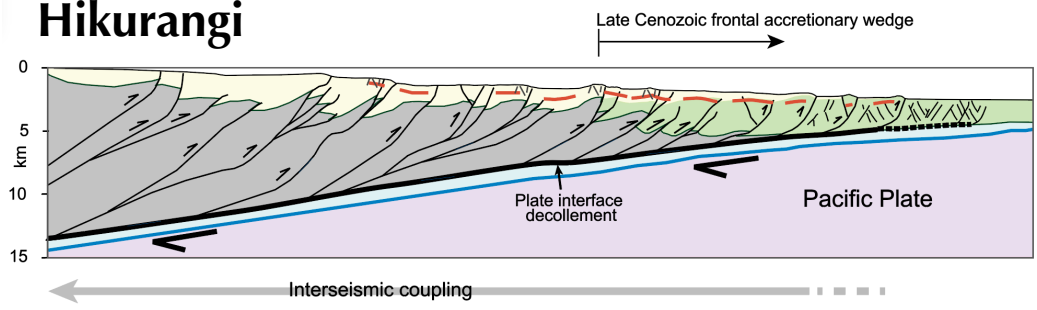


Fig. 1 The global distribution of models included in Slab2. Models are colored by depth. Slab2 and the code base used to create it are openly available via ScienceBase (31).

Sediment-hosted megathrusts are globally common

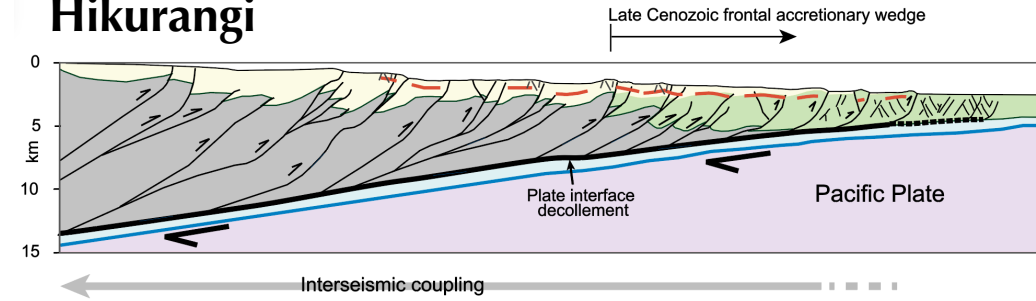
Hikurangi



Watson et al. (2021)

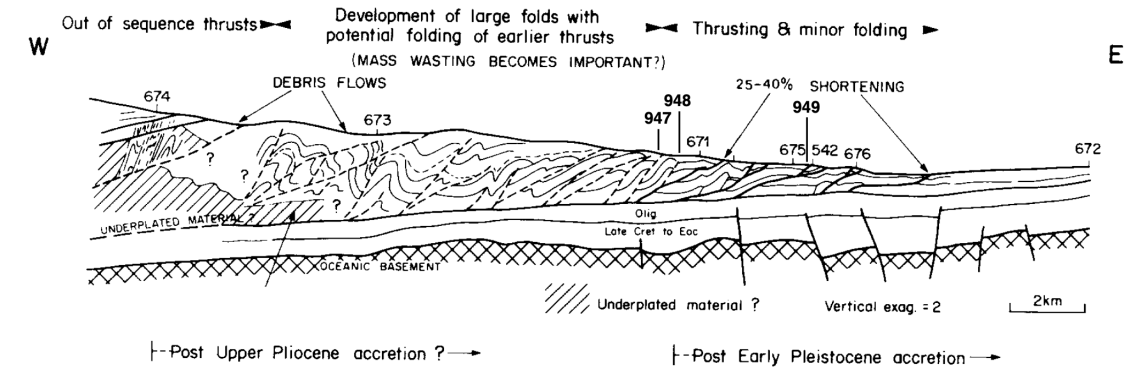
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Watson et al. (2021)

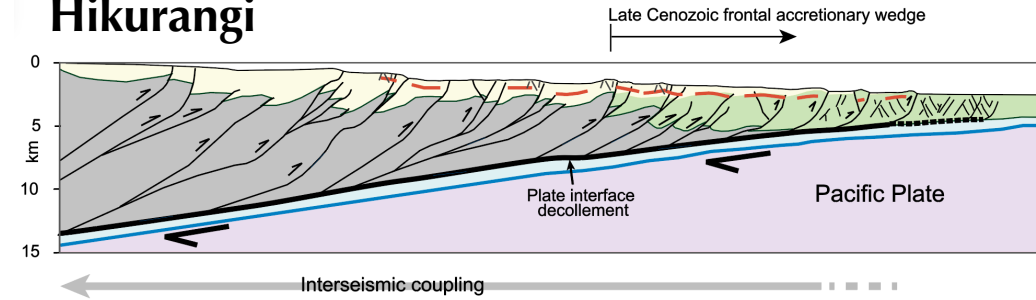
Barbados



Shiple et al. (1997)

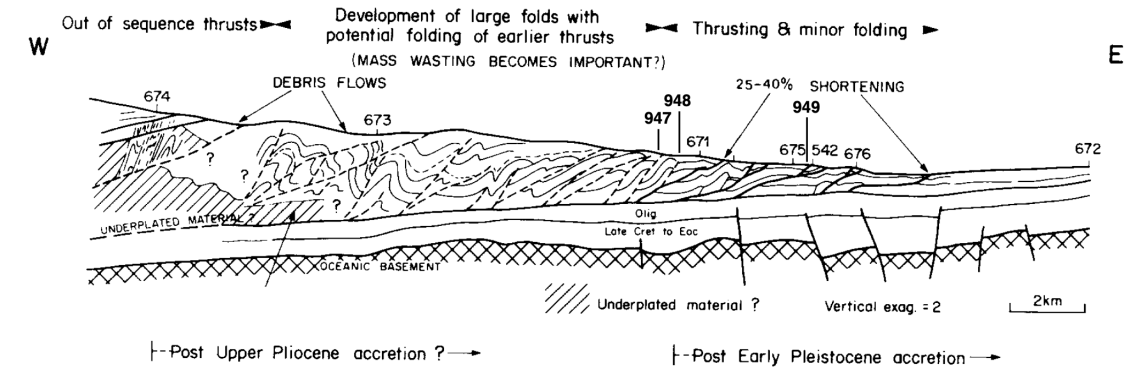
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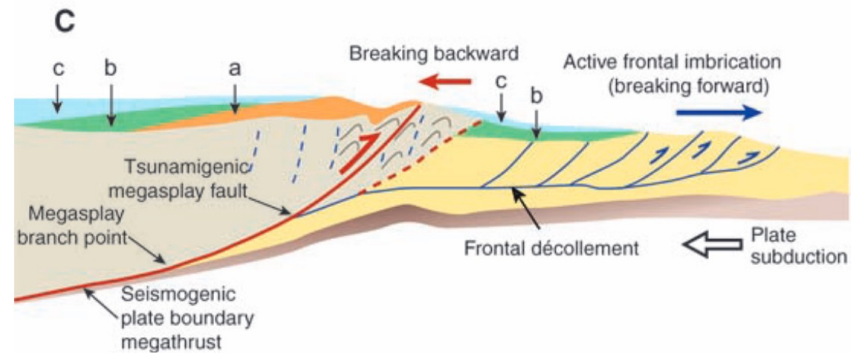
Watson et al. (2021)

Barbados



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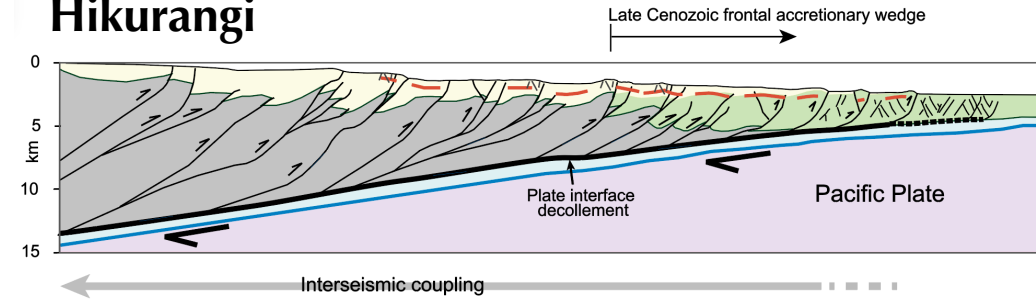
Nankai



Moore et al. (2007)

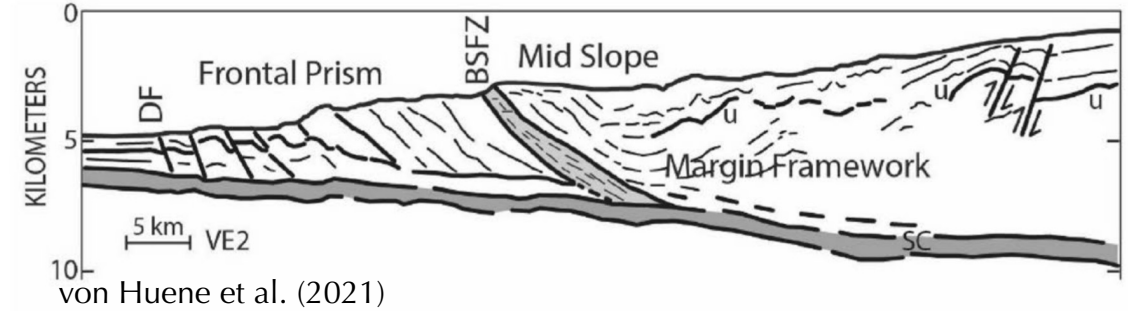
Sediment-hosted megathrusts are globally common

Hikurangi

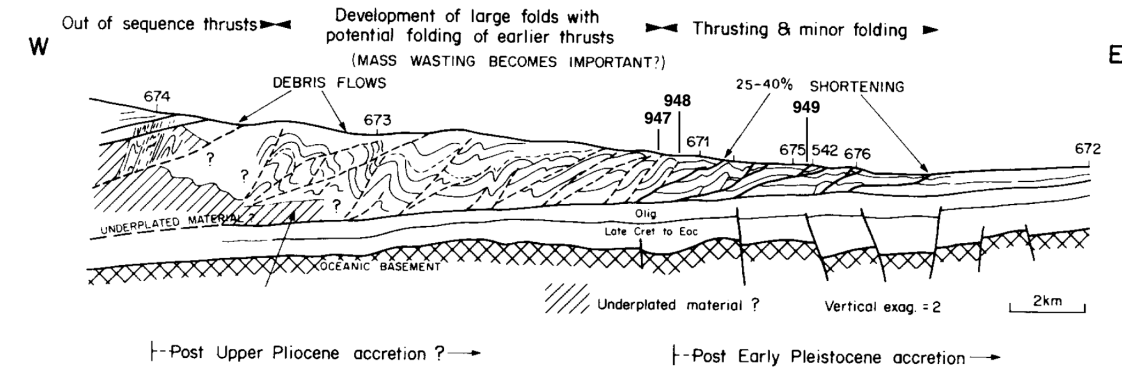


Watson et al. (2021)

Alaska

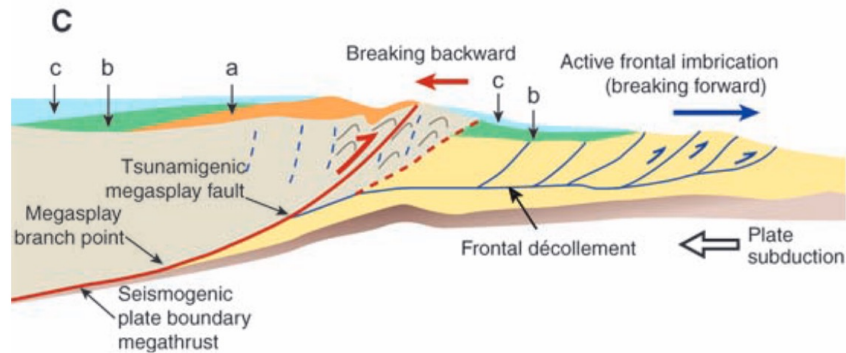


Barbados



Shiple et al. (1997)

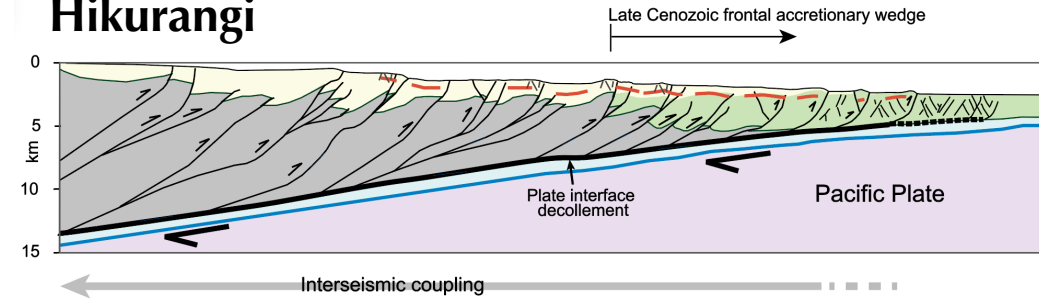
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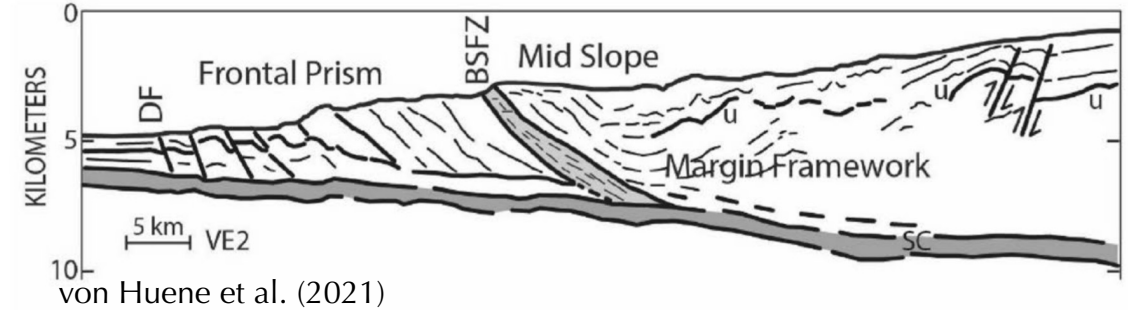
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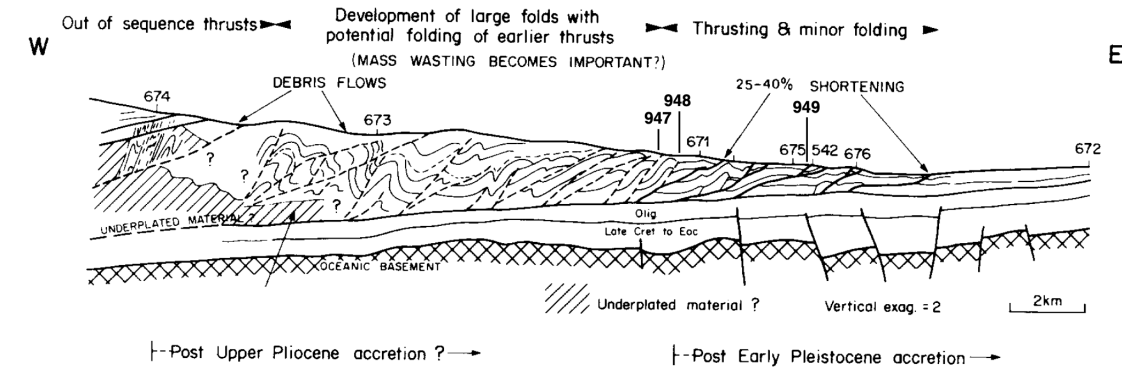


Watson et al. (2021)

Alaska

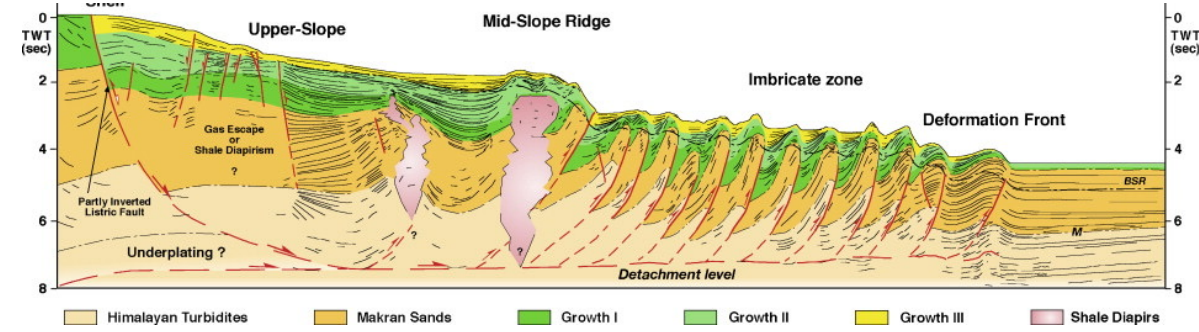


Barbados



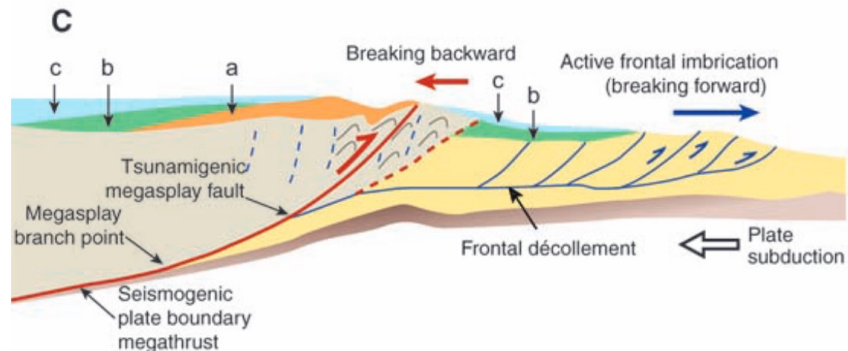
Shiple et al. (1997)

Makran



Grando & McClay (2007)

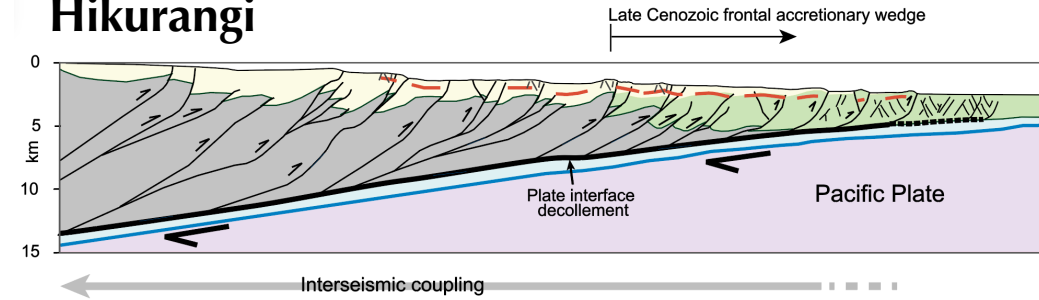
Nankai



Moore et al. (2007)

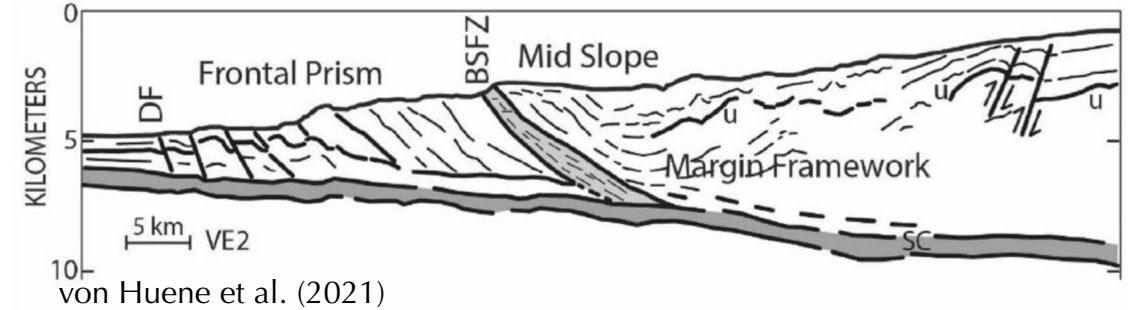
Sediment-hosted megathrusts are globally common

Hikurangi



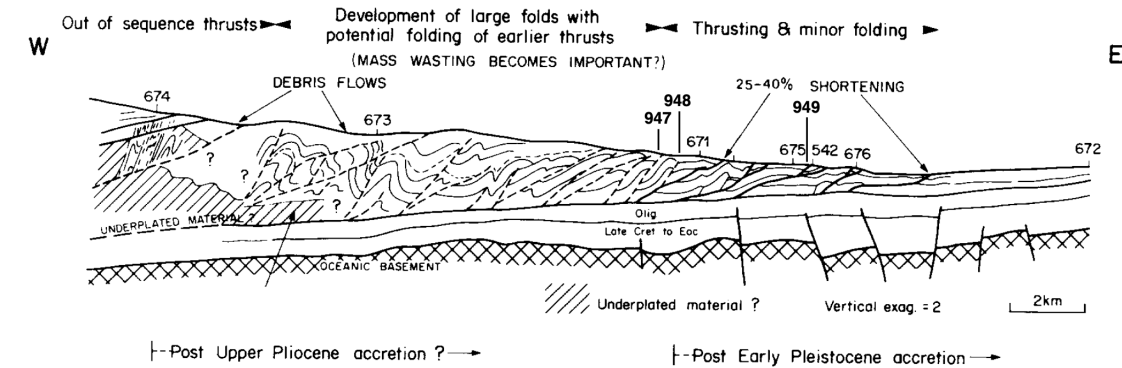
Watson et al. (2021)

Alaska



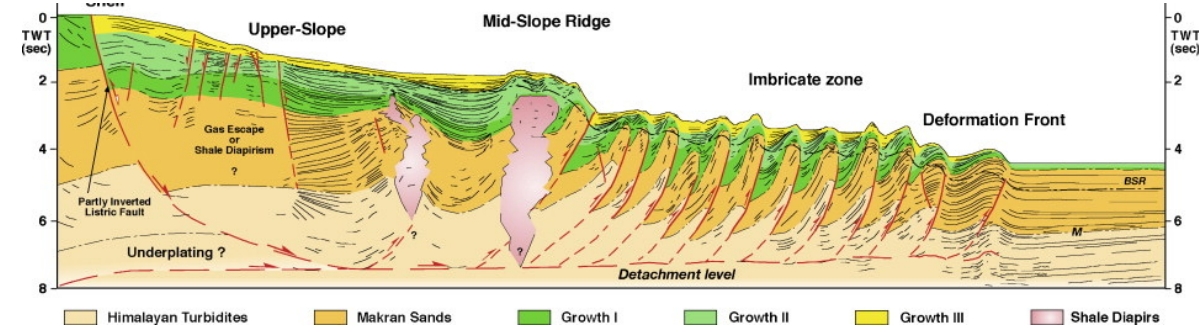
von Huene et al. (2021)

Barbados



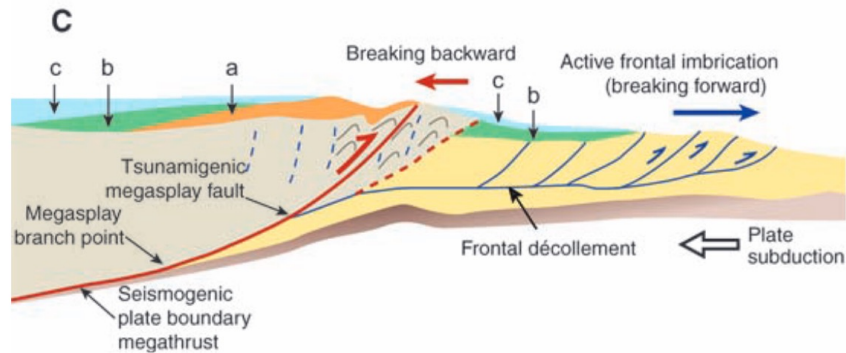
Shiple et al. (1997)

Makran



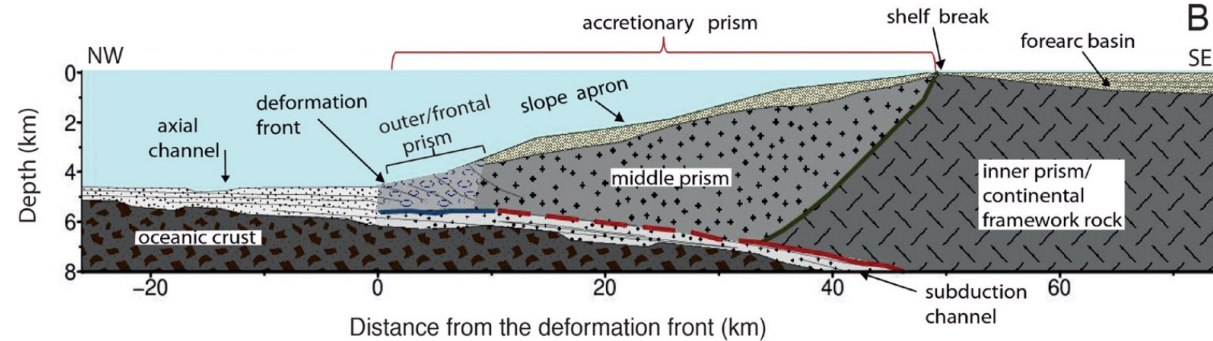
Grando & McClay (2007)

Nankai



Moore et al. (2007)

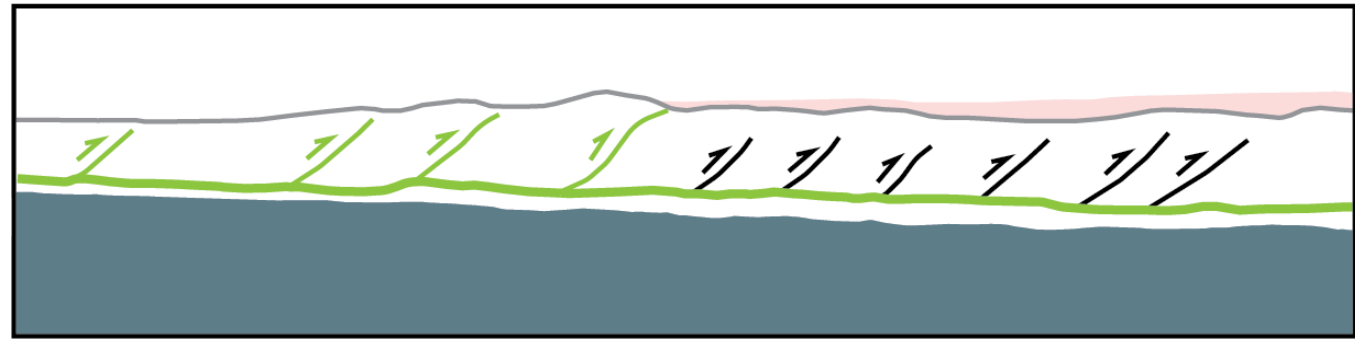
Chile



Tréhu et al. (2019)

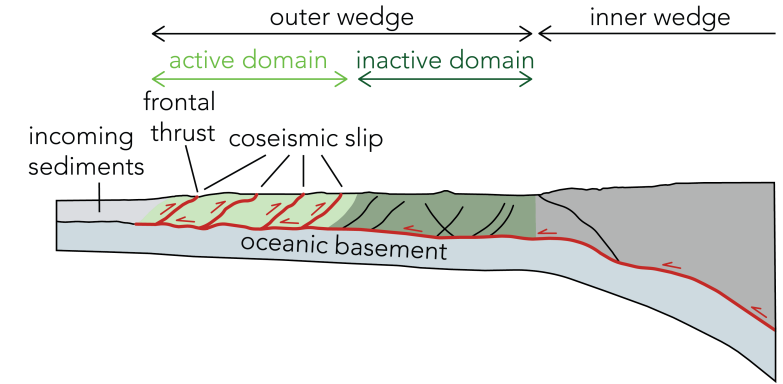
Sediment-rich megathrusts host larger earthquakes

- The fault zone host rock (basalt vs. sediments) is a key control on rupture mechanics
- Link between thick downgoing sediments and large earthquakes is well-established
- A **smoother** plate interface hosted in sediments promotes seismogenic slip and slip to the trench
- A **shallow** plate interface could increase near-surface wedge deformation and thus tsunamigenesis



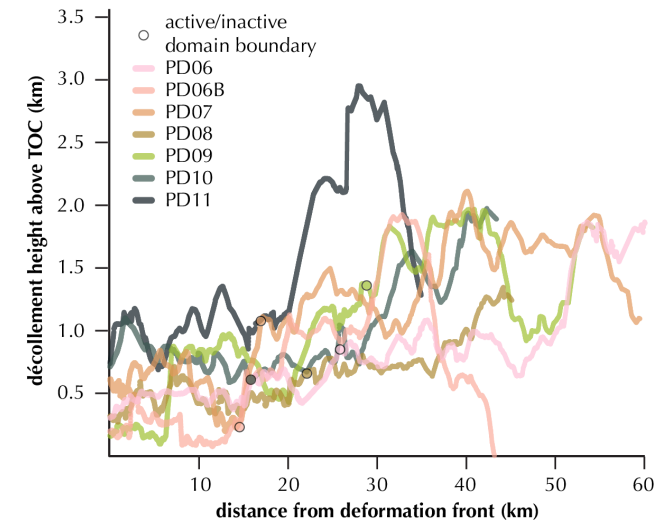
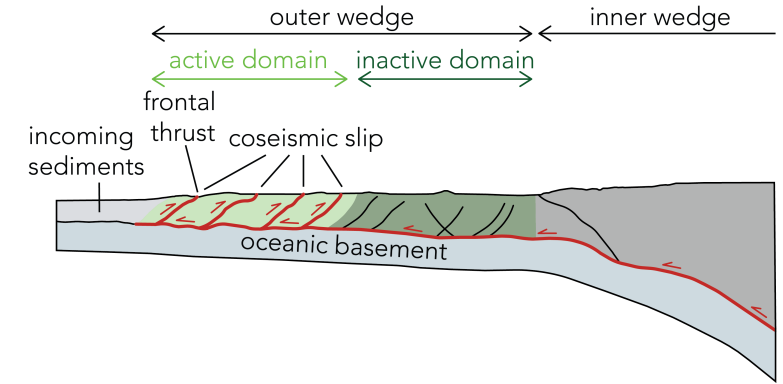
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- New work suggests the megathrust fault is up to 3 km shallower than recent models, which could profoundly increase near-surface wedge deformation

- The décollement is completely hosted within the sediments, which may impact rupture mechanics

