State and Evolution of Fluid Pressure Above the Shallow Cascadia Megathrust: Insights from Observations and Models

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- benefit from discussions with Kelin Wang[1,2], Earl Davis[2], Demian Saffer[3], Susan Ellis[4], and Shuoshuo Han[3]

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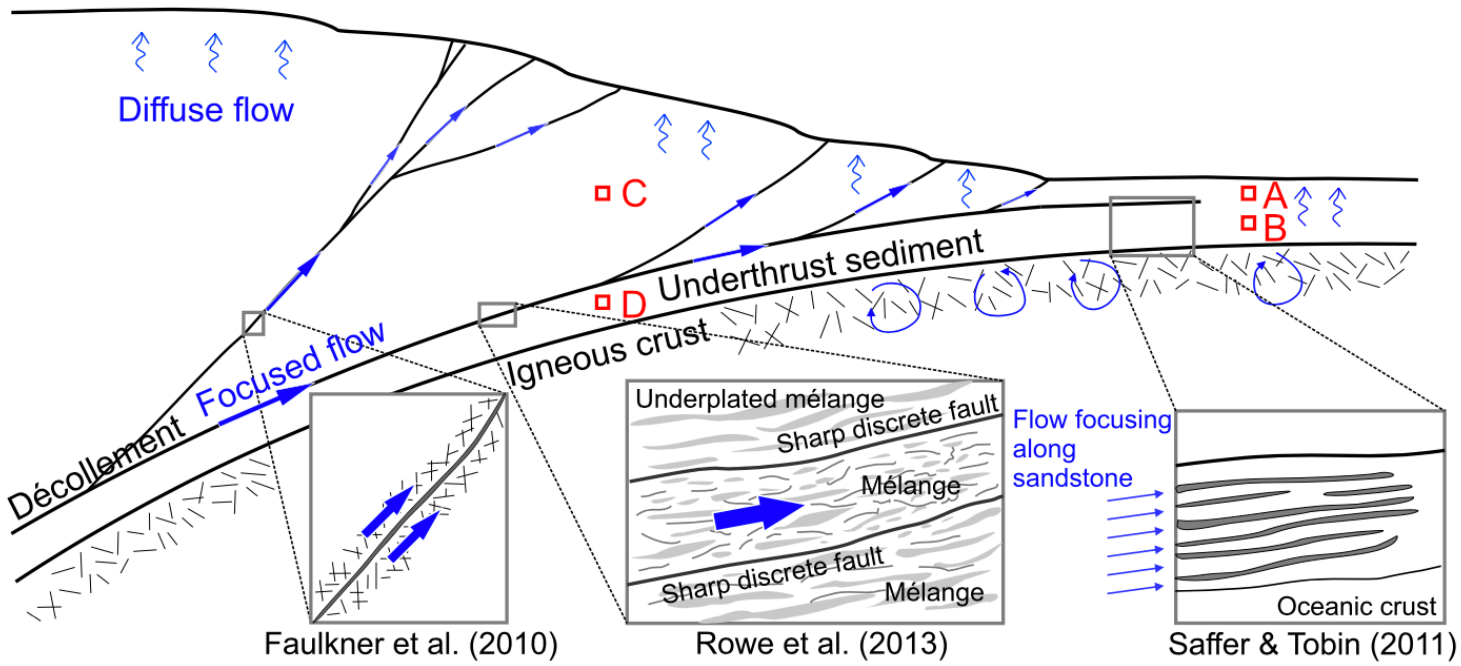
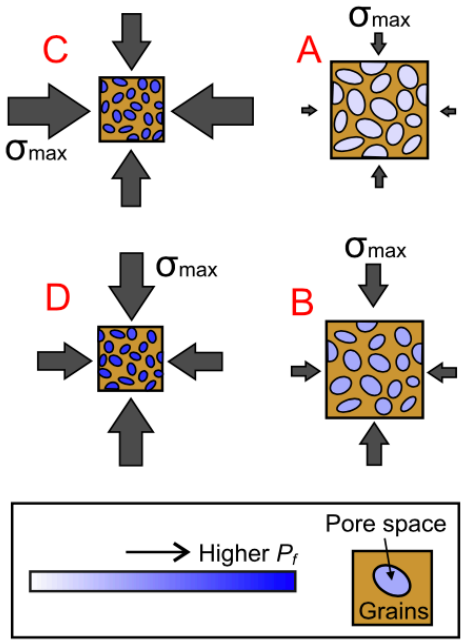
3. Institute for Geophysics – The University of Texas at Austin
4. Ellis Geodynamics, New Zealand

Along-term "steady-state" view: mechanical loading and limited drainage cause fluid overpressure

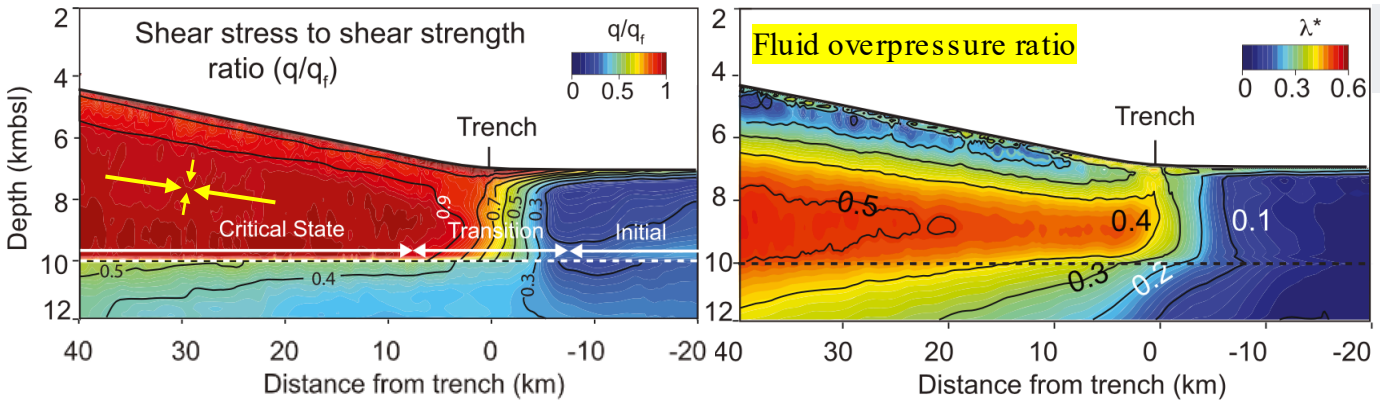




A → C
Sediment accretion

B → D
Sediment subduction

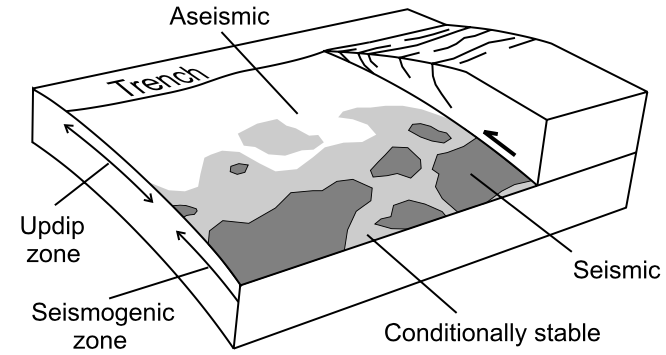
Sun et al. (2020),
Saffer and Tobin (2011)

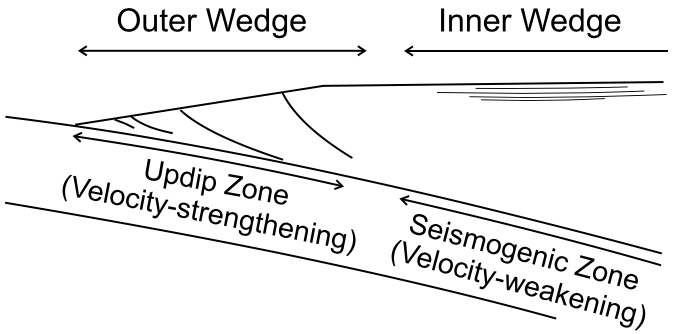


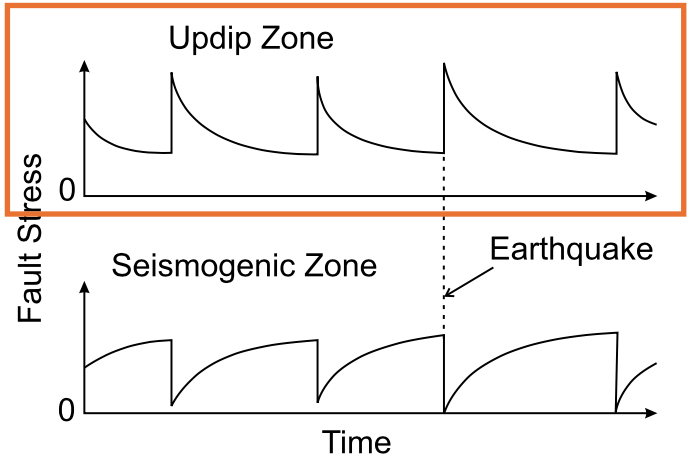
$$\frac{P_f - P_{hydro}}{P_{litho} - P_{hydro}}$$

- Shear-enhanced compaction/fluid pressurization plays a key role (Nikolinakou et al., 2023)

The dynamic Coulomb wedge



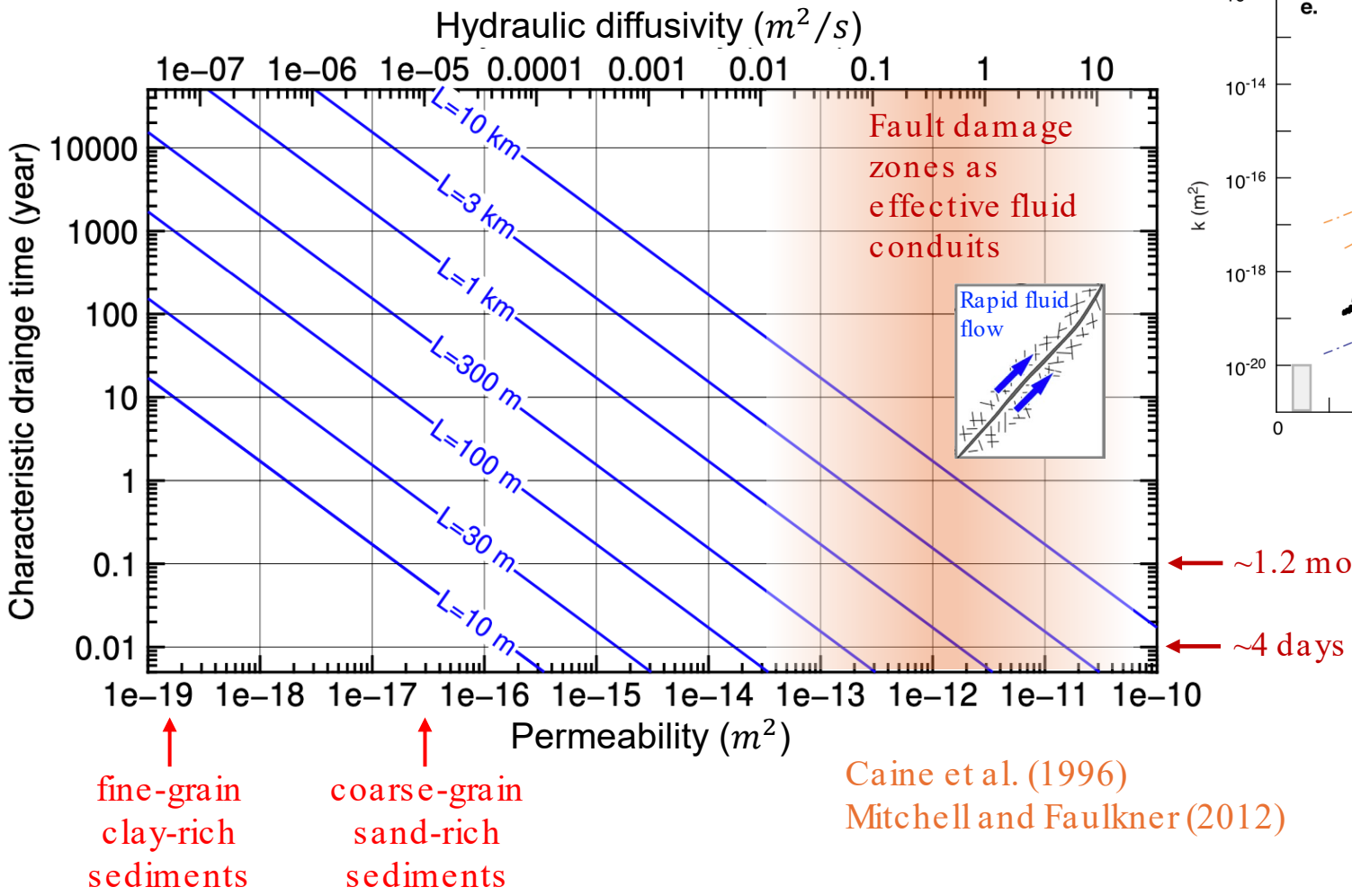




What about fluid pressure?

Wang and Hu (2006)

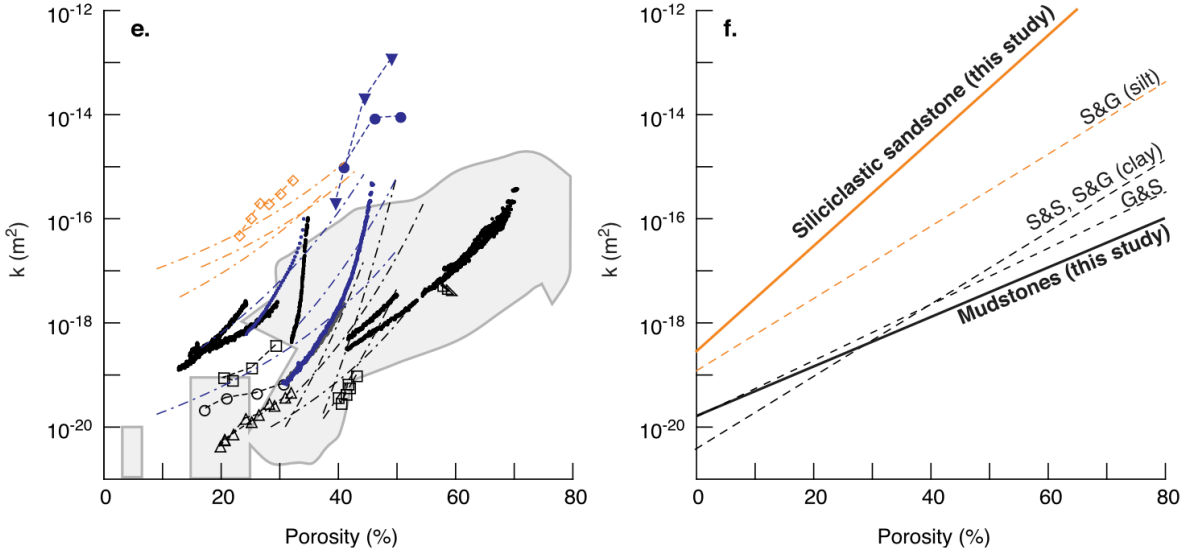
The broad range of permeability and fluid drainage timescales



~1.2 months

~4 days

Caine et al. (1996)
Mitchell and Faulkner (2012)



Kitajima and Saffer (2014)

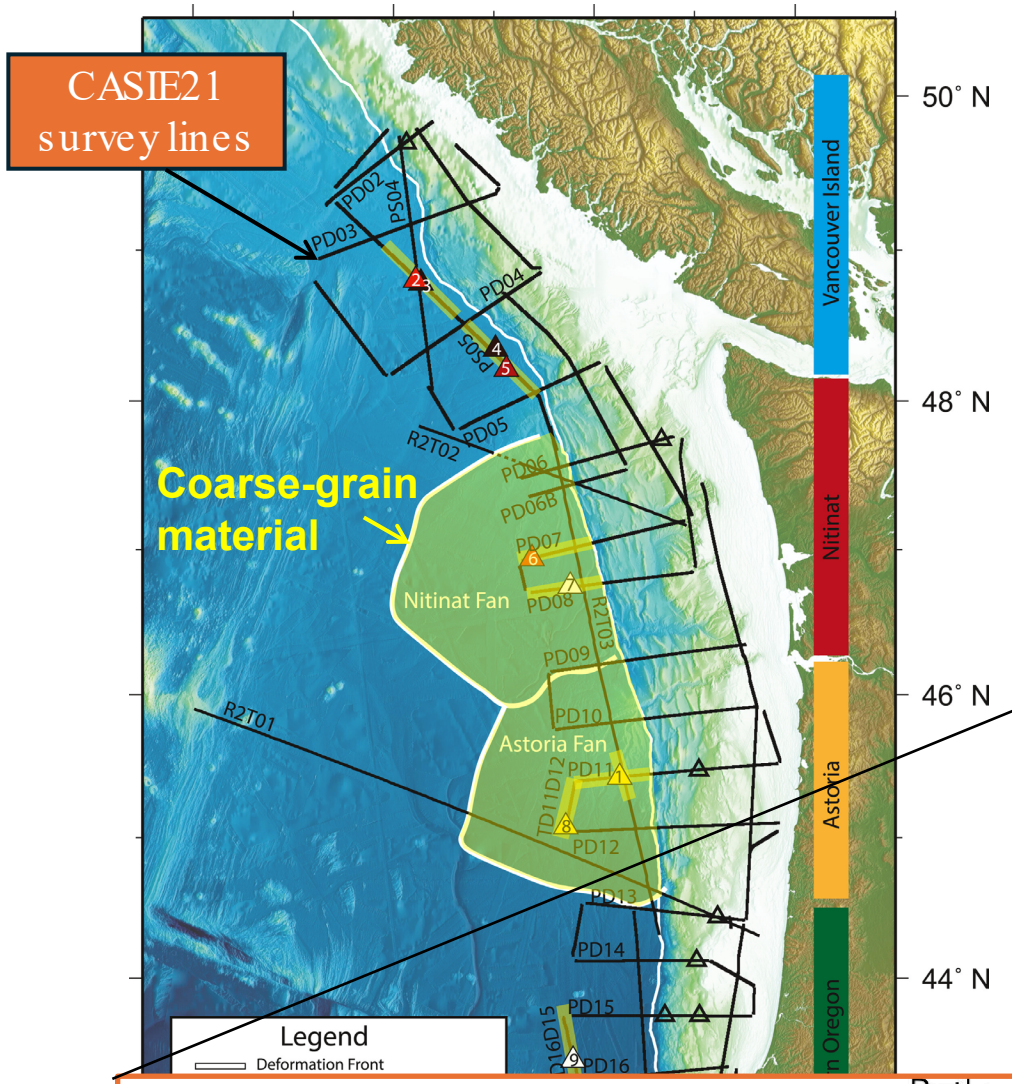
$$t_d \propto L^2/d$$

characteristic drainage time

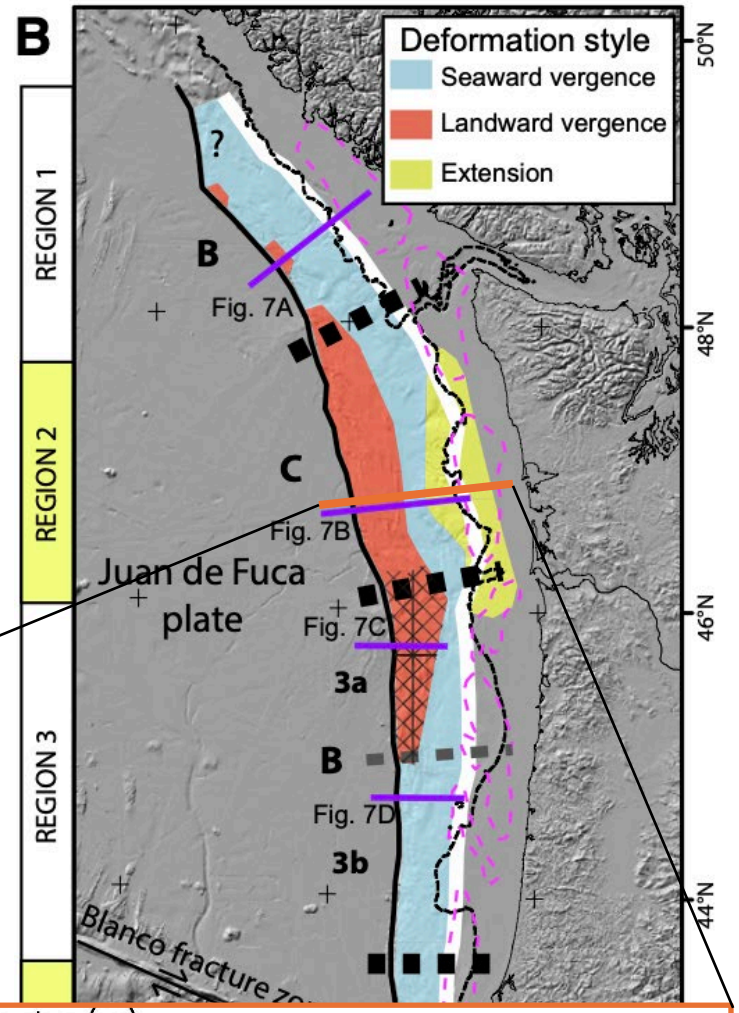
drainage path length

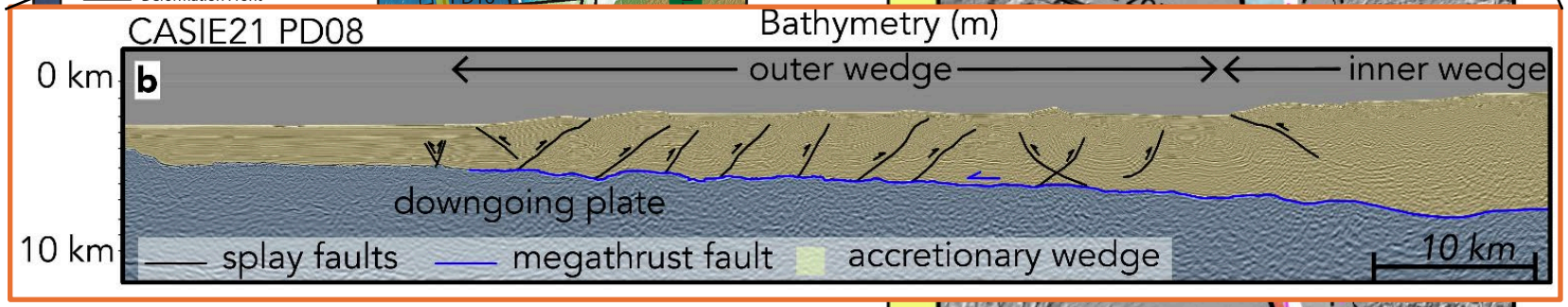
hydraulic diffusivity

- Nitinat Fan and Astoria Fan: coarse-grain material (sands, gravels, glacial-sourced sediments and turbidites)
- Their along-strike extent roughly corresponds with the landward vergence zone



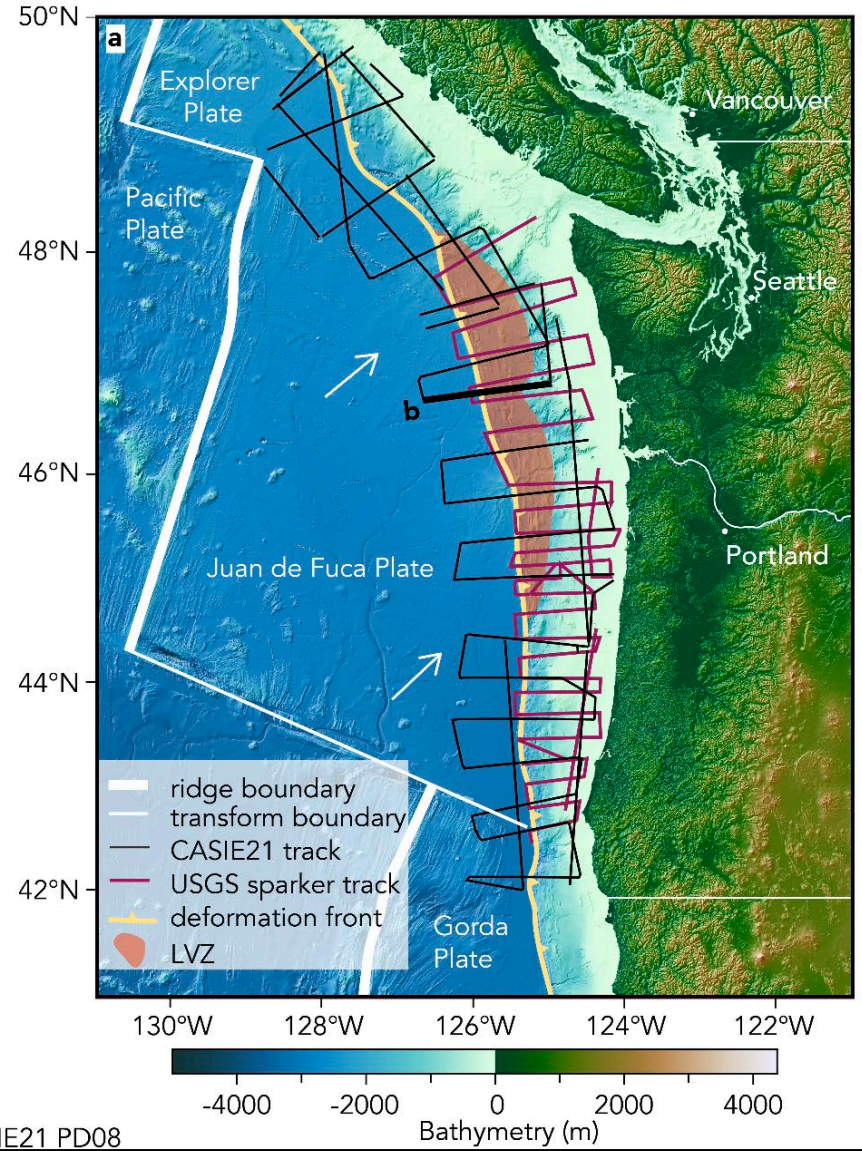
Watt and Brothers (2020)

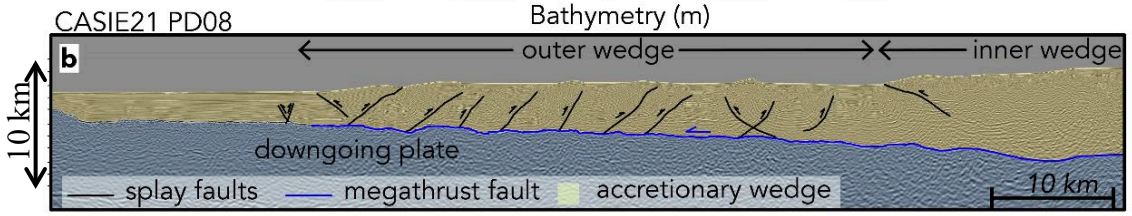


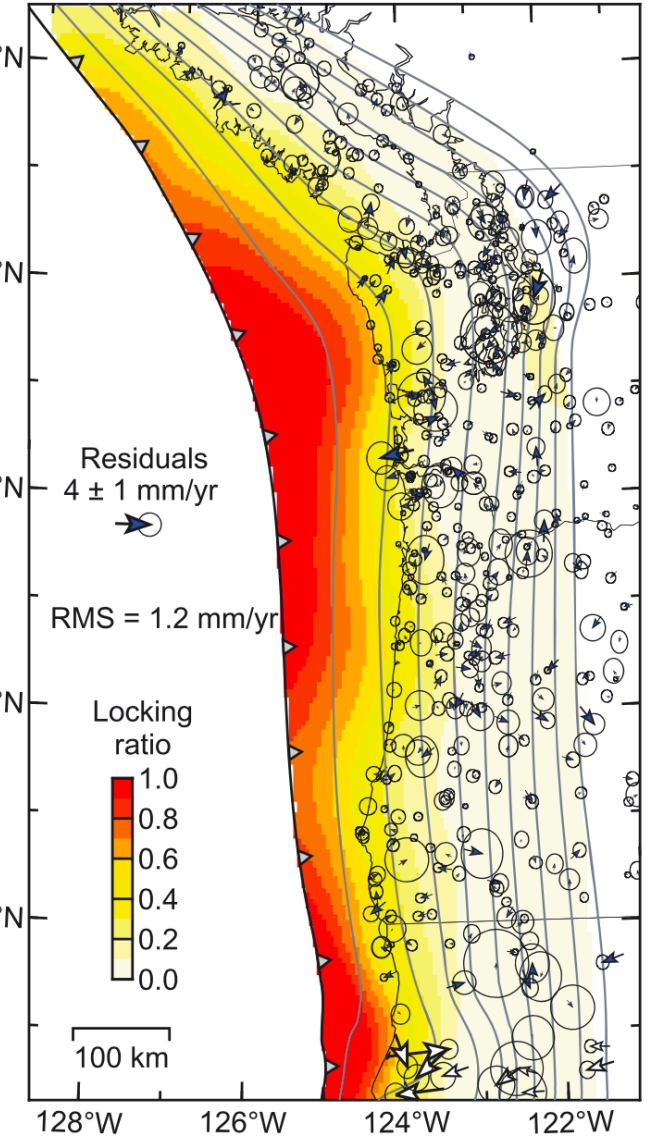


Lee et al. (2025)

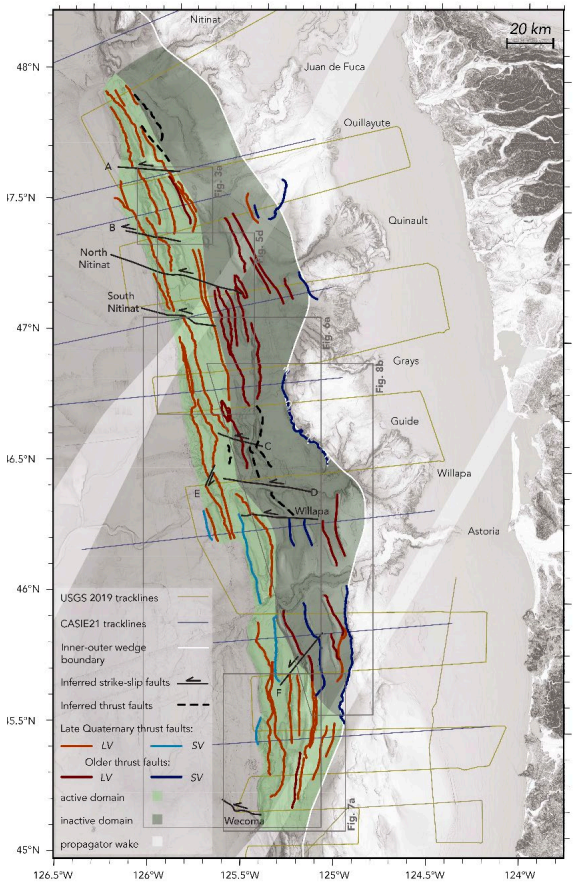
Ledeczi et al. (2024)

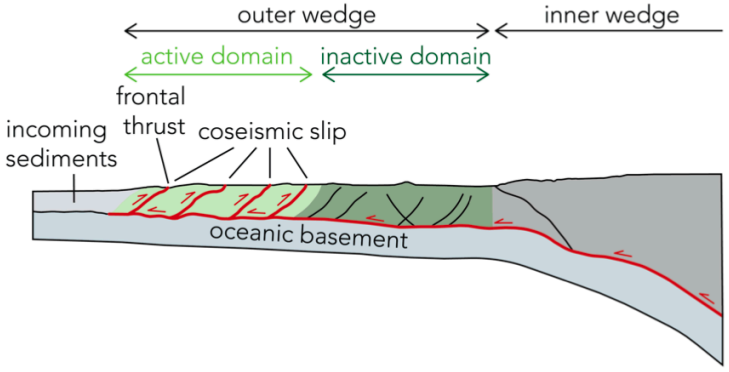




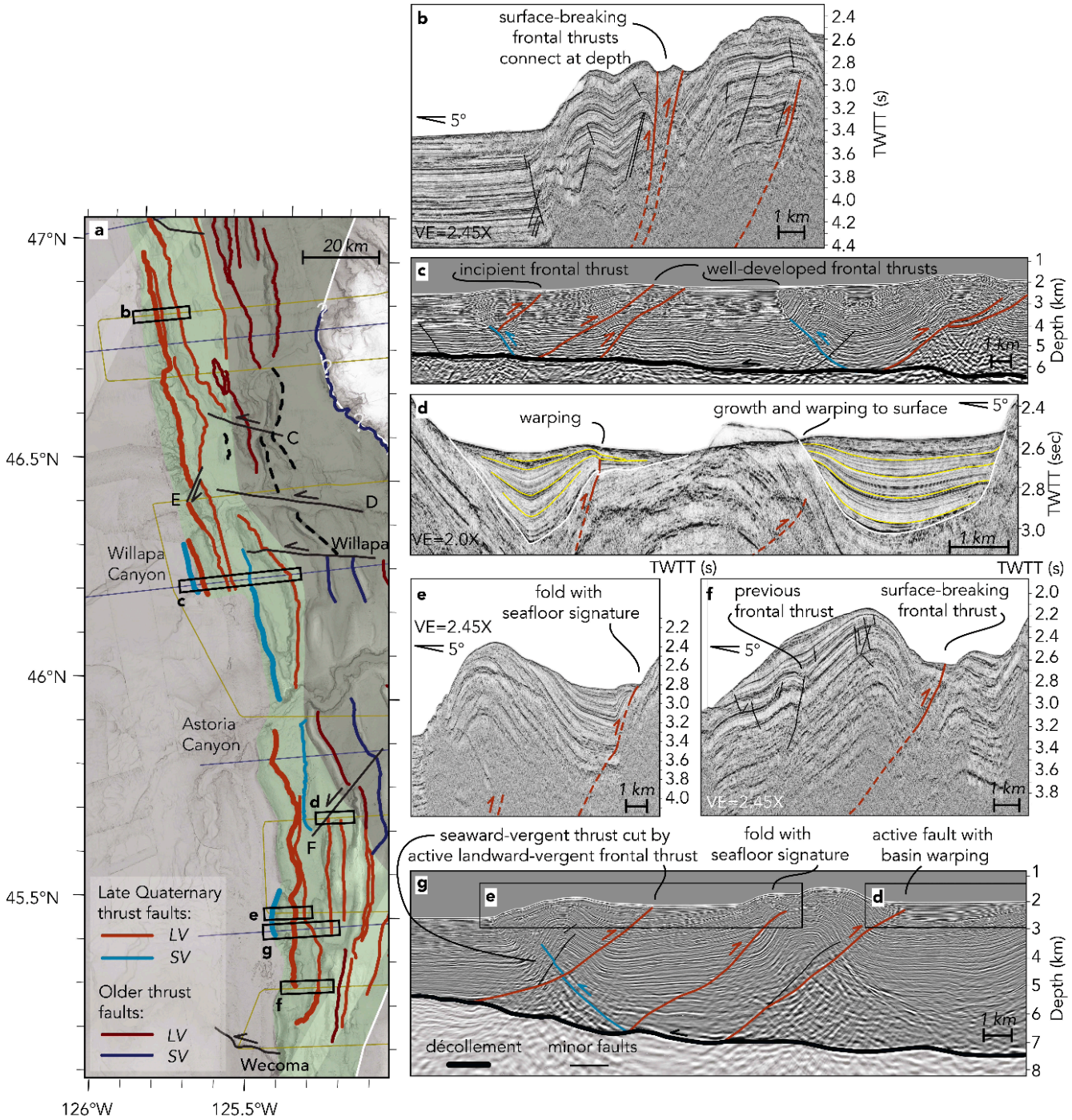


Li et al. (2018)



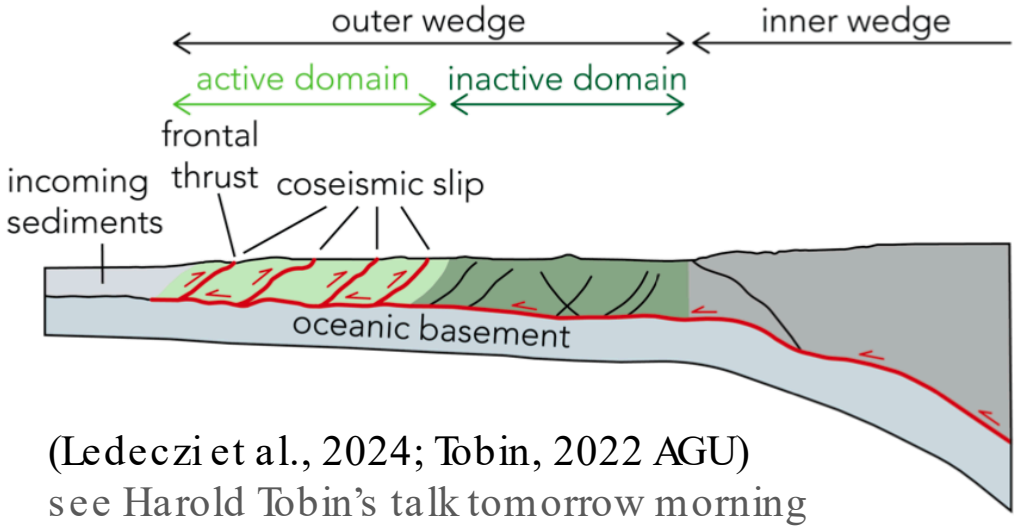


Ledeczi et al. (2024)



Active outer-wedge upper-plate faults:

- Developed at the time of large megathrust earthquakes
- Enhanced fluid escape along these activated faults
- Fluid escape is also faciliated by the coseismic fluid pressurization



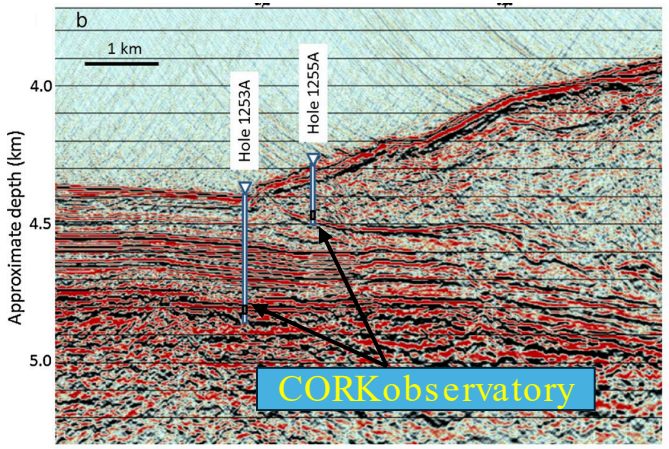
(Ledeczi et al., 2024; Tobin, 2022 AGU)

see Harold Tobin's talk tomorrow morning

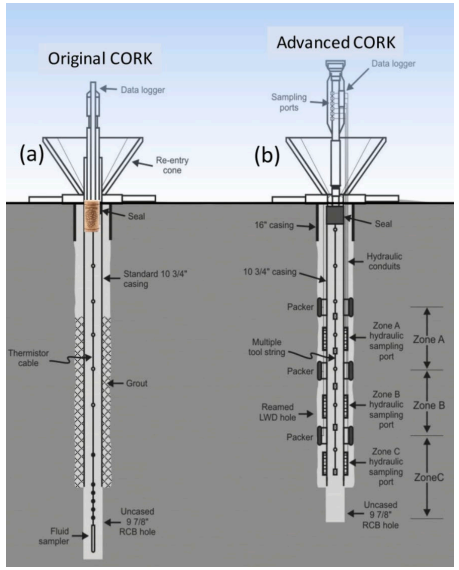
In-situ observations of fluid pressure increase in the outer wedge during shallow megathrust slip

Costa Rica, off Nicoya

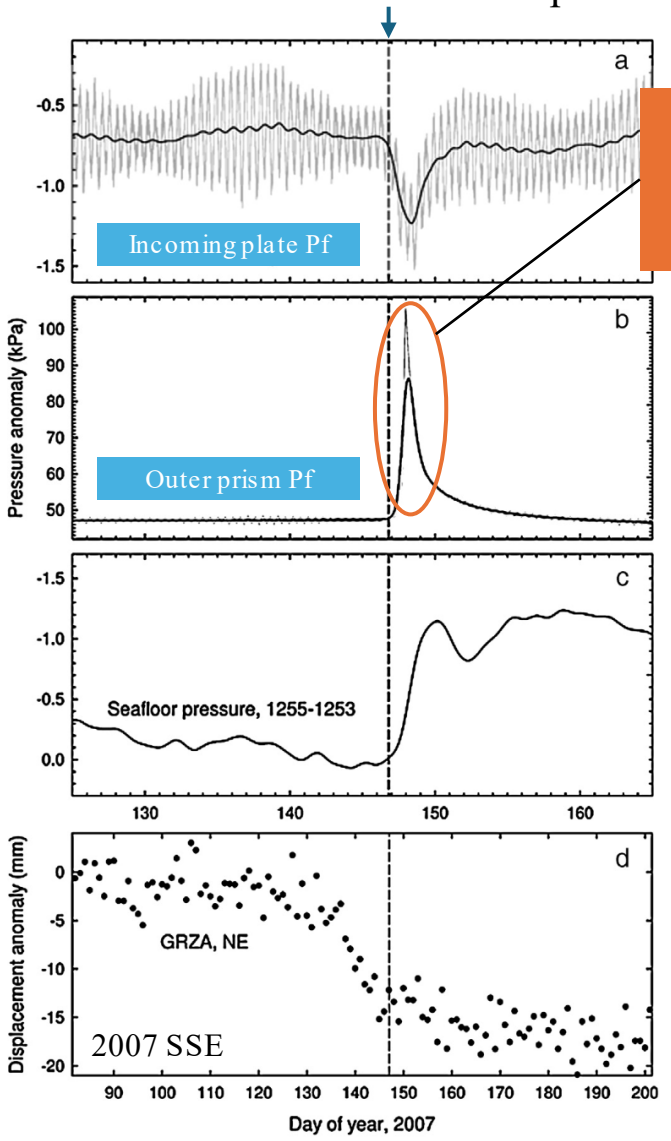
Davis et al. (2015)



See Davis et al. (2025, CJES Review)



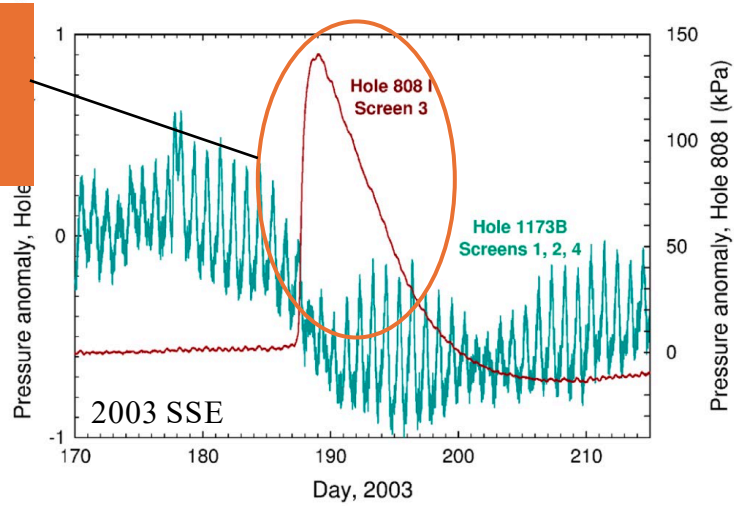
onset of shallow slip

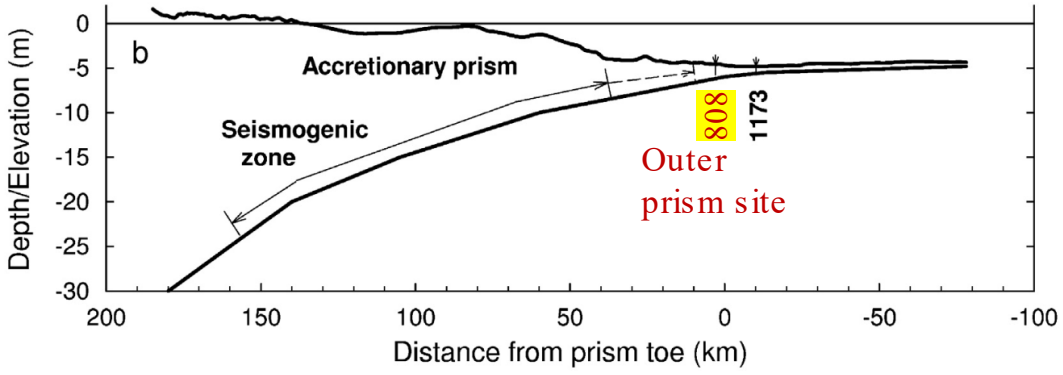


Rapid Pf increase, followed by fast drainage

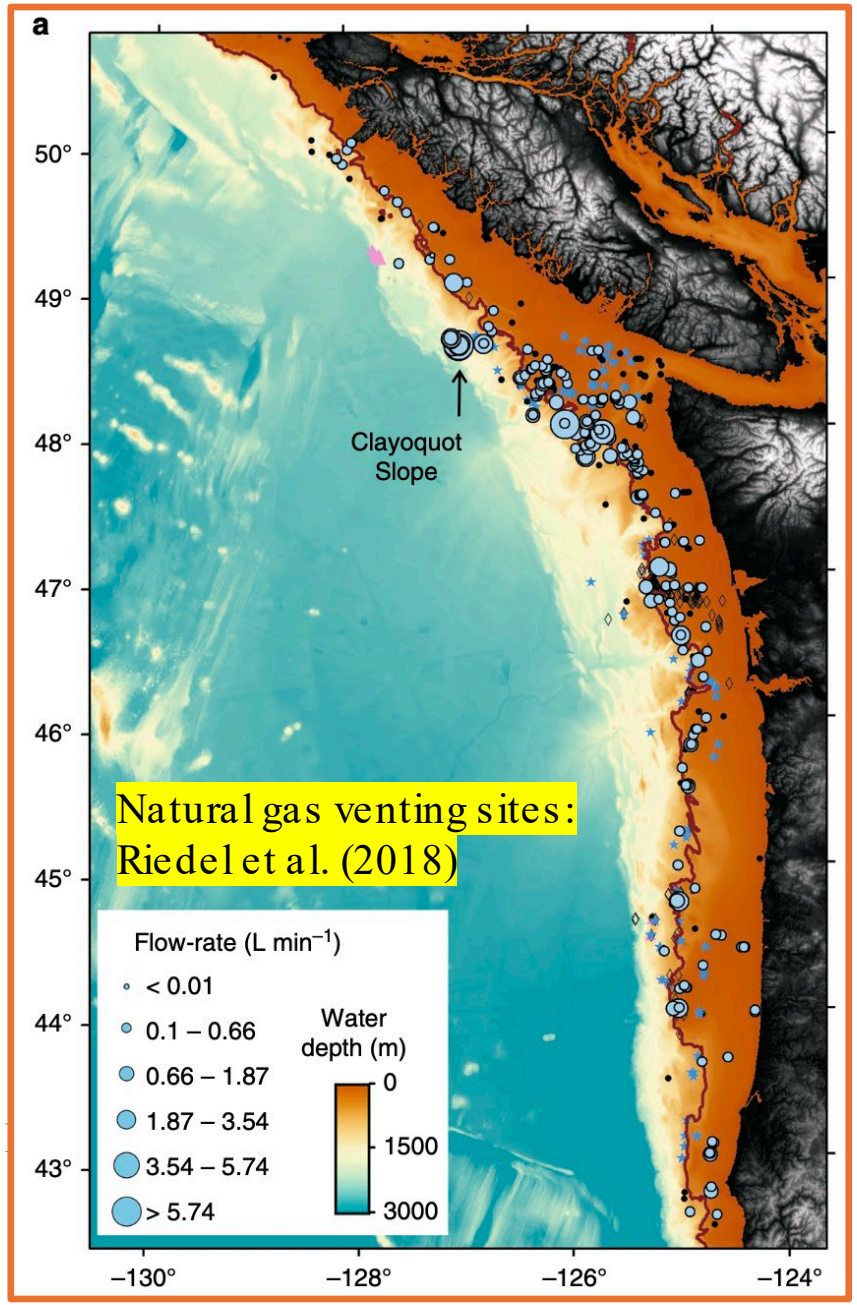
Nankai, off Cape Muroto

Davis et al. (2013)





SSE: slow slip event



Coseismic fluid
- driven by late
- pervasive fau
- coseismic flu
  upper-plate f

Immediately po
- fast dewater

Late inter-seisn
- outer wedge
- evidence for

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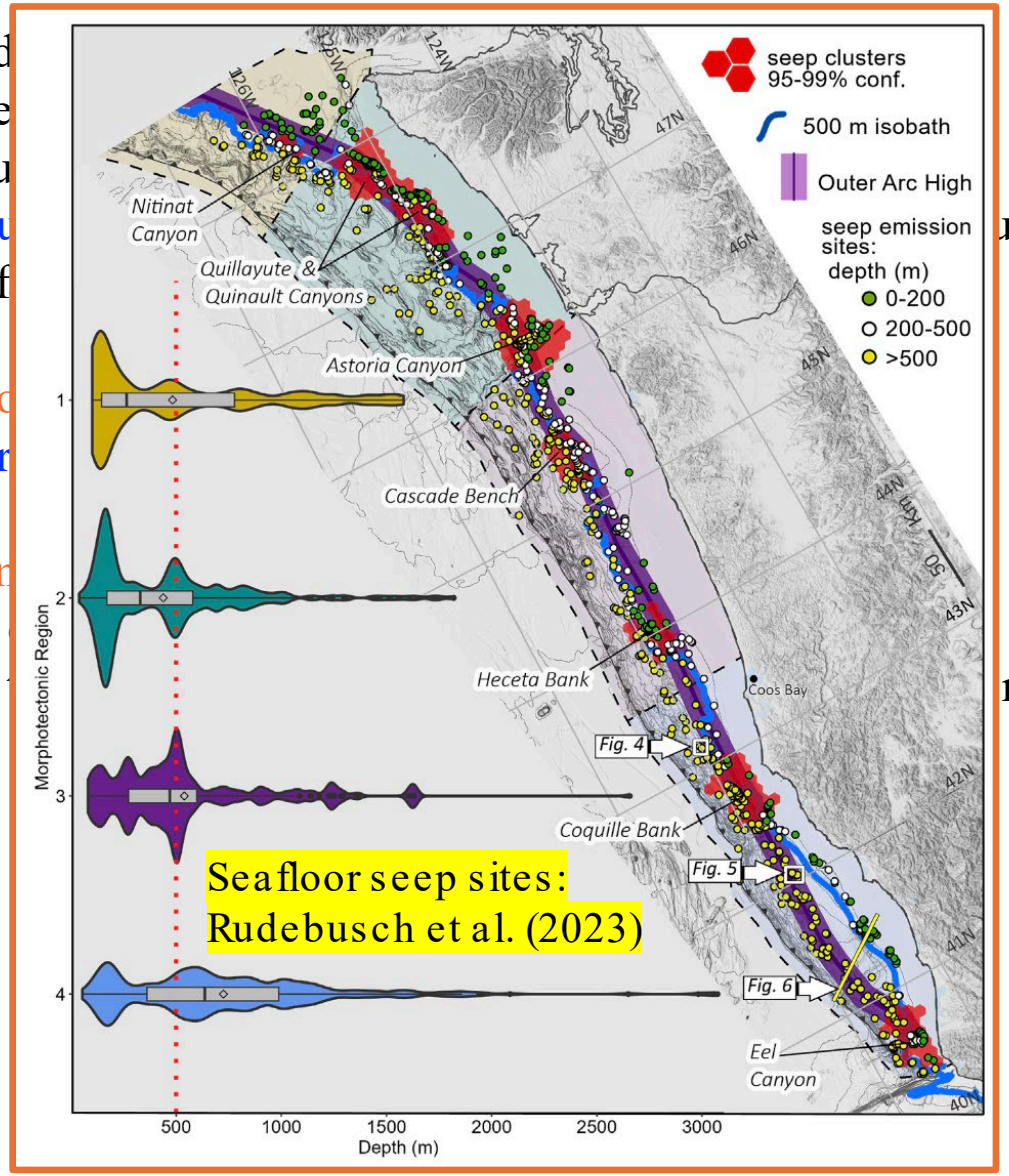
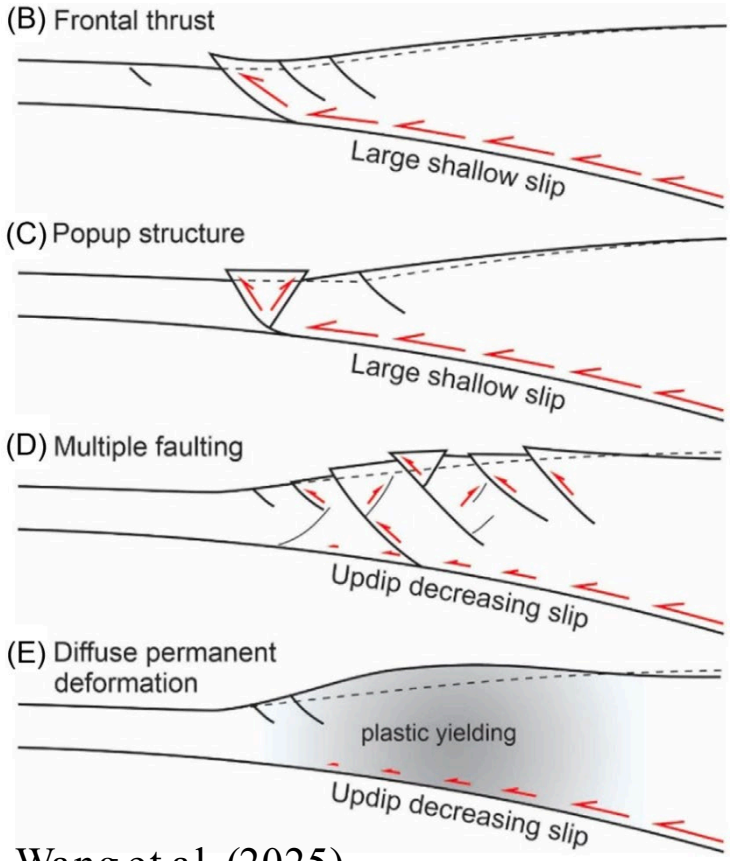
r wedge





Wang et al. (2025)

Possible scenarios for central Cascadia

Coseismic fluid pressurization in the outer wedge
- driven by lateral shortening
- pervasive faulting of the frontal wedge
- coseismic fluid pressurization further weakens the megathrust and upper-plate faults, causing them to slip

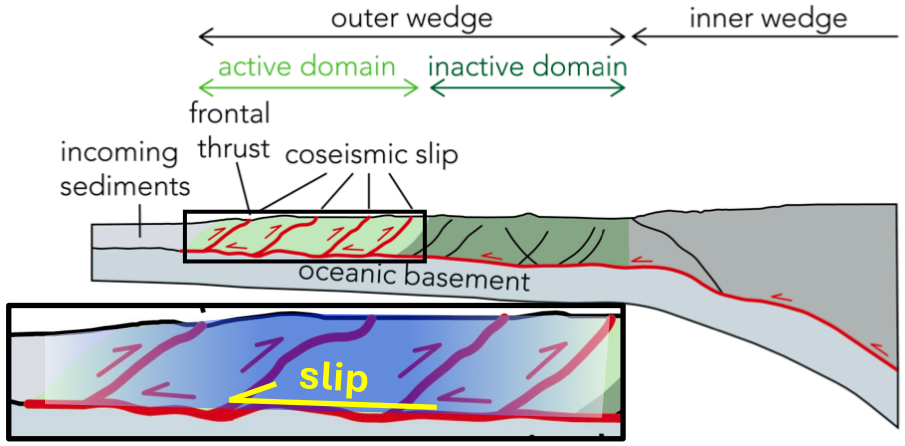
Immediately post-seismic:
- fast dewatering along upper-plate faults

Late inter-seismic phase (present-day):
- outer wedge dewatering rate substantially subsides
- evidence for the lack of active venting and seeping in the outer wedge

Over geologic times:
- Consolidation state of the outer wedge is further enhanced.
- consistent with seismic observations (e.g., Han et al., 2017)

The strong and over-consolidated outer-wedge facilitates inter-seismic strain accumulation (locking) and stick-slip fault behaviour.

Coseismic pressurization (rapid fluid pressure increase)



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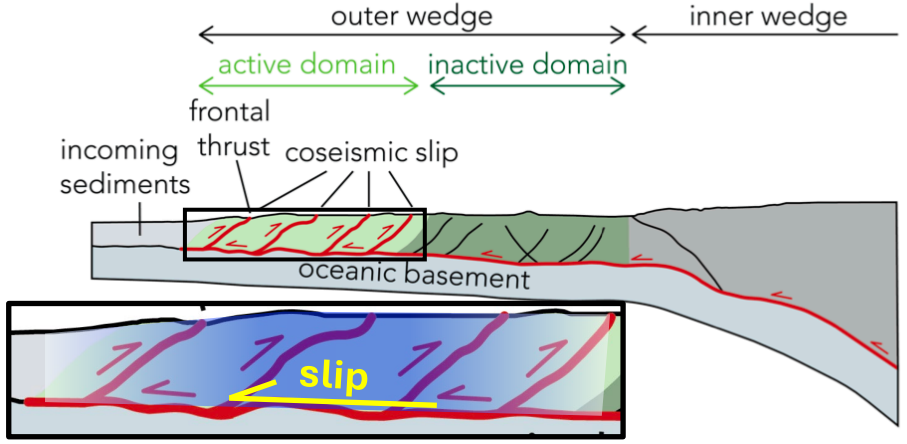
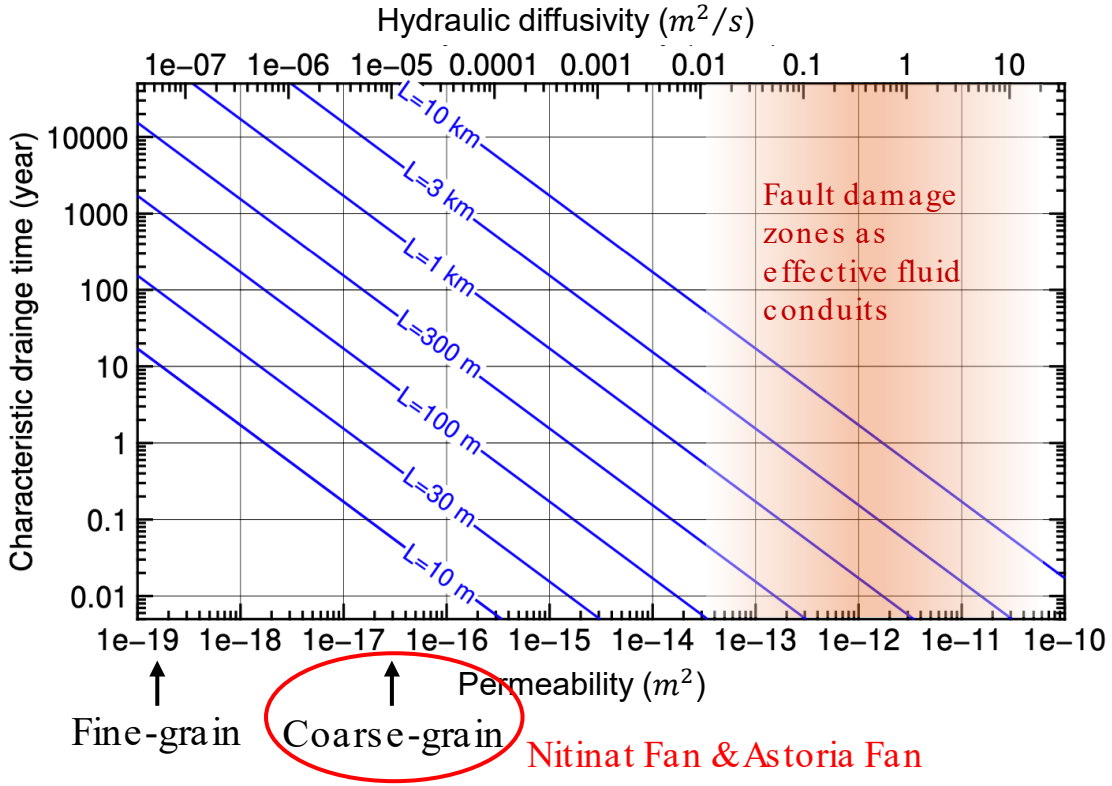
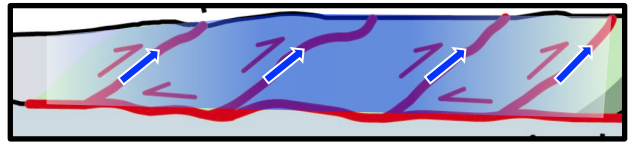




Fast dewatering
immediately after the rupture



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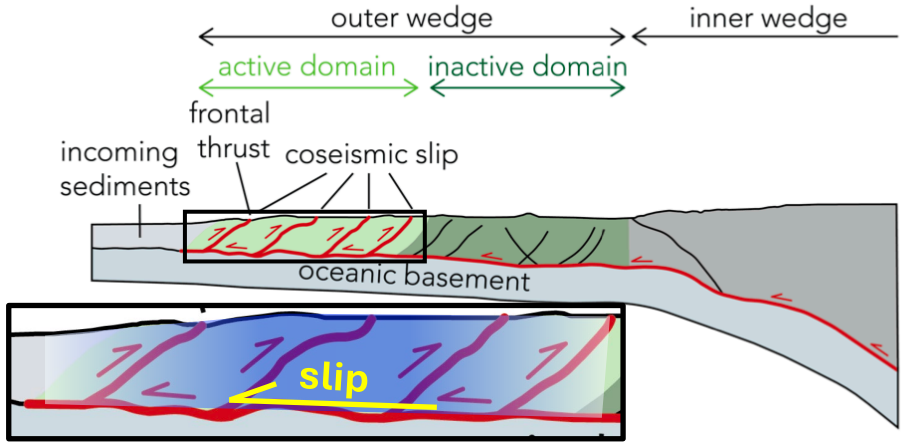

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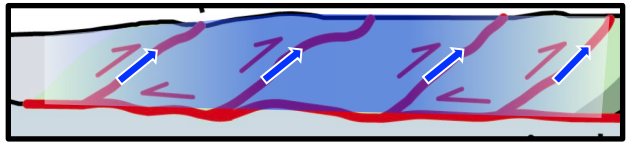

Late-interseismic (present-day):

- No substantial fluid overpressure in the outer wedge
- CORKobservations at Northern Cascadia U1364Asuggest steady Pf increase due to megathrust locking
  (Davis et al., 2023; Sun and Davis, in prep)

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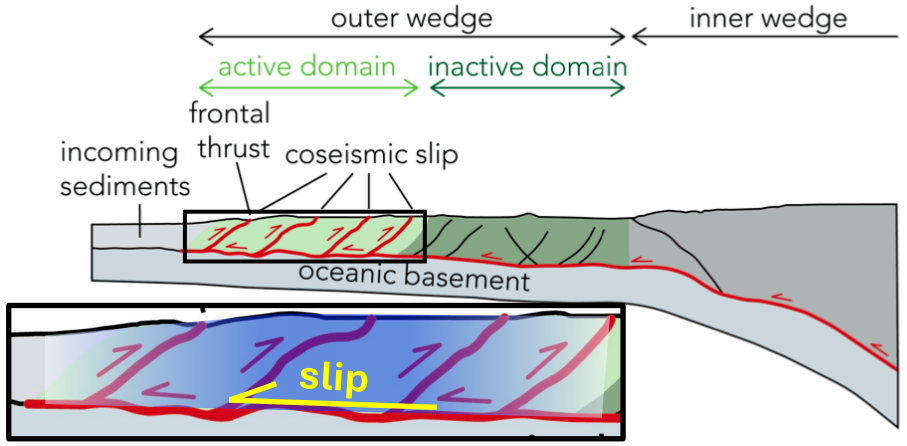

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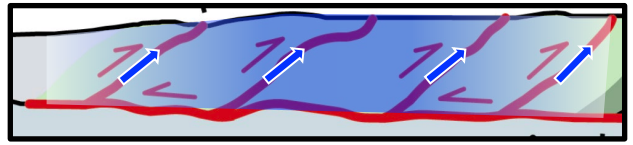
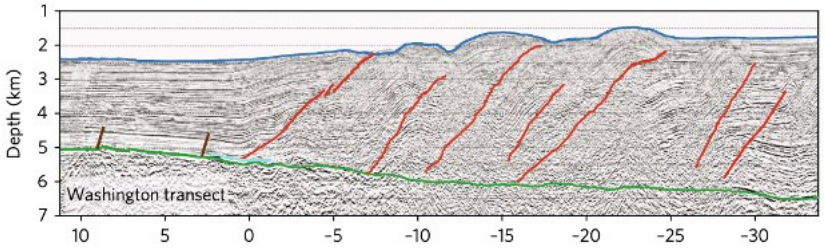


Over multiple EQ cycles: significant over-consolidation of the outer wedge → facilitates stick-slip fault behaviour



Han et al. (2017)
See Danqi Jiang's poster

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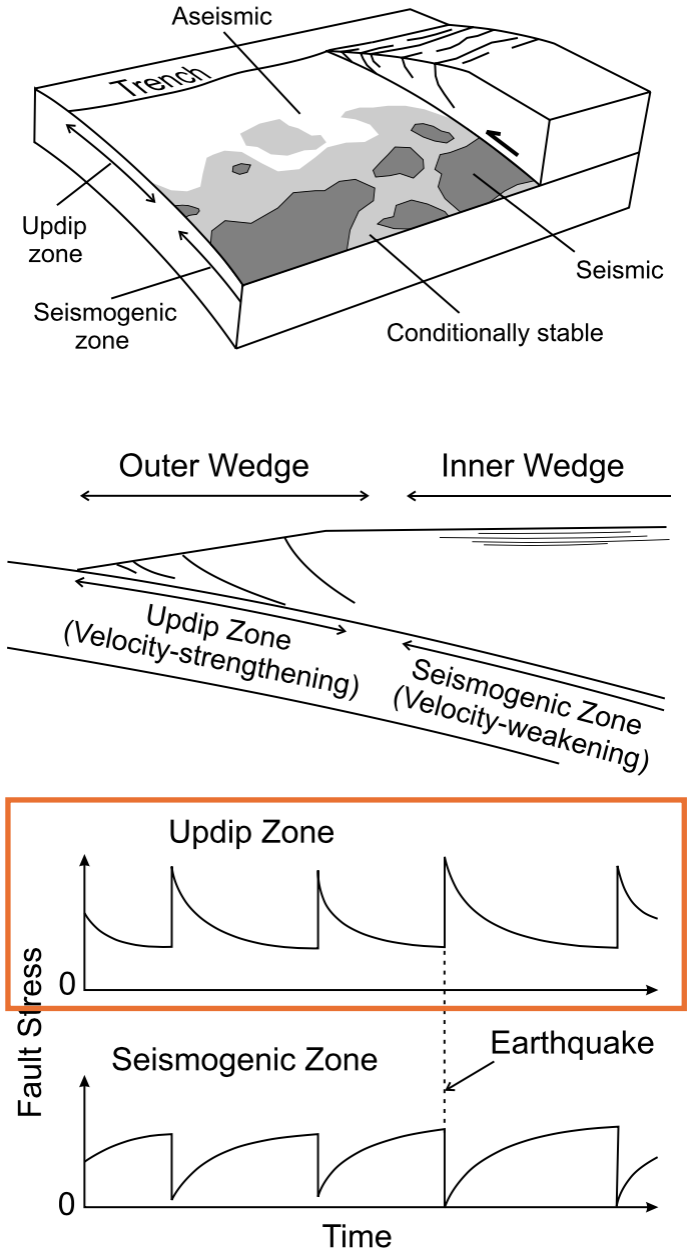
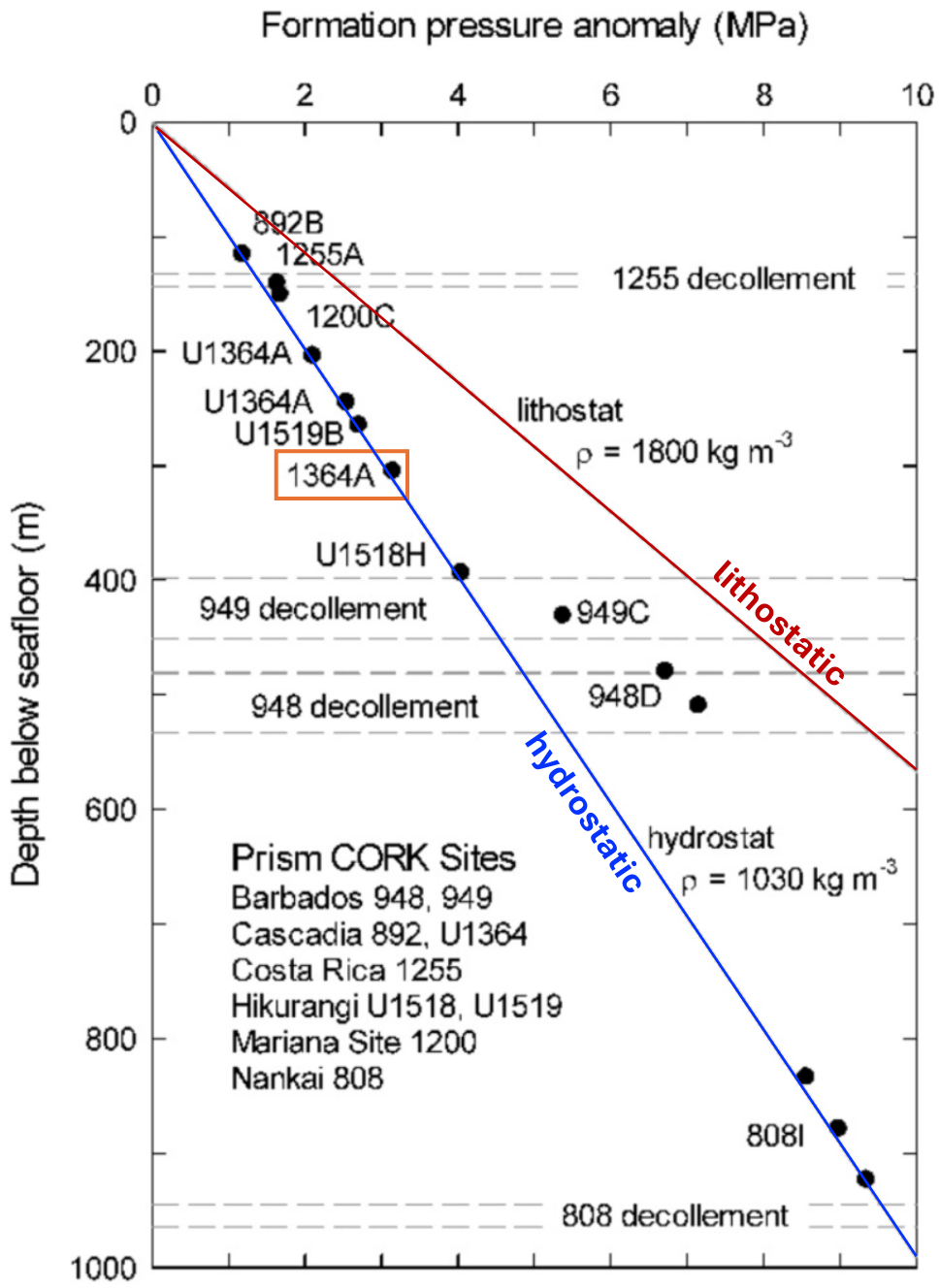


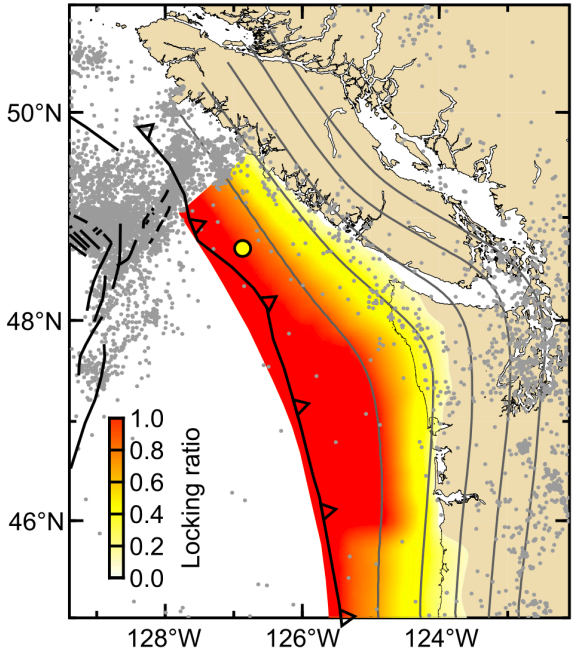
Wang and Hu (2006)

What about fluid pressure?

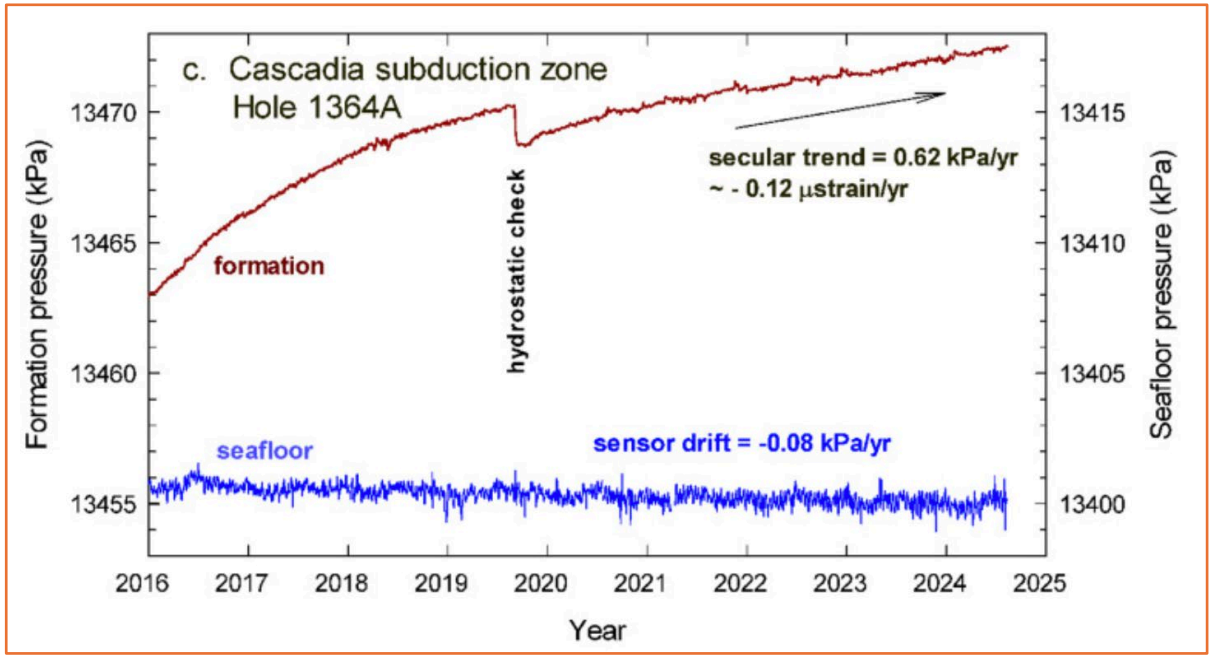
- At central Cascadia, fluid pressure in the outer wedge is not high at all time.
- Exceedingly high fluid pressure can be reached at the times of large earthquakes, followed by rapid dewatering and pressure decrease.
- The seismically observed over-consolidated outer wedge reflects a cumulative effect of efficient dewatering over many earthquake cycles, plus the "background" fast dewatering due to the abundance of coarse-grain material.
- Fault drainage plays a key role, and fault-zone permeability must be subjected to large temporal variations (hydraulic fracturing, fault healing, etc.).

backup slides





Davis, Sun et al. (2023, 2025)



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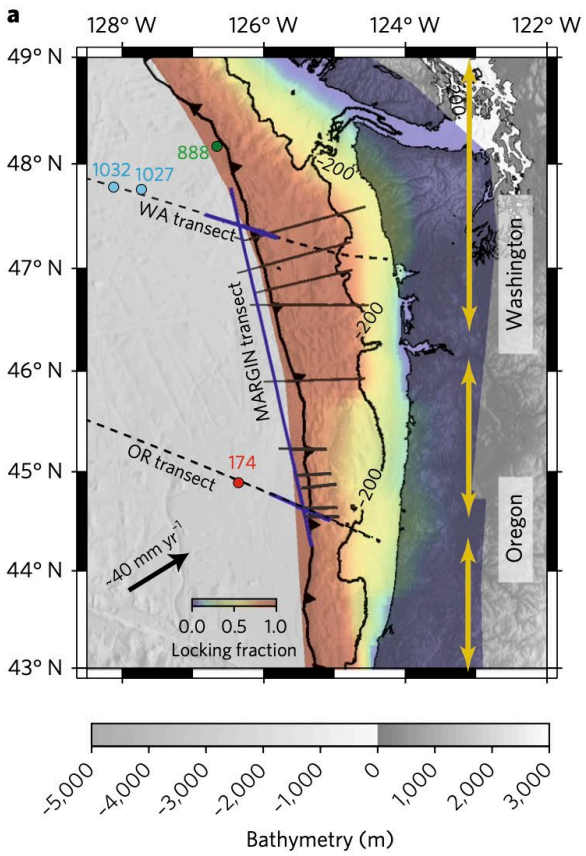
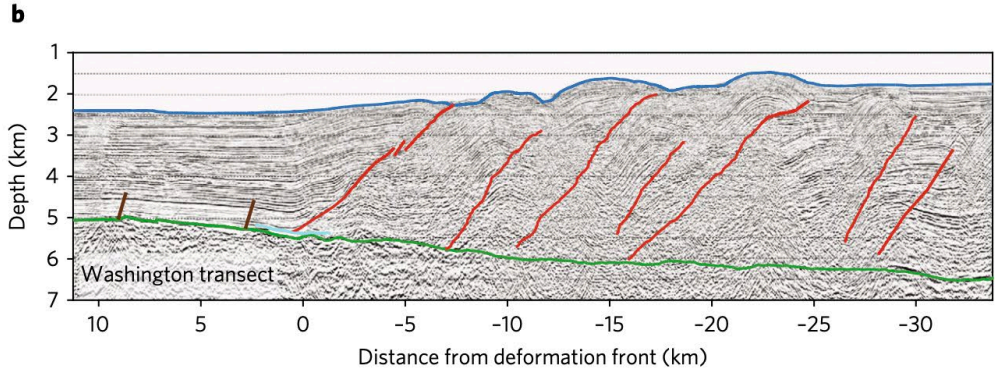
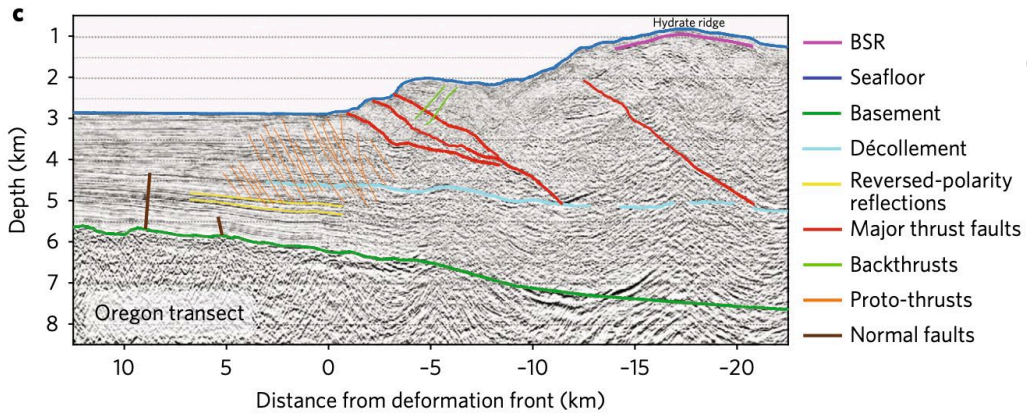
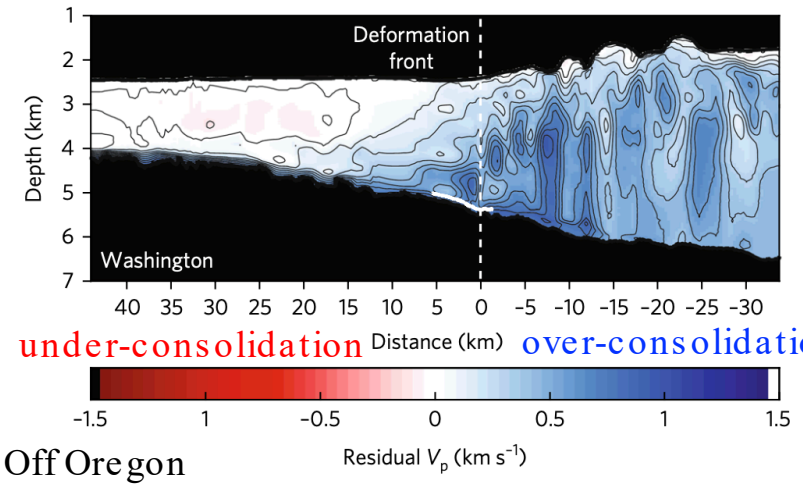






Han et al. (2017)

Off Washington



Off Oregon