Workshop on the Mechanics of the Earthquake Cycle

ICTP, Trieste, Italy, 16 – 27 October 2023

Strength of the subduction megathrust (Part 1)

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Tianhaozhe Sun and Jiangheng He: Geological Survey of Canada

1. Thermal-petrologic field of subduction zones
2. Defining megathrust strength
3. Low strength estimated from forearc force balance
4. Low strength estimated from frictional heating
5. Megathrust rheology and slip behaviour

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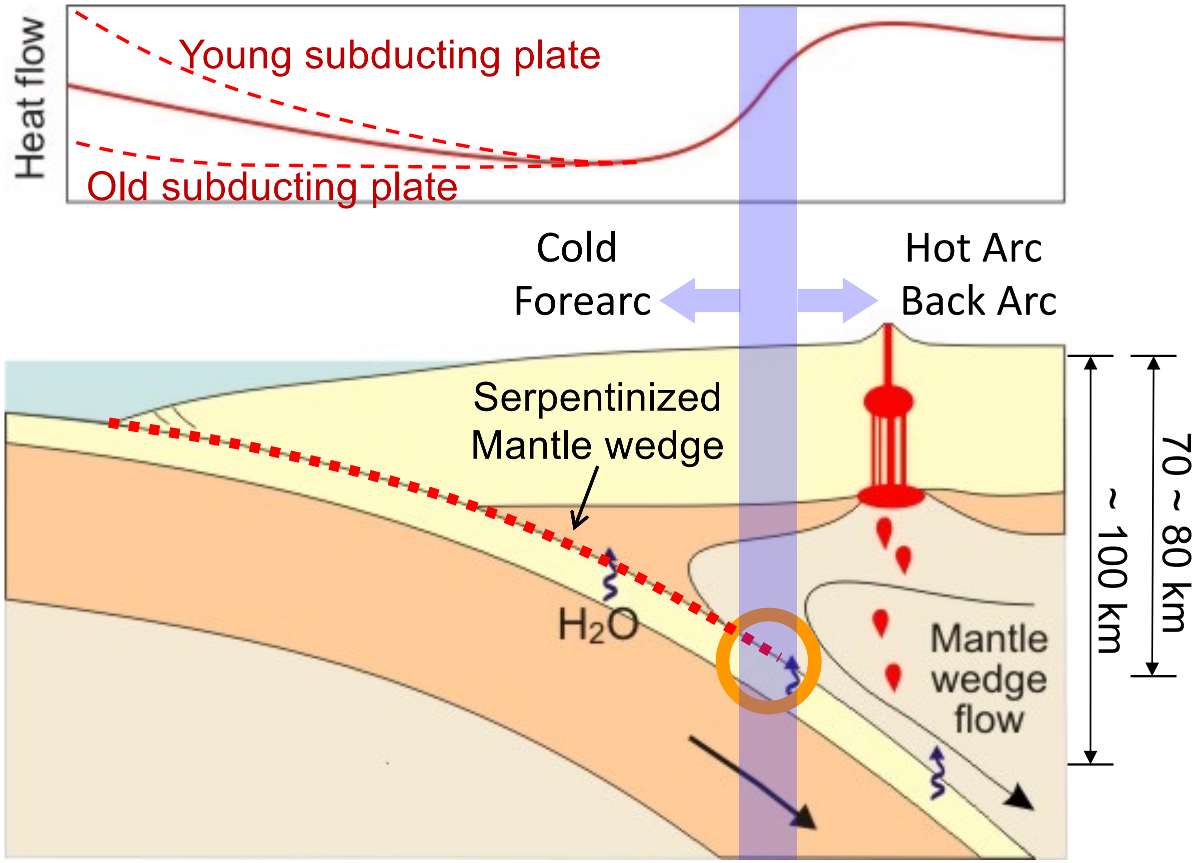
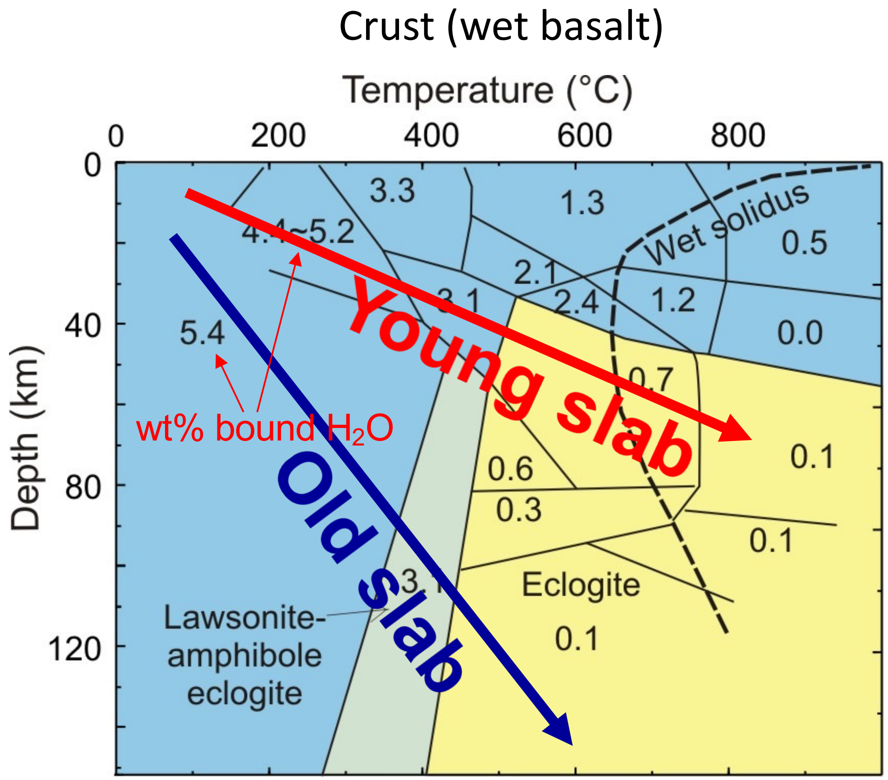
Fundamental to subduction zone dynamics:

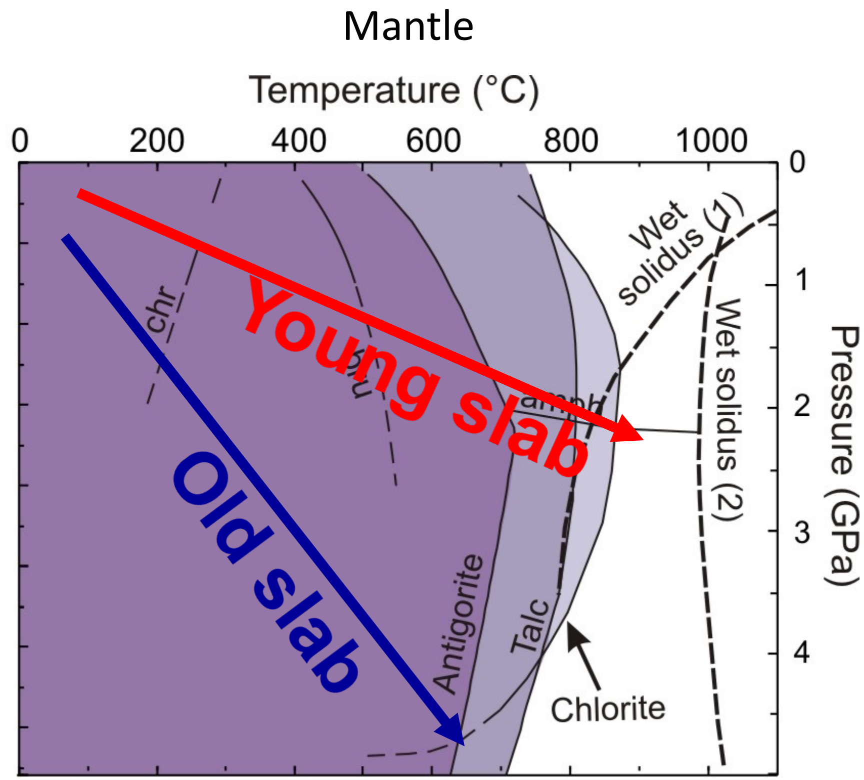
- Thermal contrast between forearc and arc-backarc
- MDD – Maximum Depth of Decoupling between slab and mantle wedge, ~70–80 km
- Age-controlled thermal state of the subducting plate



Dehydration of the subducting slab



Phase diagram from Hacker et al. (2004)

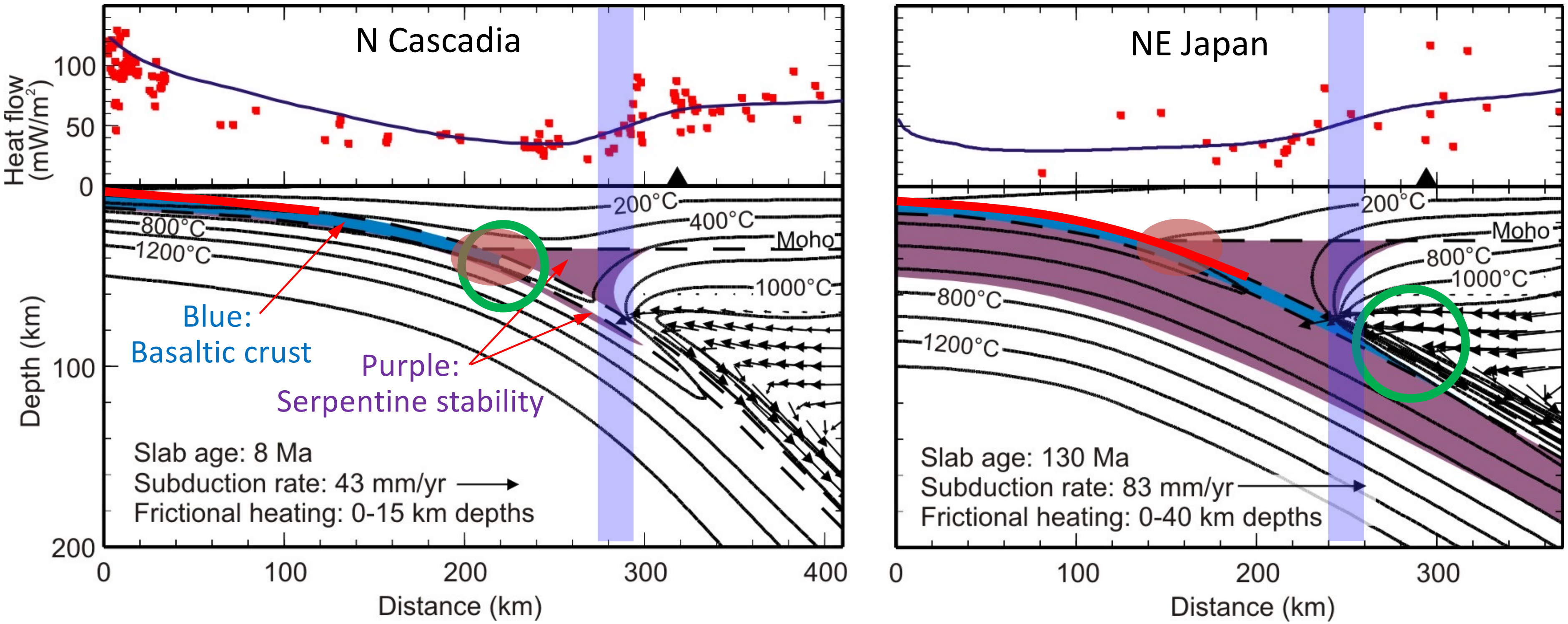


Reactions from Schmidt and Poli (1998)

Wet solidus: (1) Schmidt and Poli (1998), (2) Grove et al. (2003)

End-member young- and old-slab subduction zones

(Wada and Wang, 2009 G3; also Peacock, van Keken, Hacker, Syracuse, …)



Less fluid in slab; shallow dehydration
Hydrated mantle wedge corner
Shallow seismogenic limit

More fluid in slab; deep dehydration
Less hydrated mantle wedge corner
Deep seismogenic limit

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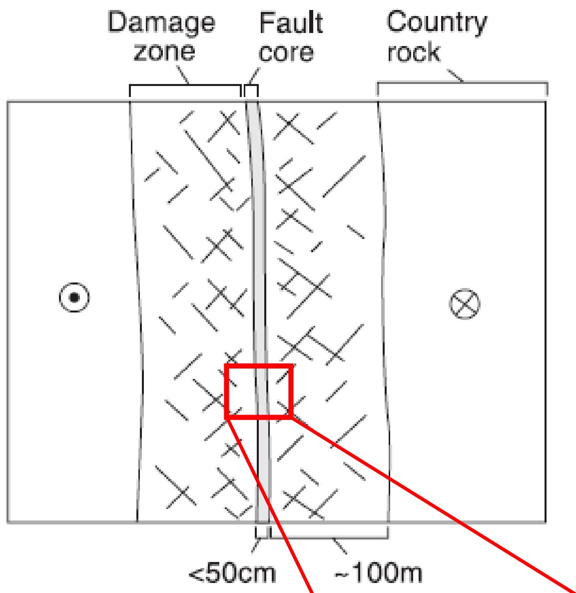
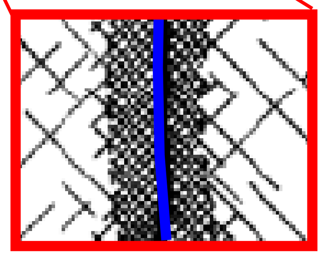
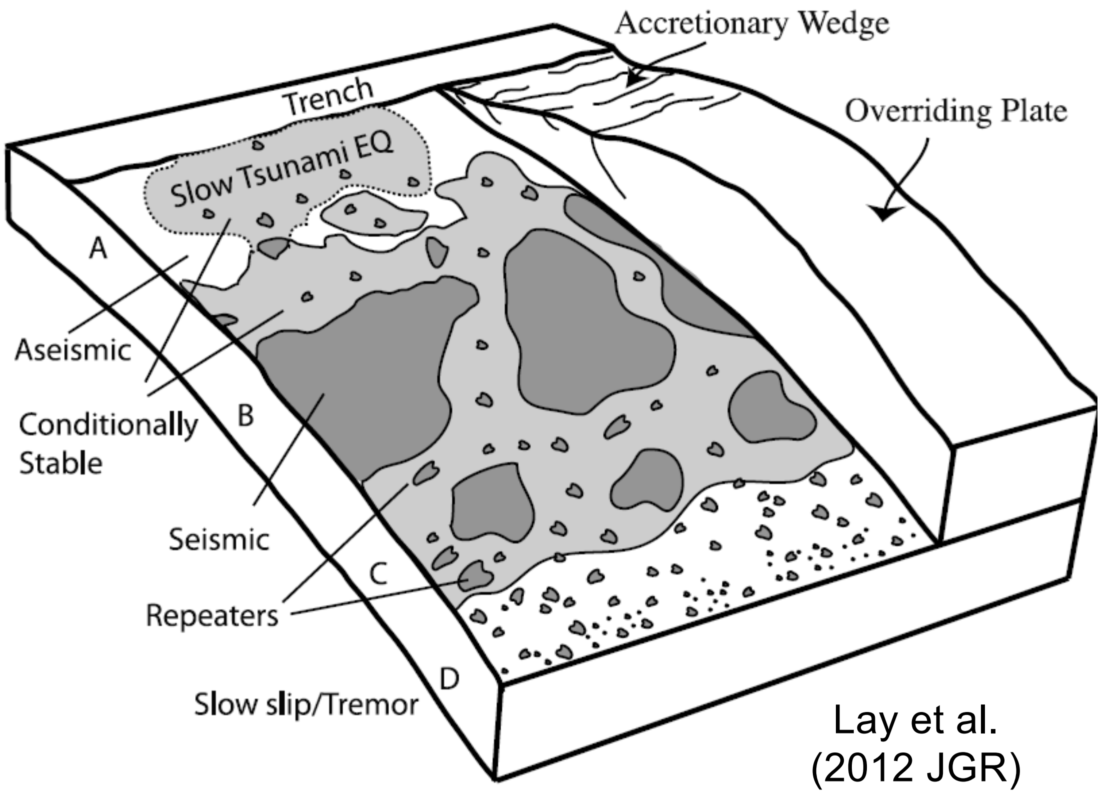
A simple model for a crust fault



Principal Slip Zone (PSZ)
A few mm – cm thick



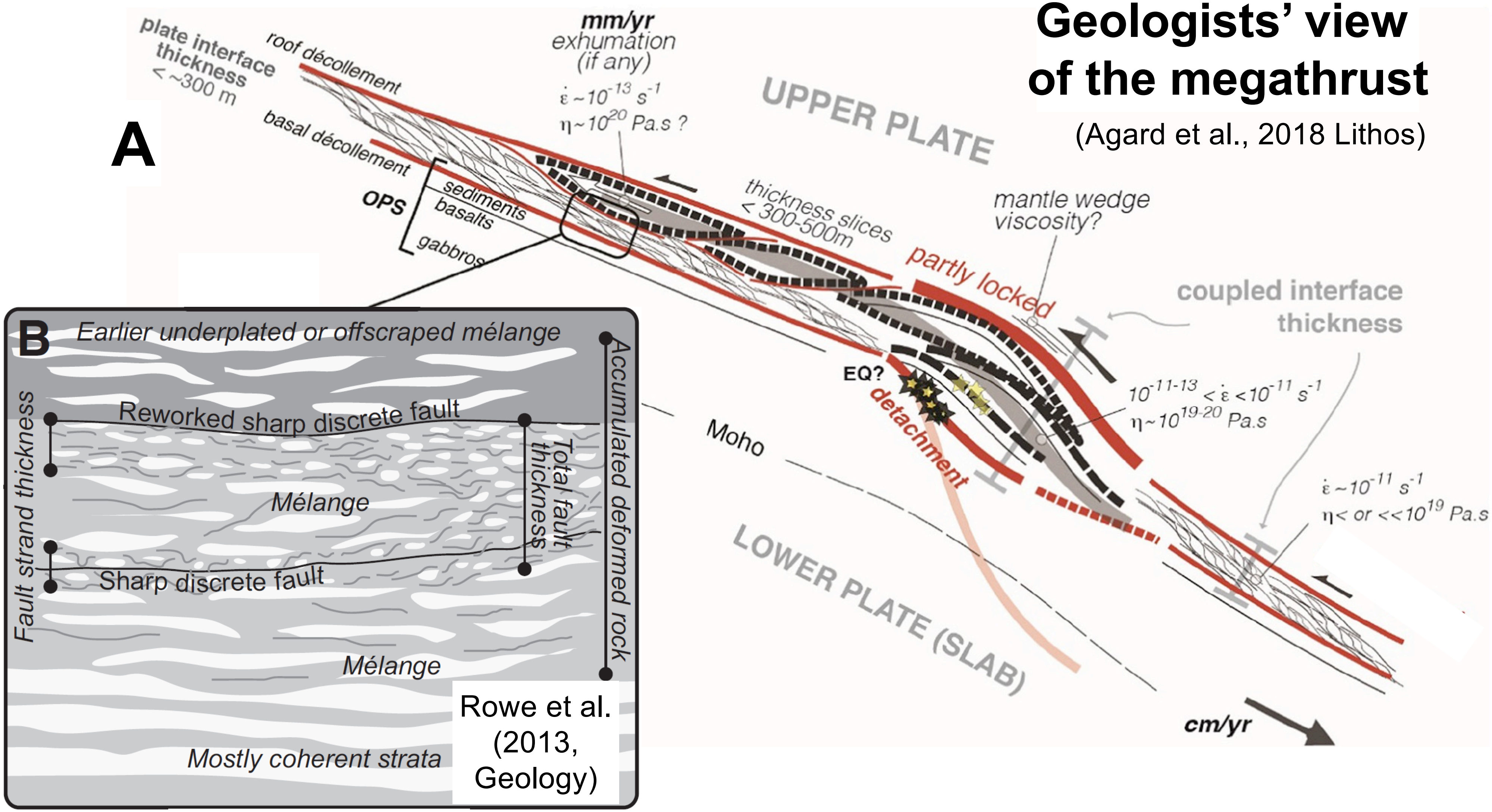
A model for subduction megathrust



Lay et al. (2012 JGR)

Geologists' view of the megathrust

(Agard et al., 2018 Lithos)



Rheology of the megathrust

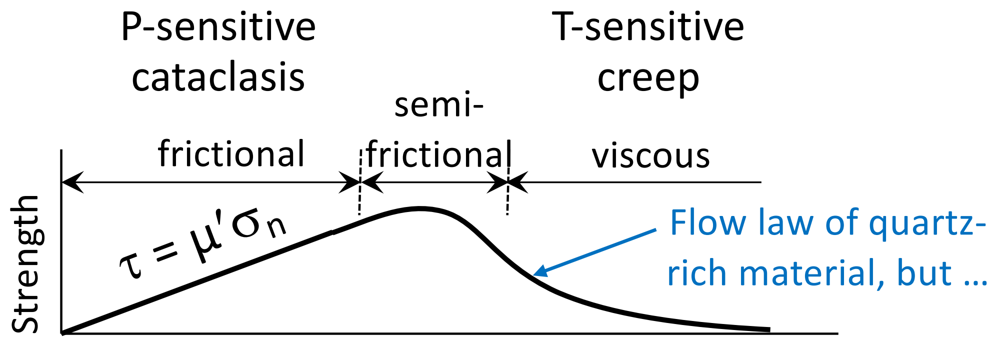
Frictional segment (main role):

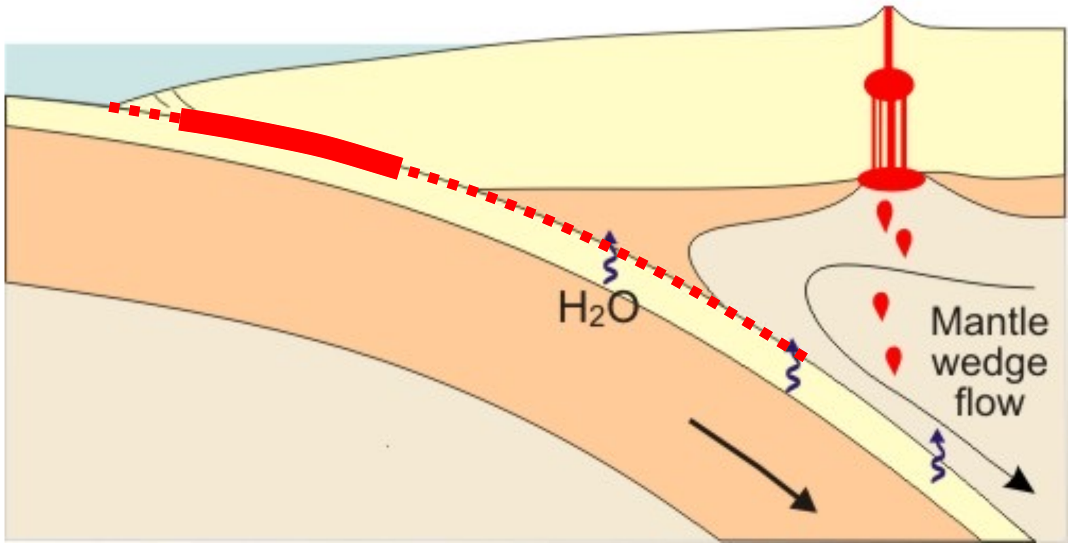
$$\tau = \mu(\sigma_n - P_f) = \mu\bar{\sigma}_n$$
$$= \mu(1 - P_f/\sigma_n)\sigma_n = \mu'\sigma_n$$

- $\bar{\sigma}_n$ is the effective normal stress
- $\mu' = \mu(1-\lambda)$ is the effective coefficient of friction, with $\lambda = P_f/\sigma_n \approx P_f/\rho g z$.
- Strength vs. stress.

Viscous segment (supporting role):

- Thermally activated viscous creep
- Often assume quartz-rich material





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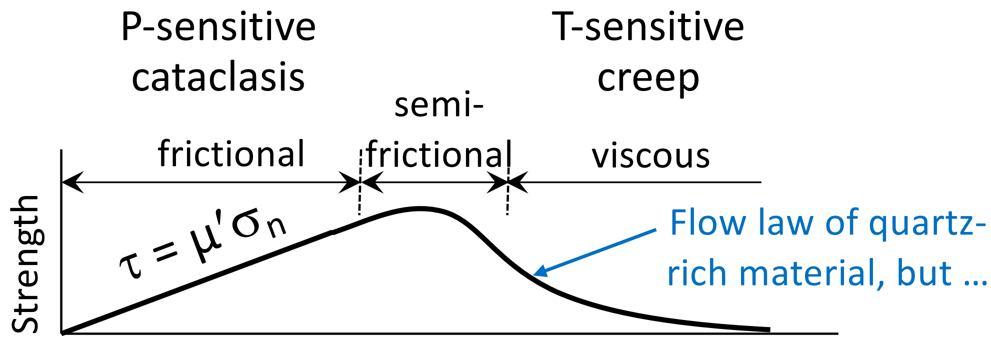
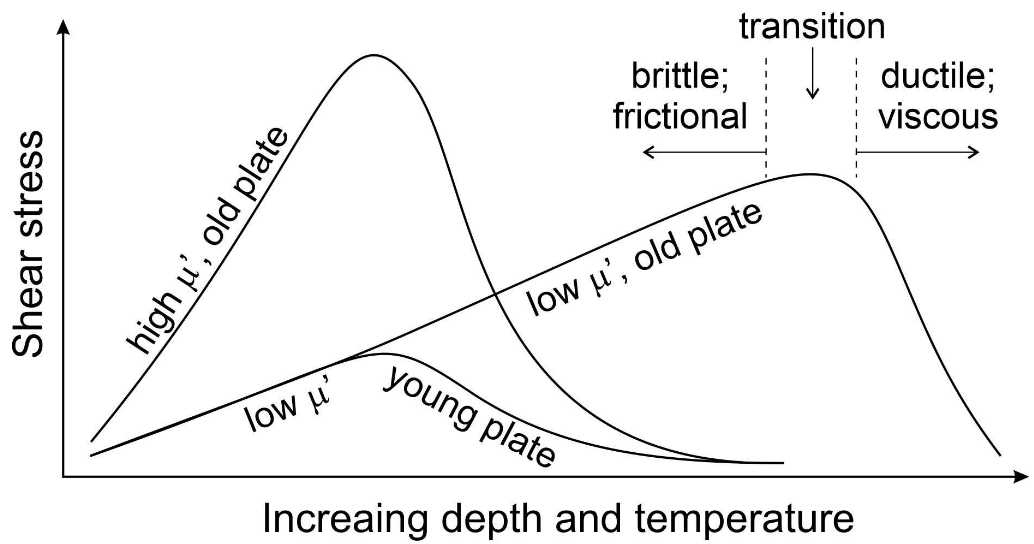




More on frictional strength $\tau = \mu' \sigma_n = \mu \bar{\sigma}_n$

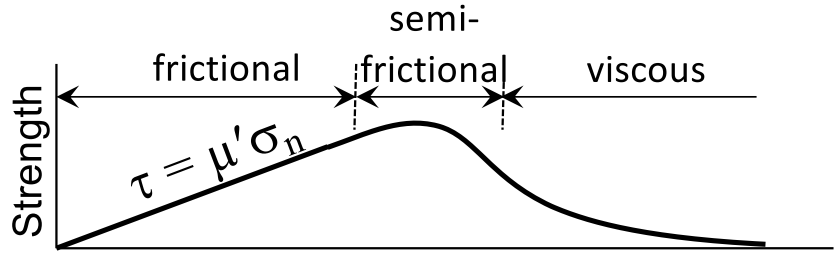
What does μ do in earthquakes?

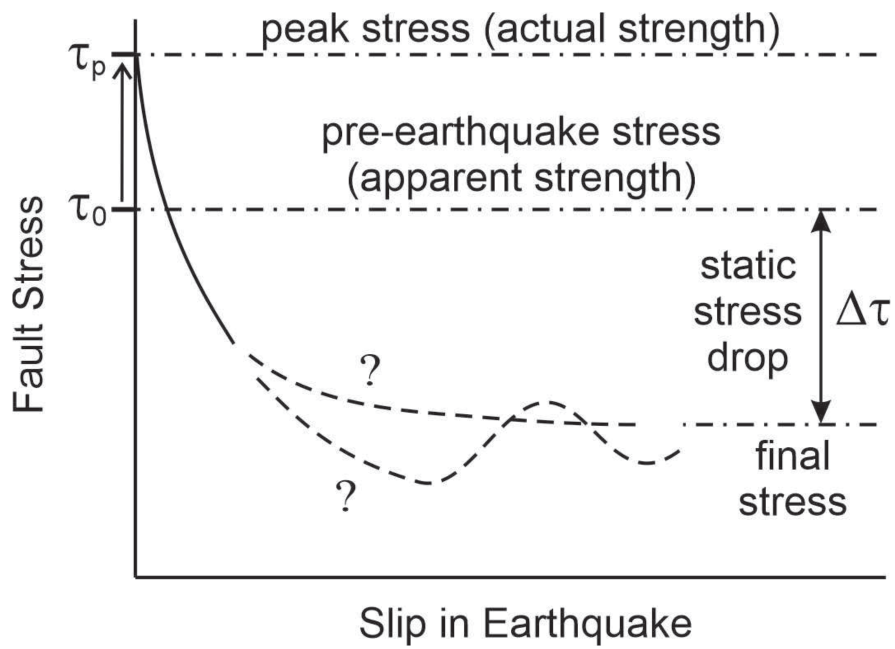
Decrease ($-\Delta\mu$), e.g., velocity-weakening or dynamic weakening. But increase as well ($+\Delta\mu$).

What is the strength of a stick-slip fault?

It is the apparent strength τ_o that we study, not the actual strength τ_p.

For a creeping fault, $\tau_o = \tau_p$





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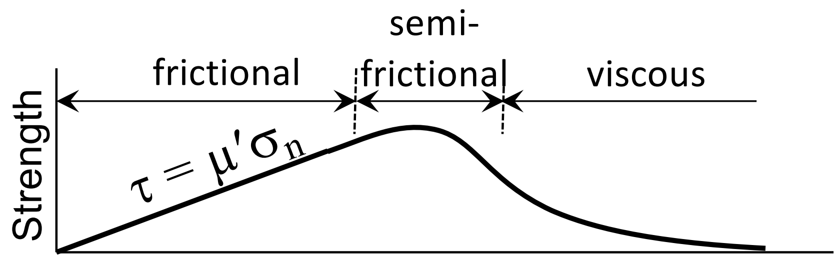
How weak is weak?

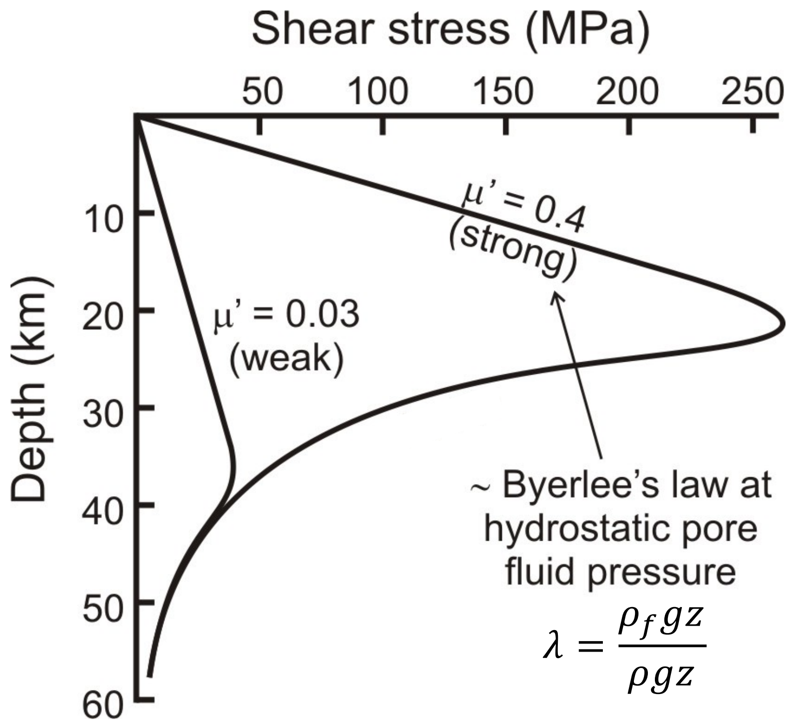
The reference value of $\mu' = \mu(1-\lambda) \approx 0.4$, based on Byerlee's law ($\mu \approx 0.7$) with hydrostatic fluid pressure ($\lambda \approx 0.4$).

Why weak?

Either μ is low or λ is high.

Rupture dynamics is far from adequate.





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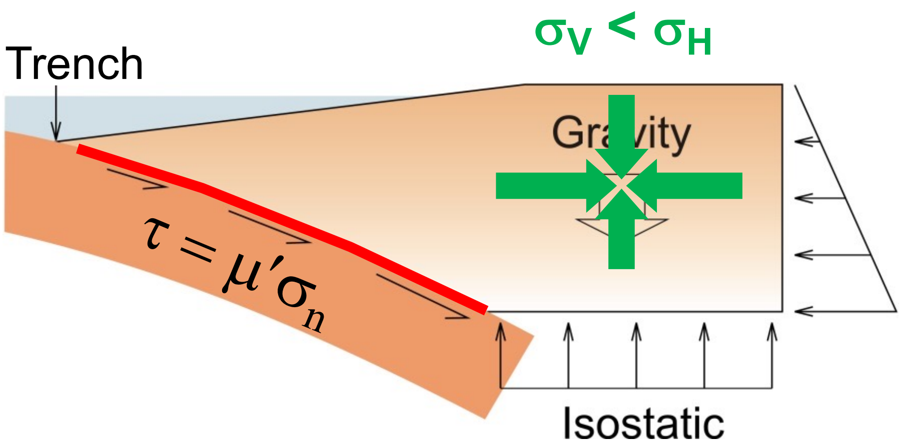
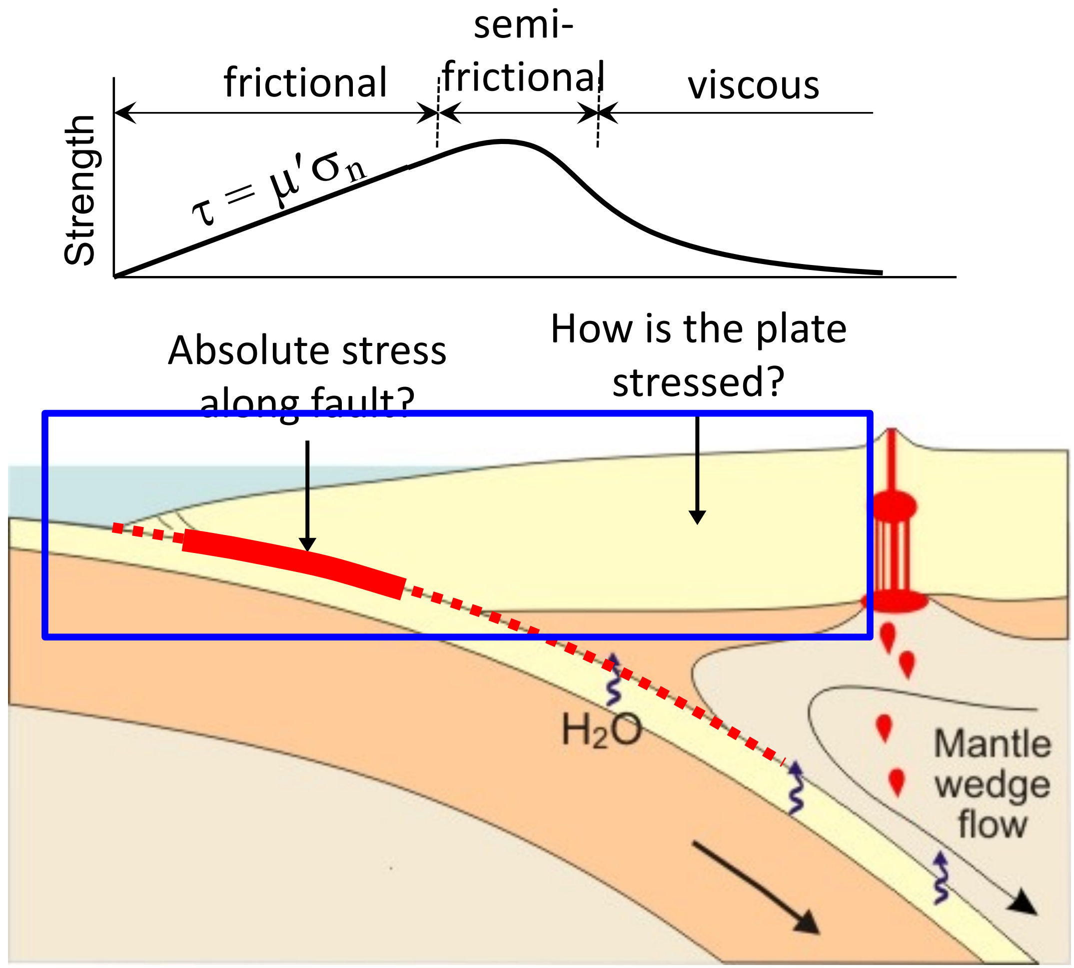
Forearc force balance

- Gravity causes extensional stress
- Megathrust stress causes compression





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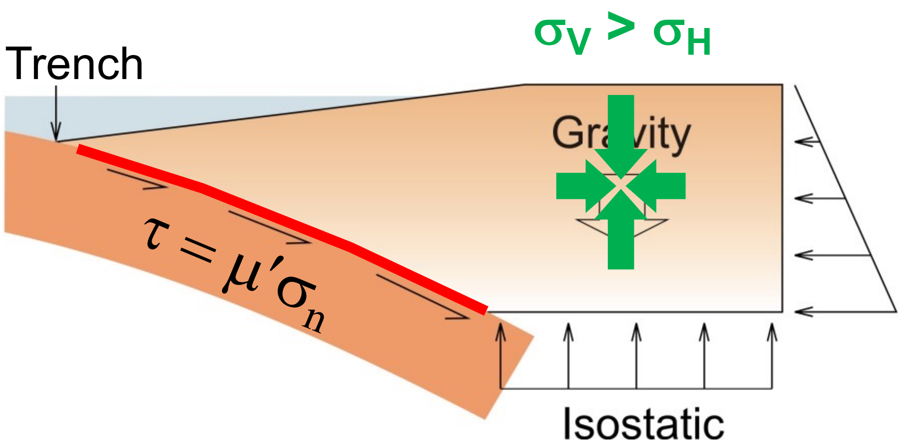

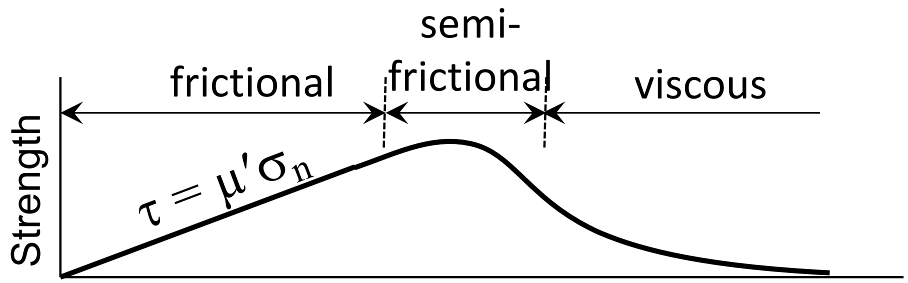

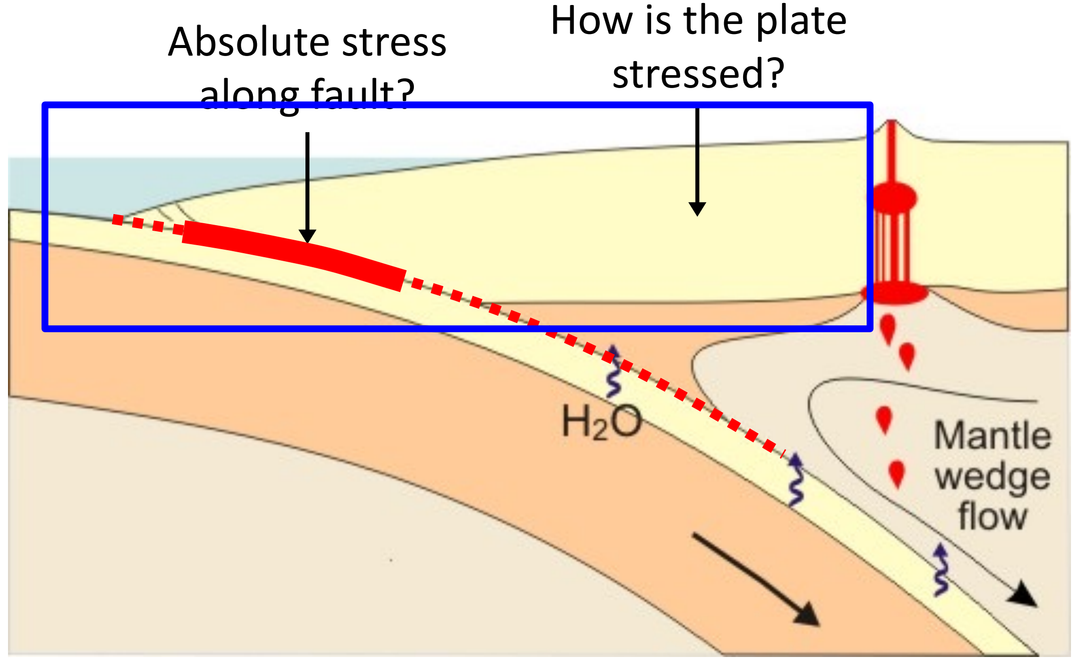

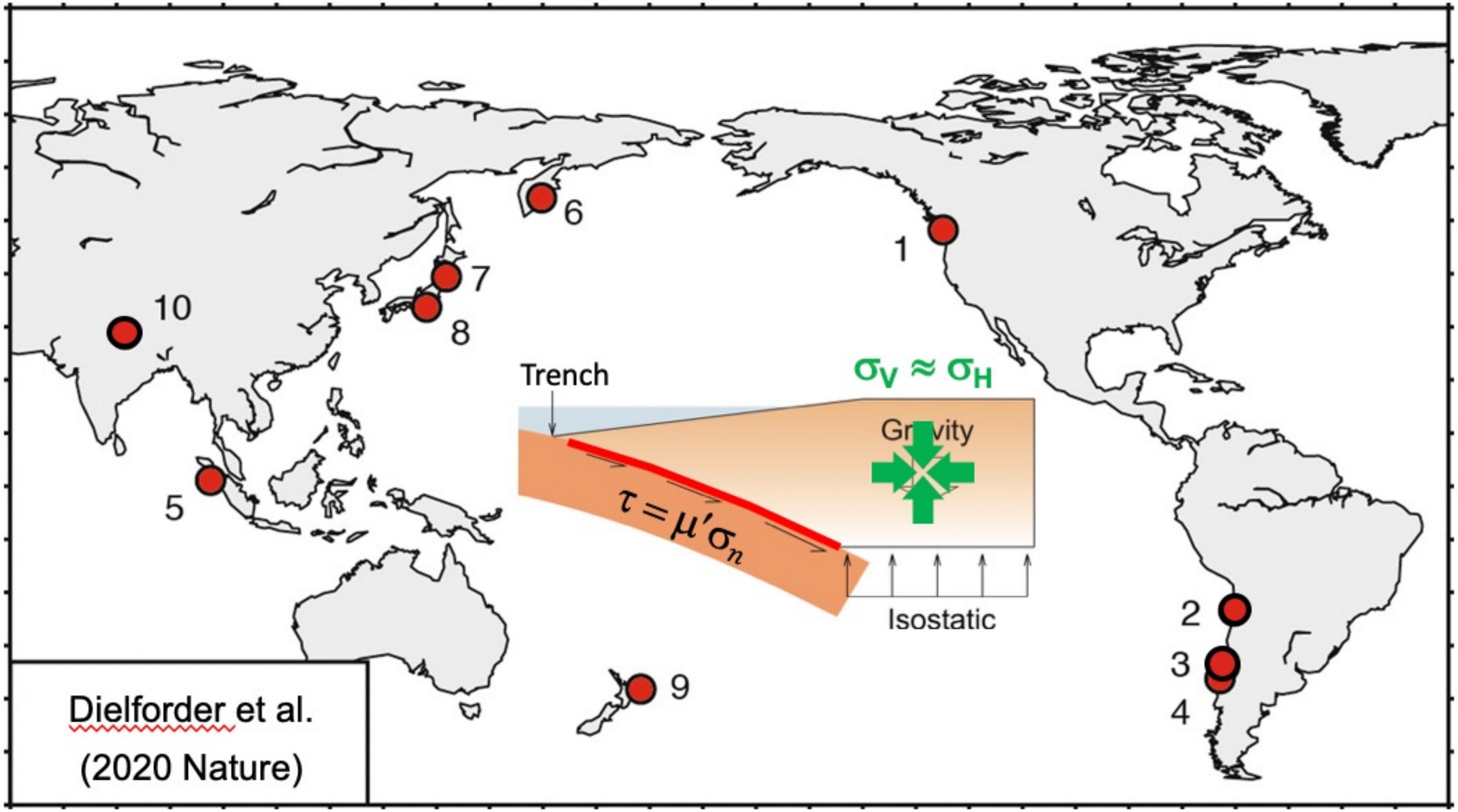

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Trench
σV ≈ σH
Gravity
τ = μ′σn
Isostatic
Dielforder et al.
(2020 Nature)

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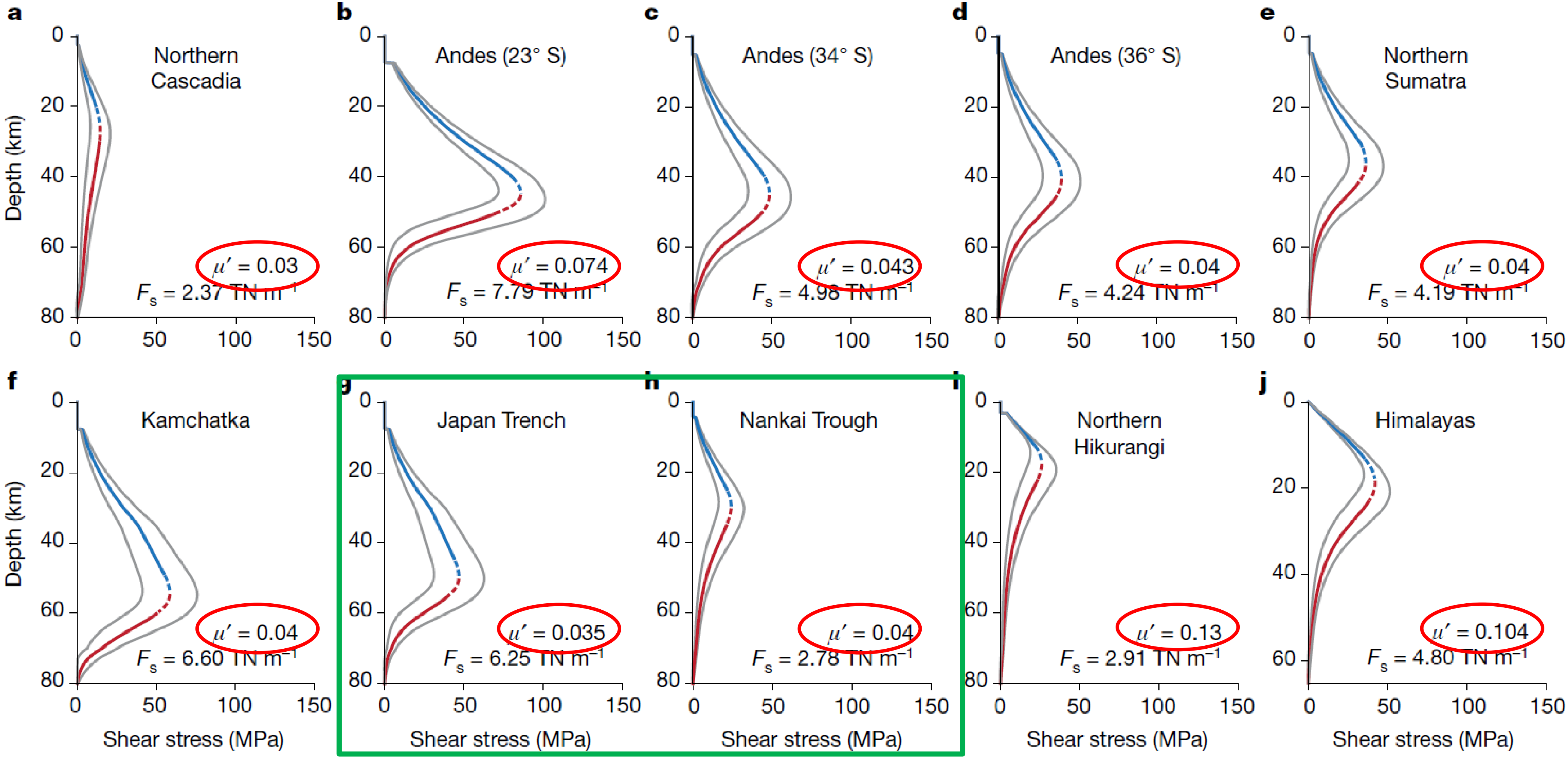
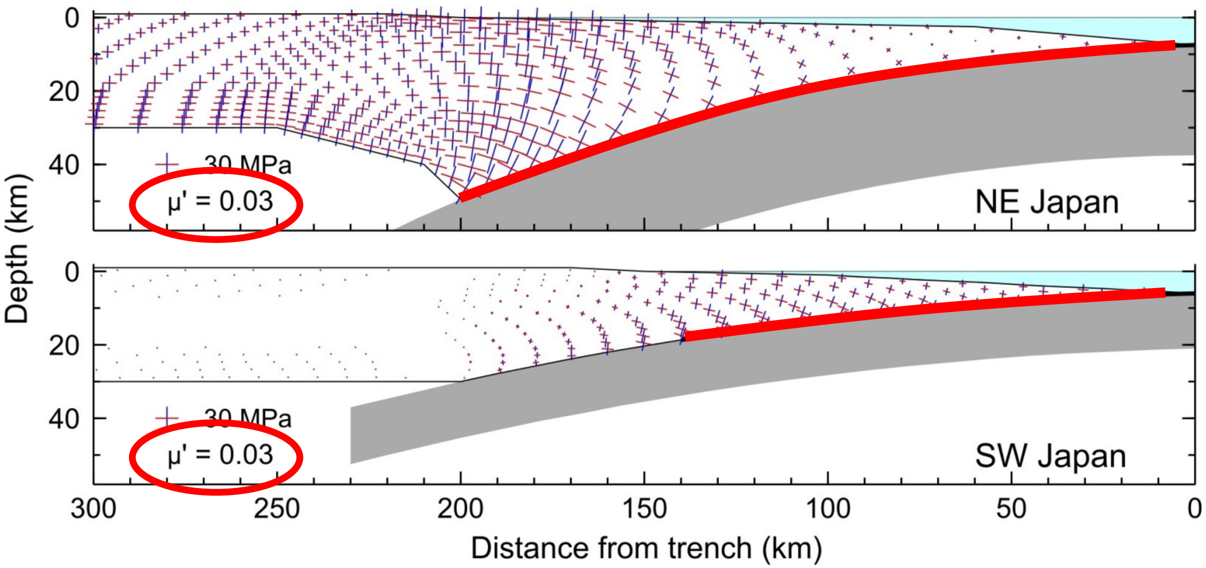
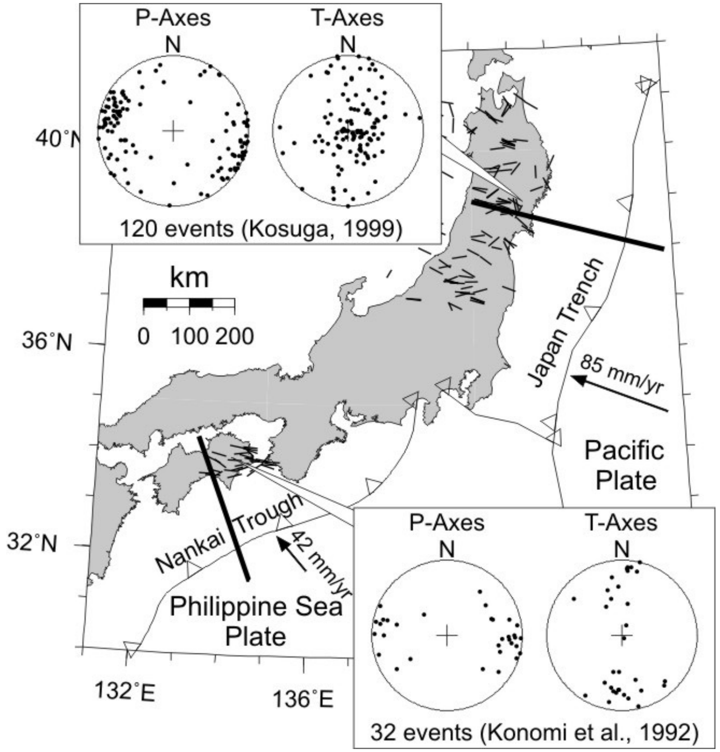
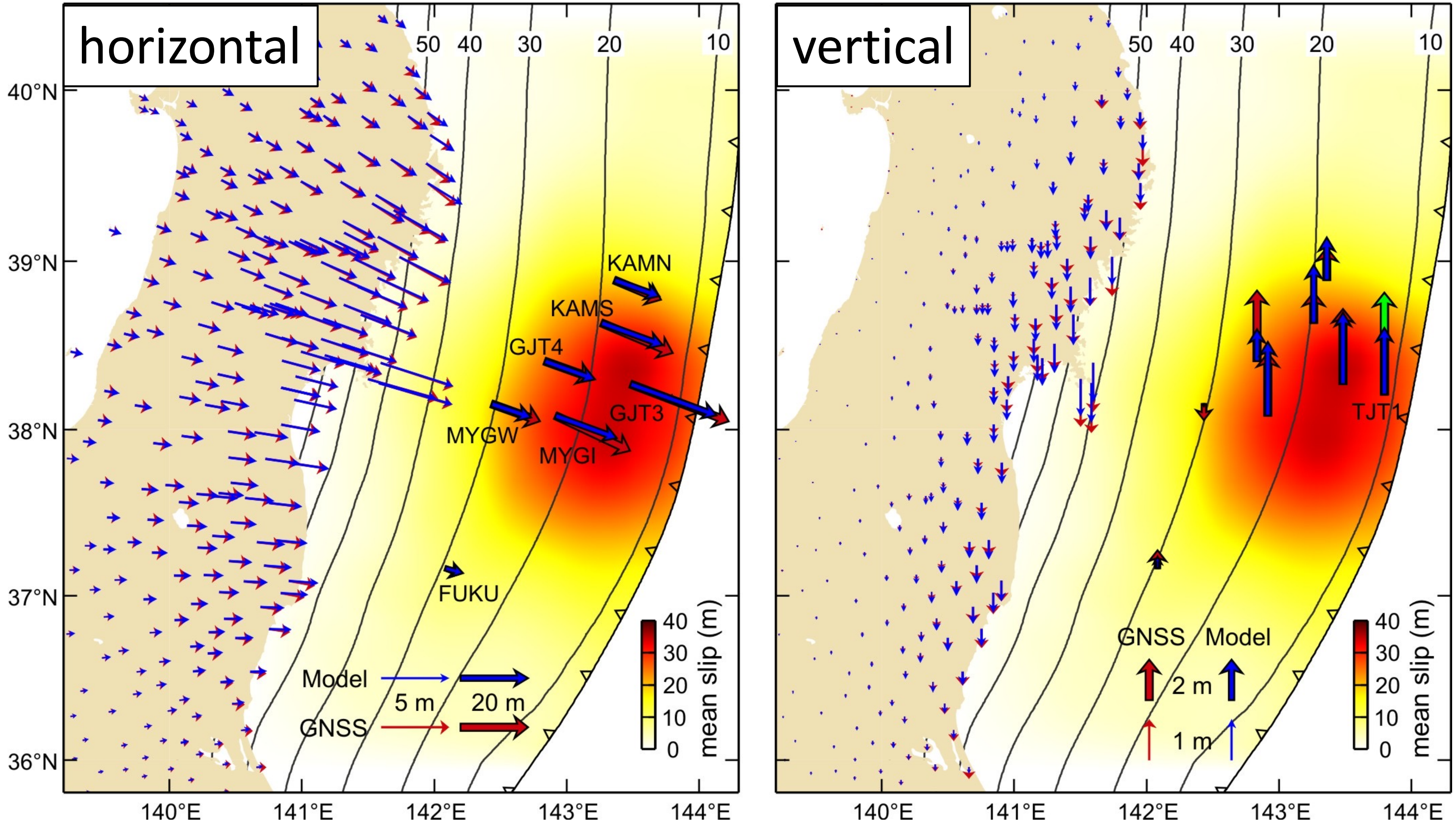






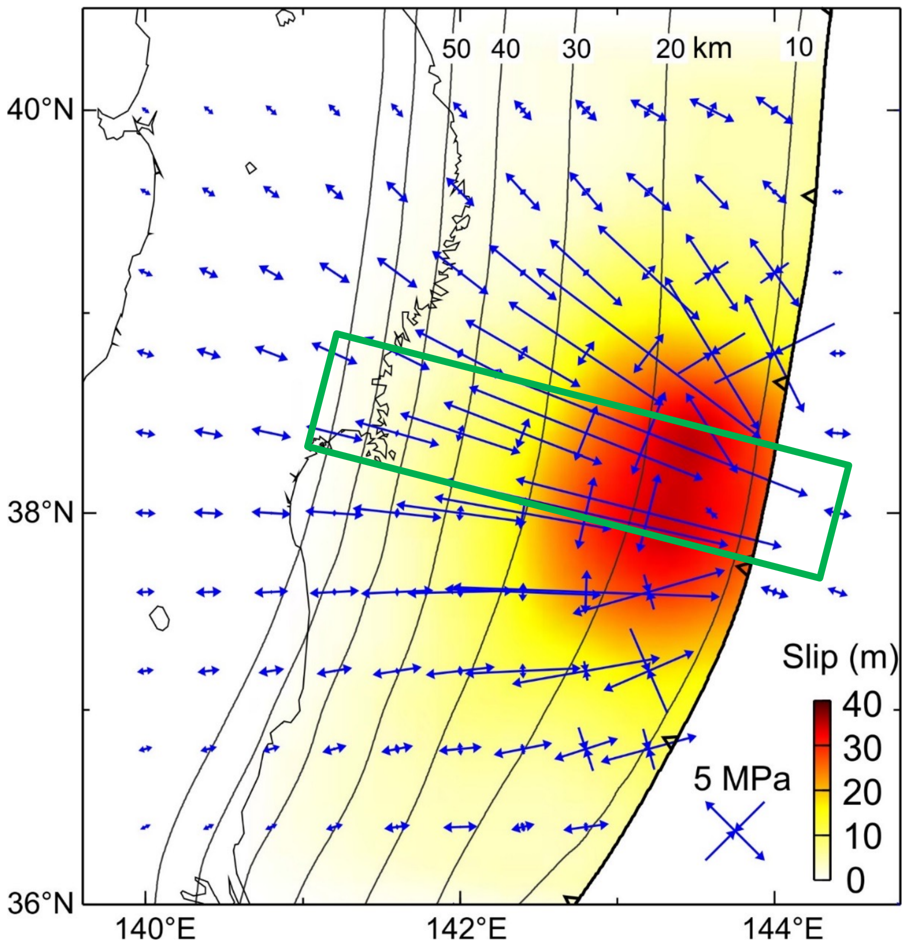
Wang and Suyehiro (1999 GRL)

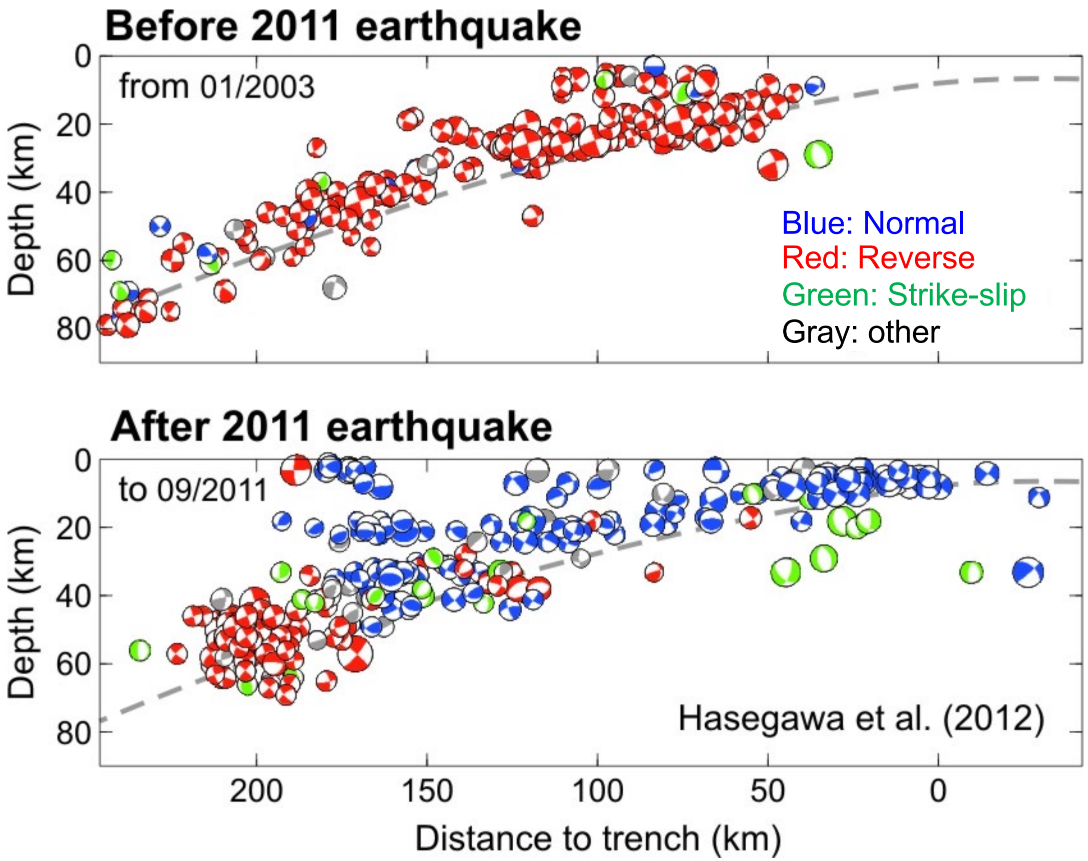
Average slip of 43 published rupture models



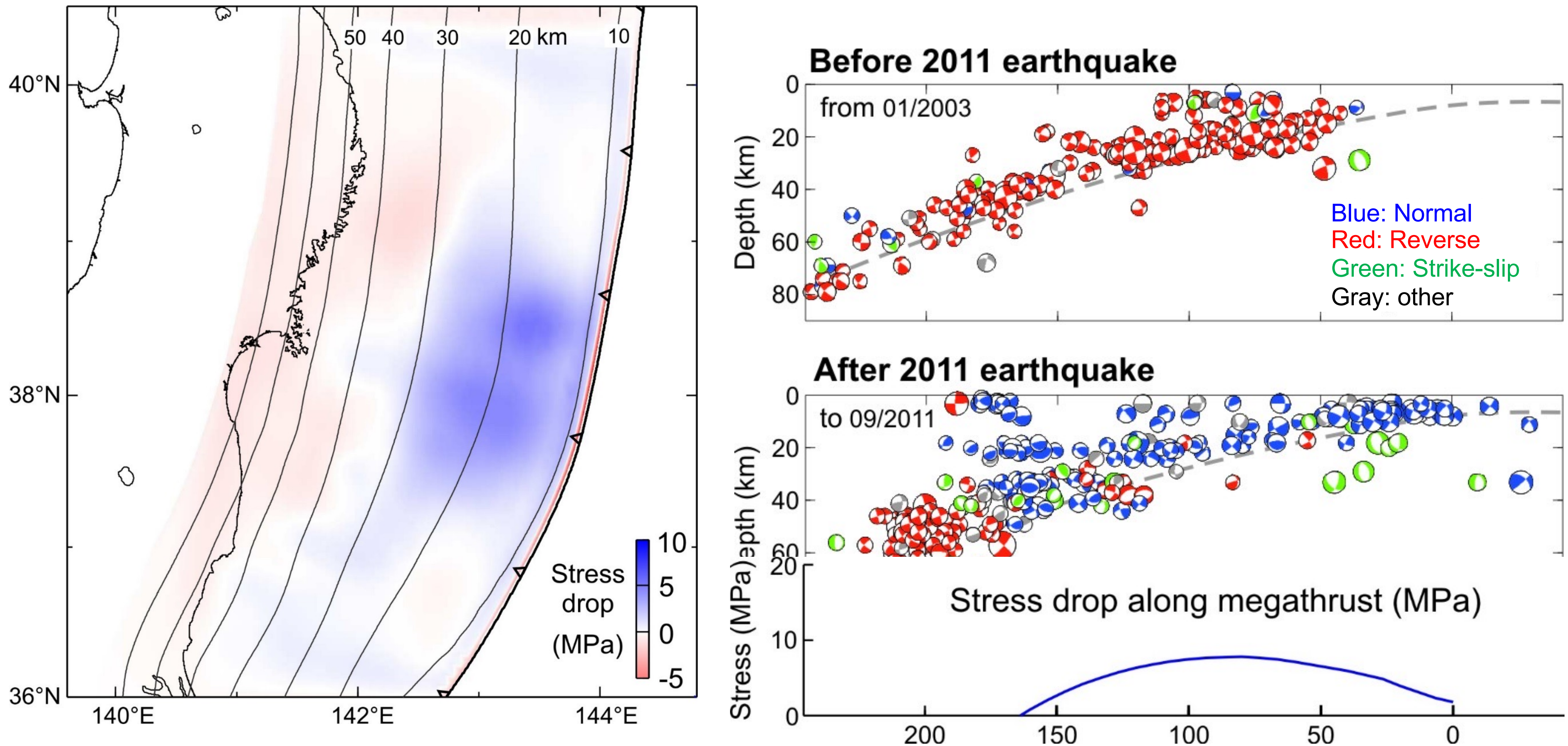
Wang et al. (2018, Geosphere)

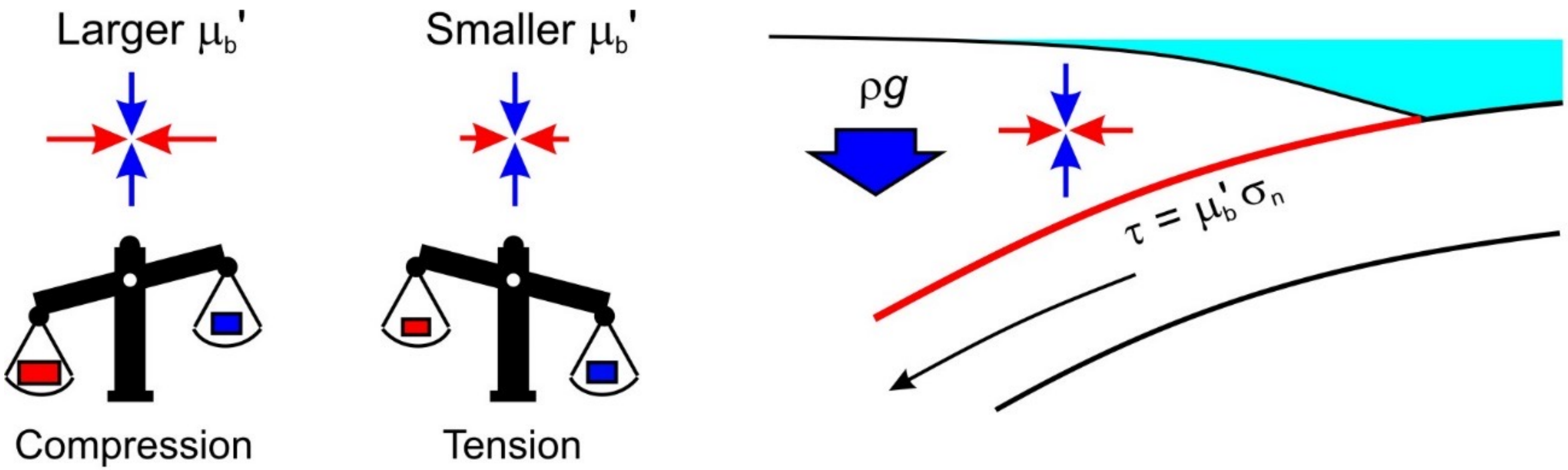
Stress induced in the shallow crust





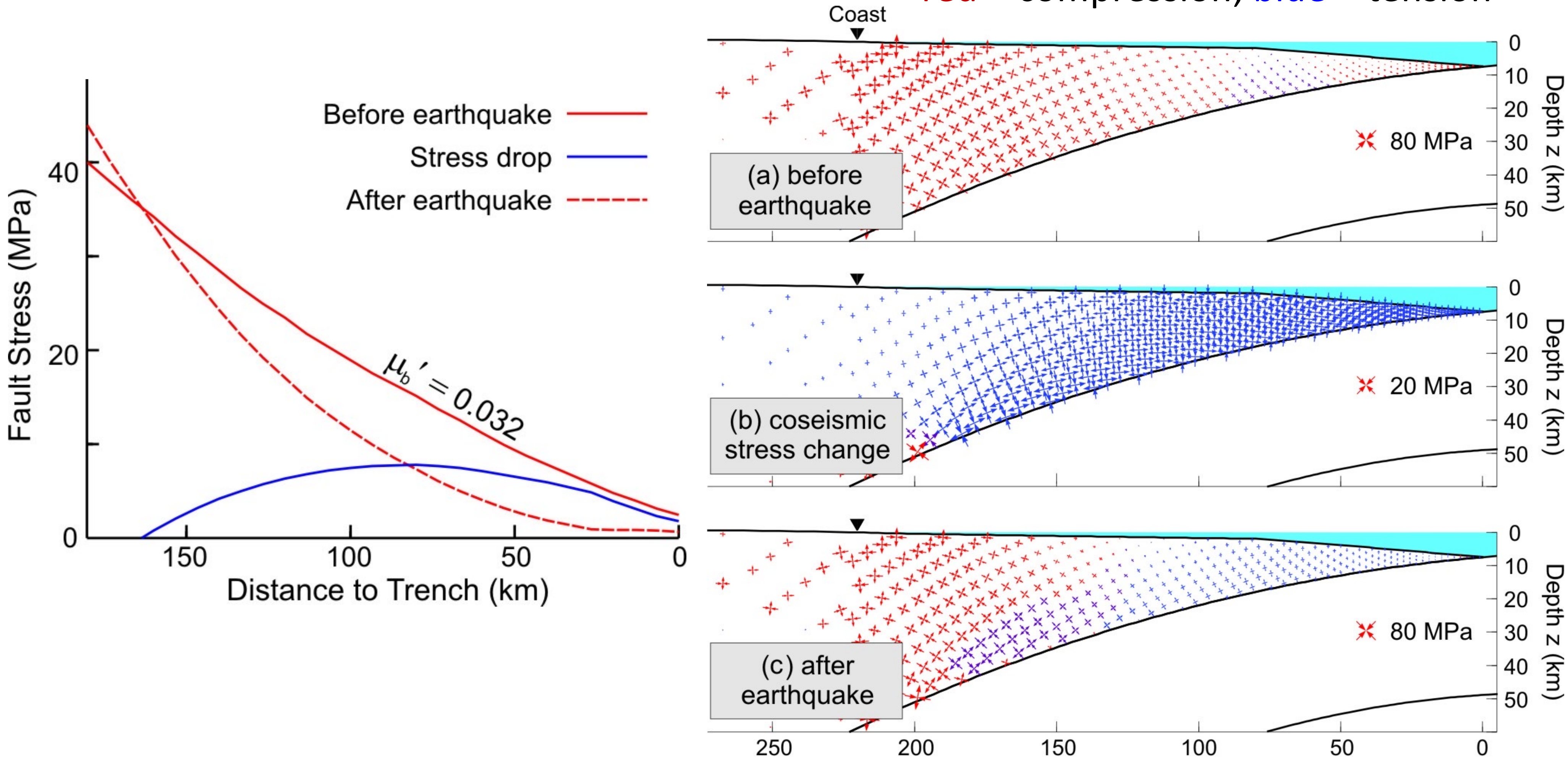
Stress drop along megathrust





Larger μ_b'
Smaller μ_b'
Compression
Tension
ρg
$\tau = \mu_b' \sigma_n$

red – compression; blue – tension



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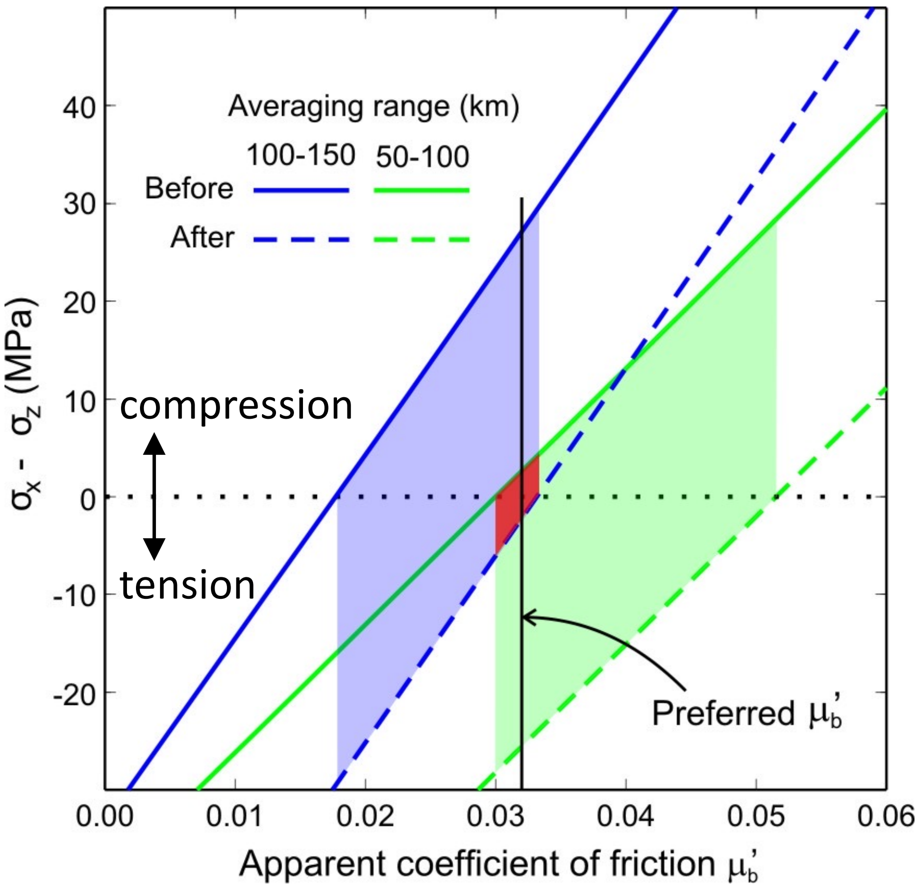

Wang et al. (2018 JGR)