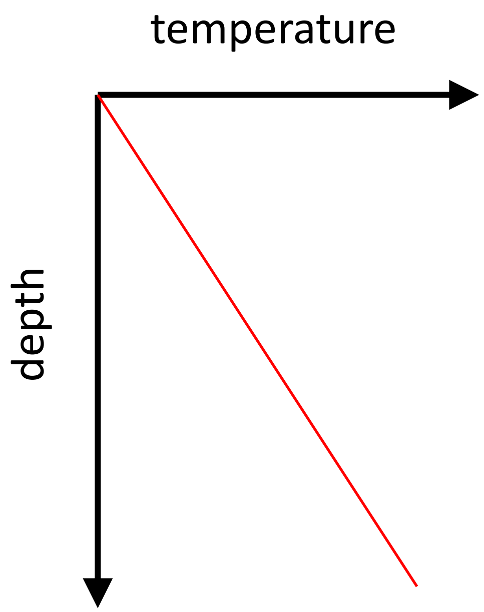
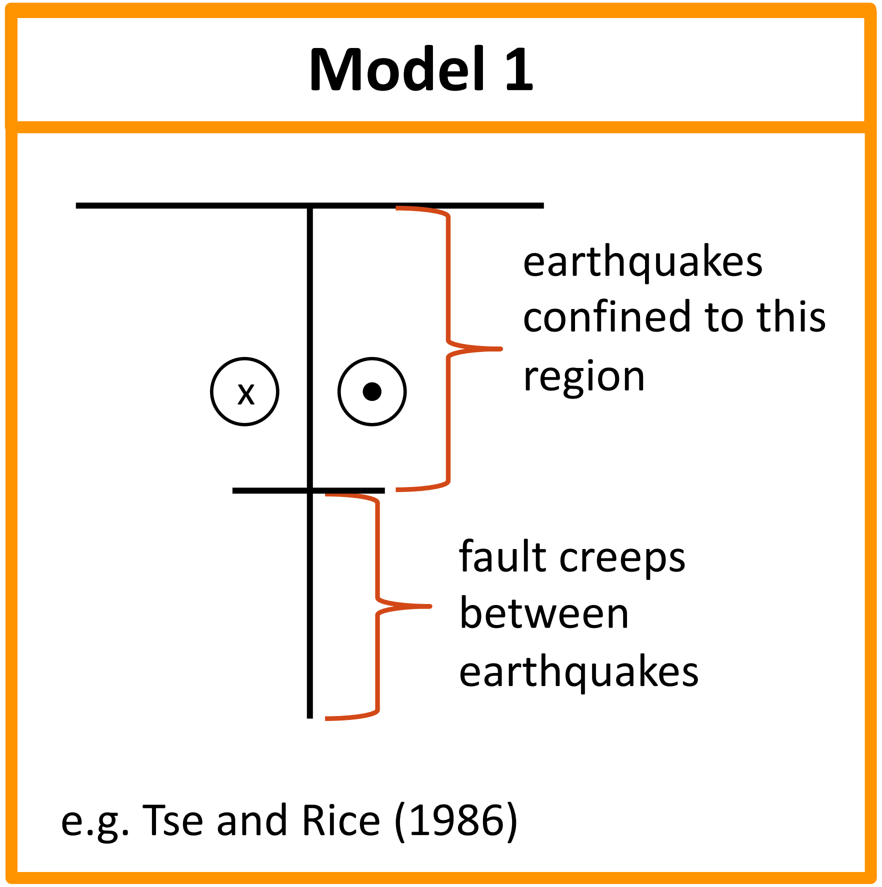
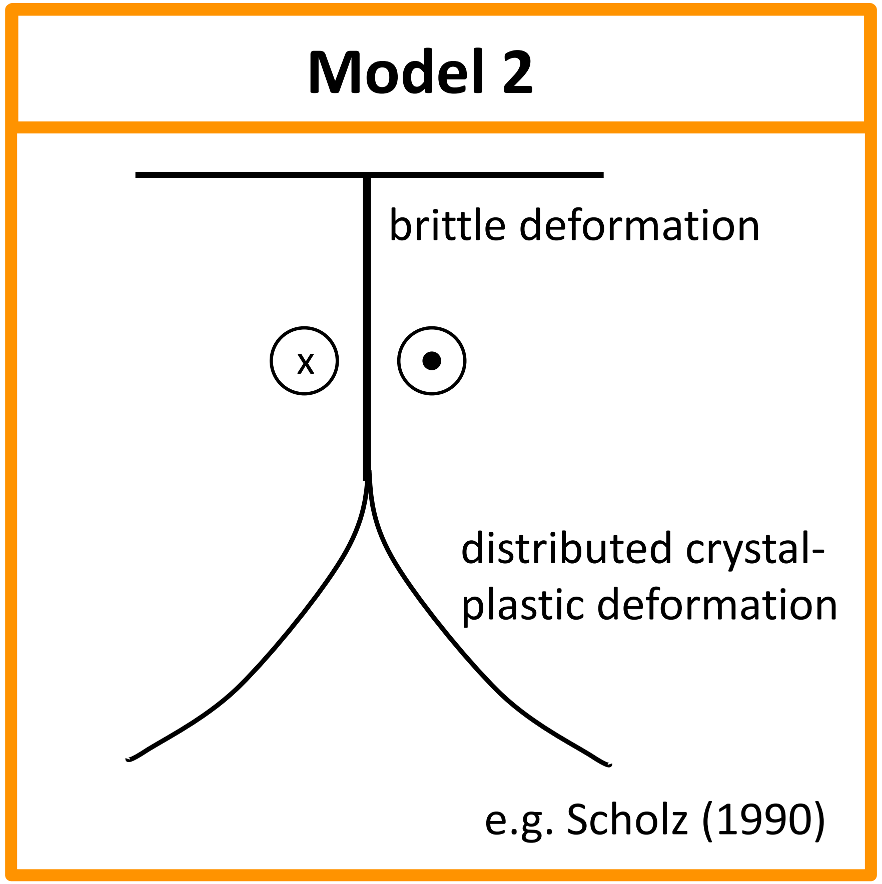
Predictions of the brittle-ductile transition and lithospheric stress from viscoelastic earthquake cycle simulations

KALI ALLISON (UNIVERSITY OF MARYLAND) AND ERIC DUNHAM (STANFORD UNIVERSITY)

Transitions in deformation style

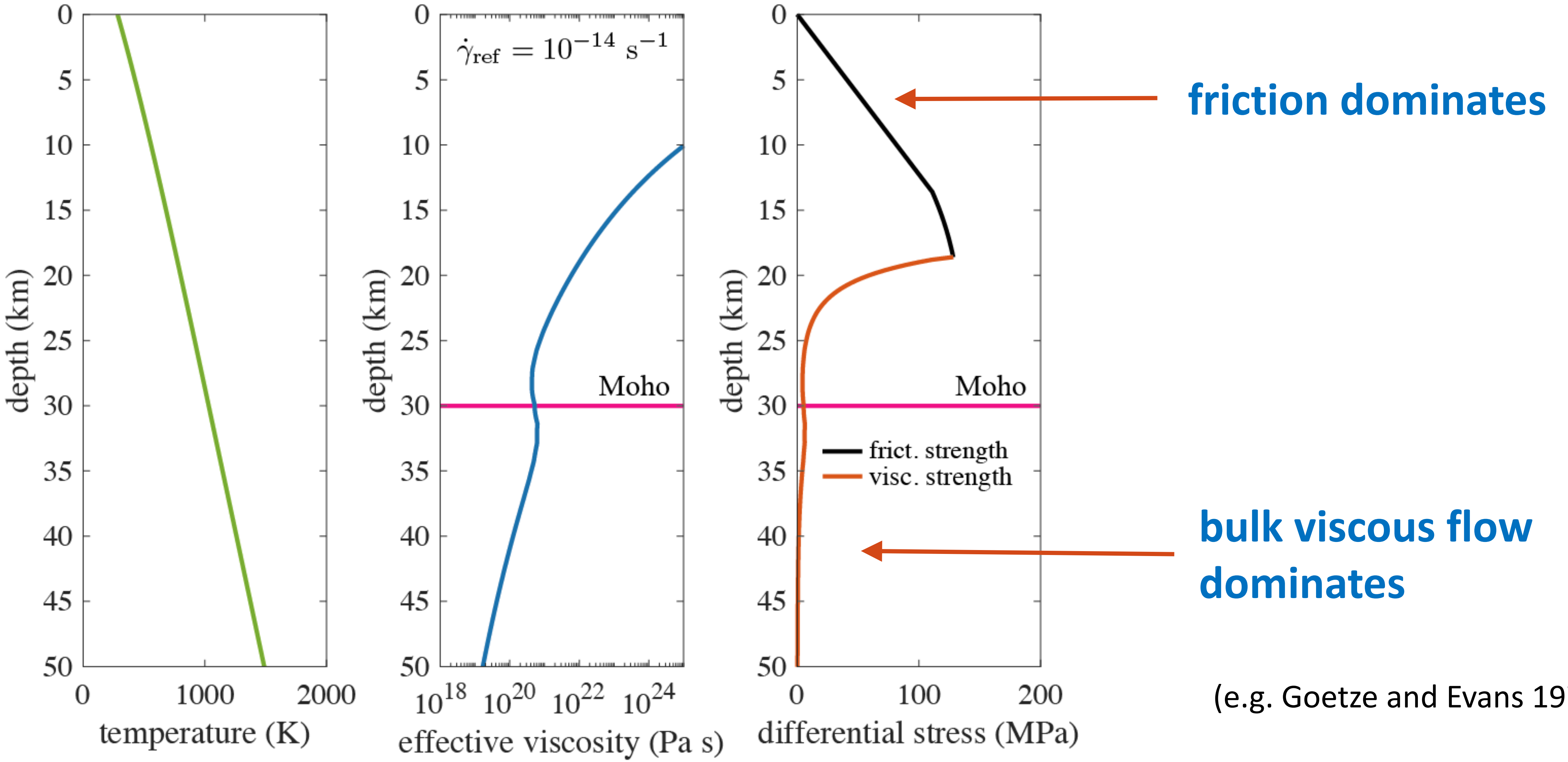






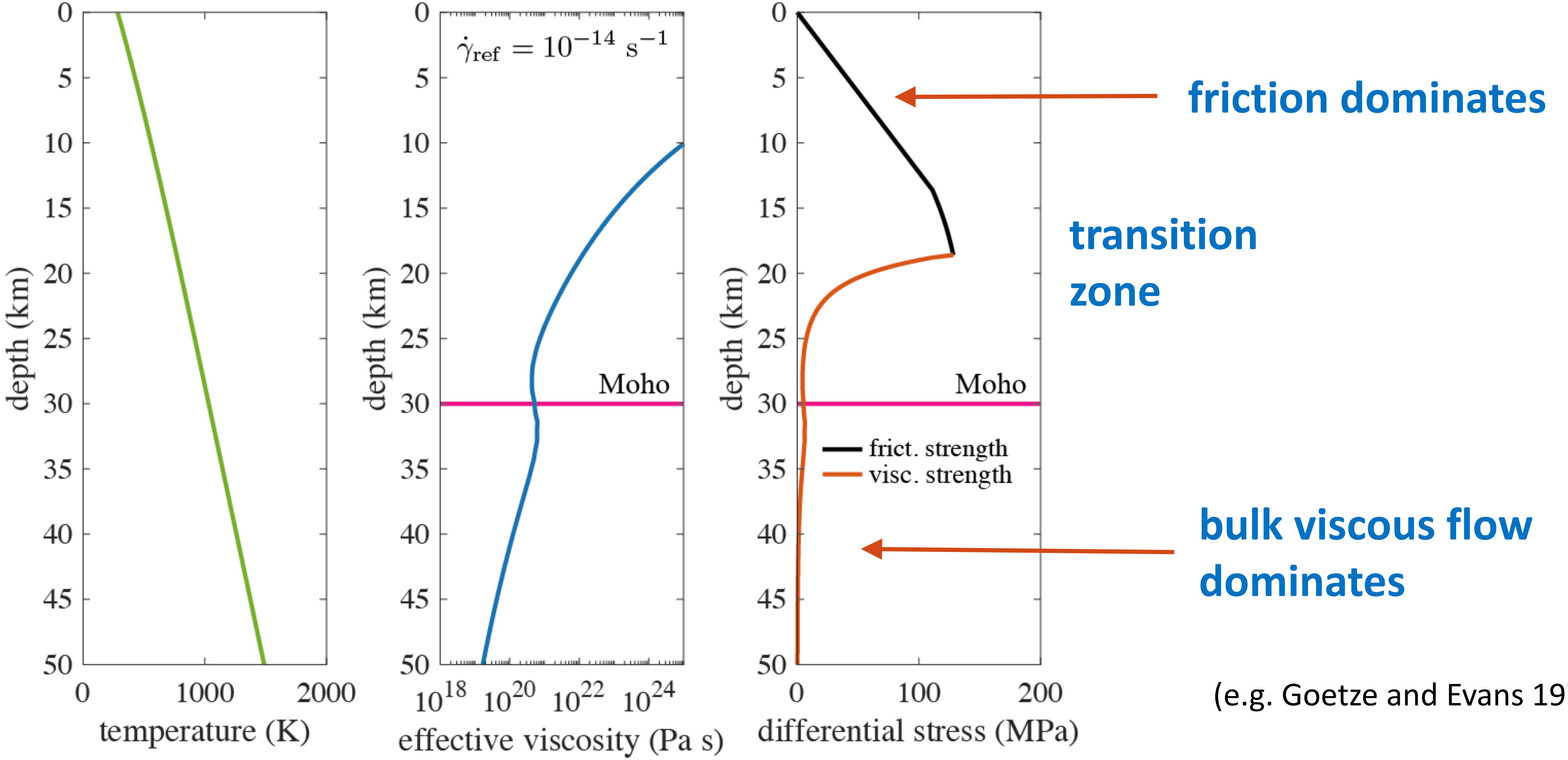
(diagrams show a vertical strike-slip fault for simplicity)

Combining friction and viscoelasticity



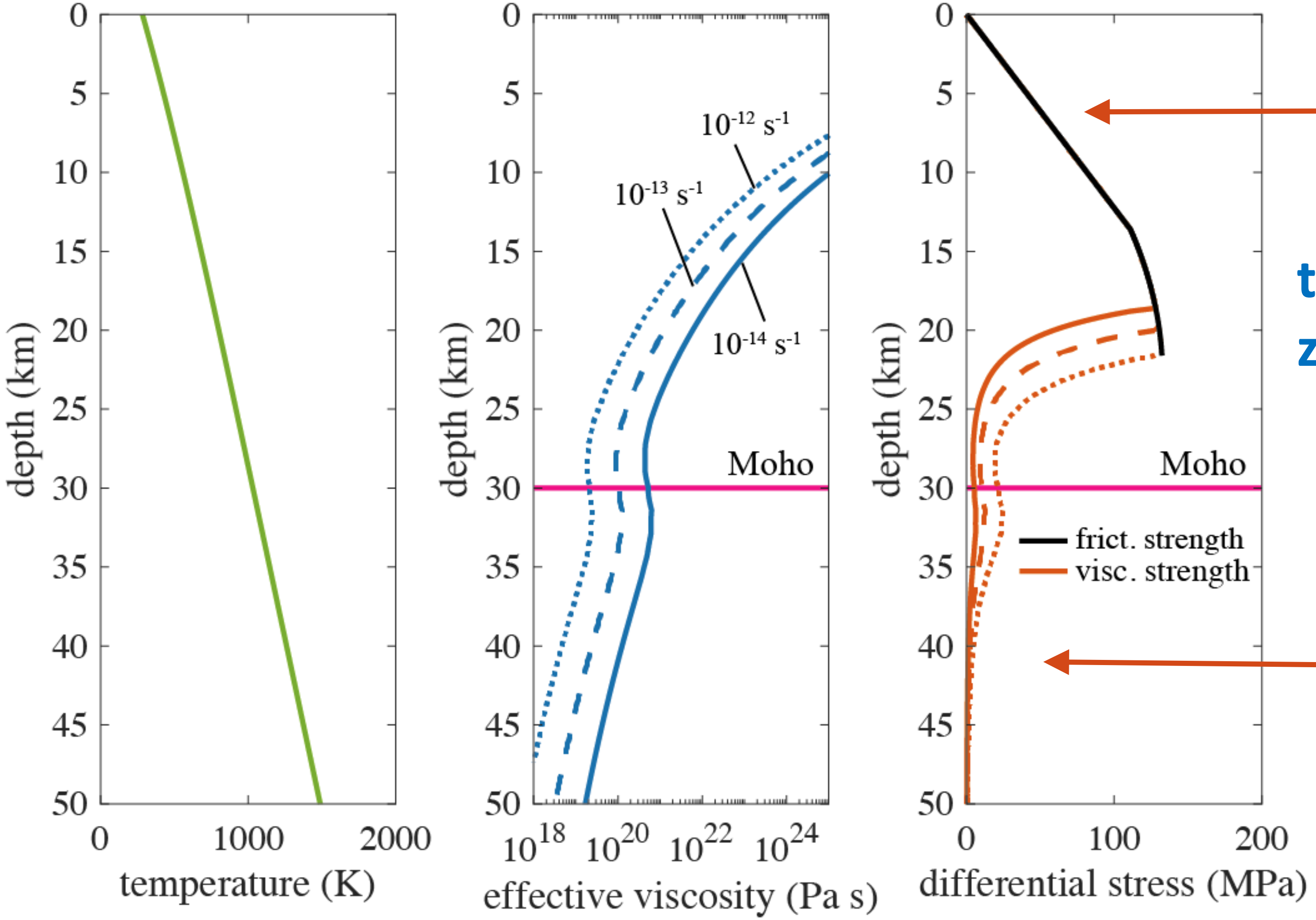
(e.g. Goetze and Evans 1979)

Combining friction and viscoelasticity



(e.g. Goetze and Evans 1979)

Effect of assuming strain rate



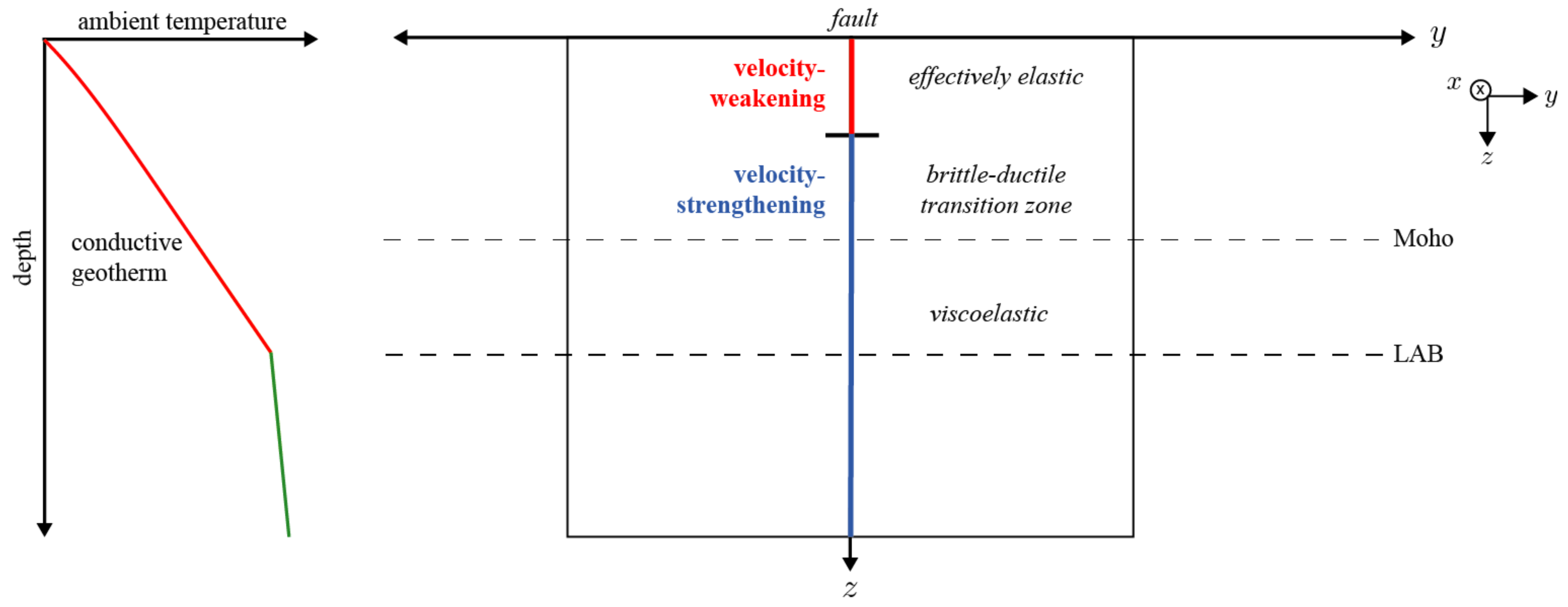
friction dominates

transition zone

bulk viscous flow dominates

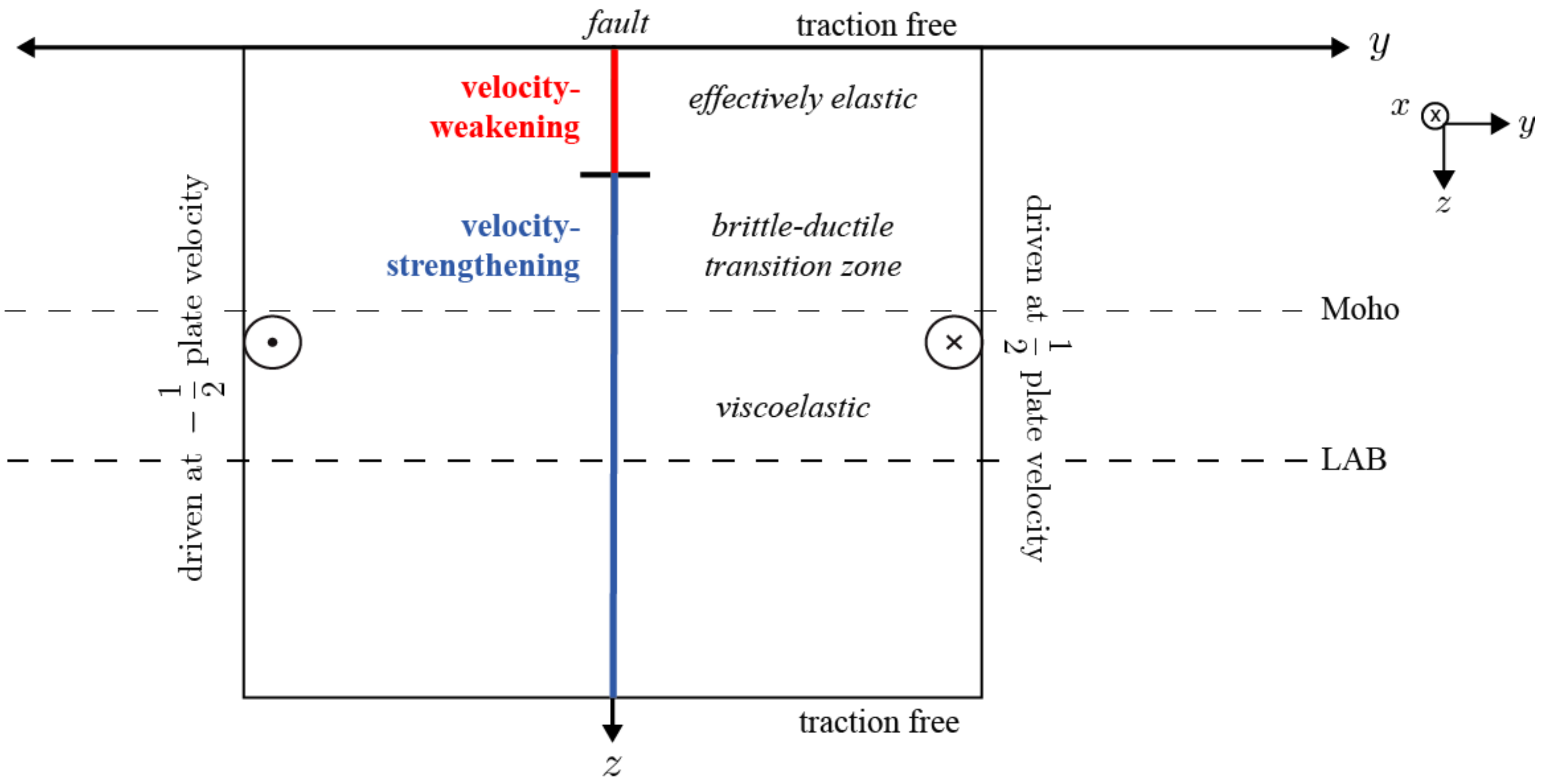
(e.g. Goetze and Evans 1979)

Building the model

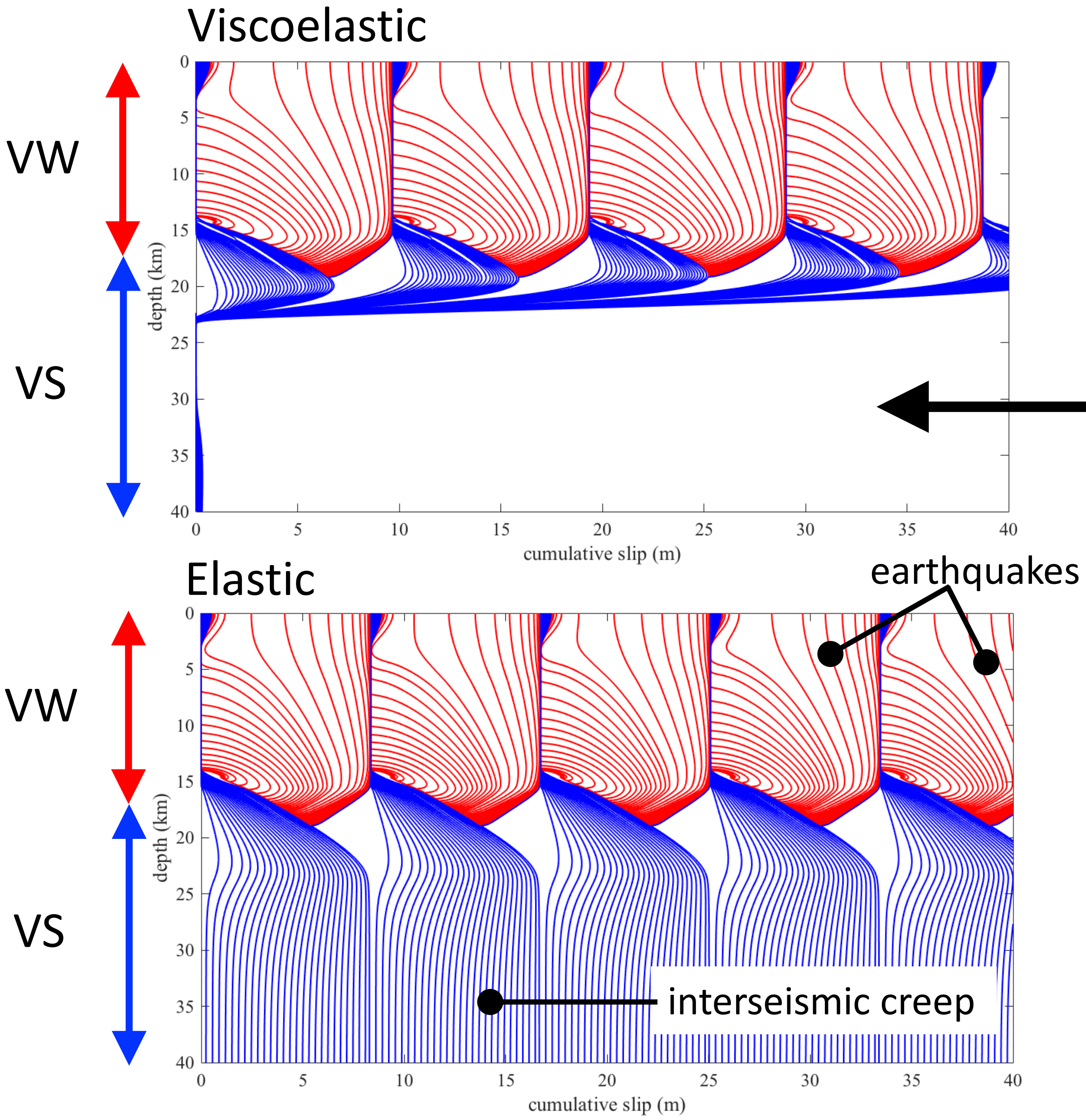


method described in Allison and Dunham (2017)

Building the model



method described in Allison and Dunham (2017)



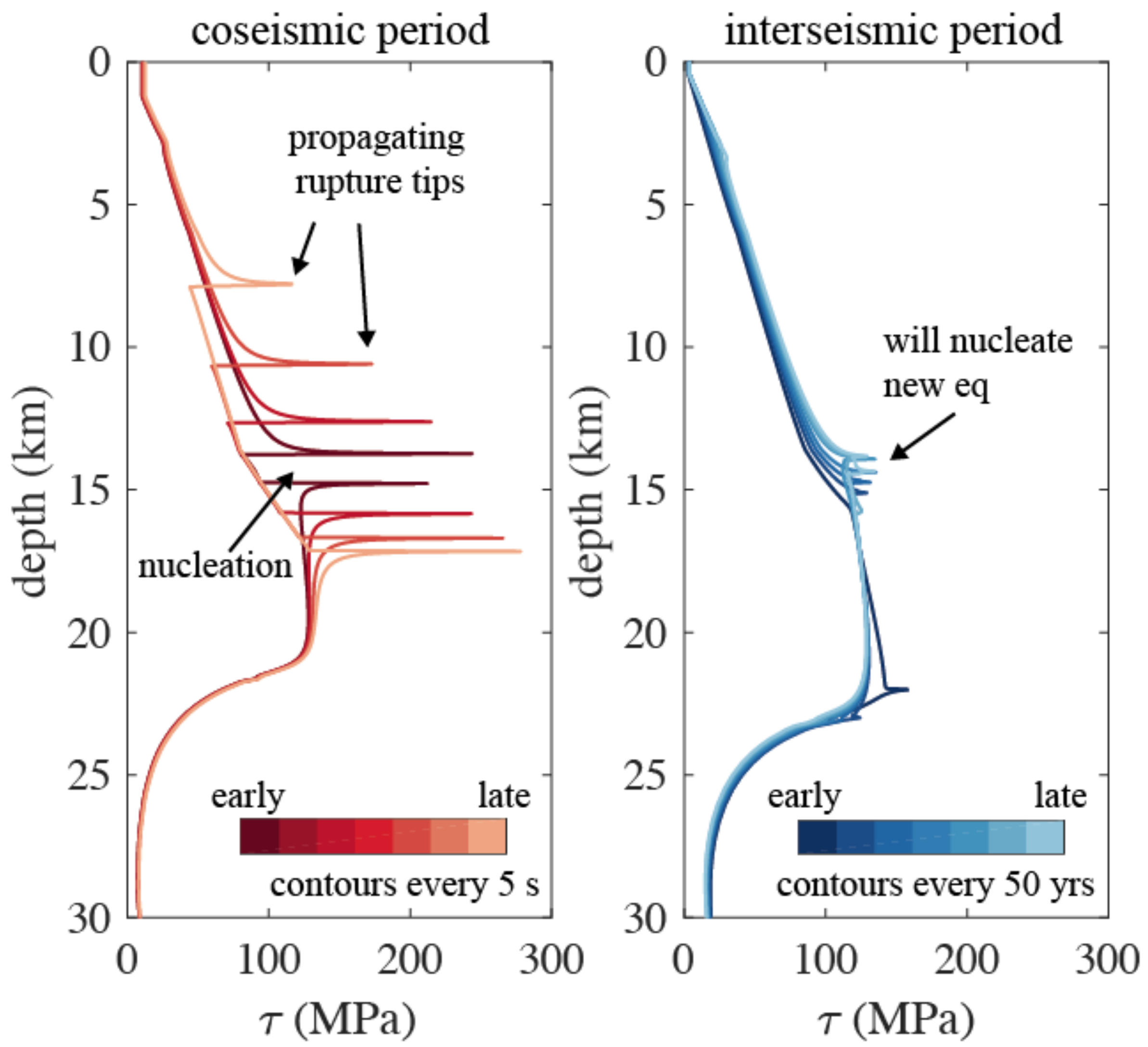
recurrence interval: 307 years
nucleation depth: 14.5 km
down-dip limit of eq. slip: 19 km

bulk viscous flow prevents interseismic fault creep

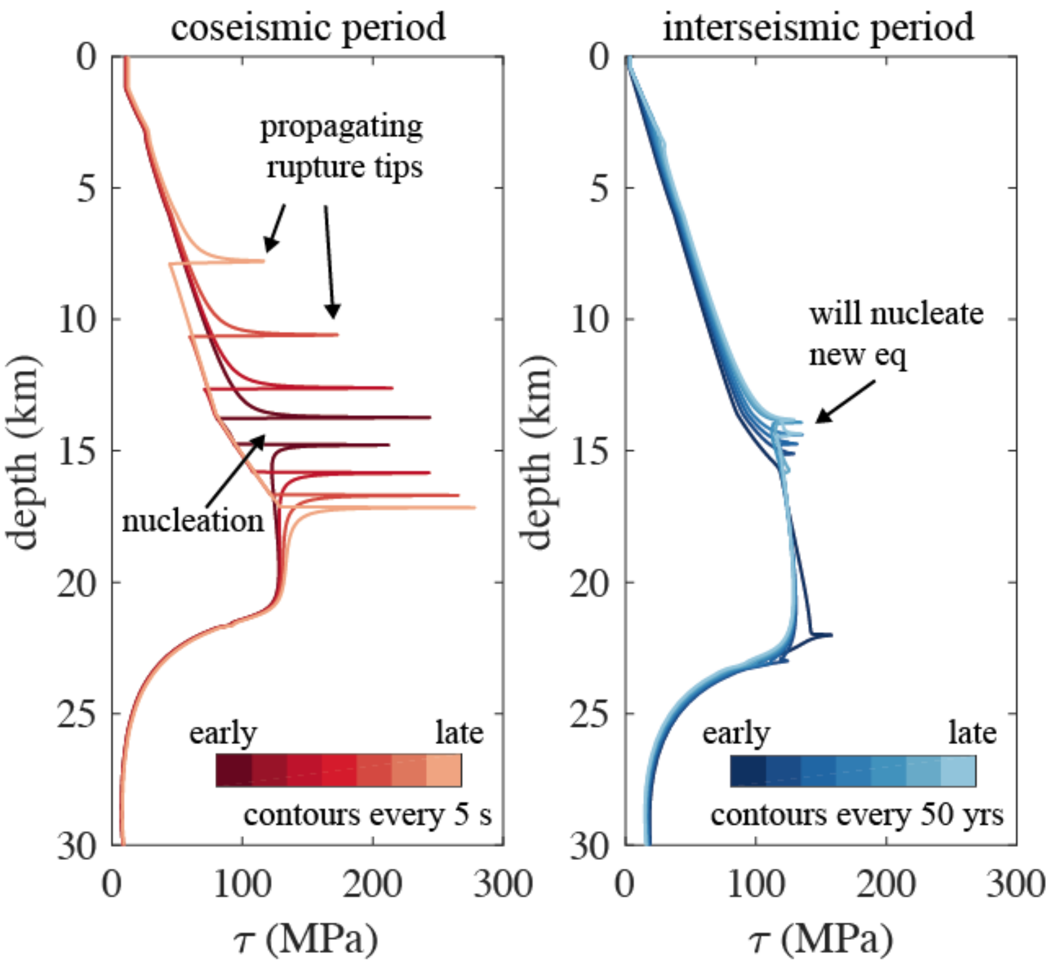
recurrence interval: 266 years
nucleation depth: 14.5 km
down-dip limit of eq. slip: 19 km

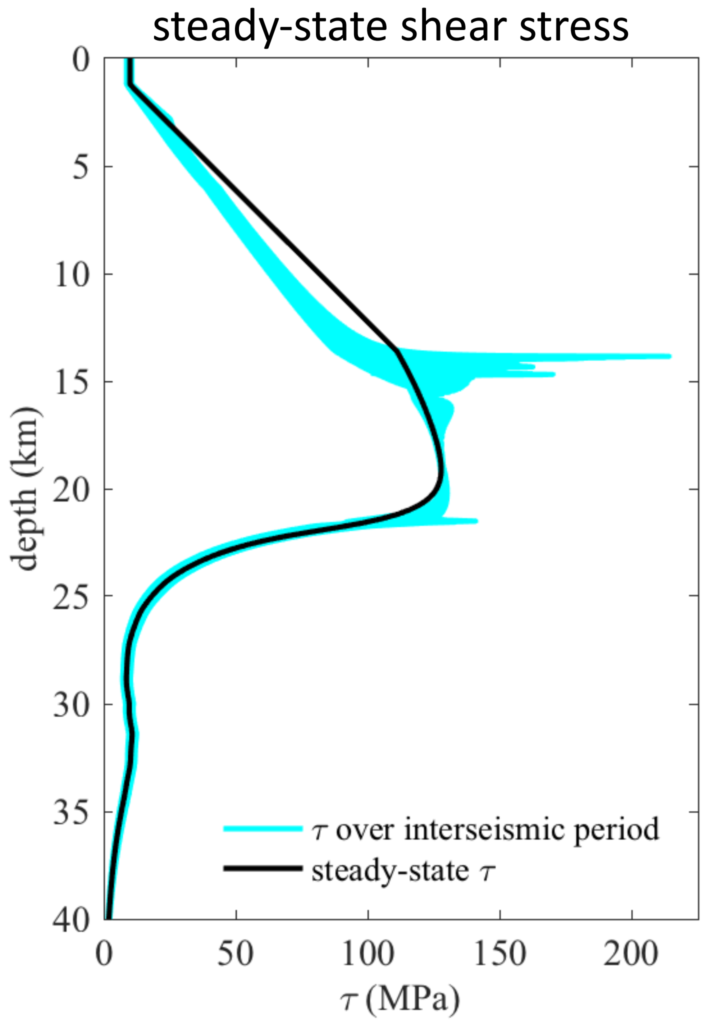
red: contoured every 1 s
blue: contoured every 10 years

Shear stress on the fault through cycle

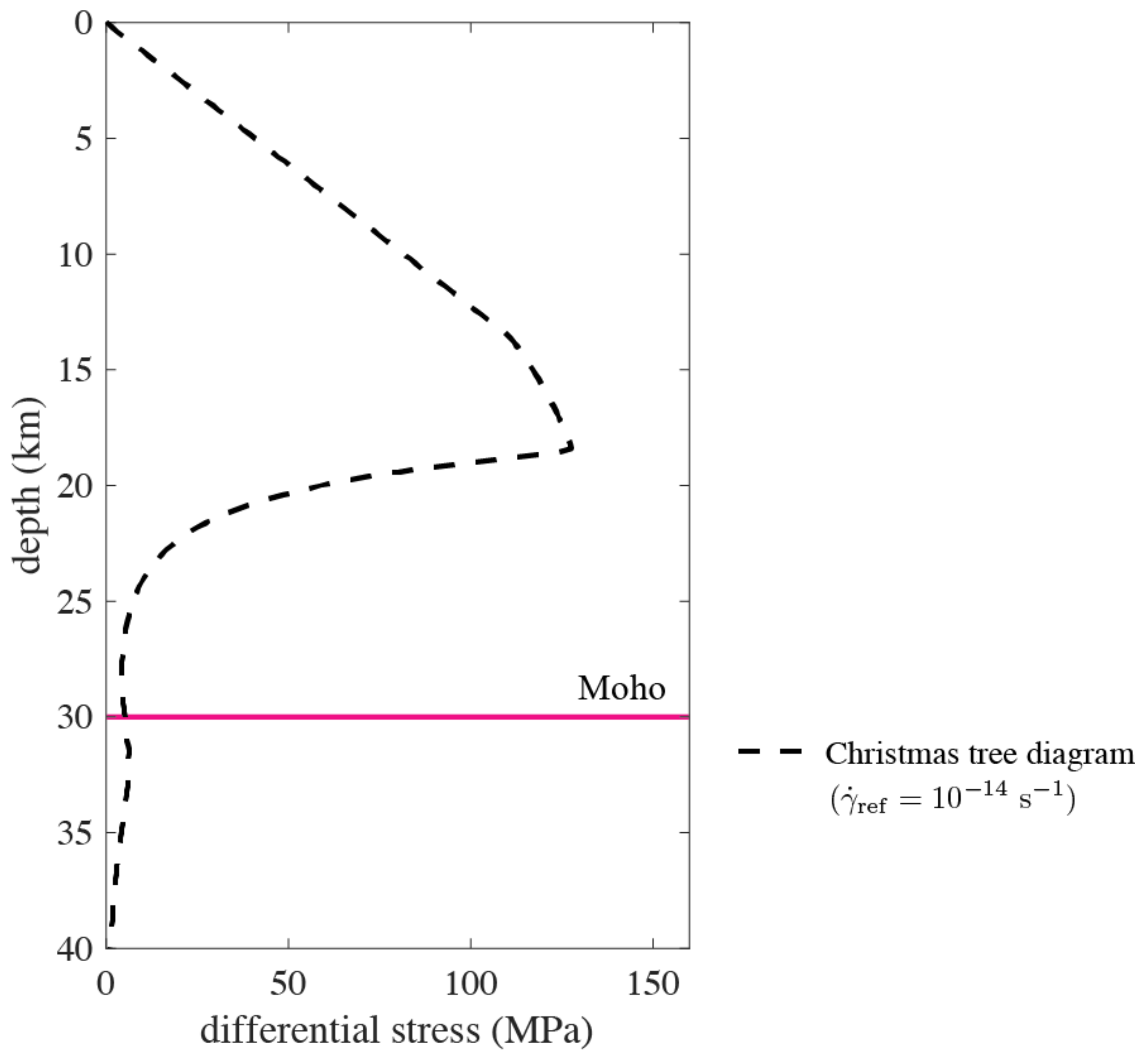


Using a steady-state calculation to characterize stress



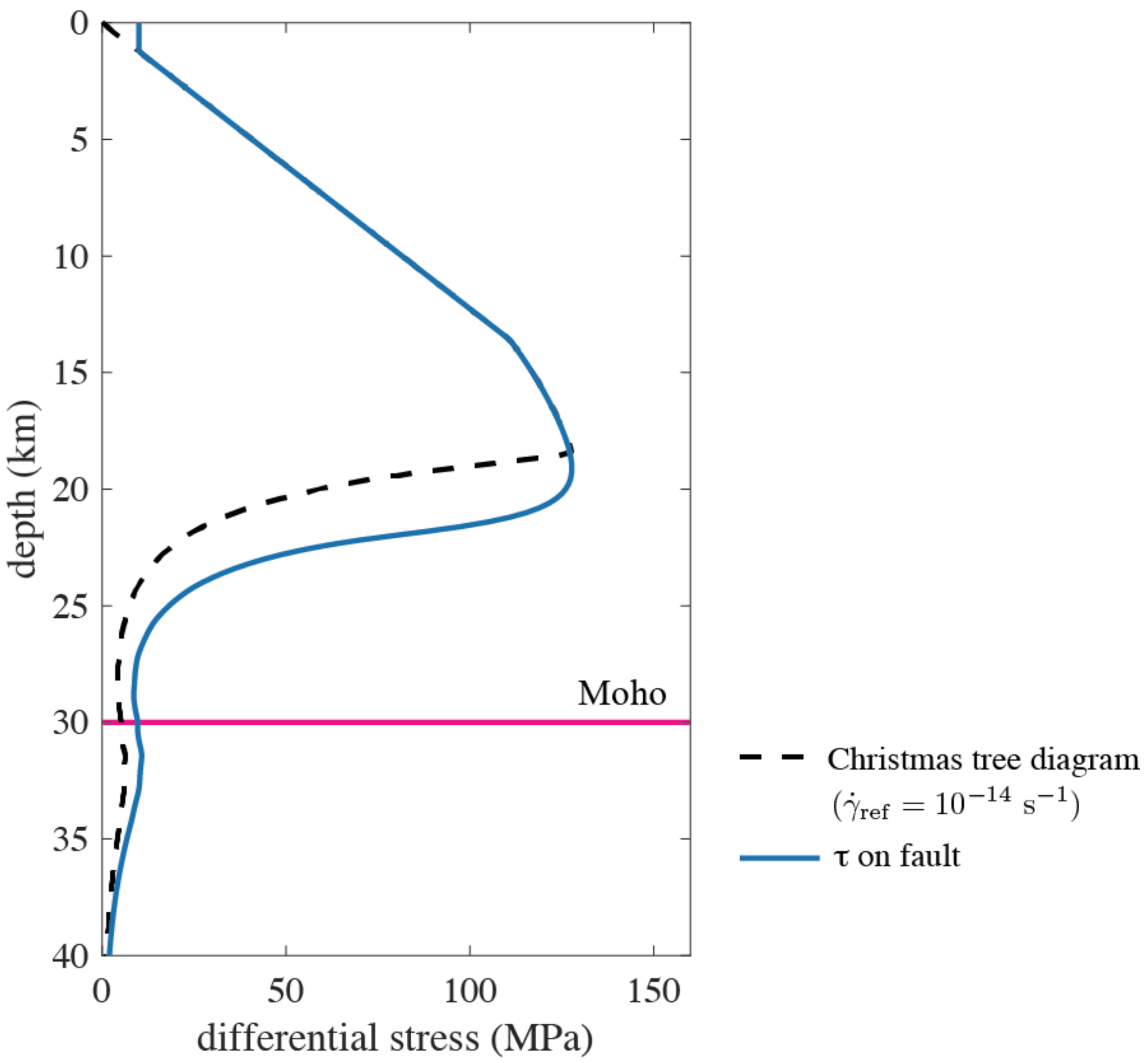


How accurate was the estimate which was based on a steady-state flow and a constant reference strain rate?



The strain rate beneath the fault is higher than 10^{-14} s^{-1}.

This pushes the brittle-ductile transition slightly deeper than was estimated.



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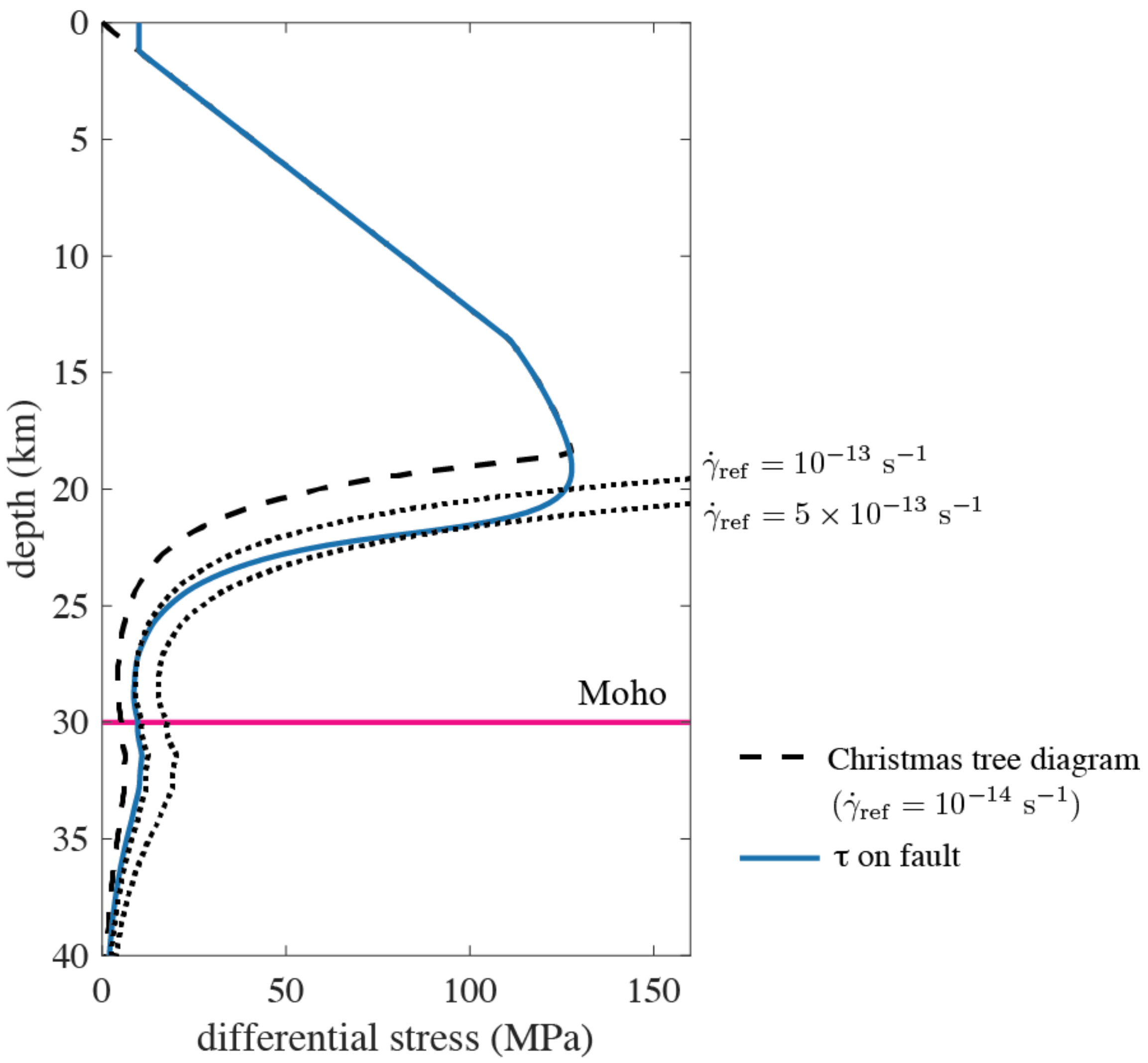
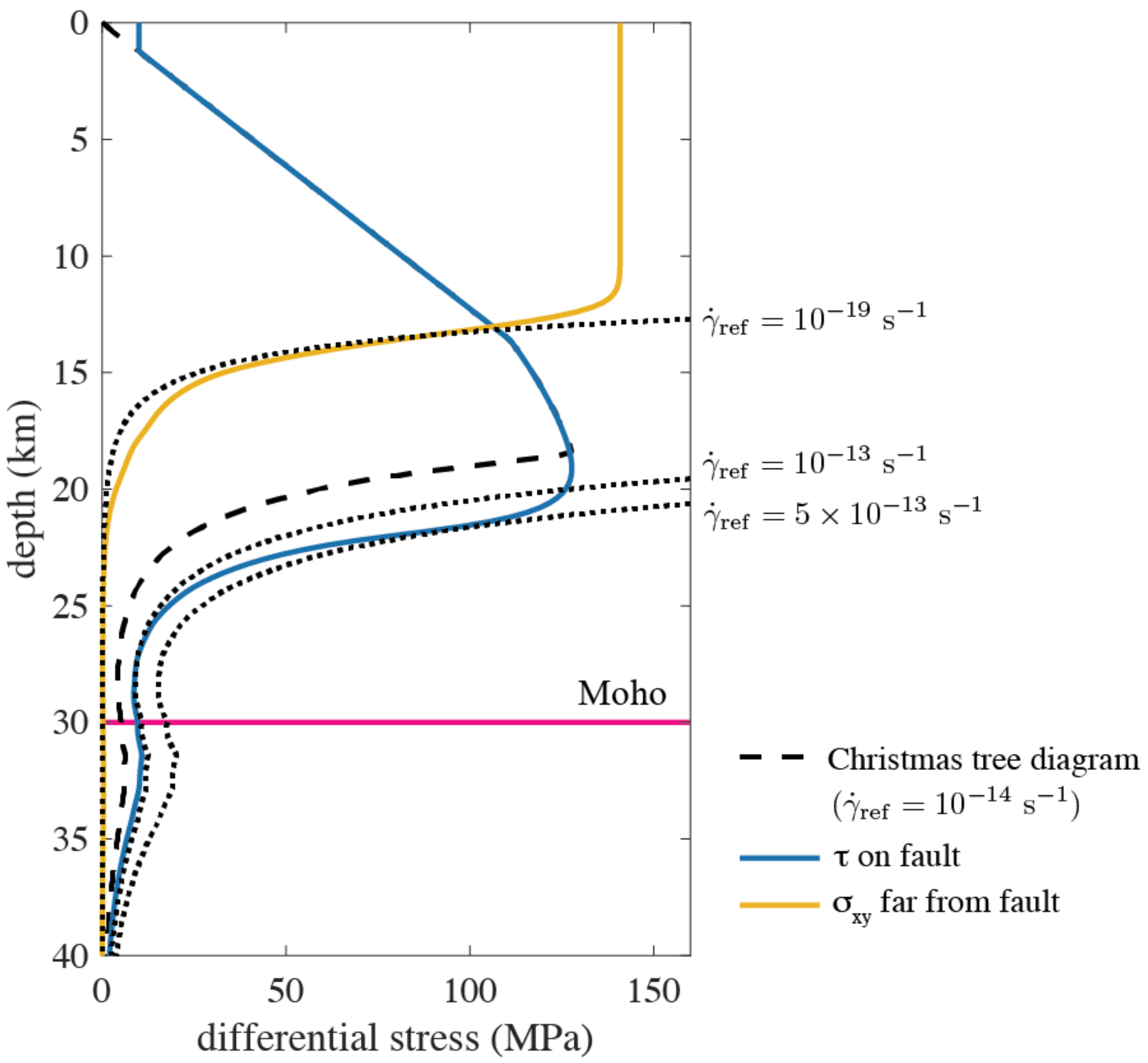
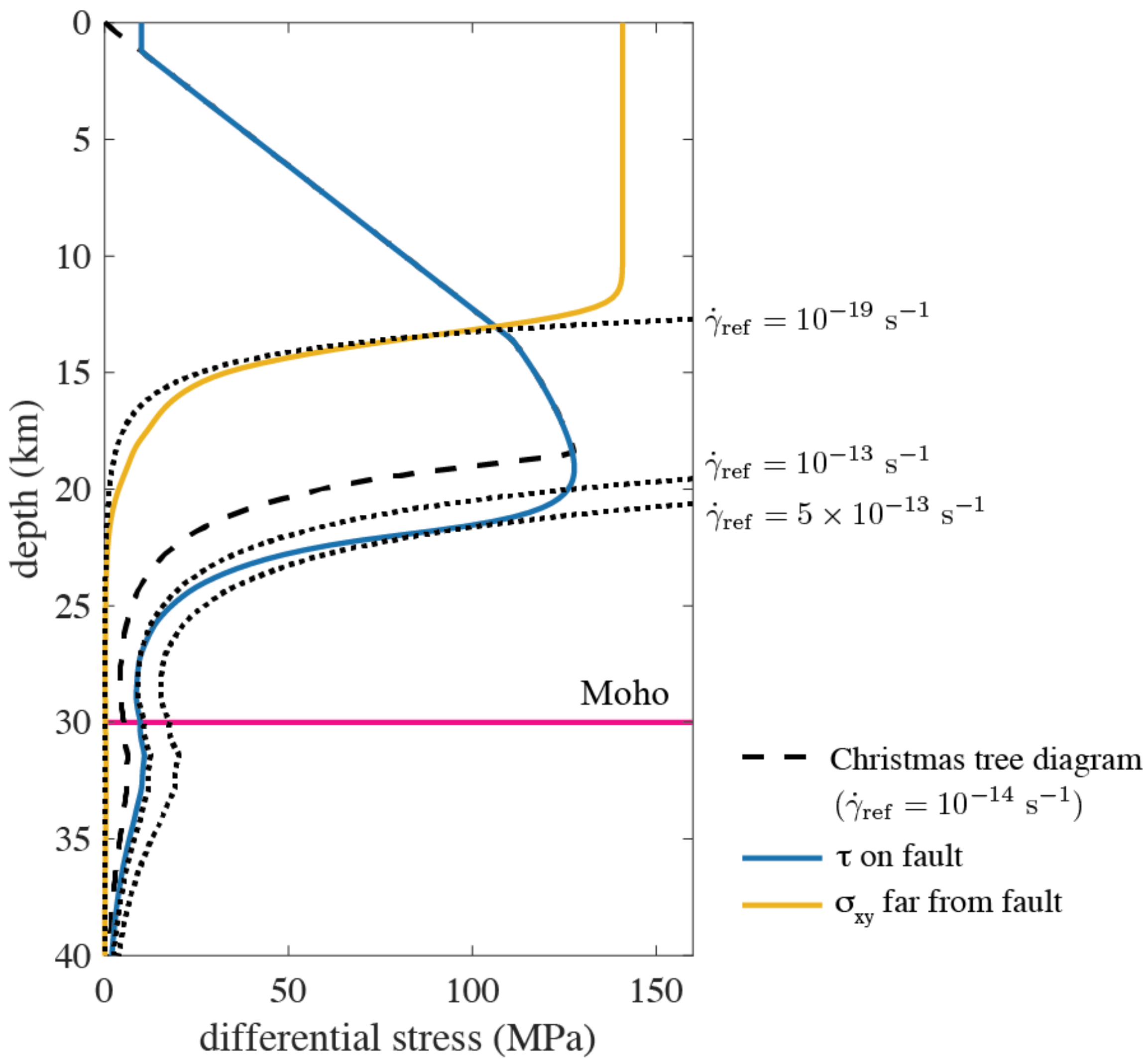


Far from the fault, the strain rate is much lower, and therefore the transition is much shallower.

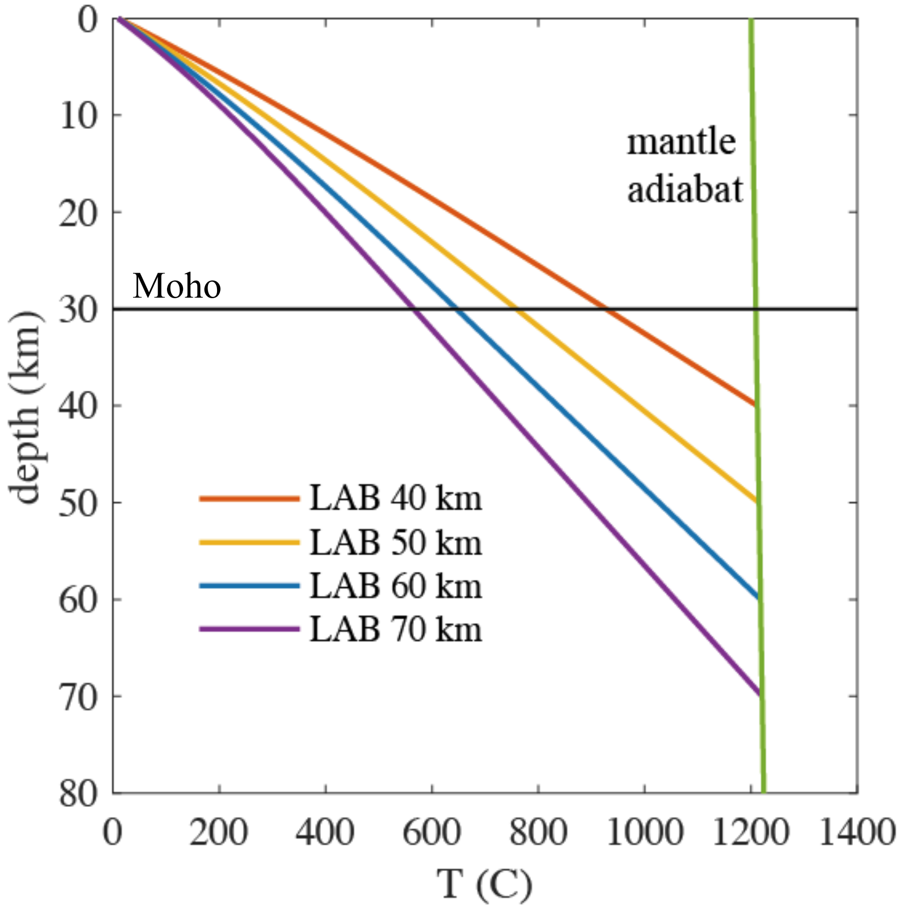


What could change these results?

- assumed composition, water content
- geotherm
- pore fluid pressure
- shear heating
- additional weakening mechanisms (e.g. foliation)



Background geotherm T_{amb}



LAB depth in southern CA

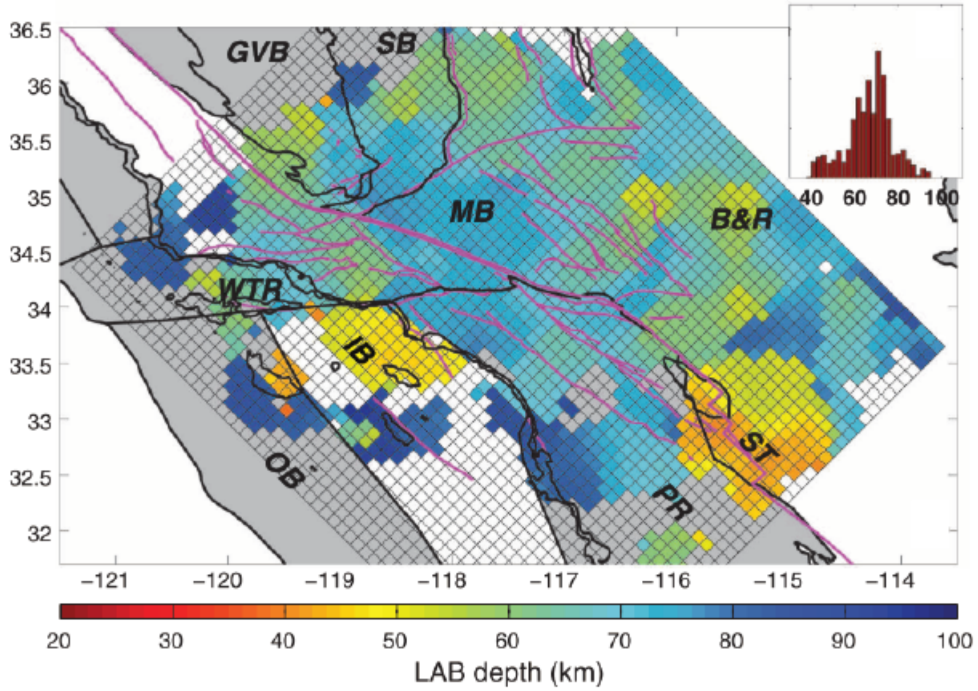
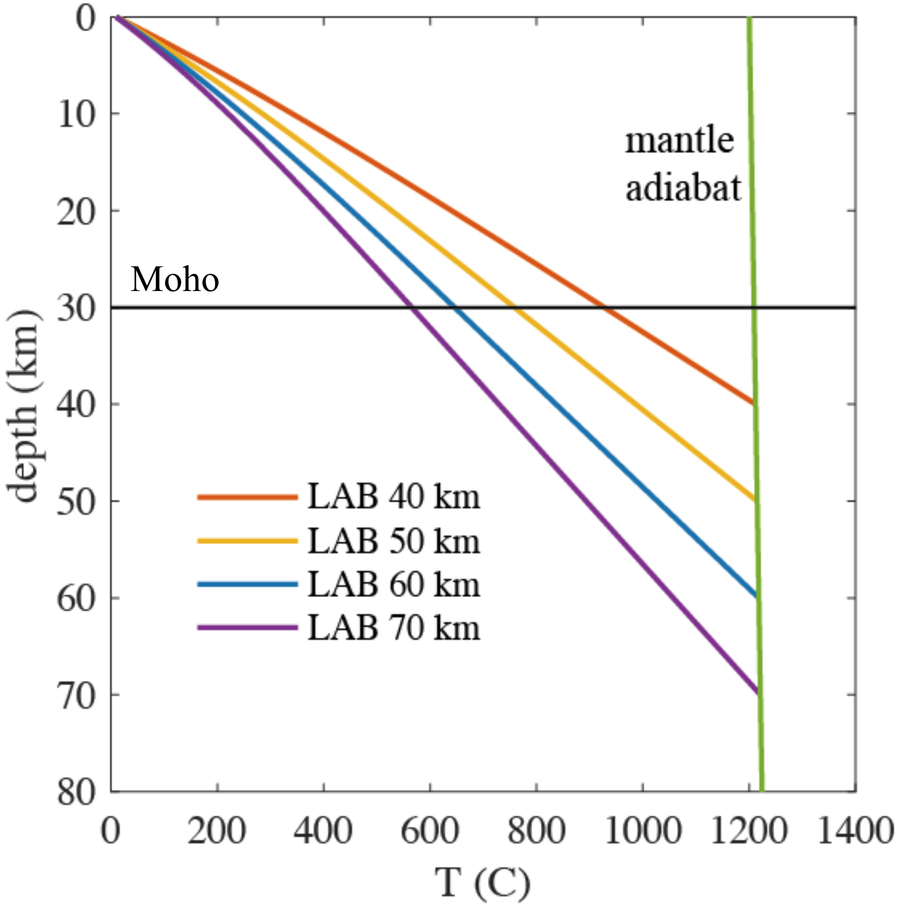
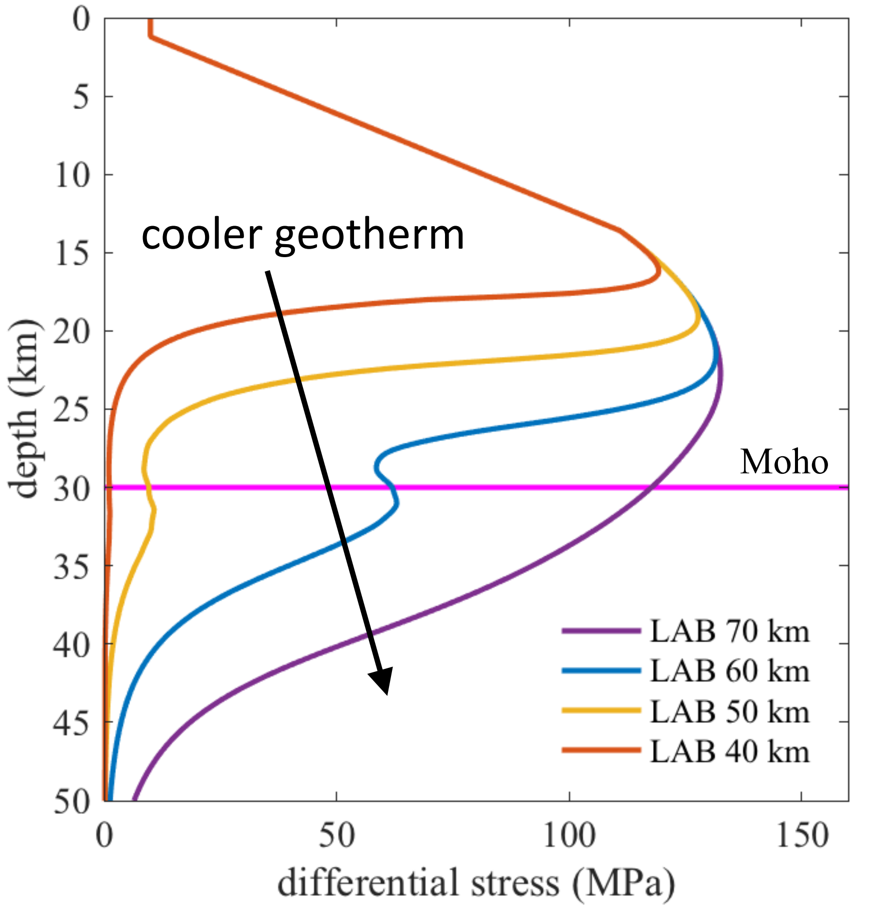


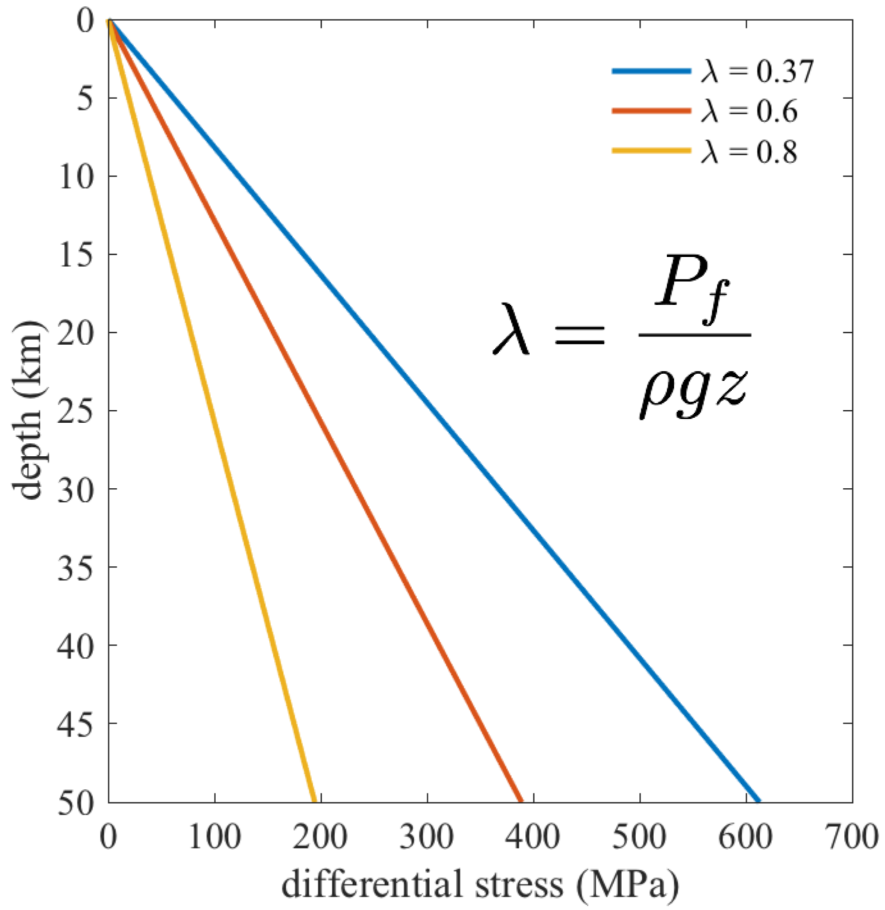
figure from Lekic (2011)

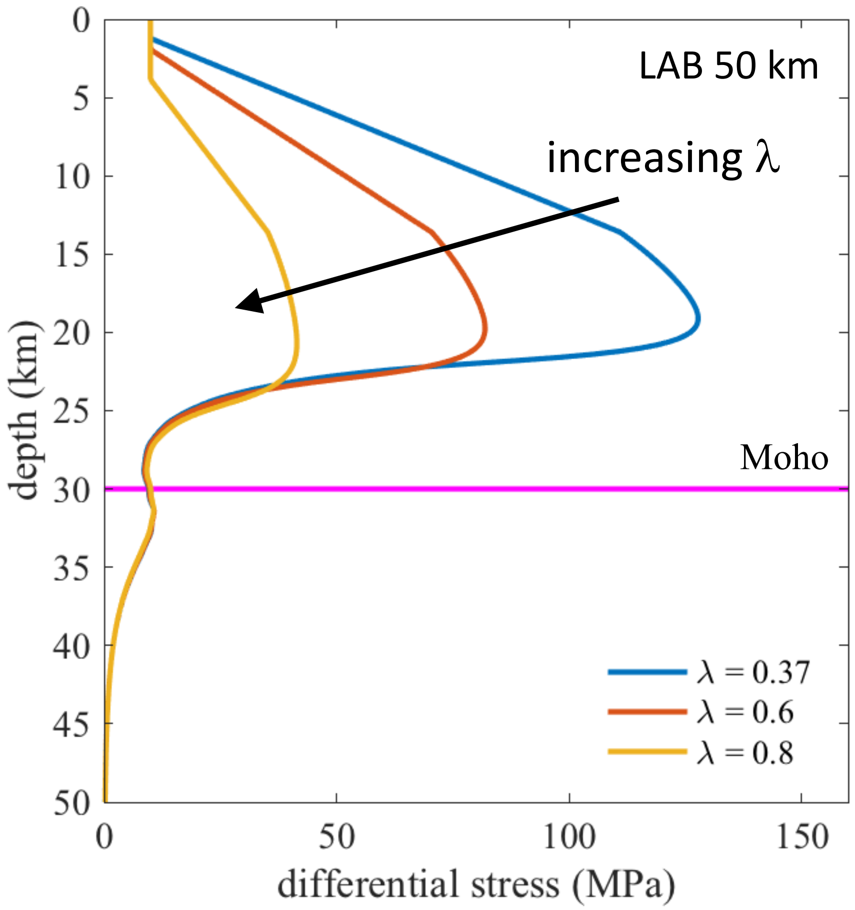
The warmer the geotherm, the shallower the BDT.





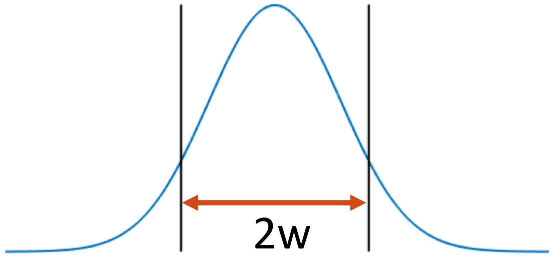
Decreasing pore pressure produces a lower effective normal stress, and therefore a lower shear stress.





Shear heating

frictional and viscous dissipation generate heat



w = 0.1 – 10 m
frictional shear zone width

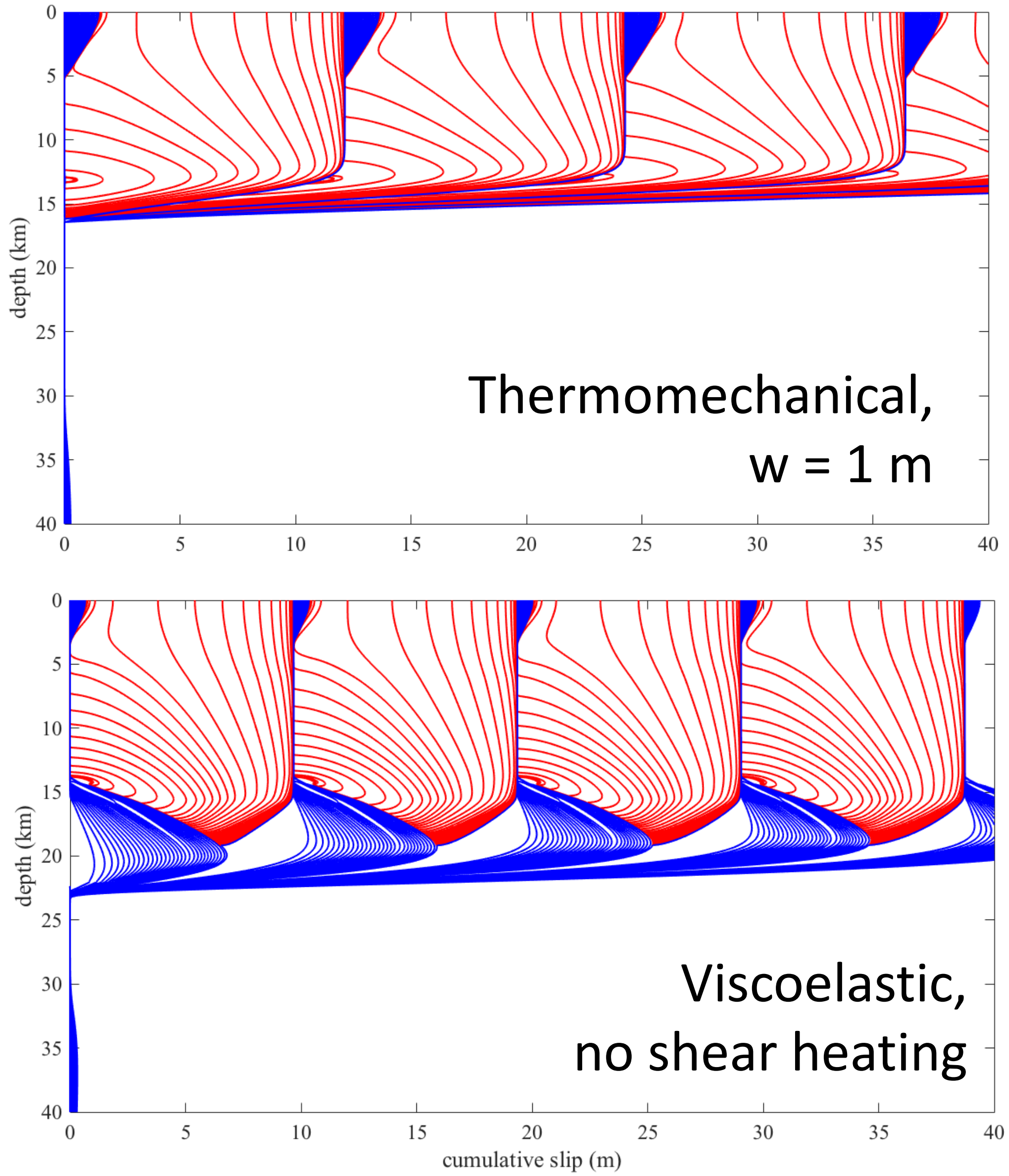
increasing temperature decreases the effective viscosity

$$\eta_{\mathrm{eff}} = e^{B/T} A^{-1}/(\bar{\tau}^{n-1})$$

viscous strain rates and stresses change

$$\frac{\partial \gamma_{ij}^{V}}{\partial t} = \eta_{\mathrm{eff}}^{-1} \sigma_{ij}$$

LAB 50 km, λ = 0.37

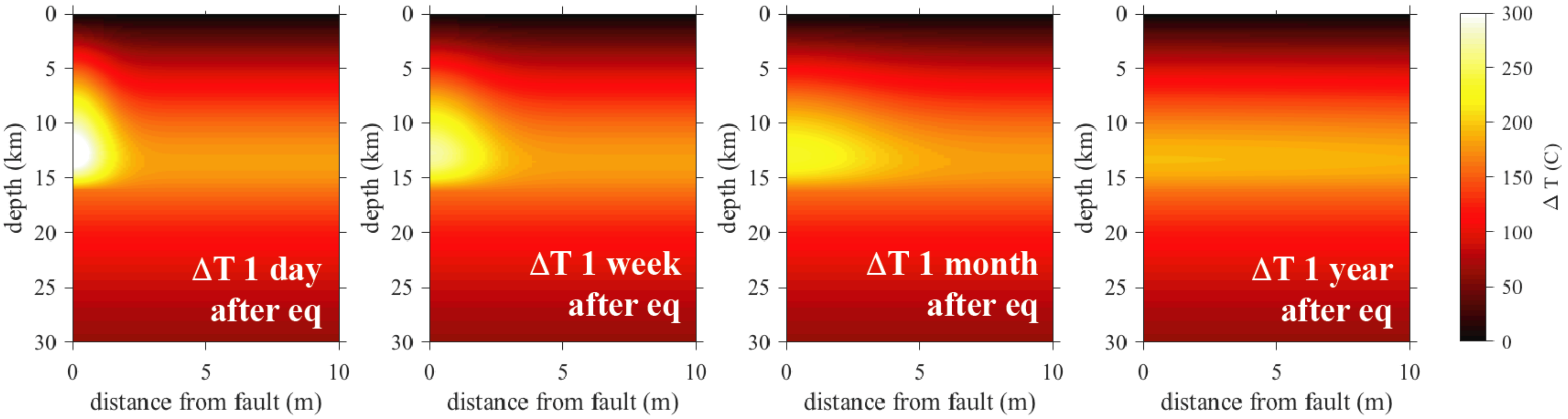


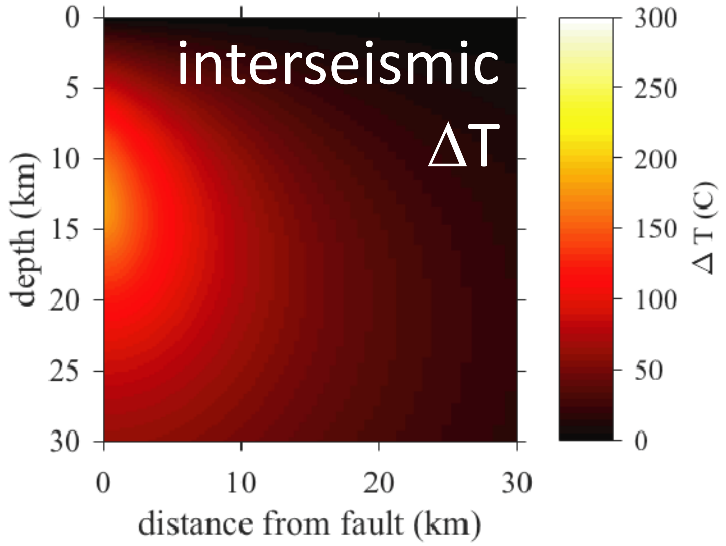
recurrence interval: 386.5 years
nucleation depth: 13.1 km
down-dip limit of eq. slip: 16.1 km

recurrence interval: 307 years
nucleation depth: 14 km
down-dip limit of eq. slip: 19.1 km

red: contoured every 1 s
blue: contoured every 10 years

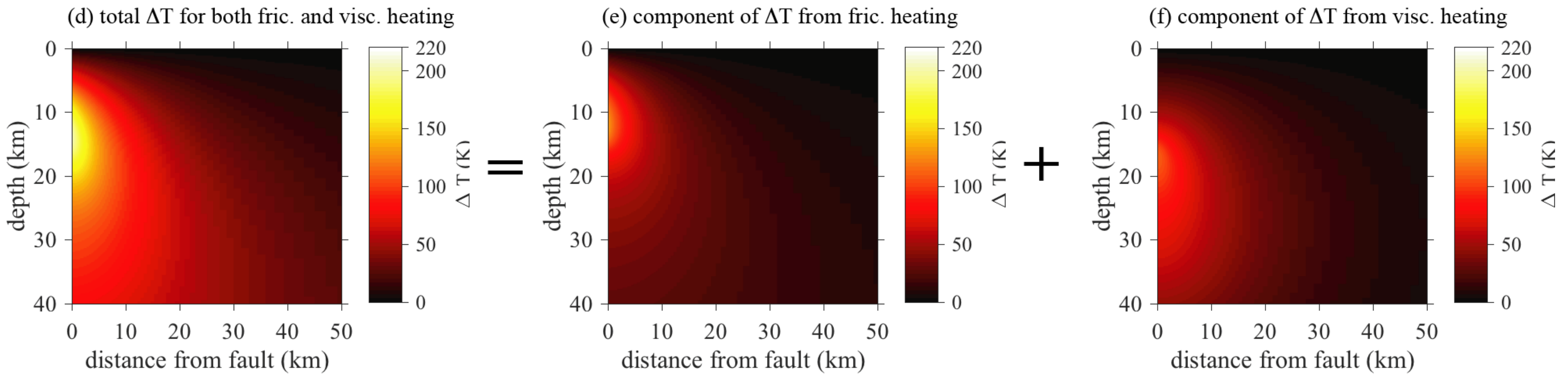
Transient temperature rise on top of ambient geotherm





LAB 50 km, λ = 0.37, w = 1 m

Relative importance of frictional and viscous shear heating



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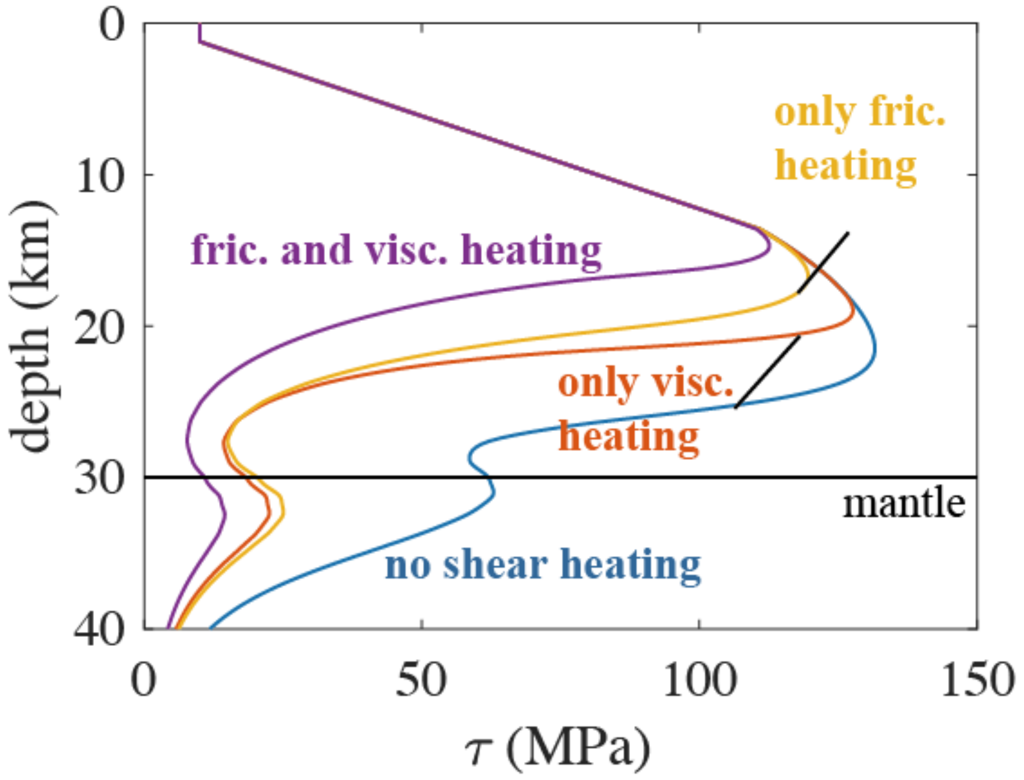
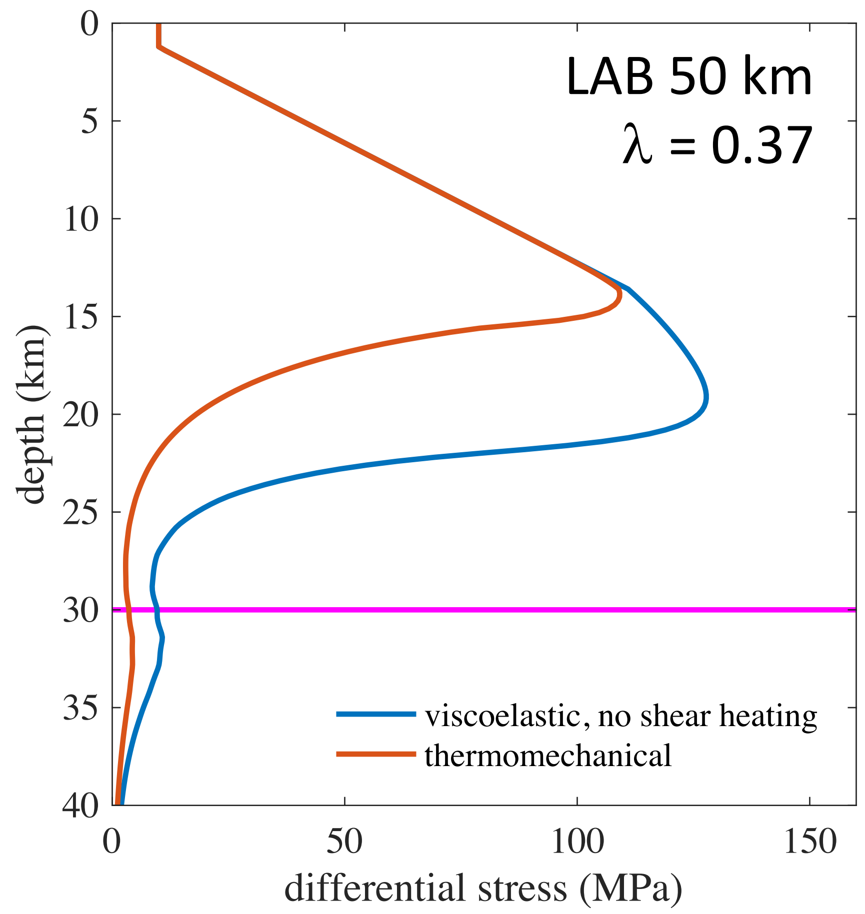
Relative importance of frictional and viscous shear heating



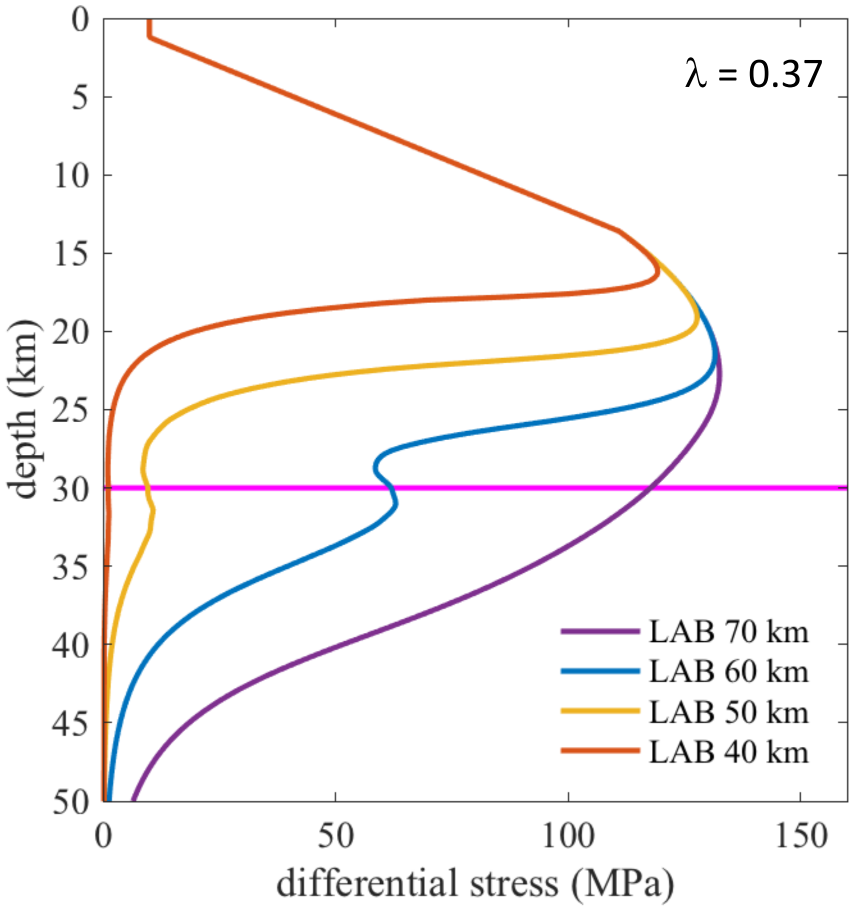
LAB 60 km, λ = 0.37, w = 1 m

Shear heating significantly weakens the root of the fault, shallowing the BDT.

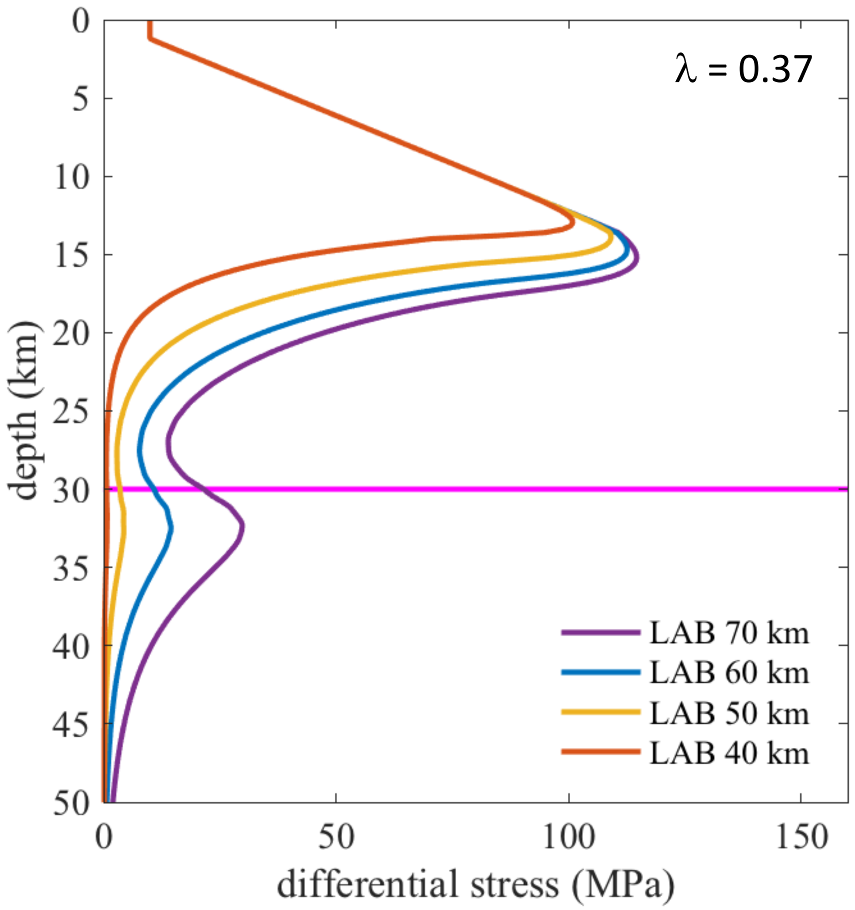


Effect of varying geotherm

viscoelastic, no shear heating

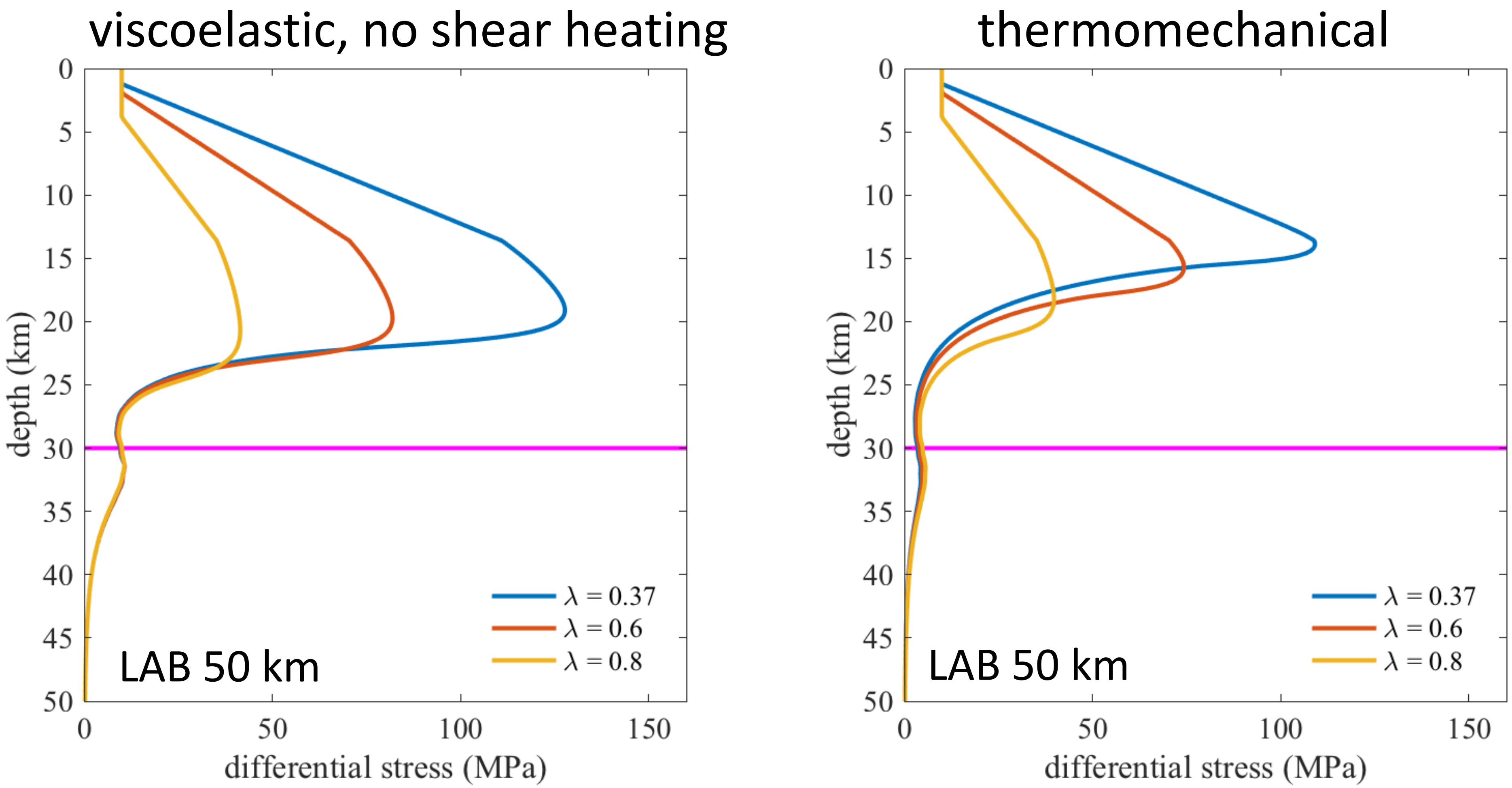


thermomechanical



Effect of varying pore pressure

$$\lambda = \frac{P_f}{\rho g z}$$



Conclusions

- Assuming steady-state flow and a constant reference strain rate does not capture the spatial pattern of stress on or off of the fault.
- However, a steady-state simulation in which the fault slips steadily without the transient effects of earthquakes, can be used to predict stress in the lithosphere as a function of rheology, friction, and plate rate information (with a significant reduction in computational cost).
- Modelling approaches like this could be used to evaluate the consistency of between the CRM and the CSM.