The effect of shear heating on the earthquake cycle

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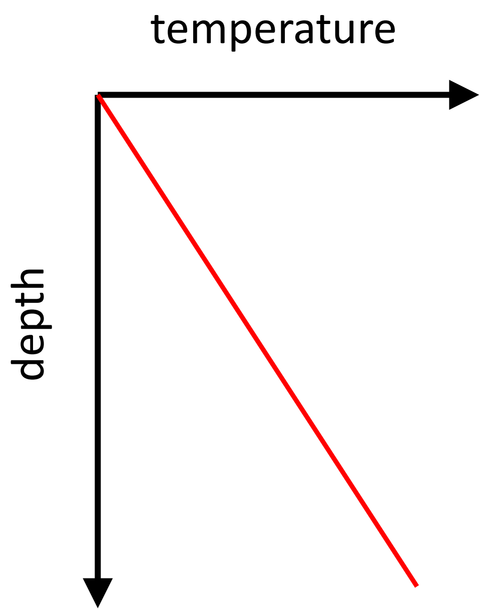
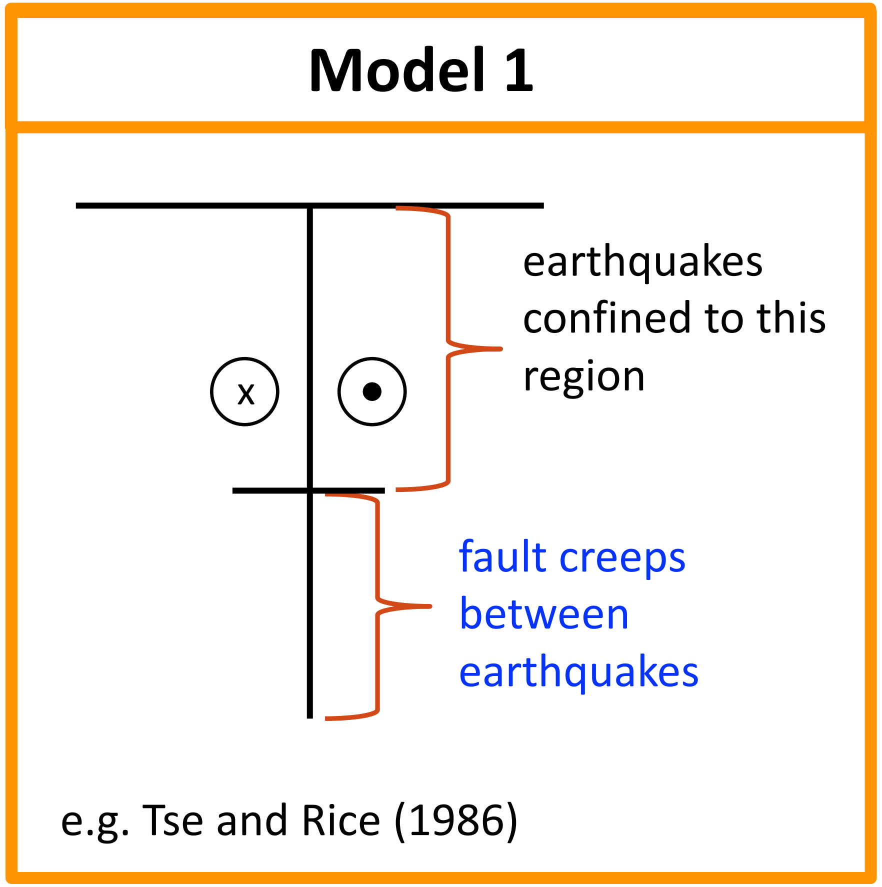
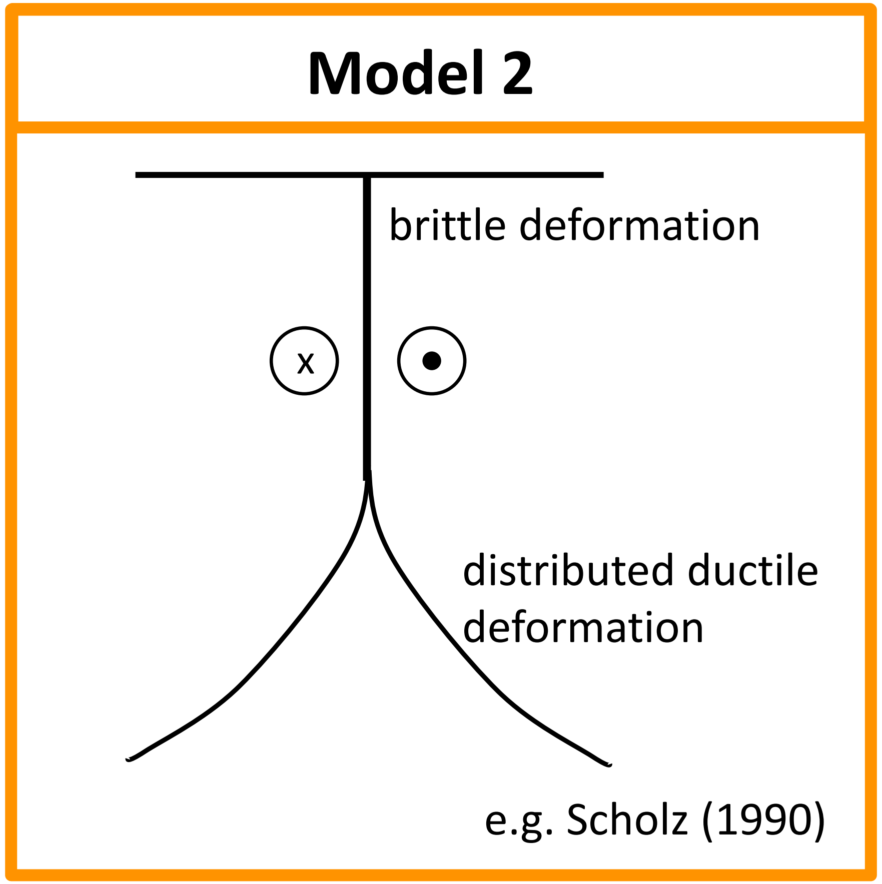
What does the deep root of a fault look like?

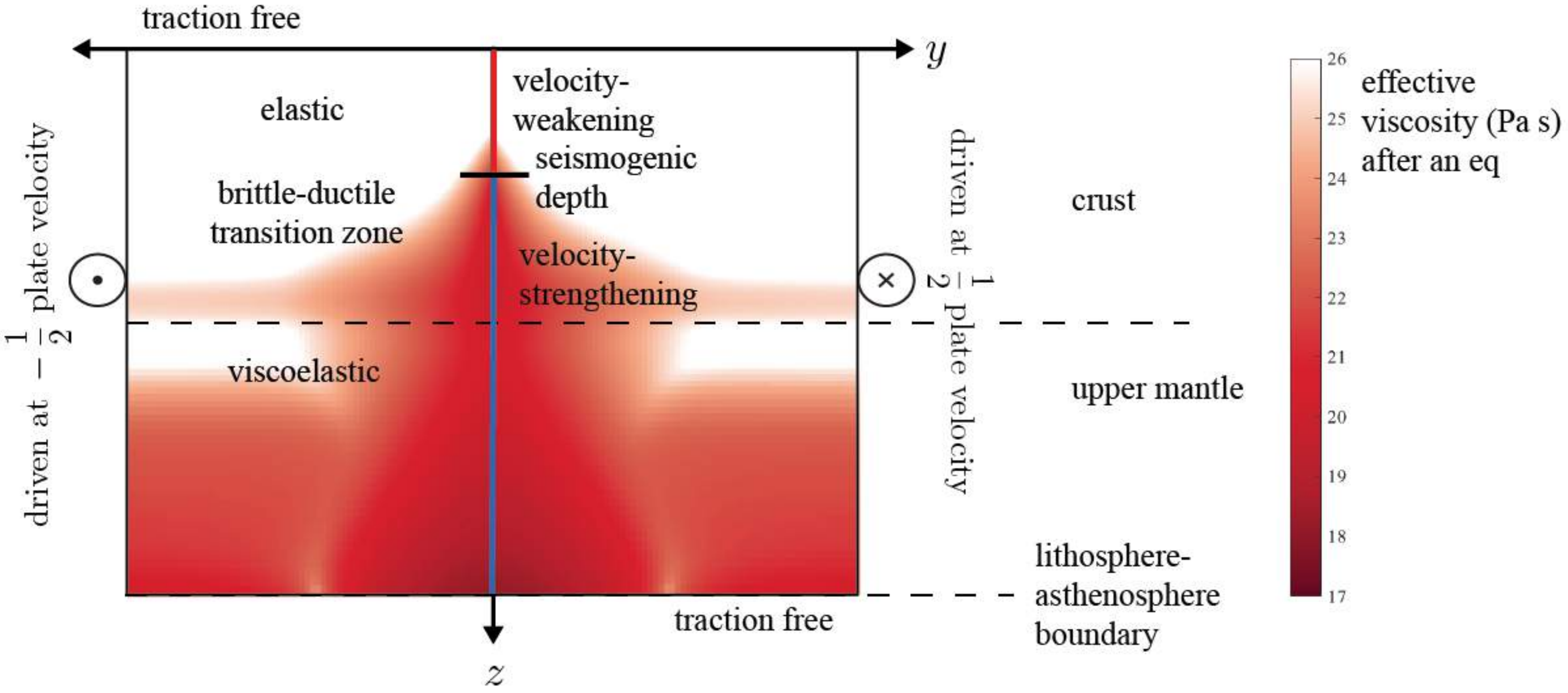




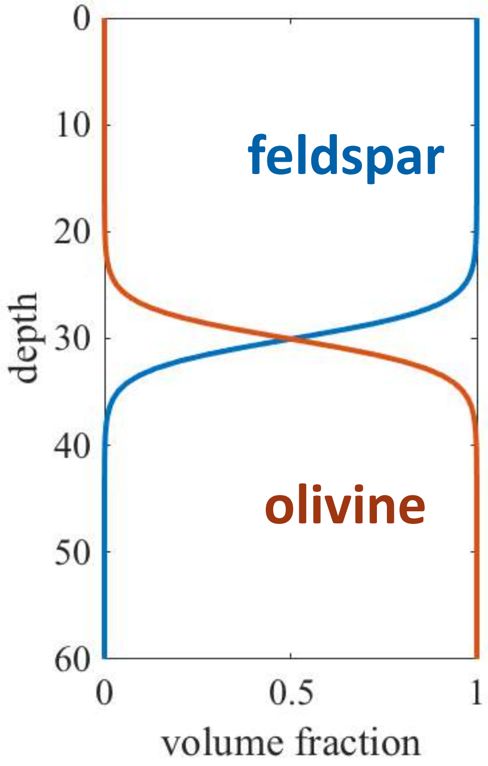


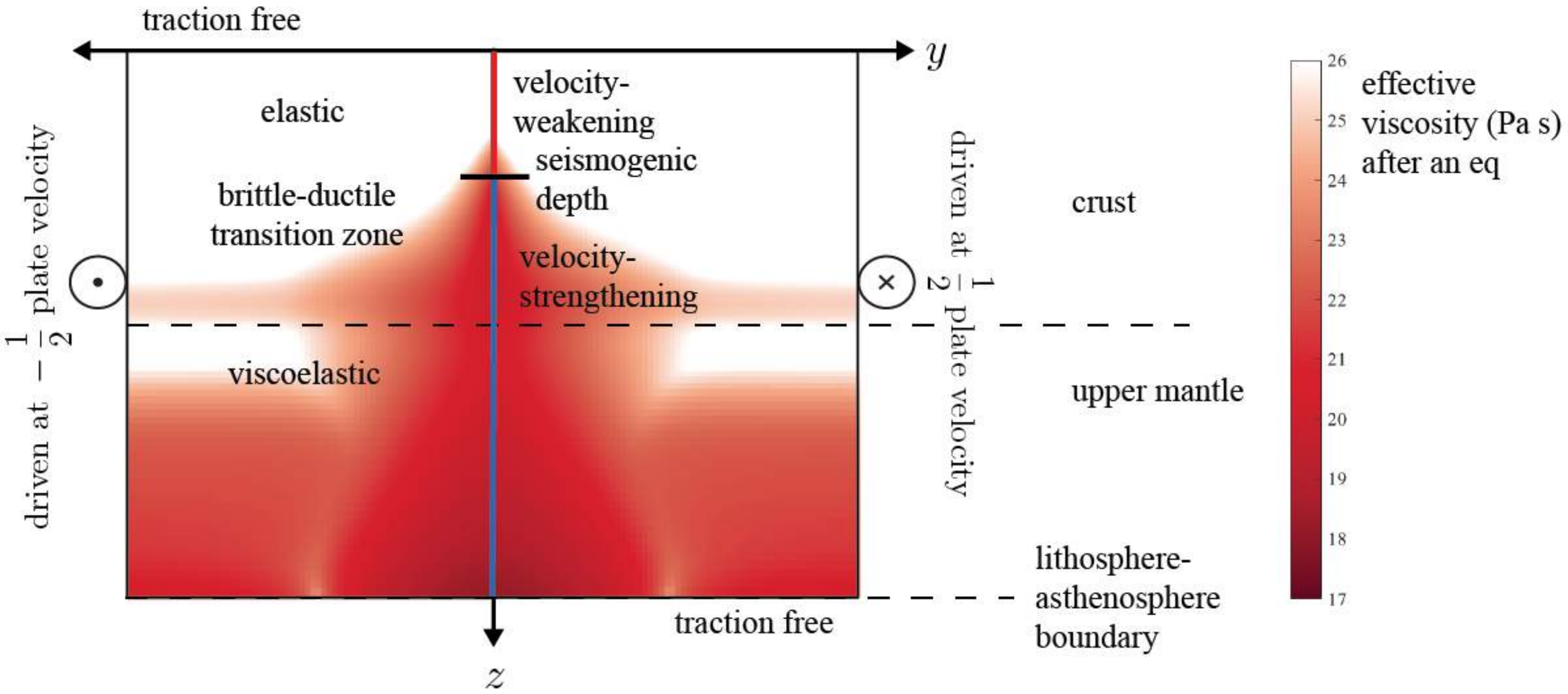
(diagrams show a vertical strike-slip fault for simplicity)

Model: 2D earthquake cycle simulation of a strike-slip fault



Model: 2D earthquake cycle simulation of a strike-slip fault





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

	A (MPa^{-n} s^{-1})	B (K)	n	source
feldspar	1.58 x 10^3	4.15 x 10^4	3	Rybacki et al. (2006)
olivine	3.6 x 10^3	5.77 x 10^4	3.5	Hirth and Kohlstedt (2003)

Governing equations

quasi-dynamic momentum balance

$$\frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} = 0$$

Hooke's law

$$\sigma_{ij} = \mu \left(\frac{\partial u}{\partial x_i} - \gamma_{ij}^V \right)$$

Power-law for dislocation creep

$$\dot{\gamma}_{ij}^V = \eta_{\text{eff}}^{-1} \sigma_{ij}$$

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

Fault boundary conditions

$$\tau = \sigma_{xy}(0, z) - \eta_{\text{rad}} V/2 = f(\psi, V) \sigma_N$$

force balance (with radiation damping)

$$\dot{\psi} = G(\psi, V)$$

aging law

$$\delta = 2u(0, z)$$

The energy equation

$$\frac{\partial T}{\partial t} = \alpha_{th} \nabla^2 T + \frac{1}{\rho c}(Q_{rad} + Q_{fric} + Q_{visc})$$

$\alpha_{th} = 1 \text{ mm}^2/\text{s}$ thermal diffusivity

Q_{rad} radioactive heat generation

$Q_{fric} = \tau V \left(\frac{1}{\sqrt{2\pi} w} e^{-y^2/2w^2} \right)$ frictional shear heating

$Q_{visc} = \bar{\tau} \dot{\bar{\gamma}}^V$ viscous shear heating

Shear heating

frictional and viscous dissipation generate heat

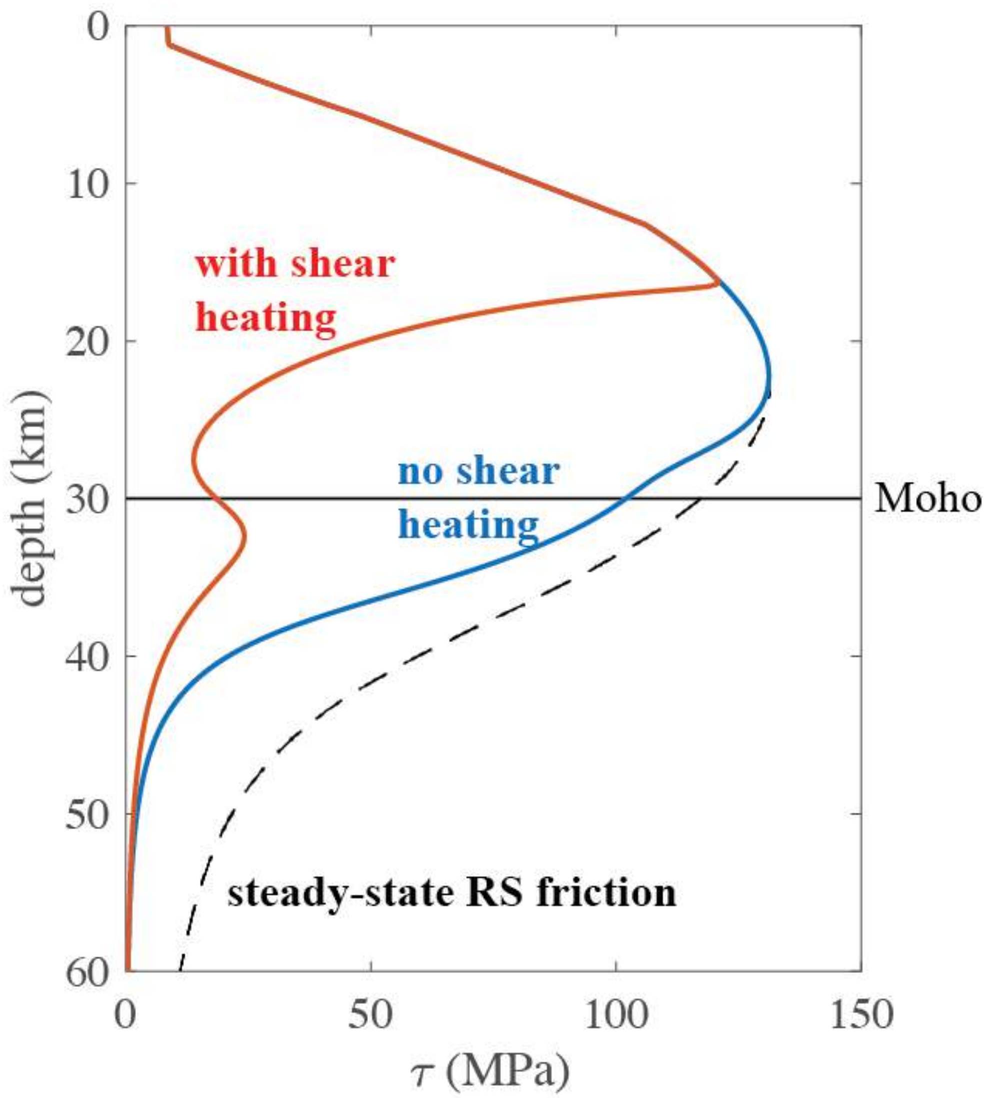
increasing temperature decreases the effective viscosity

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

viscous strain rates and stresses change

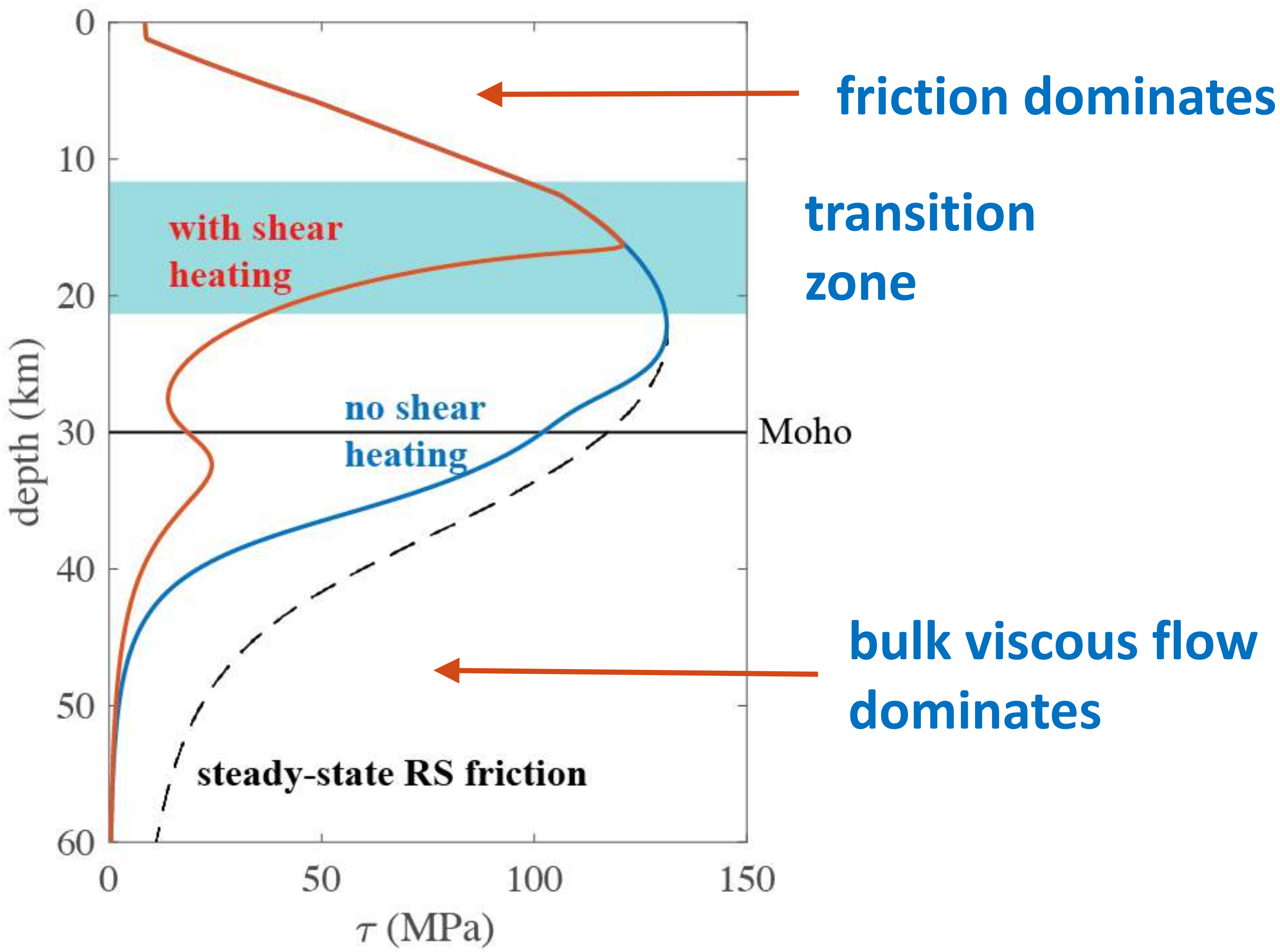
$$\frac{\partial \gamma_{ij}^{V}}{\partial t} = \eta_{\text{eff}}^{-1} \sigma_{ij}$$

How does shear heating impact shear stress?



assuming hydrostatic pore pressure

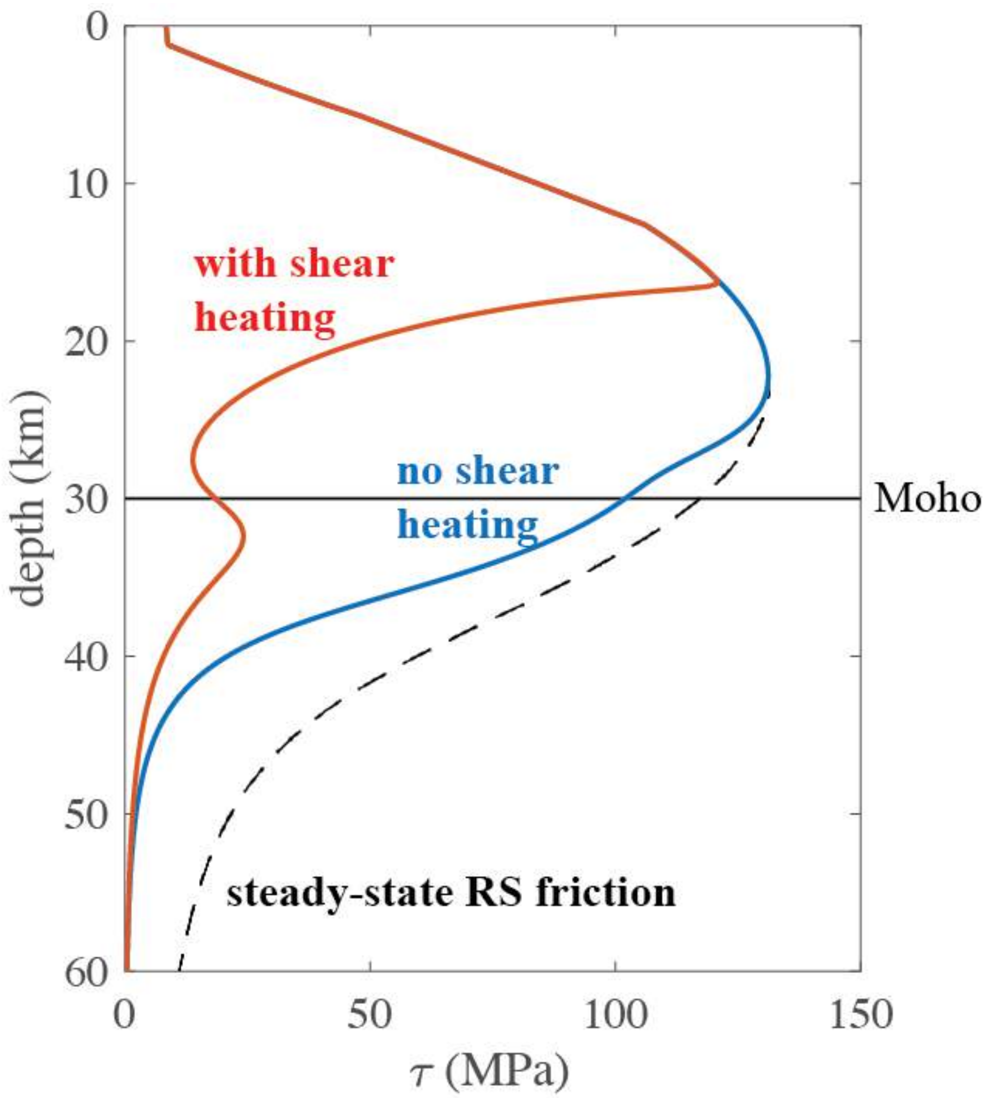
How does shear heating impact shear stress?

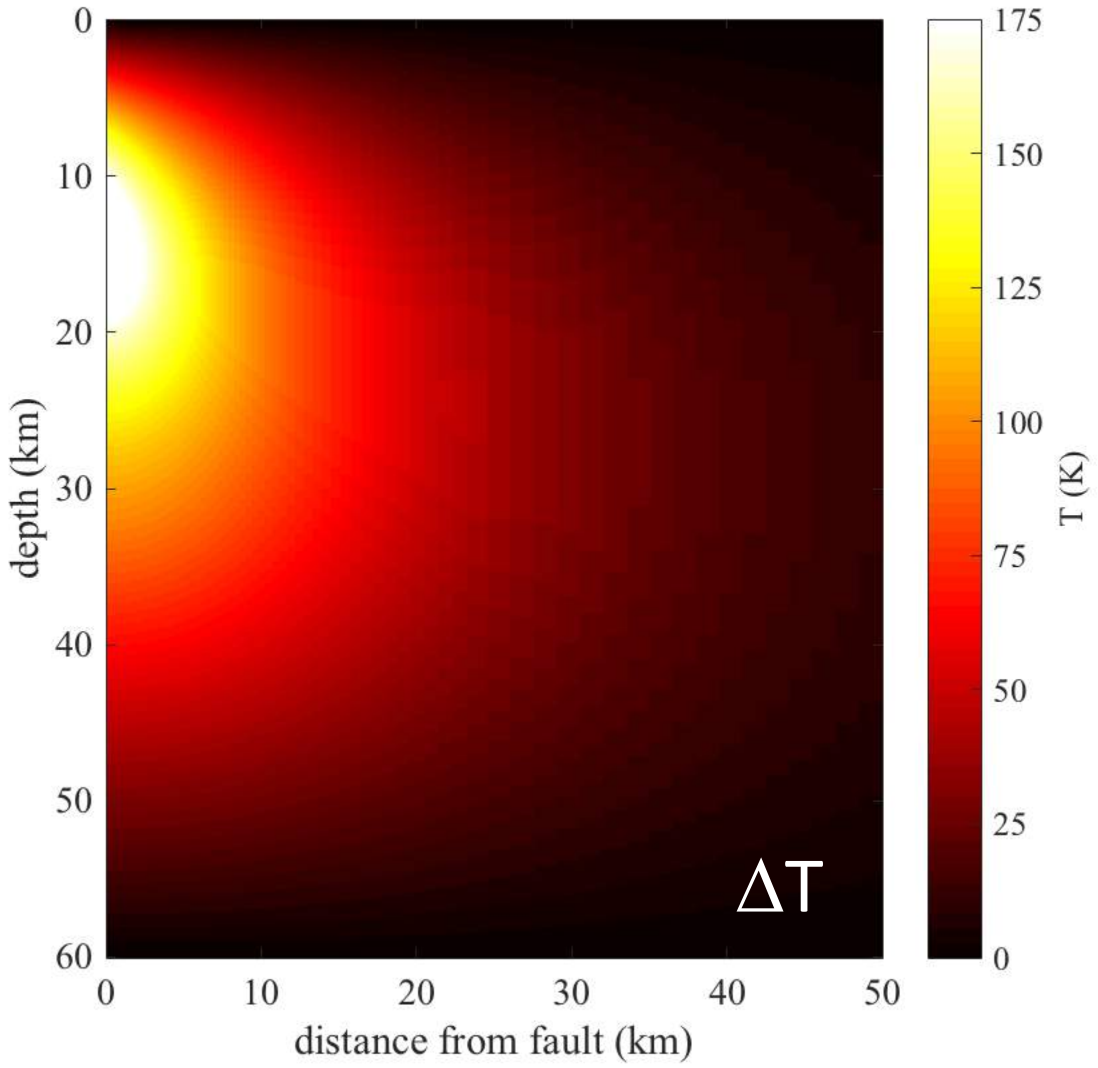


assuming hydrostatic pore pressure

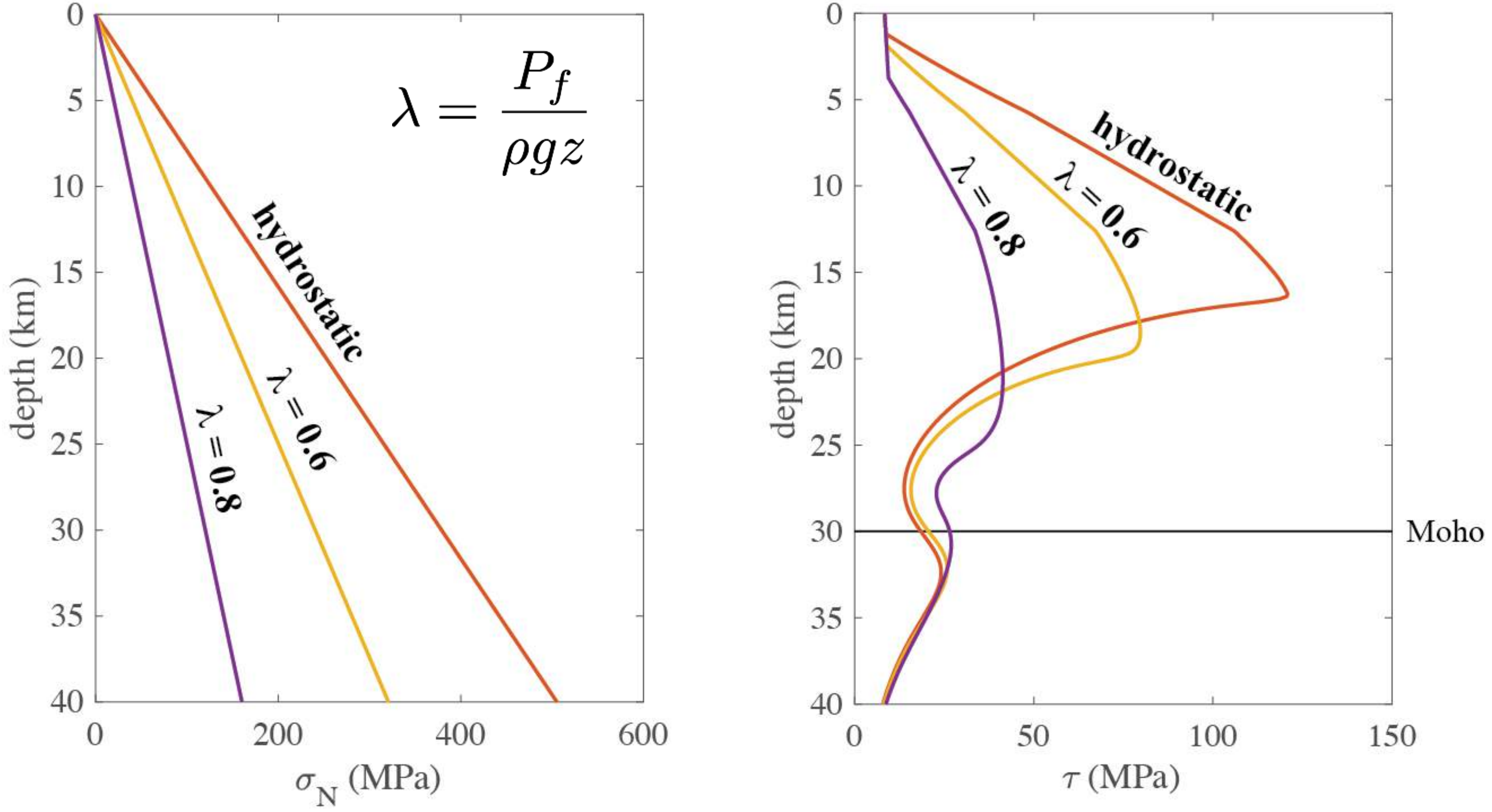
Resulting thermal anomaly

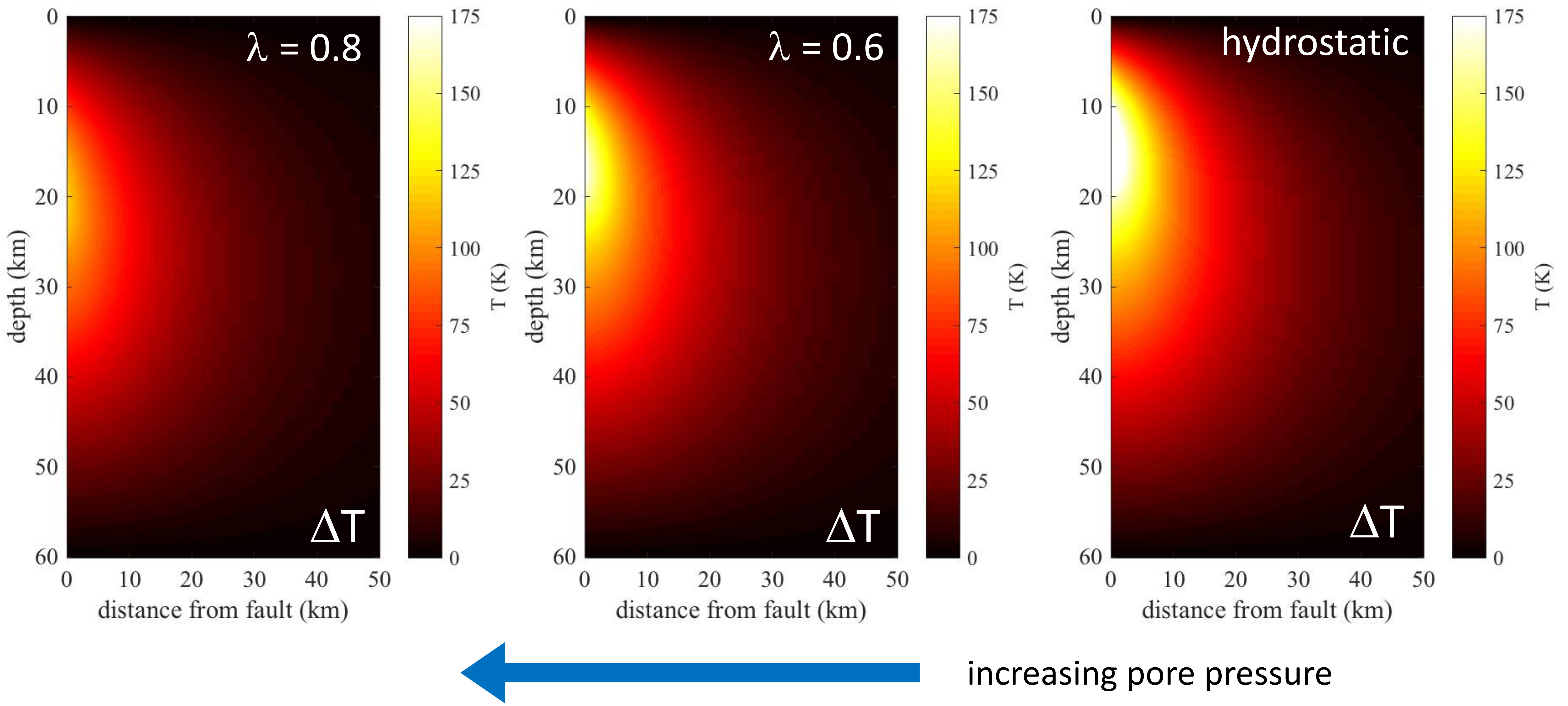
assuming hydrostatic pore pressure



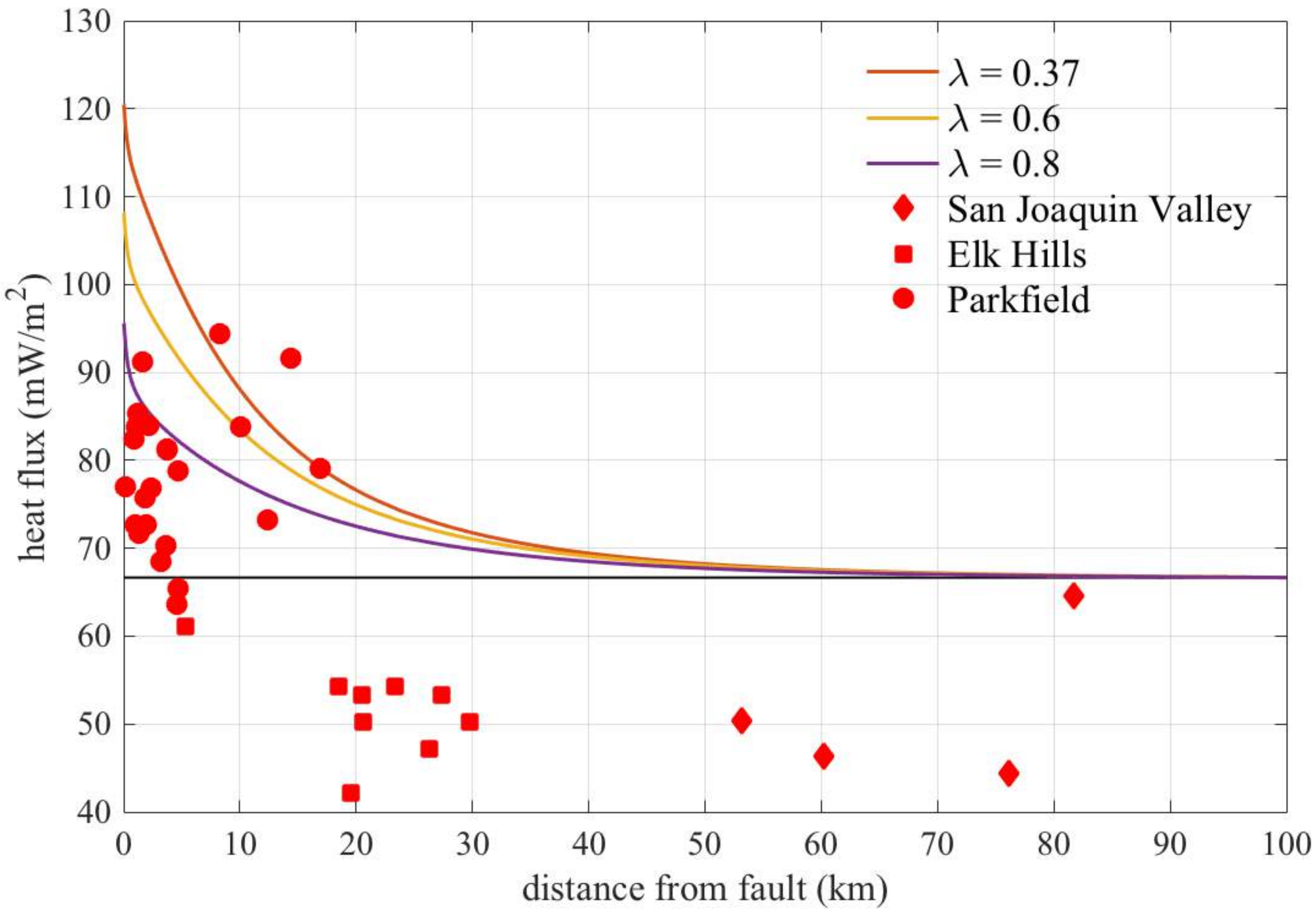


Increasing pore pressure moves the brittle-ductile transition deeper.



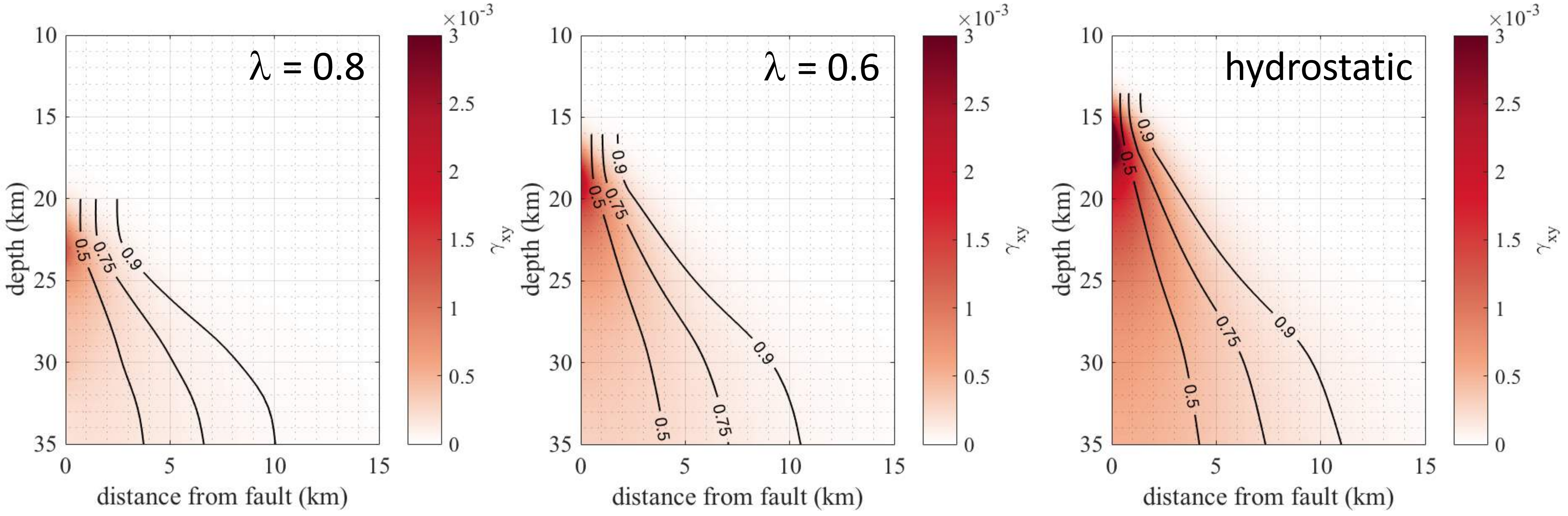

λ = 0.8
λ = 0.6
hydrostatic
ΔT
ΔT
ΔT
depth (km)
distance from fault (km)
T (K)
0 10 20 30 40 50 60
0 10 20 30 40 50
0 25 50 75 100 125 150 175
increasing pore pressure

Surface heat flux



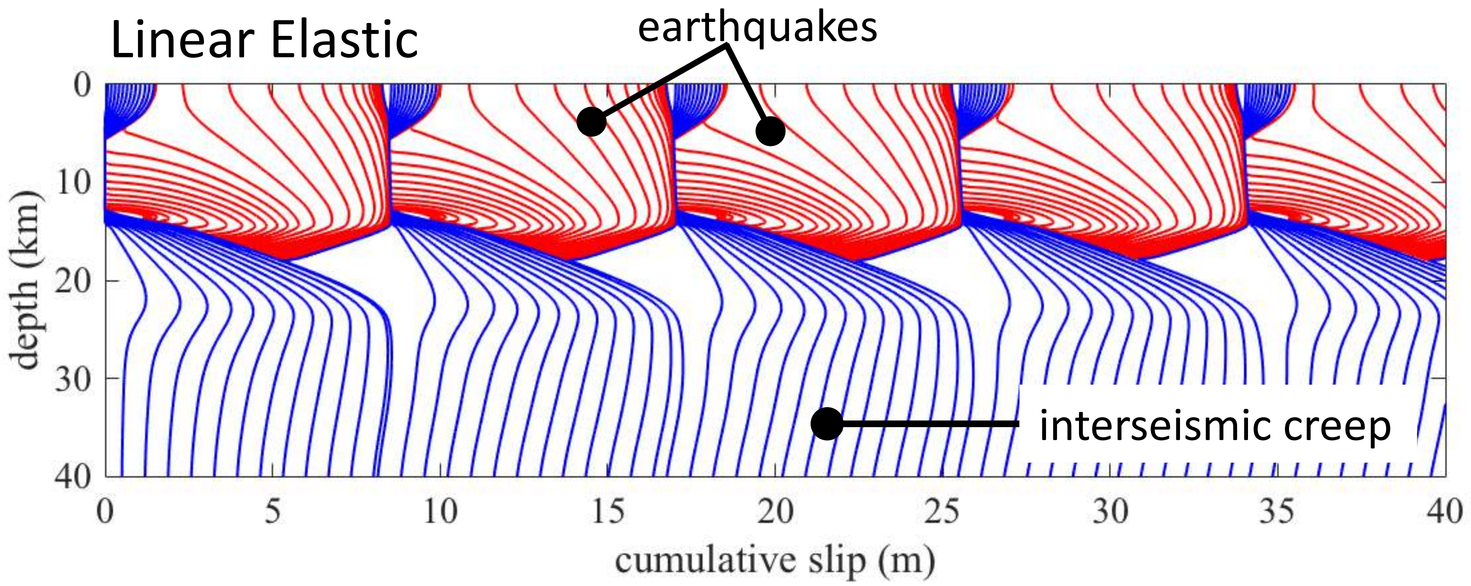
Data (red dots) from Takeuchi and Fialko (2012)

Higher pore pressure leads to a narrower shear zone beneath the fault.



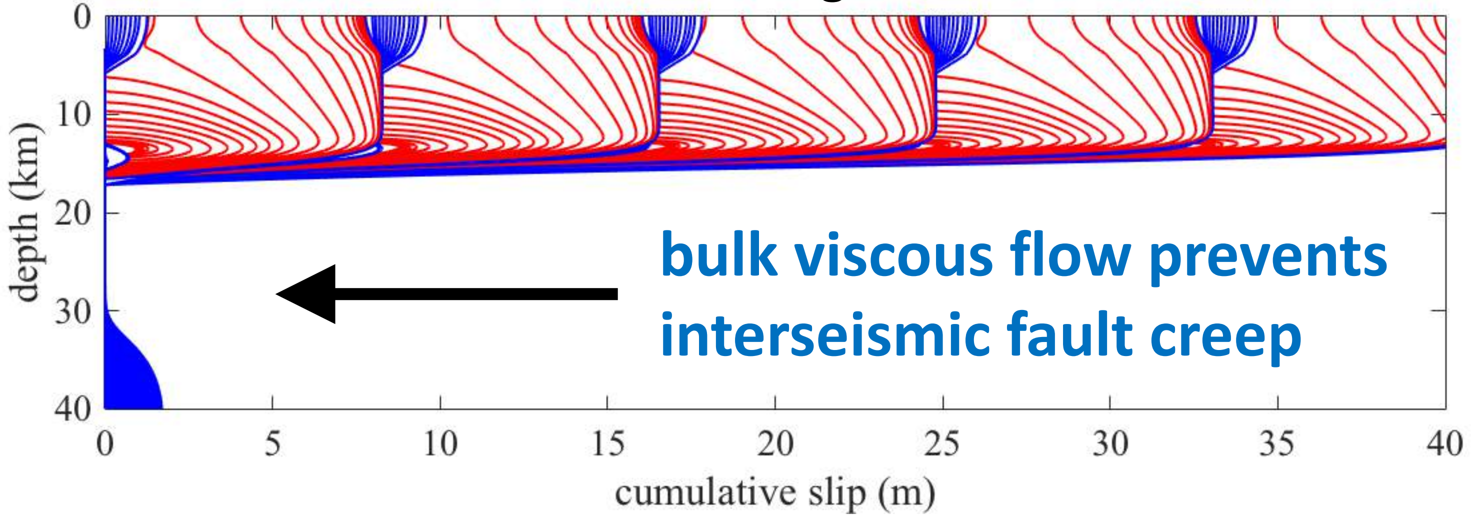
increasing pore pressure

Linear Elastic



recurrence interval: 263 years
nucleation depth: 13.5 km
down-dip limit of eq. slip: 17.8 km

Viscoelastic with shear heating

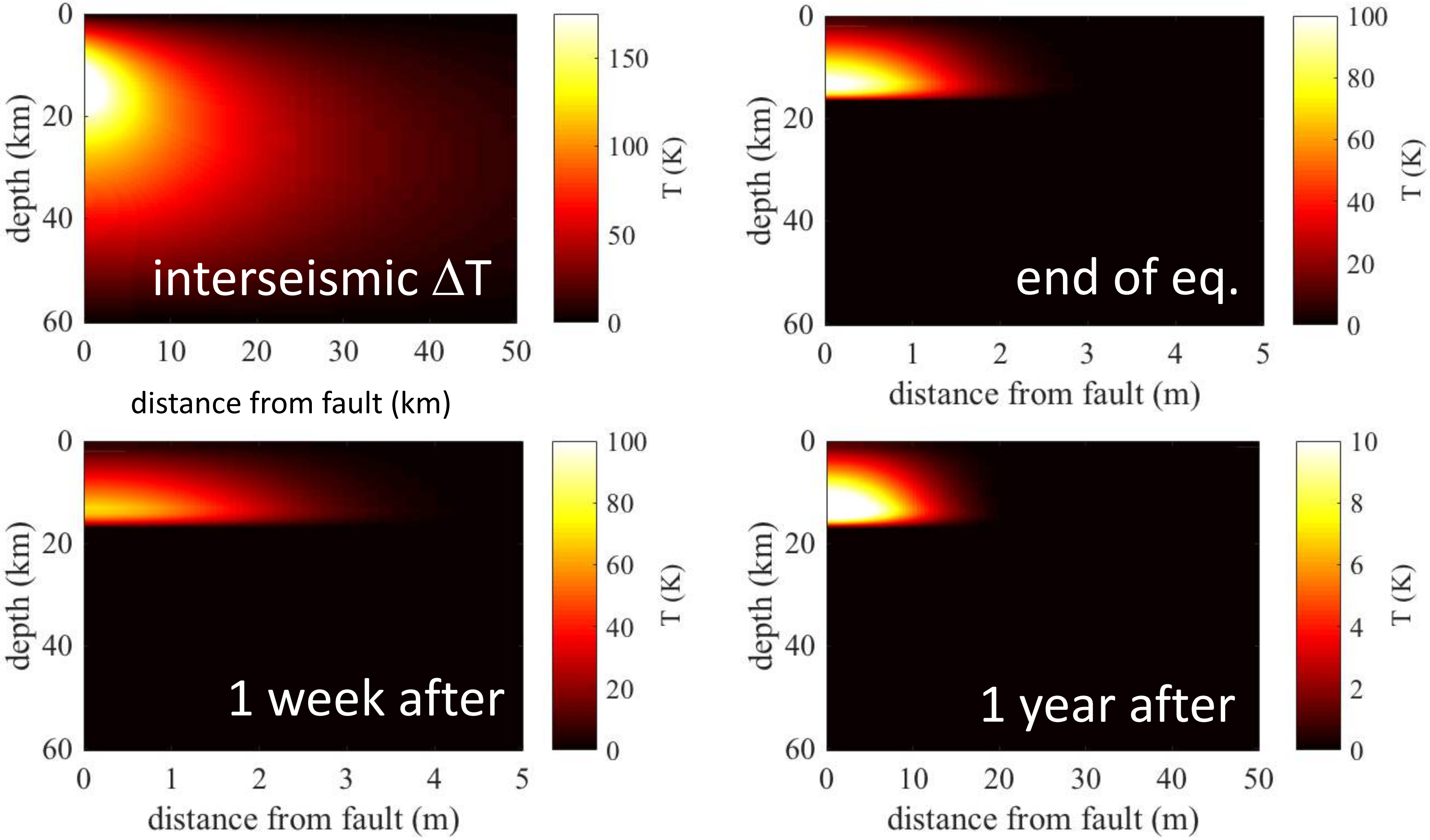


recurrence interval: 260 years
nucleation depth: 13.5 km
down-dip limit of eq. slip: 16.4 km

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

Temperature change resulting from heat generated during coseismic slip.

w = 1 m



Decreasing frictional shear zone size increases the maximum temperature change