Going from stable creep to aseismic slow slip events in the ductile realm

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Slip spectrum
From aseismic to seismic

- **Aseismic events**
  - Long-term SSE (~0.5-5 years)
  - Short-term SSE (~2-6 days)

- **Seismic events**
  - VLF earthquakes (~10-100 s)
  - Low frequency tremor, ETS (2 to 8 Hz)
Stable sliding at depth?

Slip acceleration between 80 and 30 km depth before Tohoku-oki EQ

episodic/stable creep aseismic creep migration

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Mavrommatis et al. (2014)

https://sites.google.com/site/amavrommatis/research
Why?

- High pressure & temperature ➡ most likely ductile
- What are the mechanisms?
Why?

- High pressure & temperature ➡ most likely ductile
- What are the mechanisms?
Grain size - shear heating feedback

\[ \Phi = \tau : \dot{\varepsilon}_i (\tau, R, T) \]

\[ \frac{dR}{dt} = \frac{G(T)}{\rho R^{p-1}} - \frac{\lambda F_R}{\gamma} R^2 \tau : \dot{\varepsilon}_{dis} \]

Rozel et al. (2011)

Very nonlinear!

\[ \frac{\partial T}{\partial t} = \nabla (\kappa \nabla T) + \frac{1 - \lambda}{\rho C} [\tau : \dot{\varepsilon}_{dis}(\tau, T') + \tau : \dot{\varepsilon}_{diff}(\tau, R, T')] \]

\[ + \frac{\gamma G(T)}{\rho C p F_R R^{p+1}} \]

Thielmann et al. (2015)
Works in 1D
For a slab in simple shear

Figure 1: Model setup. A perturbed zone with width $h$ is embedded in an otherwise homogeneous matrix with initial grain size $R_0$ and temperature $T_0$ of width $L$. The whole slab is deformed under simple shear with a given velocity $v_0$. The red and blue line are schematic profiles of creep law prefactors ($A_{\text{mat}}, A_{\text{pert}}$) and velocity and show their variation in the $x$-direction.

Seismic time scale!
But in 2D?

M2Di: Concise and efficient MATLAB 2-D Stokes solvers using the Finite Difference Method

Ludovic Räss, Thibault Duretz, Yury Y. Podladchikov, and Stefan M. Schmalholz

**TM²2Di**
- multiphysics coupling:
  - deformation
  - temperature
  - microstructure
  - viscoelastic
  - composite rheologies
  - grain size evolution
  - fully energy conservative

[Diagram of finite differences staggered grid]

Finite Differences staggered grid

Energy conservative fully benchmarked

\[ \dot{\varepsilon}_{BG} = 10^{-14} \ 1/s \]
\[ T_{BG} = 900 \ K \]
Simple shear setup

- rheology: viscoelastic
  - dislocation creep, diffusion creep, low temperature plasticity
- olivine creep parameters

$\log_{10} R [m]$
Simple shear setup

- background temperature \( T_{BG} = 900 \text{ K} \)
- background strain rate \( \dot{\varepsilon}_{BG} = 2.5 \cdot 10^{-13} \text{ 1/s} \)
Shear zone initiation...
... propagation ...

- $\log_{10} \dot{\xi}_{II}$
- $\log_{10} \mathcal{R}$
- $\Delta T \ [K]$
... merging
Same, but different variables

Stress focusing causes ductile rupture
Continued propagation

$\tau_{II} \cdot 100$ [MPa]

$v_x$ [mm/yr]
Largest velocities at merging

$\tau_{II} \cdot 100$ [MPa]

$\nu_x$ [mm/yr]
Conclusions

- the combination of shear heating and grain size reduction is capable of
  ➡ creating a localised shear zone
  ➡ result in significantly elevated velocities
  ➡ causing a transition from steady creep to aseismic slow slip