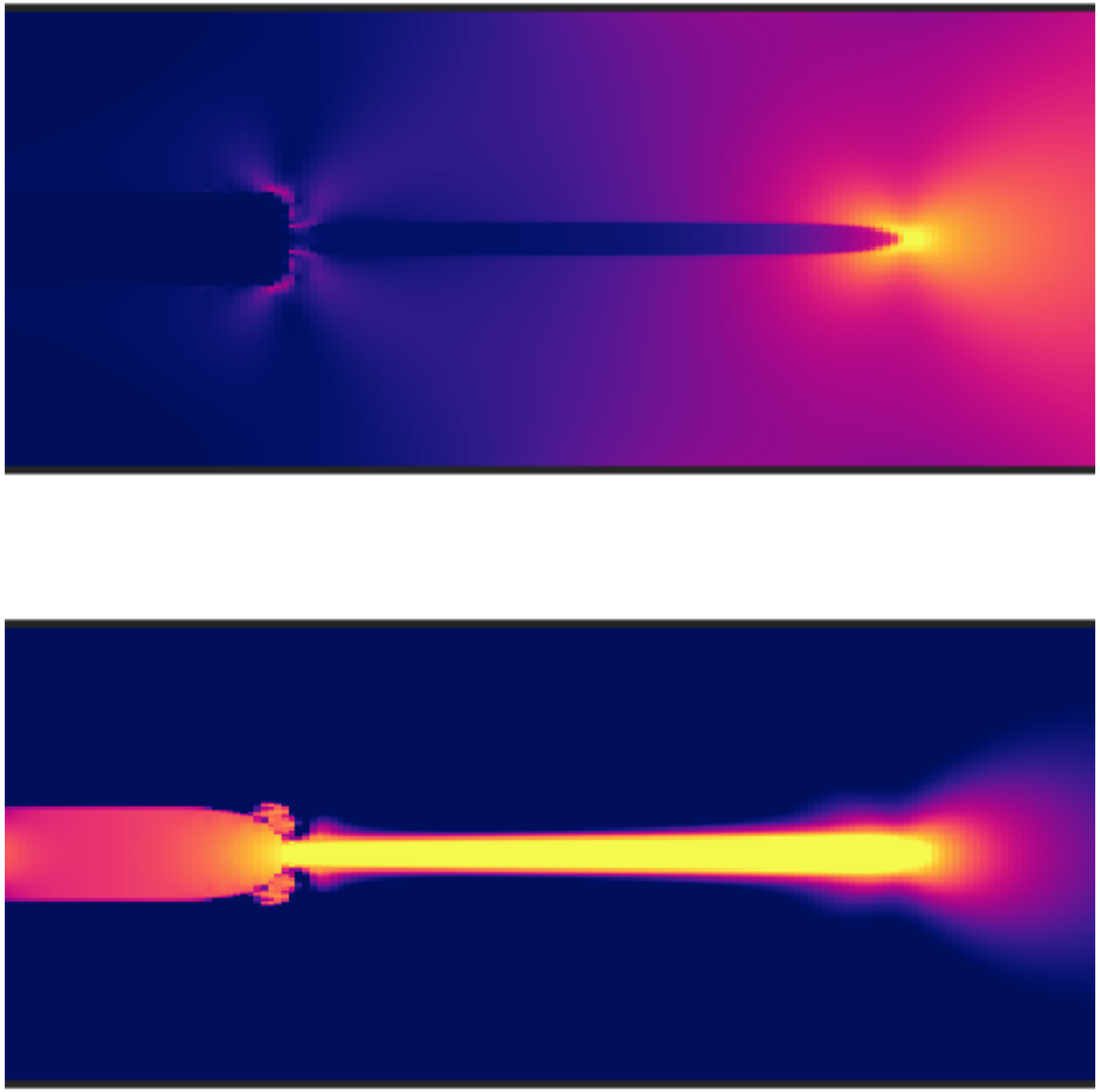
Going from stable creep to aseismic slow slip events in the ductile realm

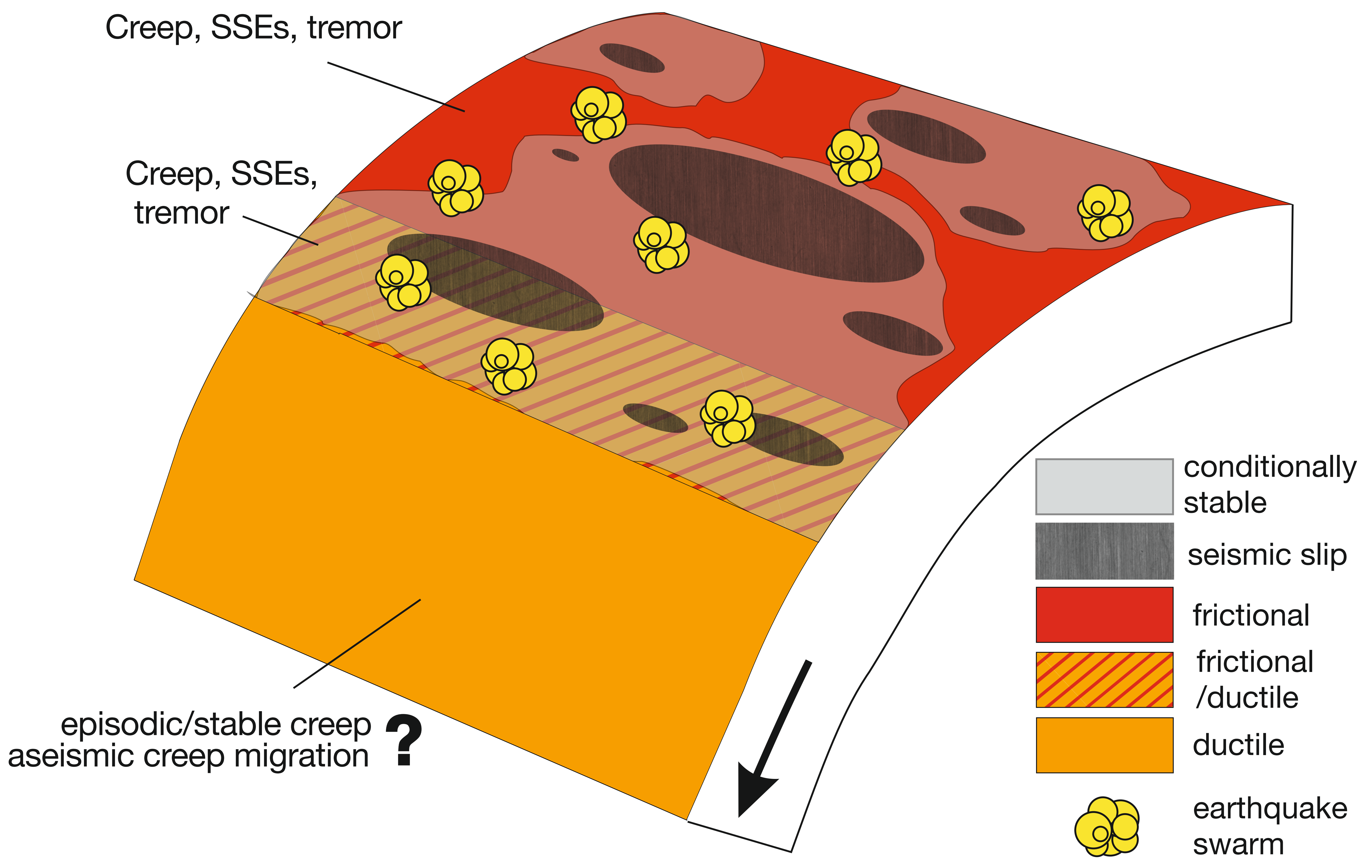
M. Thielmann, T. Duretz



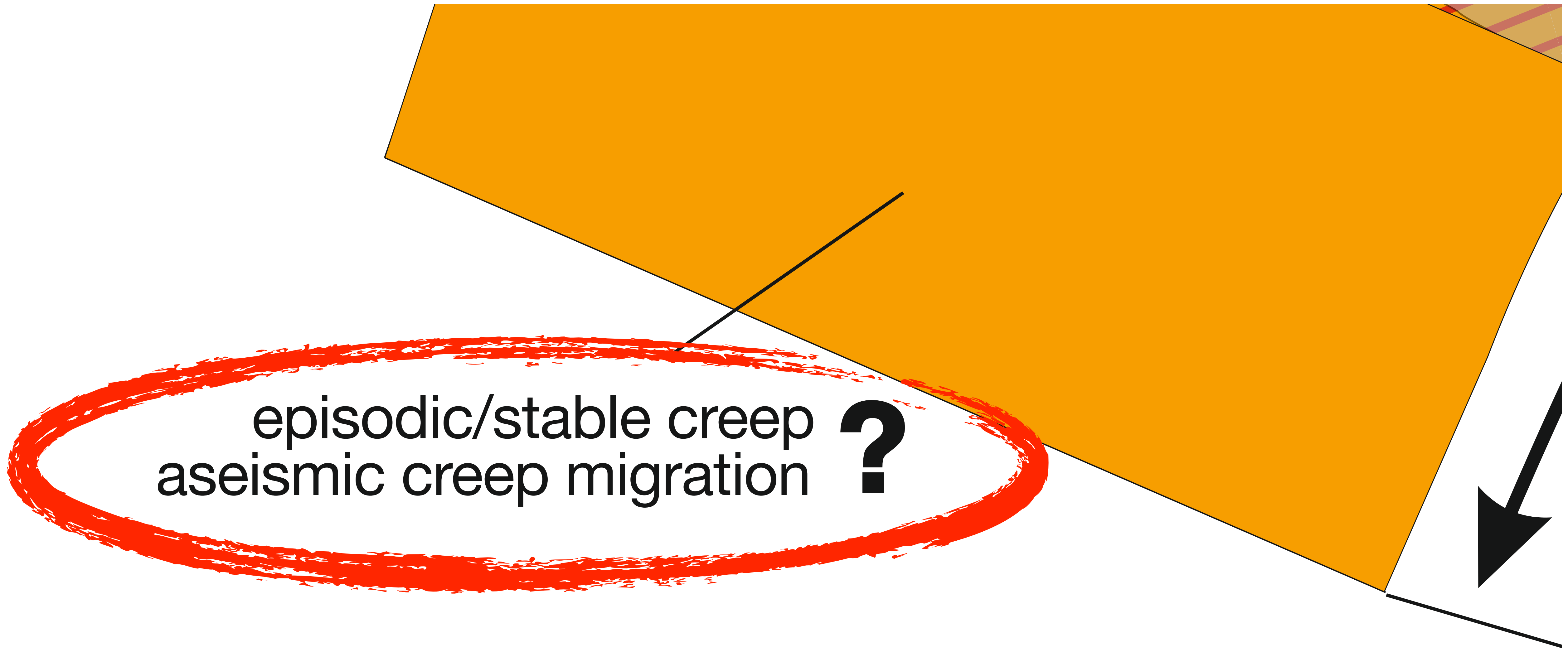
Slip spectrum

From aseismic to seismic

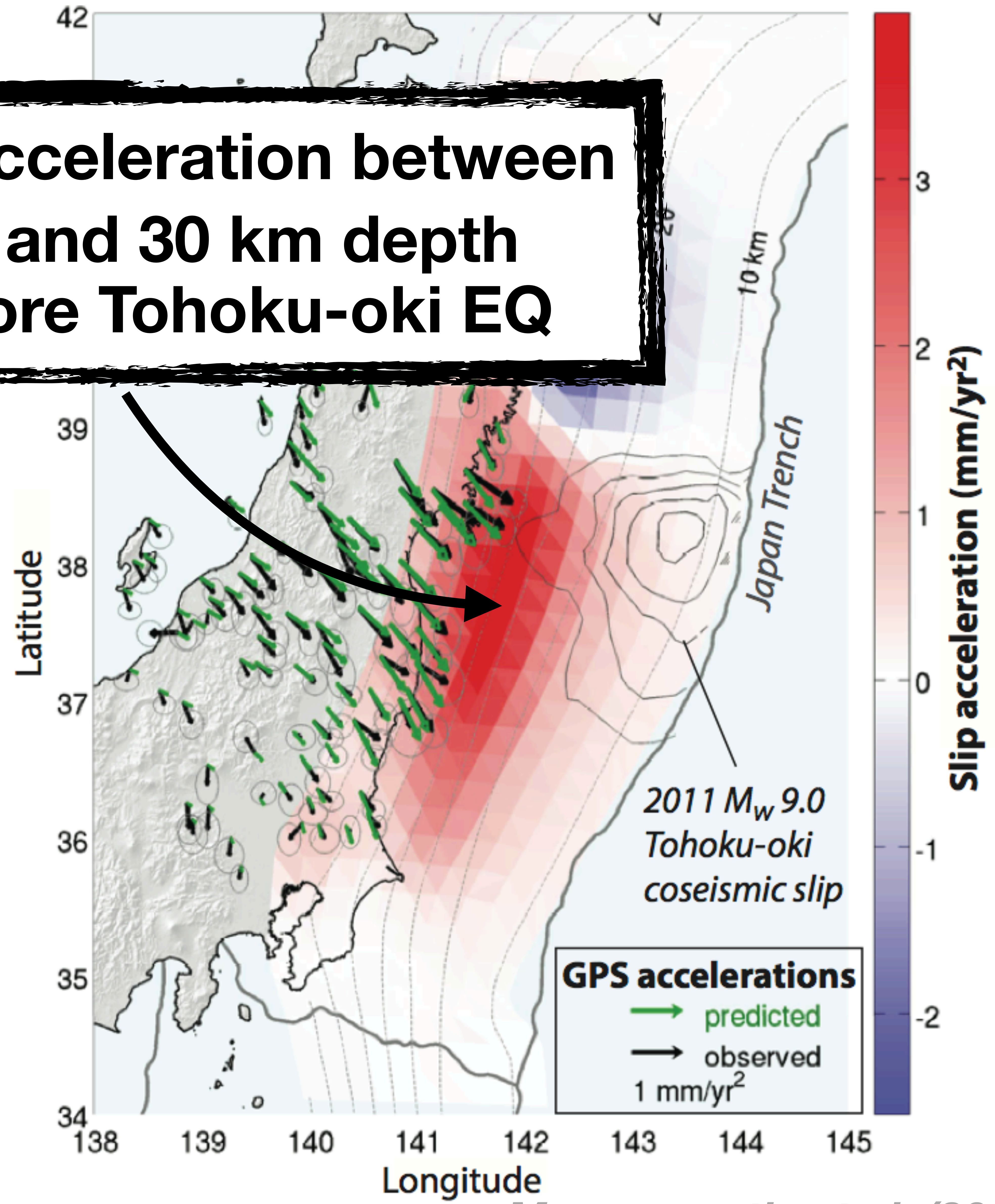
- Aseismic events
  - Long-term SSE (~0.5-5 years)
  - Short-term SSE (~2-6 days)
- Seismic events
  - VLF earthquakes (~10-100 s)
  - Low frequency tremor, ETS (2 to 8 Hz)



Stable sliding at depth?



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



Mavrommatis et al. (2014)

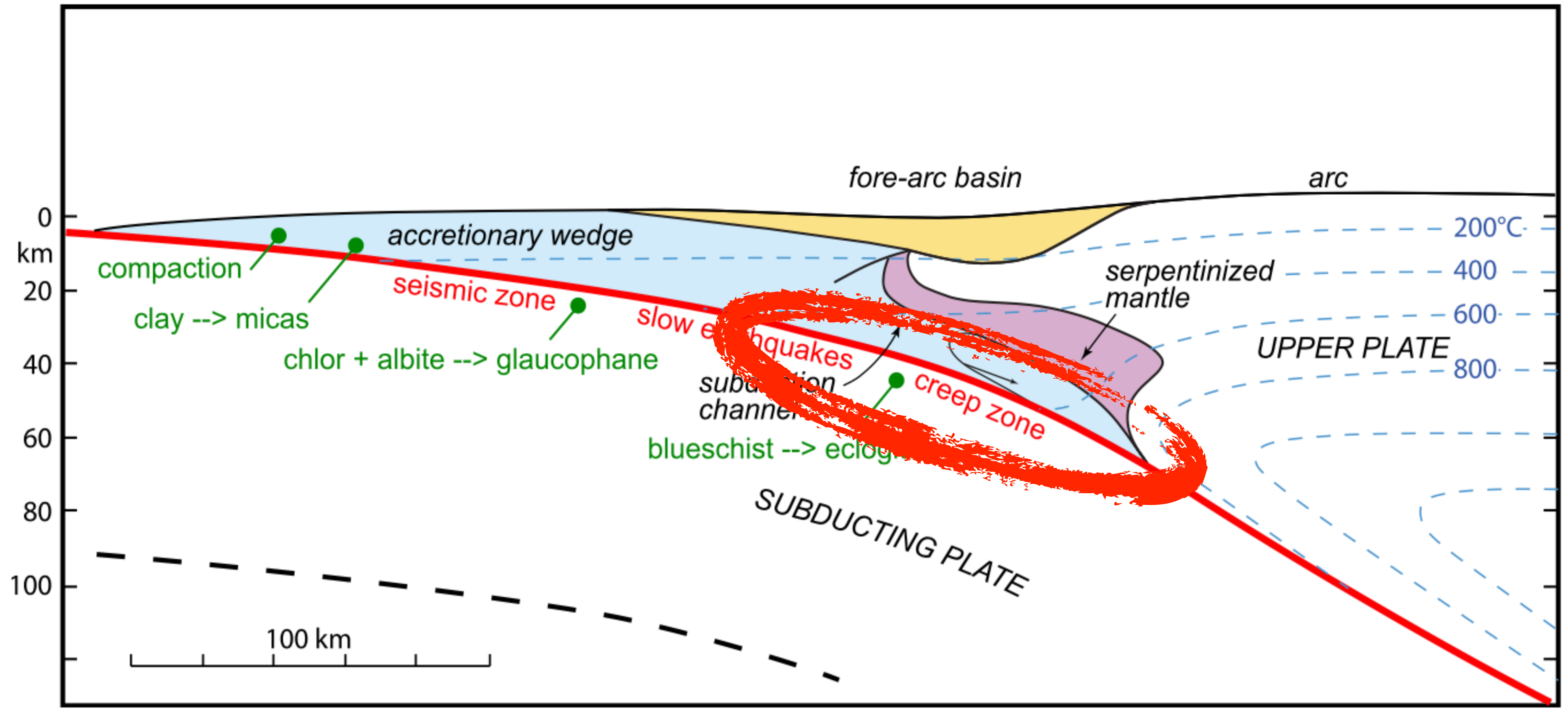
https://sites.google.com/site/amavrommatis/research

Why ?

- High pressure & temperature

  ➡ most likely ductile

- What are the mechanisms ?



Platt et al. (2018)
https://rdcu.be/b3V87
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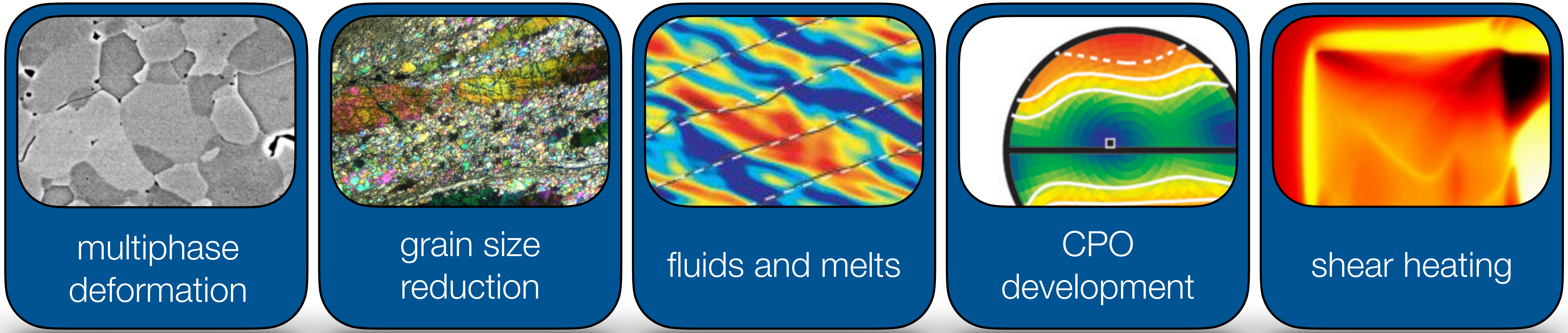

Farla et al. (2013), L.Hansen, Katz et al. (2006), Wang et al. (2013), Noda and Lapusta (2013)

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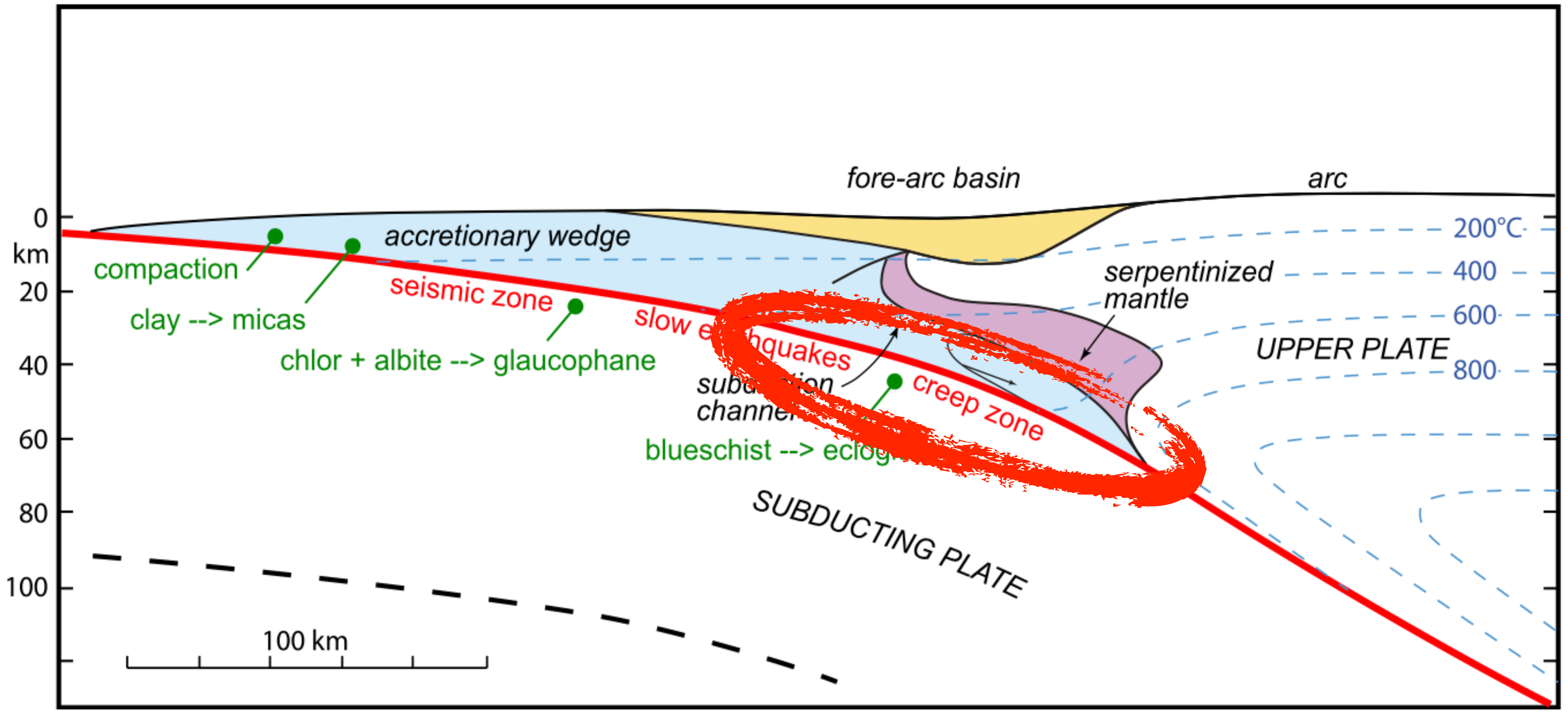
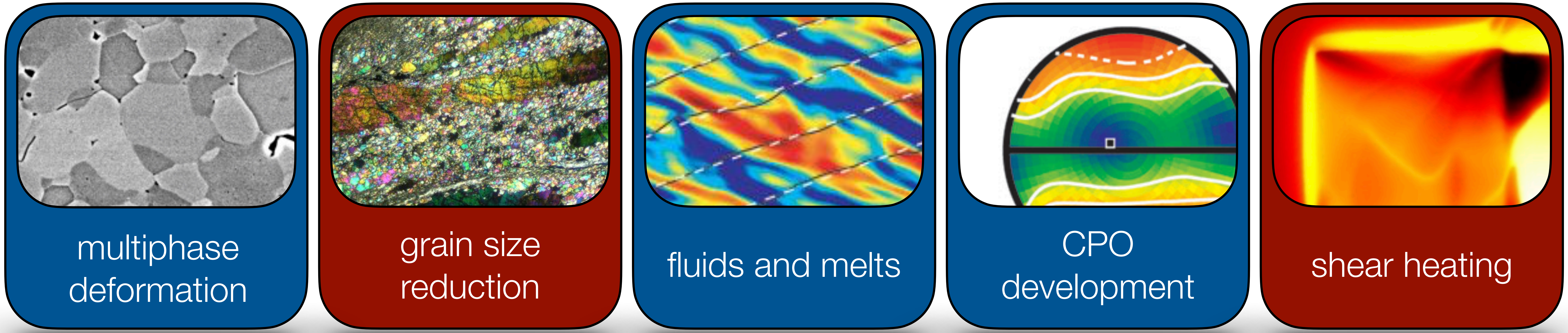


Platt et al. (2018)



Farla et al. (2013), L.Hansen, Katz et al. (2006), Wang et al. (2013), Noda and Lapusta (2013)

Grain size -shear heating feedback

$$\Phi = \boldsymbol{\tau} : \dot{\boldsymbol{\varepsilon}}_i \left(\boldsymbol{\tau}, \mathcal{R}, T\right)$$

$$\frac{d\mathcal{R}}{dt} = \frac{\mathcal{G}(T)}{p\mathcal{R}^{p-1}} - \frac{\lambda F_{\mathcal{R}}}{\gamma}\mathcal{R}^2 \boldsymbol{\tau}:\dot{\boldsymbol{\varepsilon}}_{dis}$$

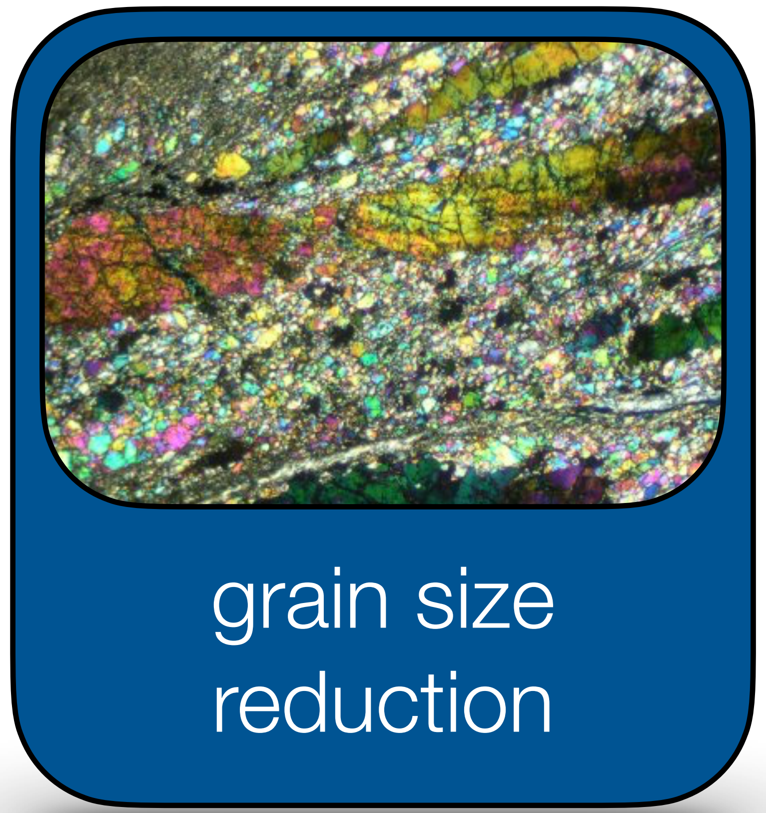
Rozel et al. (2011)

$$\frac{\partial T}{\partial t} = \nabla\left(\kappa \nabla T\right) + \frac{1-\lambda}{\rho c}\left[\boldsymbol{\tau} : \dot{\boldsymbol{\varepsilon}}_{dis}(\boldsymbol{\tau}, T) + \boldsymbol{\tau} : \dot{\boldsymbol{\varepsilon}}_{dif}(\boldsymbol{\tau}, \mathcal{R}, T)\right]$$

$$+ \frac{\gamma \mathcal{G}(T)}{\rho c p F_{\mathcal{R}} \mathcal{R}^{p+1}}$$

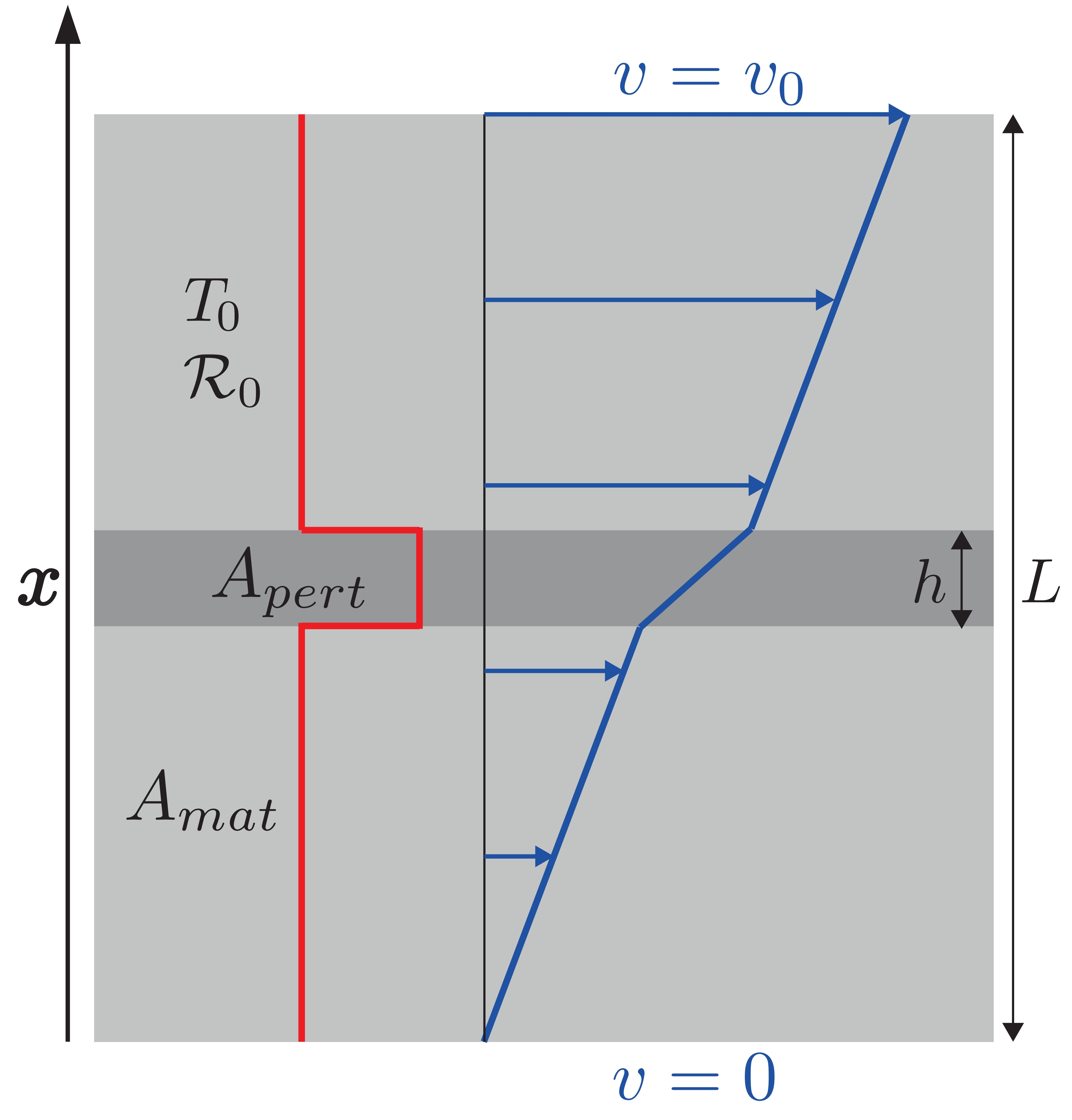
Thielmann et al. (2015)

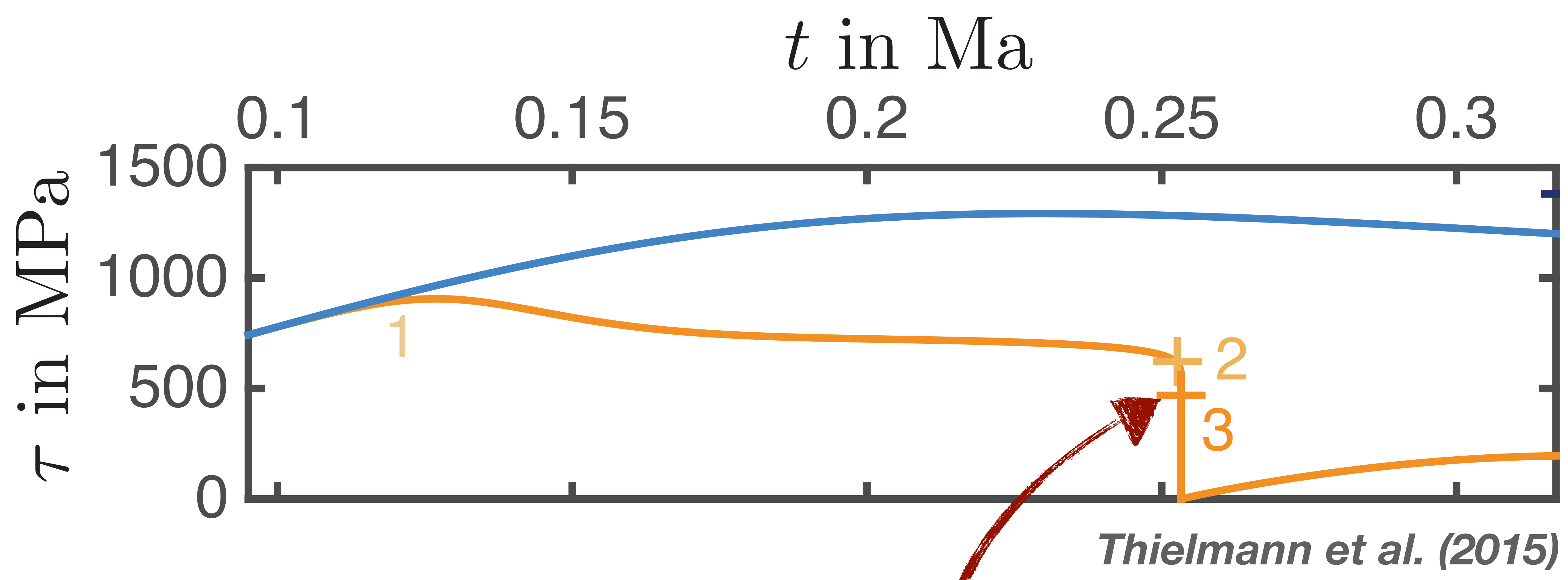
Very nonlinear!



Works in 1D

For a slab in simple shear





Seismic time scale !

But in 2D?

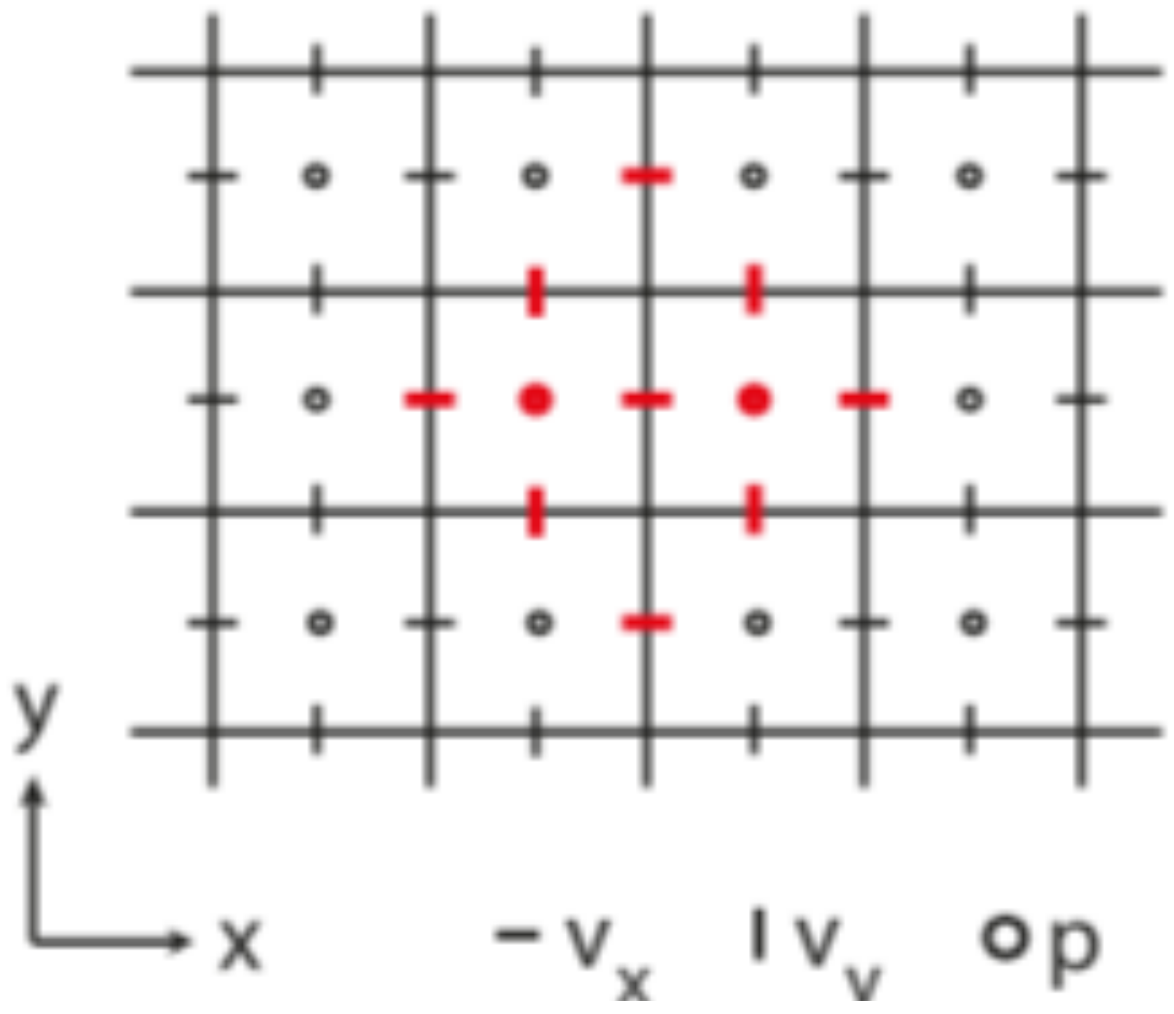
M2Di: Concise and efficient MATLAB 2-D Stokes solvers using the Finite Difference Method

Ludovic Räss[1], Thibault Duretz[1], Yury Y. Podladchikov[1], and Stefan M. Schmalholz[1]

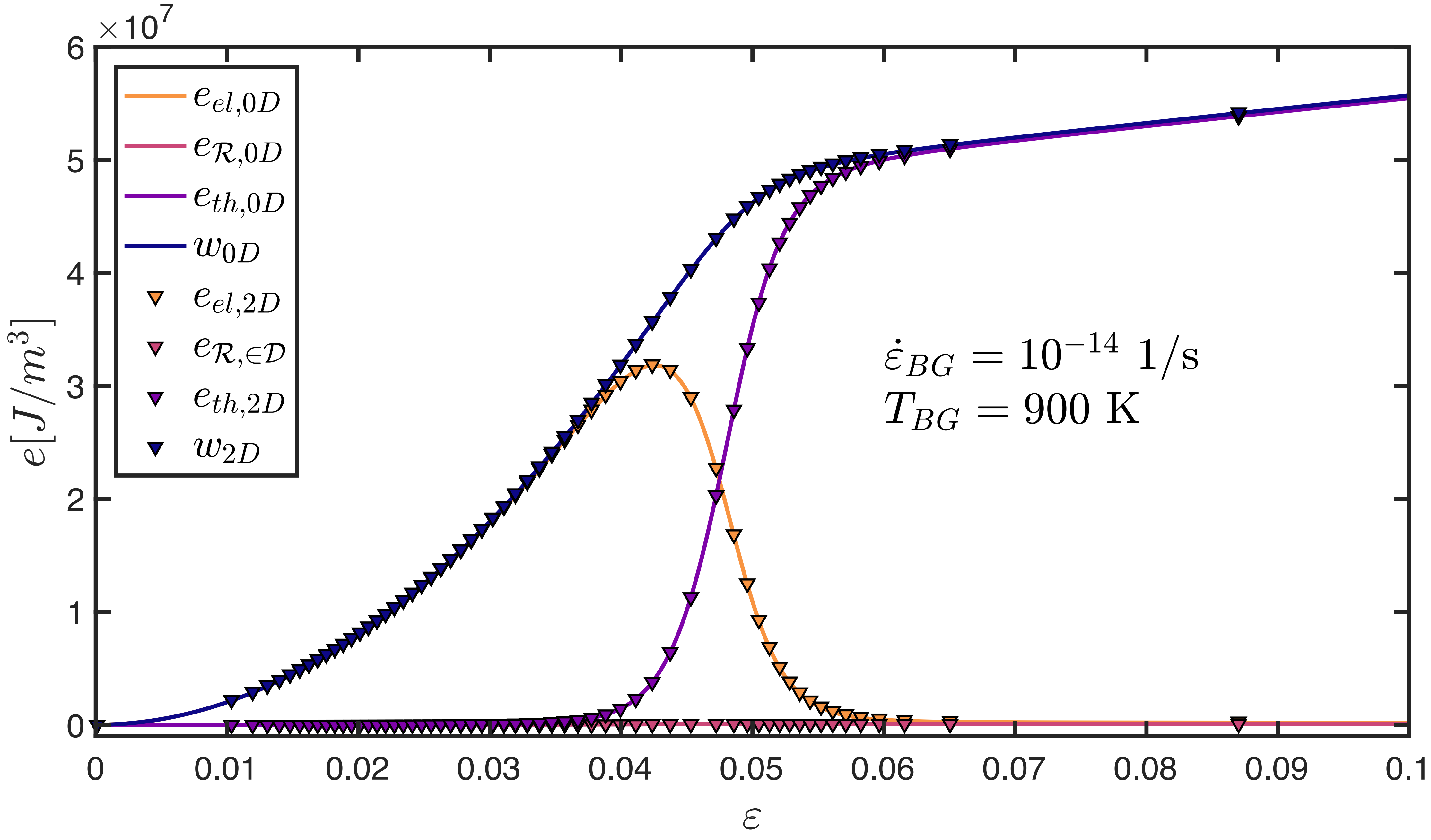
TM²2Di

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

Finite Differences staggered grid

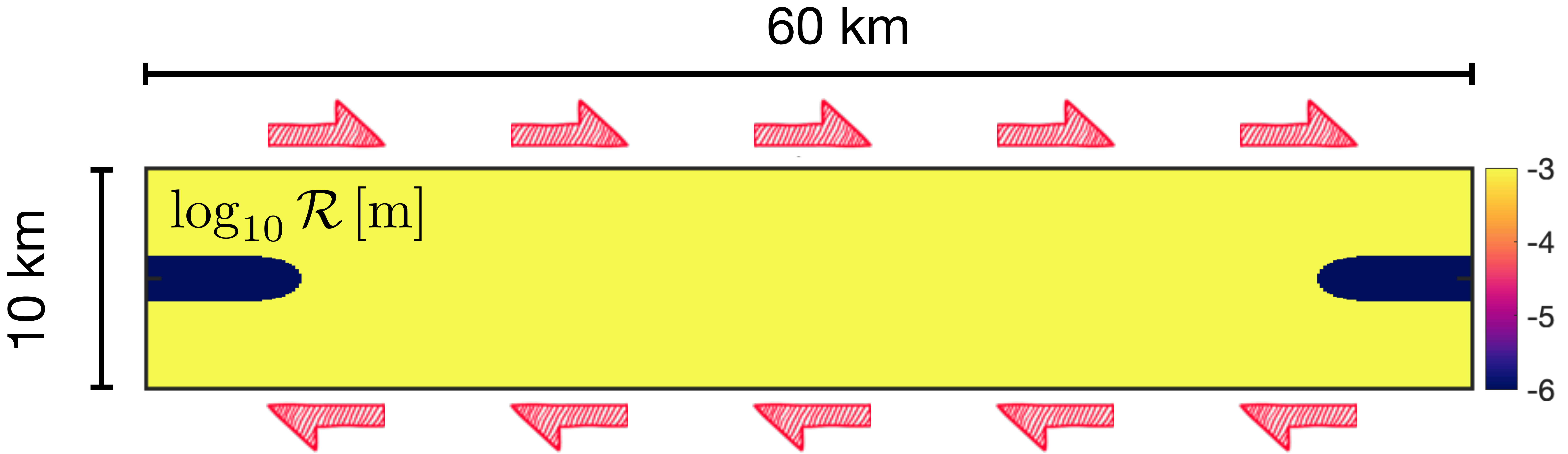


Energy conservative fully benchmarked



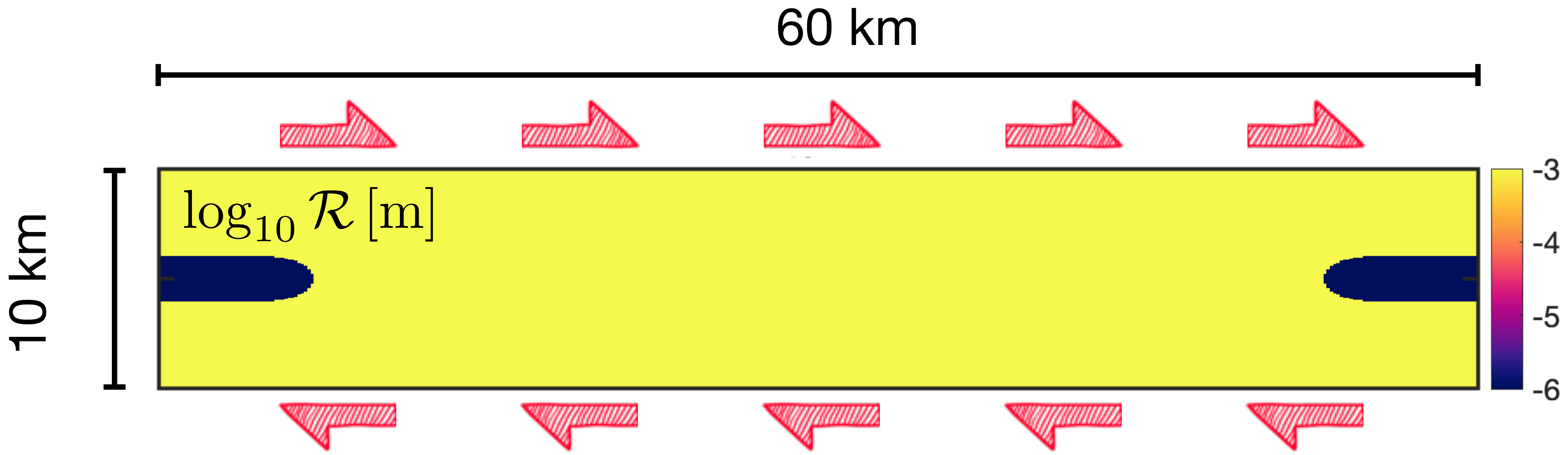
Simple shear setup

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

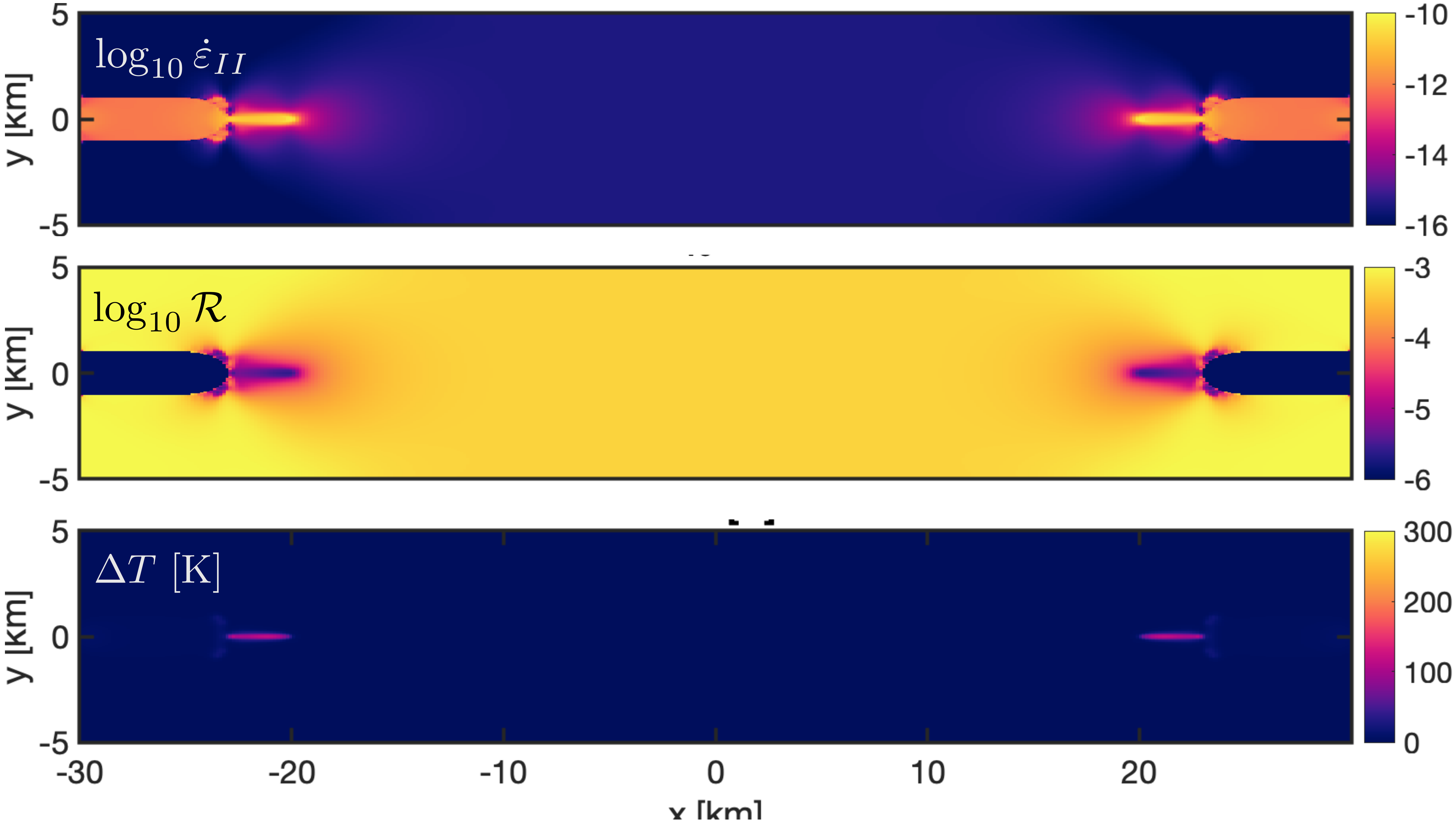


Simple shear setup

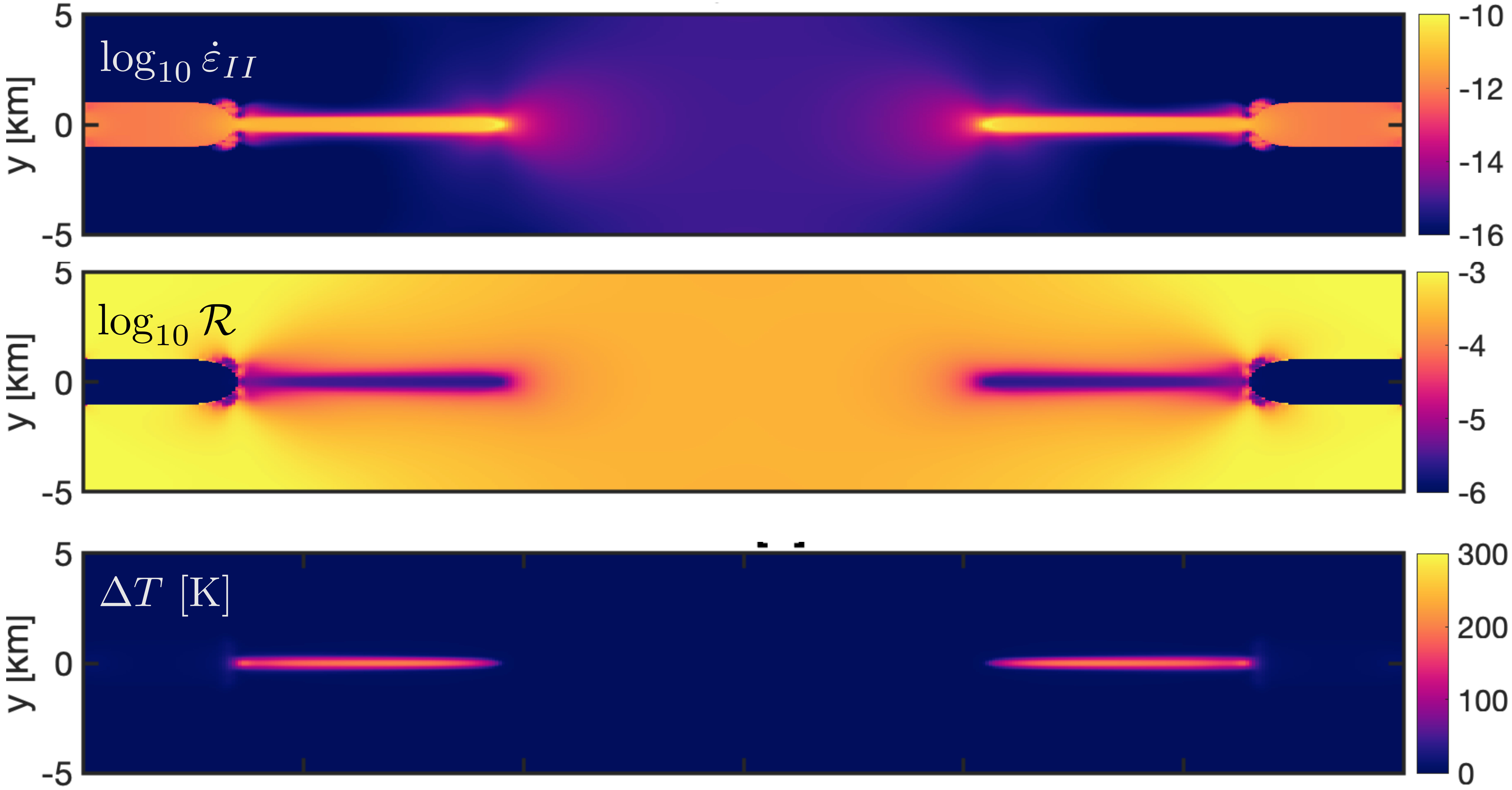
- background temperature $T_{BG} = 900\ \mathrm{K}$
- background strain rate $\dot{\varepsilon}_{BG} = 2.5 \cdot 10^{-13}\ 1/\mathrm{s}$



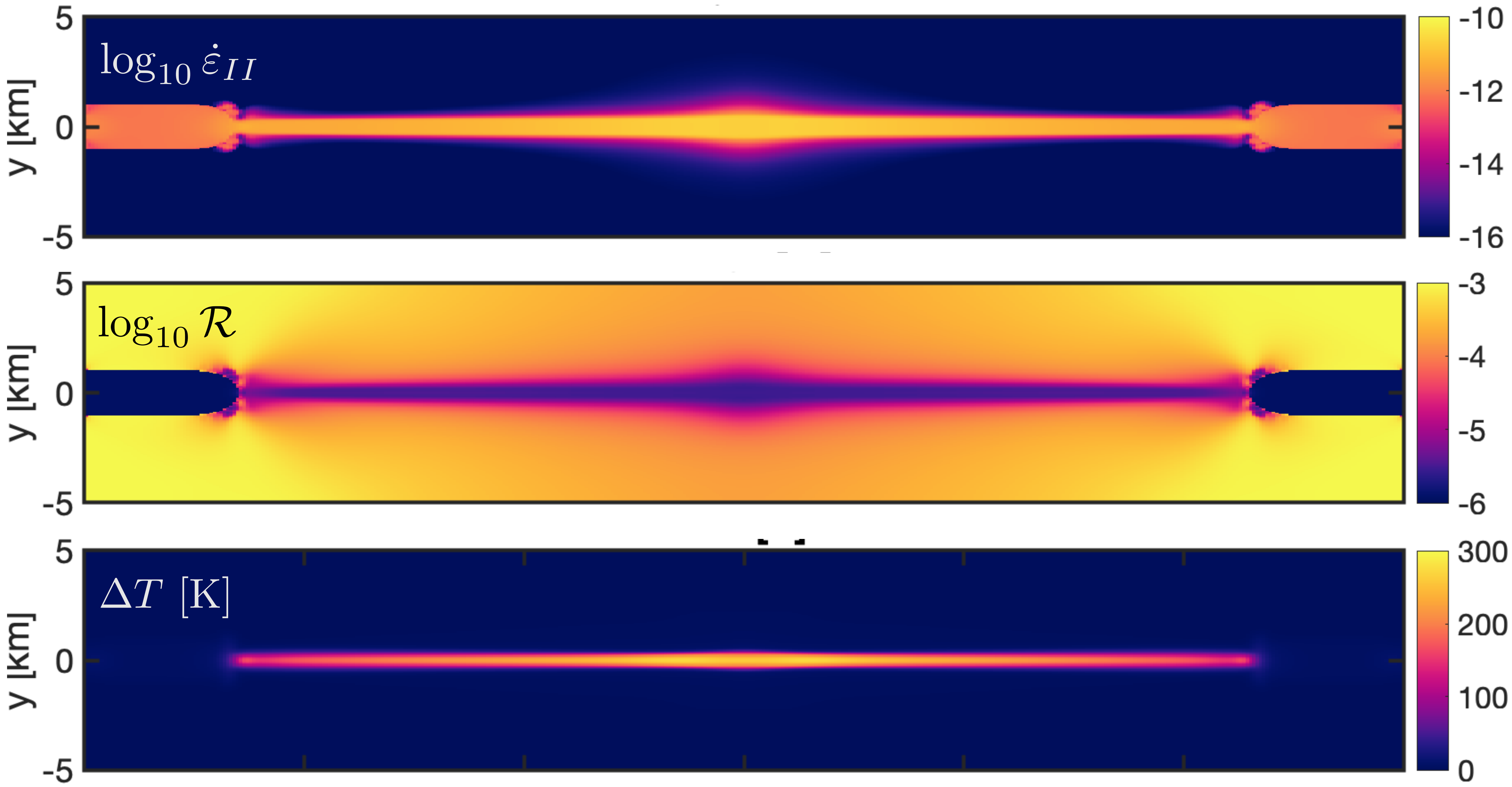
Shear zone initiation…



… propagation …



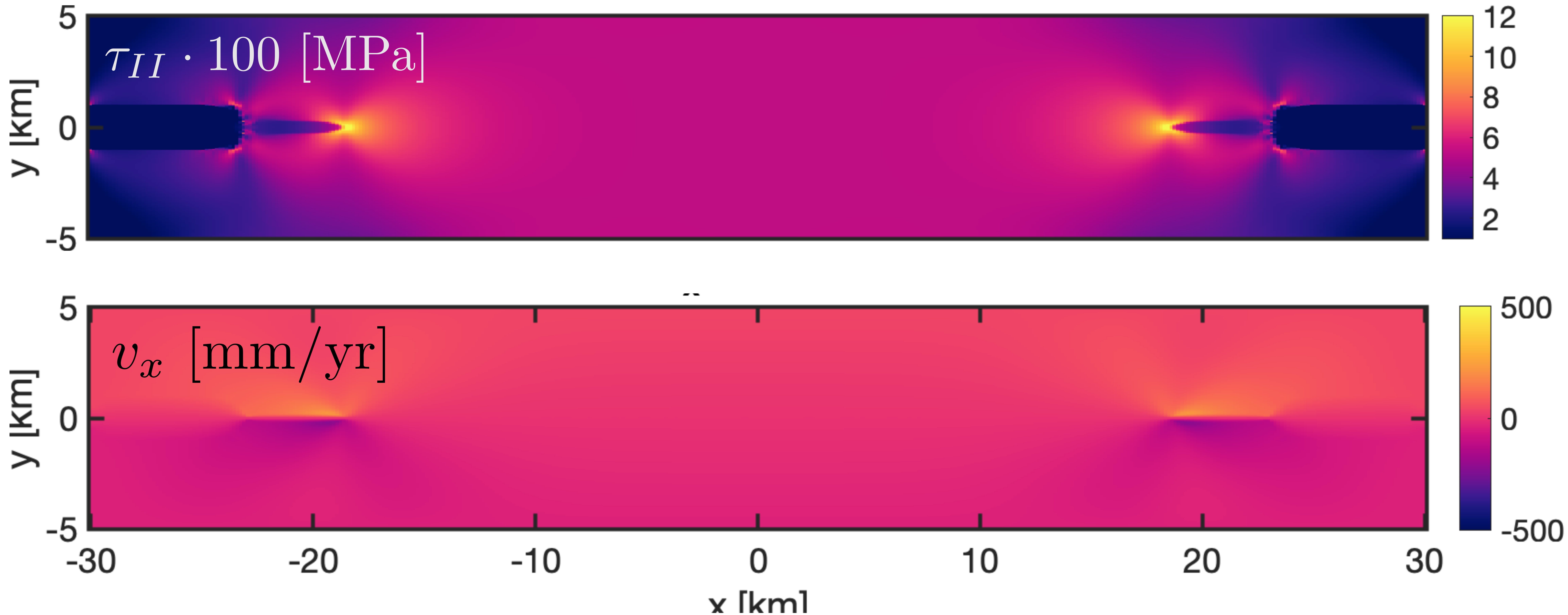
… merging



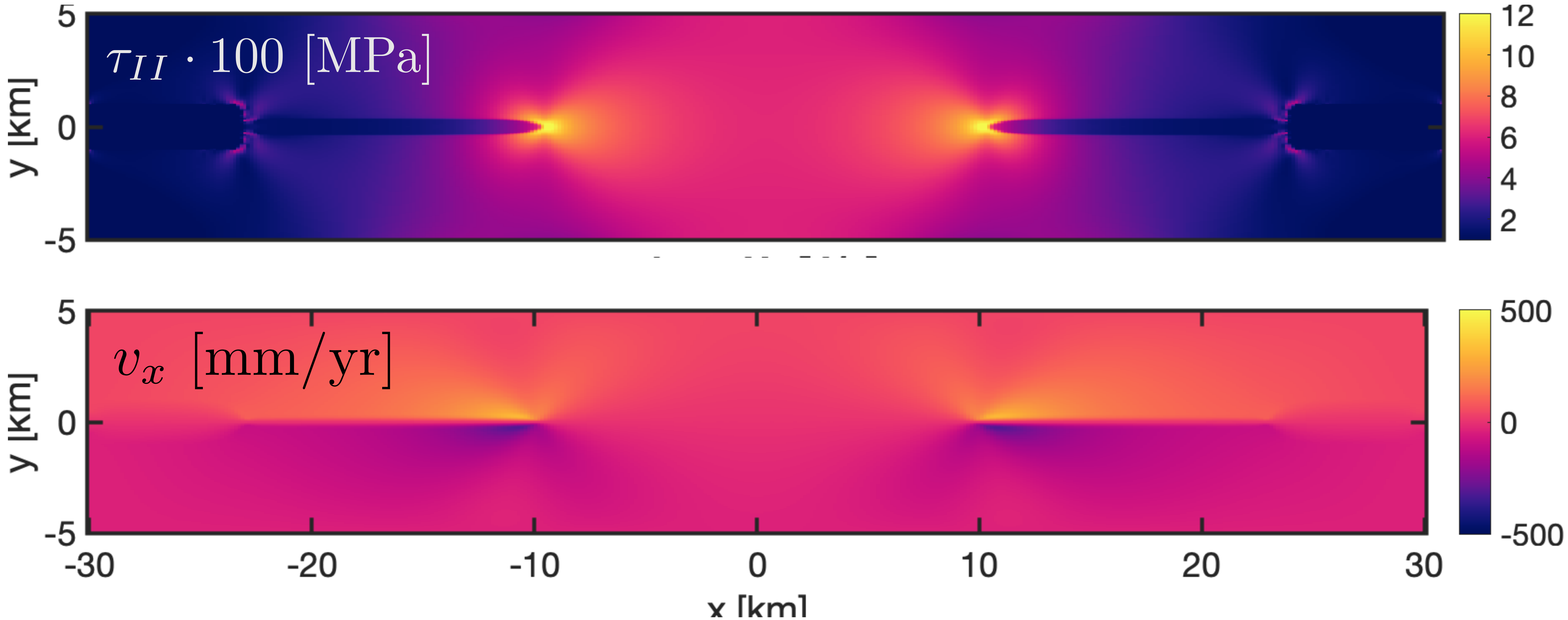
$\log_{10} \dot{\varepsilon}_{II}$
$\log_{10} \mathcal{R}$
ΔT [K]
y [km]
5
0
-5
-10
-12
-14
-16
-3
-4
-5
-6
300
200
100
0

Same, but different variables

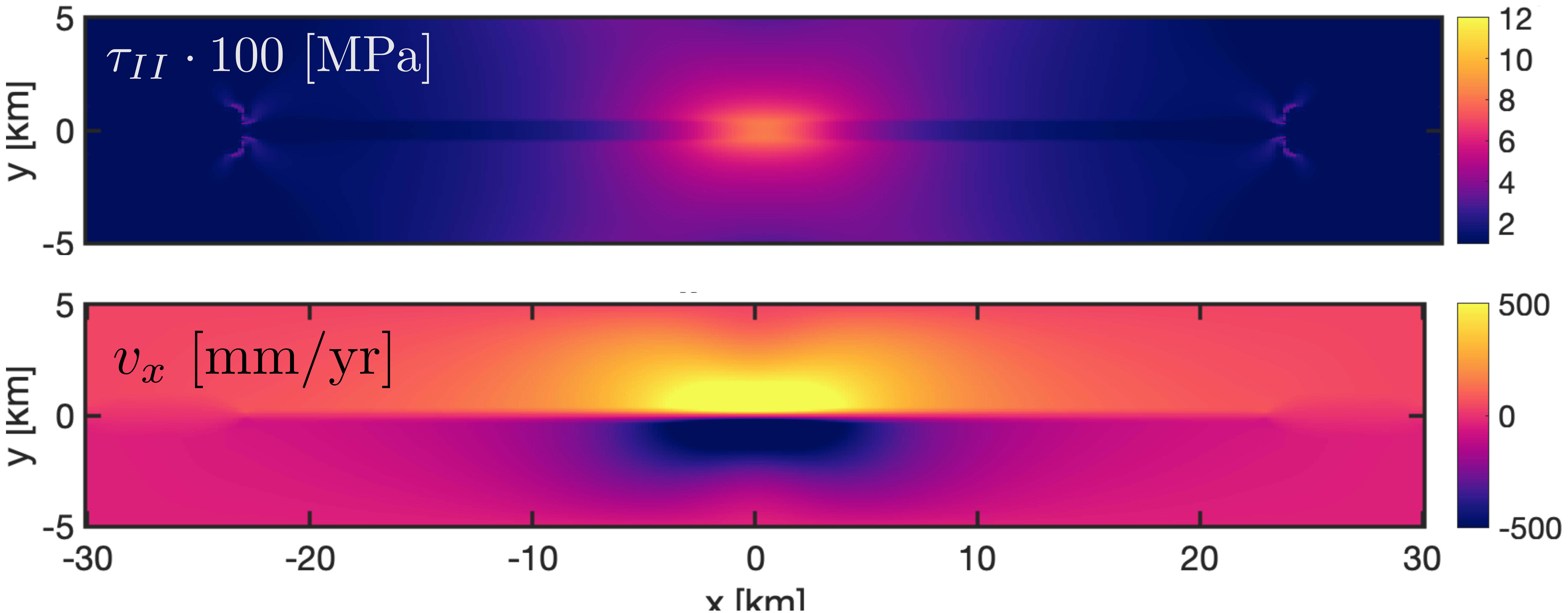
Stress focusing causes ductile rupture



Continued propagation



Largest velocities at merging



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