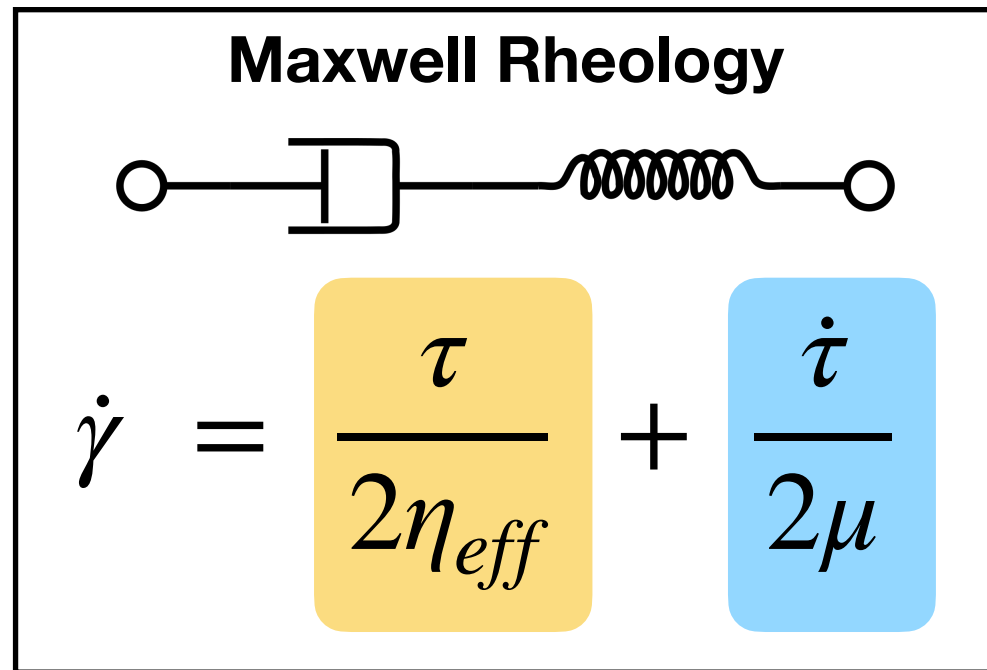


Shear banding in a micromechanics-based damaged material

Léo Petit, J.-A. Olive, H. S. Bhat, L. Le Pourhiet, and A. Schubnel

leo.petit@ens.fr

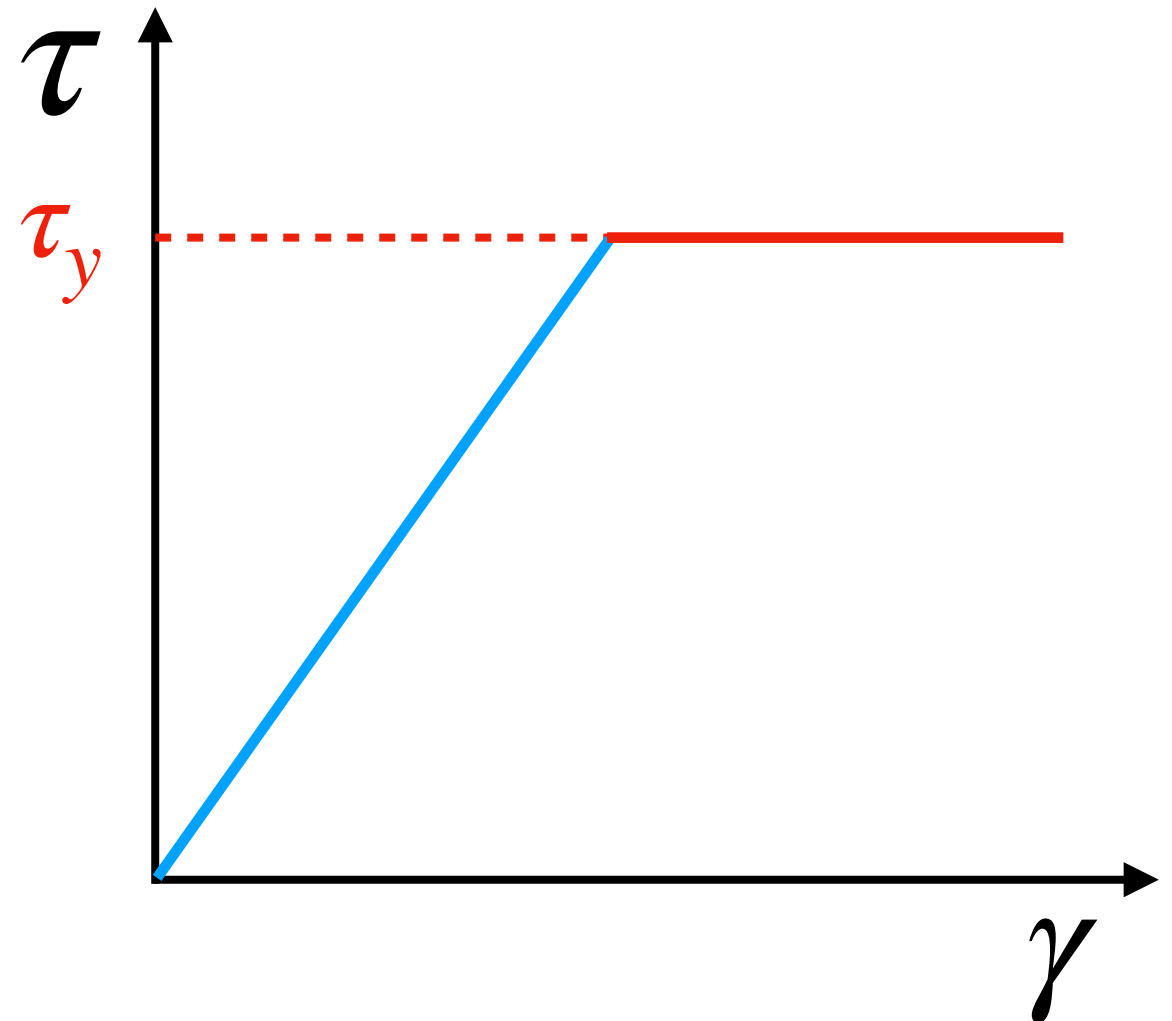
Classical brittle deformation rheology in long term tectonics models



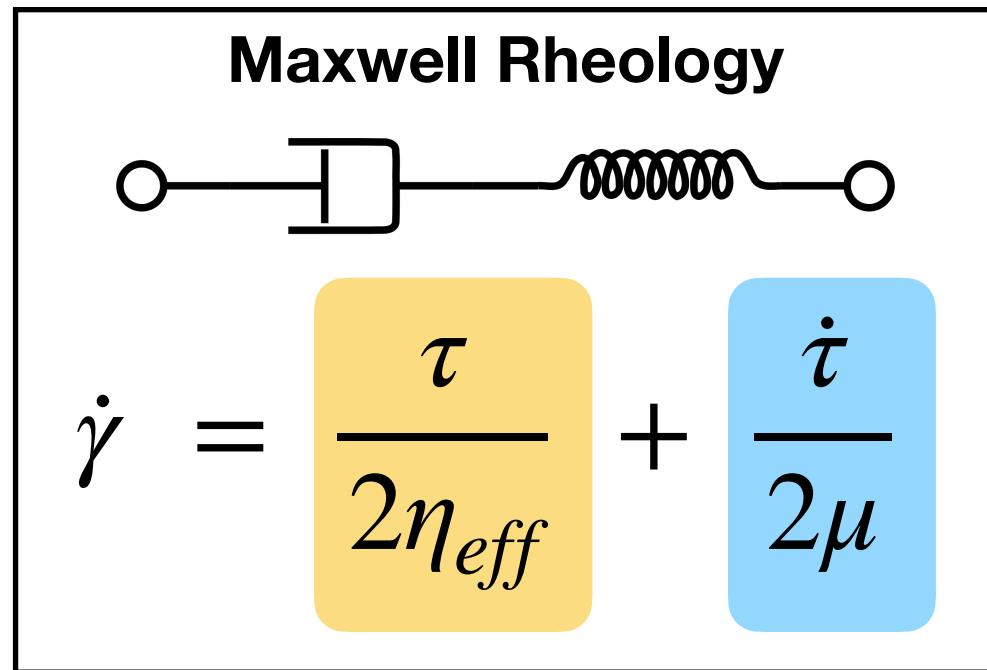
+

Yield criterion

$$\tau_y = A\sigma_m + B$$



Classical brittle deformation rheology in long term tectonics models

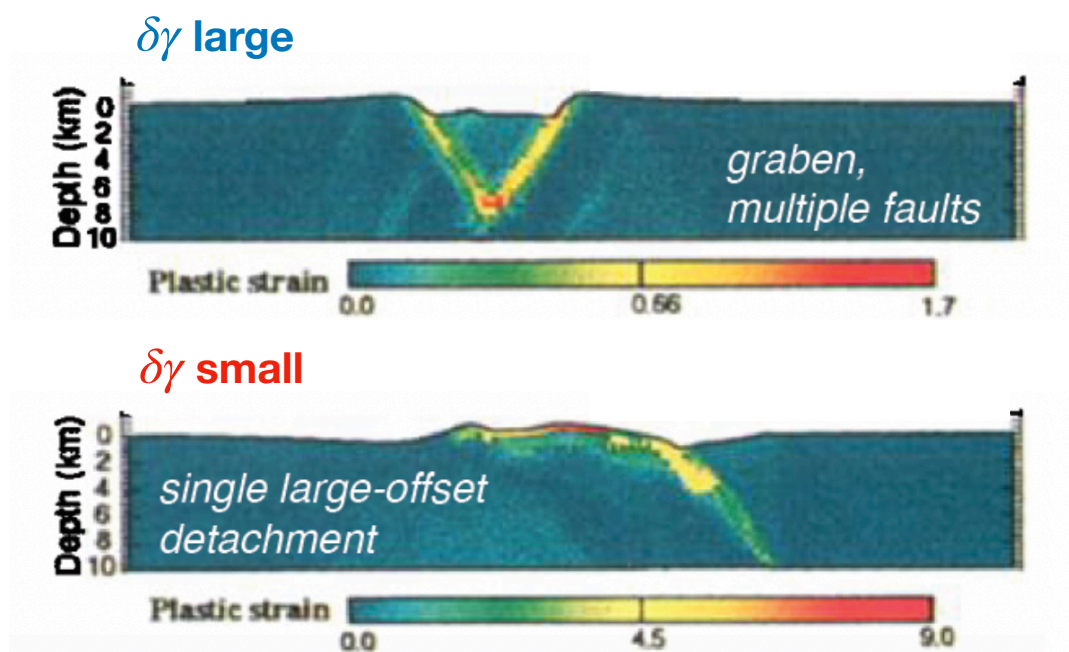


+

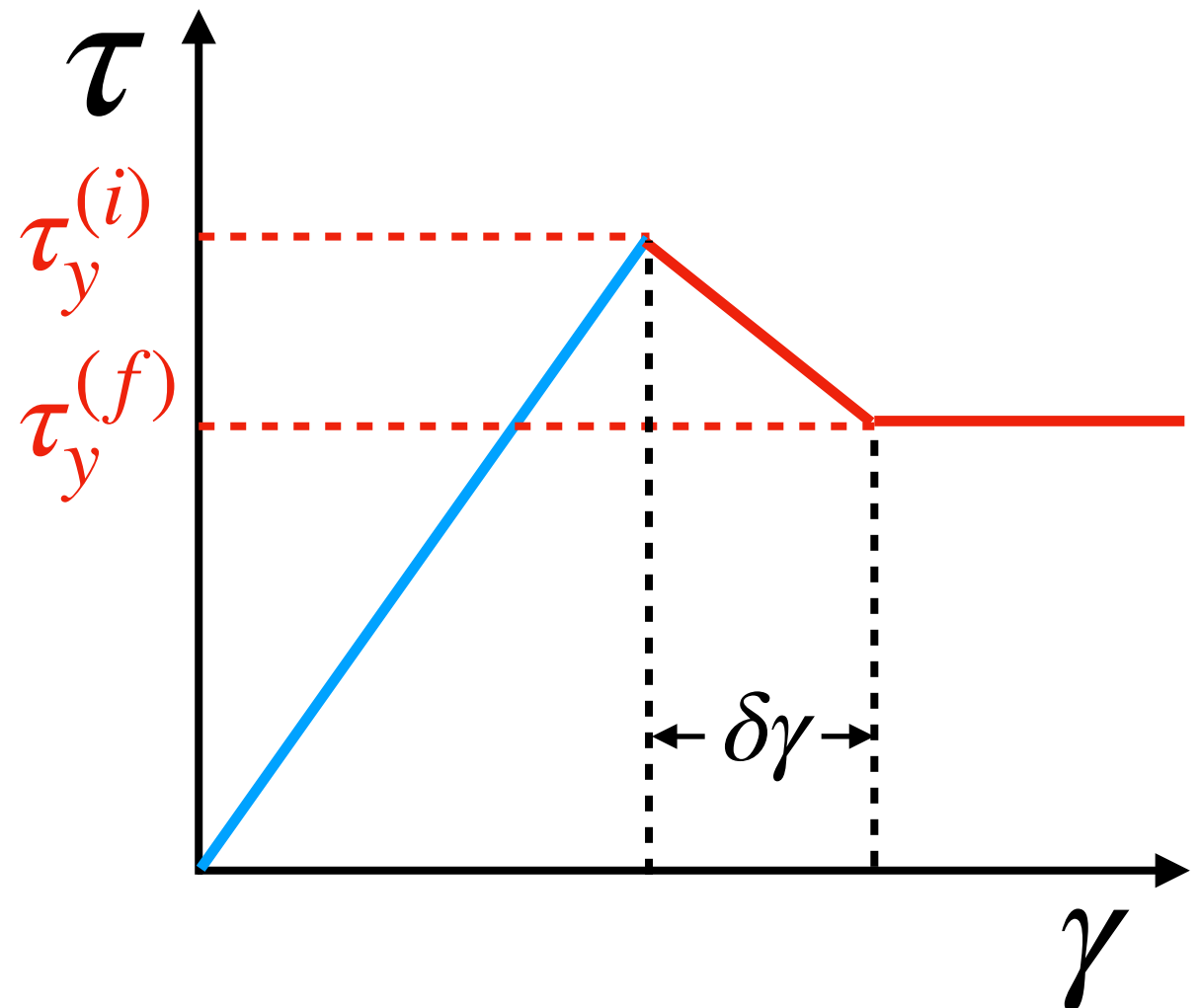
Yield criterion

$$\tau_y = A\sigma_m + B$$

Strain weakening of the yield stress triggers diverse mode of strain localization

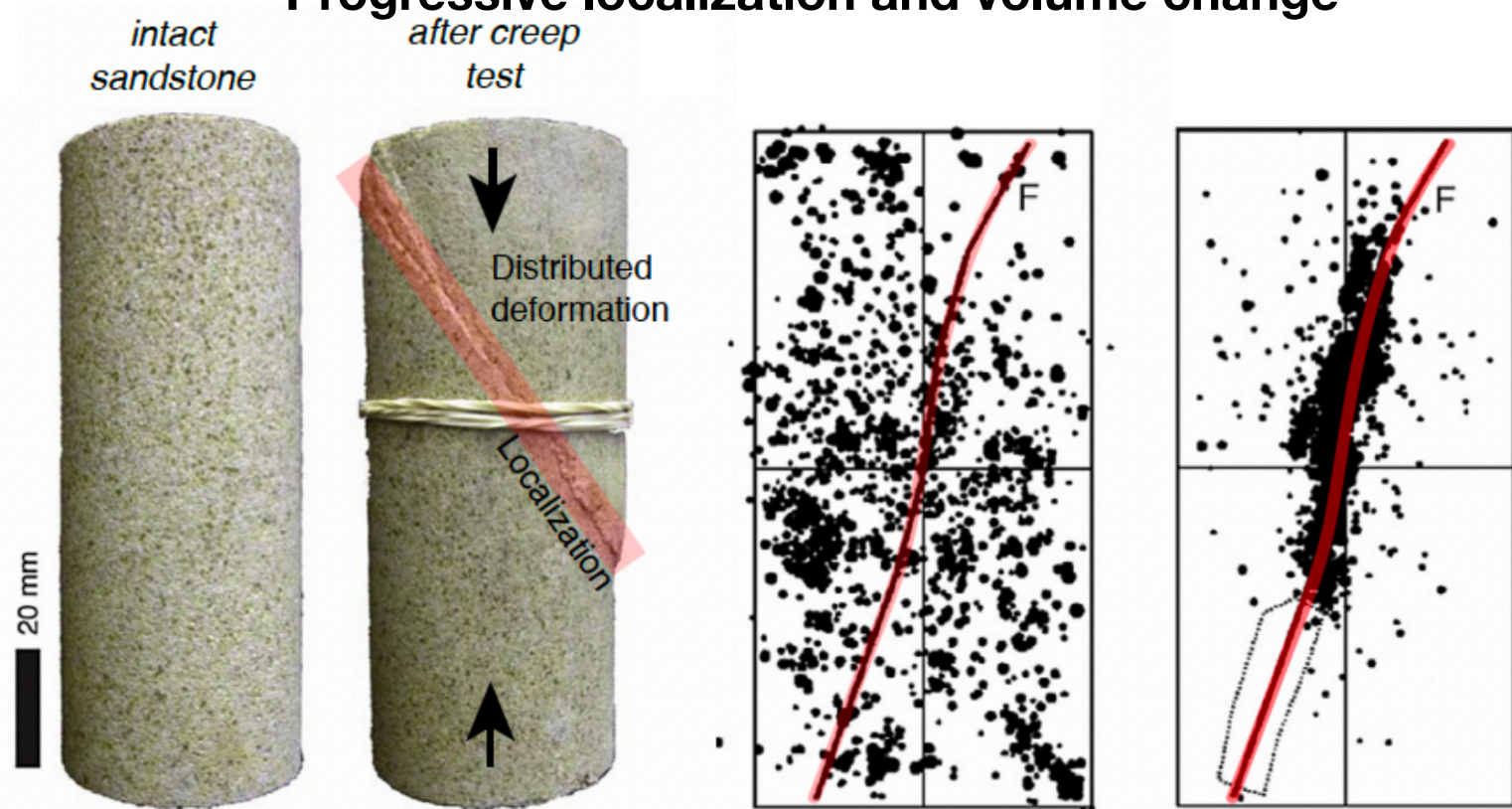


Lavier et al. [2000]



Brittle deformation experiments

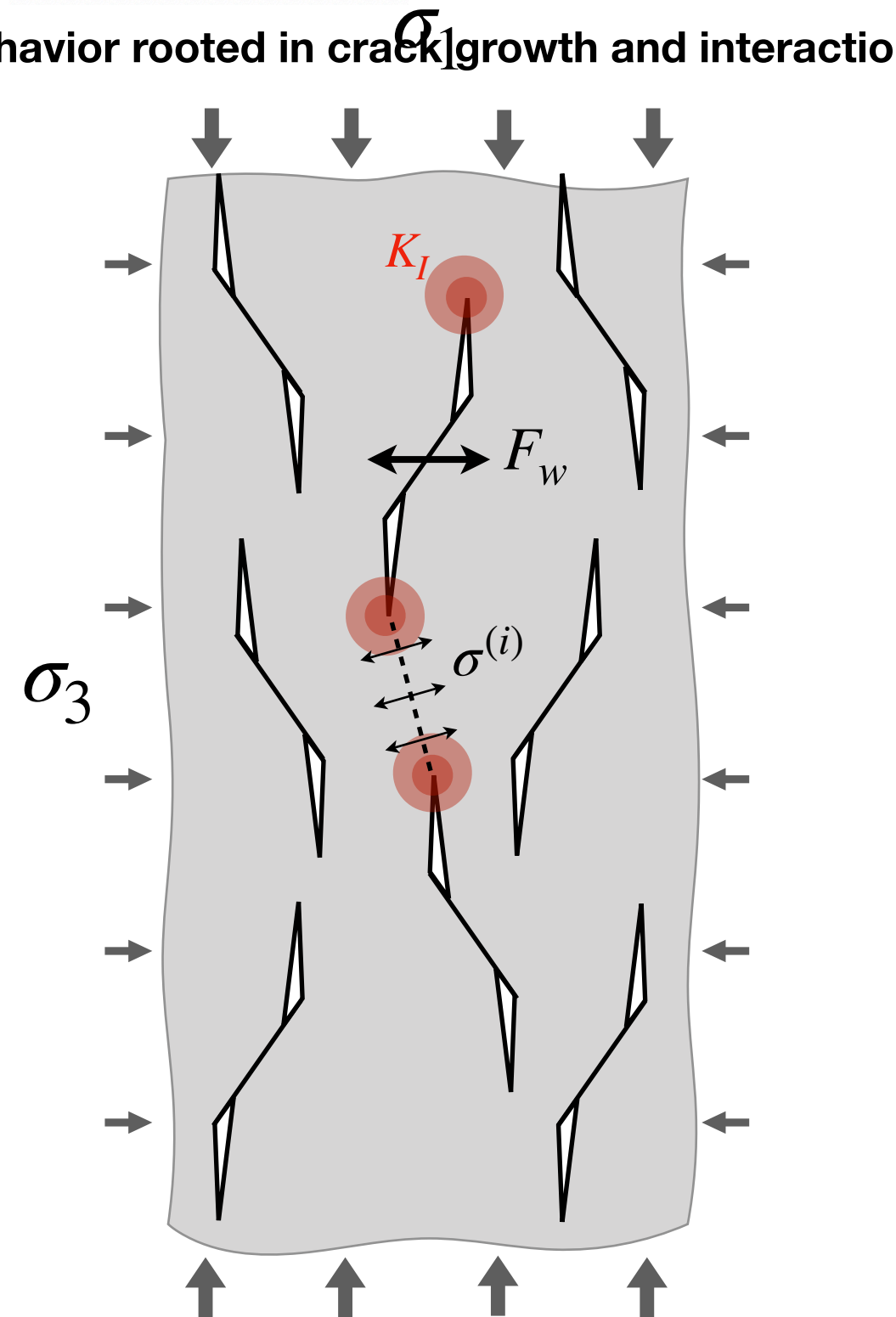
Progressive localization and volume change



Brantut et al. [2013]

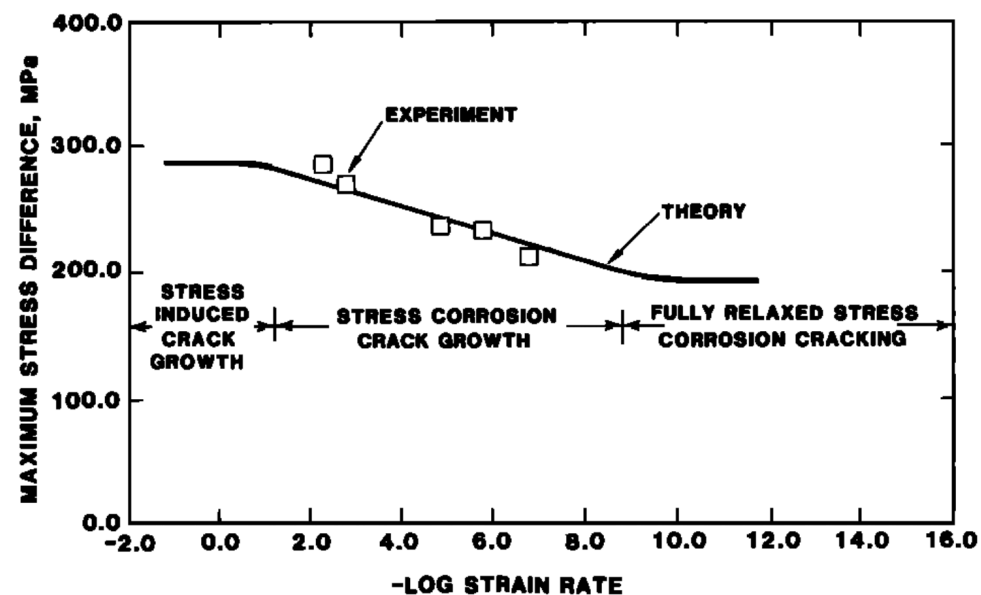
Lockner et al. [1991]

Behavior rooted in crack growth and interaction



Strain rate dependence of peak strength

WESTERLY GRANITE
(WET, UNCONFINED)

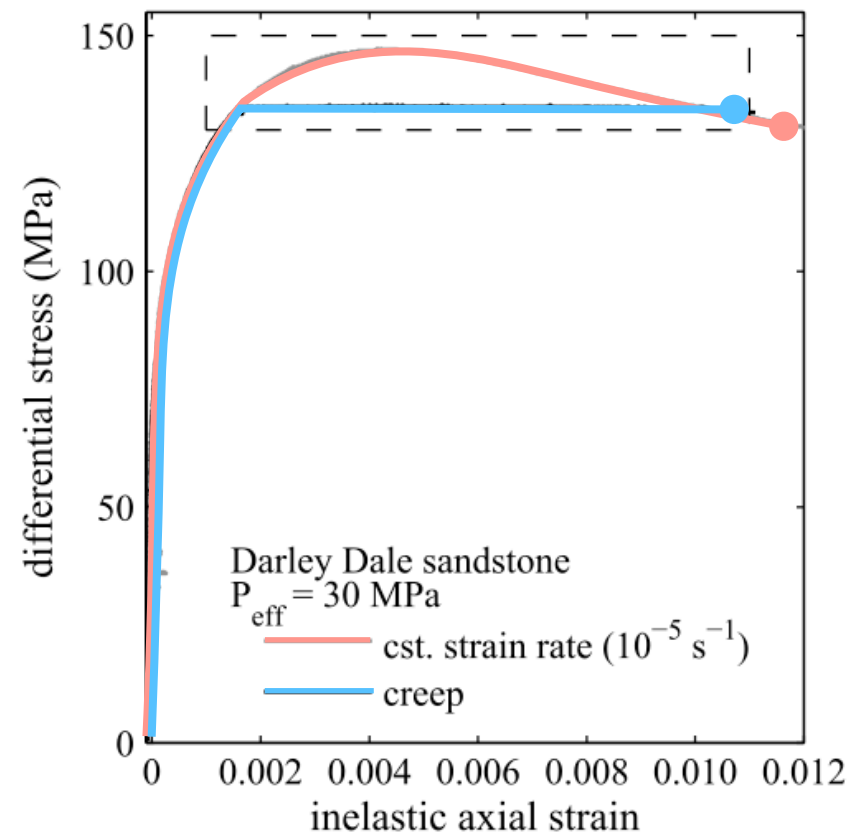


Costin [1983]

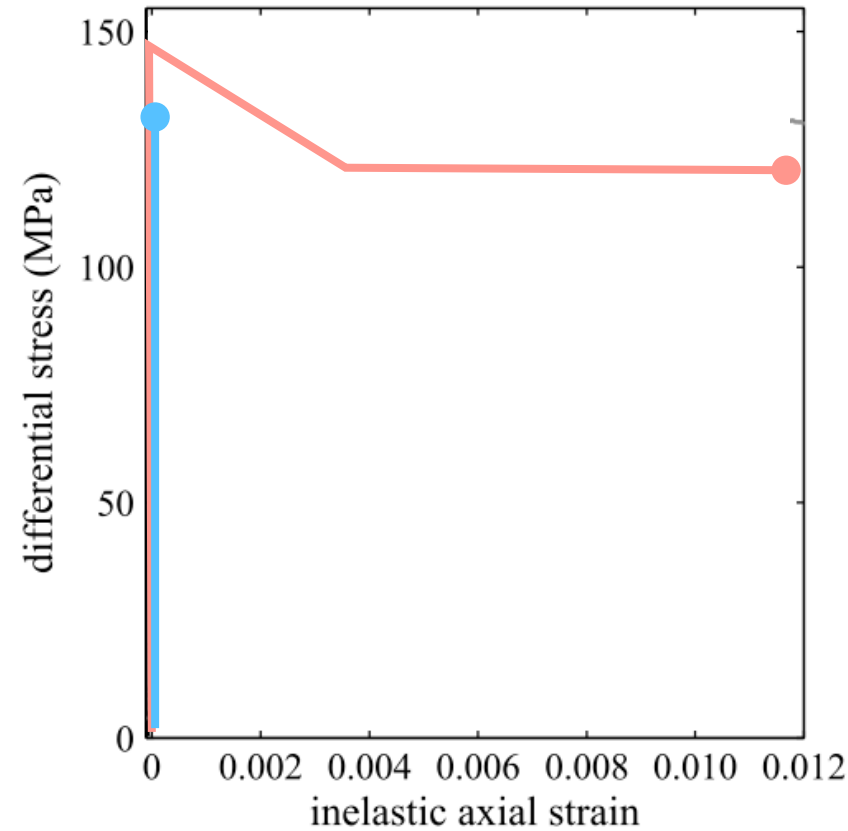
Rock deformation experiments vs tectonic models

Triaxial experiments

[Brantut et al. 2013]

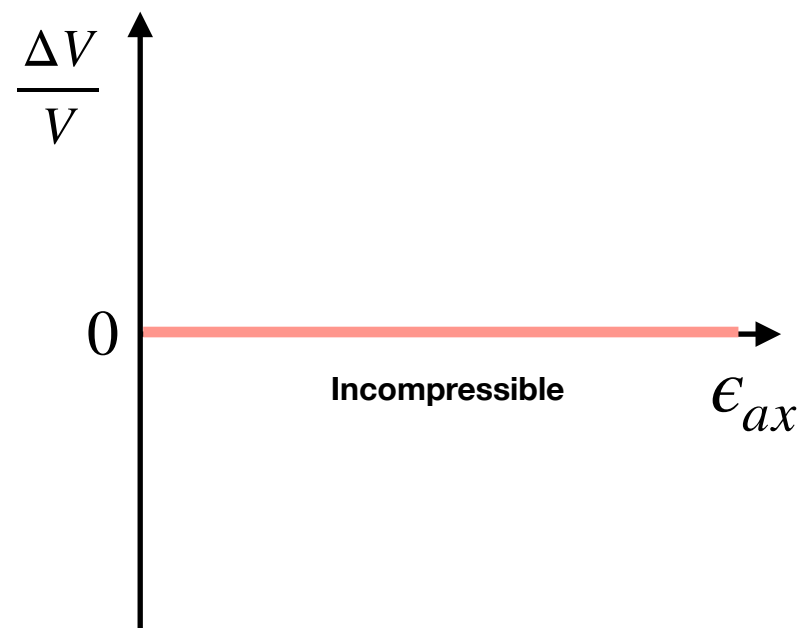
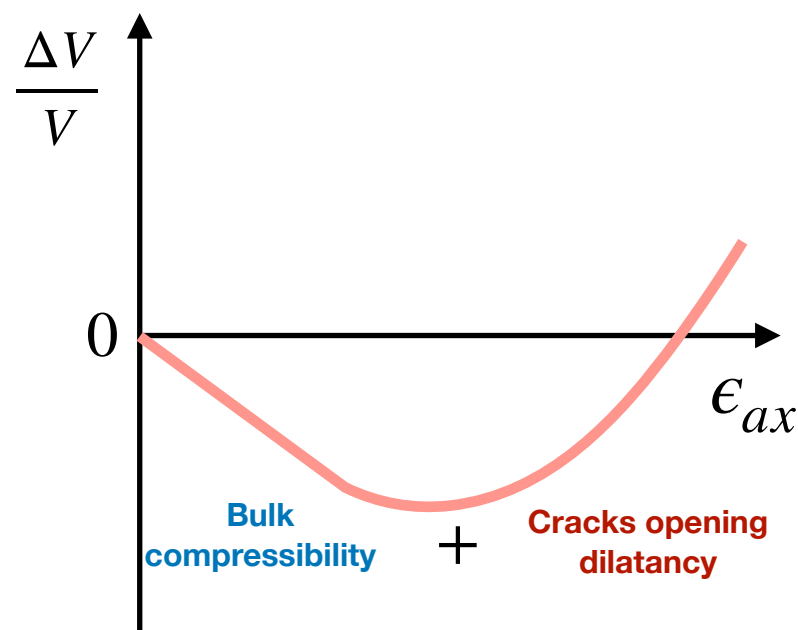


Tectonic models



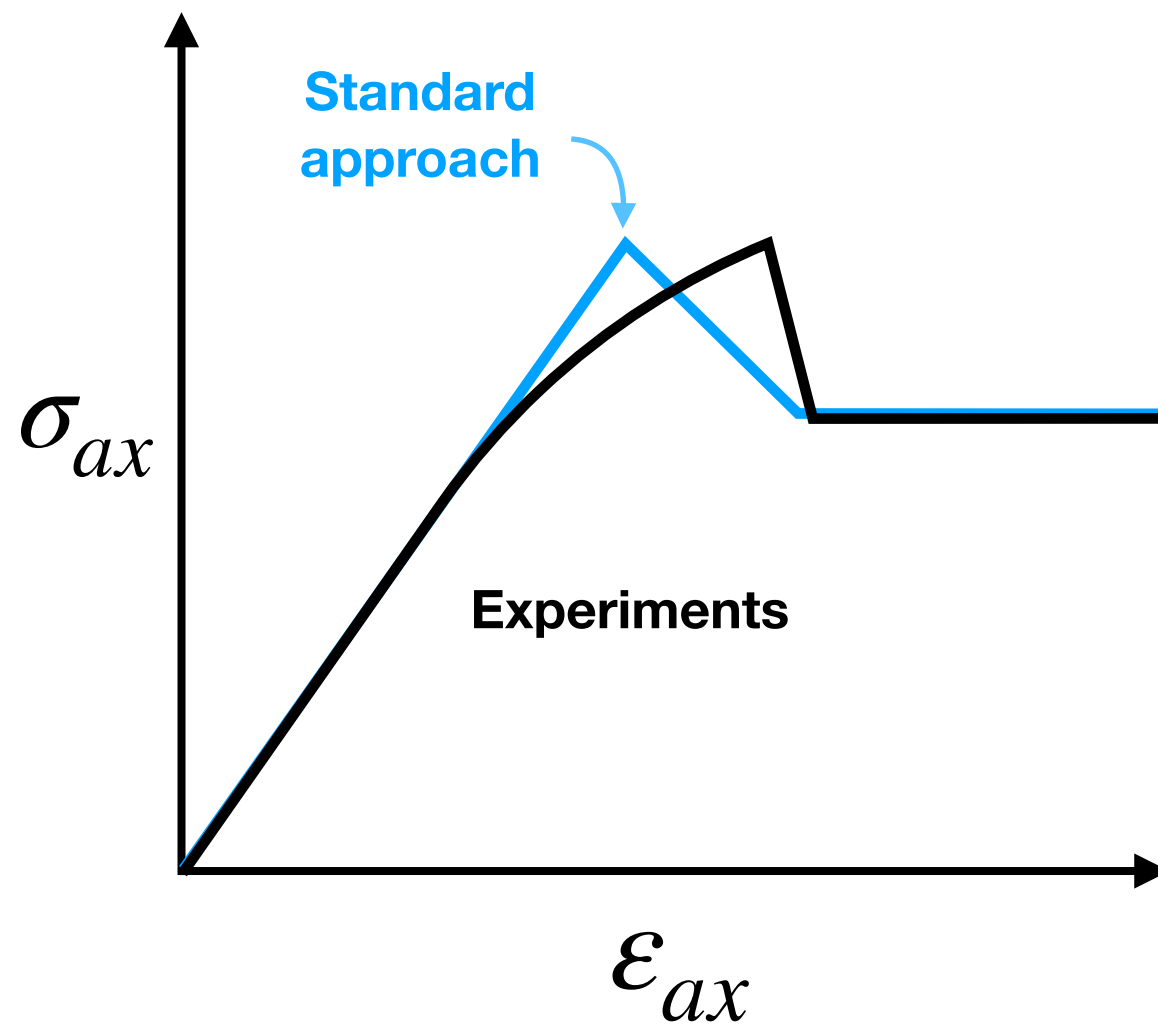
**Standard approach =
perfect plasticity +
incompressibility**

**Strain rate dependence
not captured**



**Volumetric deformation
not captured**

Experiments vs model



**Pre-peak elastic
moduli weakening
is not captured
either**

simplified effective damaged rheology

We need an effective rheology that accounts for the experimental brittle behavior of rocks, and that can hence be calibrated experimentally and upscaled.

Strain rate dependence
Internal state
Crack dilatancy
Elastic moduli weakening

simplified effective damaged rheology

Elastic behavior with moduli weakened by damage D

$$\epsilon'_{ij} = \frac{s_{ij}}{2G(1-D)}$$

Time
differentiation

Maxwell effective rheology

$$\dot{\epsilon}'_{ij} = \frac{s_{ij}\dot{D}}{2G(1-D)^2} + \frac{\dot{s}_{ij}}{2G(1-D)}$$



+

Dilatancy source term

$$\dot{\epsilon}_{kk} = \frac{1}{3}\alpha\dot{D}$$

=

$$\dot{\epsilon}_{ij} = \frac{s_{ij}\dot{D}}{2G(1-D)^2} + \frac{\dot{s}_{ij}}{2G(1-D)} + \frac{1}{3}\alpha\dot{D}\delta_{ij}$$

simplified effective damaged rheology

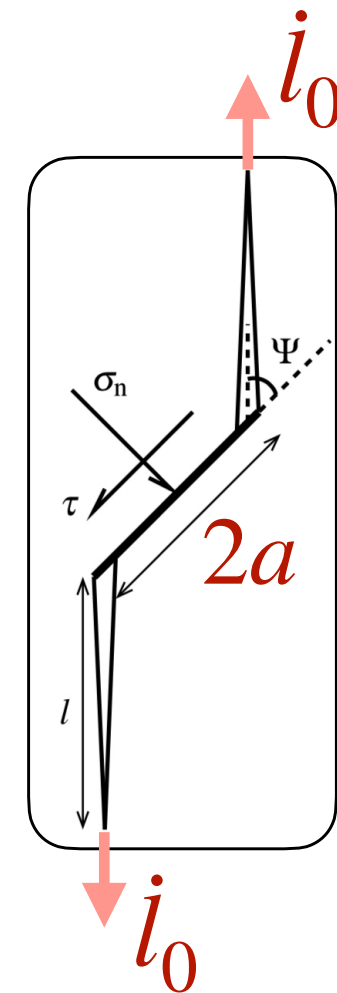
Damage growth law :

$$\dot{D} = \frac{1}{T_D} \frac{(\tau - \sigma_y)^m}{S^m}$$

$\sigma_y = P \sin \phi + C \cos \phi$ is the Mohr-Coulomb yield stress

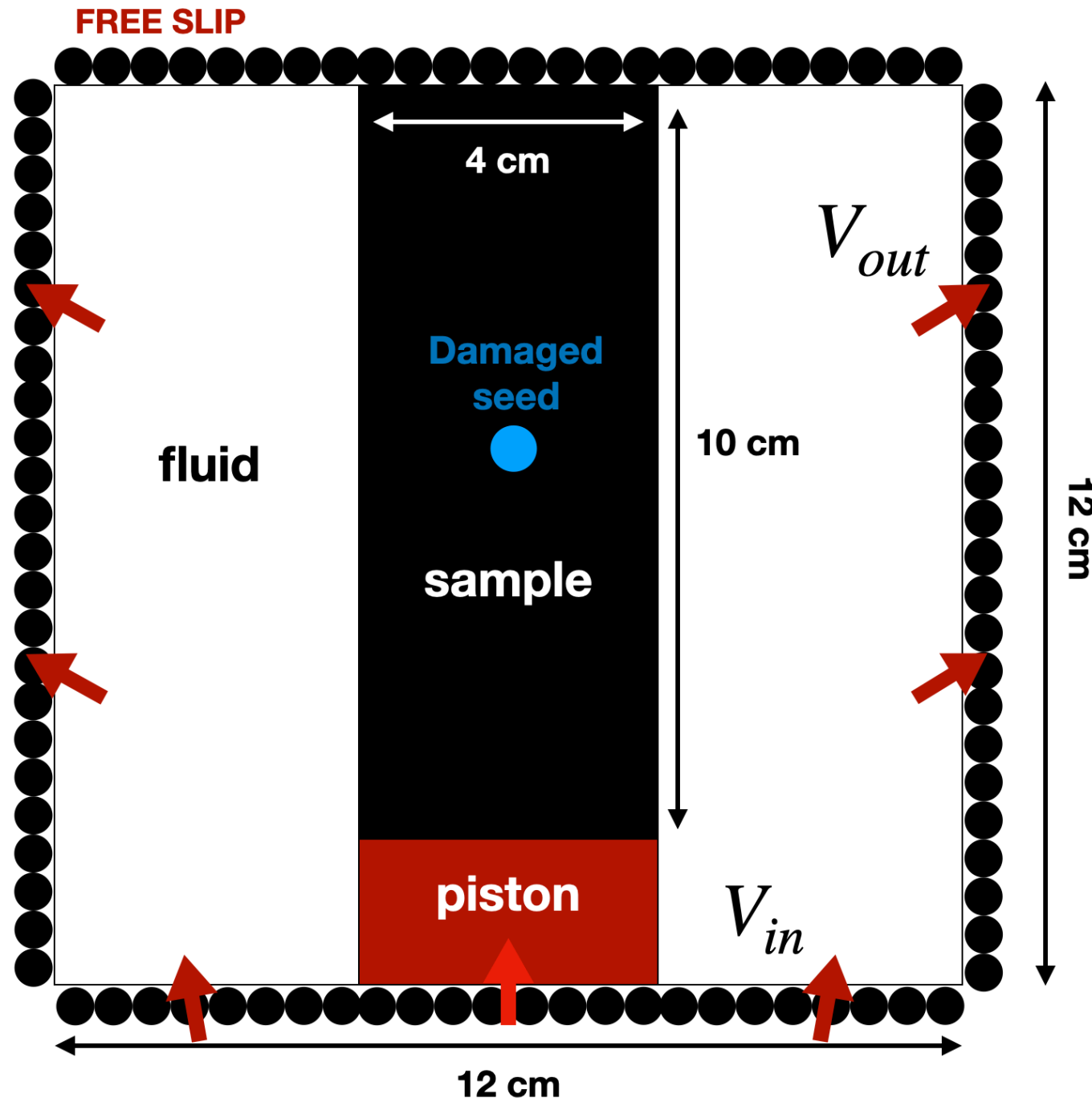
$T_D = \frac{a}{\dot{l}_0}$ is a characteristic crack growth time

$S = \frac{K_{IC}}{a^{1/2}}$ is a characteristic crack growth stress



Benchmark : Numerical press

Solve 2D plane strain linear momentum and mass conservation on a finite difference staggered grid



Incompressible material :

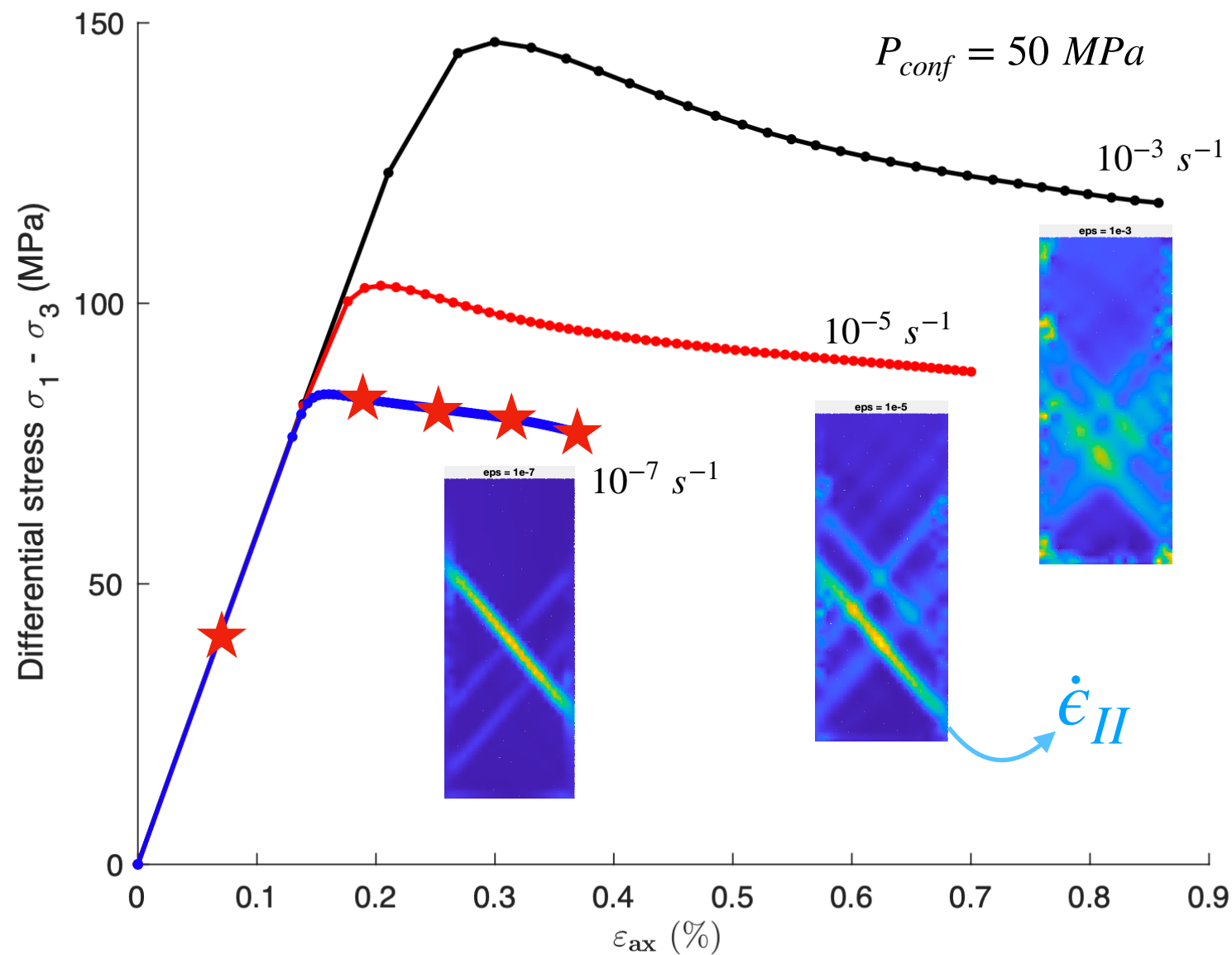
- $G = 30 \text{ GPa}$
- $\nu = 0.5$

Micromechanical parameters :

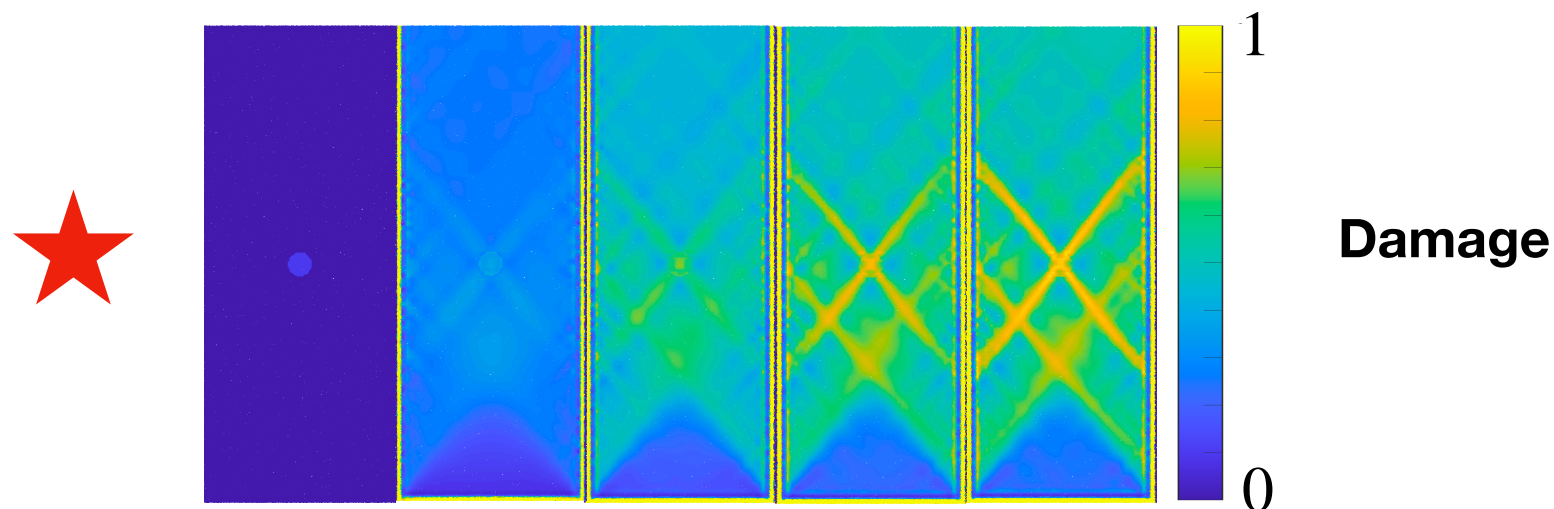
- $D_{sample} = 0$
- $D_{seed} = 0.1$
- $\dot{l}_0 = 10^{-4} \text{ s}^{-1}$
- $a = 1 \text{ mm}$
- $K_{IC} = 1 \text{ MPa} \cdot \text{m}^{1/2}$
- $\phi = 30^\circ$
- $C = 10 \text{ MPa}$
- $\alpha = 0$

No crack induced dilatancy

Preliminary results



- Realistic stress-strain curves with tangent modulus weakening, peak stress and stress drop
- Smoothly transitions towards plastic shear bands
- Peak stress increases with strain rate
- Strain localization facilitated at slower strain rates



Conclusions and perspectives

- **An alternative to plasticity and strain weakening for shear band generation in long term tectonic models**
- **Effective viscoelastic formulation based on subcritical crack growth laws**
- **Captures strain rate dependence of brittle behavior, including brittle creep / cataclastic flow**
- **Allows micro-mechanical interpretations and experimental calibrations**

Next steps :

- **Implementing inelastic dilatancy**
- **Upscaling from sample to crustal scale**