Transition from thermal pressurization (TP) to dilatant strengthening (DS) during stick-slip ruptures on saturated saw-cut thermally cracked westerly granite

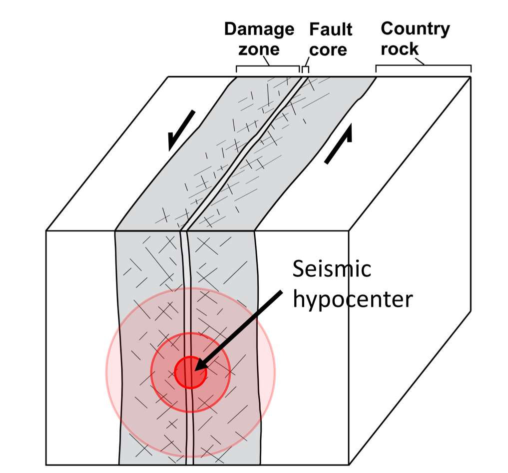
EGU26 GENERAL ASSEMBLY
Vienna, Austria
3–8 May 2026

Caiyuan Fan (*fan@geologie.ens.fr*), Gang Lin, Jérôme Aubry, Damien Deldicque, Carolina Giorgetti, Harsha S. Bhat, Alexandre Schubnel

Laboratoire de Géologie, École Normale Supérieure/CNRS UMR 8538, PSL University, Paris, France

1. Introduction

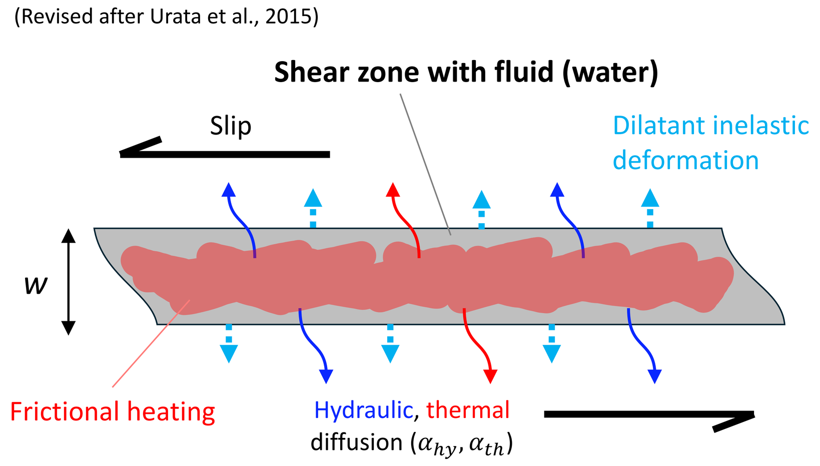
Earthquakes by fault weakening



(Mitchell and Faulkner, 2009)

Thermal–hydraulic–mechanical processes during fault slip

(Revised after Urata et al., 2015)



Theoretical description (Rice, 2006)

$$\frac{\partial T}{\partial t} - \frac{\tau V}{\rho c w} = \alpha_{th} \frac{\partial^2 T}{\partial y^2}$$

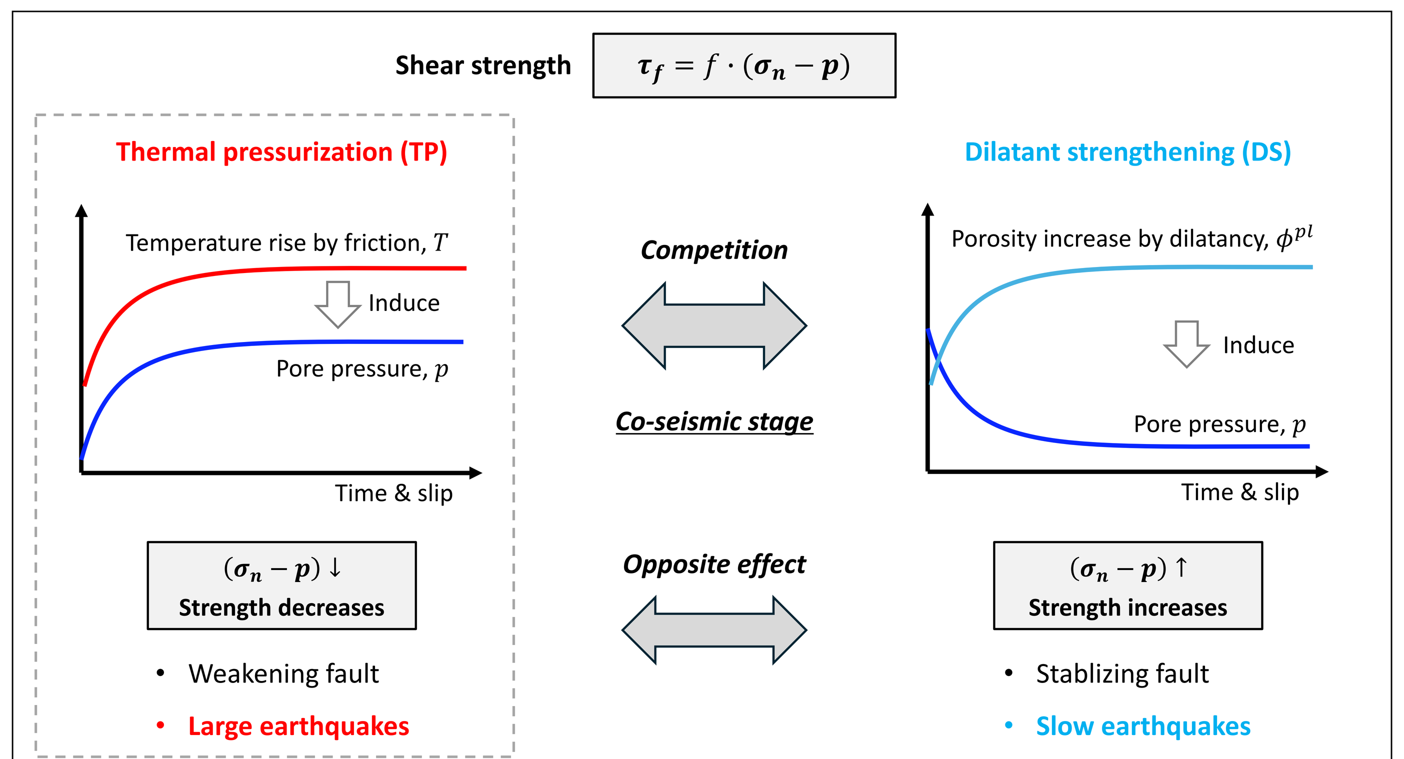
$$\frac{\partial p}{\partial t} - \Lambda \frac{\partial T}{\partial t} + \frac{1}{\beta}\frac{\partial \phi^{pl}}{\partial t} = \alpha_{hy} \frac{\partial^2 p}{\partial y^2}$$

Relative efficiency of DS to TP for fluid pressure responses (Segall et al., 2010)

$$\frac{E_p}{E_T} = \frac{\rho c}{f_0 \Lambda \beta (\sigma - p^\infty)} \left(\frac{\varepsilon w}{d_c}\right)\left(\frac{\alpha_{th}}{\alpha_{hy}}\right)$$

(Larger E_p/E_T → Stronger DS dominance)

Pore pressure's effect on strength and two opposite mechanisms



NOT observed in stick-slip experiments! **TP-DS competition on a same fault?**

This experimental study

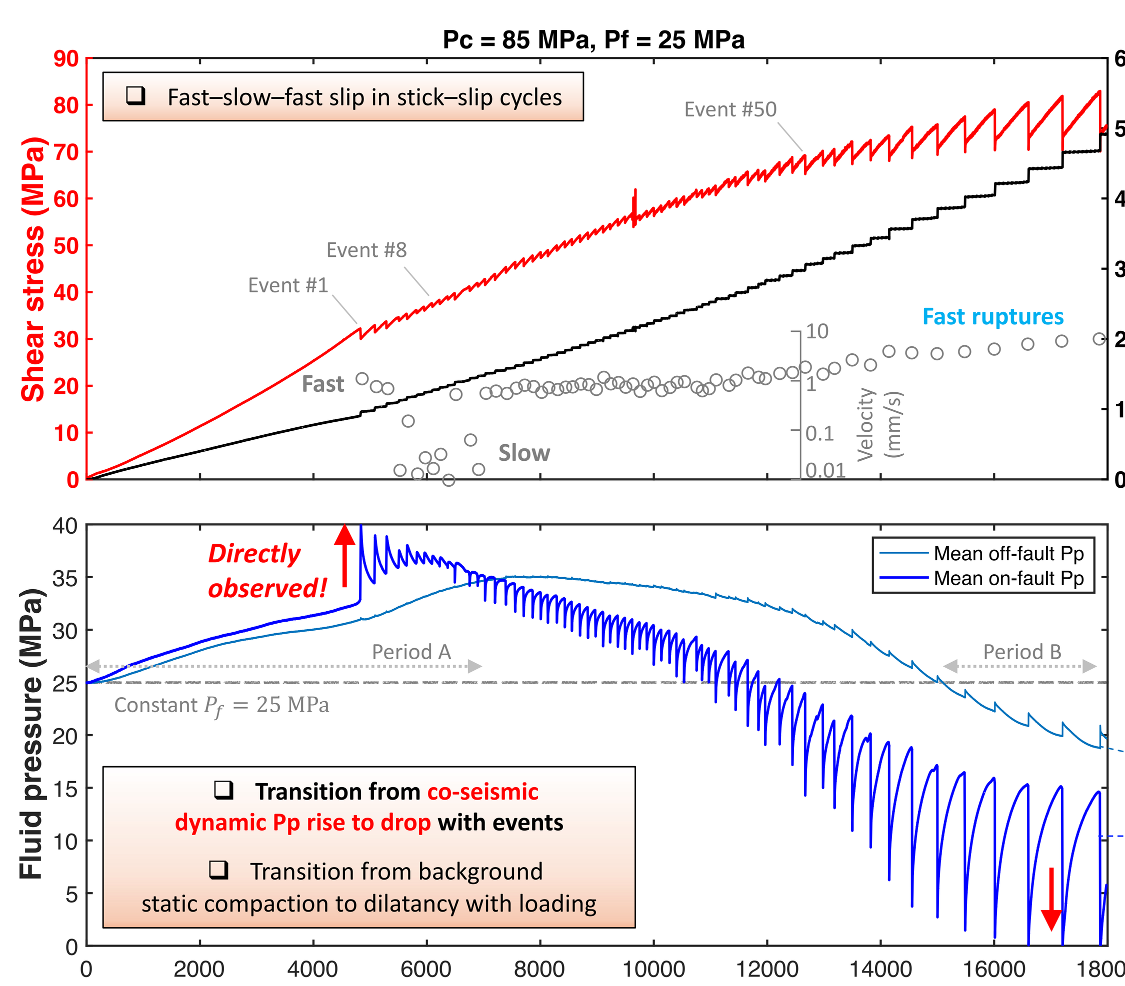
- **Objective**
  - Constraint TP condition
  - TP-DS competition
- **Method**
  - Triaxial stick-slip tests
  - On-fault pore fluid pressure (Pp) measurements
  - Three effective confining pressures (Pc-Pf= 30, 45, 60 MPa)
- **Four experiments**

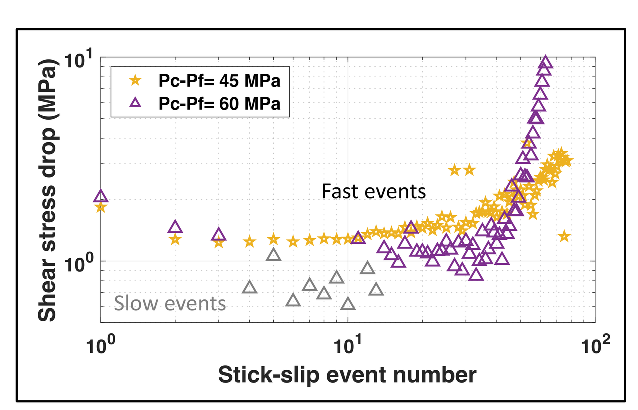
(Condition and Symbol) — Shown below: WGF10

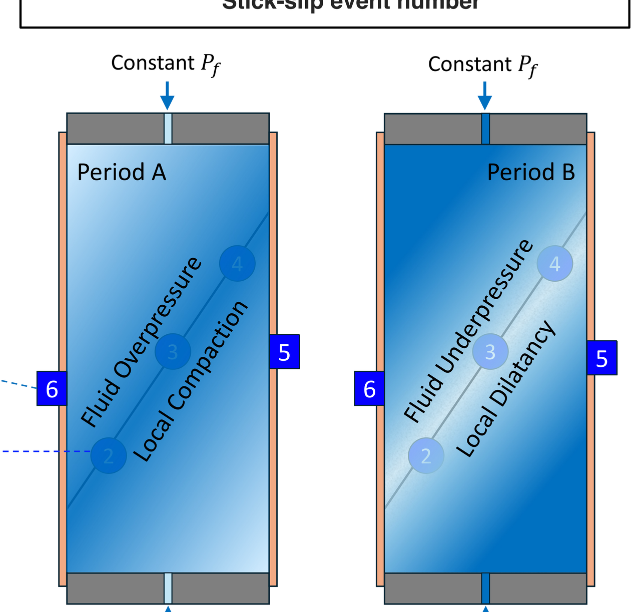
30 MPa	45 MPa	60 MPa	45 MPa
○ WGF9	□ WGF7	△ WGF10	☆ WGF8
Permeability ~ 10^{-20} m^2			10^{-19} m^2

2. Experimental Result

Direct experimental record of pore pressure (rise & drop) evolution during stick-slip rupture cycles

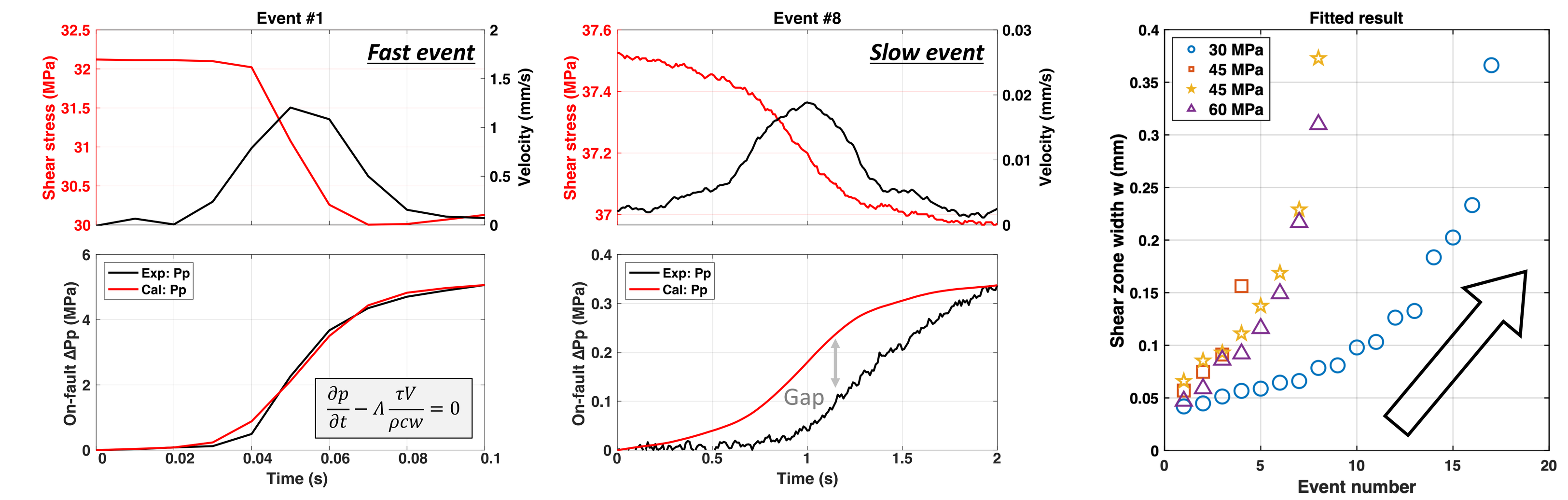




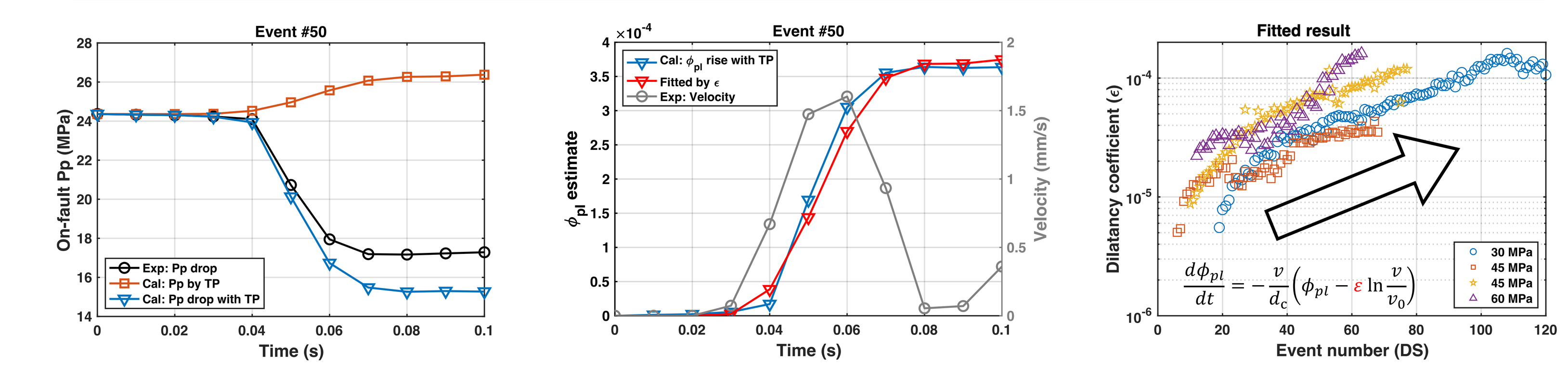


3. Analysis and discussion

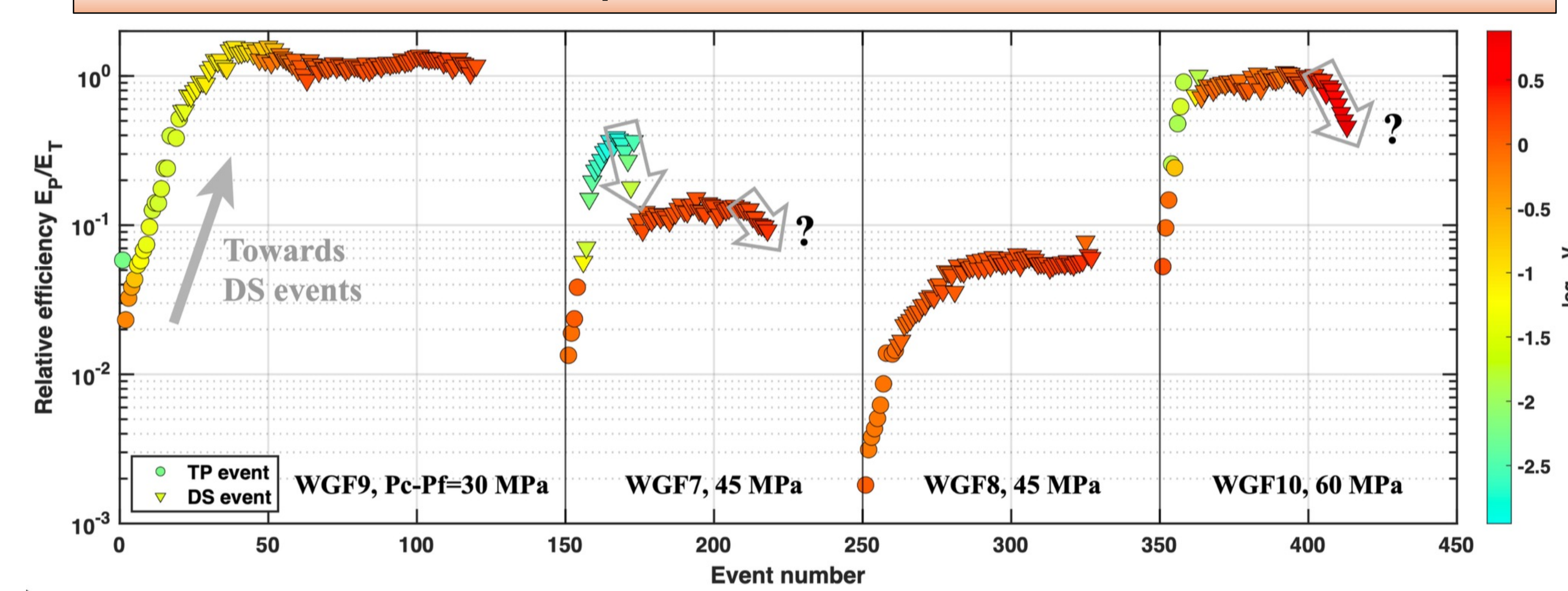
(1) TP model (undrained, adiabatic assumption) reproduces recorded co-seismic pore pressure rise



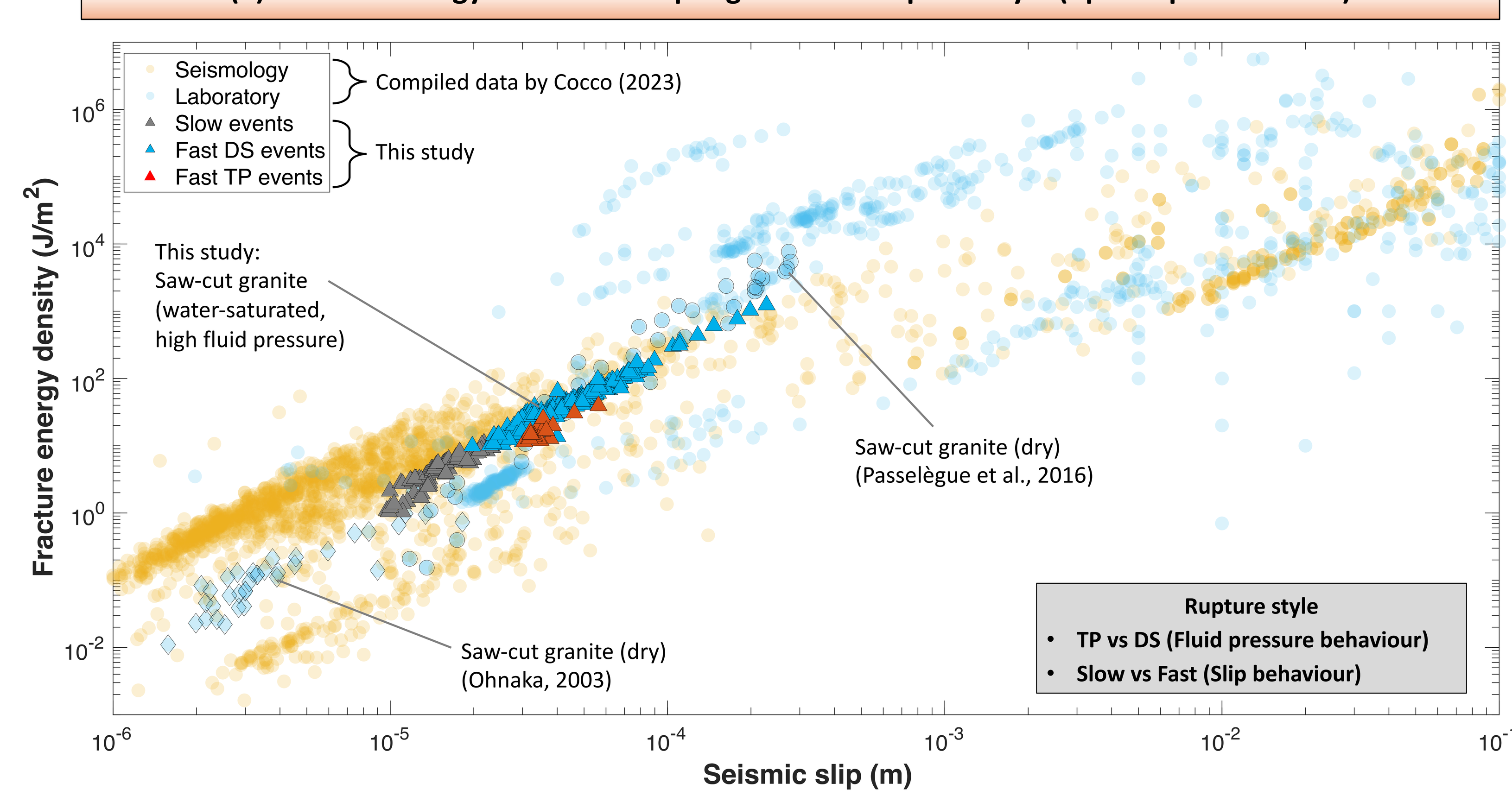
(2) Dilatancy (undrained, adiabatic assumption) reproduces recorded co-seismic pore pressure drop



(3) Evolution of relative efficiency (E_p/E_T), showing a systematic shift toward DS-dominated behaviour



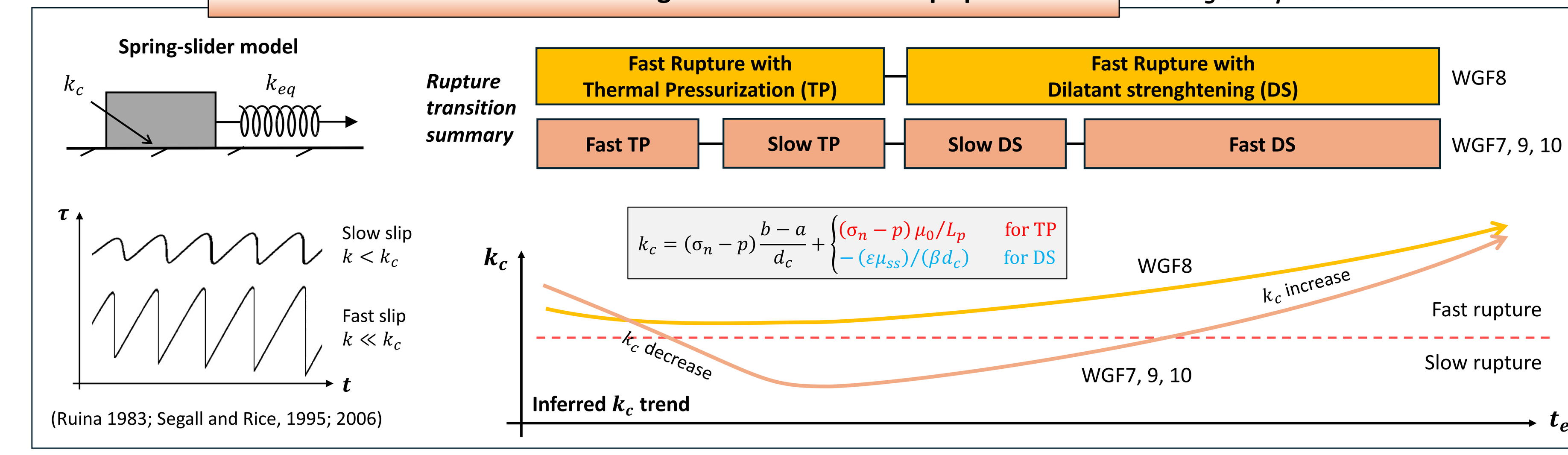
(4) Fracture energy scales with slip regardless of rupture style (Pp & slip behaviours)



4. Physical picture of the rupture cycles

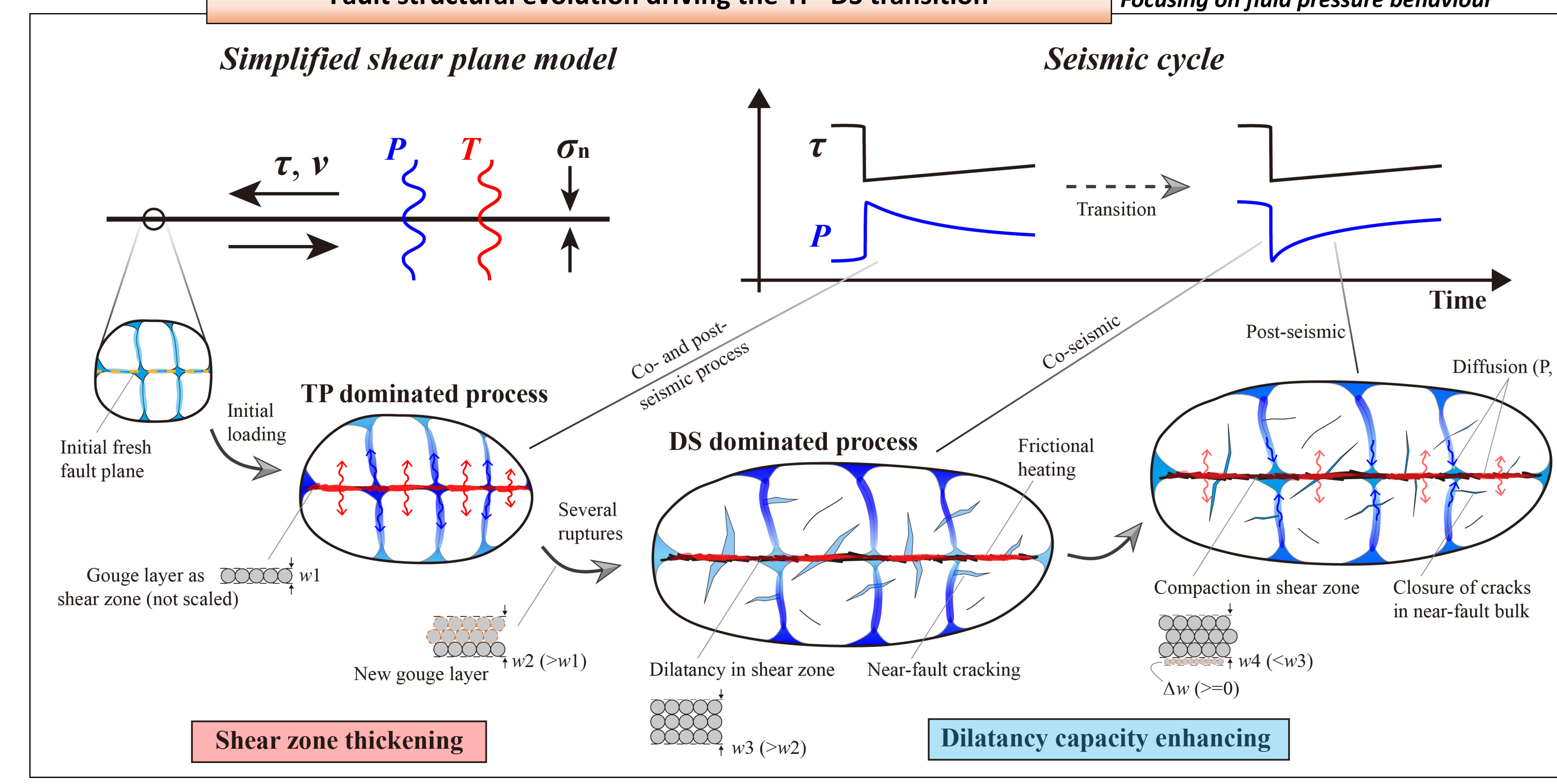
Critical stiffness evolution driving the Fast-slow-fast slip spectrum

Focusing on slip behaviour



Fault structural evolution driving the TP–DS transition

Focusing on fluid pressure behaviour



Open question: Dilatancy should stabilize faults, why do fast ruptures still occur despite large co-seismic Pp drops?

Take-home Messages

1) Direct experimental evidence of continuous co-seismic pore pressure (Pp) evolution during triaxial stick-slip rupture series is obtained.
2) Co-seismic Pp transitions with events from TP-driven increases to DS-driven drops during rupture, accompanied by a fast–slow–fast slip spectrum.
3) Structural evolution of the shear zone (thickening) drives the transition, progressively enhancing dilatancy over thermal pressurization (TP).

OSPP

EGU26-9839

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