Fluid injection and the mechanics of frictional stability of shale-bearing faults

Marco M. Scuderi and C. Collettini

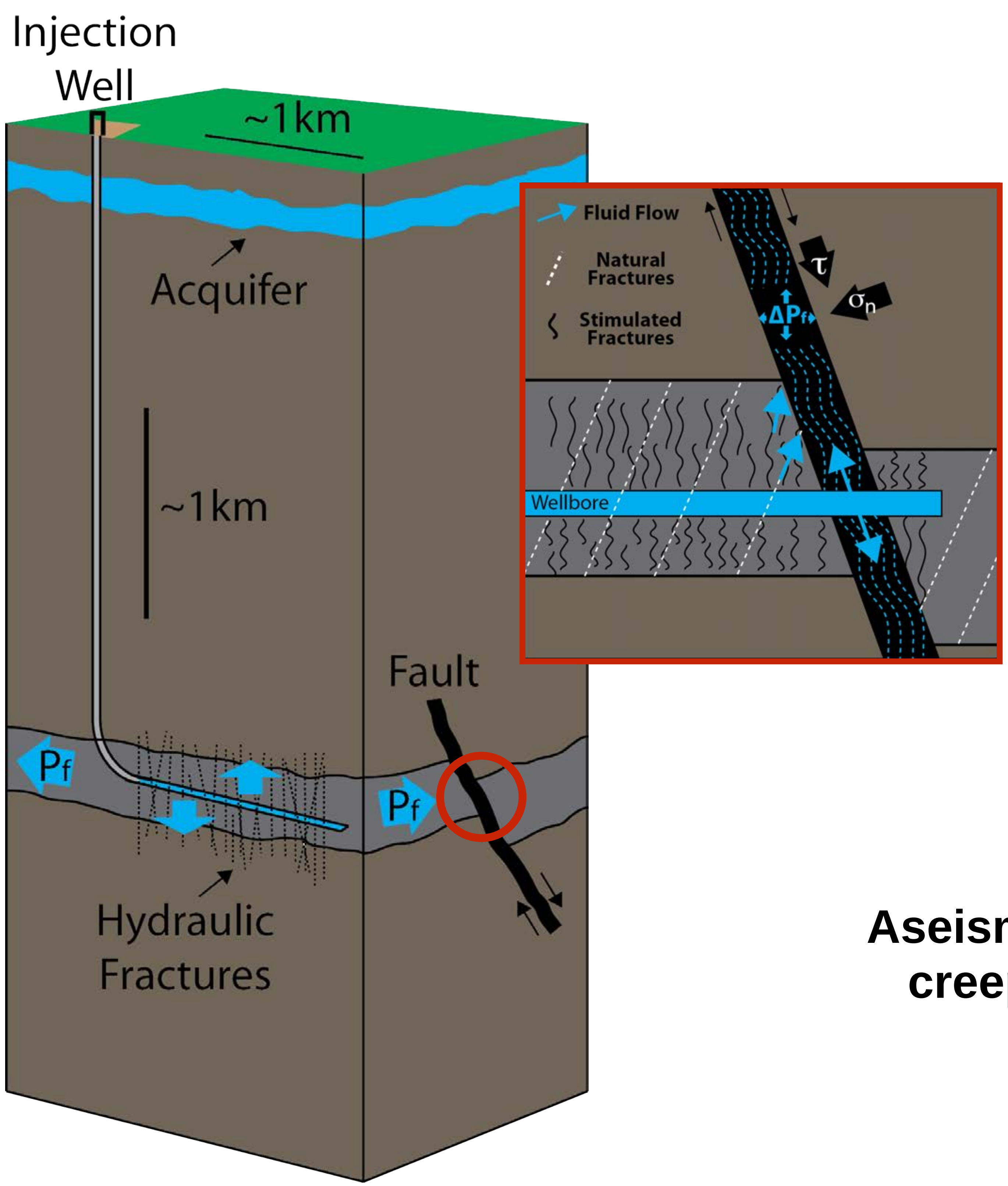
"La Sapienza" University of Rome, Italy

3rd induced seismicity workshop, Davos

European Union Horizon 2020
Marie Sklodowska-Curie
FEAT No. 656676

European Research Council
Seventh Framework Programme
"Ideas" Starting Grant
GLASS: 259256

Injection induced earthquakes



Modified after
Davies et al., 2013

What is the fault response to fluid pressure stimulation?

Large scale fluid injection can generate overpressure and induce seismicity by reactivating existing ancient faults.

Important to characterize:

<u>Type of slip behavior</u>

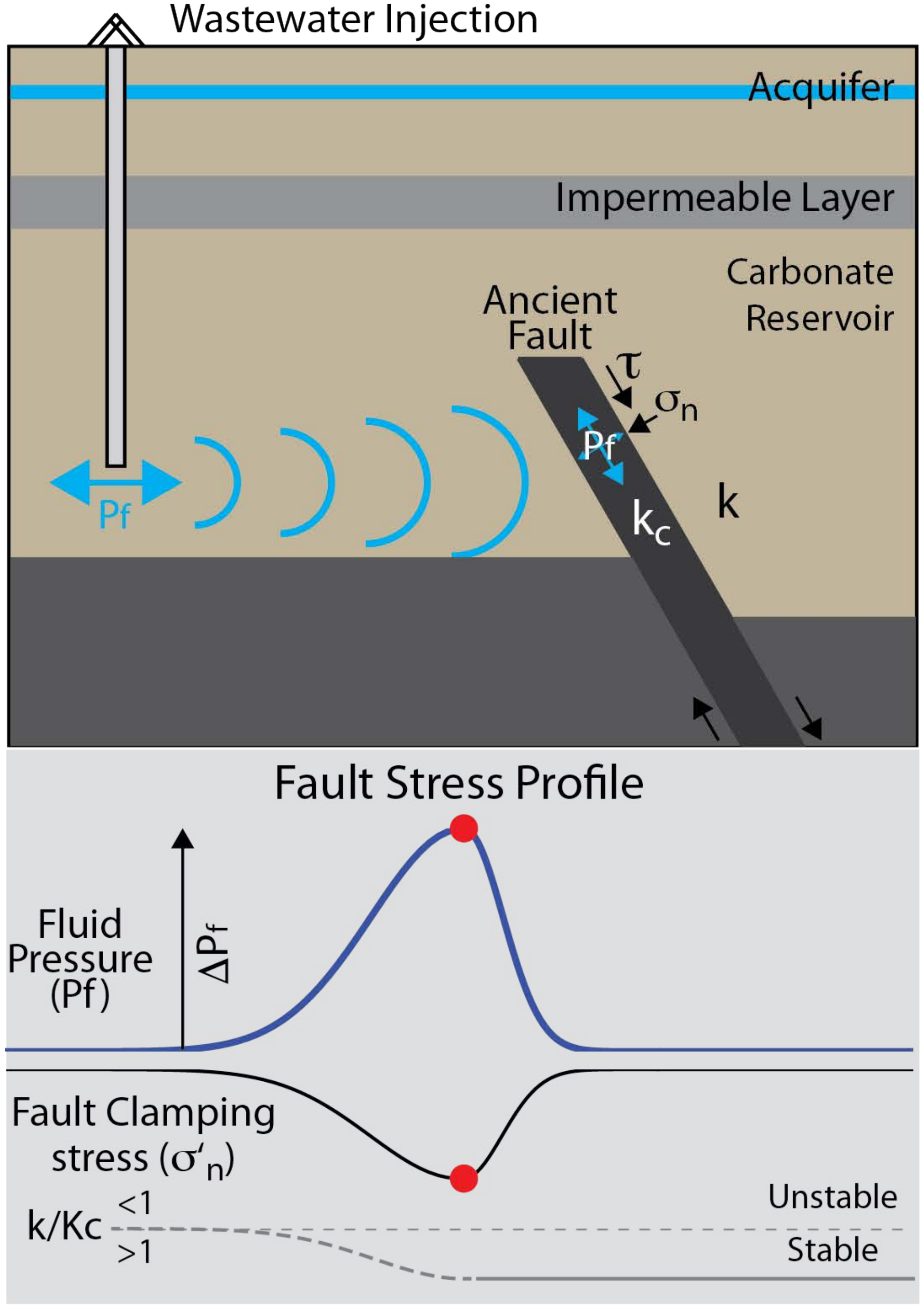
Aseismic creep

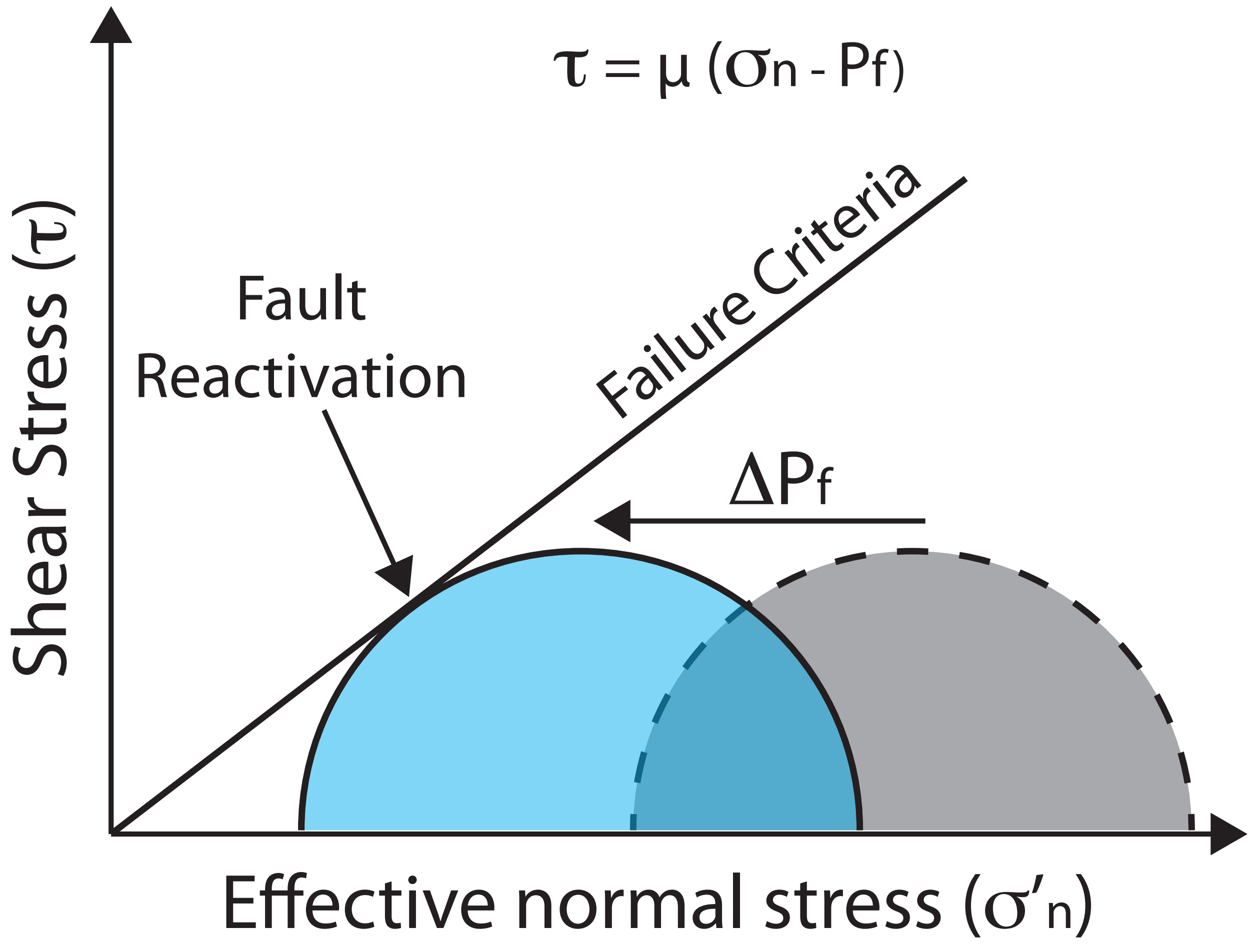
Slow-slip → Slow energy release rate

Fast-slip → high energy release rate

Fault Reactivation vs. Frictional Slip Stability

The increase in fluid pressure along a fault will decrease the effective normal stress that clamps the fault in place favoring fault reactivation





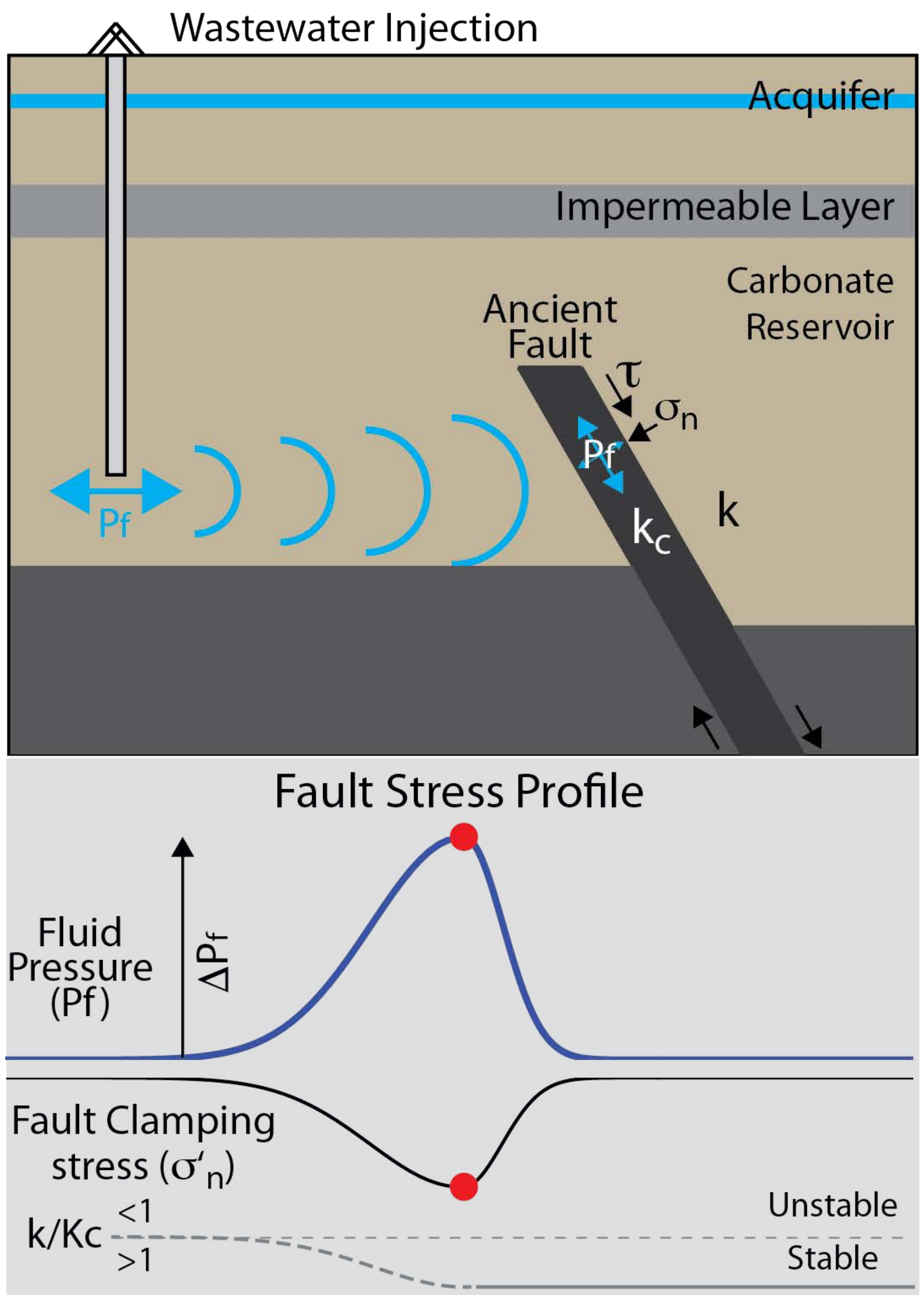
Hubbert and Rubey, 1959 Bull. Geol.Soc. Am

Fault Reactivation vs. Frictional Slip Stability

Upon reactivation slip behavior is described via the **Rate- and State- Frictional Properties**:

(1) potentially seismic (Velocity Weakening)

(2) aseismic (Velocity Strengthening)



Criterion for fault stability

defined by the critical stiffness kc

$$k_c = \frac{(\sigma_n - P_f)(b-a)}{D_c}$$

$k < k_c$	$k \sim k_c$	$k > k_c$
Unstable sliding	Conditionally stable sliding	Stable sliding

Gu et al., 1984 JGR; Leeman et al., 2016 Nat.Comm.

Outstanding questions:

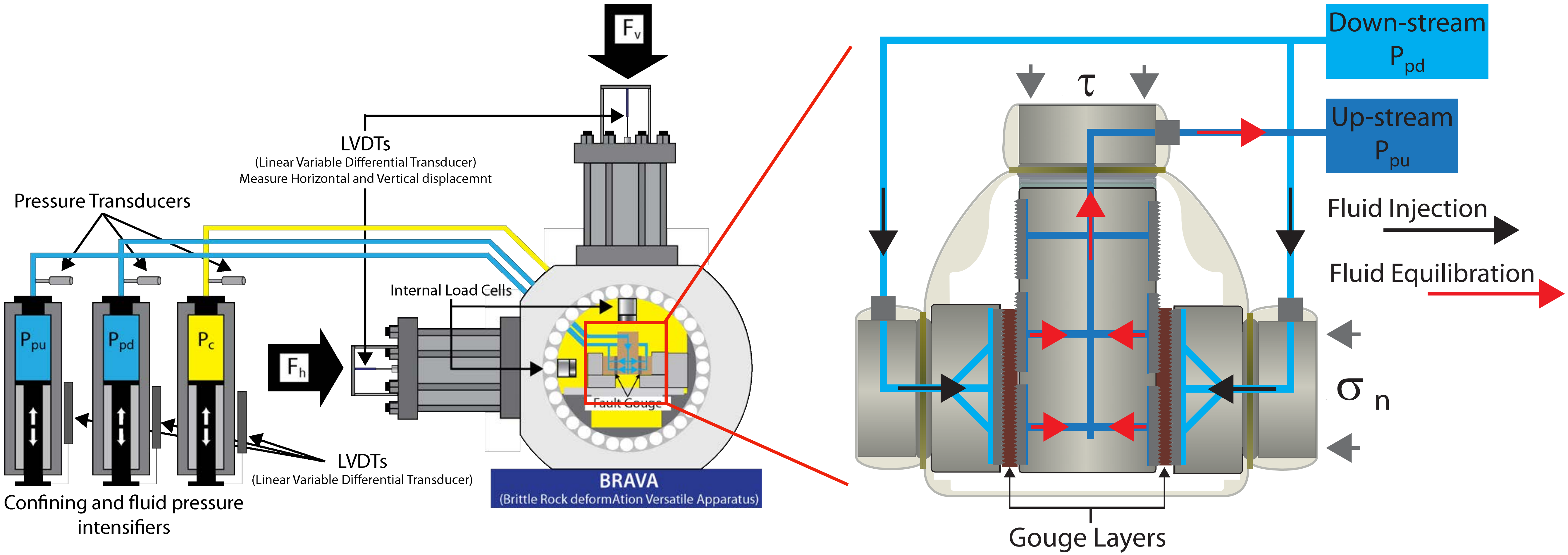
- What is the coupling between hydrological and mechanical properties of a simulated fault during fluid pressurization?
- How fault rheology and frictional stability are influenced by fluid pressurization?

Experimental set-up

Biaxial Apparatus

in a Double Direct Shear configuration

within a Pressure Vessel



Details in Scuderi et al., 2017 EPSL

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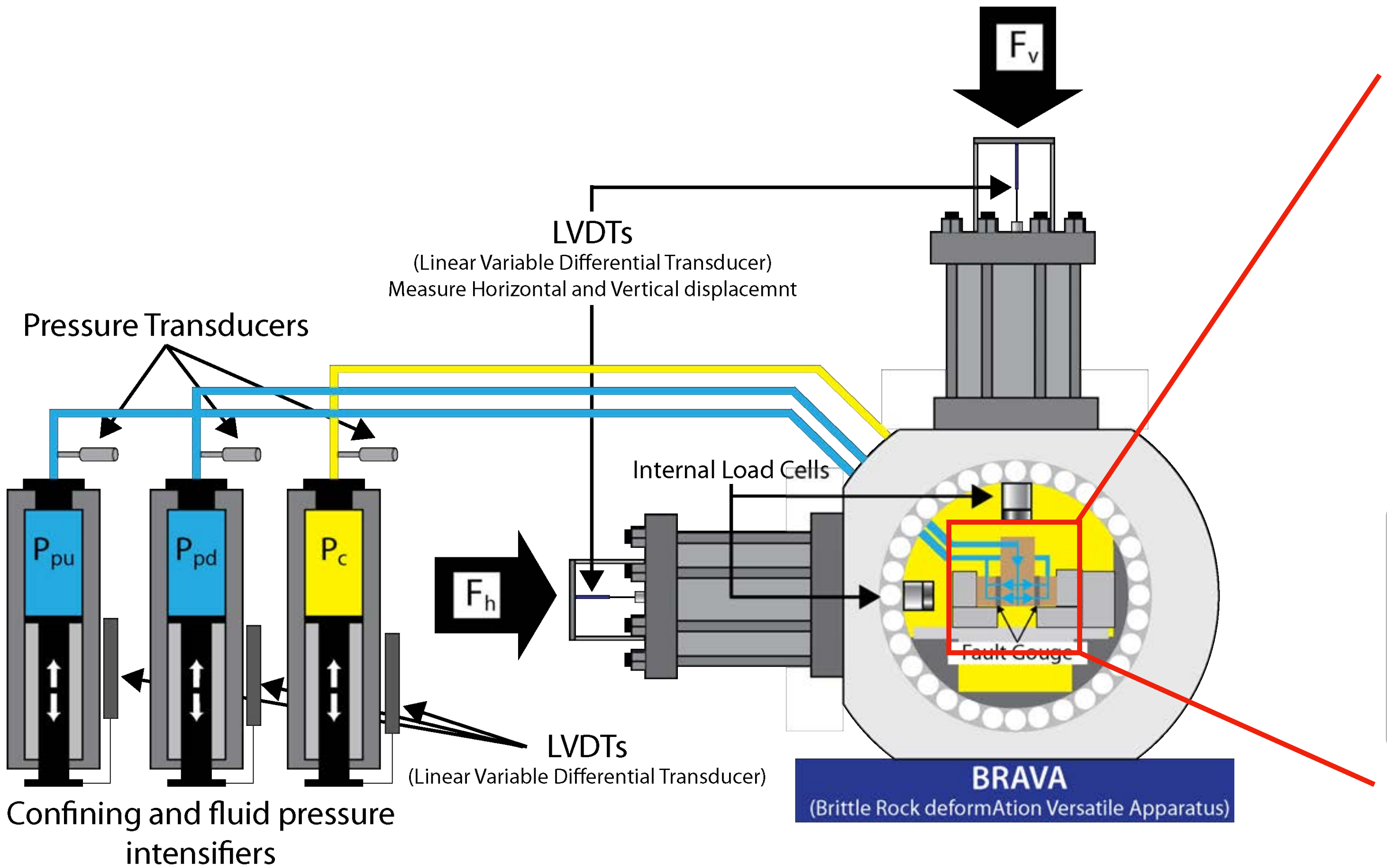
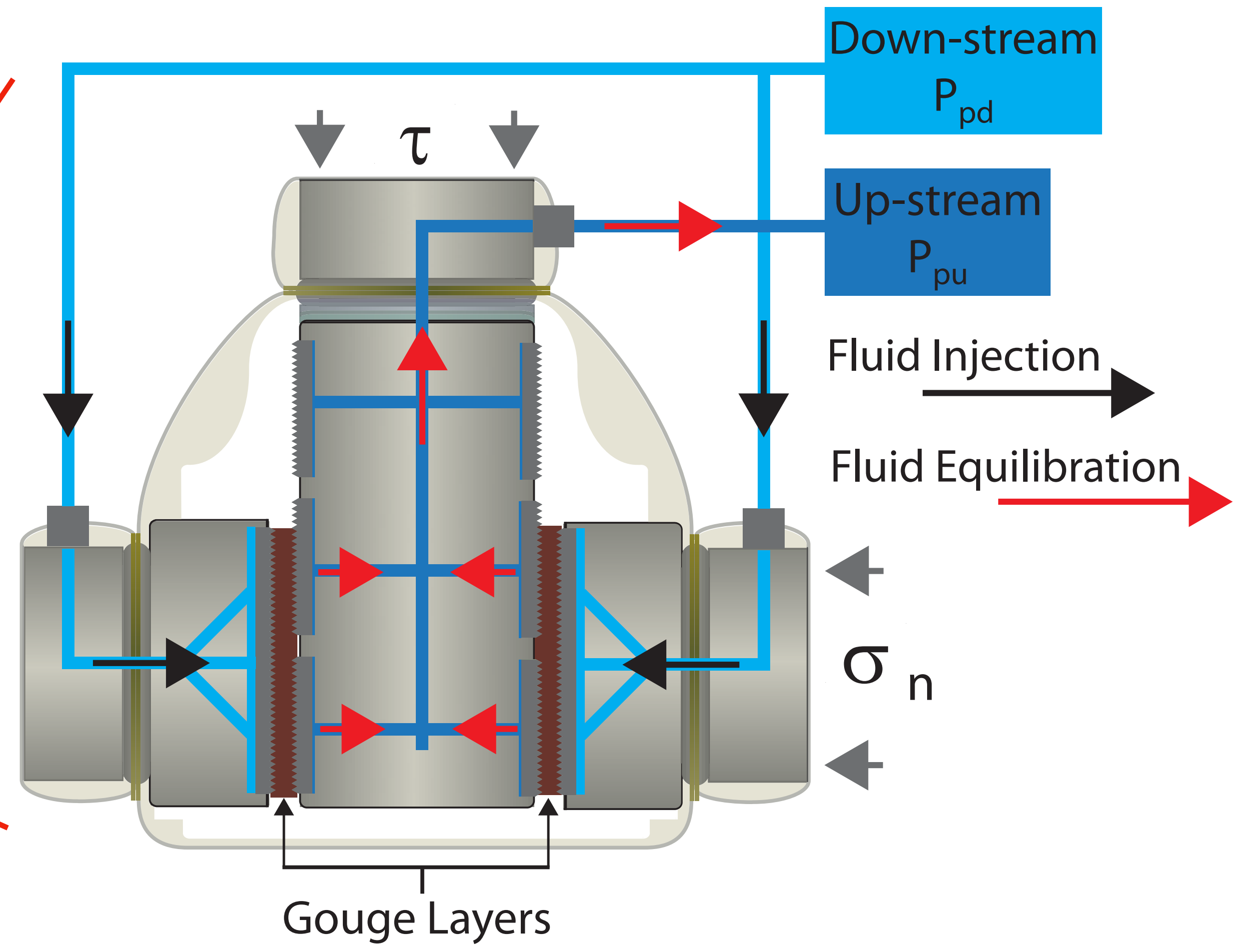


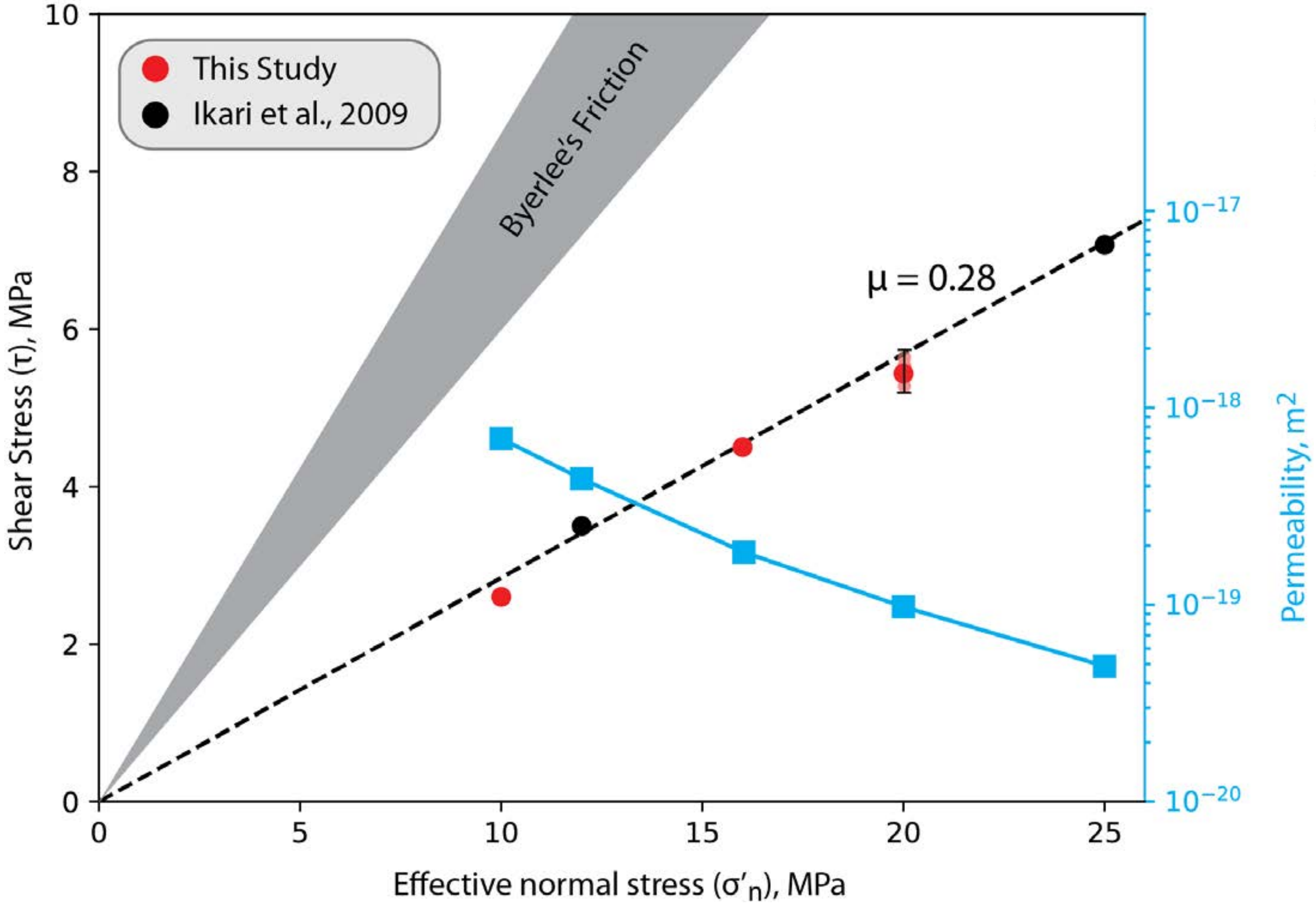


Shale simulated fault gouge: Illite (60%), Quartz (27%), Kaolinite (9%)

Details in Scuderi et al., 2017 EPSL

Results

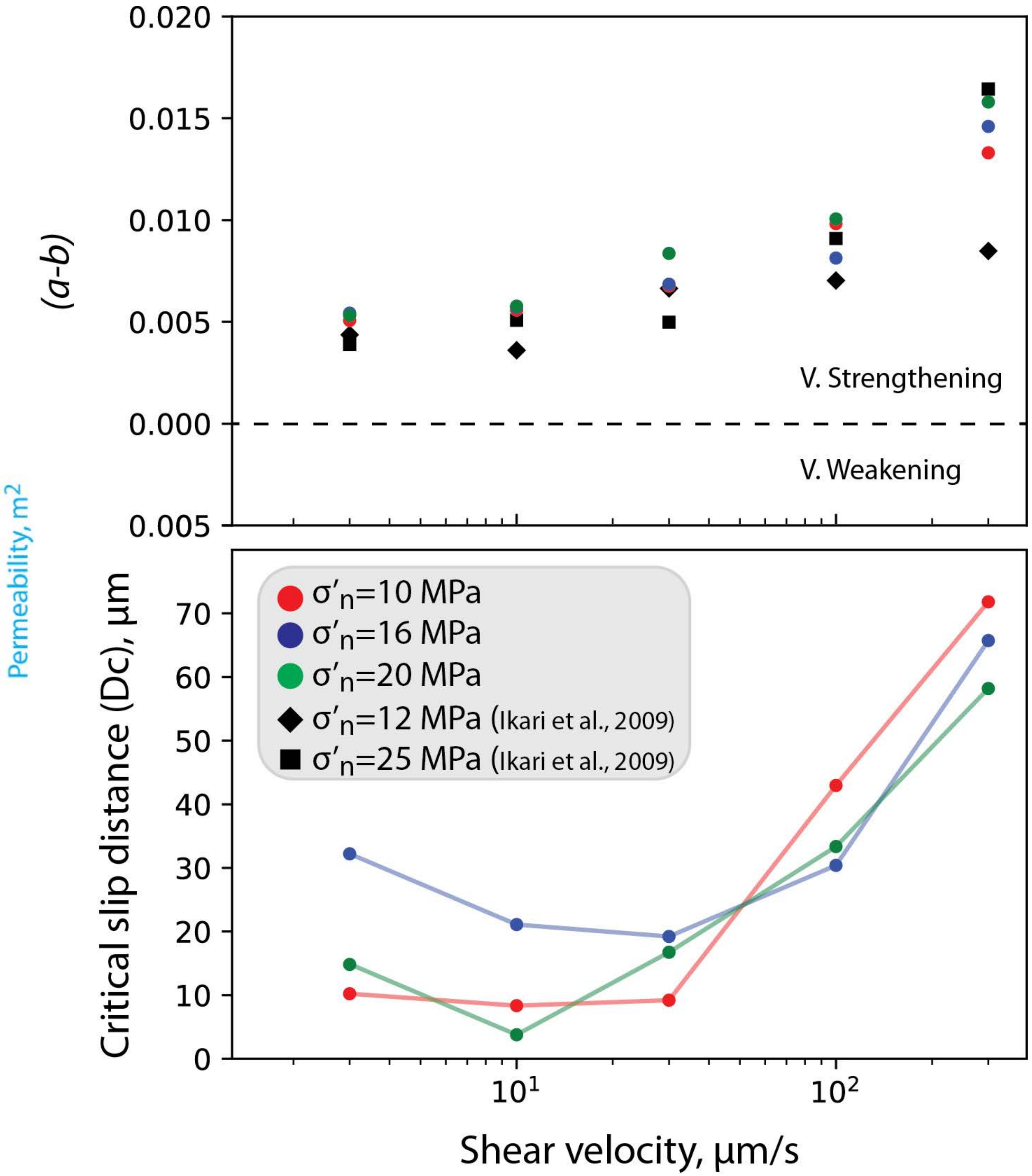
Frictional strength



Fault strength is low μ=0.28

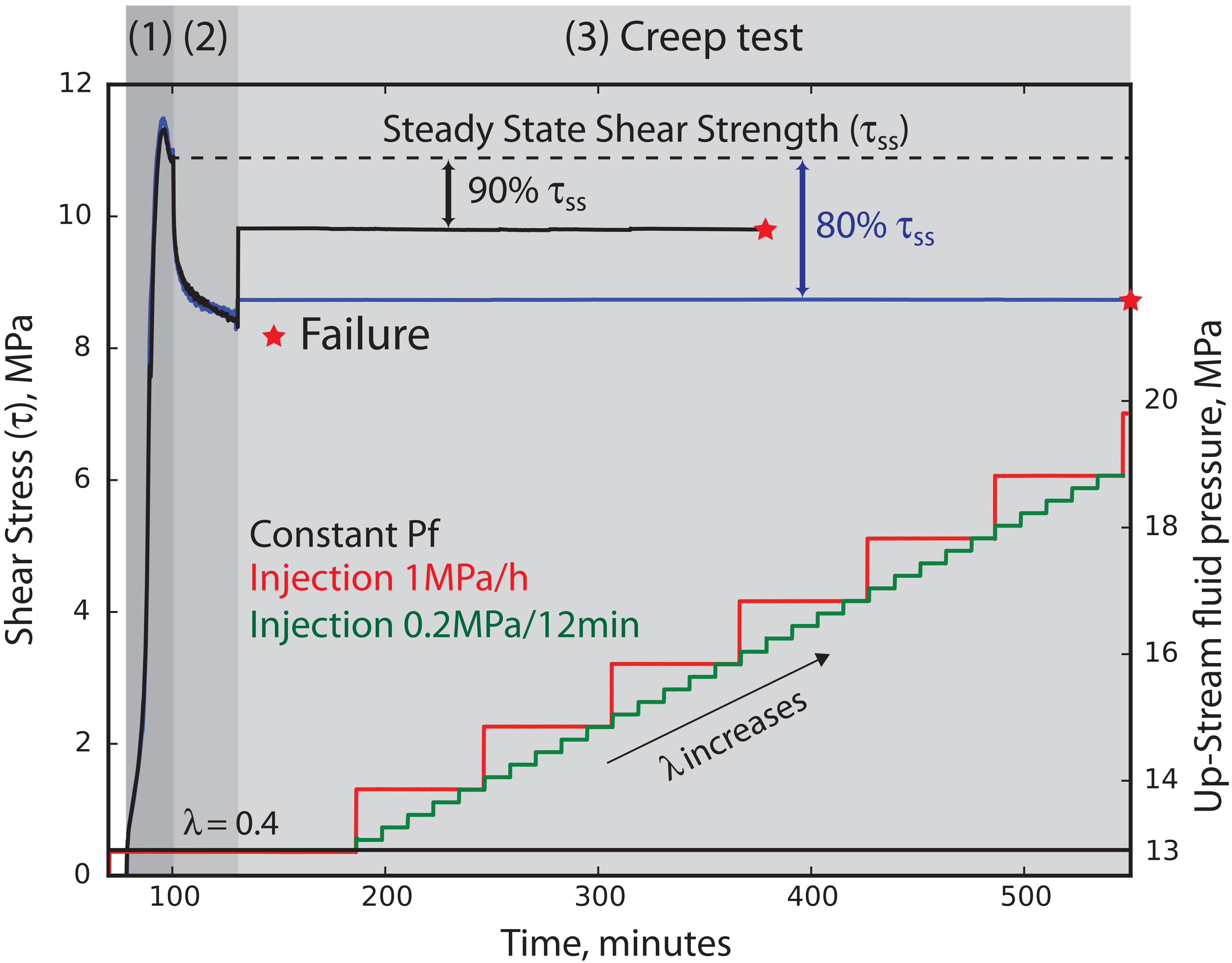
Fault permeability k~10^{-19} [m^2]

Rate- and state- properties



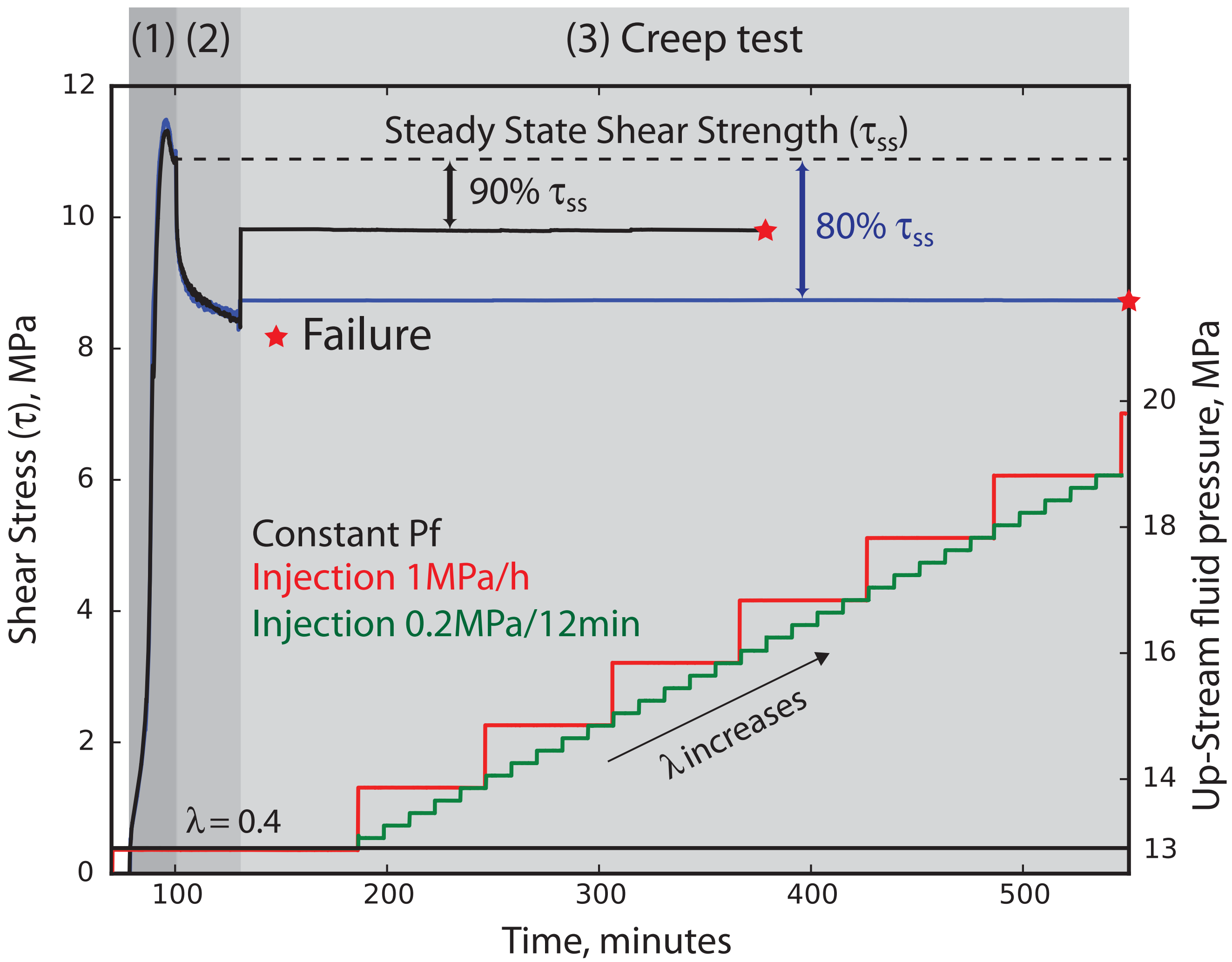
Scuderi and Collettini, 2018 JGR

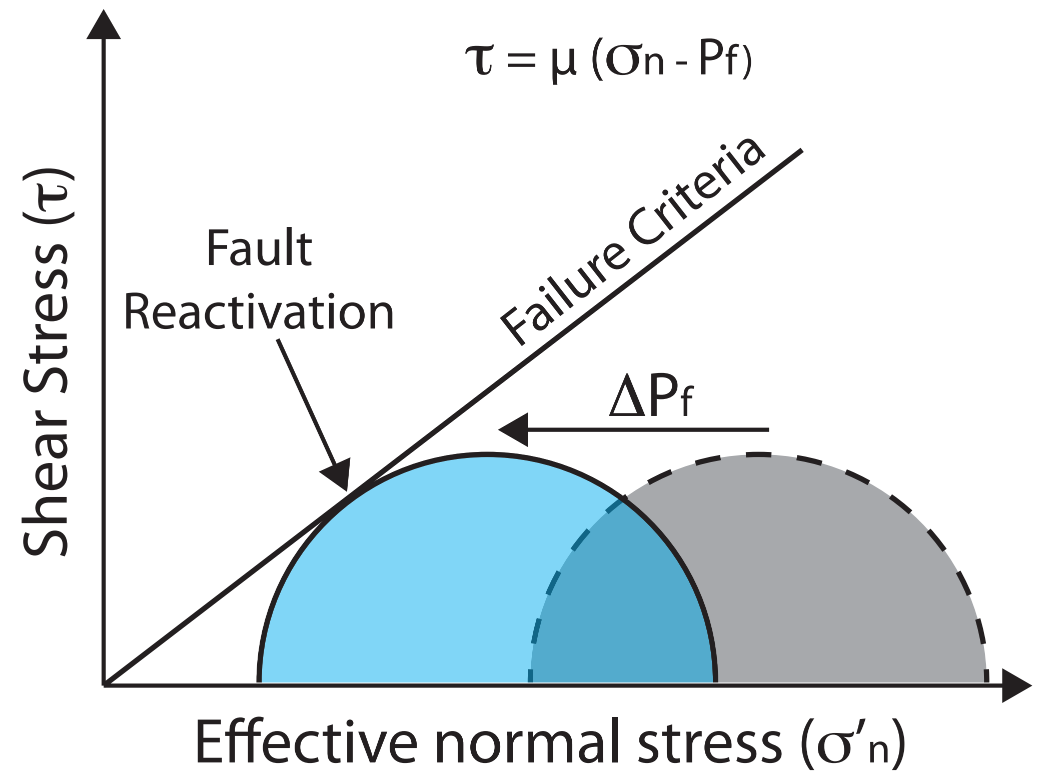
Creep Experiments



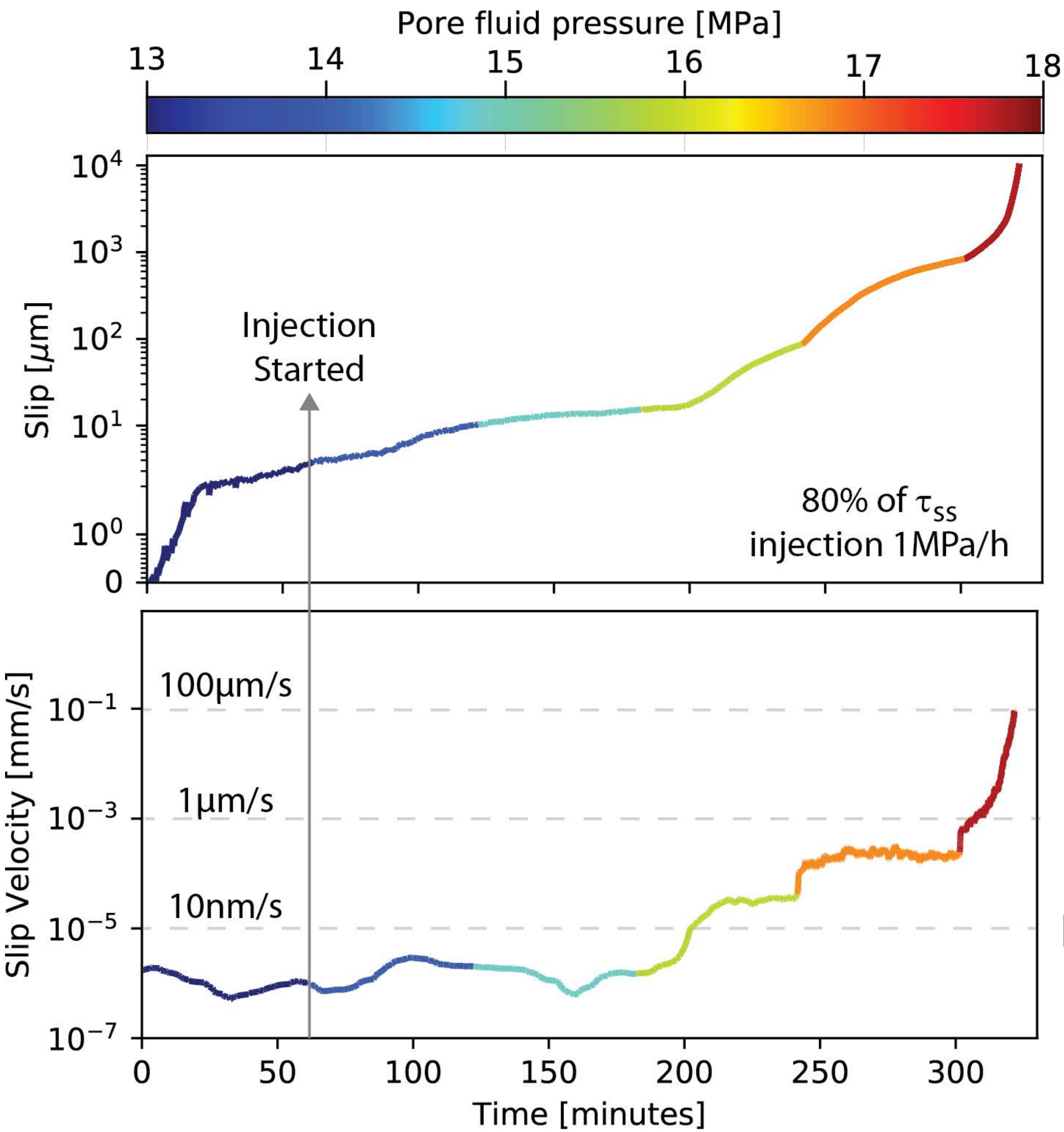
Details in Scuderi et al., 2017 EPSL; Scuderi and Collettini, 2018 JGR

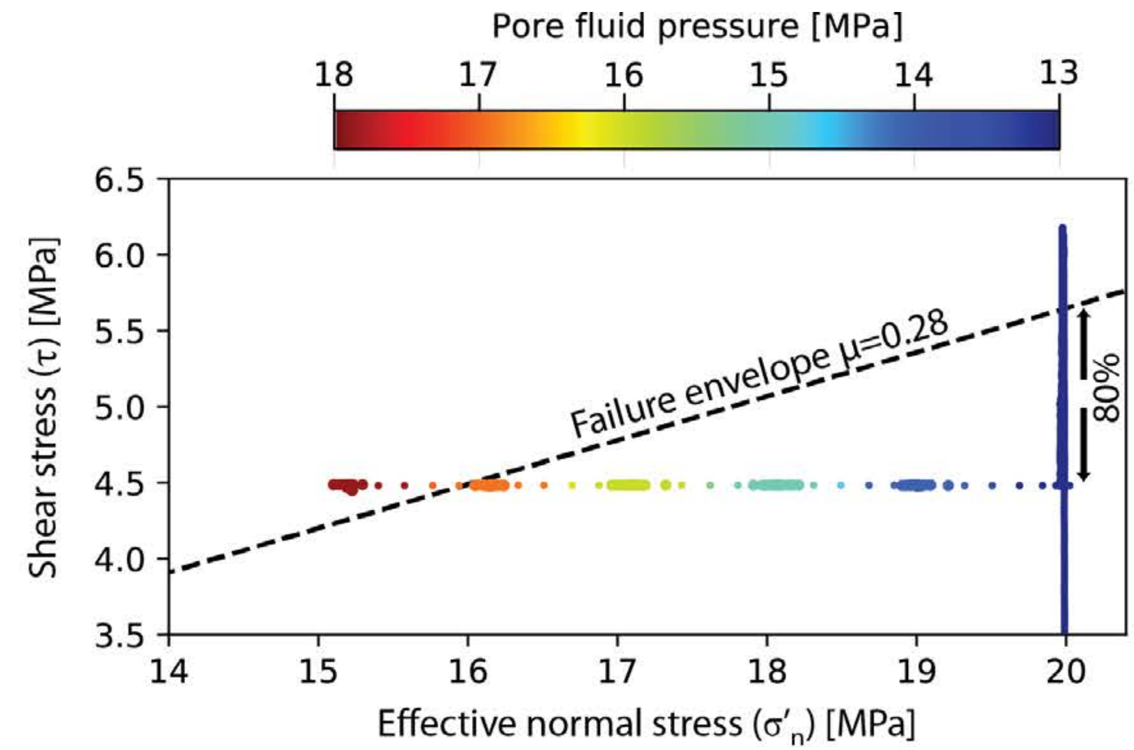
Creep Experiments





Creep Experiments - slip behavior upon fluid pressurization



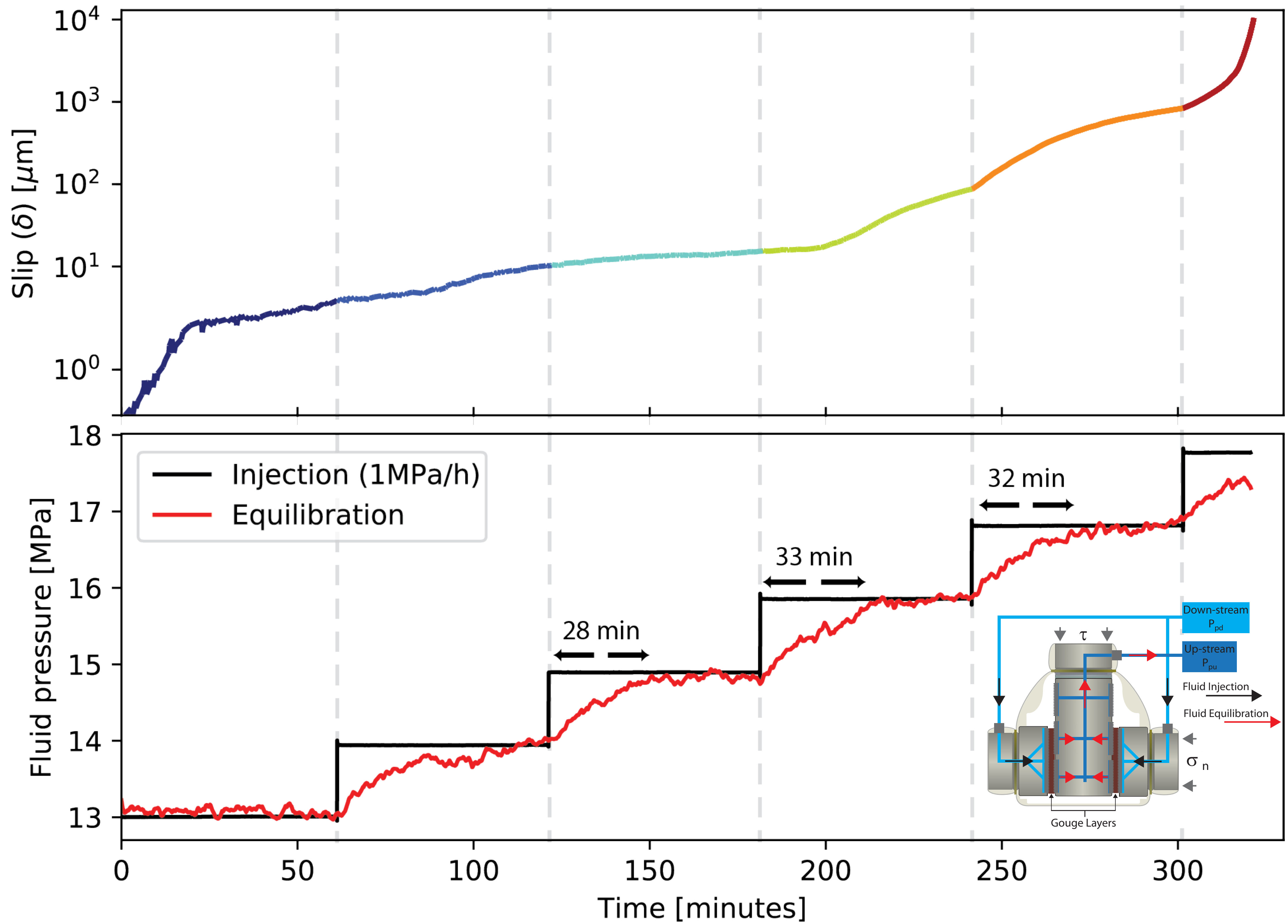


Increase fluid pressure causes fault acceleration followed by steady state slip at higher slip rate

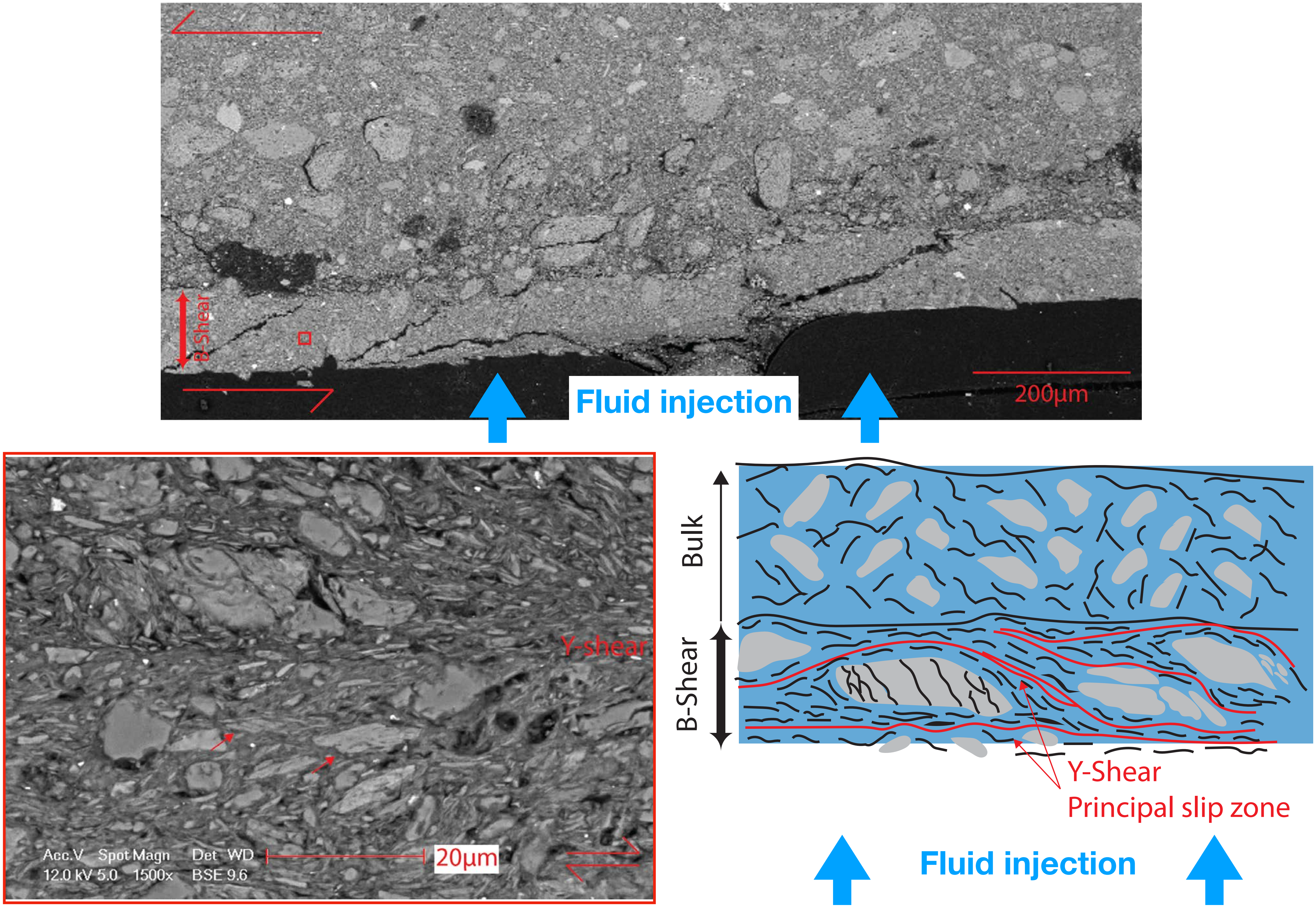
Fault acceleration remains slow with peak slip velocity of ~ 100μm/s

Scuderi and Collettini, 2018 JGR

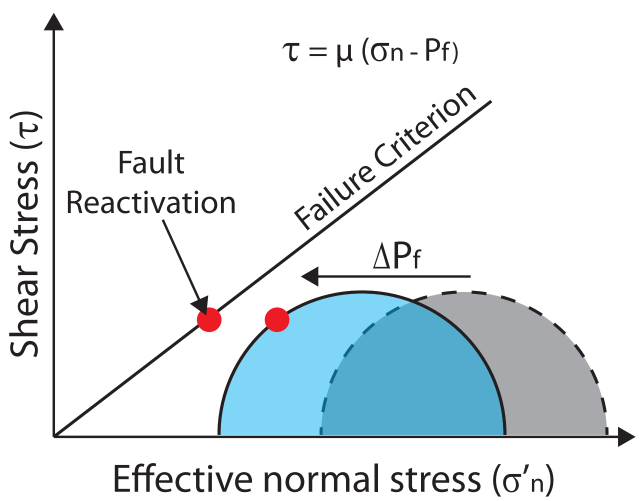
Creep Experiments - Fluid diffusion

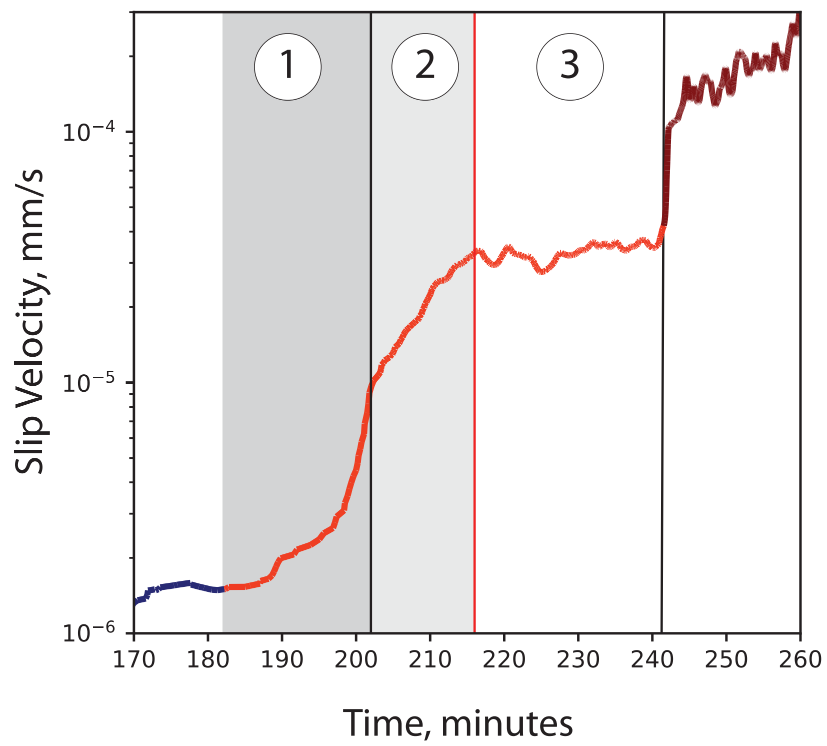


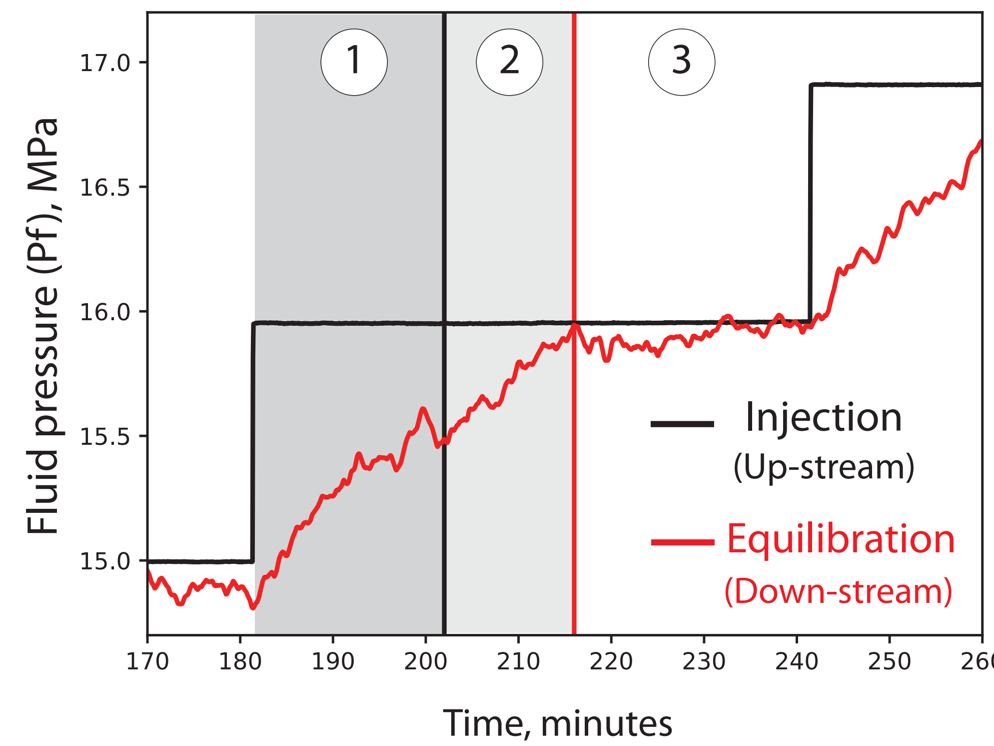
Creep Experiments - Fault zone structure

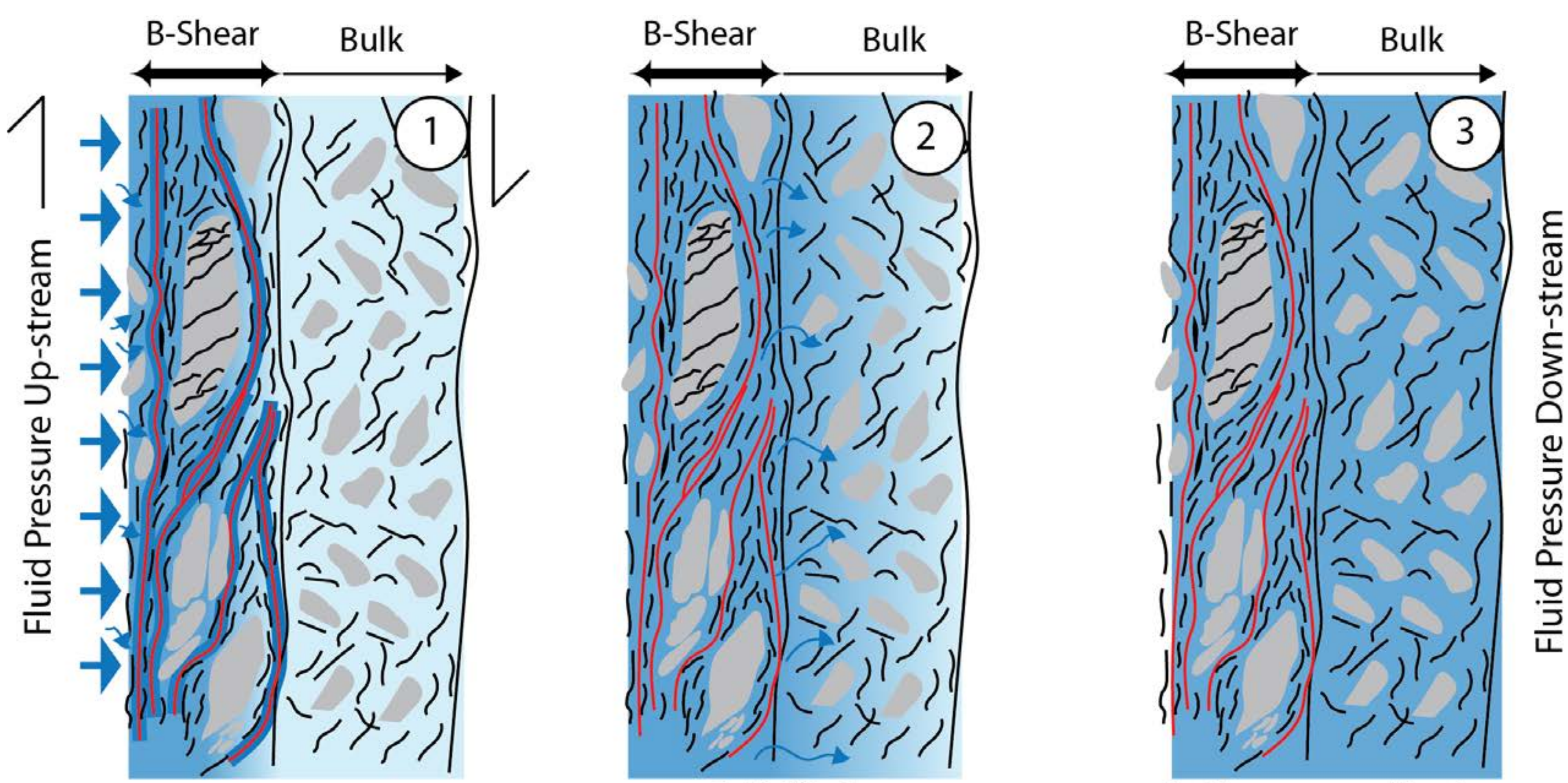


Conceptual model for fault zone deformation









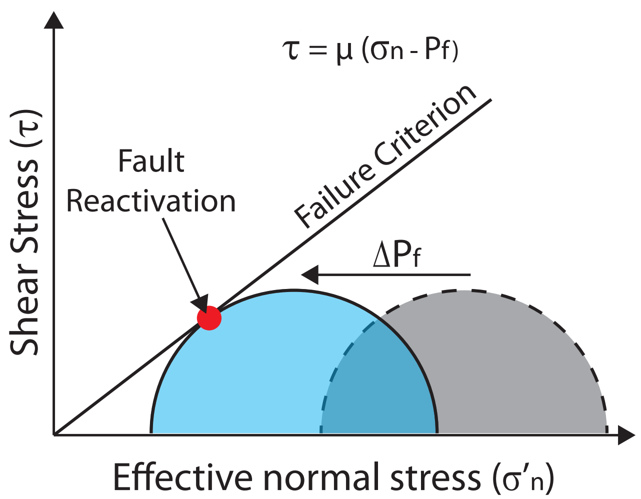
Overpressurized principal slip surfaces
Fault gouge accelerates

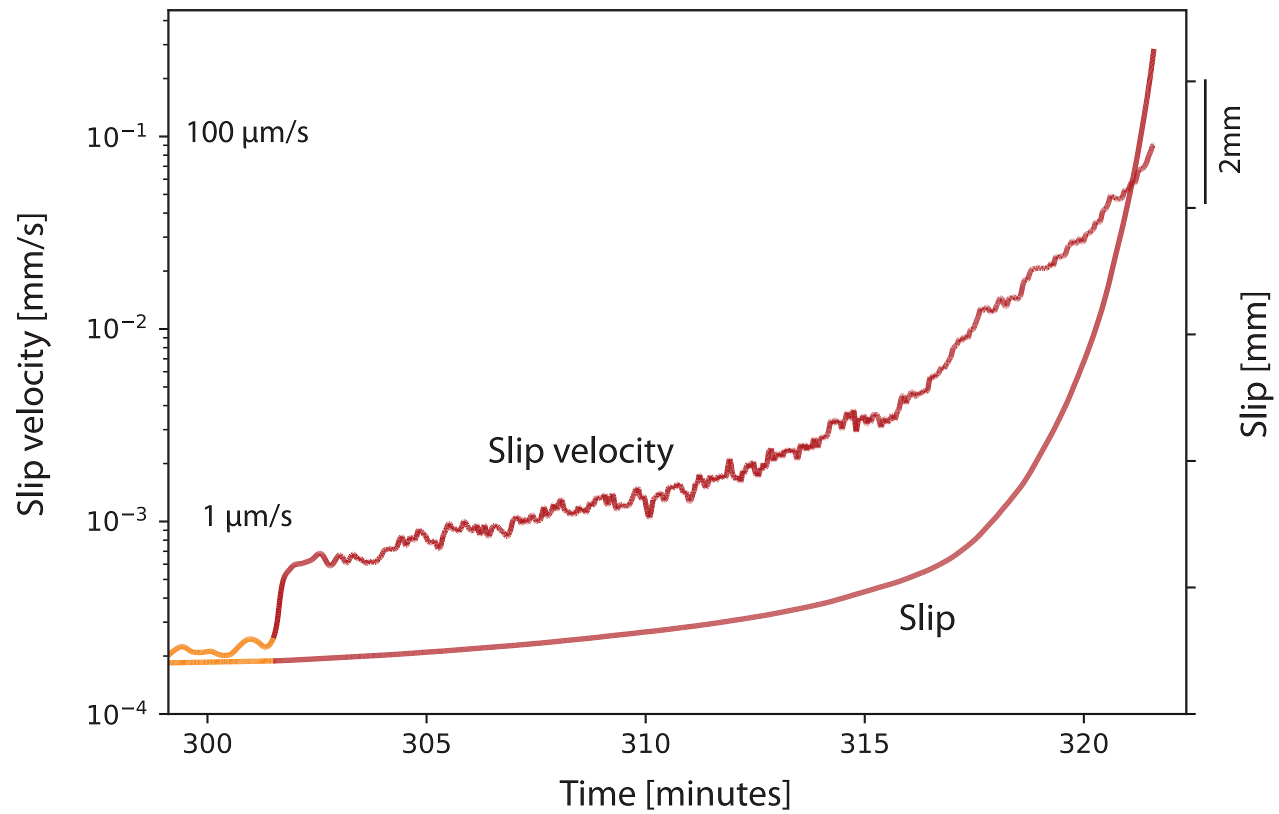
Fluid diffusion
Fault gouge decelerates

Fluid pressure equilibration fault gouge slip at new velocity

Scuderi and Collettini, 2018 JGR

Conceptual model for fault zone deformation

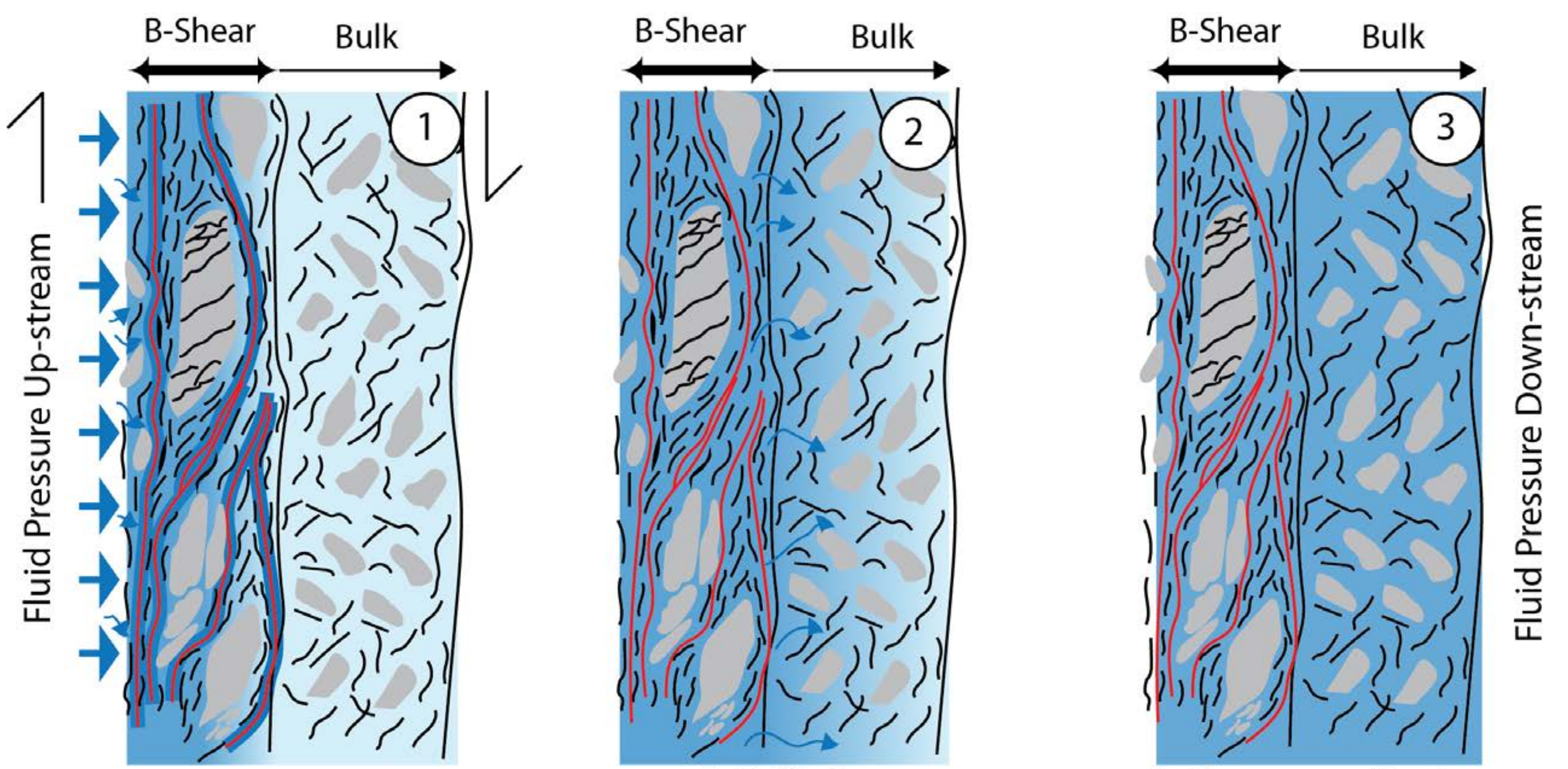




Time of acceleration
~20 minutes

Accumulated slip
~10 mm

Slip velocity remains
< 100 μm/s

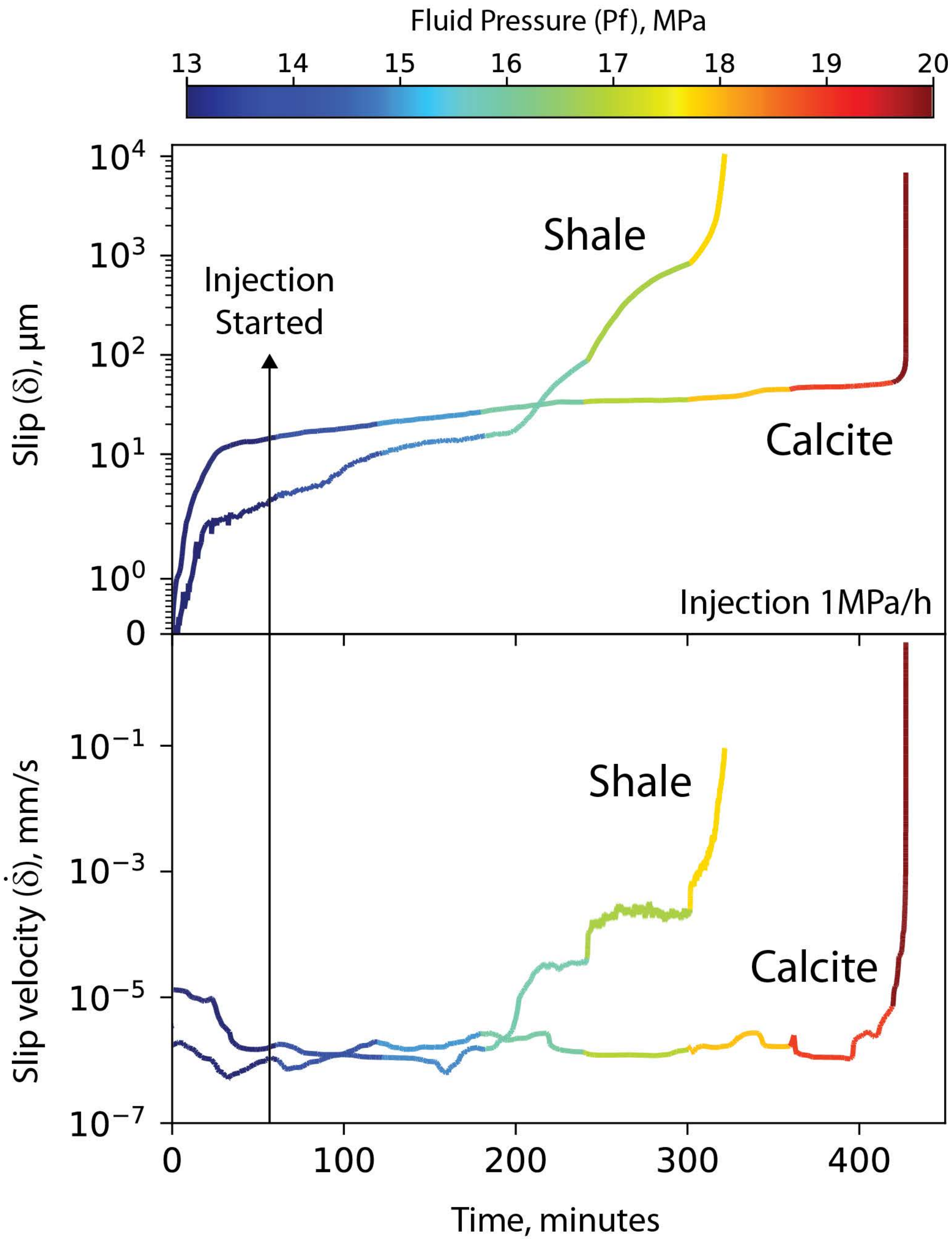


Overpressurized principal slip surfaces
Fault gouge accelerates

Fluid diffusion
Fault gouge decelerates

Fluid pressure equilibration
fault gouge slip at new velocity

Do fault gouge always fails by slow slip upon fluid pressurization?



Details in:
Scuderi and Collettini, 2016 SciRep
Scuderi et al., 2017 EPSL;
Scuderi and Collettini, 2018 JGR

Summary

• Fluid pressurization can promote slow but accelerated fault slip in a fault gouge that is characterized by velocity strengthening behavior (i.e. aseismic creep) acting as an efficient weakening mechanism.

• The observed fault slip behavior is the result of the complex interaction between hydrological, frictional and structural properties of the fault gouge.

• Accelerated aseismic creep can transfer stress to adjacent fault patches that are prone to earthquake nucleation providing a mechanism to trigger seismicity.

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