Thermal Pressurization in Laboratory Experiments

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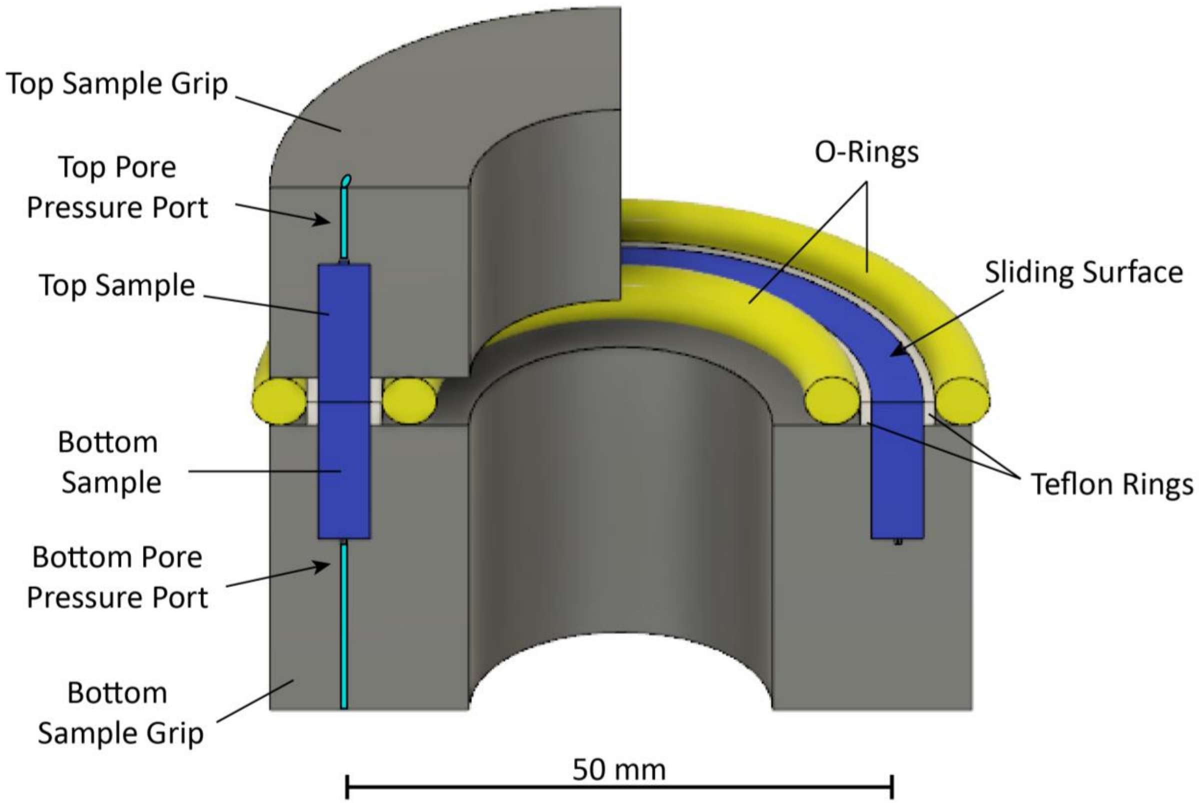
Motivation

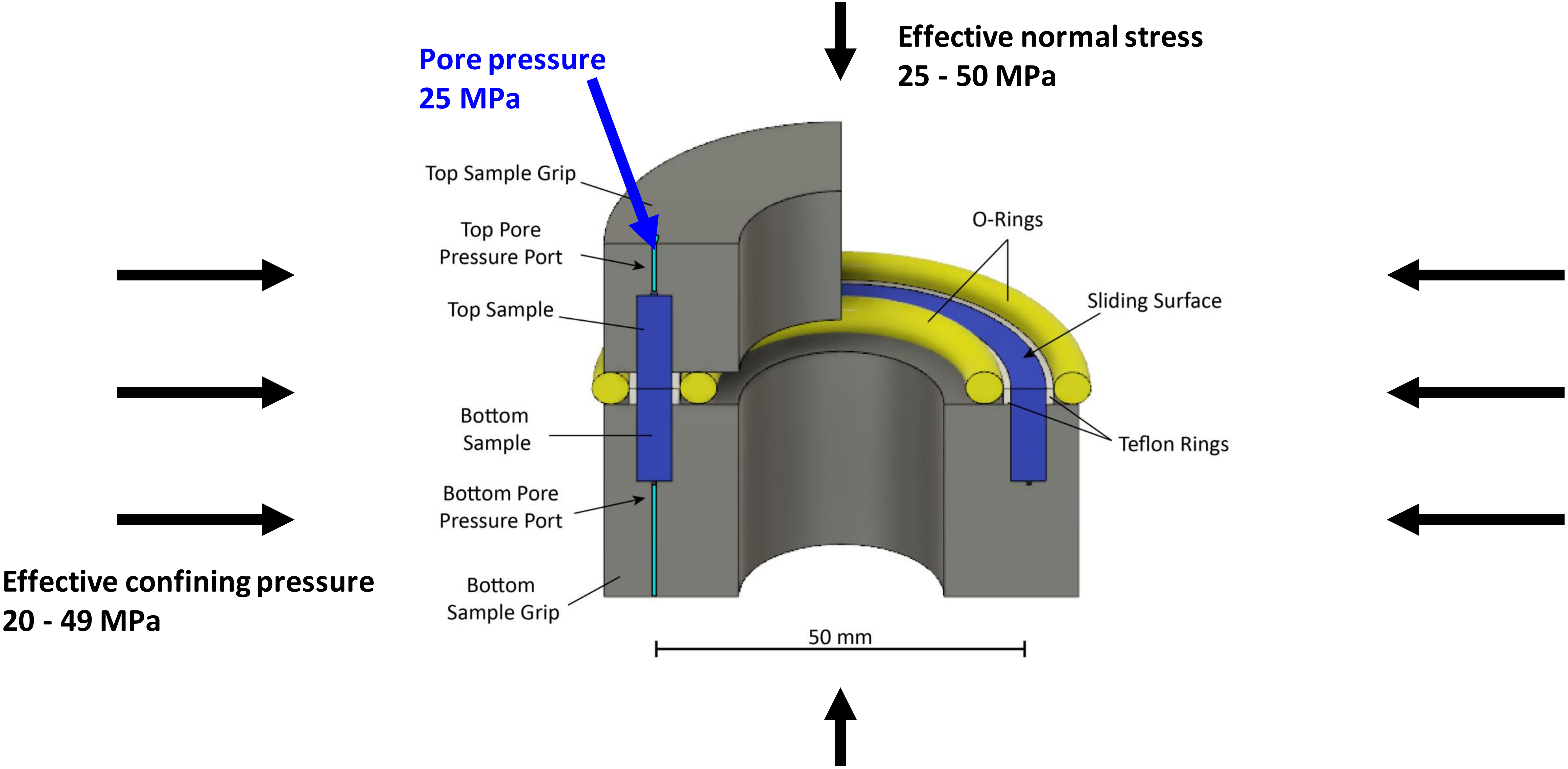
- TP is expected to be a dominant mechanism in EQs (e.g., Sibson, 1973).
- TP models explain the calculated fracture energy from EQs (e.g., Viesca & Garagash, 2015).
- No real data for TP except for theoretical predictions.

Experimental setup – sample assembly

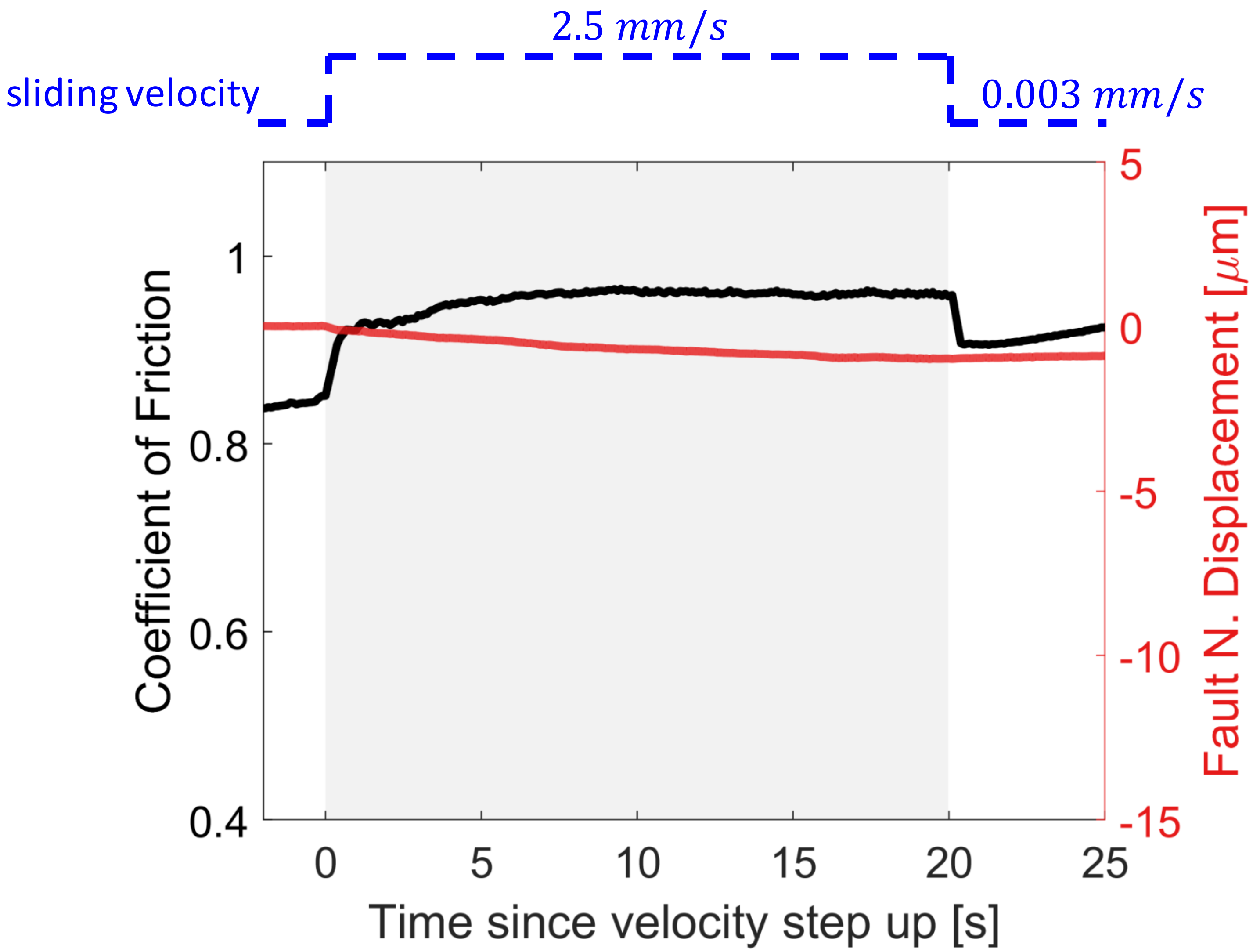


- This assembly sits within a pressure vessel.

Experimental setup – experimental conditions

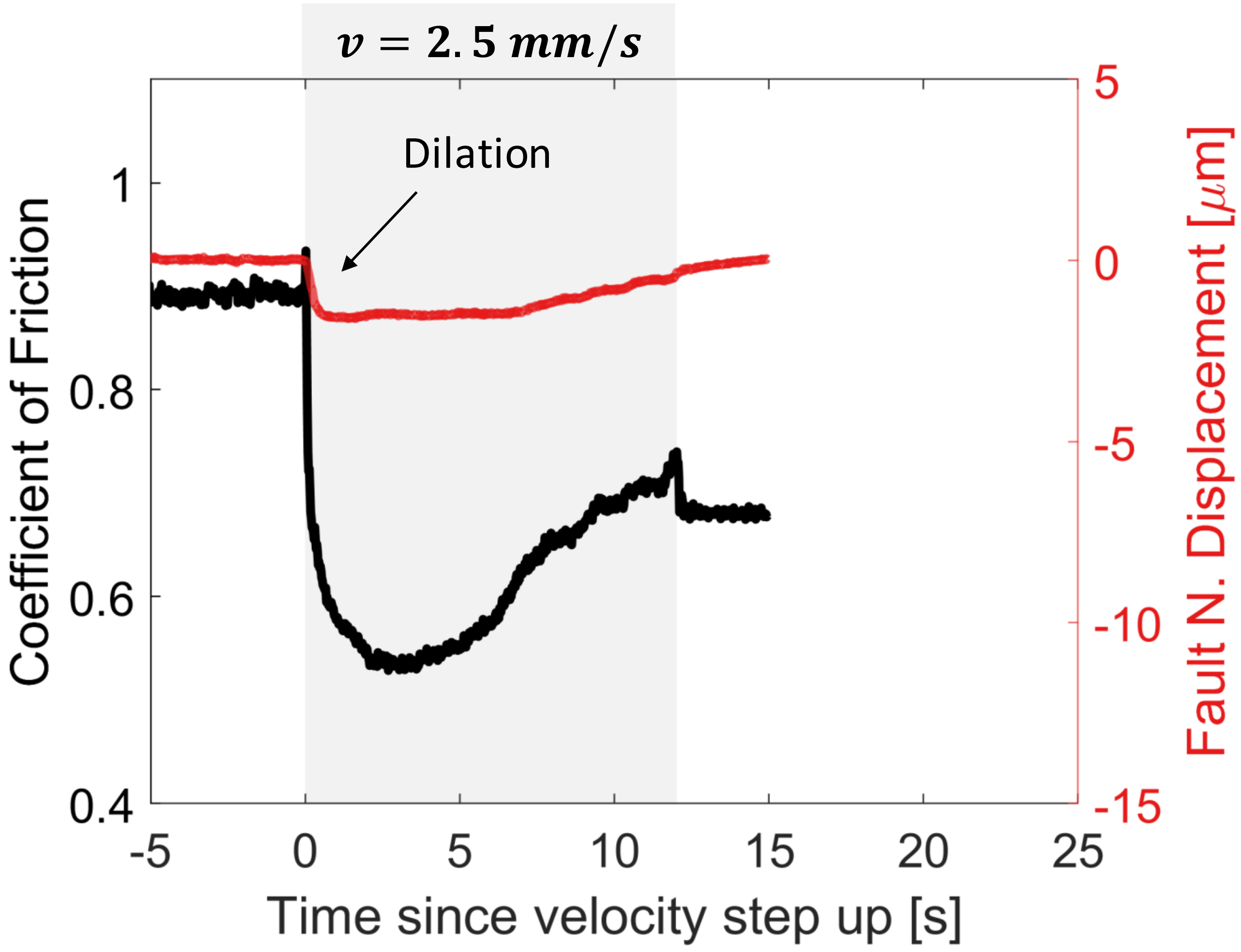


Dry experiments – friction increases with velocity



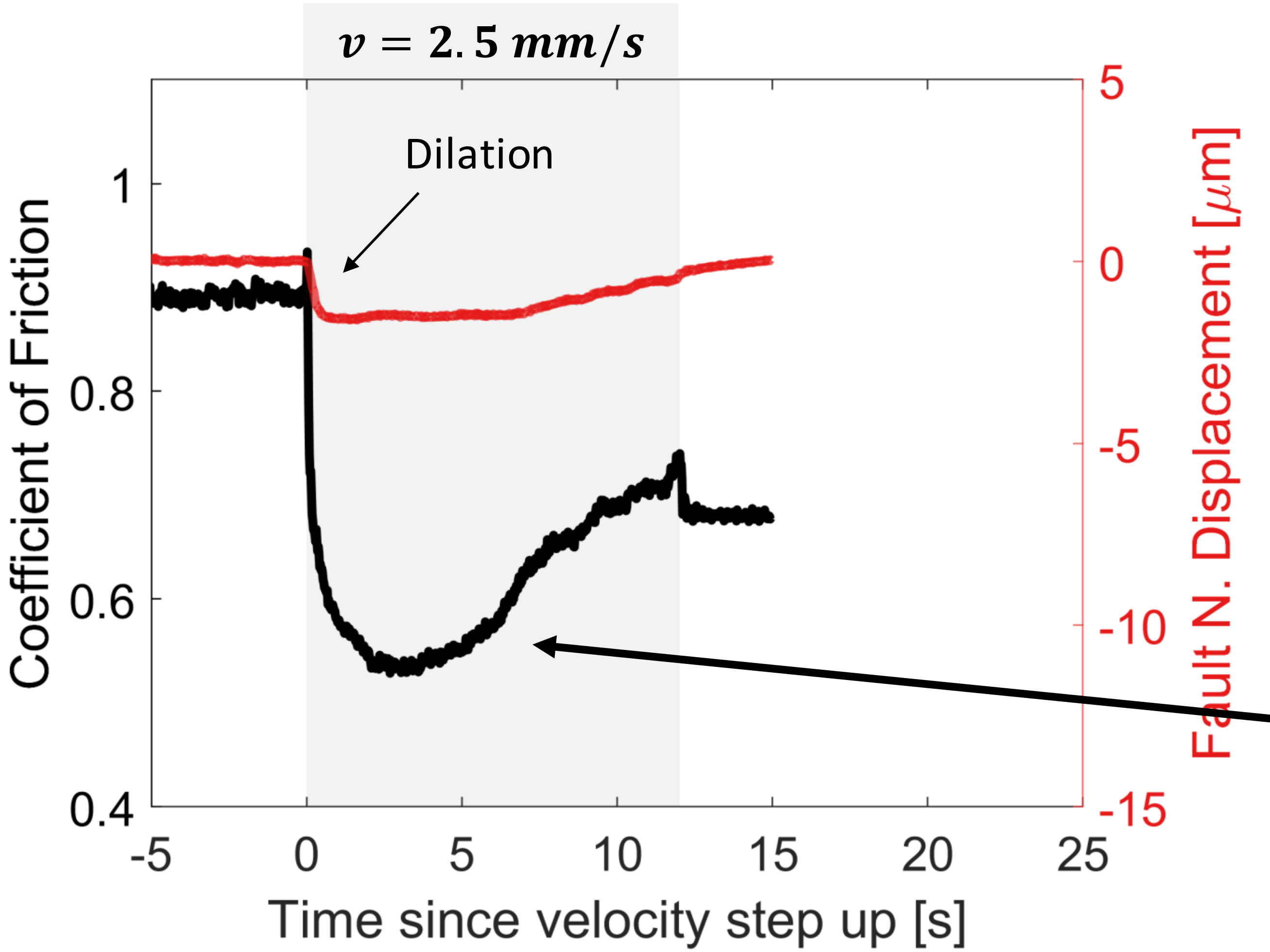
- Velocity step experiments.
- Very little dilation (negative fault normal displacement).

Low displacement faults – 43% weakening



- Displacement before velocity step up 10 mm
- permeability ~ $\mathbf{10^{-20}}\ m^2$

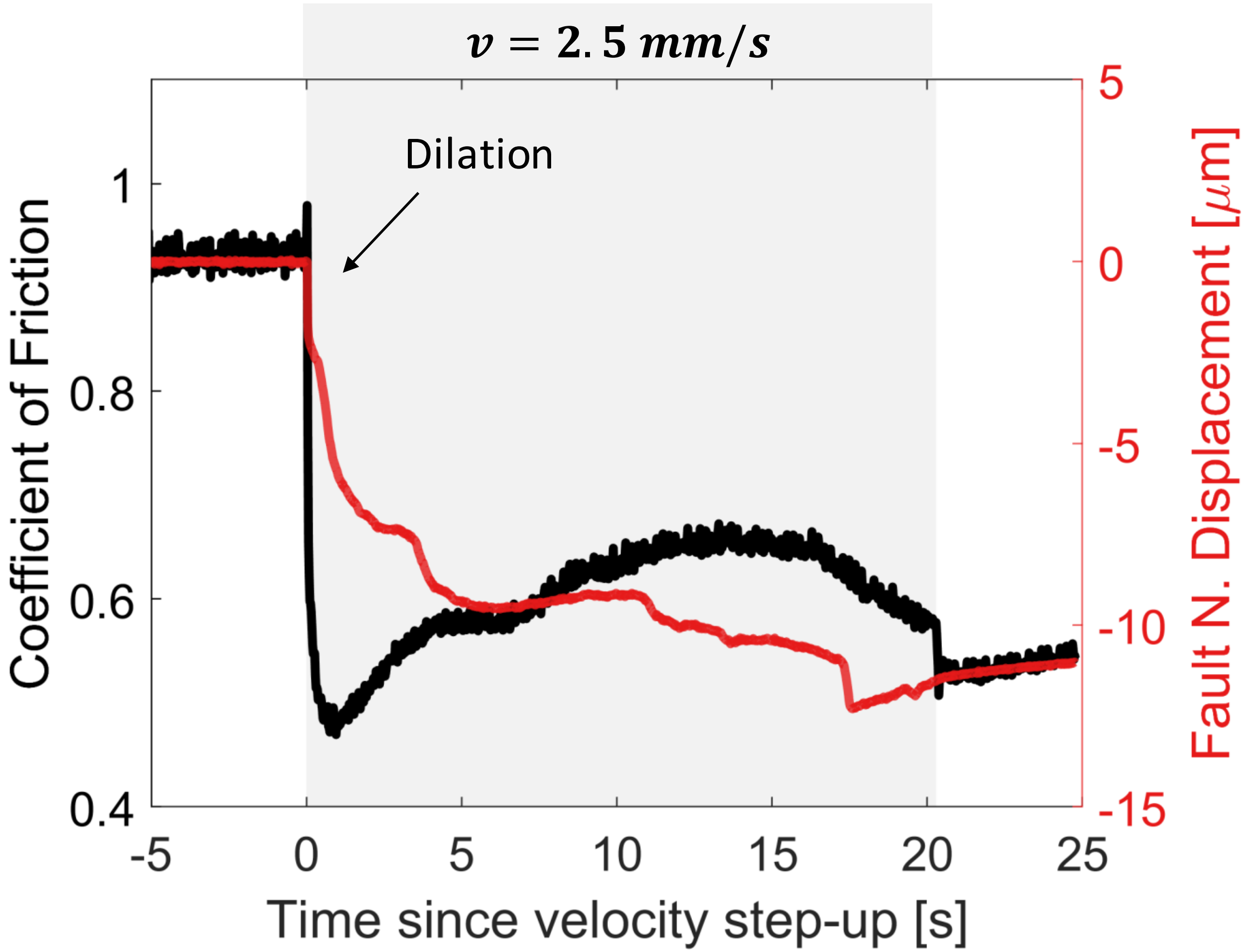
Low displacement faults – 43% weakening



- Displacement before velocity step up 10 mm
- permeability ~ $\mathbf{10^{-20}}\ m^2$

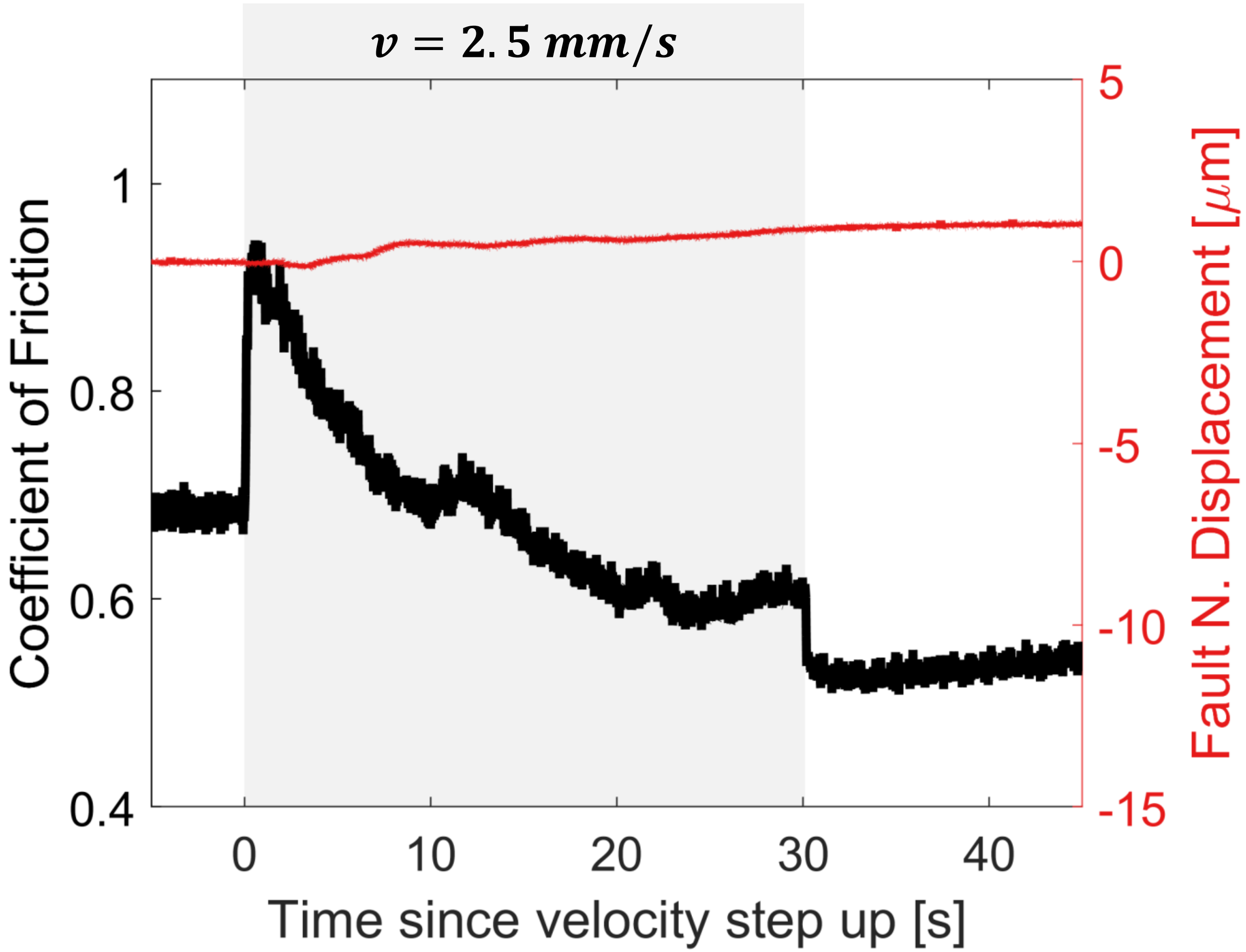
Origin of strengthening is unclear, probably due to microcracking around the fault.

Low displacement faults– 52% weakening



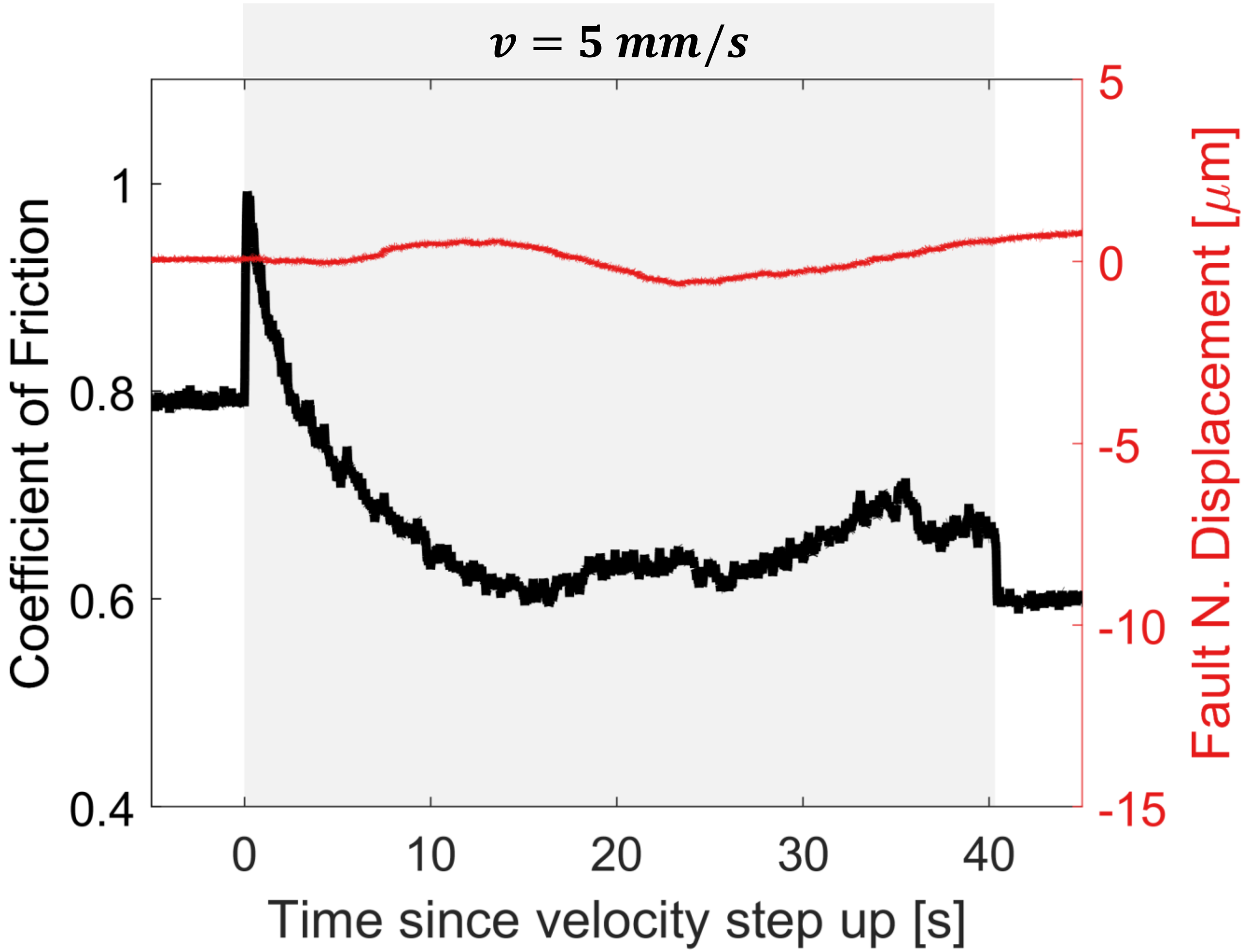
- Displacement before velocity step up 26 mm
- permeability ~ $\mathbf{10^{-21}}\ m^2$

High displacement faults– 37% weakening



- Displacement before velocity step up > 1 m
- permeability ~ $\mathbf{10^{-20}}\ m^2$

High displacement faults – 40% weakening



- Displacement before velocity step up > 1 m
- permeability ~ $\mathbf{10^{-20}}\ m^2$

How do these faults differ mechanically?

Generation term

Diffusion term

Heat equation : $$\frac{\partial T}{\partial t} = Q + \kappa \nabla^2 T$$

Pore pressure equation : $$\frac{\partial p}{\partial t} = \mathbf{\Lambda} \frac{\partial T}{\partial t} + \alpha \nabla^2 p$$

T = temperature
t = time
Q = heat generation
κ = thermal diffusivity
Λ = pressurization factor
α = hydraulic diffusivity

After Rice (2006)

How do these faults differ mechanically?

Fluid thermal expansivity

Pore space thermal expansivity

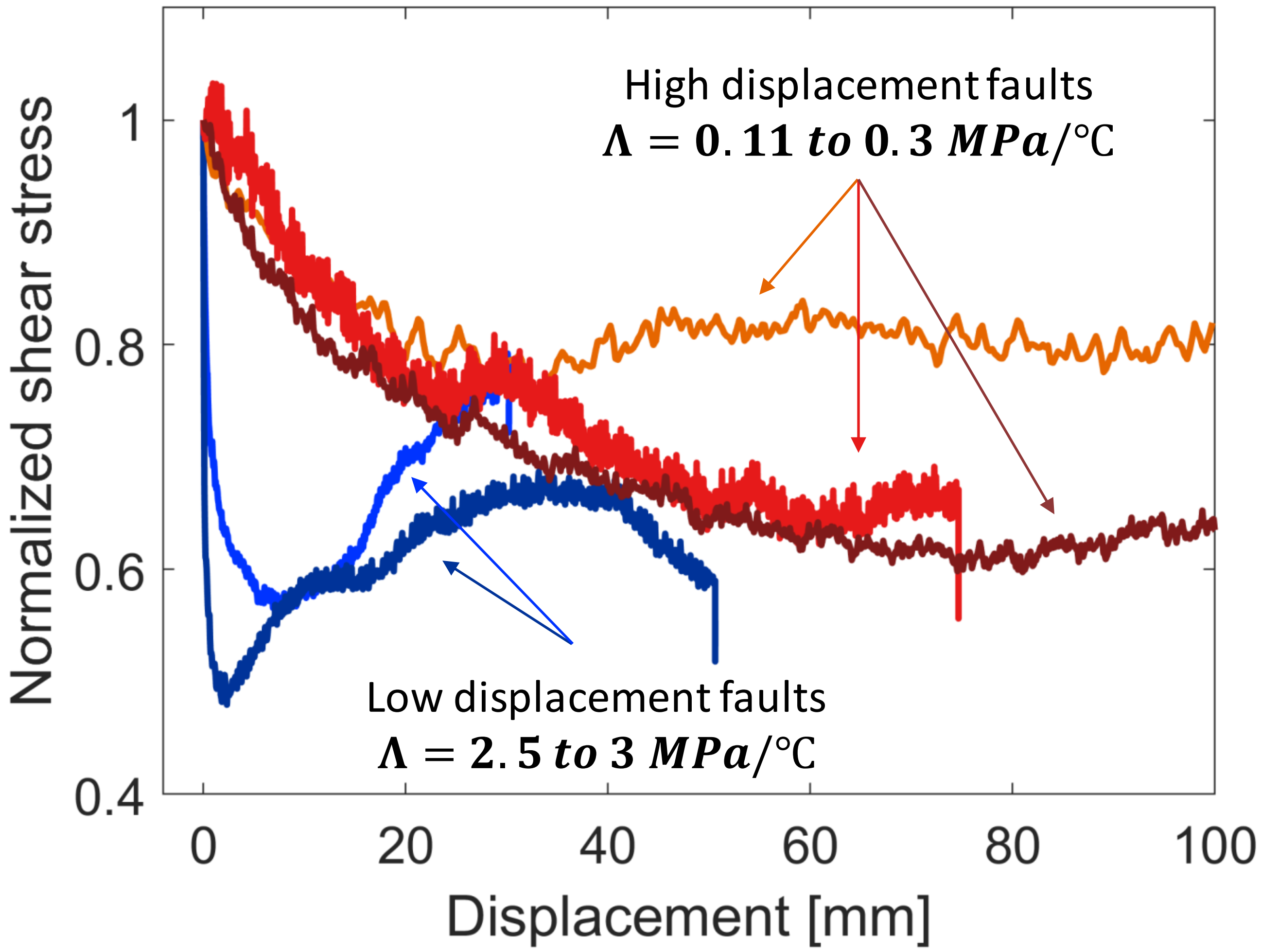
$$\Lambda = \frac{\gamma_f - \gamma_\phi}{\beta_f + \beta_\phi}$$

Fluid compressibility

Pore space compressibility

After Rice (2006)

Estimates of Λ based on experiments



Summary

- Larger stress drops but over shorter durations in low displacement faults, slower pressurization rates over longer durations in high displacement faults.

- Pressurization factor Λ is estimated to be $0.1 - 0.3\ \ MPa/℃$ for high displacement faults, 10 times smaller than for low displacement faults.

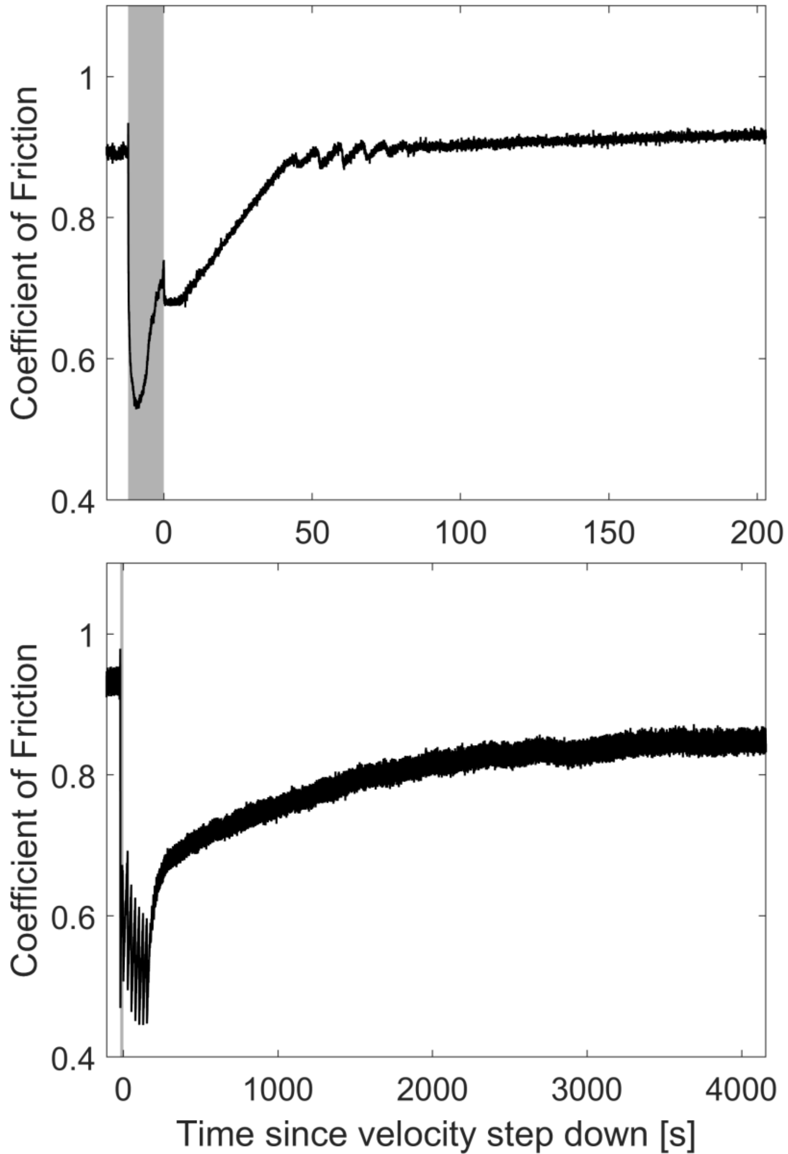
- The difference in Λ between the two fault types underlines the importance of the fault's pore space compressibility.

- However, preliminary experiments suggest that dilatancy due to fault roughness could eliminate thermal pressurization weakening.

Frictional reloading – supports pore pressure buildup

permeability
$\sim \mathbf{10^{-20}}\ \mathrm{m}^2$

permeability
$\sim \mathbf{10^{-21}}\ \mathrm{m}^2$



- Frictional reloading after the fast-slip segment takes longer for the lowest-permeability sample.
- Reloading rates are evidence that pore pressure increased during the fast slip segment.

Fitting model to data – Λ