Mineralogical Controls on Shear Strength and Slip Stability in Caprock Faults

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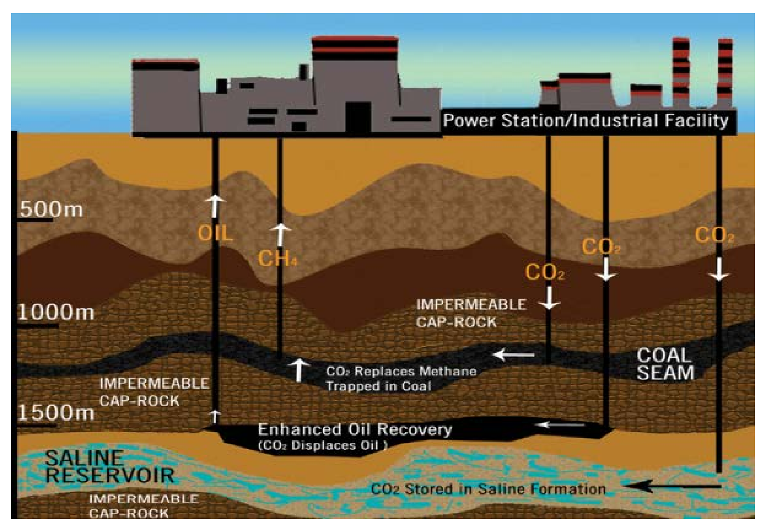
INTRODUCTION

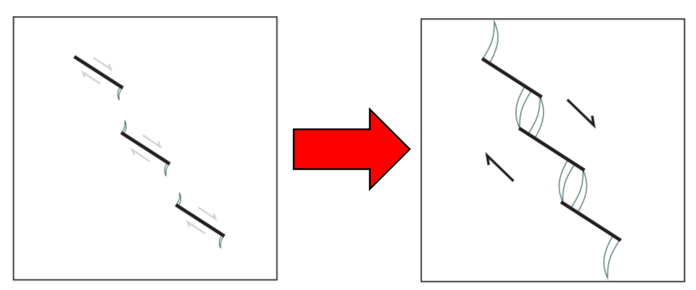
Caprocks are natural sedimentary formations that overlie CO_2 injection reservoirs. These natural seals are relied-upon for containment of pressurized fluids for 100s to 1000s of years. Human injection induced slip on pre-existing faults and component fractures implicates a significant mechanism for large scale breaching of caprocks (seals) on CO_2 storage reservoirs and for uncontrolled loss of inventory.

These uncertainties of caprock performance and durability require rigorous investigation on the shear strength, slip stability, and rheologic evolution under slip events. Whether faults will fail seismically or aseismically, how the permeability will evolve, and especially what are the effect of mineralogy and texture of faults on these mechanical responses, are key questions.



(Curtesy of World Resources Institute Org.)

Fault Breaching?
Permeability Evolution?



[Faulkner, et al. 2010]

- Pre-existing faults may be reactivated during or after sequestration.
- Reactivated faults may slip seismically, or creep.
- What regime will the slip event follow?
- Which slip regime will be beneficial?

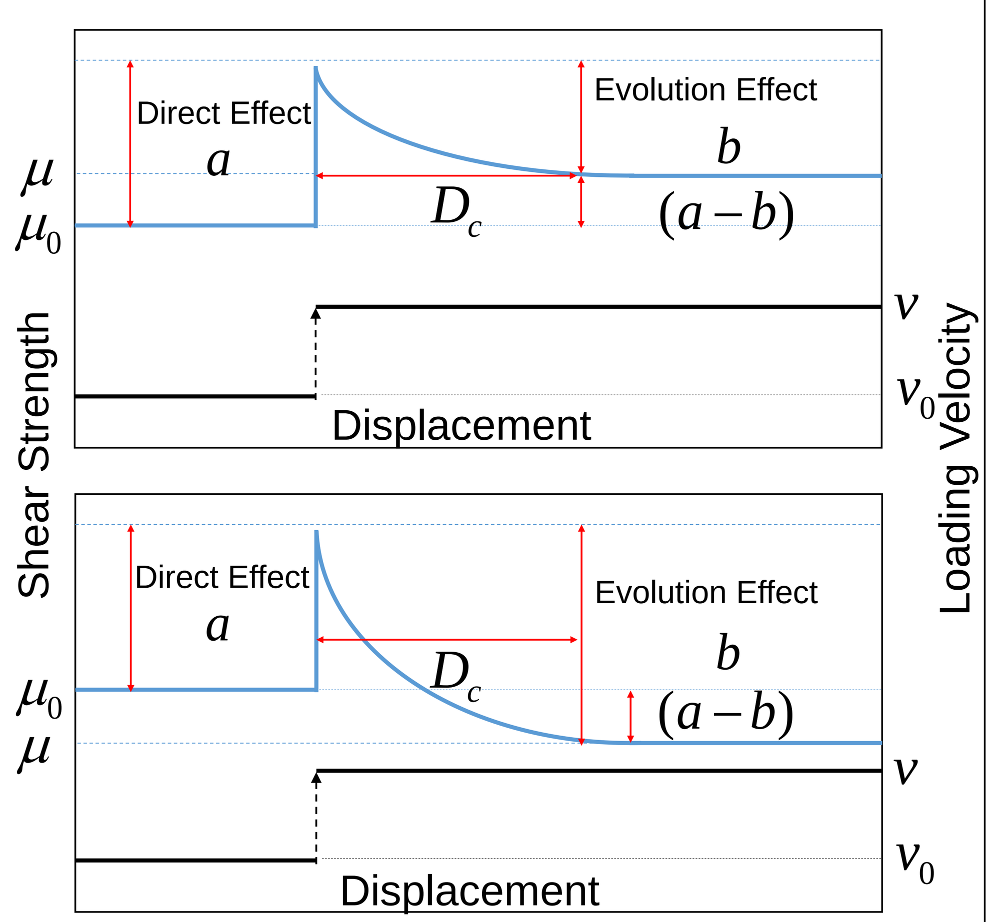
Velocity Strengthening

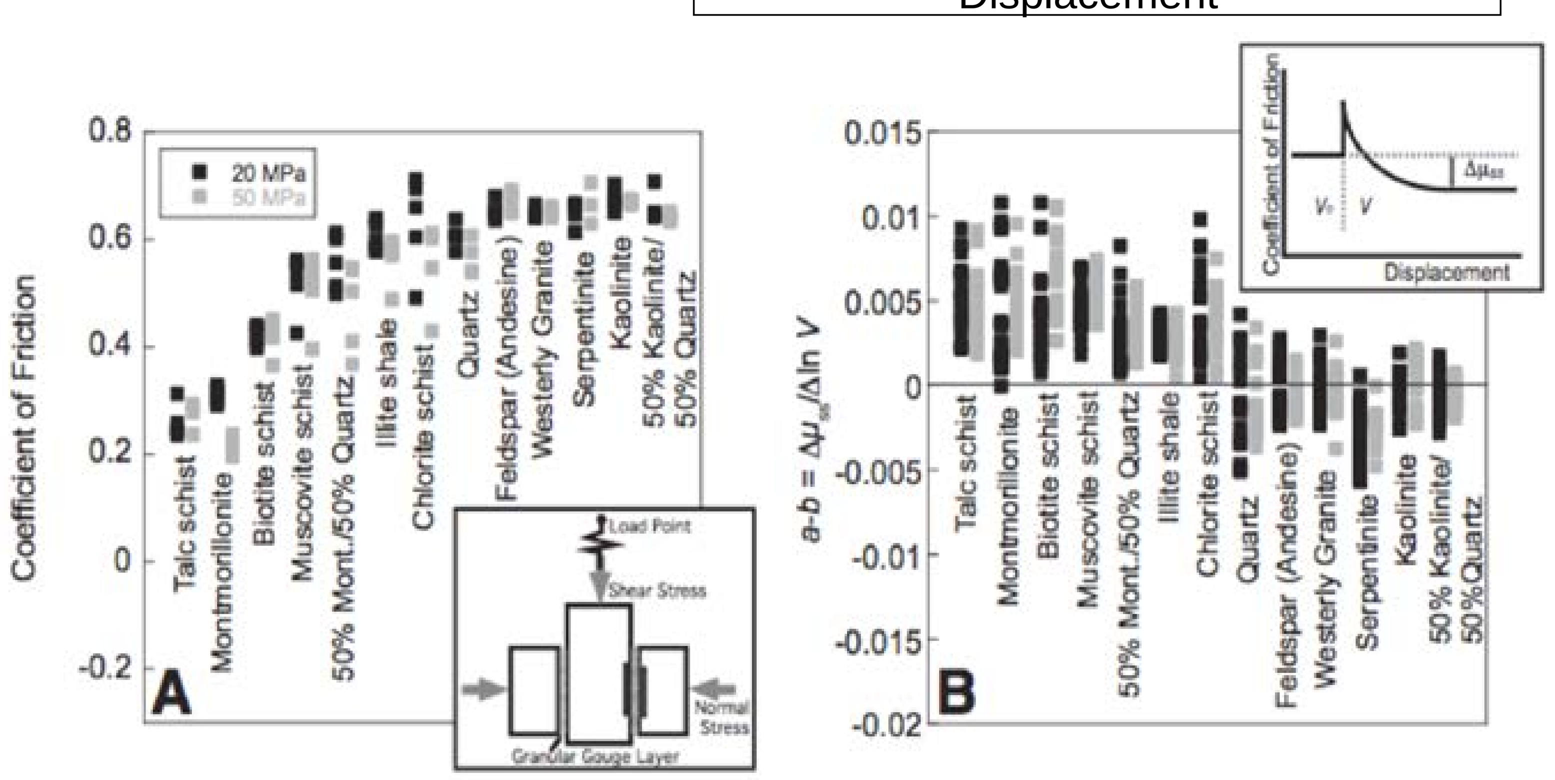
a-b>0 suggests velocity strengthening resulting in aseismic slip and manifest as creep.

Velocity Weakening

a-b<0 suggests velocity weakening brittle response and seismic slip may occur.

[Dieterich, 1979; Ruina, 1983]





Seismic or aseismic failure behavior can be closely linked to mineralogy. [Ikari et al. 2011]

HYPOTHESIS

- Reactivated faults can either slip seismically, increasing permeability.
- Or the faults can slip aseismically, potentially reducing permeability.
- These behaviors are potentialy controlled by mineralogy.

OBJECTIVES

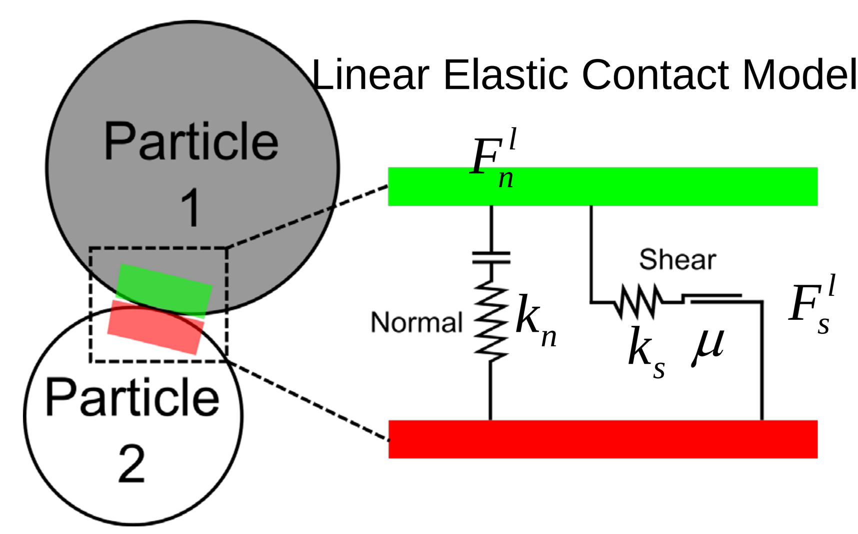
- Examine mineralogical controls on the bulk shear strength of faults.
- Examine mineralogical controls on slip stability of faults.
- Examine mineralogical controls on permeability evolution of faults.

METHOD

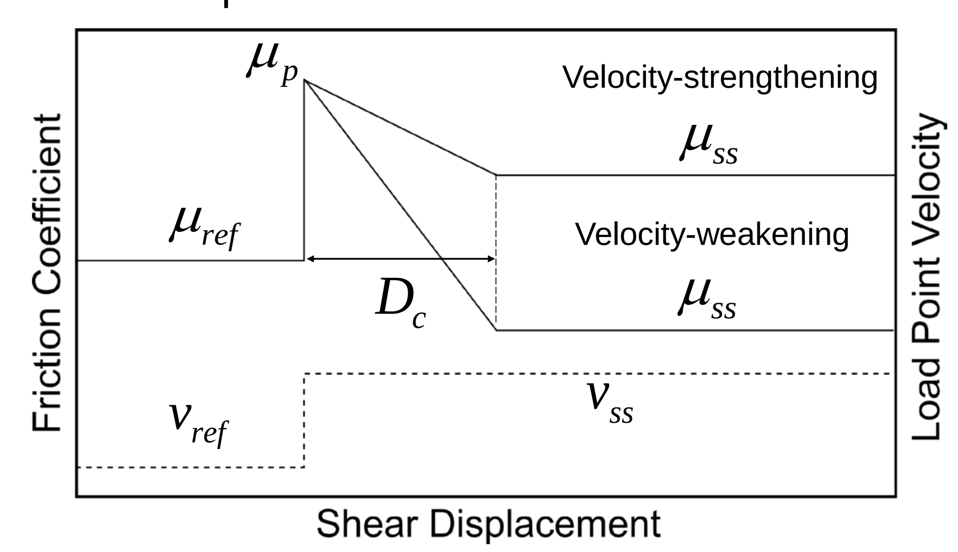
DISTINCT ELEMENT MODELING

Biaxial Direct Shear Experiments:
(1) Constant Velocity
(2) Velocity-stepping

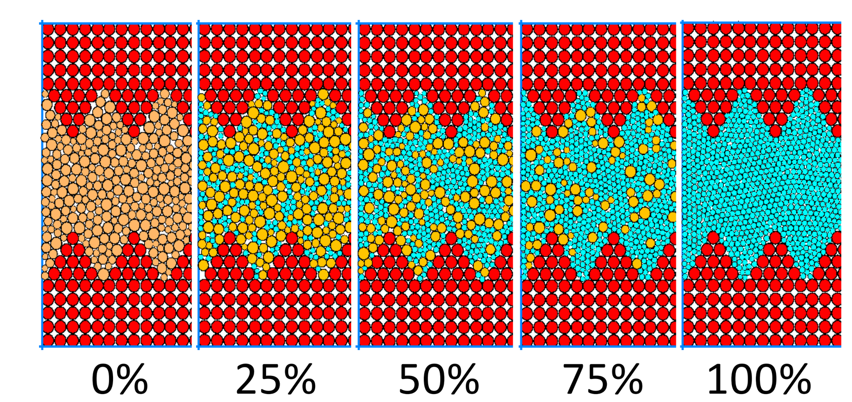
Linear Elastic Contact Model



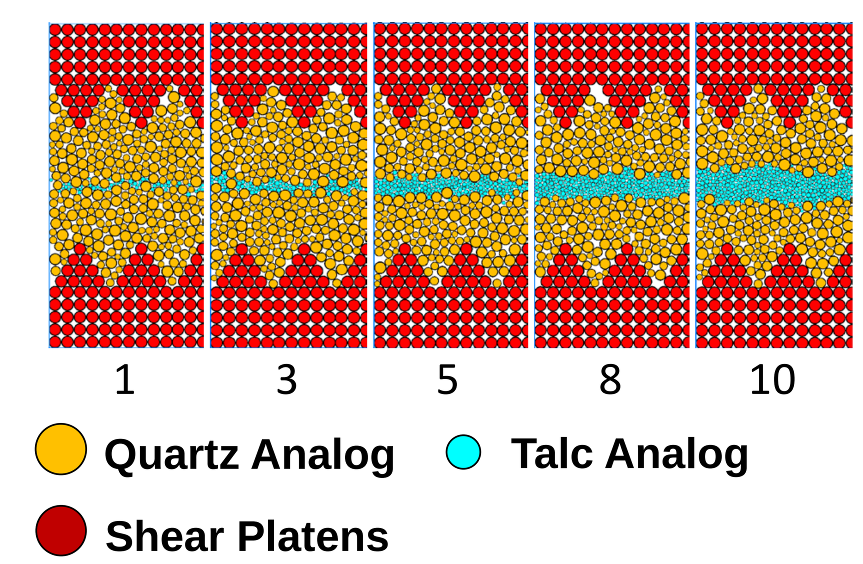
Simplified Rate-state Friction Law



Homogeneous Mineral Mixtures



Heterogeneous Mineral Mixtures



$$\mu_{ss} = \mu_{ref} + (a-b)\ln\left(\frac{V_{ss}}{V_{ref}}\right)$$

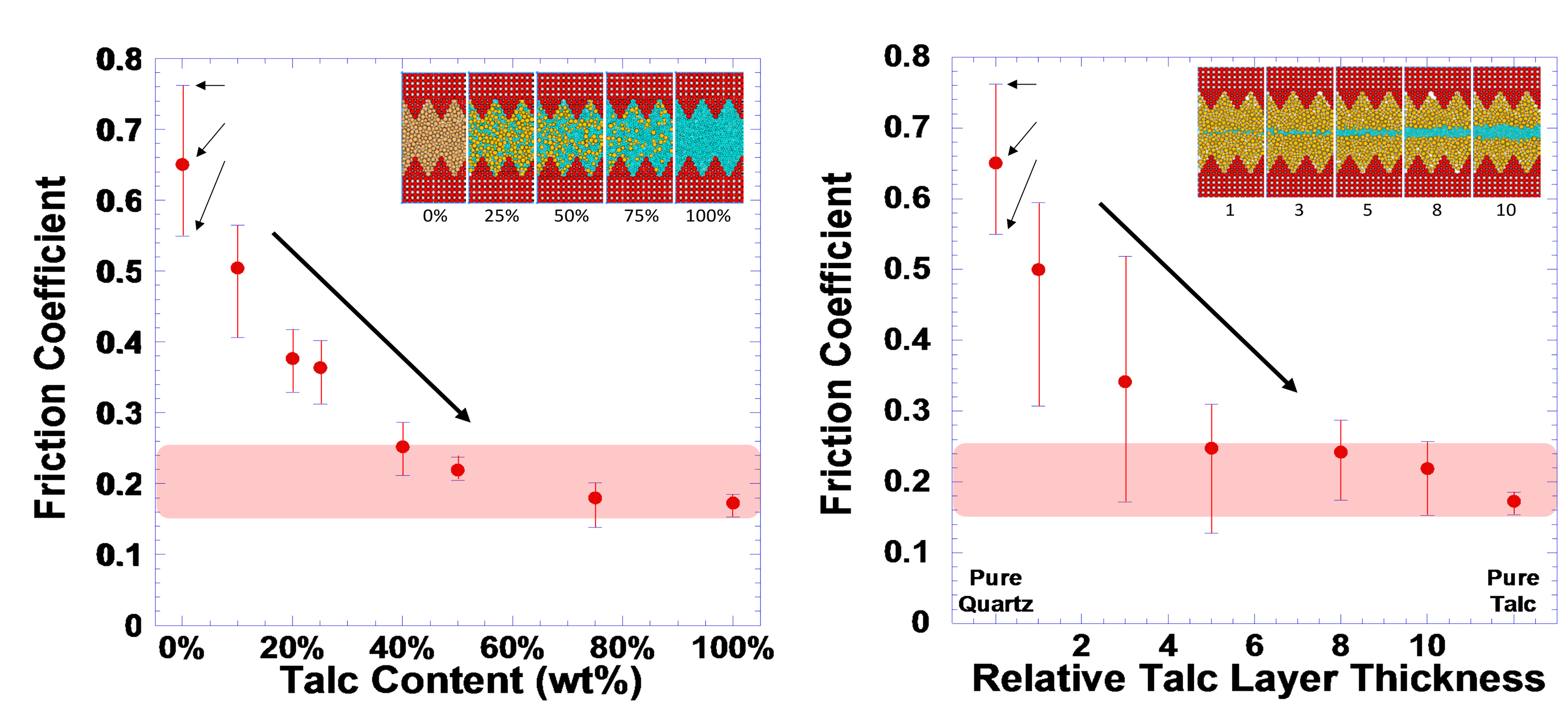
$$\mu_p = \mu_{ref} + a\ln\left(\frac{V_{ss}}{V_{ref}}\right)$$

$$\mu = \begin{cases} \mu_p & D_{acc} = 0 \\ \mu_p - \left(\frac{\mu_p - \mu_{ss}}{D_c}\right) D_{acc} & D_{acc} \in (0, D_c) \\ \mu_{ss} & D_{acc} = D_c \end{cases}$$

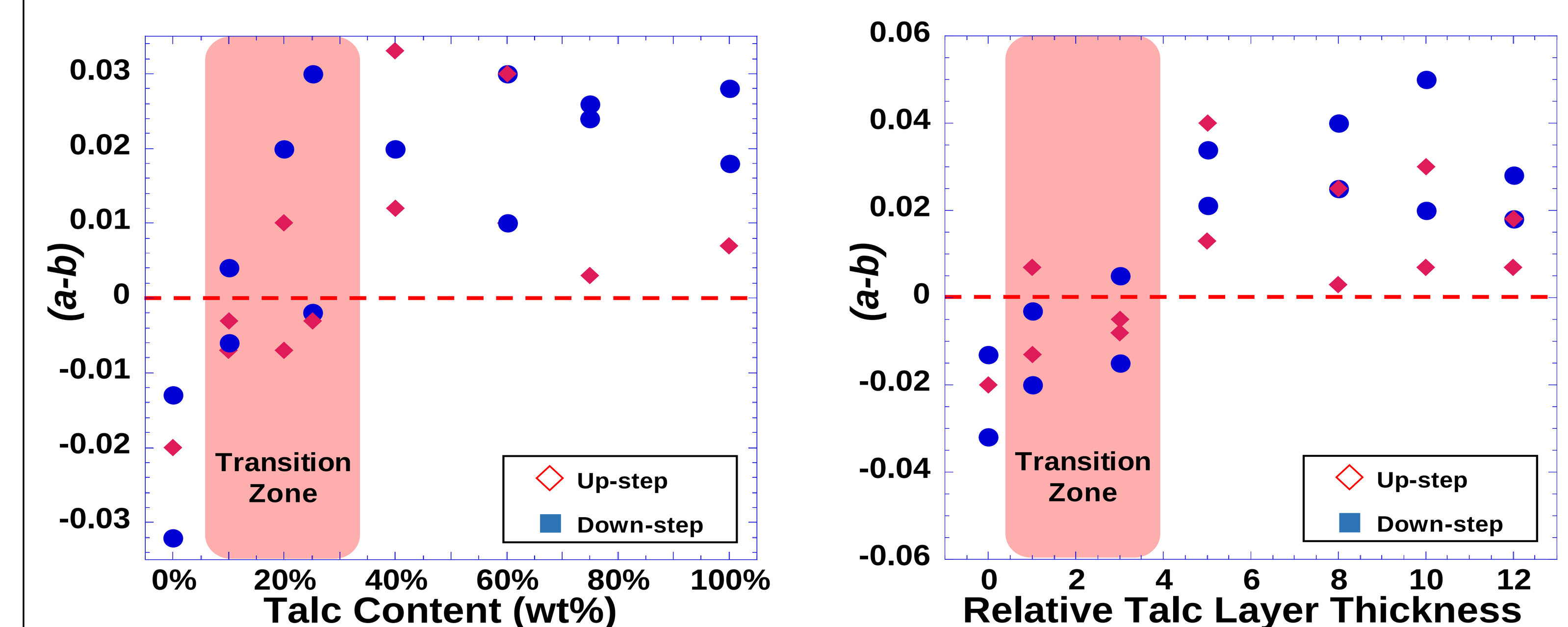
μ_p : the peak friction due to direct effect;
μ_{ss} : the steady state friction after evolution effect;
μ_{ref} : the reference friction coefficient of last velocity change;
D_{acc} : accumulated relative shear displacement.

RESULTS

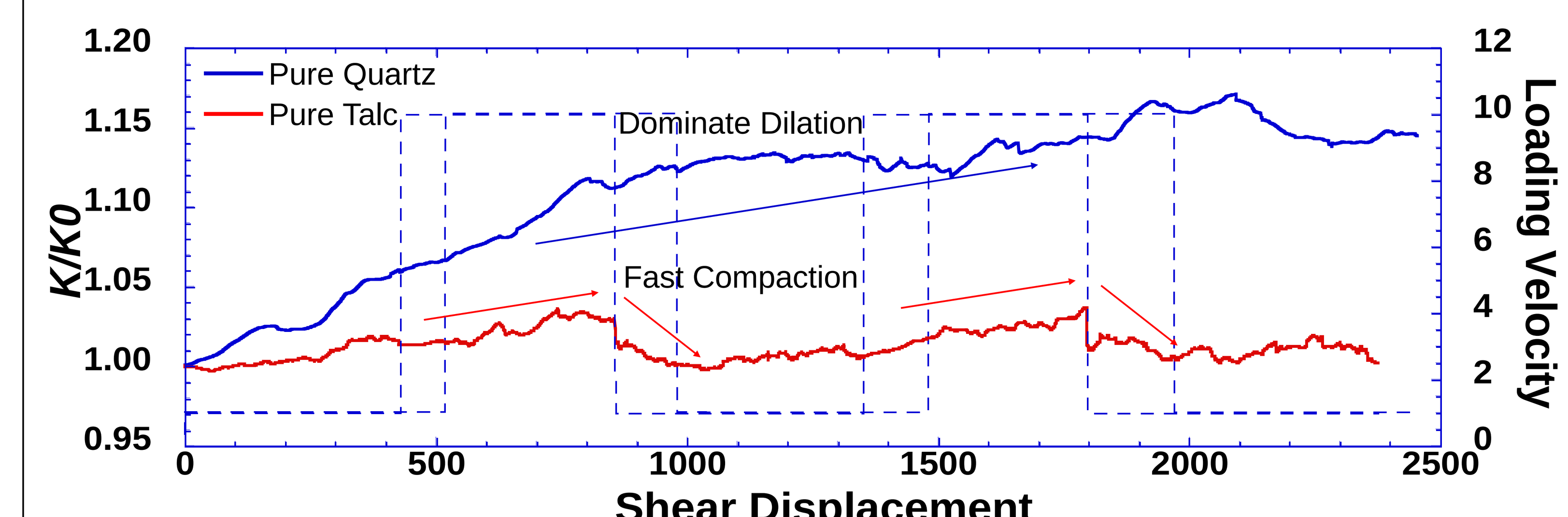
TRANSITION IN SHEAR STRENGTH



TRANSITION IN SLIP STABILITY



PERMEABILITY EVOLUTION



CONCLUSIONS

- Talc has a significant effect on reducing the shear strength of quartz dominate fault gouge. This effect is enhanced when talc forms a through-going layer in the gouge.
- In a synthetic gouge consisting of talc and quartz, relatively small amounts of talc can transform the stability behavior of the gouge from velocity-weakening to velocity strengthening.
- Quartz tend to dilate upon an increase of shear velocity but no apparent compaction after a decease of shear velocity, indicating permeability enhancement; while talc dilates slowly upon an increase of shear velocity but compacts quickly after a decrease of shear velocity, indicating a potential permeability destruction effect.
- The linear simplification of rate-state friction law simulating grain-grain contact is able to represent the stability evolution of granular fault gouge.

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