Weakening Effects of Iron Oxide Coatings in CO_2-altered Reservoirs and Caprocks

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INTRODUCTION

Shear strength is crucial in determining the slip of faults. Studies show that natural faults tend to slip at much lower resolved shear stress than laboratory inferred stresses. This weakening of natural faults can be related to chemical alteration of the mineralogy of the reservoir and the corresponding fault zone. Laboratory investigations have explored the effects of CO_2-alteration on the fracture toughness of sandstone (~50% quartz, ~23% illite-smectite clay minerals). Test results (short rod and double torsion tests) of natural sandstone samples with long-term CO_2 alteration retrieved from Crystal Geyser, Utah show significantly lower fracture toughness than adjacent, unaltered samples. Microstructural analysis shows that the Fe-coating (hematite) which commonly serves as cementation between strong tectosilicate grains is dissolved after CO_2 bleaching and altered to goethite globules. Interestingly, goethite can form a tribological film with water on surfaces, showing a low friction coefficient of 0.1~0.2. These interesting observations suggest a possible mechanism for a weakening effect in these CO_2 altered rocks, i.e. the Fe-coating, which is altered from hematite cementation to goethite. Although present only in trace amounts, this plays a significant role in determining the frictional strength and stability of the fault zone.

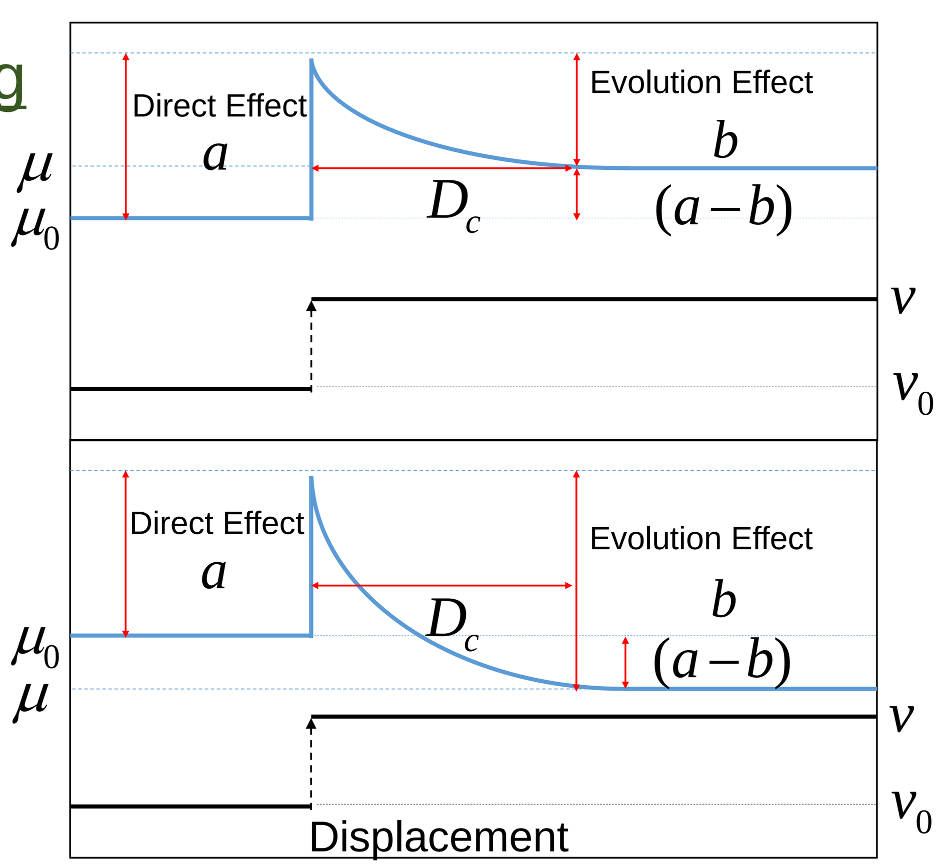
- CO2 alteration may produce goethite and weaken reservoir rocks and pre-existing faults.
- Weakened rocks may fail/fracture under stress and reactivated faults may slip seismically, or creep.
- What regime will the slip event follow?
- Which slip regime will be beneficial?

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]

HYPOTHESIS

- Pristine faults feature high shear strength, can slip seismically, potentially increasing permeability.
- CO_2 altered Faults are weakened, can slip aseismically, dissipate seismic energy over time, potentially reducing permeability.

OBJECTIVES

- Examine effect of Fe-coating on bulk shear strength of faults.
- Examine effect of Fe-coating on slip stability of faults..
- Examine permeability evolution of faults before/after CO_2 alteration.

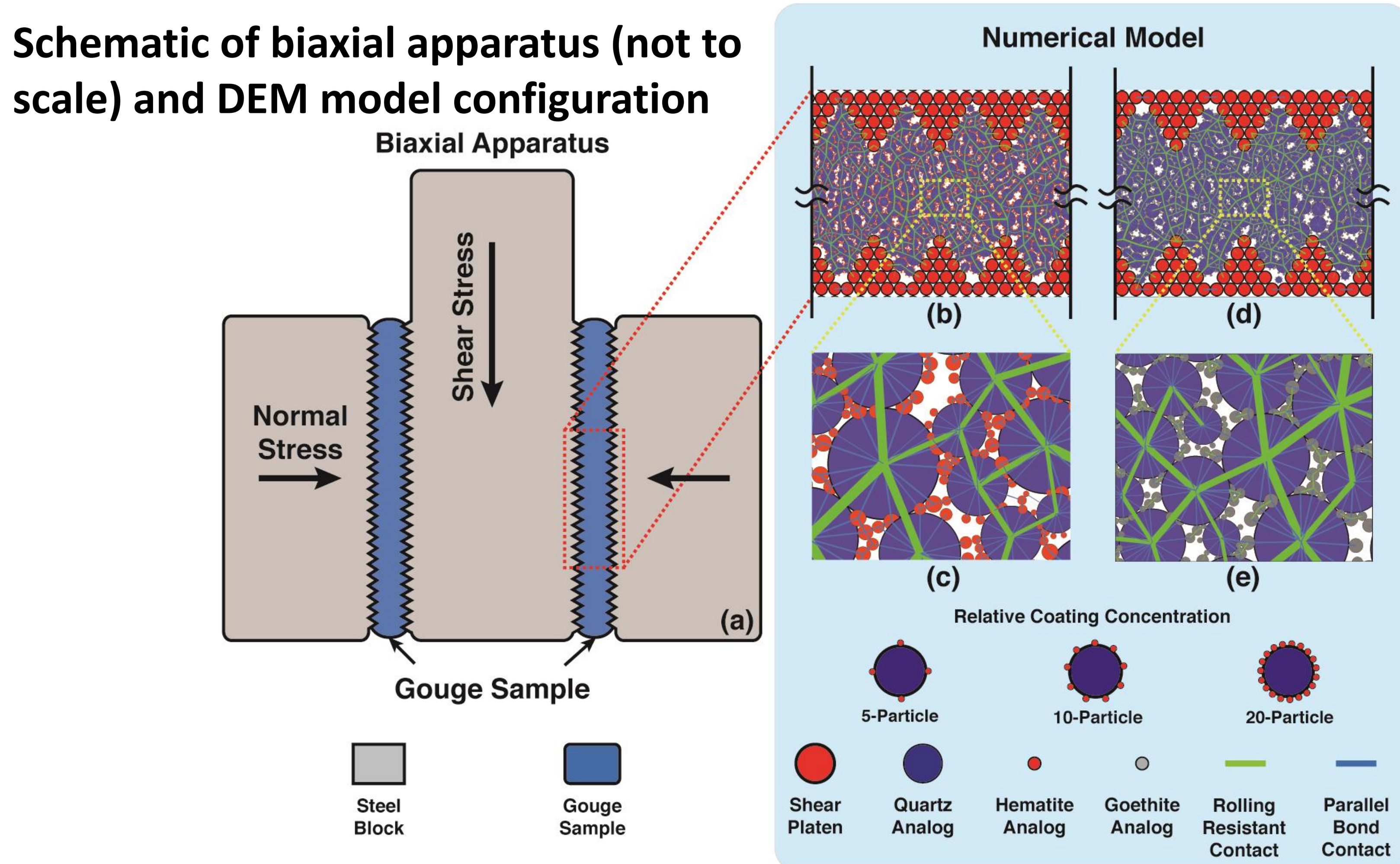
METHOD

DISTINCT ELEMENT MODELING

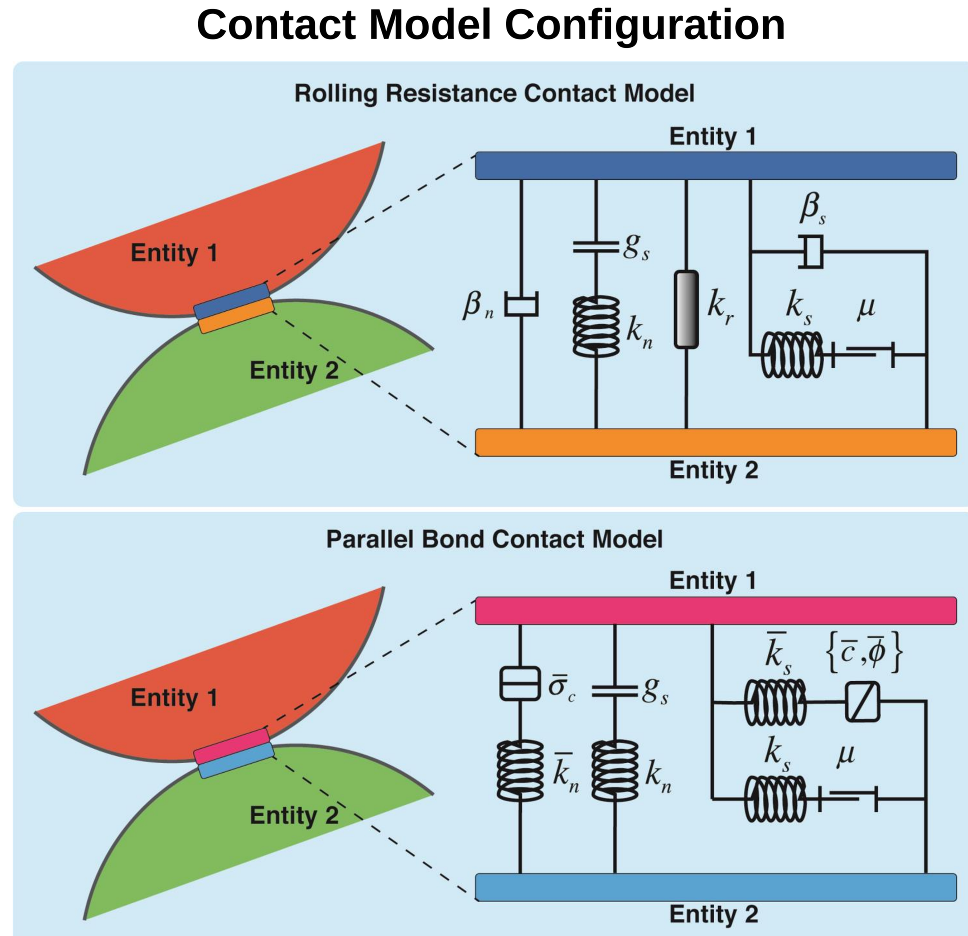
Biaxial Direct Shear Experiments

(1) Constant Velocity
(2) Velocity-stepping

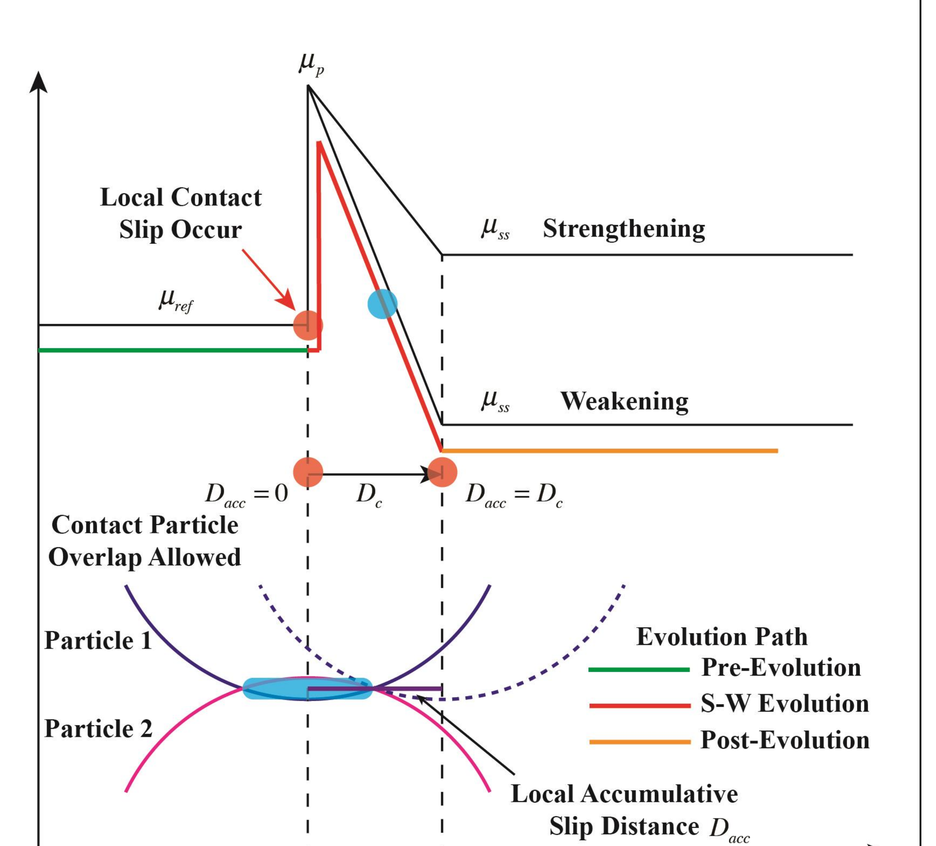
Schematic of biaxial apparatus (not to scale) and DEM model configuration



Contact Model Configuration



Slip Weakening Law on Contacts



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

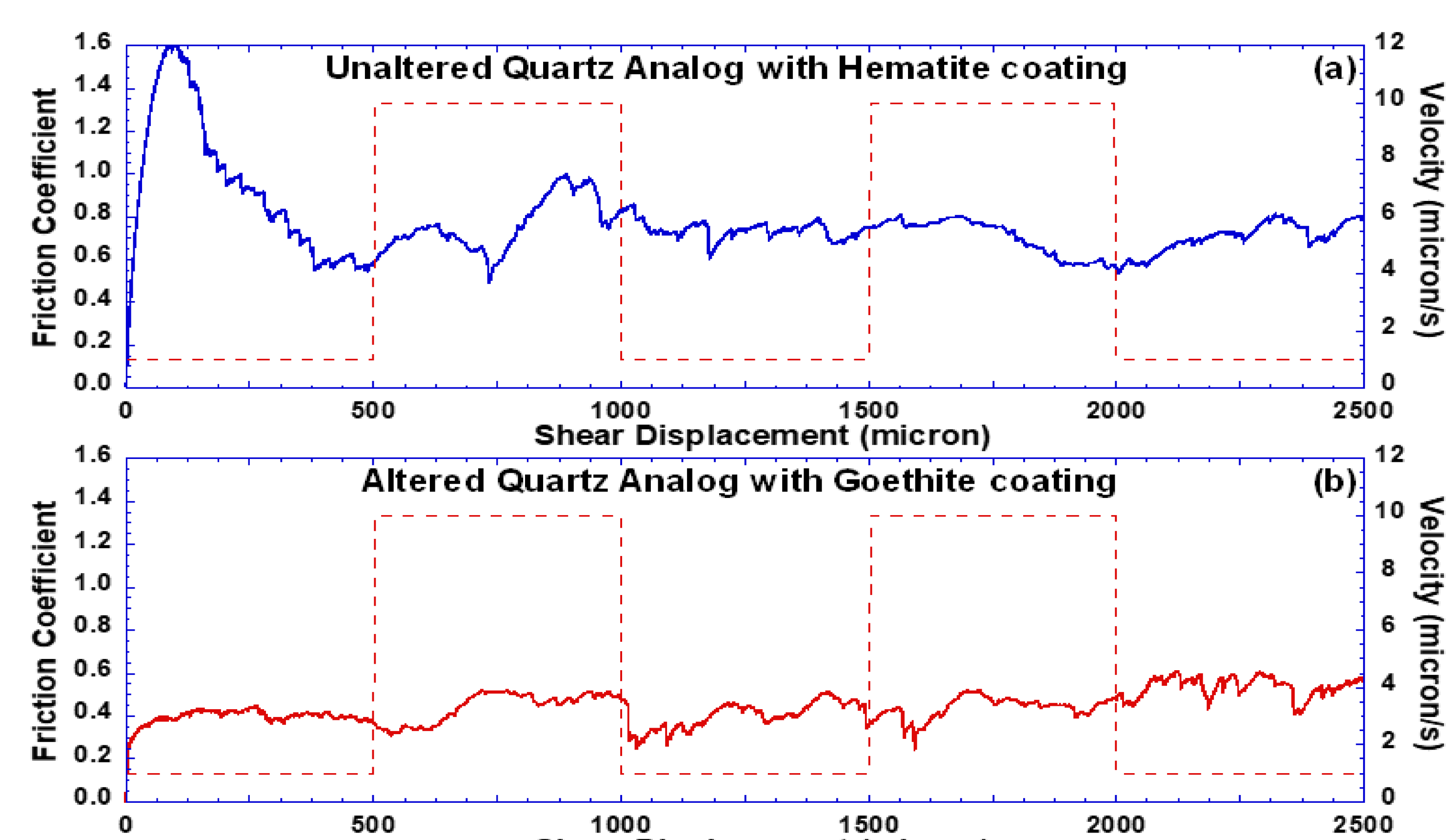
$$\mu_p = \mu_{ref} + a\ln\left(\frac{V_{ss}}{V_{ref}}\right)$$

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

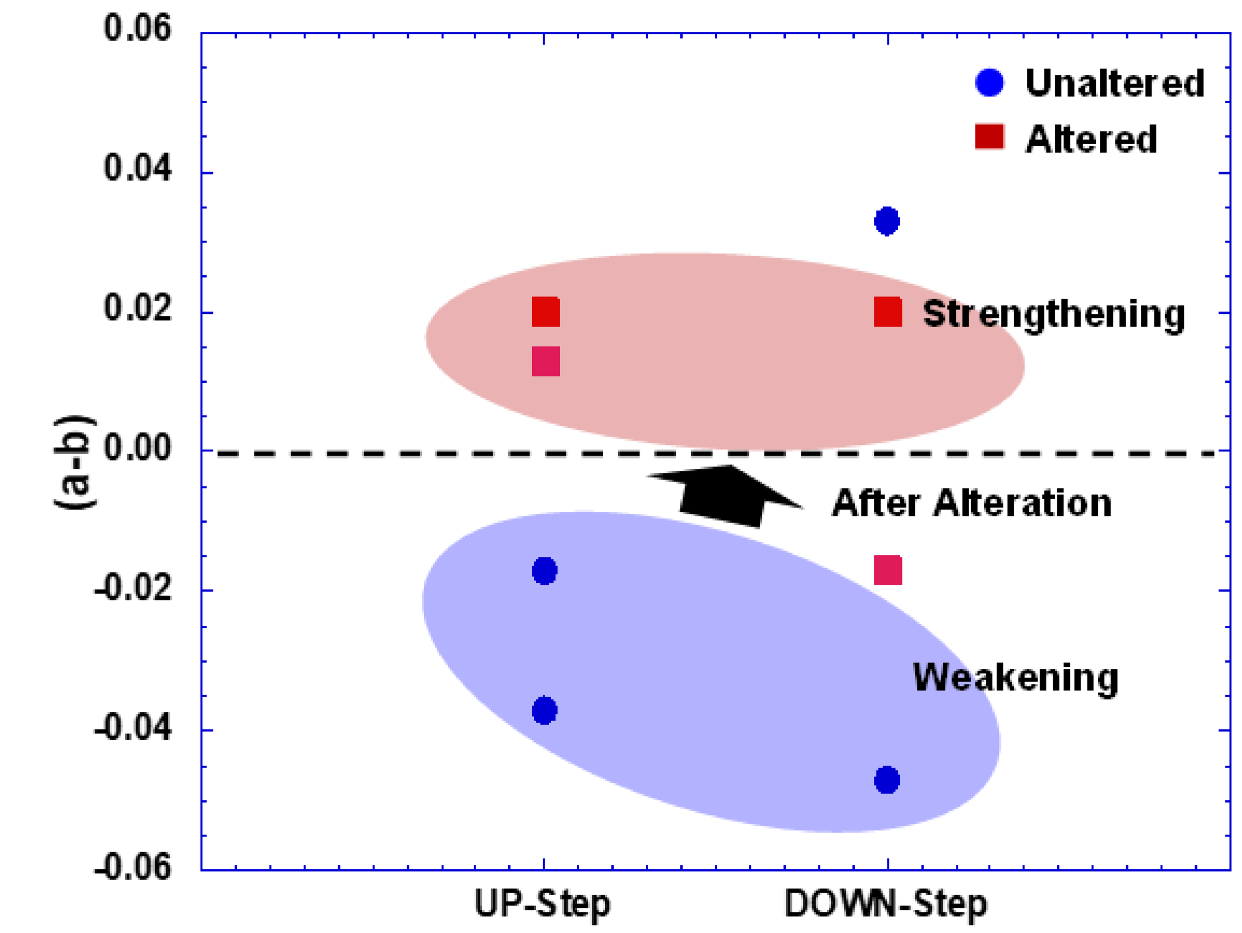
μ_p : the peak friction due to direct effect;
μ_{ss} : the steady state friction after evolution effect;
μ_{ref} : the reference friction coefficient of last velocity change;
D_{acc} : accumulated relative shear displacement.

NUMERICAL SIMULATION RESULTS

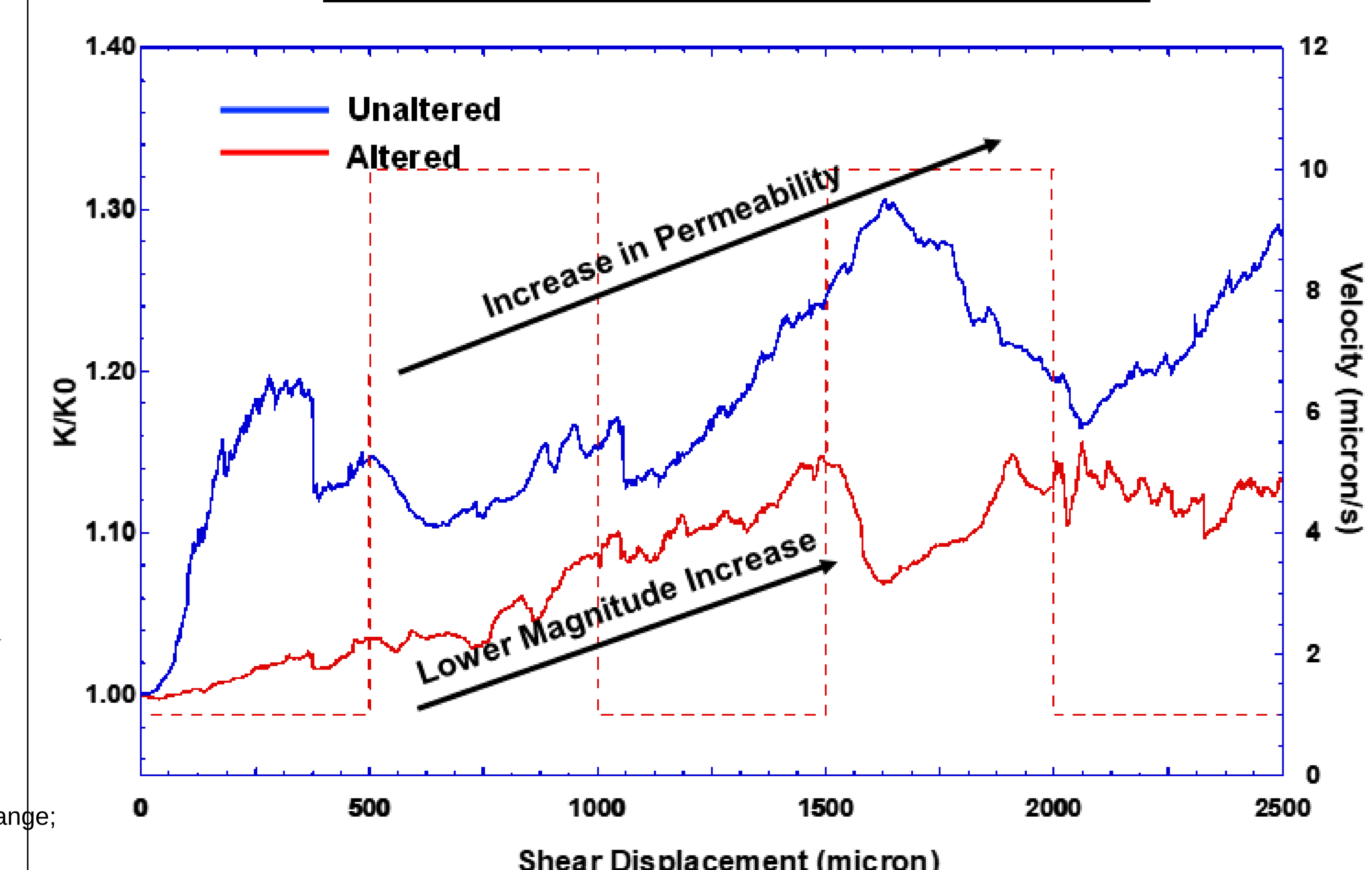
Shear Strength Evolution



TRANSITION IN SLIP STABILITY



PERMEABILITY EVOLUTION



CONCLUSIONS

- The shear strength of altered faults associated with goethite coating is reduced.
- The weakening effect of the goethite coating does not depend on the concentration of the coating particle once a goethite-dominated effect is established.
- The coating-dominated weakening effect is independent of applied normal stress, implying that coating induced weakening can occur at any stress conditions in the upper Earth crust.
- Slip instability may potentially shift from velocity-weakening to strengthening after alteration. Permeability enhancement is depressed after alteration.

REFERENCES

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