The Effects of Pore Fluid Pressure on the Frictional Behavior of Serpentinite: Implications for Slow Slip in Subduction Zones

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Abstract

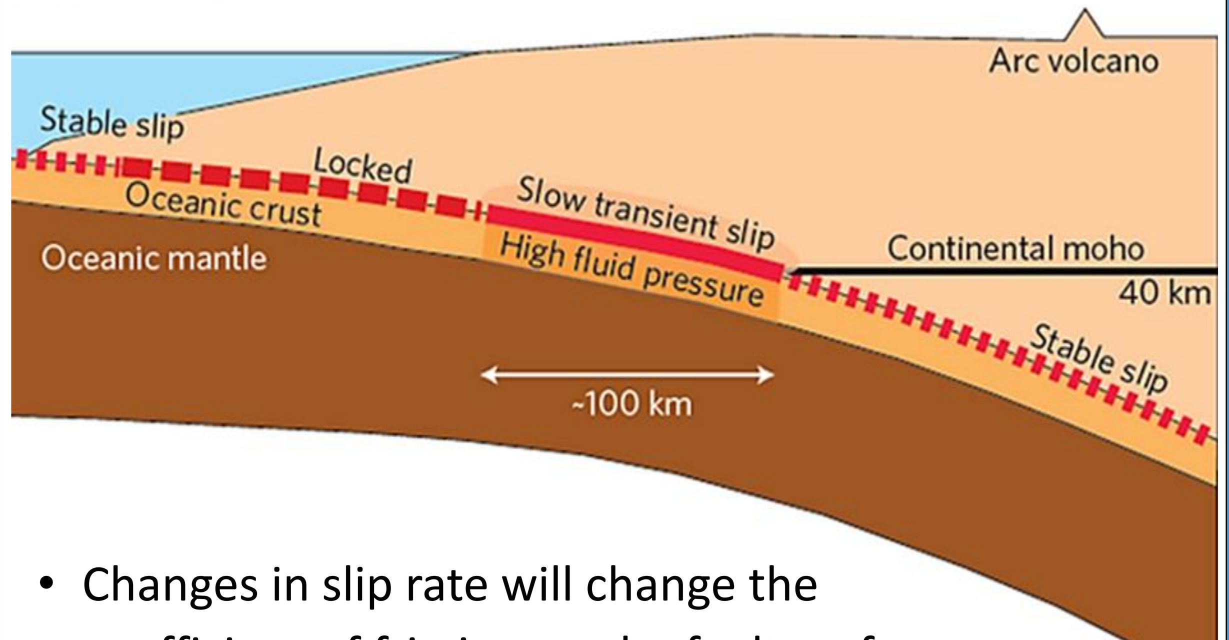
Slow slip events in subduction zones are constrained within regions of near-lithostatic (i.e. *very* high) pore fluid pressure[1]. The role of high pore fluid pressure and its effects on frictional sliding processes may provide a link to understanding slow slip behavior. Using the hot-press triaxial deformation apparatus, I conduct a series of four friction tests on simulated fault gouge of antigorite serpentinite, a relevant lithology in subduction zones. Variations in frictional behavior and dilatancy of Verde Antique Serpentinite are documented at various pore fluid pressures and effective stresses to test the following:

Hypotheses

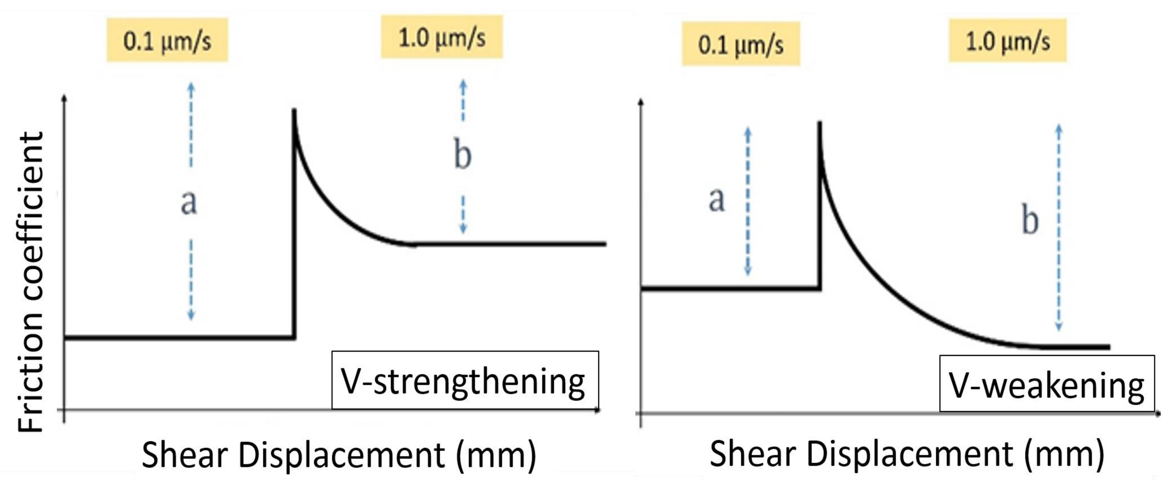
(1) Low effective stress promotes frictional stability, and high effective stress promotes frictional instability.

(2) Frictional stability is enhanced with elevations in pore fluid pressure and confining pressure, independent of effective stress.

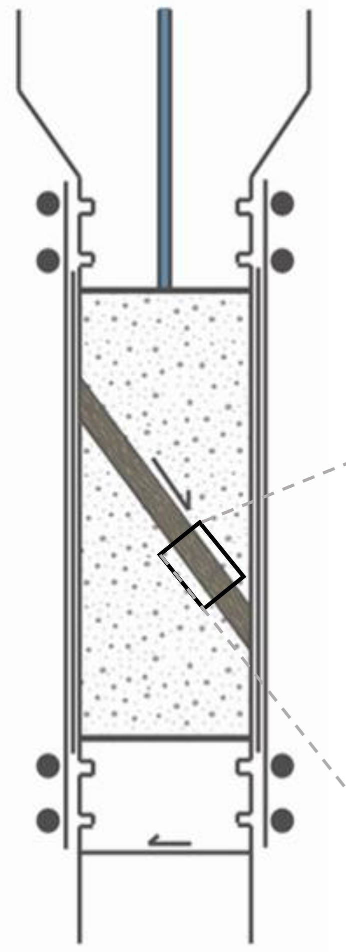
Background



- Changes in slip rate will change the coefficient of friction on the fault surface
- **Velocity-strengthening** = steady state friction increases w/sudden increase in slip rate (**Stable**)
- **Velocity-weakening** = steady state friction decreases w/sudden increase in slip rate (**Unstable**)

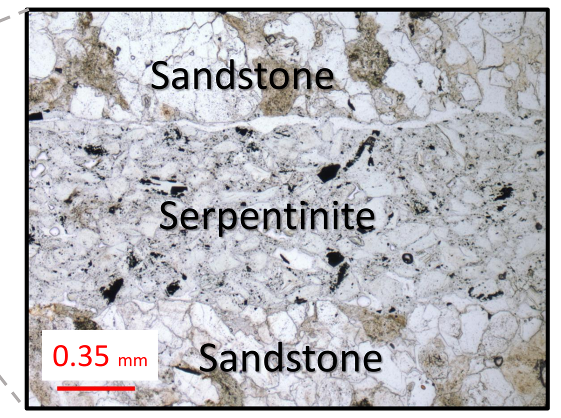


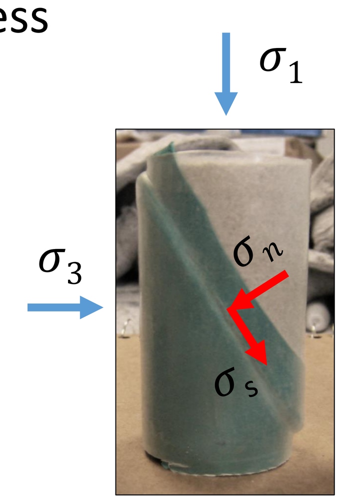
Sample and Procedure

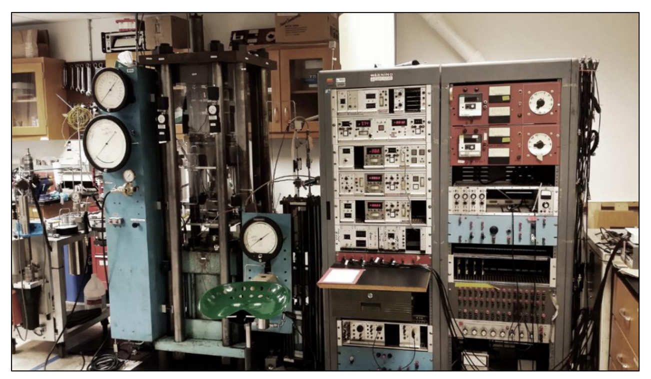


The Verde Antique Serpentinite is:

1. Jacketed with three polyolefin jackets
2. Crushed into fault gouge < 150 um
3. Sandwiched between two driving blocks of porous sandstone
4. Loaded into the hot-press







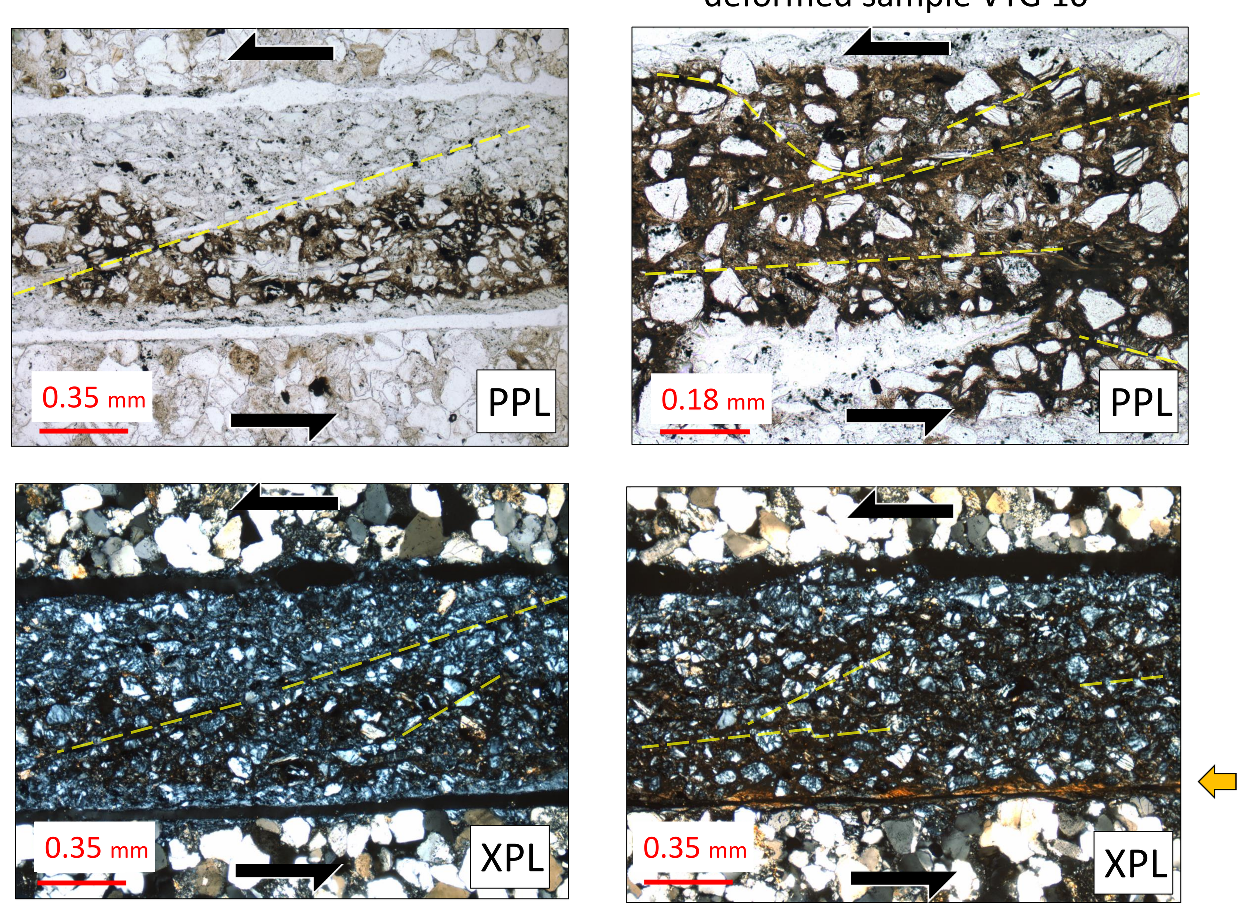
Hot-press apparatus

- Triaxial stress state
- Axial stress = σ_1
- Confining pressure = σ_3
- Normal stress σ_n and shear stress σ_s

Sample ID	Confining Pressure (Mpa)	Pore fluid pressure (Mpa)	Effective normal stress (Mpa)	Measured friction coefficient (σ_s/σ_n)	Number of velocity steps	Frictional behavior
VTG 7	75	5	70	0.594-0.659	6	v-weakening
VTG 8	65	55	10	0.723-0.784	8	v-strengthening
VTG 9	135	65	70	0.640-0.687	6	v-weakening/strengthening
VTG 10	135	125	10	0.785-0.874	8	v-strengthening

Microstructures

Fracture orientations and localized slip in deformed sample VTG 10

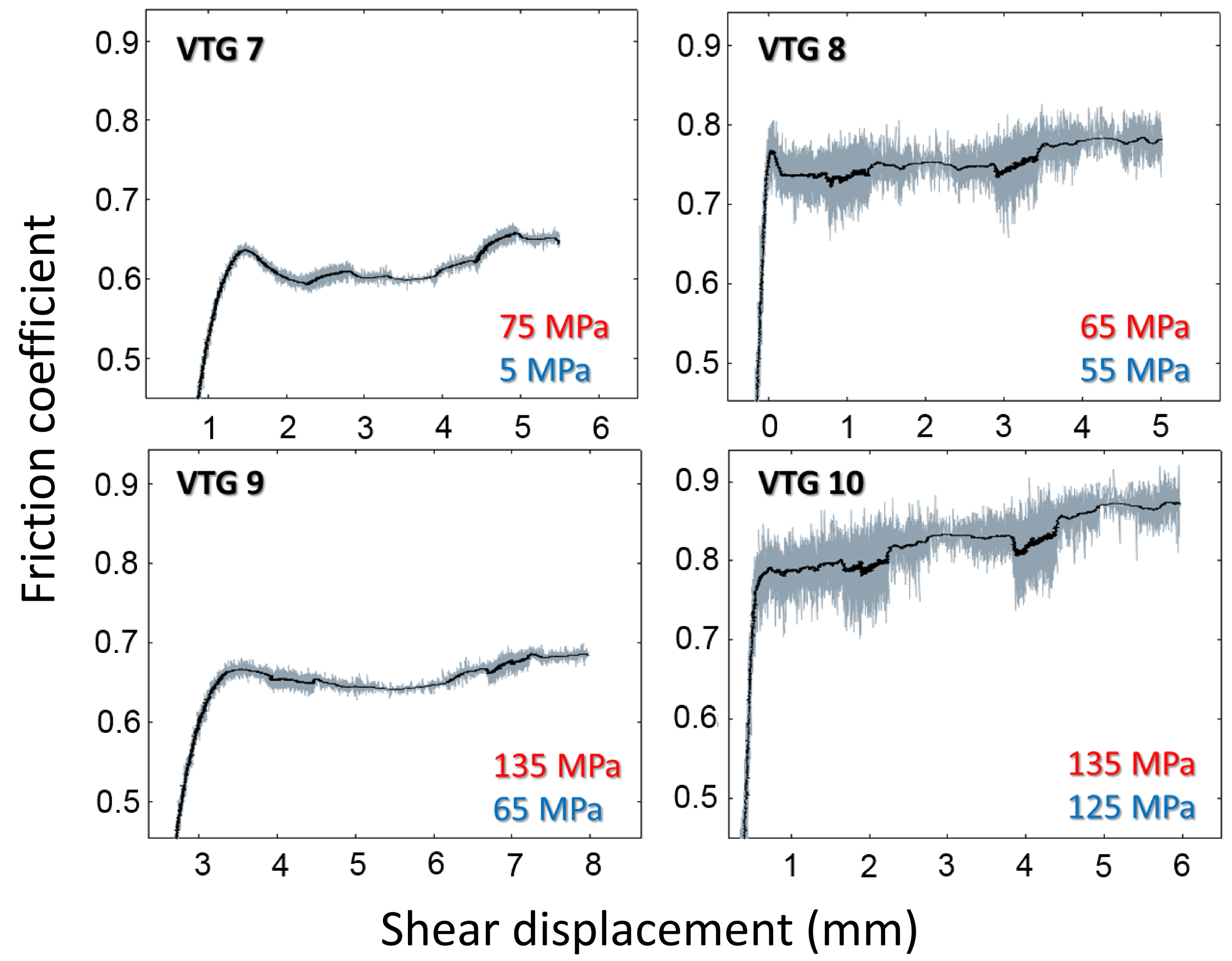


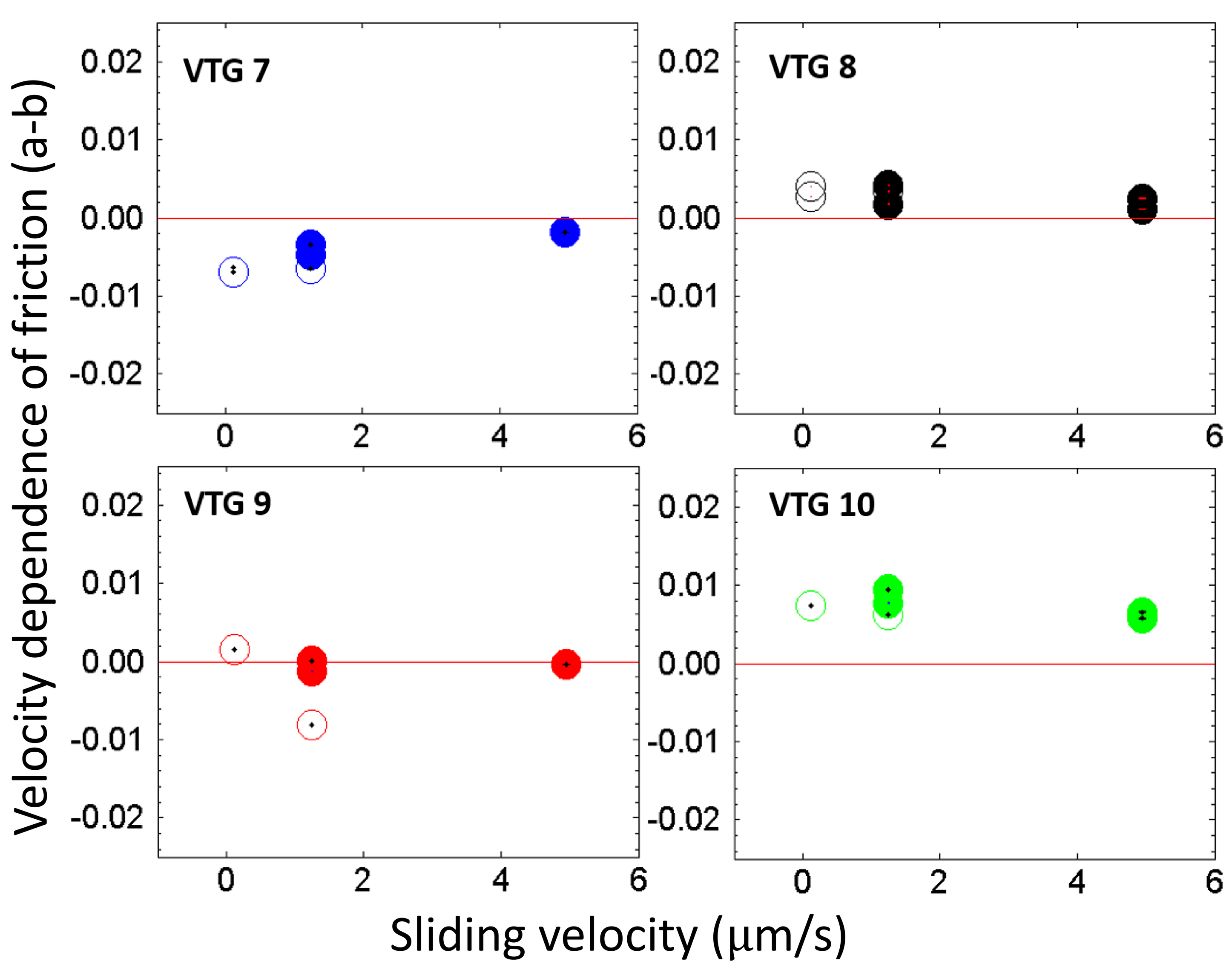
Experimental Results

$$\mu = \frac{\sigma_{shear}}{\sigma_{normal}}$$

velocity steps (μm/s)

~0.53 0.12 1.24 4.94 1.24 0.12 1.24-> -> (4.94) (1.24)





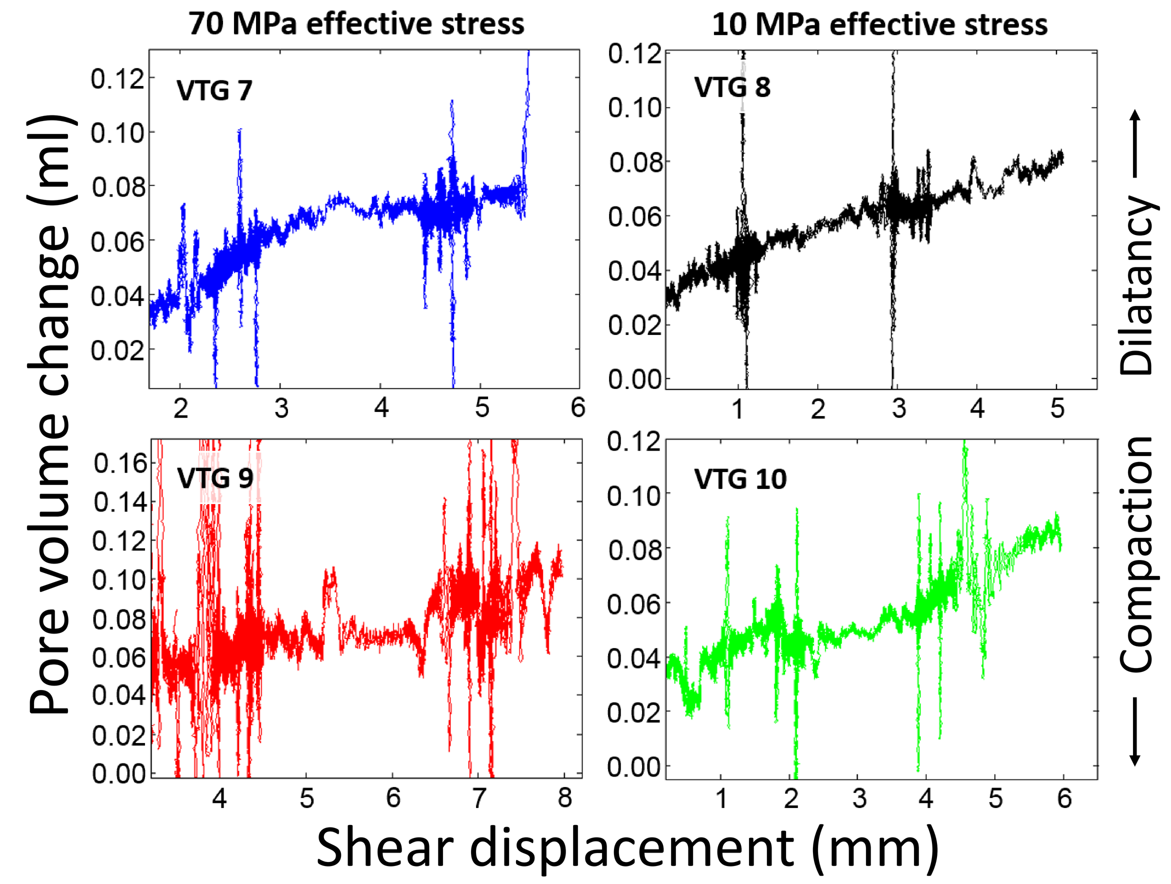
Calculated *a-b* values for each of the experiments. Positive *a-b* values above the reference line indicate velocity-strengthening, and negative *a-b* values below indicate velocity-weakening.

$$a - b = \frac{d\mu_{ss}}{\ln(V_f/V_o)}$$

Velocity increase ↑ (filled circles)

Velocity decrease ↓ (open circles)

Dilatant Hardening?



Despite poor resolution of the signal, sample VTG 9 appears to dilate suddenly with high velocity-weakening and increased strain hardening. This may indicate dilatant hardening as an arresting mechanism of slow slip.

Conclusions

- Heterogeneities of fluid pressure within slow slip regions could control variations in slip activity:
  - Lower-fluid-pressure zones could increase potential for frictional instability on faults leading to non-volcanic tremor
  - Higher-fluid-pressure zones could stabilize slip
- Elevations in both fluid pressure and lithostatic stress with increasing depth could enhance fault stability, independent of (i.e. with no change in) effective stress
- Shear is accommodated by fracture orientations (R_1, P, Y) and localized slip along host-gouge contact

Suggestions for Future Work

- Document and analyze microstructures
- Determine better method of signal processing pore volume change measurements
- Measure critical slip distance D_c to obtain another useful constitutive frictional parameter
- Conduct similar experiments with added conditions (e.g. elevated temperature, variable fluid chemistry)

References

[1] Peng, Z. and J. Gomberg (2010), An integrated perspective of the continuum between earthquakes and slow-slip phenomena, *Nature Geoscience* **3**, 599 – 607