Revisiting lab observations of the deep stable-unstable faulting transition, dilatancy, and the poromechanics of fault zones - Earthscope Mtg Portland - 10/2010

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Revisiting lab observations relevant to deep periodic rapid slip and tremor

1) the deep stable - unstable friction transition
   - rate dependence

2) the high speed cutoff - what is it (what it is)
   - expectations at high temperature
   - implications for dilatancy

3) stress- slip - dilatancy relations
   - inconsistencies
   - near failure behavior
   - poroelastic effects?

4) new experiments - failure with pore pressure + slow slip events in the lab
what does friction rate dependence have to do with the extent of the transition zone?

(Shtetsky, 1978; Tse and Rice, 1986)

- 'a transition zone' is between s/uns boundary and 'completely plastic' (b=0) - defines deep extent of large rupture)

- in the context of rate dependent friction, tremor and deep slip require negative rate dependence, at great depth

(after Tse and Rice, 1986)
are our models of rate and temperature dependent friction an over-simplification of the lab data?

- s/uns transition depth depends on velocity - this is one way to produce deep, transient brittle behavior
The s/us low speed transition to rate strengthening (2 mechanisms)

• $V_0 = f(T)$ should be in models of the transition zone

(data from Reinen et al. 1994)
s/us transition extrapolated in temperature…..

- extrapolation of existing data to seismic speeds suggests possible transient brittle behavior to great depth

- this is probably not reasonable because of the high speed cutoff
expected transition back to rate strengthening at higher slip speed: 'the high speed cutoff' (e.g., Shibazaki and Iio, 2003)

halite, room T

(Shimamoto, 1986)
**what's a high speed cutoff?**

Nakatani and Scholz (2006) also see Dieterich (1978; 1979)

High speed cutoff is slip speed above which there is effectively no change in contact area.

\[ V_c = \frac{d_c}{t_c} \]

- \(d_c\): contact dimension
- \(t_c\): time constant of contact scale yielding

For transition zone models the issue is at what slip speed is the cutoff at high \(T\) and \(P\)?

There's no lab data at temperature - the cutoff is treated as something like a free parameter in slow slip models.
more complete friction model of transition zone might include high speed cutoff ($V_c$) and s/uns transition ($V_0$), both depending on $T$ (and perhaps on $P$).

**halite, room T**

*Shimamoto (1986)*

modified from *Scholz (1990)*
friction dilatancy relationship used in models of slow slip (Segall and Rice) - from rate step

Quartz gouge

(data from Marone et al. 1990)

(Segall and Rice, 1995)

- porosity is rate dependent - its another manifestation of the state variable (of the evolution effect)
dilatancy in materials without a pronounced evolution effect:

muscovite gouge, room T

(talc gouge, room T) **(Scruggs, 1998)**

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**Monday, November 1, 2010**
step-test based formulation in simulation of periodic failure (dry or drained)

periodic stress drop

very small amounts of precursory slip

‘co-seismic’ slip-induced dilatancy

inter-event time dependent compaction
actual periodic failure experiments

- ‘co-seismic’ compaction rather than dilation in experiments

quartz gouge (wet)

initially bare quartzite (dry)
are poroelastic effects important in gouge layers?

**Strong stress-induced anisotropy**

- Pore pressure increase (compaction) with shear stress drop
- This effect is largest at low effective stress

*Measurement* all at $p=100$ bars

\[
A' = \frac{\partial P}{\partial \tau} |_{\sigma_n}
\]

*Lockner and Beeler, unpublished*
**nmb’s to do list:**

*stable - unstable - stable transitions are rate and temperature (and pressure) dependent (explore implications in fault models)*

*more experiments at higher speeds at a wider range of \( T \) and \( P \)*

*more experiments on relevant compositions*

*dilatancy in fault zones approaching and during failure is not understood*

*stickslip experiments with and without pore fluid*

*experiments at elevated \( T \)*

*poroelastic properties of fault zones are unexplored*

*experiments nearer failure - more relevant compositions*
new experiments: periodic failure, initially bare granite w/ pore fluid

loading: constant rate + small amplitude sine wave

(Lockner and Beeler, 1999)

Bartlow et al
**previous results:** dry (Lockner and Beeler, 1999)

**objective:** determine influence of pore fluid pressure on triggered failure

**two frequencies of interest:**

\[ f_a = \frac{\dot{\tau}}{2\pi a \sigma_e} \]

1/ nucleation duration

(Dieterich, 1992)

**new results** (Bartlow et al):

- \( f_a \) is larger at lower effective stress as expected

- correlations deviate from the dry results at frequencies of \( \sim 20s \)

- dilatancy hardening?
more new results (no oscillating stress): static stress drops

diff erent behavior at lower effective stress:

- unusually low stress drops at lower effective stress

- complex stress drop history at largest displacements

- slow events
alternating slow and dynamic events at large displacements at low effective stress:

Bartlow et al

duration:

Bartlow et al
summary of new stick-slip experiments with pore pressure (bare granite, room temperature)

$f_a$ increases with decreasing effective stress

pore fluid affects triggered failure at frequencies of ~20 s (undrained/dilatancy effect?)

slow events at elevated pore pressure -

Bartlow et al
end