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*Title:* Nonlinear dynamical triggering of slow slip

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**TITLE:** Nonlinear Dynamical Triggering of Slow-Slip

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**ABSTRACT BODY:** Among the most fascinating, recent discoveries in seismology have been the phenomena of triggered slip, including triggered earthquakes and triggered-tremor, as well as triggered slow, silent-slip during which no seismic energy is radiated. Because fault nucleation depths cannot be probed directly, the physical regimes in which these phenomena occur are poorly understood. Thus determining physical properties that control diverse types of triggered fault sliding and what frictional constitutive laws govern triggered faulting variability is challenging. We are characterizing the physical controls of triggered faulting with the goal of developing constitutive relations by conducting laboratory and numerical modeling experiments in sheared granular media at varying load conditions. In order to simulate granular fault zone gouge in the laboratory, glass beads are sheared in a double-direct configuration under constant normal stress, while subject to transient perturbation by acoustic waves. We find that triggered, slow, silent-slip occurs at very small confining loads (~1-3 MPa) that are smaller than those where dynamic earthquake triggering takes place (4-7 MPa), and that triggered slow-slip is associated with bursts of LFE-like acoustic emission. Experimental evidence suggests that the nonlinear dynamical response of the gouge material induced by dynamic waves may be responsible for the triggered slip behavior: the slip-duration, stress-drop and along-strike slip displacement are proportional to the triggering wave amplitude. Further, we observe a shear-modulus decrease corresponding to dynamic-wave triggering relative to the shear modulus of stick-slips. Modulus decrease in response to dynamical wave amplitudes of roughly a microstrain and above is a hallmark of elastic nonlinear behavior. We believe that the dynamical waves increase the material non-affine elastic deformation during shearing, simultaneously leading to instability and slow-slip. The inferred triggered slow-slip on the San Andreas Fault at Parkfield, CA., due to December, 2003 M*w*6.5 San Simeon Earthquake (Breguier et al., *Science* 321, p.1478, 2008) shows very similar characteristics to what we observe in the laboratory, suggesting an extremely low *in situ* effective stress or a weak fault and a nonlinear-dynamical triggering mechanism [We gratefully acknowledge the support of the U. S. Department of Energy through the LANL/LDRD Program for this work].

http://www.lanl.gov/orgs/ees/ees11/geophysics/nonlinear/nonlinear.shtml

# Nonlinear Dynamical Triggering of Slow Slip


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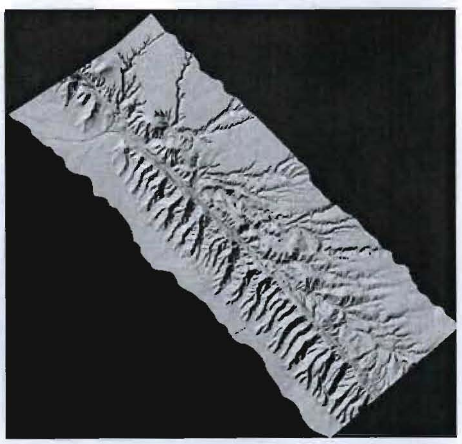
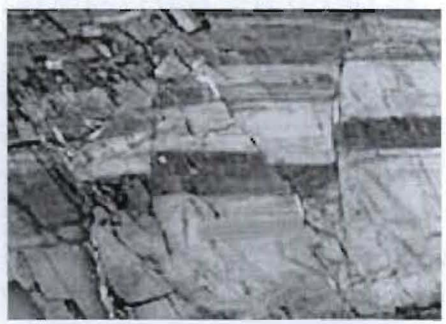
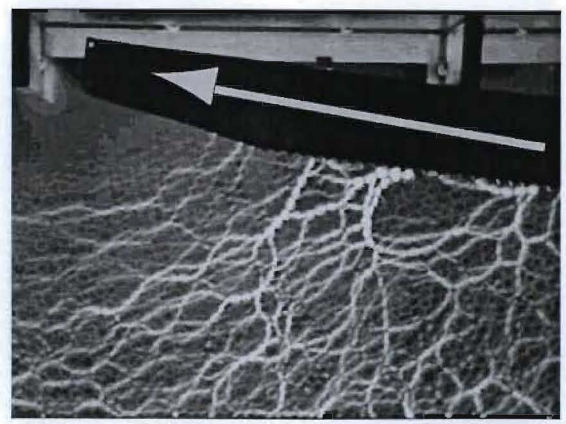
***Pierre-Yves LeBas*** *(Los Alamos)*
*Eric Daub (Los Alamos)*
***Chris Marone*** *(Pennsylvania State University)*

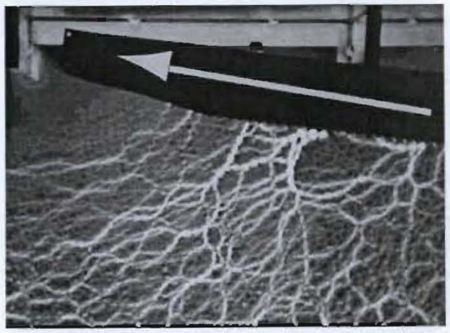







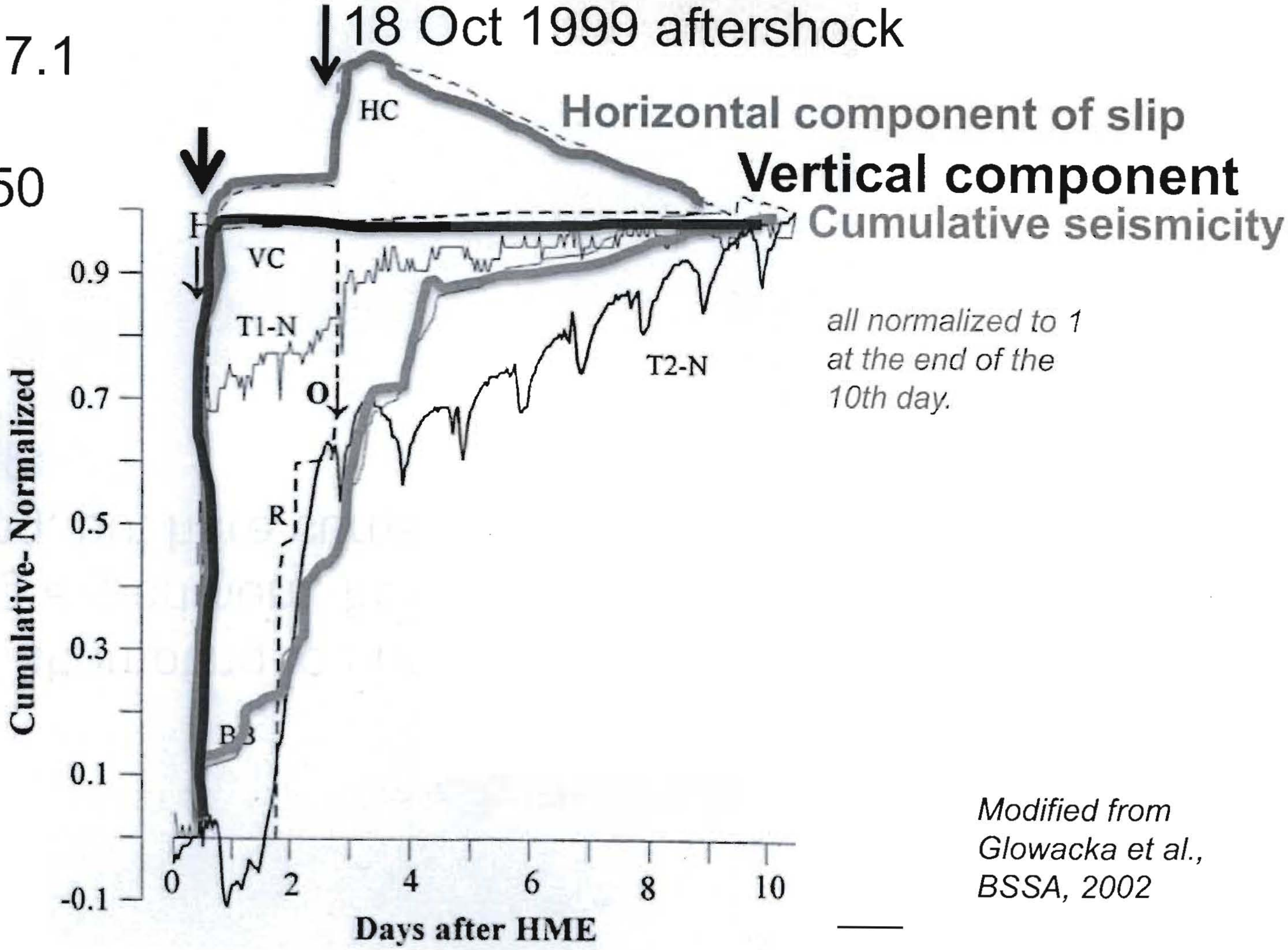
# Outline

*i.* *Context:* Dynamic triggering
*ii.* Stick-slip experimental apparatus
*iiii.* Triggered slip/silent slip
iv. Conclusions



# A *silent*, *slow slip* triggering scenario on the Imperial Fault, CA

16 Oct 1999 M7.1
Hector Mine
Earthquake, 250
km distant




*all normalized to 1 at the end of the 10th day.*

*Modified from Glowacka et al., BSSA, 2002*

We are attempting to understand all slip behaviors applying experiment, field observation and modeling, but here currently focusing on triggered slow-slip.

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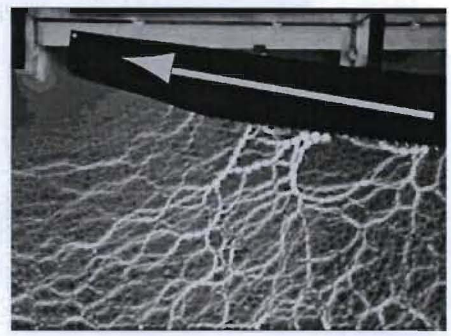
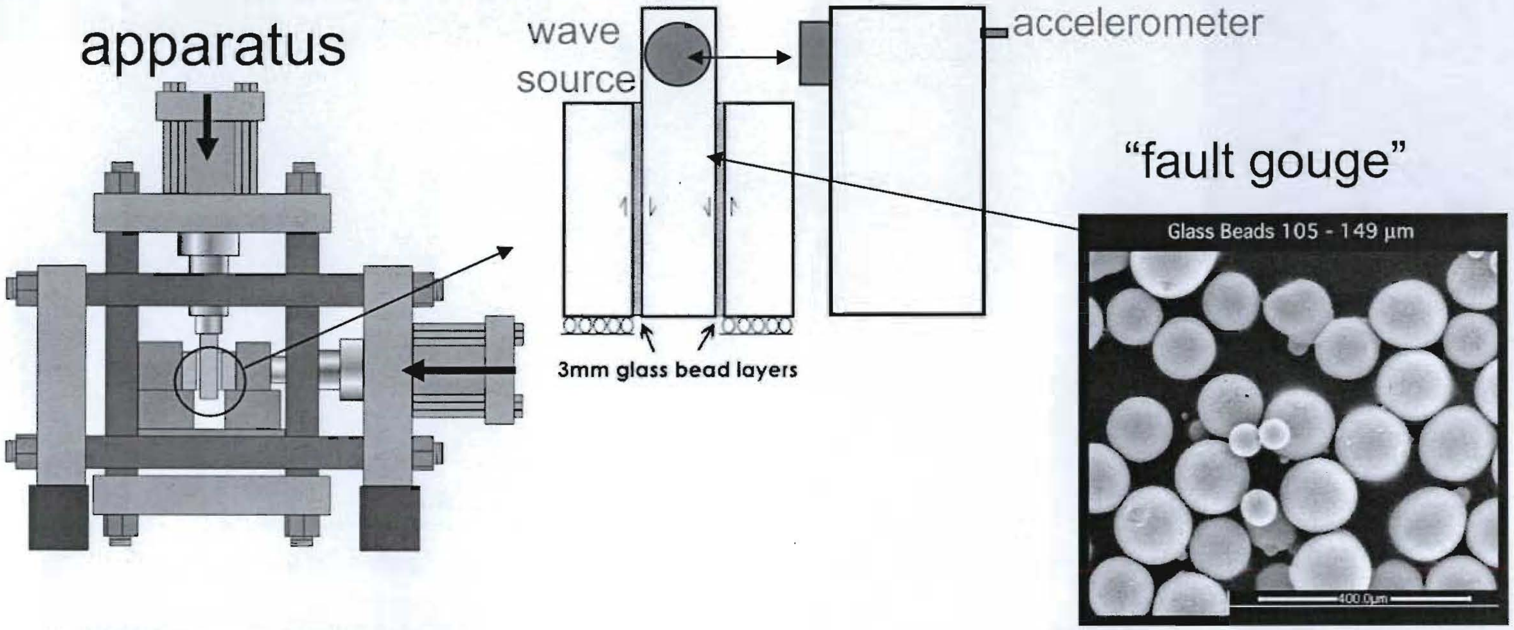


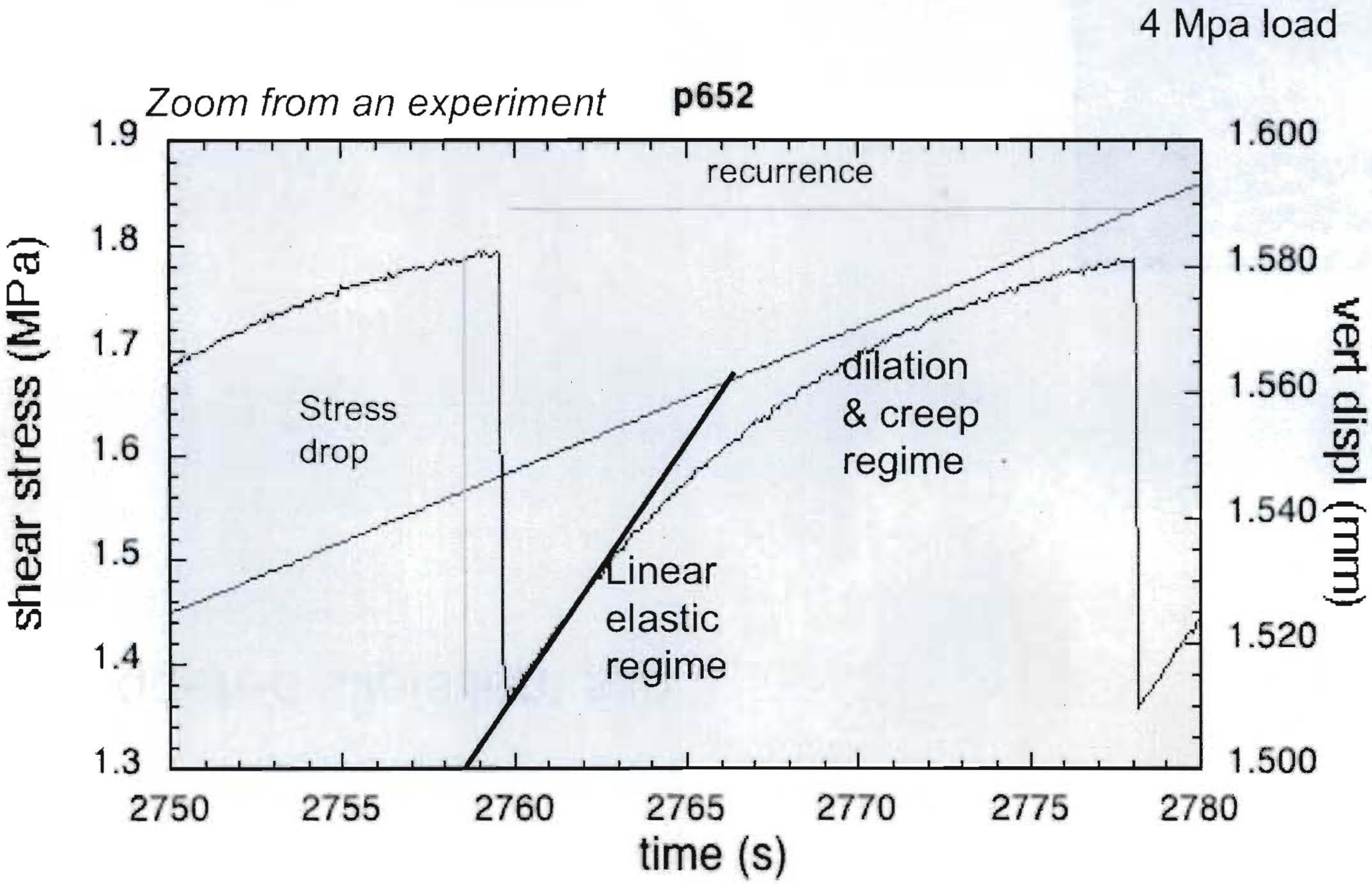
# The Marone earthquake apparatus at Penn State

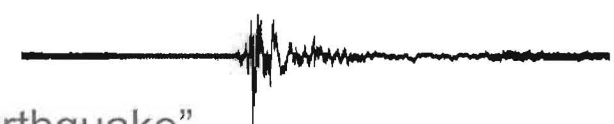



- 1-10 MPa normal stress
- background shear loading rate of 1-100 µm/sec

- 3 mm layers of soda lime beads
- 0.105-0.149 mm size distribution

# Stick-slip instabilities without wave perturbation



“earthquake”

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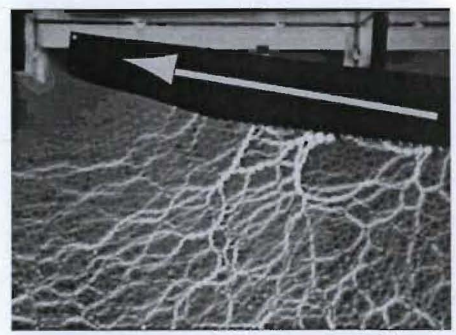
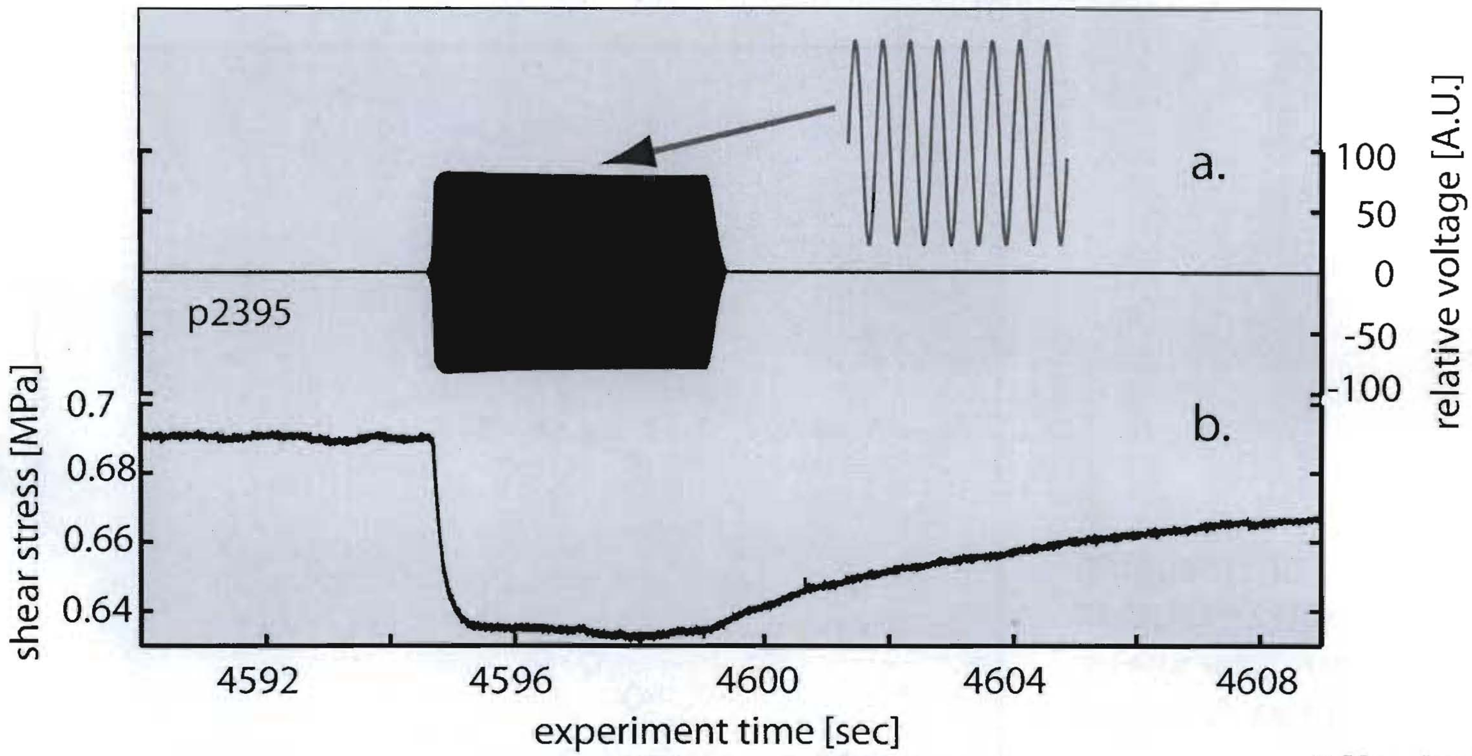


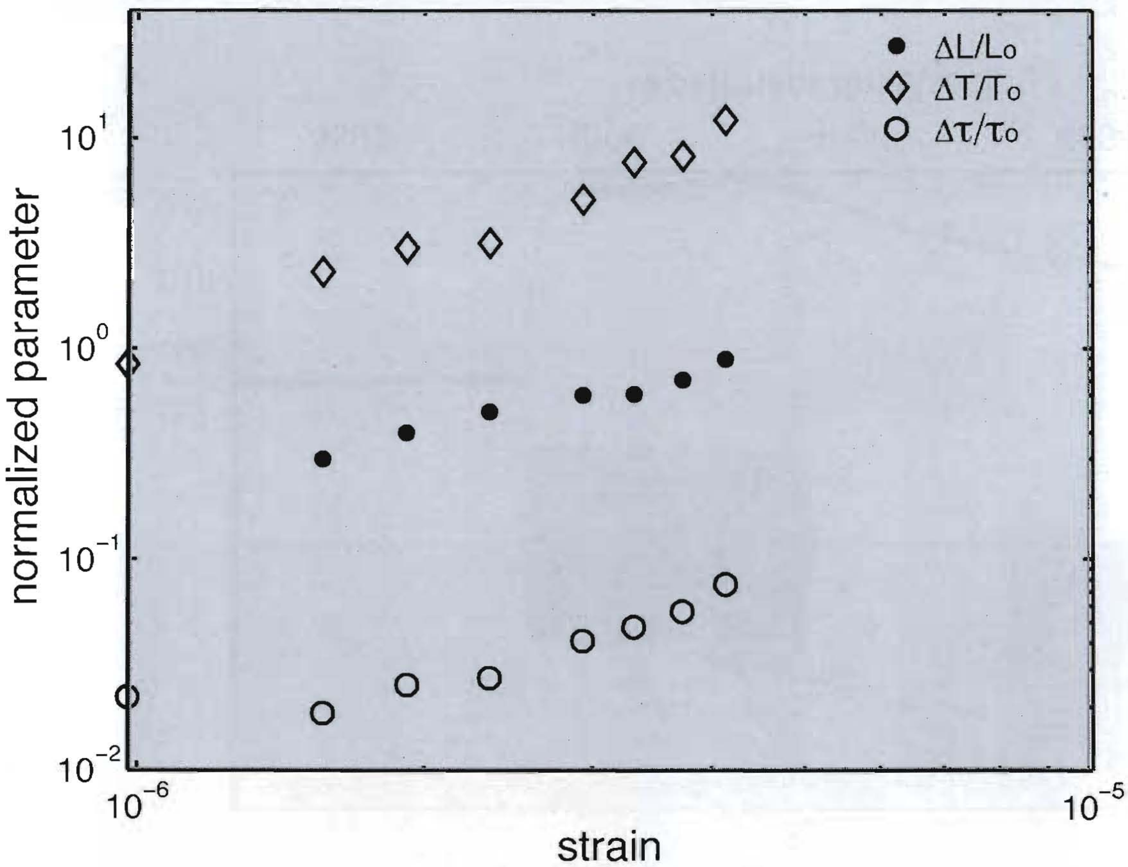
# Triggered slow, ~silent slip




***2 Mpa load***

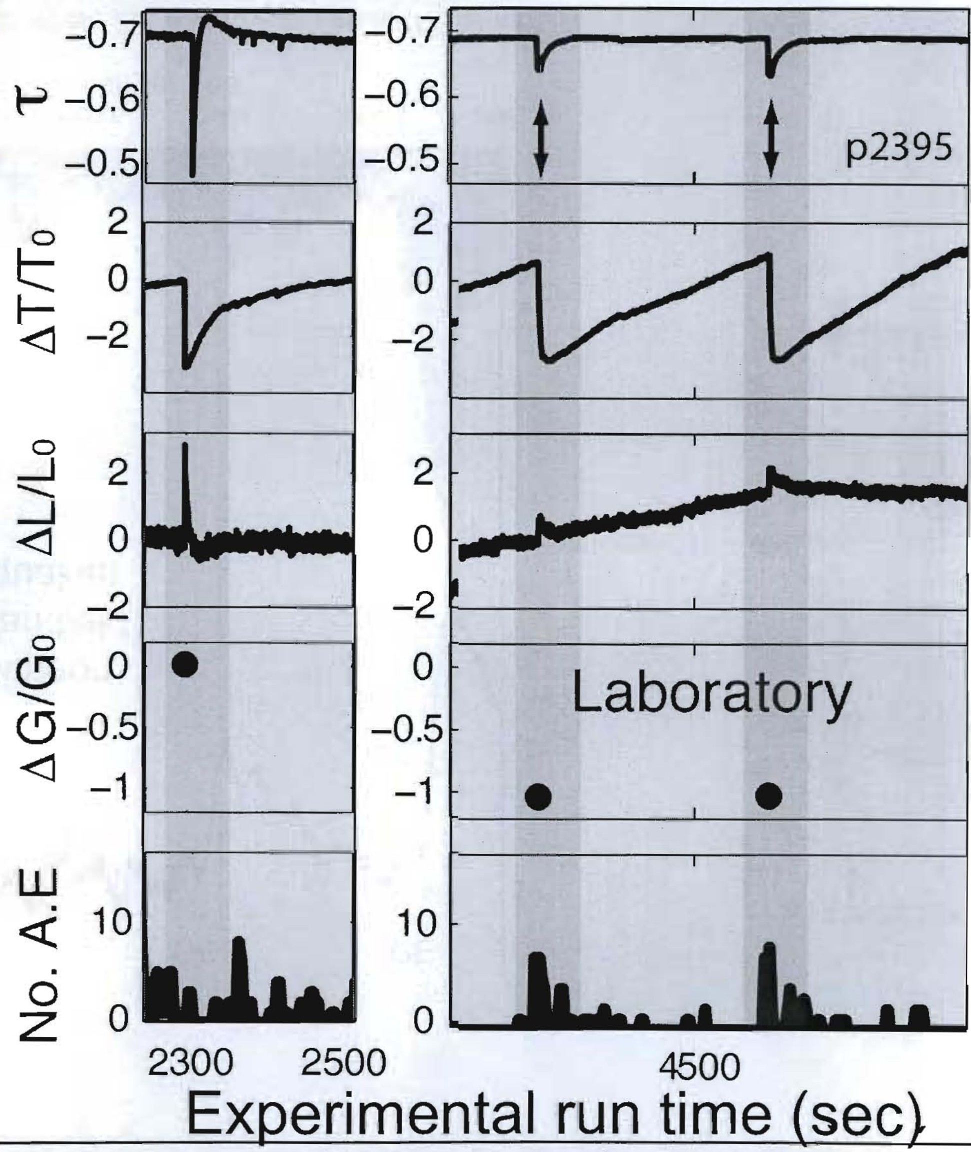
***Triggering slow slip only occurs at loads <=2 Mpa; we are approaching plasticity at these pressures.***

# Triggered slow, strain amplitude dependencies



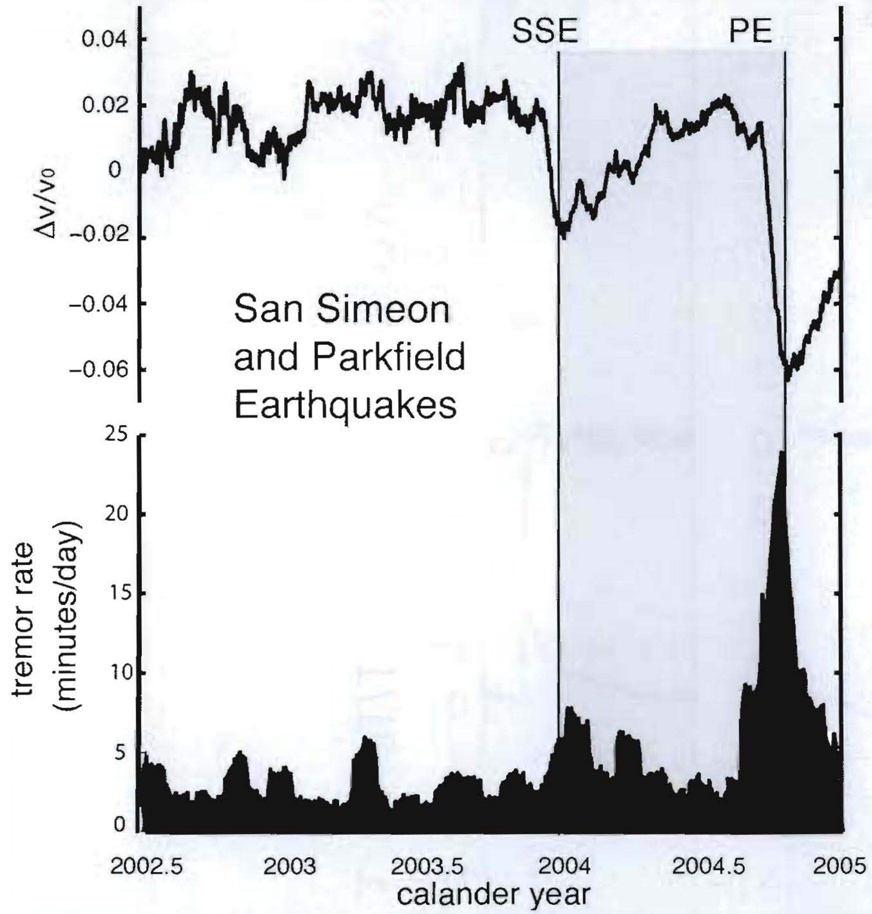

**Amplitude dependent modulus and thickness change, as well as long recovery of thickness, shear stress etc., indicate a <u>elastically nonlinear mechanism</u>.**

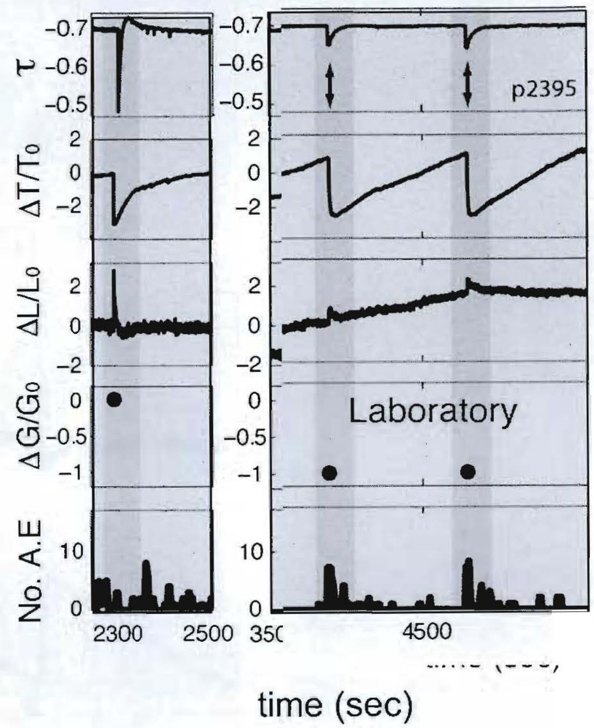
# Stick-slip versus triggered slow slip




*From Johnson et al, in preparation, 2010*

# Triggered slow slip and tremor in Earth




*Modified from Brenguier et al., 2008, and Nadeau and Guilhem, 2009.*

# Summary

**1-3 Mpa load conditions:**
slow slip & instantaneous triggering + delayed triggering and tremor + long recovery.

Triggering slow slip is an *elastically nonlinear process.*

*We believe that some of our results may help understand triggering of slow-slip in Earth.*