The role of lithology in fault re-strengthening: A case study of the 2011 Prague, Oklahoma induced earthquake sequence

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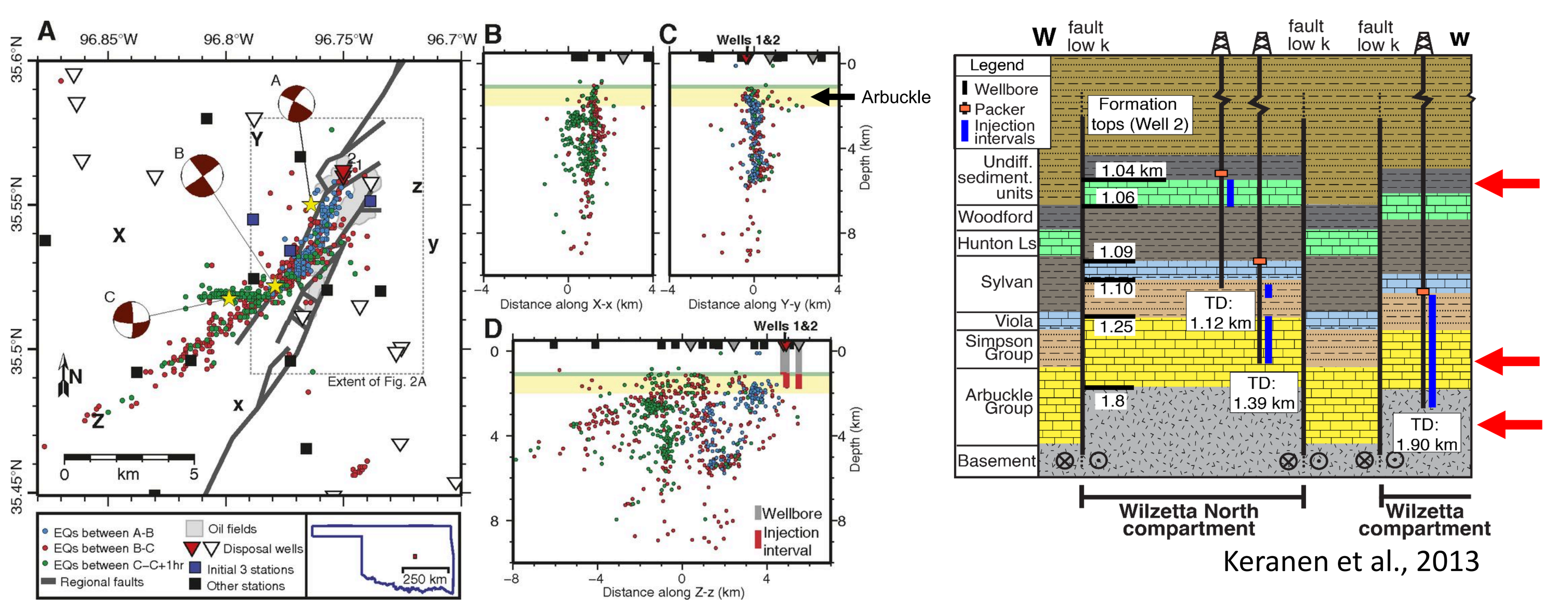
Introduction

Fault strength heterogeneity has first-order control on where earthquakes nucleate and how slip is distributed. Such variability may arise from lithological variations in frictional healing rates along faults. However, it is difficult to link laboratory studies of frictional healing and observed healing rates from repeating earthquakes, because of uncertainty of earthquake depth locations and complicated stratigraphy in fault zones. Here, we study the 2011 Prague earthquake sequence which occurred in simple, layered geology and has a catalog with extremely accurate depth locations. Earthquakes in the catalog are both in the granitic basement and the sedimentary cover. We performed friction experiments on samples from the relevant lithologies (→ below) collected from the Oklahoma Petroleum Information Center core repository, as well as field sites.



Keranen et al., 2013

Our combined lab and seismic dataset allow us to pose the following questions:

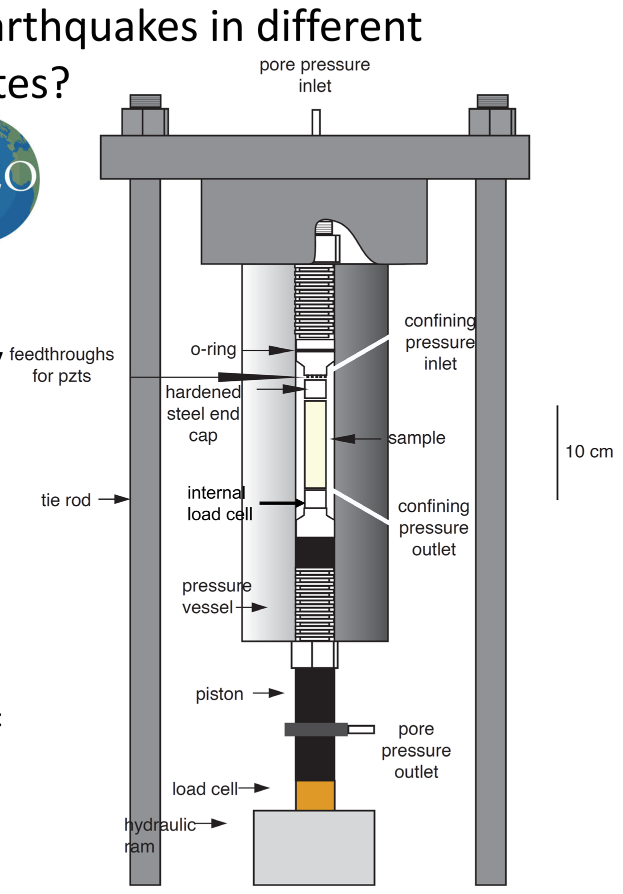
1) What is the overall frictional strength of granitic basement and the overlying sedimentary rocks in Oklahoma?

2) How does frictional healing vary with lithology and pore pressure in the lab?

3) Do healing rates measured from repeating earthquakes in different lithologies reflect variations in lab healing rates?

Experimental Setup

Triaxial deformation experiments were run in the Rock Mechanics Lab at the Lamont-Doherty Earth Observatory

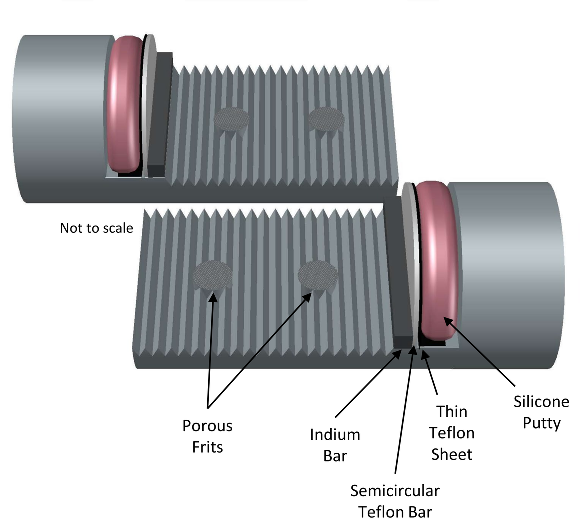


Experiment Conditions

- Confining pressure: 25-100 MPa (reflecting depths of 1-4 km)
- Pore Pressure: 0-75 MPa (0%, 20%, 75% of P_c for each lithology)
- Slide-hold-slide tests with 3-3000s holds, 10 µm/s slides

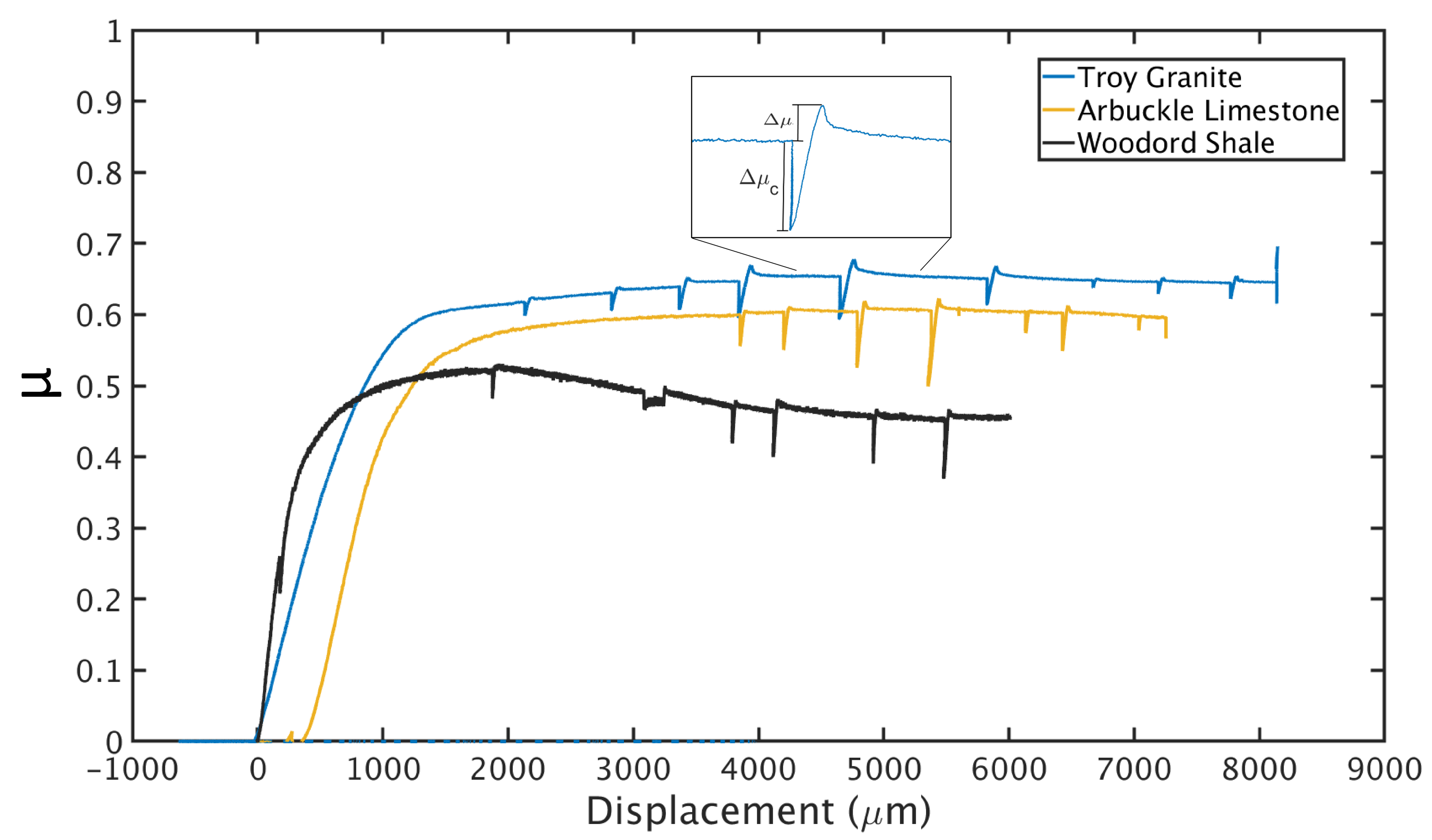
L-Block Direct Shear Configuration

- 2 mm thick gouge layer lies between blocks with sawcut teeth. Porous frits allow for fluid flow
- ~8 mm of shrink wrapped silicone putty
- 2 mm indium bar, 1 mm Teflon semicircular bar, and a Teflon sheet were used to keep the putty from going into the sample

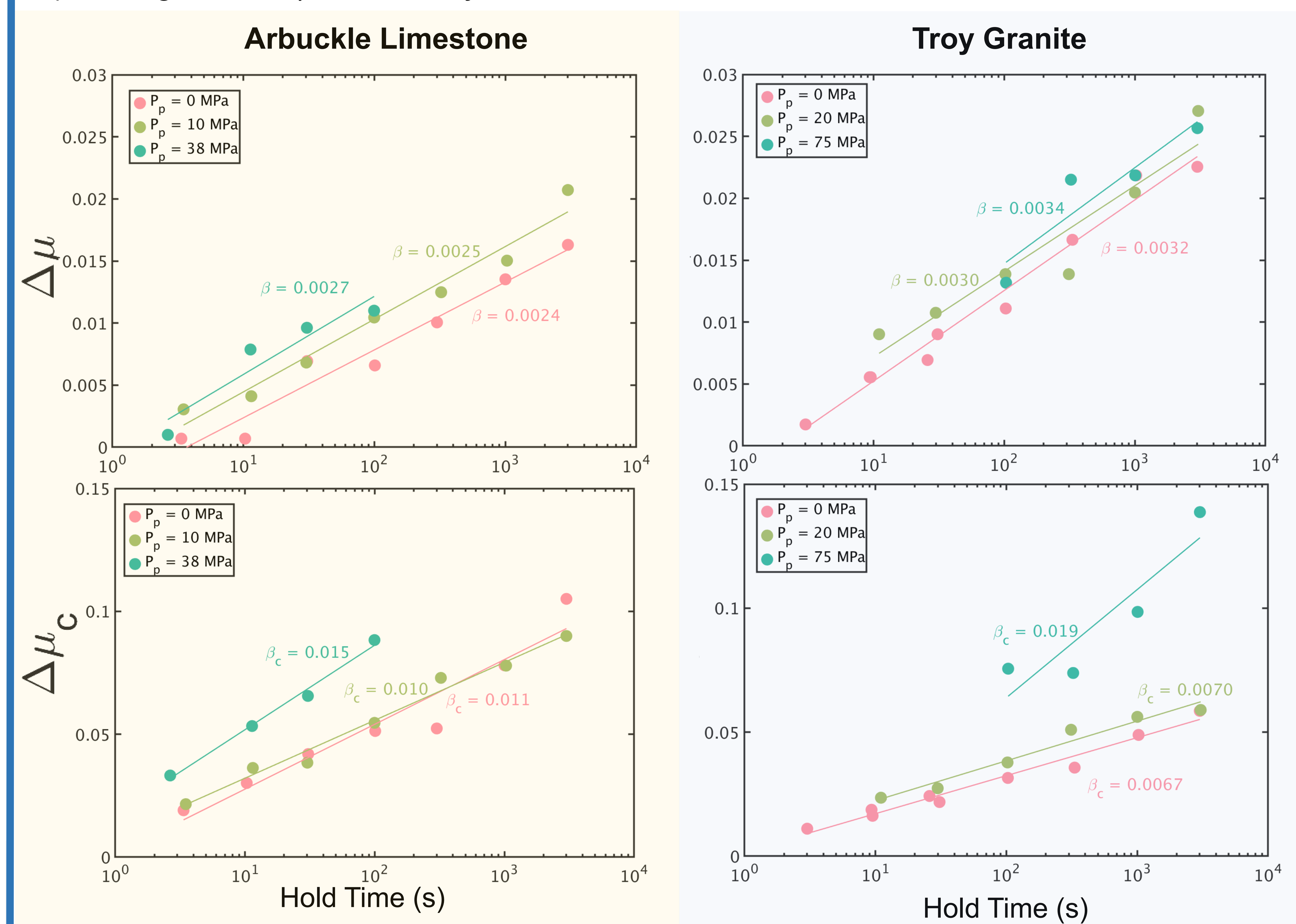


Preliminary Experimental Results

1) Steady-State Friction



2) Healing and Creep Relaxation from Slide-Hold-Slide Tests



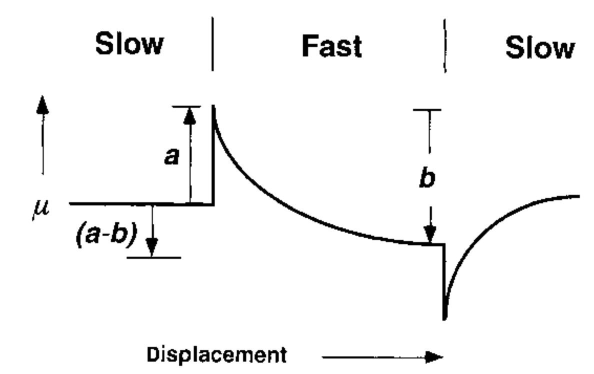
- Granitic basement is slightly stronger than the Arbuckle limestone and the Woodford shale is the weakest
- The granitic basement has a slightly faster healing rate (β) and a slower creep rate ($β_c$) than the Arbuckle limestone
- Healing rate (β) shows no relationship with pore pressure in either rock type

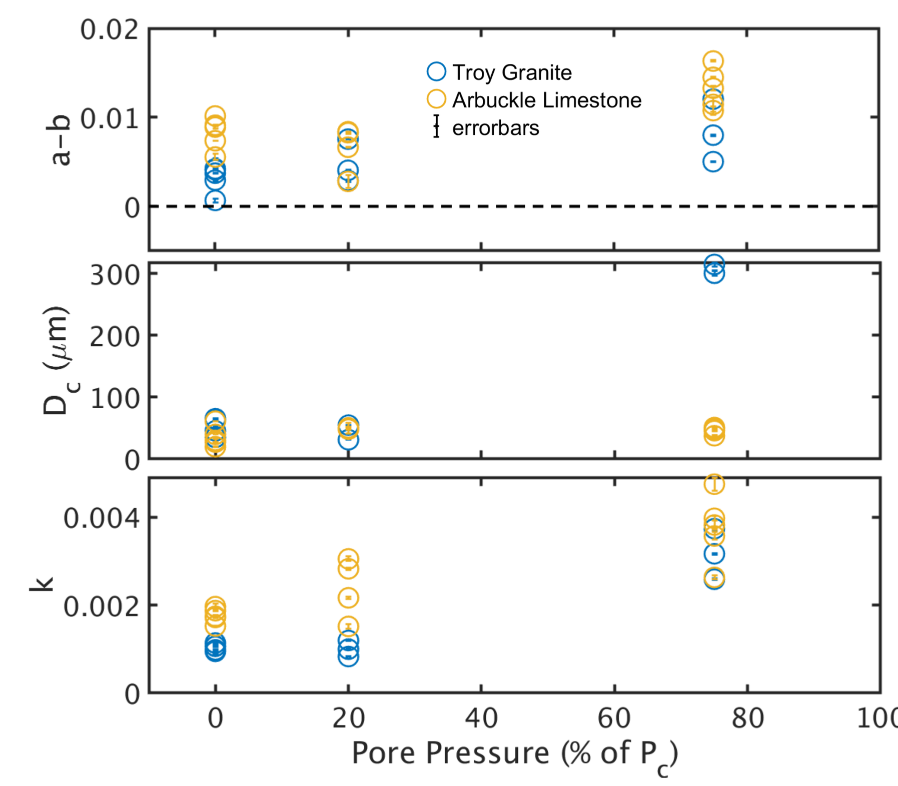
3) Preliminary Rate-State Parameters

We fit our slide-hold-slide tests using RSFit3000 (Skarbek & Savage, 2019) . In addition to the rate-state parameters, we invert for stiffness instead of constraining it.

$$\mu = \mu_0 + a\ln\left(\frac{V}{V_0}\right) + b\ln\left(\frac{V*\theta}{D_c}\right)$$

$$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c}$$





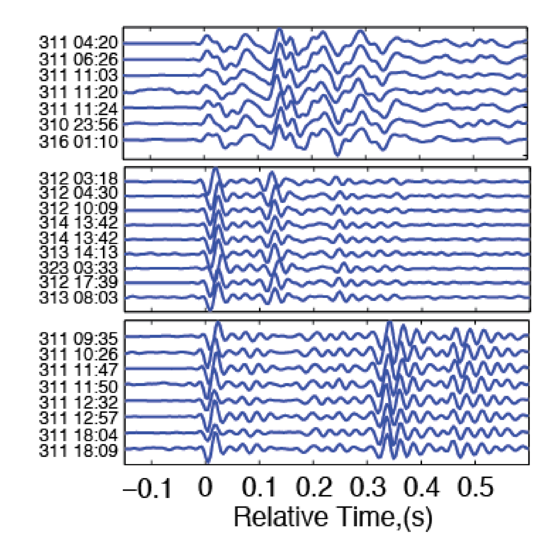
- Slight increase in *a-b* values for higher pore pressure
- Granitic basement shows large values of D_c at the highest pore pressure
- Stiffness, k, increases with increasing P_p

Preliminary Conclusions

- Basement granitic rocks are slightly stronger and have a slightly higher healing rate than the Arbuckle limestone
- Although healing rates are similar between pore pressures, absolute value of healing increases with pore pressure perhaps due to increasing stiffness

Future Work

- Find repeating events within current catalog (complete for 1 week)
- Extend earthquake catalog to months in order to capture repeating events with longer recurrence intervals
- Relocate earthquake catalog
- Compare laboratory healing results to repeating events



Earthquakes within the basement (2nd and 3rd panel) have an additional S-P conversion from the basement-sediment interface

References

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Skarbek, R., & Savage, H. M. (2019). RSFit3000: A MATLAB GUI-Based Program for Determining Rate and State Frictional Parameters from Experimental Data. *Geosphere* https://doi.org/10.31223/osf.io/tf32k