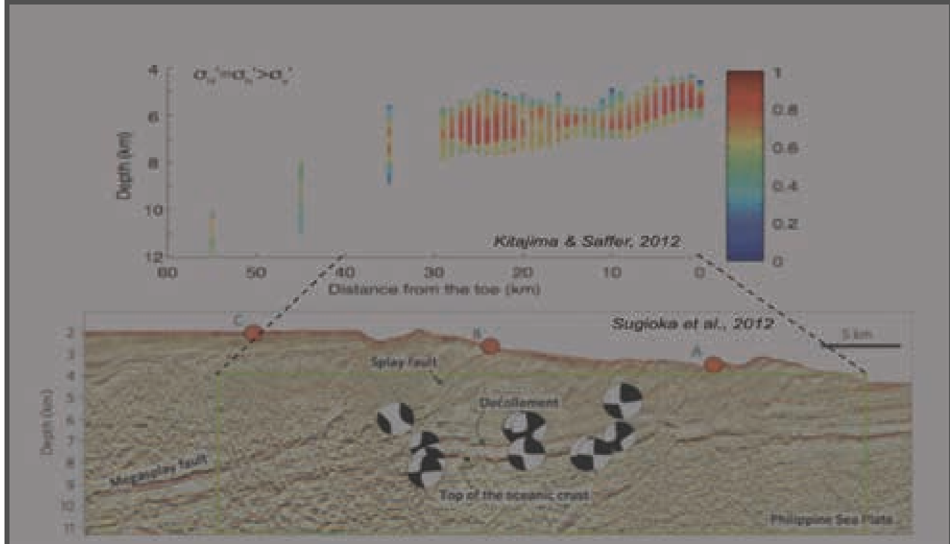
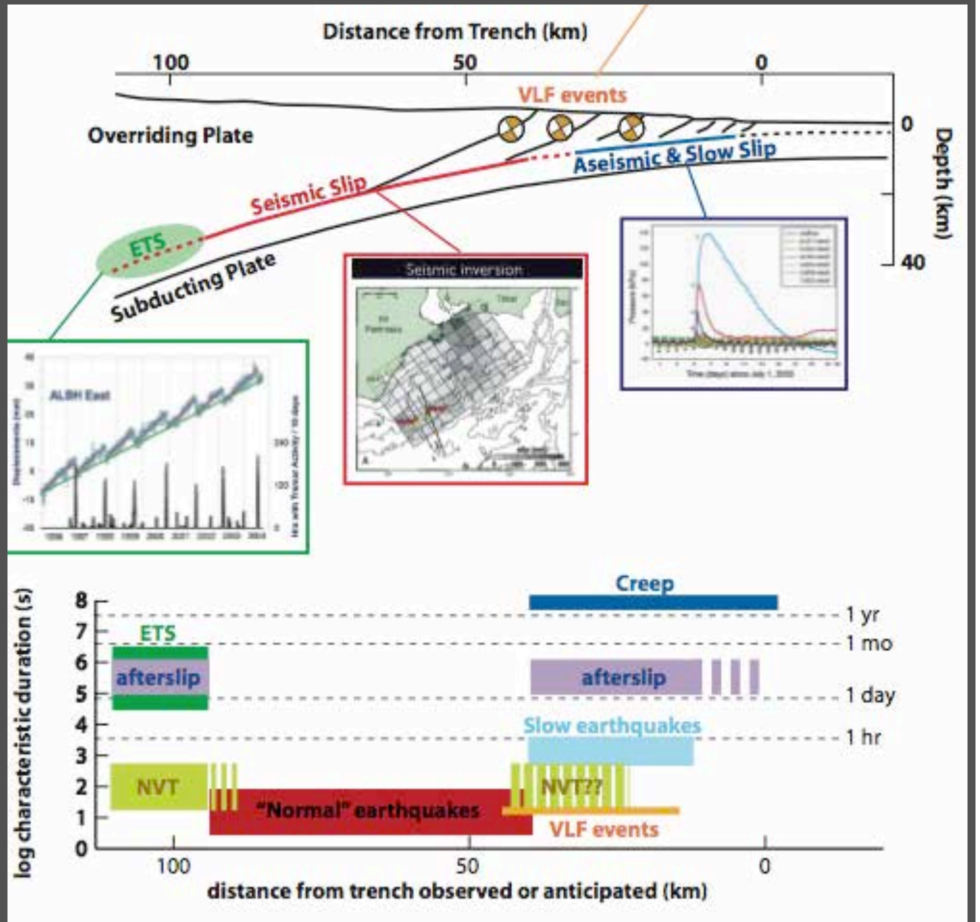
In situ conditions and the mechanics of slow earthquakes along subduction megathrusts: Insights from laboratory experiments



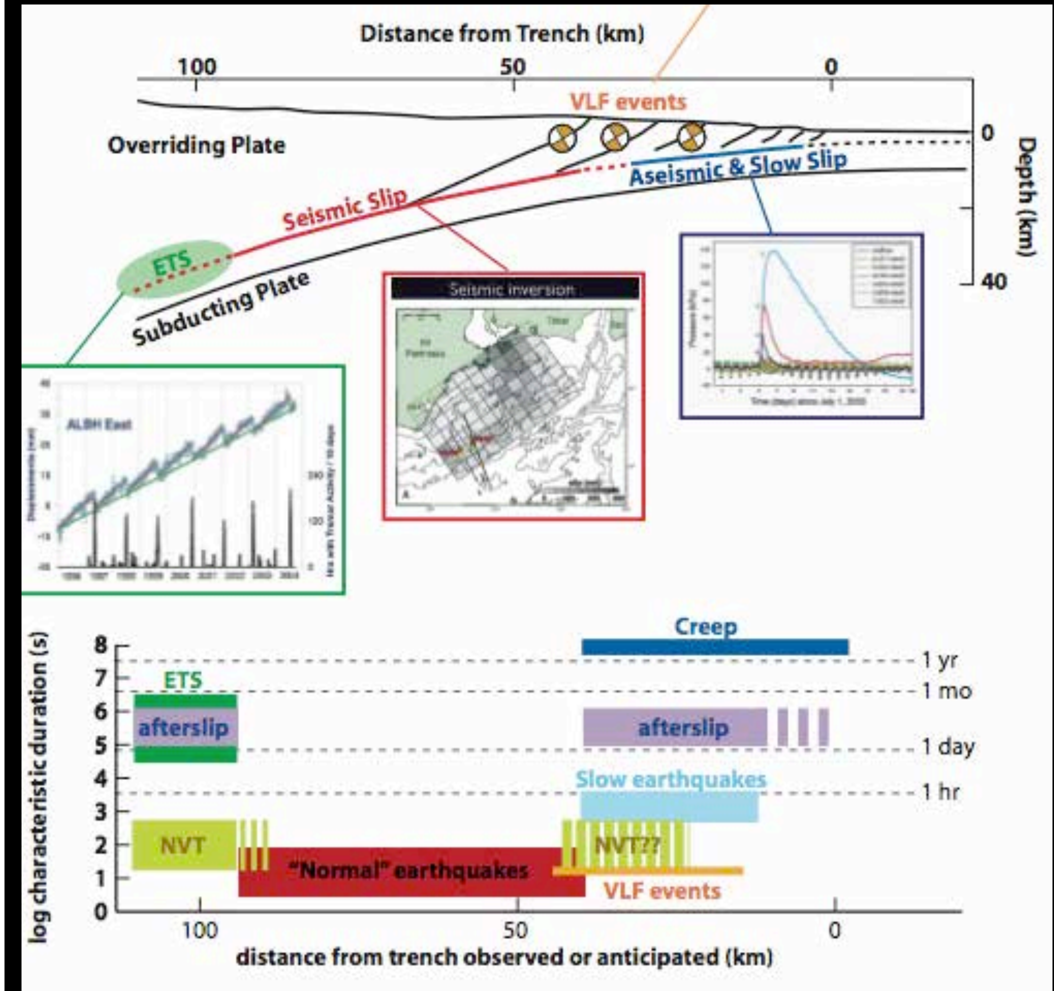


Demian Saffer[1], Hiroko Kitajima[2], John Leeman[1], Matt Ikari[3], Chris Marone[1], Marco Scuderi[4]

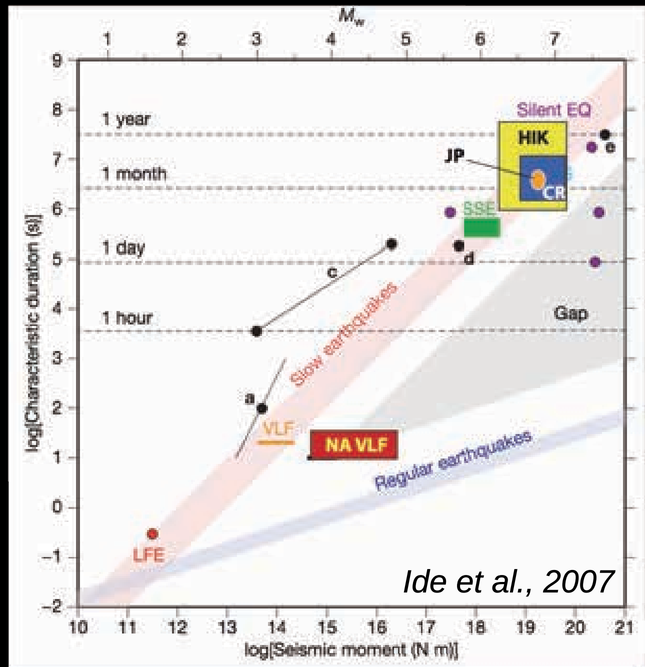
1. Penn State Univ.; 2. Texas A&M; 3. MARUM, Univ. Bremen; 4. Sapienza Univ. Rome

Spectrum of Fault Slip & Slow Earthquake Phenomena:

- Longer source duration for given magnitude than “normal” earthquakes
- Tend to occur at upper and lower edges of rupture/locking regions, though not exclusively

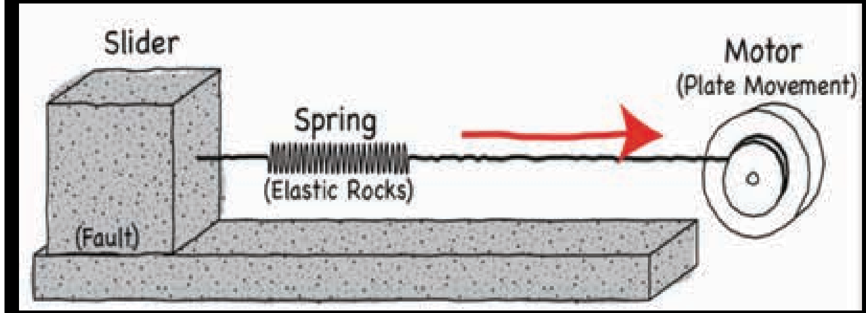


- Slip more slowly than “normal” earthquakes (*μm-mm s*$^{-1}$)
- Radiate less/no high frequency energy (VLFE)
- Detected mainly by geodetic approaches – or BBS (VLFE)



Ide et al., 2007

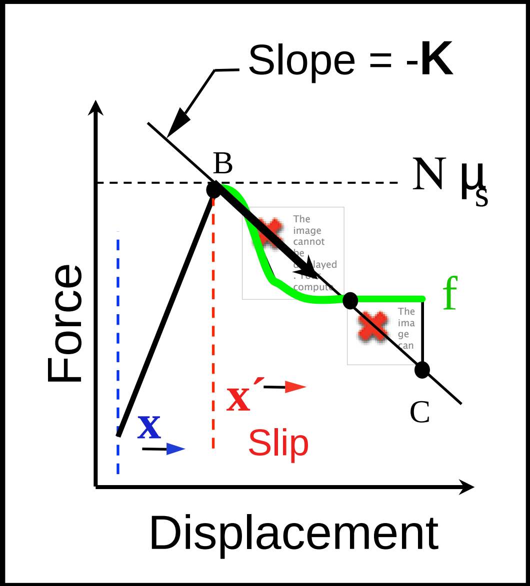
Slow earthquakes are thought to be a manifestation of *conditional stability* (transition between stable and unstable states)



Simple 1-D spring-slider system analog:

Unstable if the rate of slip weakening exceeds rate of elastic unloading:

$$K < K_c = \frac{\sigma_n' \,(b-a)}{D_c}$$

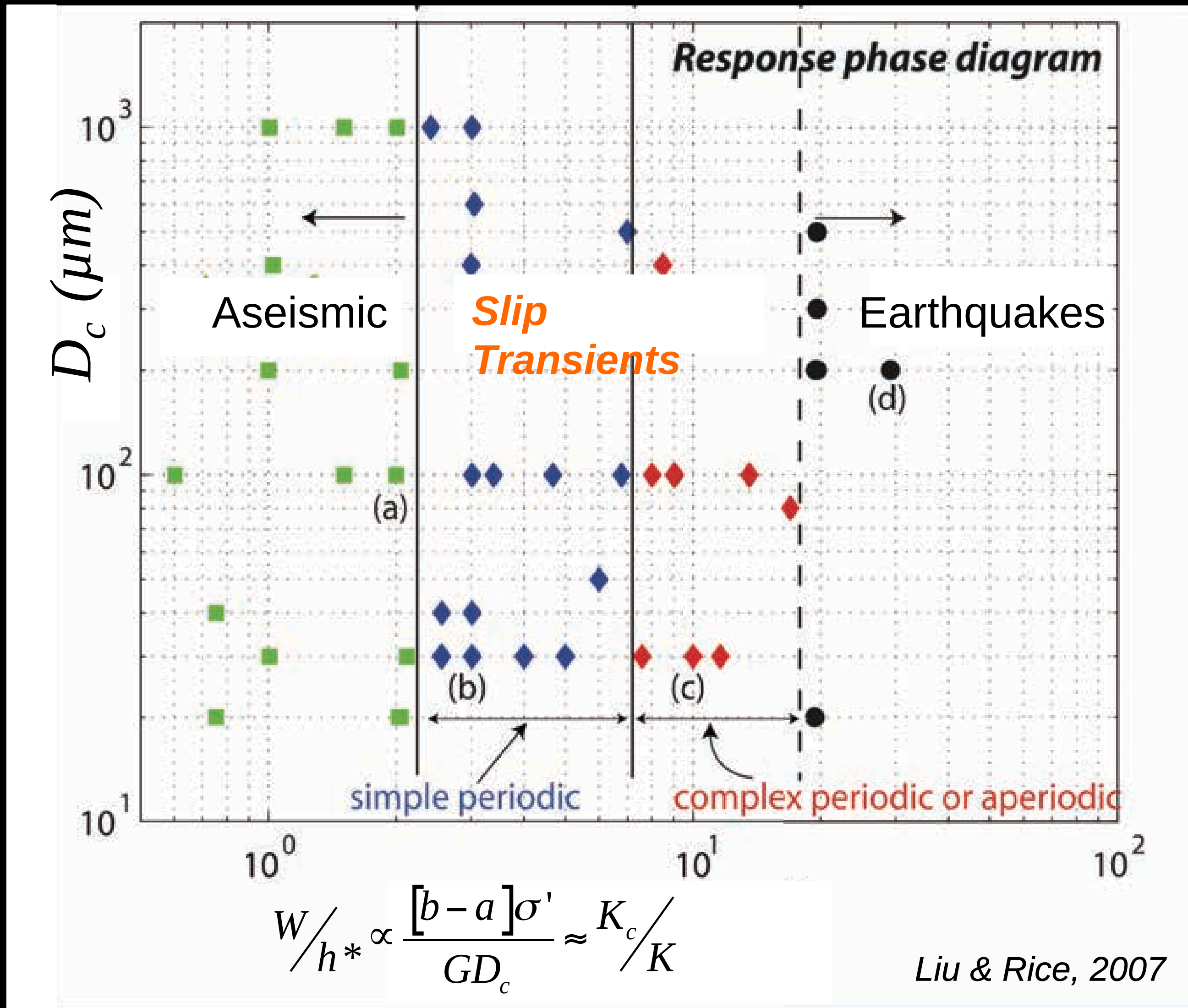


after *Scholz (2003)*

Key parameters

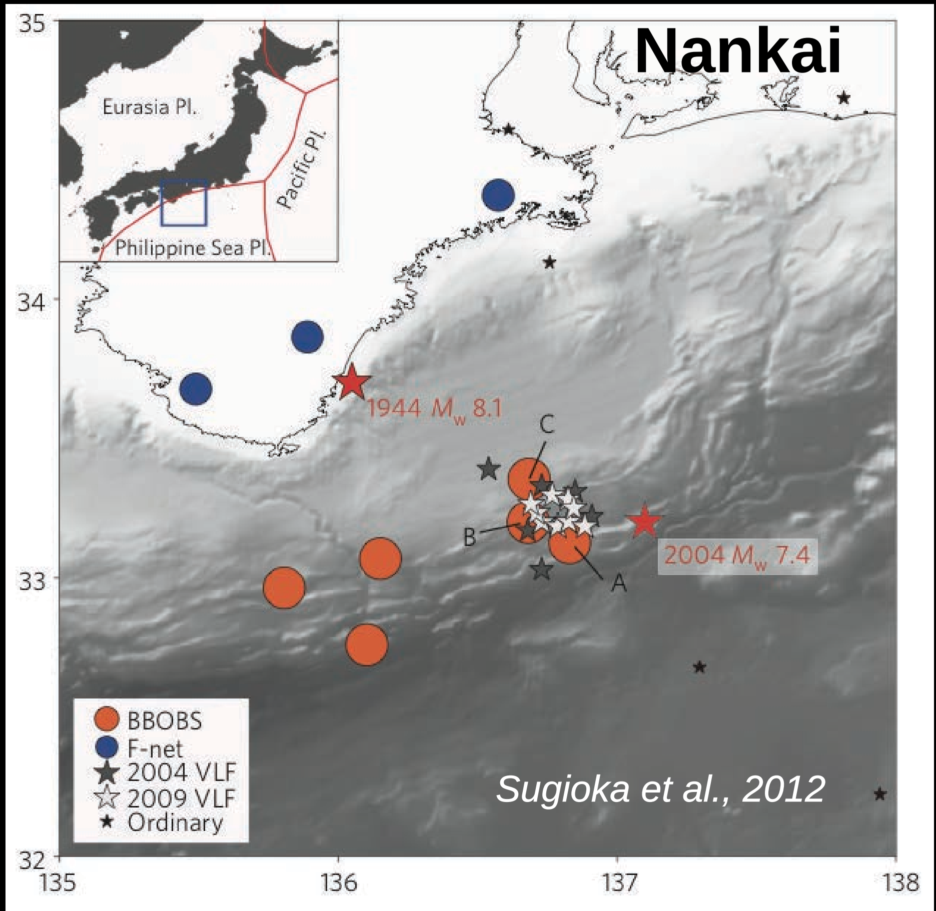
1. *σ': effective stress, pore pressure*
2. *(a-b): rate weakening of friction*
3. D_c: slip weakening distance
4. K: effective stiffness of slip patch

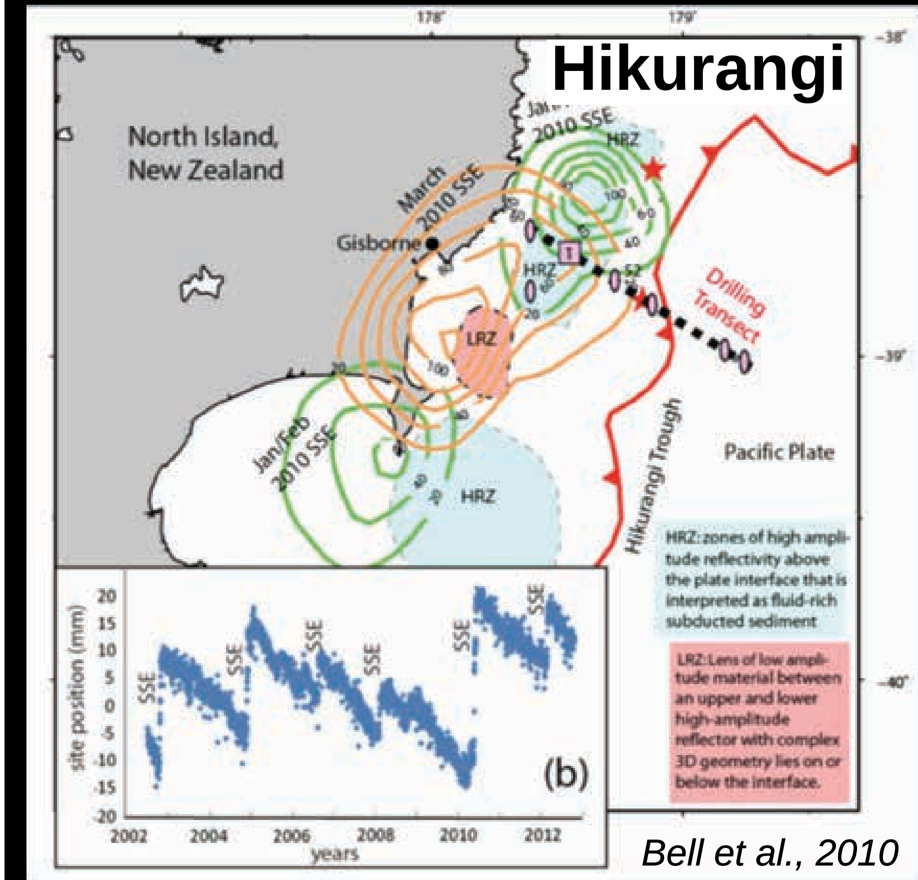
2-D numerical models of deep subduction interface support this idea; yield emergent slow slip when $K \approx K_c$.



1. Merging lab rock physics and data from regional geophysical surveys: Estimation of in situ conditions

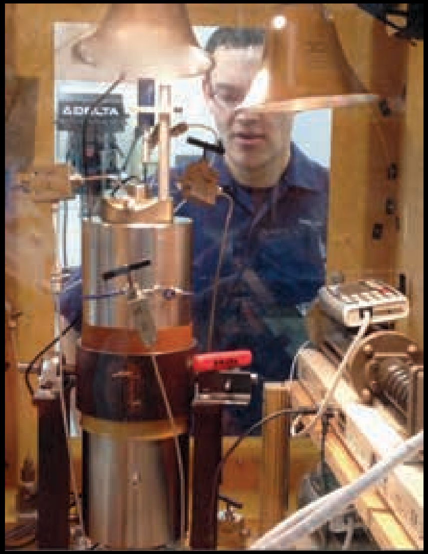
- Example from the Nankai Trough where materials relevant to shallow VLFE are accessible to high-resolution imaging and sampling by drilling
- Comparison to inferences from Hikurangi margin where similar work has been conducted

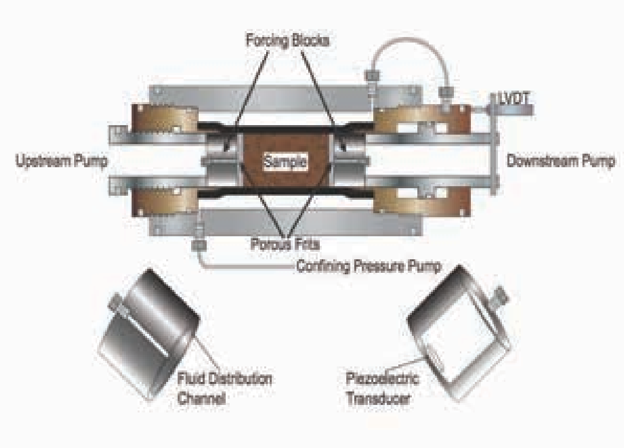


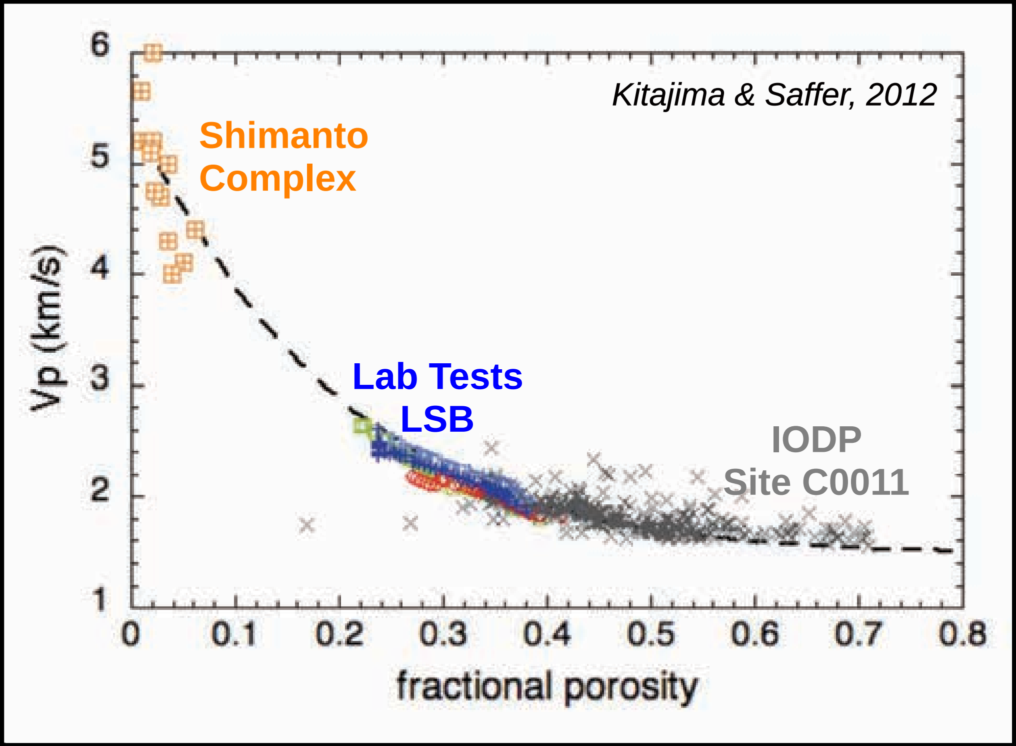


Lab Data to Define Constitutive Behavior

- Drillcore samples of subduction "inputs"
- Varied stress paths, including failure at critical state
- P- and S-wavespeed measurements (ultrasonic)







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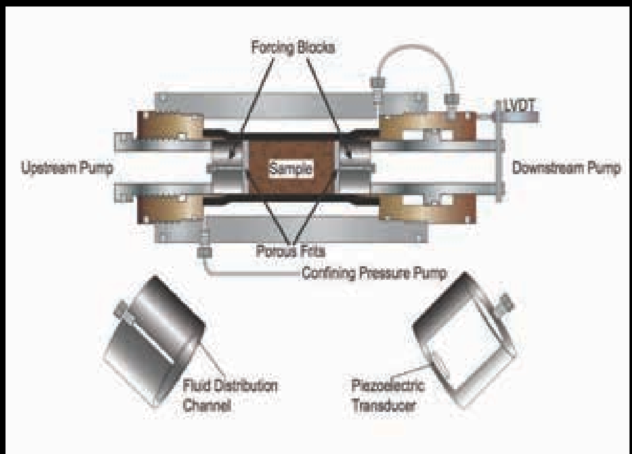
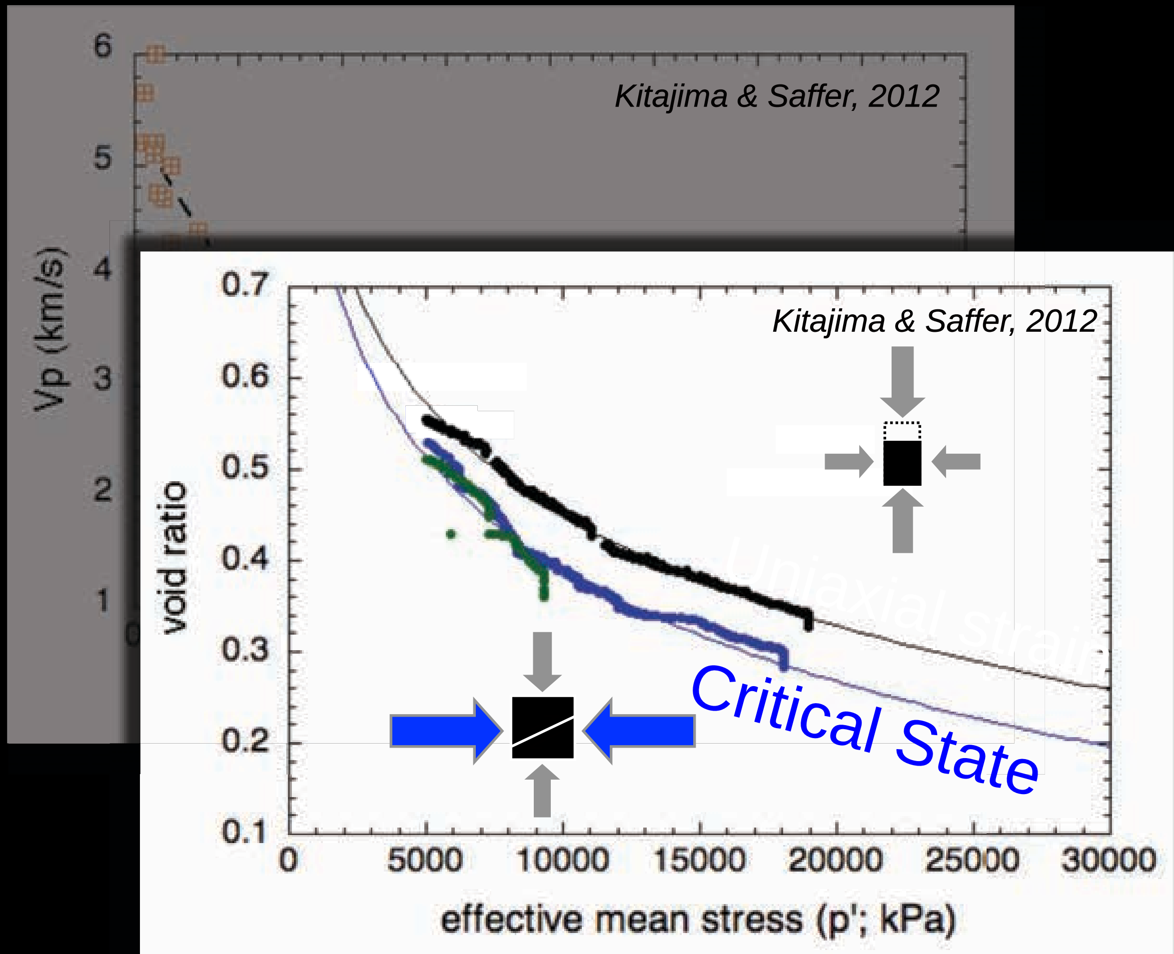
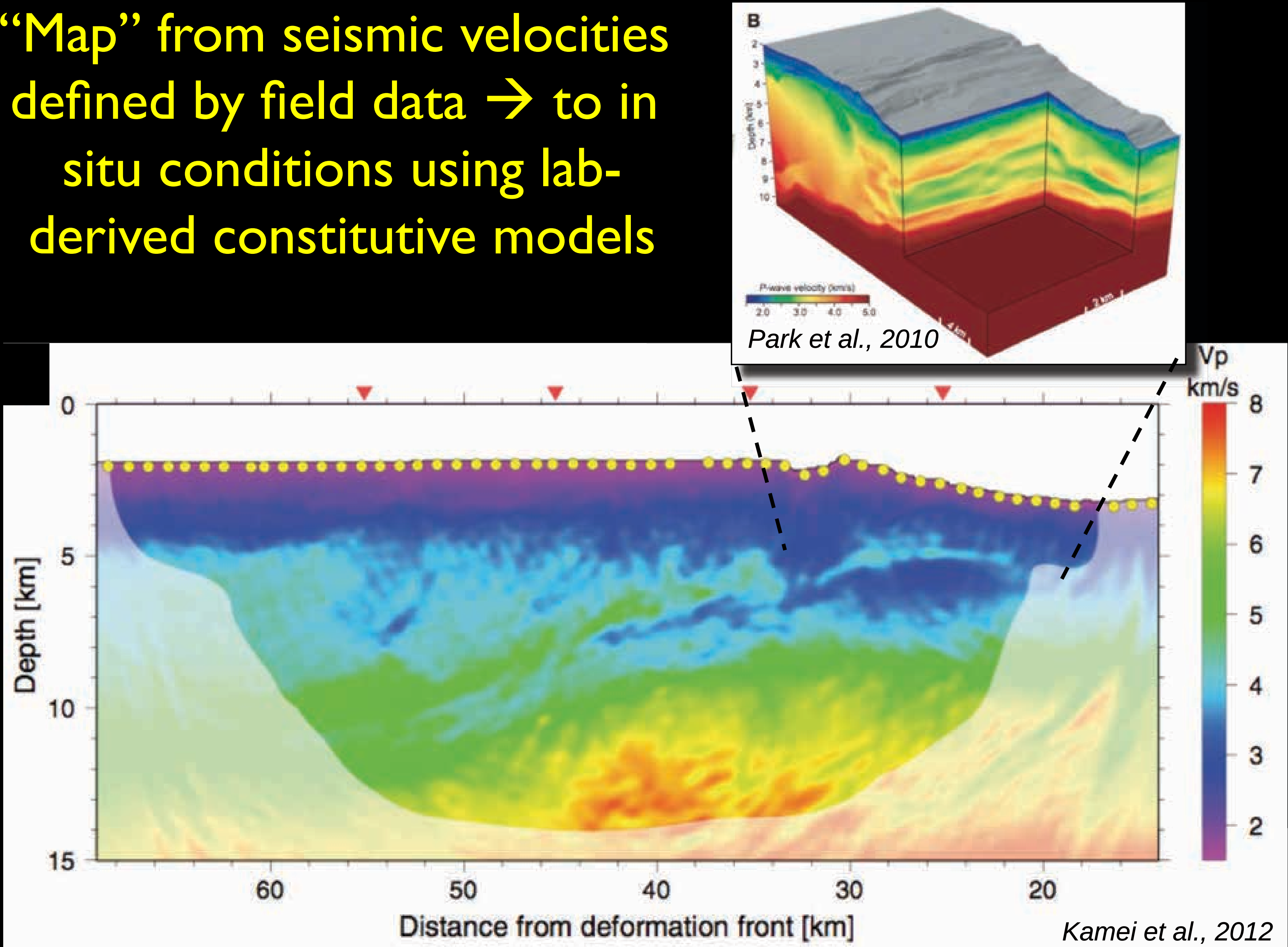
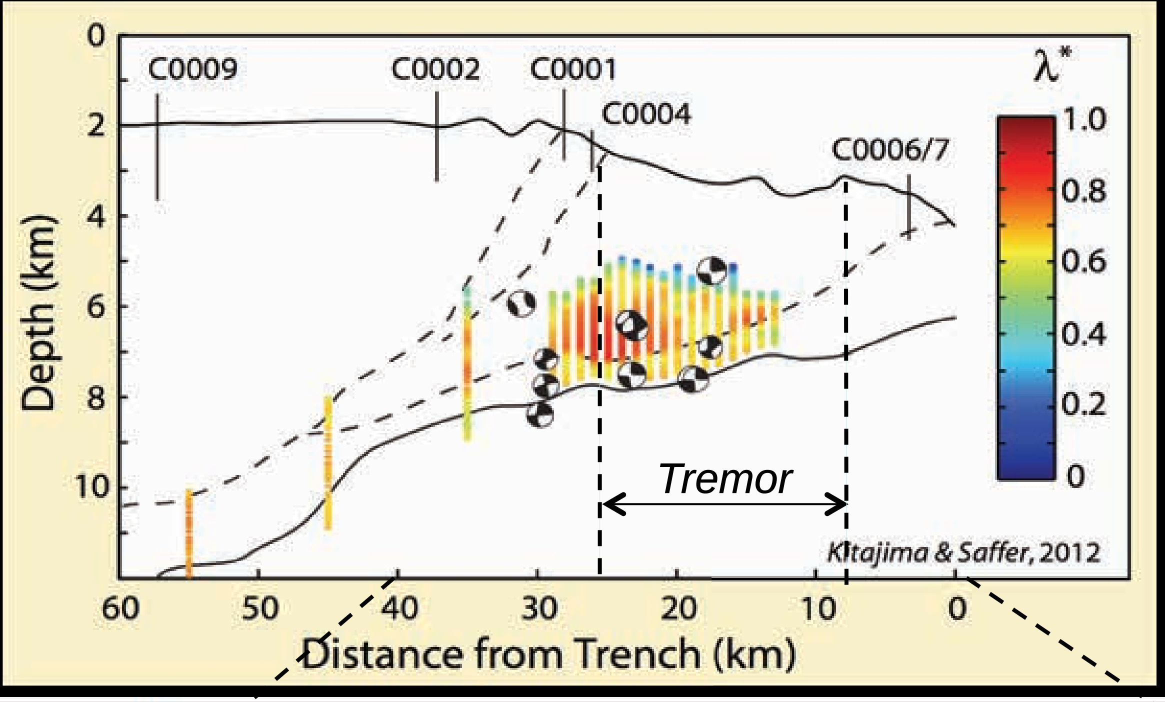


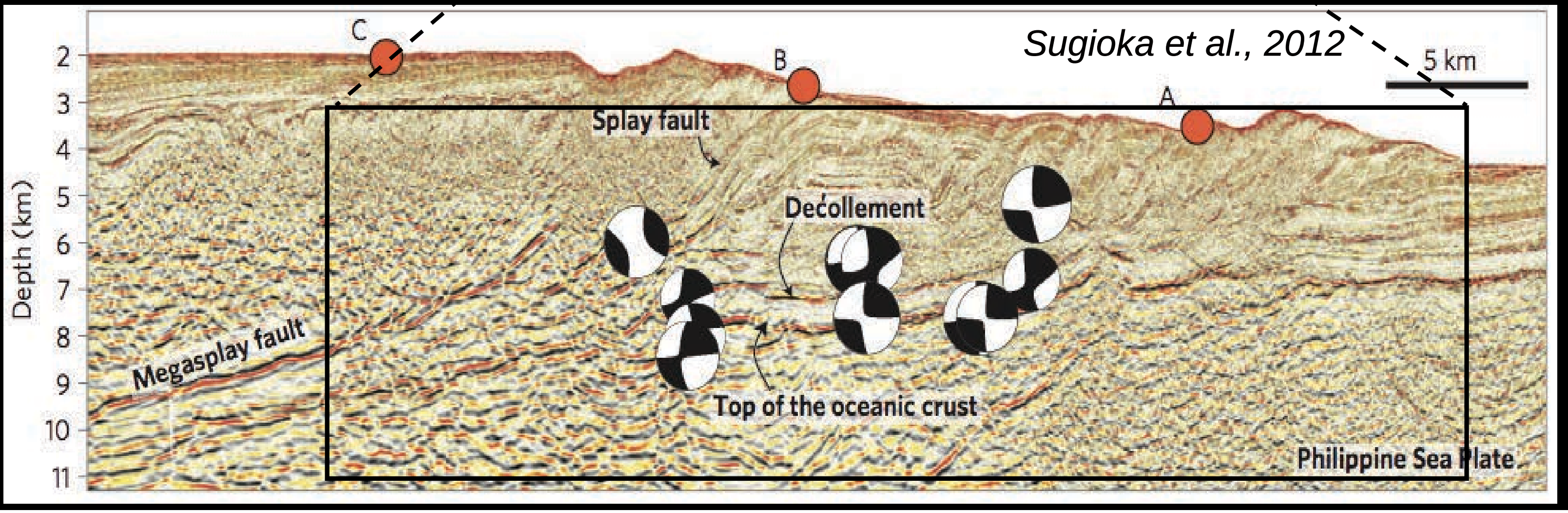


“Map” from seismic velocities defined by field data → to in situ conditions using lab-derived constitutive models

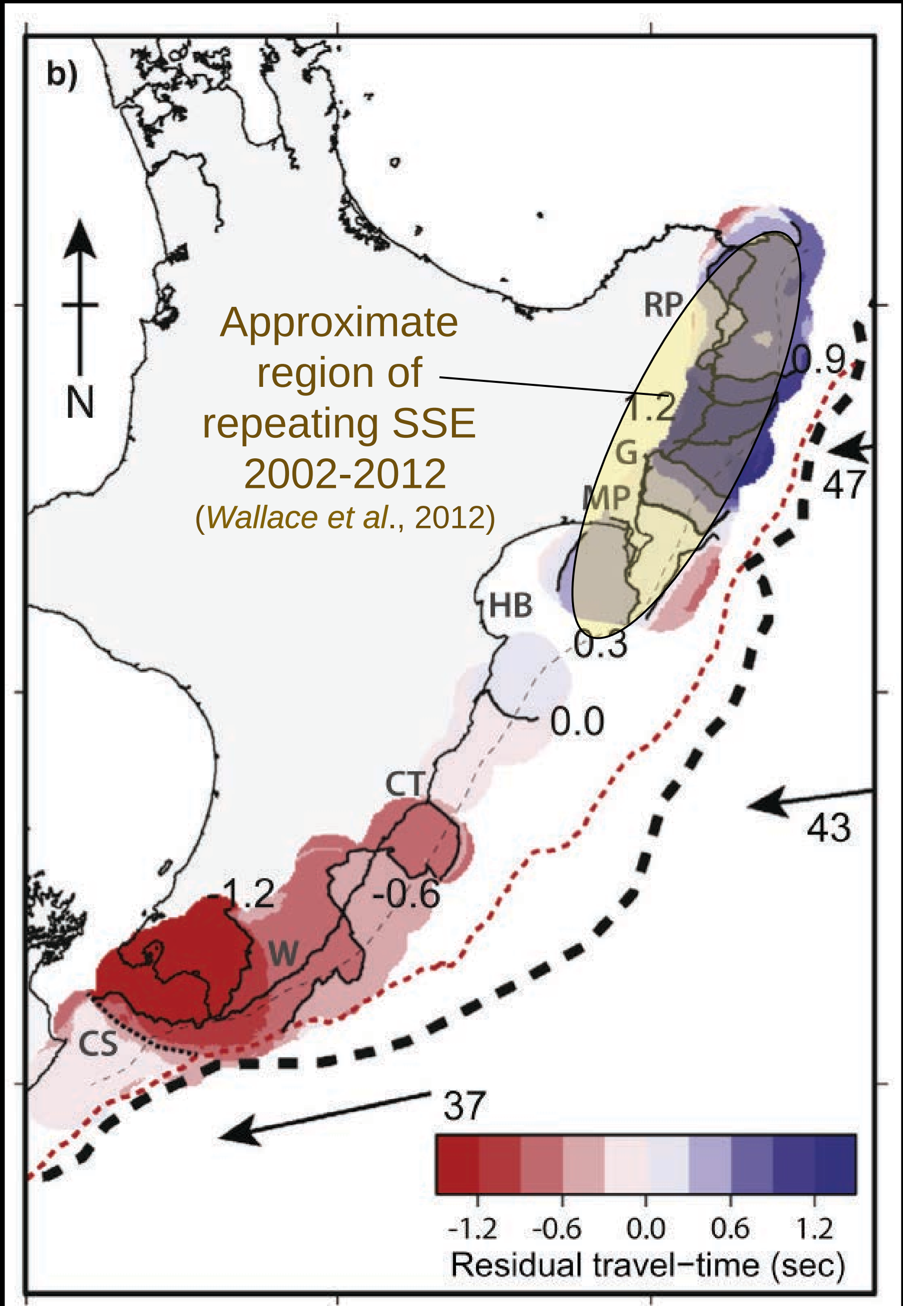


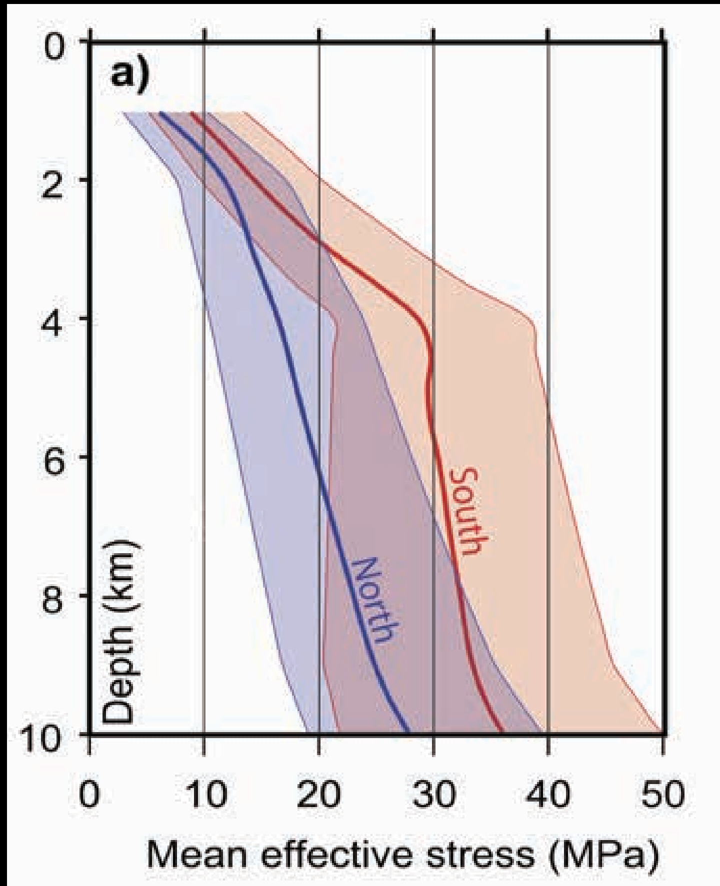
Nankai VLF events correlate with quantitatively identified region of overpressure; λ = ~0.75-0.9





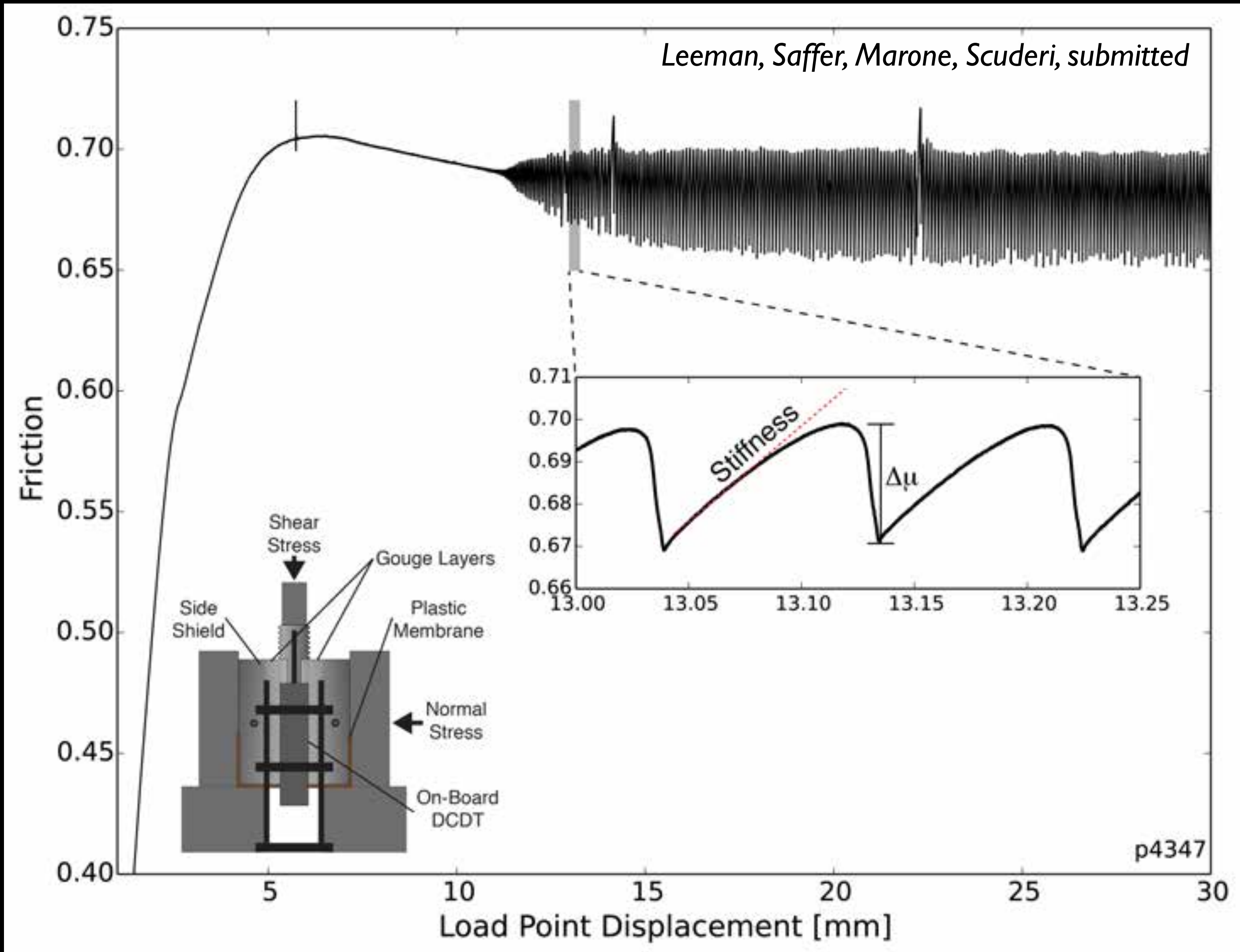
The same seems to be true for North Hikurangi SSE, though rock properties and pressure are less well constrained

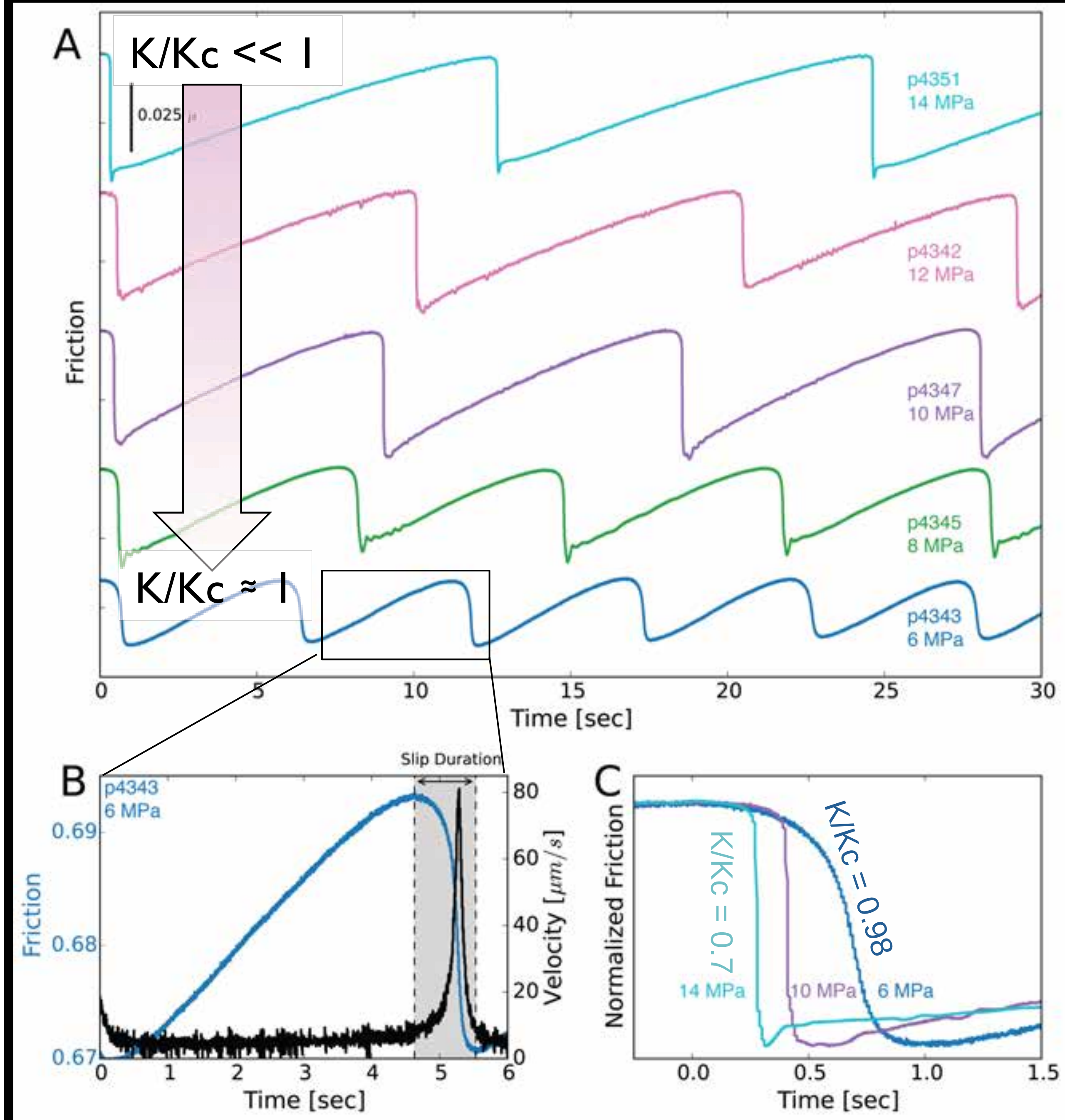




Bassett et al., 2014

2. Laboratory Shearing Experiments: Investigation of fault stability states and spectrum of slip under geophysical conditions



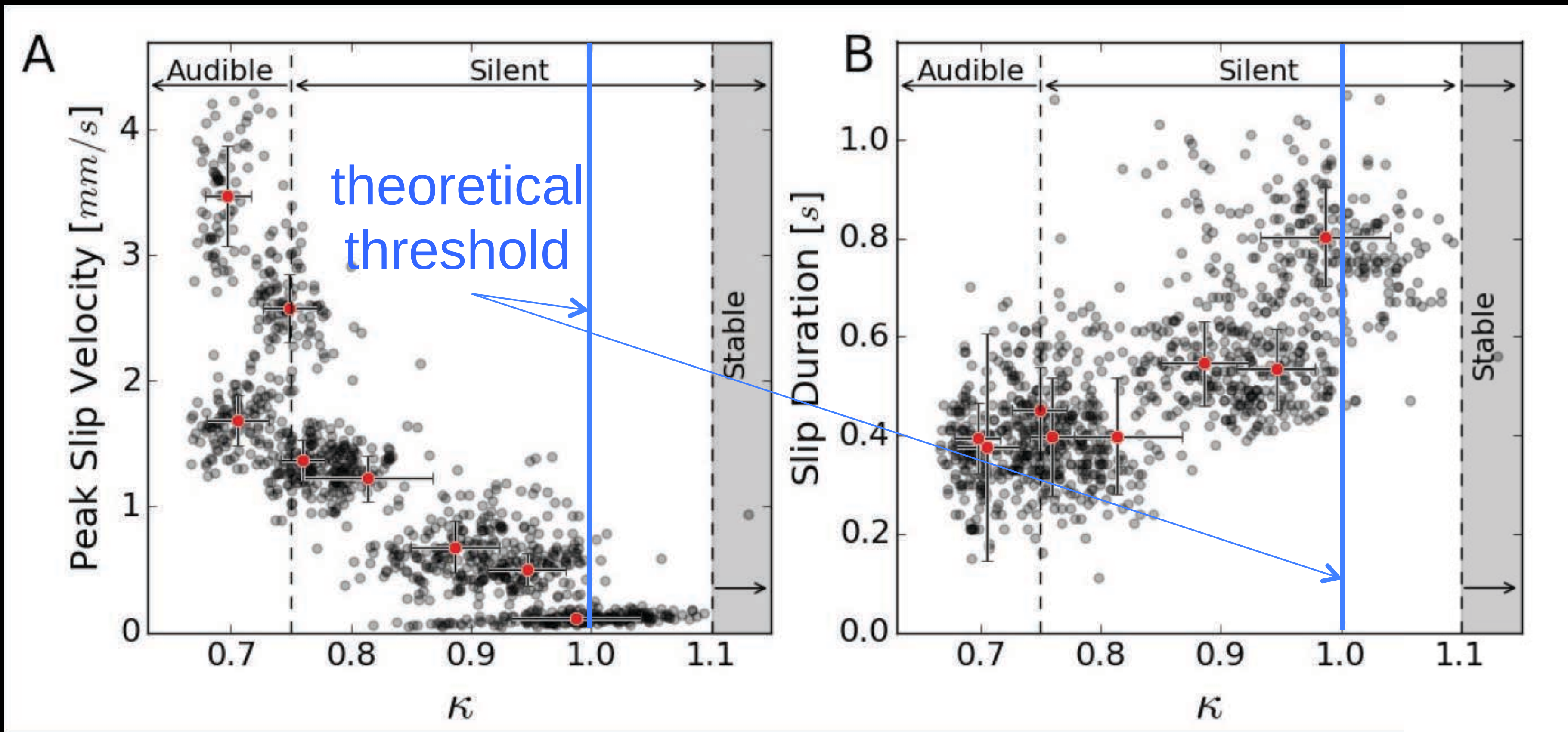


- Repetitive Slow Stick-Slip Events
- *K/Kc* controlled near transition, modulated by effective normal stress
- Slip speed, recurrence, stress all decrease systematically – and duration increases - as *K/Kc* approaches unity

Leeman, Saffer, Marone & Scuderi, submitted

Laboratory shearing study further illustrates conditions that lead to repetitive slow slip and a spectrum of failure modes:

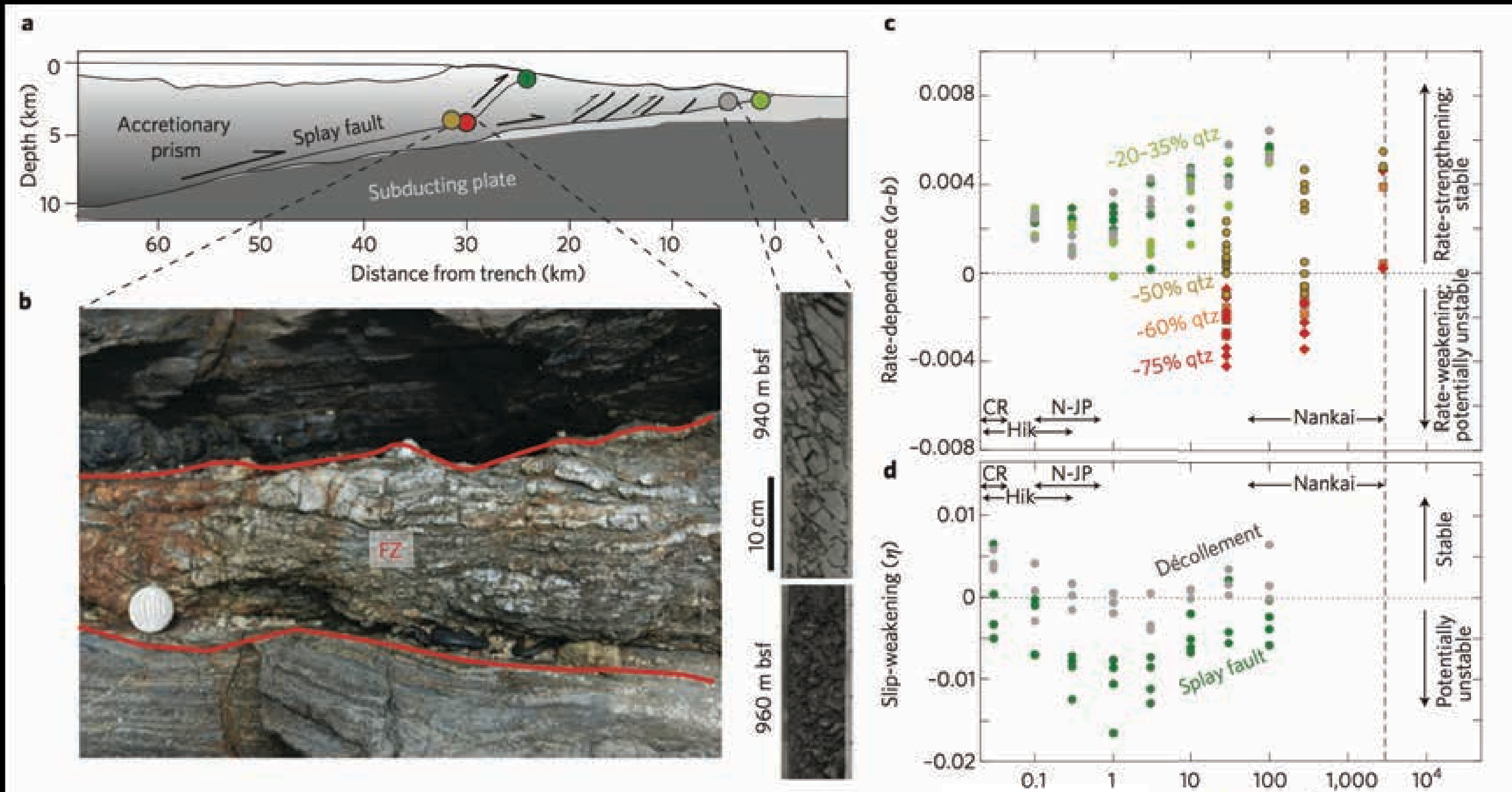
- Systematic variations in stick-slip duration and speed near the threshold suggest an explanation for spectrum of fault slip modes rooted transitional friction and low stress.



Leeman, Saffer, Marone, & Scuderi, submiited

Additional complexities in frictional behavior relevant to repetitive and slow fault slip

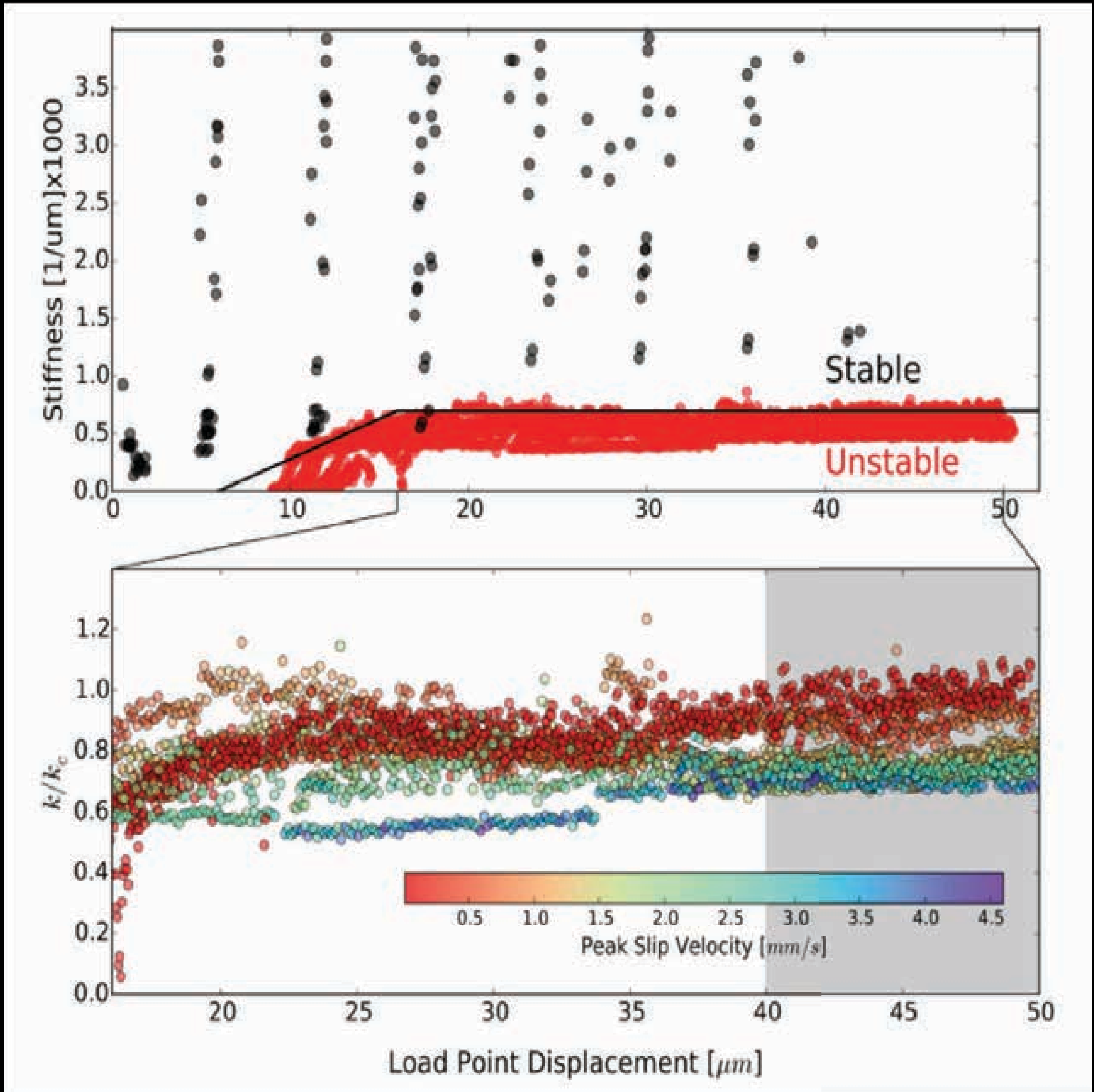
- Rate parameter (*a-b*) increases with sliding velocity → *suppress fast rupture.* Minimum at velocities comparable to SSE slip rates.
- Dc is large → *rise time?*
- Increasingly rate weakening with more qtz → *role of mineralogy, diagenesis?*



Saffer & Wallace, 2015

Summary:

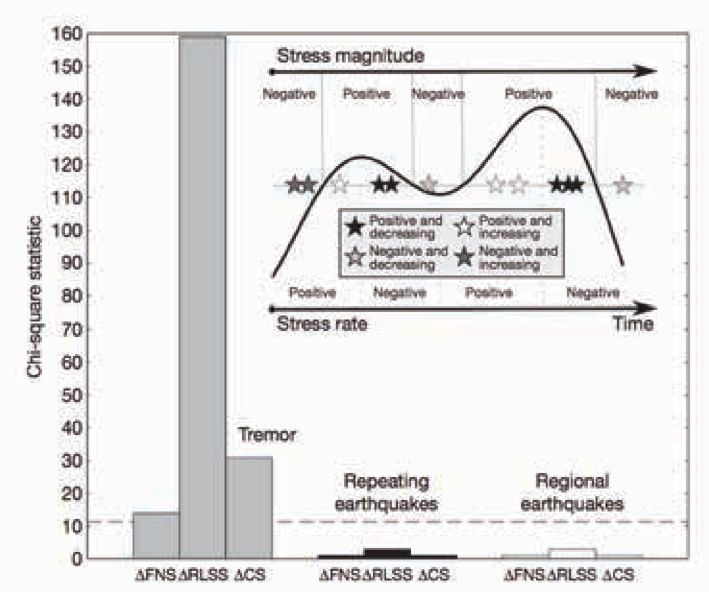
- Transitional frictional behavior and elevated pore pressure have been hypothesized as mechanisms. They indeed seem to be important.
- Pore pressure is elevated in well-characterized slow EQ source regions. This is generally consistent with other – but more ambiguous – observations in areas of deep SSE, ETS, and VLFE.
- Frictional properties point toward conditional stability, quenching behavior, and importance of fault mineralogy (silica). But more to be done here (e.g., elevated T, intact fabric, drill core from SSE).
- Friction properties and low σ' are also consistent with long rise times and low stress drops.
- Does not rule out other potentially important processes: dilatancy-hardening, role of heterogeneity or roughness.



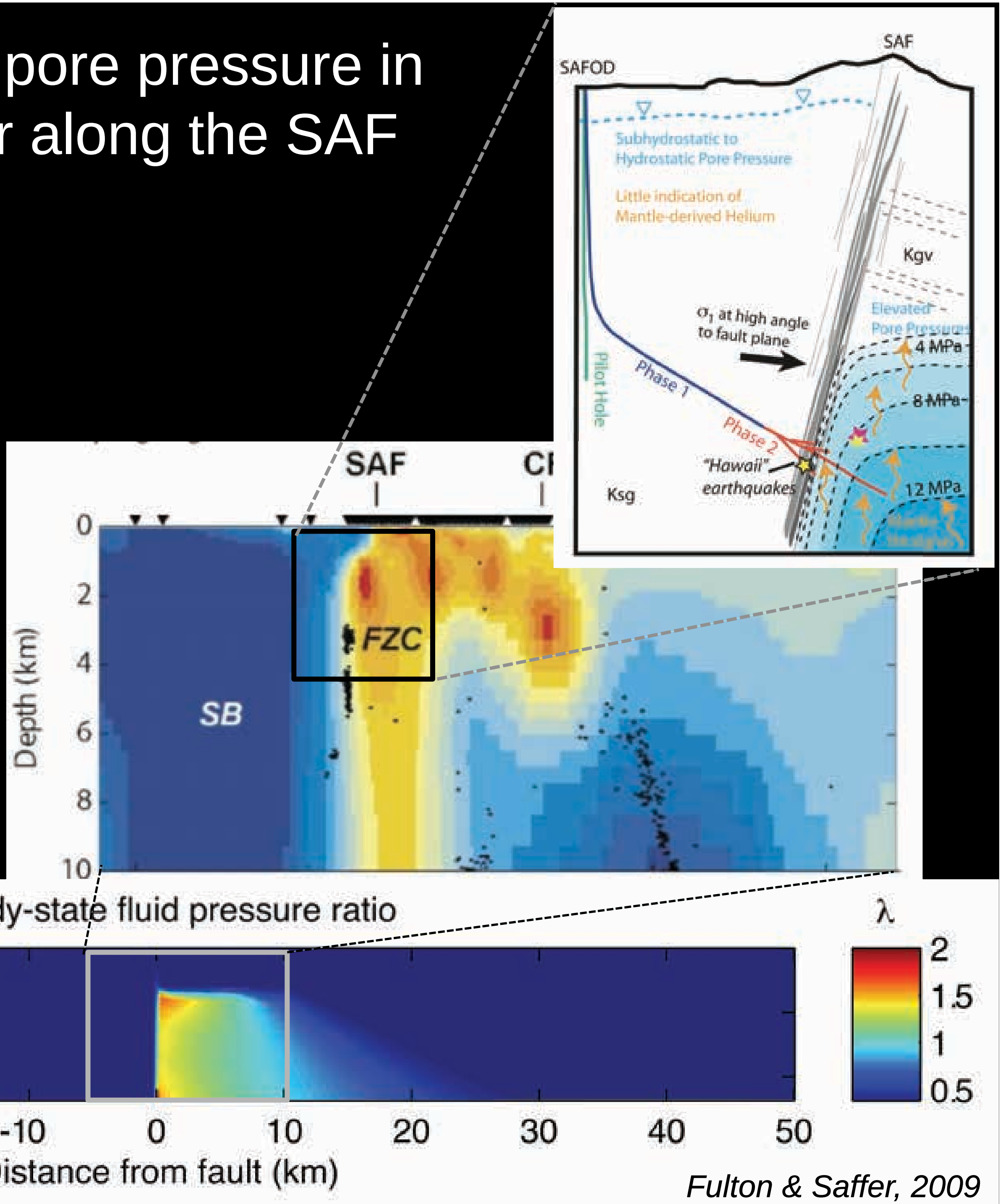
- Repetitive Slow Stick-Slip Events
- K/Kc modulated by effective normal stress in these experiments
- Slip speed, recurrence, stress all decrease systematically – and duration increases - as K/Kc approaches unity

Leeman, Saffer, Marone & Scuderi, submitted

Evidence for elevated pore pressure in source areas of tremor along the SAF



Thomas et al, 2009



Fulton & Saffer, 2009