

# Studies on the physical origin of aseismic deformation transients in the framework of rate and state friction

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# Outline

- ❖ Spontaneous aseismic deformation transients in a 2D (3D) subduction fault model, governed by rate and state friction with depth-dependent frictional properties (poster).
- ❖ **Constrain model by lab and geodetic observations**
- ❖ Model the linear relation between moment and characteristic duration of aseismic transients (poster).

# More realistic situation (finite $\bar{\sigma}$ in seismogenic zone)

Features similar to observations  
can be produced:

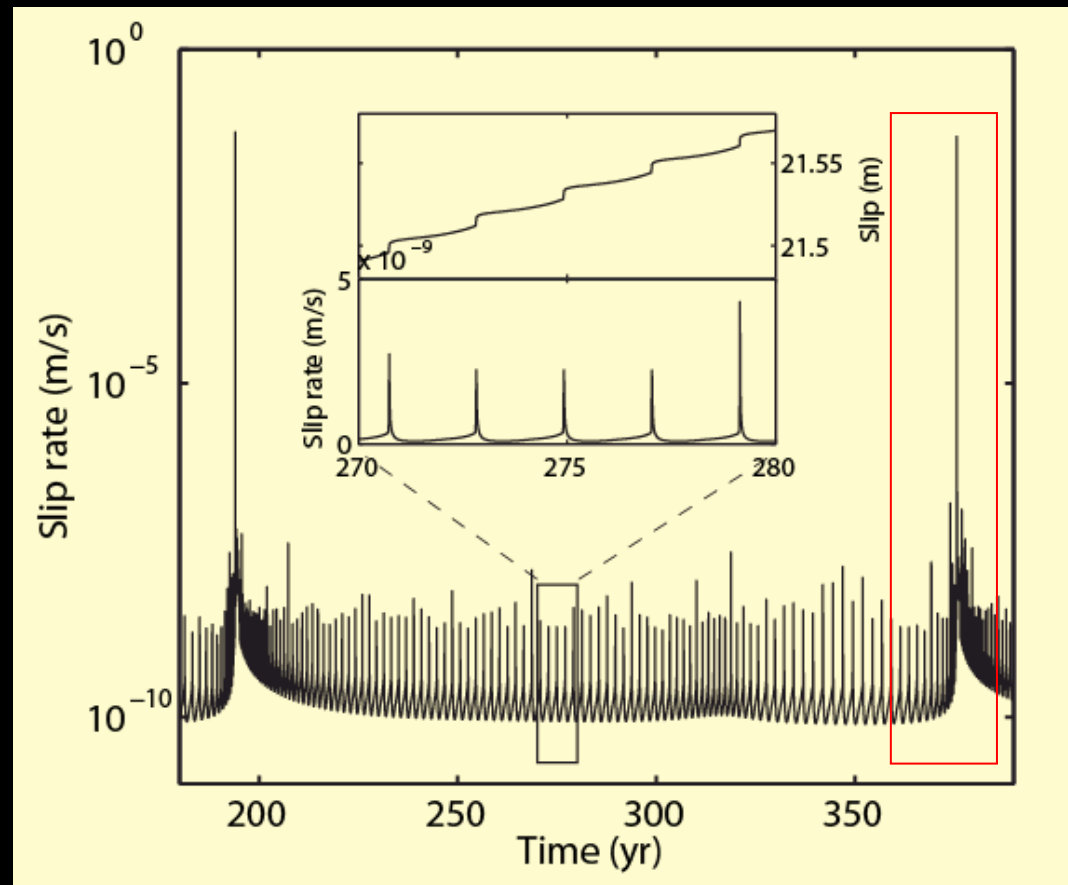
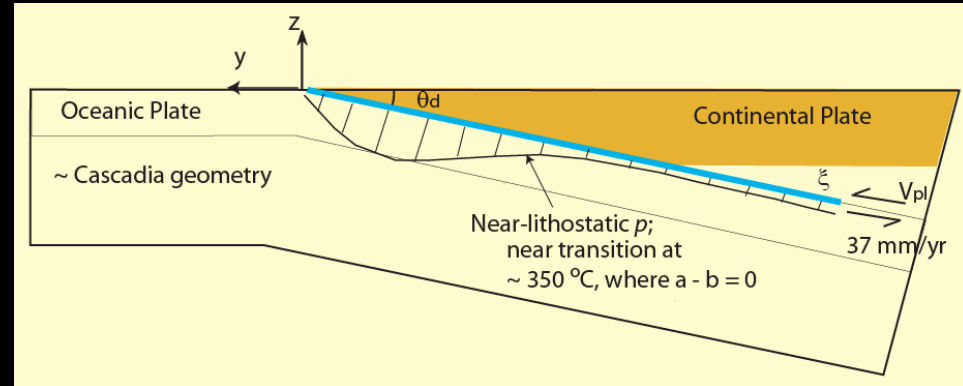
Interseismic period filled with  
aseismic transients.

Average recurrence interval of  $\sim 2$   
yrs.

Slip rate 2-4 times of  $V_{pl}$

Cumulative slip of  $\sim 1-2$  cm

→ Can be used as a  
template model to  
produce aseismic slip  
events that match  
geodetic measurements,  
using lab constrained  
friction parameters.



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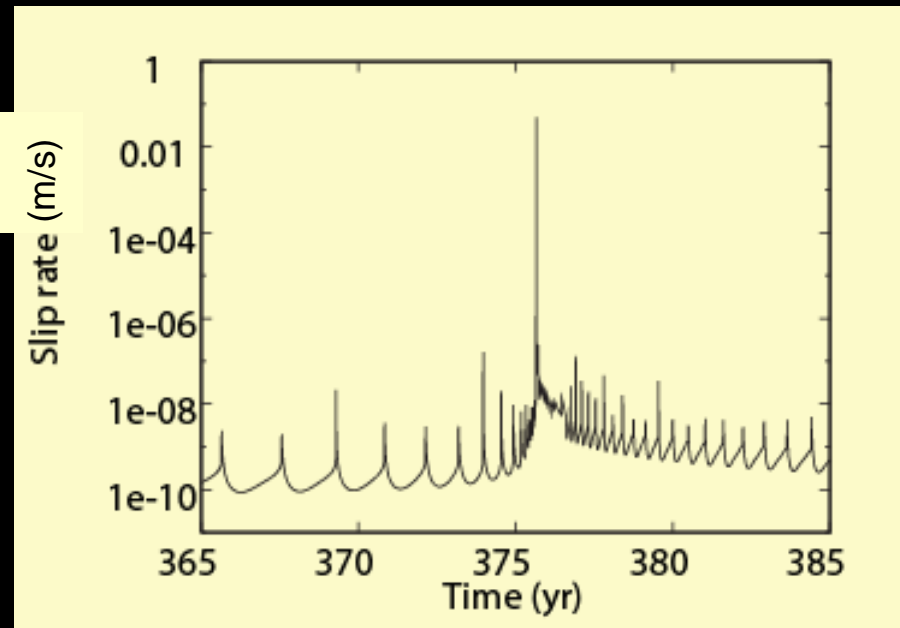
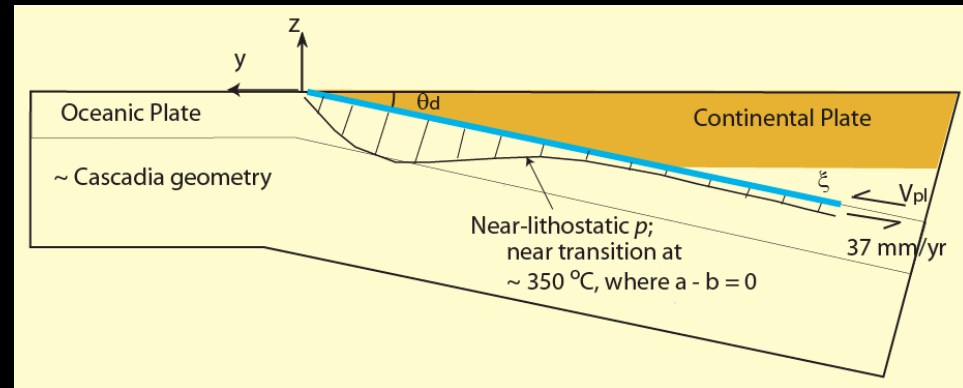
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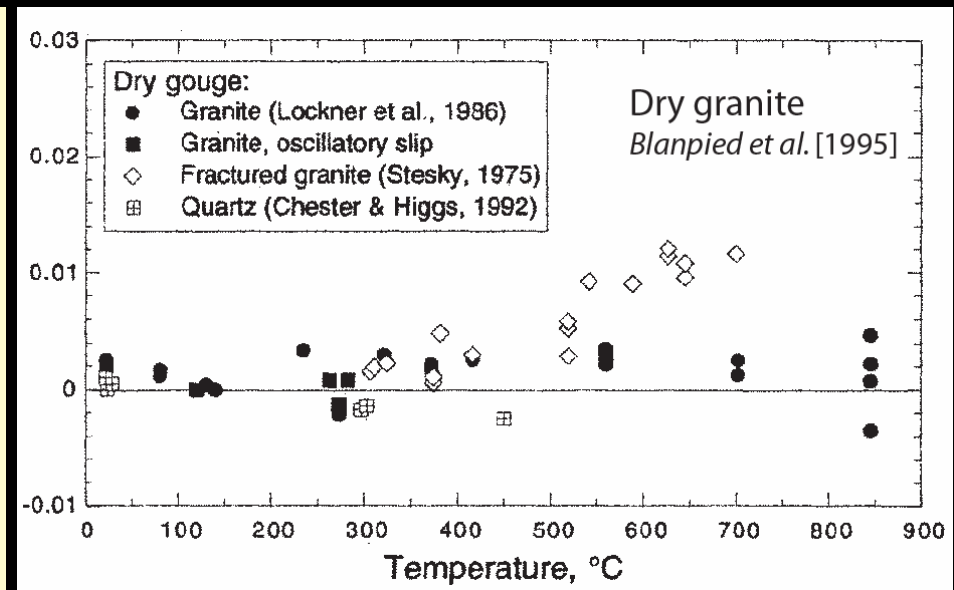
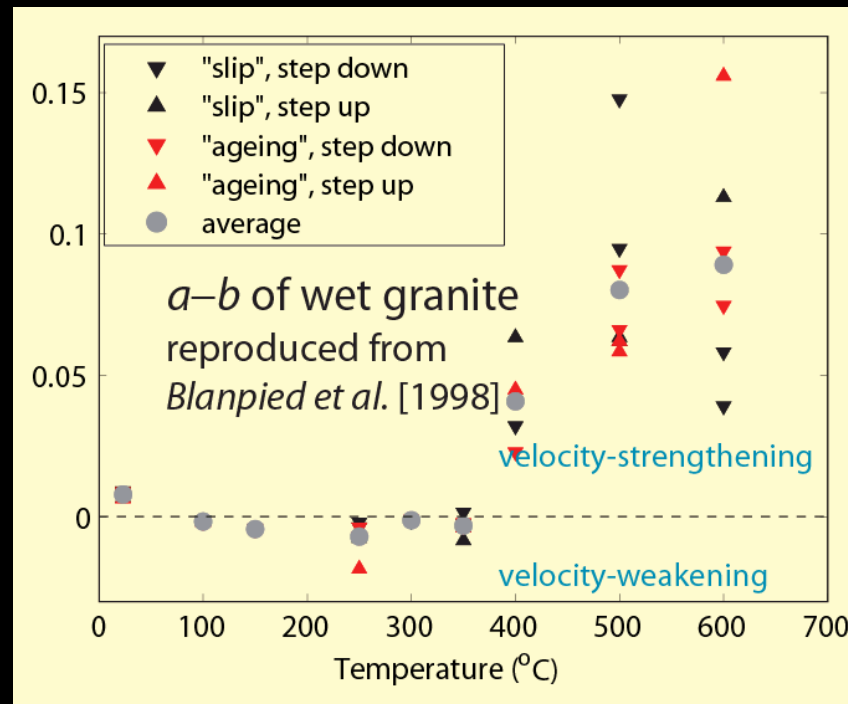
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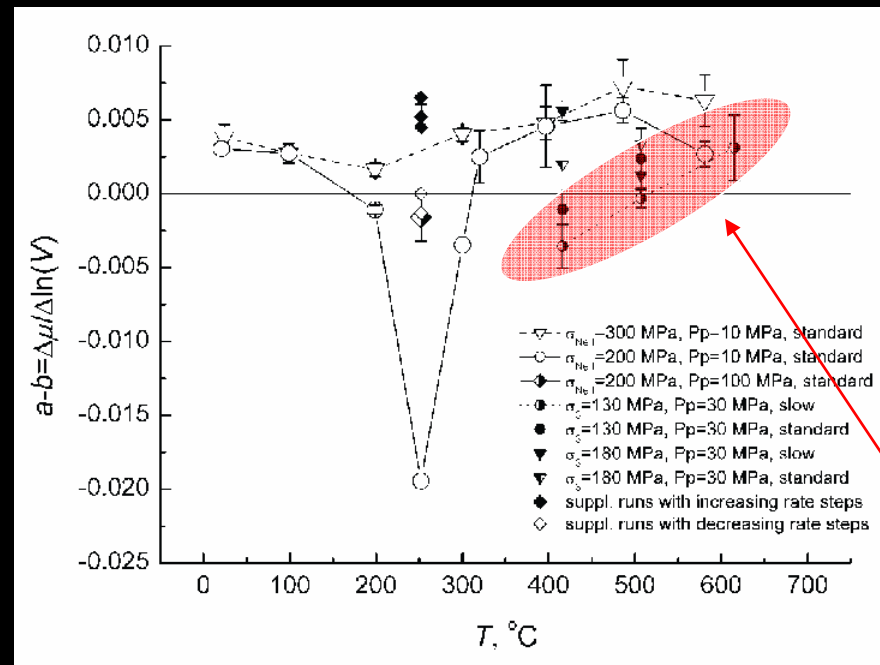
More frequent and smaller transients before  
megathrust earthquake. No systematic  
study on the “precursory” effect yet.

Lab measurements of  $a-b$  show large variations at temperatures around and above stability transition (granite,  $\sim 350^\circ\text{C}$ ; gabbro,  $\sim 510^\circ\text{C}$ )



Over the stability transition, wet granite data show much more stabilizing effect ( $a-b \sim 0.1$  at  $\sim 600^\circ\text{C}$ ) than the dry granite data ( $a-b \sim 0.01$  at  $\sim 600^\circ\text{C}$ ). High positive values of  $a-b$  strongly prohibit the downdip propagation of aseismic slip.

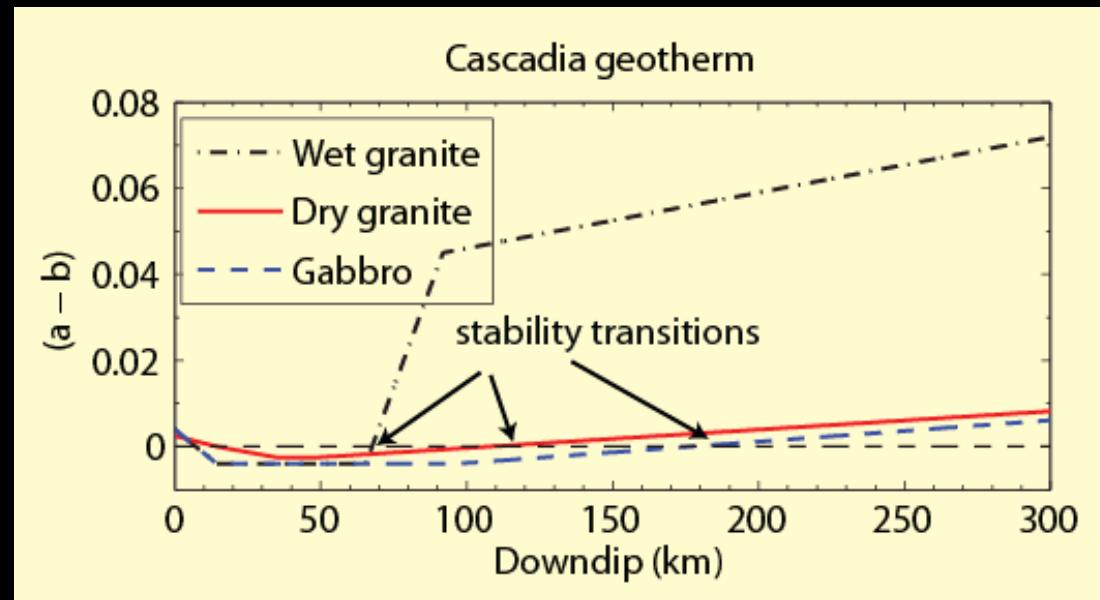
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Gabbro is a better proxy for oceanic crust. Under **supercritical water conditions** ( $p_{\text{H}_2\text{O}} \sim 22 \text{ MPa}$ ,  $T \sim 374^\circ\text{C}$ ), velocity-weakening to strengthening stability transition takes place around  $510^\circ\text{C}$ . And at higher temperatures (up to  $\sim 600^\circ\text{C}$ ),  $a-b$  is smaller than 0.01. Experimental data from He et al., 2006, 2007.

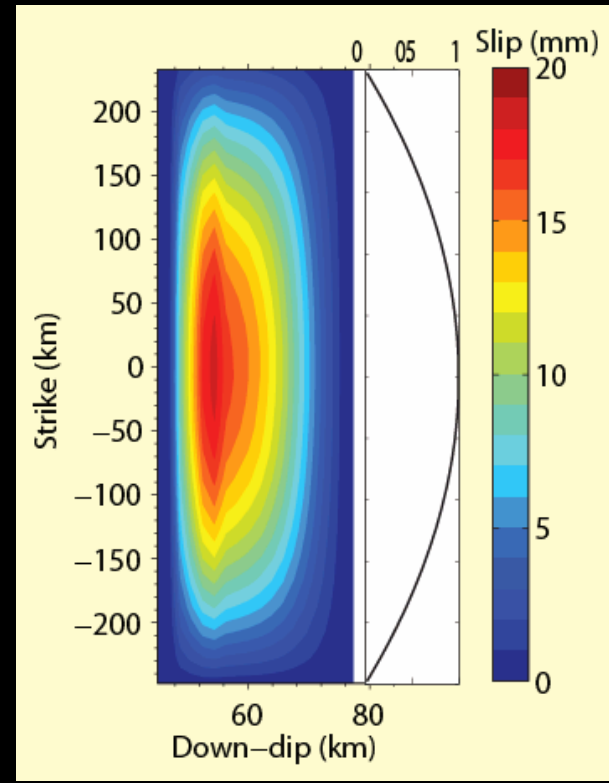
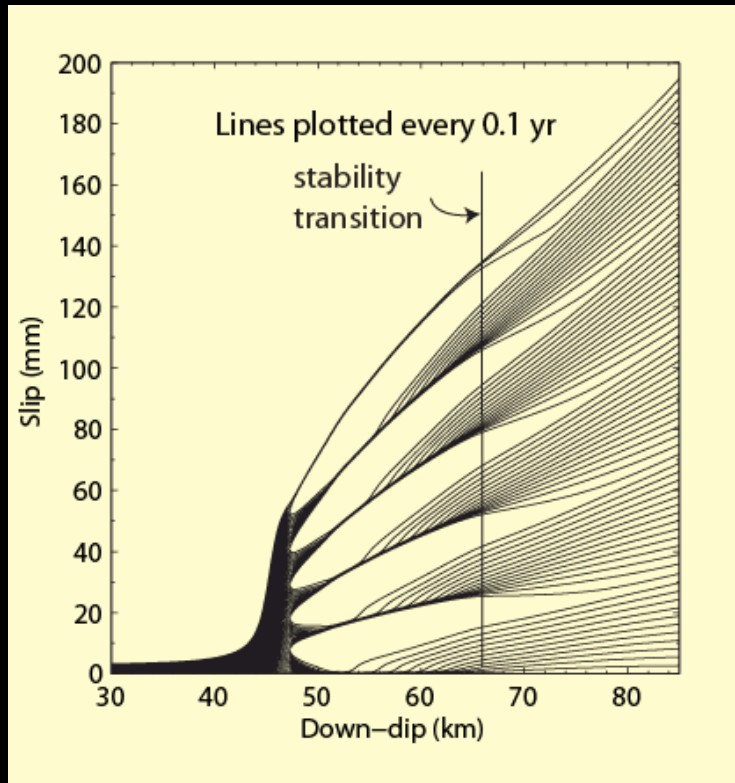
When applied to the thrust fault model (taking Cascadia for example), that results in significant differences in the

- ❖ depths of stability transition;
- ❖ downdip extent of the velocity-strengthening region activated during an aseismic slip episode



Thermal model from Hydnman and Wang [1995]

A “wet granite” case:  $W=20$  km,  $\bar{\sigma} = 0.67$  MPa,  $L \sim 0.4$  mm, recurrence interval  $\sim 14$  months, aseismic slip  $\sim 2$  cm.



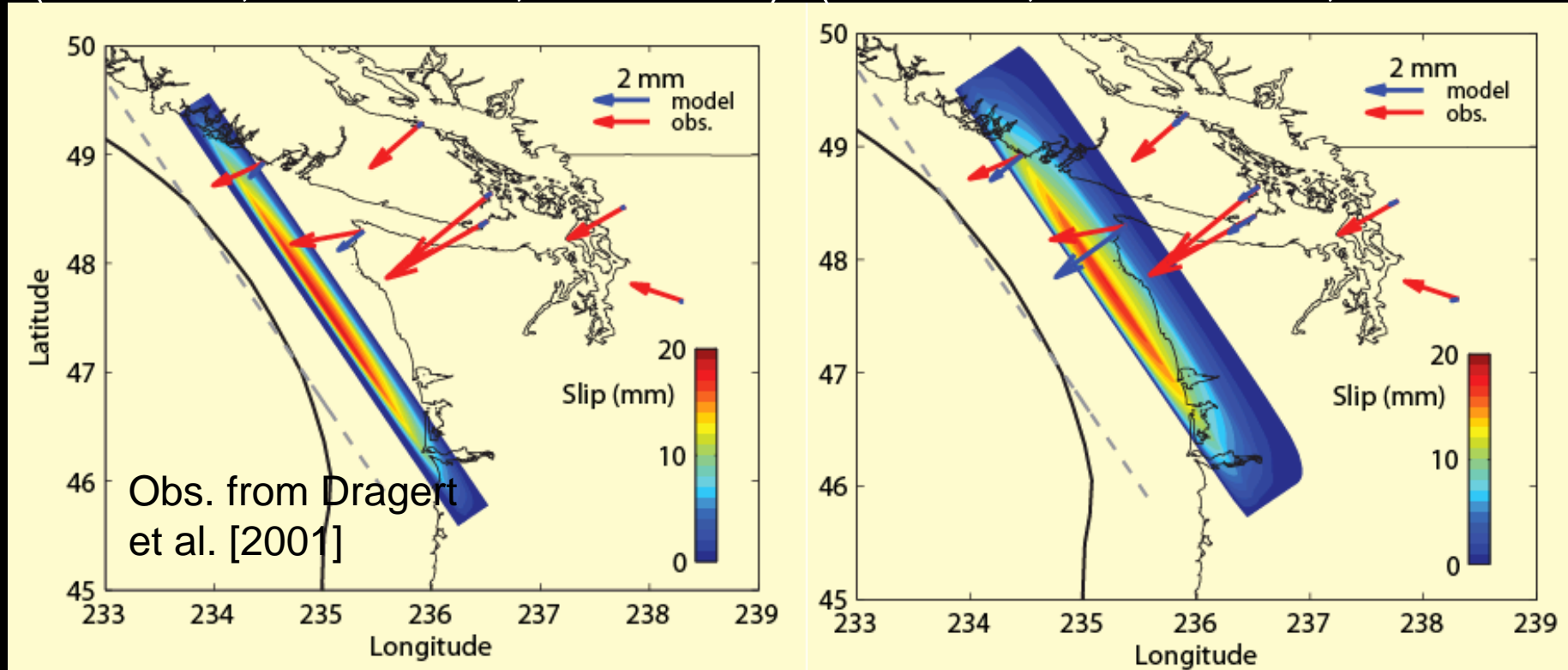
- ❖ The along-dip slip (interseismic motion removed) is used to generate a **pseudo-3d** slip on the fault plane, based on some along-strike distribution function. Surface deformation is then calculated using Okada's dislocation model in an elastic half-space, and compared with the GPS observations of the 1999 Cascadia transient [Dragert et al., 2001].

## Wet granite

( $W=20$  km,  $\bar{\sigma}=0.67$  MPa,  $L \sim 0.4$  mm)

## Dry granite

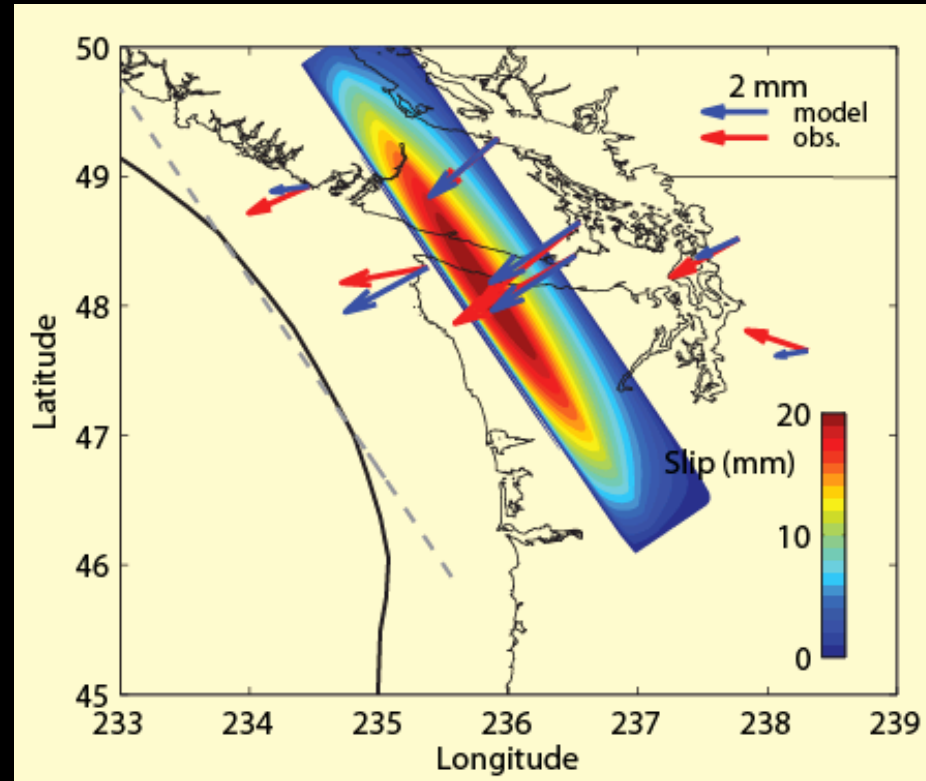
( $W=40$  km,  $\bar{\sigma}=6.25$  MPa,  $L \sim 1.67$  mm)



- ❖ Most slip occurs in the updip velocity-weakening region.
- ❖ Application of the “dry granite” data slightly helps to improve the fit, but cannot fully capture the deformation at most inland stations.
- ❖ Suggest slip occurs at further downdip depths.

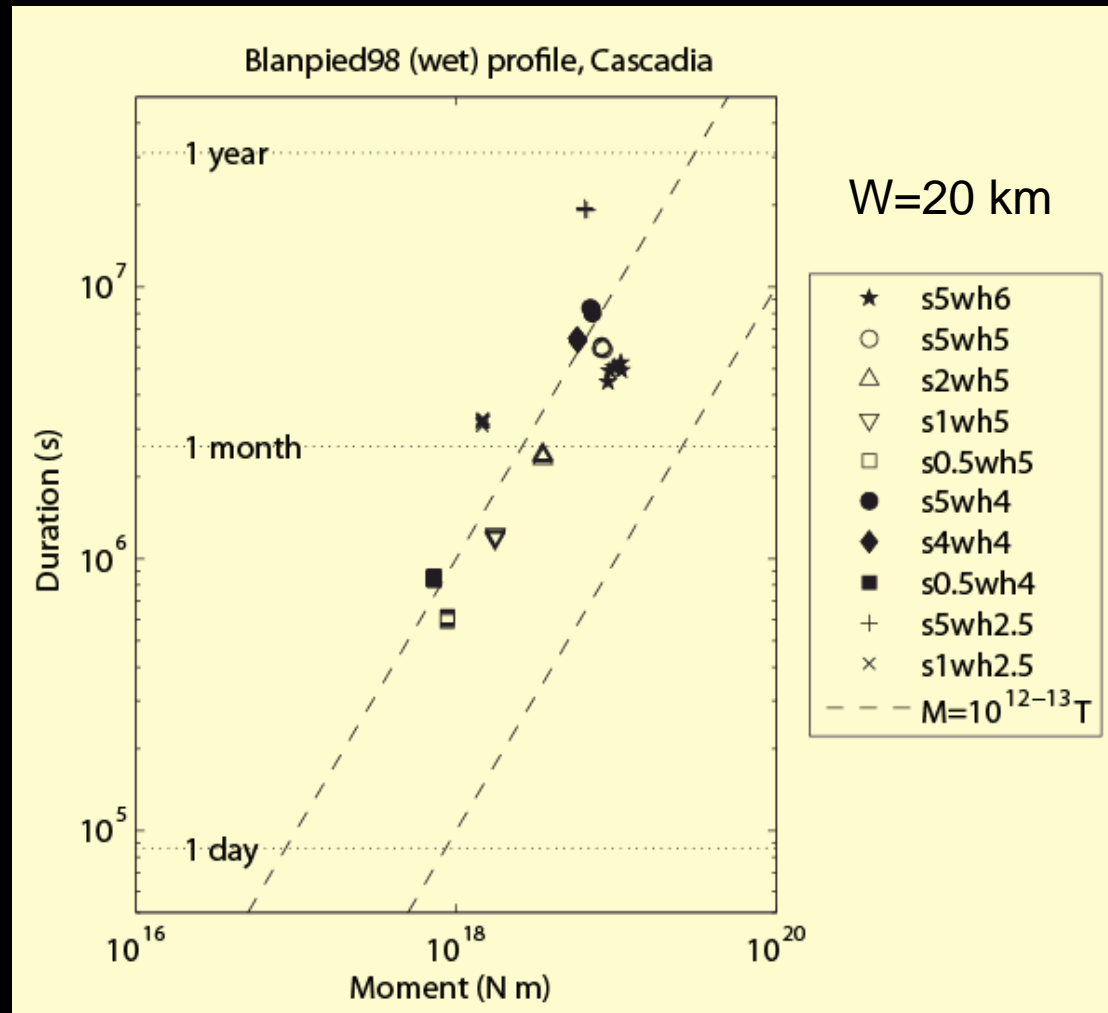
# Gabbro

( $W=40$  km,  $\bar{\sigma}=1.15$  MPa,  $L\sim 0.18$  mm)



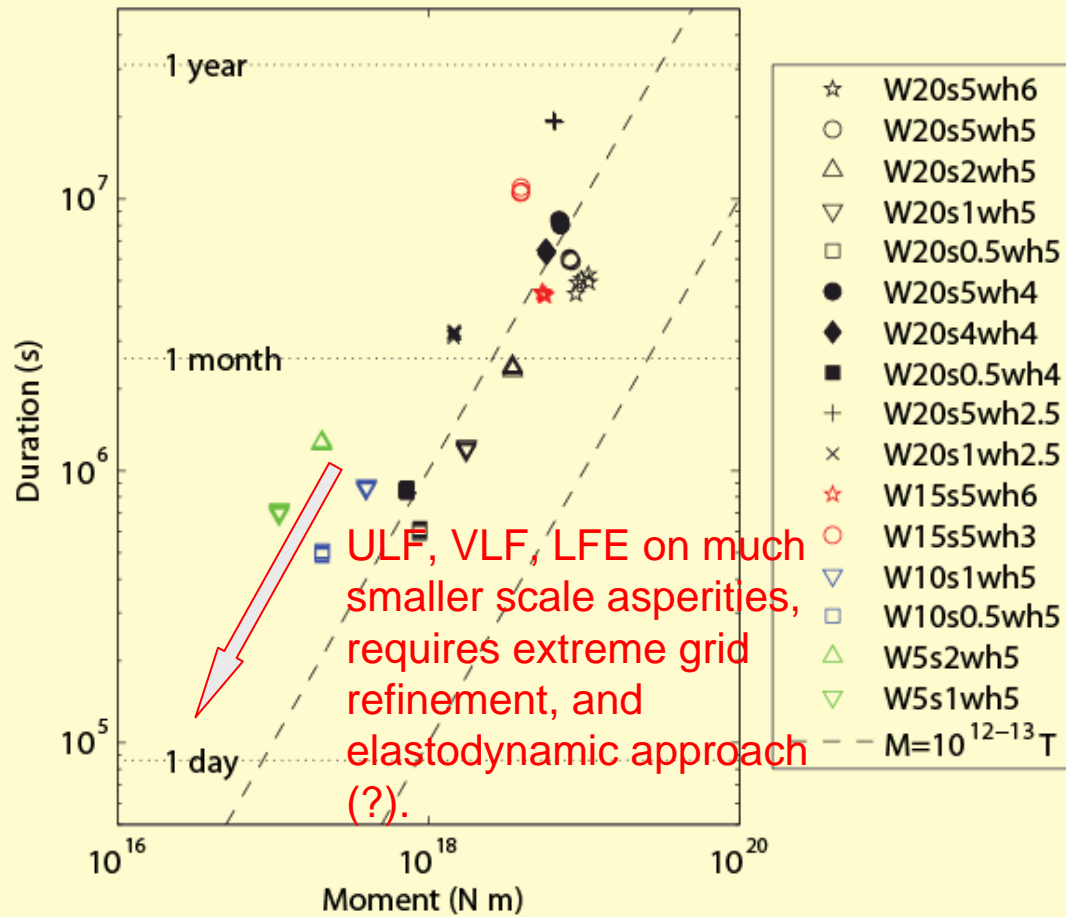
- ❖ Application of the “gabbro” gouge data significantly improves the fit at most stations, even with the pseudo-3d planar fault model.
- ❖ Much wider velocity-weakening zone allowed by a stability transition at higher temperatures, but seismogenic zone could be limited to a shallower depth due to *dilatancy stabilizing at high fluid pressure!*

Model the linear relation between moment and duration [Ide et al., 2007]: application of different rock friction data; varying along-dip width (W) and level of high fluid pressure; and moderate variations in  $W/h^*$ .

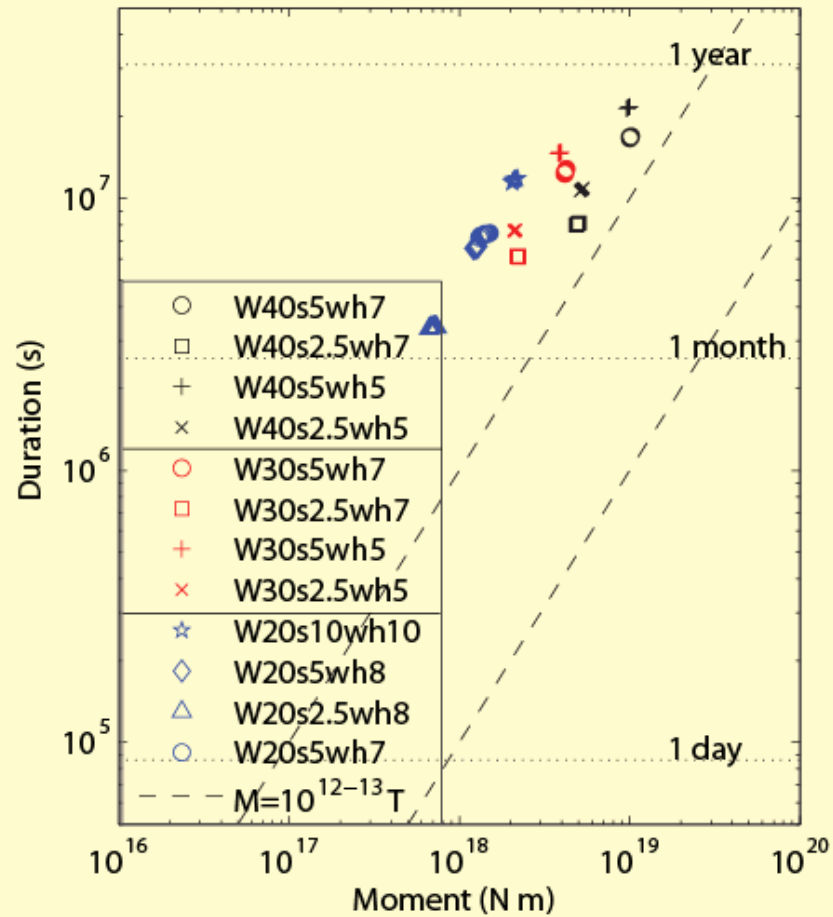


This is only 2D results!

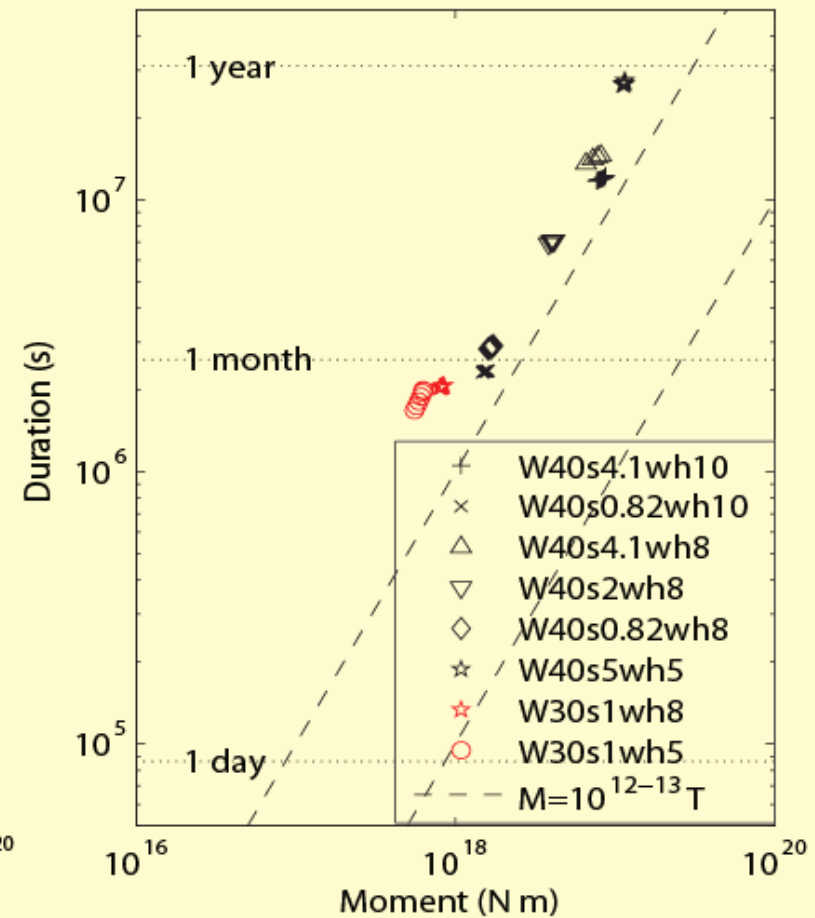
Blanpied98 (wet) profile, Cascadia



Lockner86 (dry) profile, Cascadia



Gabbro profile, Cascadia



# Conclusions

- ❖ Aseismic deformation transients can arise **spontaneously** when *rate and state friction* is applied to model subduction sequences, with low effective stress near/downdip from stability transition.
  - ☞ Recurrence interval of transients depends on effective normal stress.
  - ☞ Short-period ( $\sim 1$  yr) transients can be produced with lab-like  $L$  (of order 10-100  $\mu\text{m}$ ) and **near-lithostatic fluid pressure**  $p$  ( $\bar{\sigma} \sim 1$  MPa), near the end of the seismogenic zone, and further downdip into the stably slipping zone,
  - ☞ Petrologic and thermal structures of subduction slabs, locations of non-volcanic tremors as well as widespread triggering of tremors hint that fluid pressure may be near-lithostatic in that region.
- ❖ Transient sequences can be **triggered** by stress perturbations from earthquakes in the descending slab, or by pore pressure variations, or by along-strike variations in the seismic slip.
- ❖ Current models on the physical processes underlying aseismic transients, in the framework of rate and state friction, need to be constrained by lab (friction parameters) and field (e.g., geodetic) observations.
- ❖ Preliminary study on the moment-duration relation of transients suggests the width and level and spatial extent of high fluid pressure zone are key parameters.

