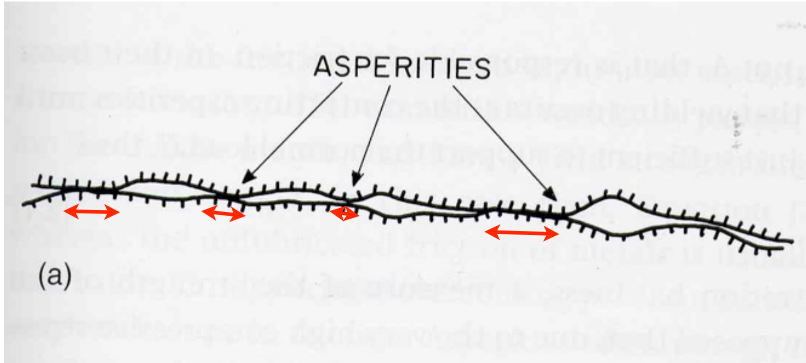
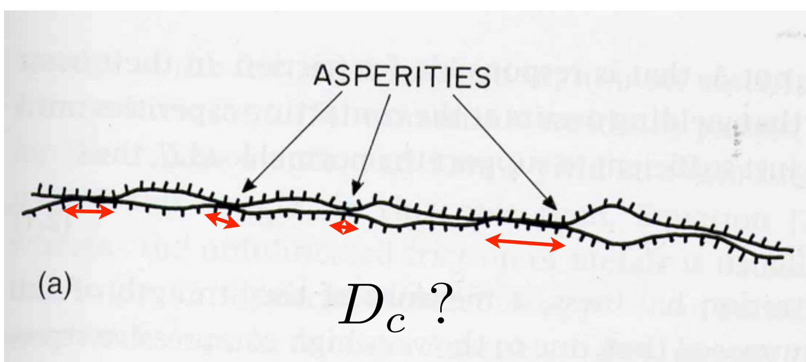
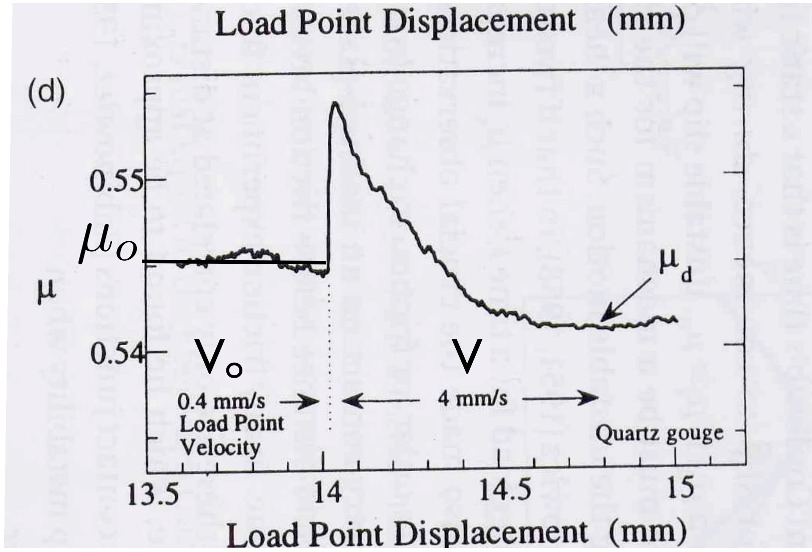



- **Friction can increase with "hold" time. This happens through growth and increasing shear strength of contacts ("asperities").**
- If sliding speeds up, the average lifespan of asperities decreases
- This means that friction drops with sliding speed
- $\theta$ is the "state variable" in RS friction law: it can be interpreted (roughly) as the age of the asperities

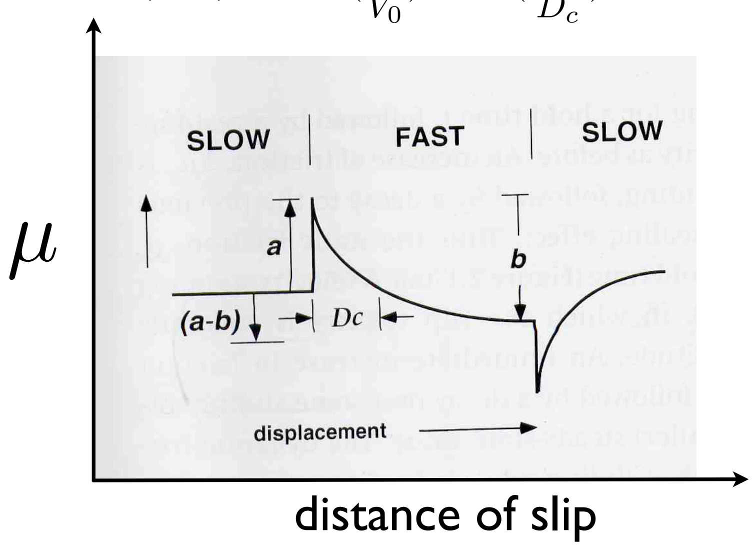



Average age of contacts is
average dimension $D_c$
divided by slip speed V

# Rate- and state- dependent friction: what the friction data look like




$$\mu = \mu_o + a ln(\frac{V}{V_0}) + b ln(\frac{V_o \theta}{D_c})$$



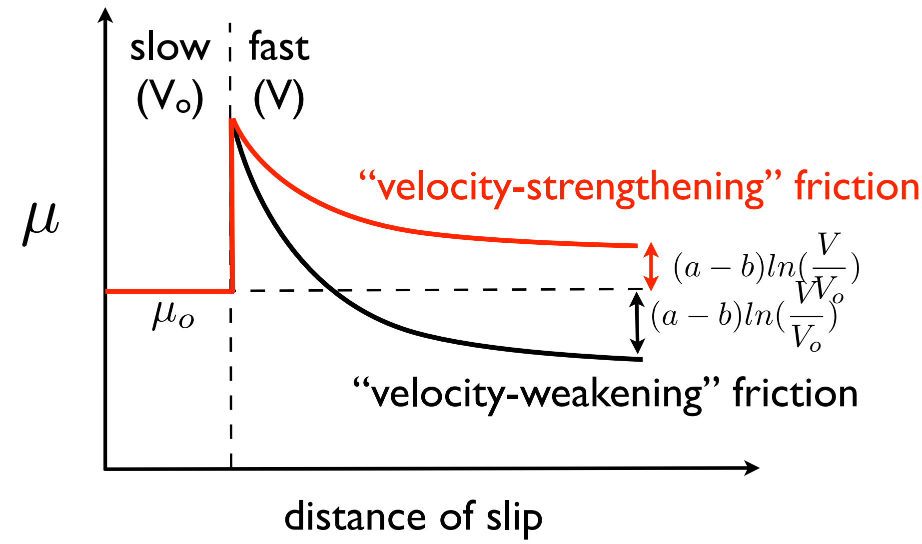

In this example, “fast” happens to be e times the speed of “slow” (e is 2.718...) so ln(V/$V_o$) = 1.

$\theta$ evolves from $\frac{D_c}{V_o}$

to $\frac{D_c}{V}$

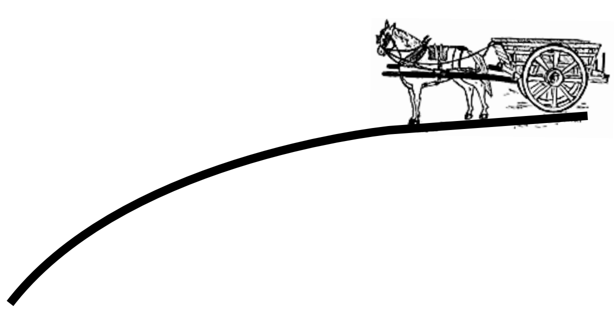
After sliding at the new velocity for a while, the state variable settles down to $\theta = \frac{D_c}{V}$

Then, the “rate and state” friction equation is just: $\mu = \mu_o + (a-b) ln(\frac{V}{V_o})$




$$\mu = \mu_o + (a-b)ln(\frac{V}{V_o})$$

velocity-strengthening friction:
faster sliding -->
stronger fault -->
slows sliding



velocity weakening friction:
faster sliding -->
weaker fault -->
even faster sliding

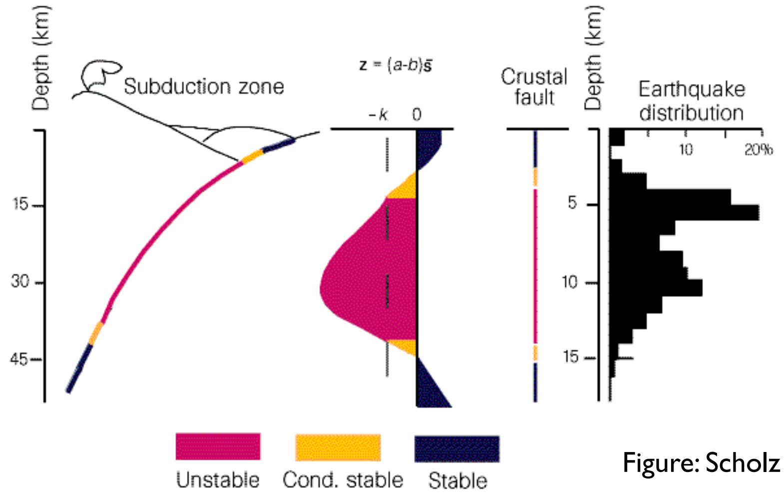



Figure: Scholz 1998

## Why velocity-strengthening friction?

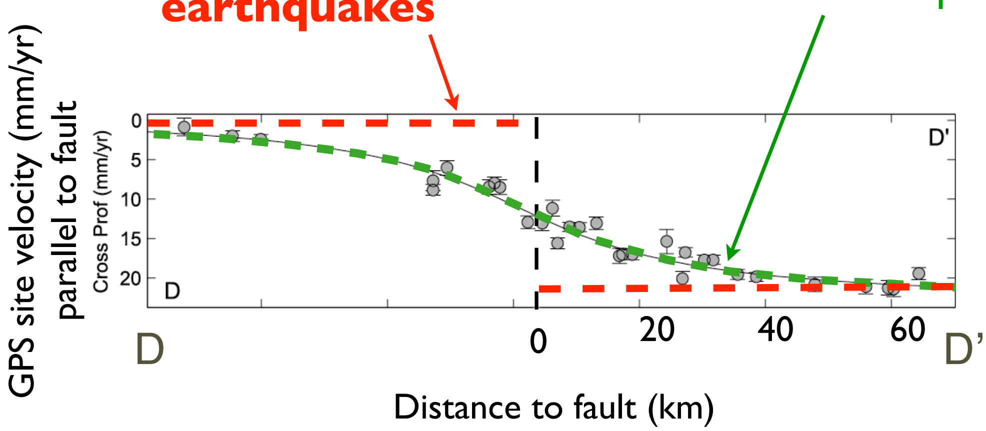
• **shallow**: granular gouge. particles must move around each other to allow relative motion of two sides of the fault. This requires volume increase with increased sliding rate, which requires energy input.

• deep: **Big a (direct effect)**. Asperities shear viscously (flow) to some extent before breaking. A higher shear stress is required to shear the asperities at a higher rate in response to a sudden increase in slip speed.

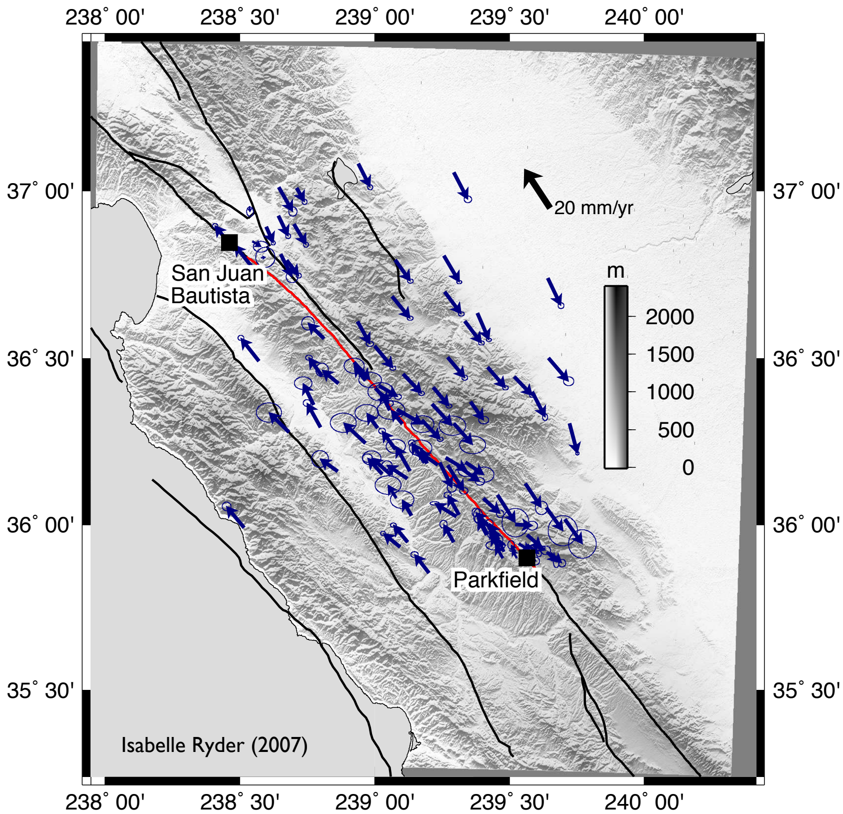
## Wouldn't it be great if ALL faults were velocity-strengthening?

creeping fault: strain and stress are both constant. Aseismic creep and **no earthquakes**

ordinary fault: crust warps around the fault (arctangent profile). strain and elastic stress build up between earthquakes



# Creeping section of the San Andreas Fault

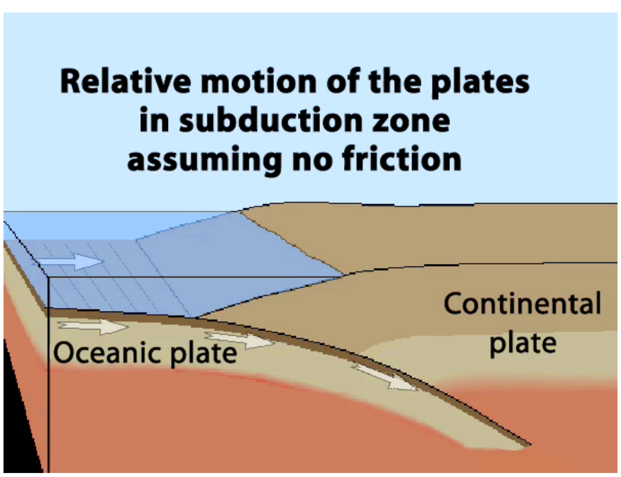


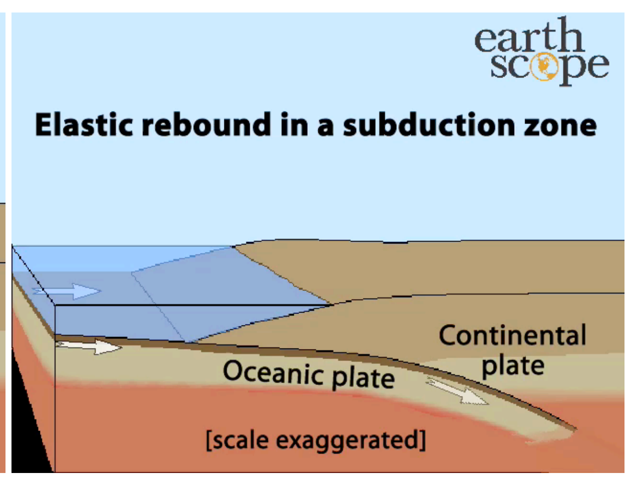

GPS velocity field shows about 30 mm/yr of relative motion but essentially **NO** straining.

It looks like one rigid block sliding past the other.

Thus stresses are not building up.

# Great Subduction Zone Earthquakes and elastic rebound

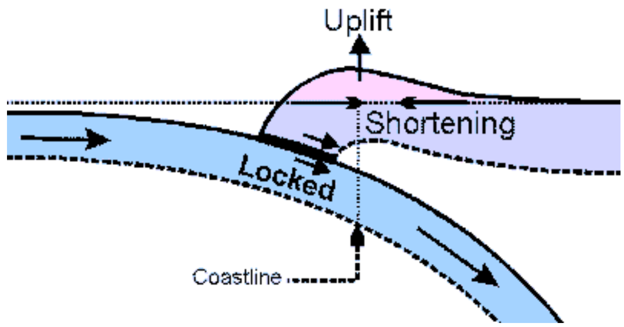


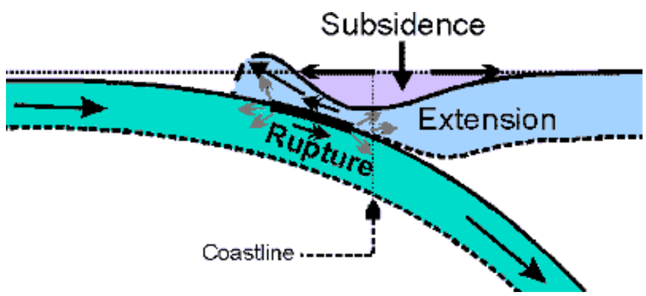

http://www.iris.edu/hq/programs/education_and_outreach/animations/5

(BTW, it's spelled "subsidence")

Subduction zone fault earthquake cycle



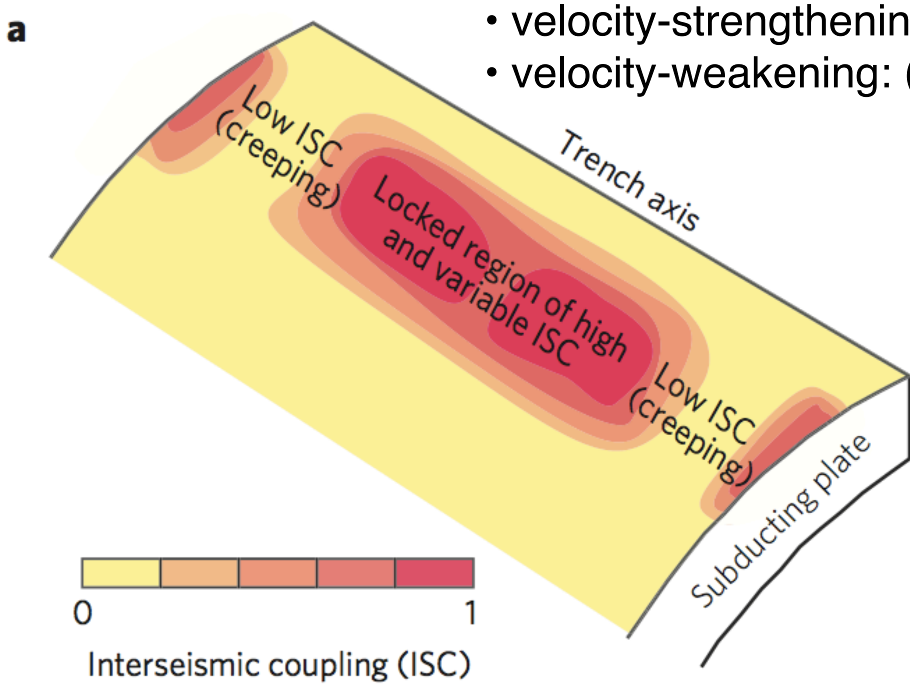

interseismic



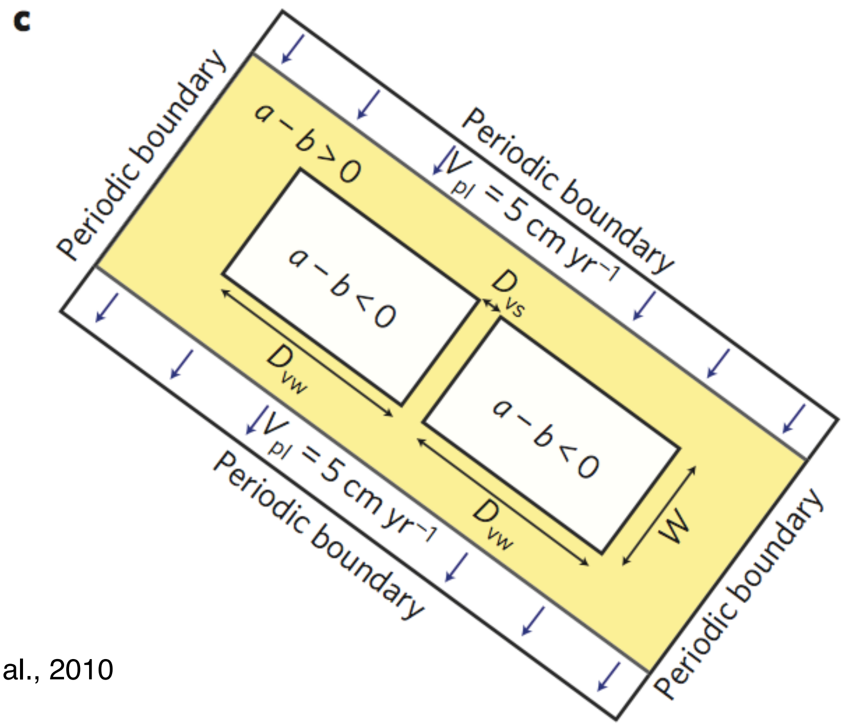

coseismic

Subduction zone fault surface, showing locked and creeping areas

- velocity-strengthening: (yellow)
- velocity-weakening: (red)

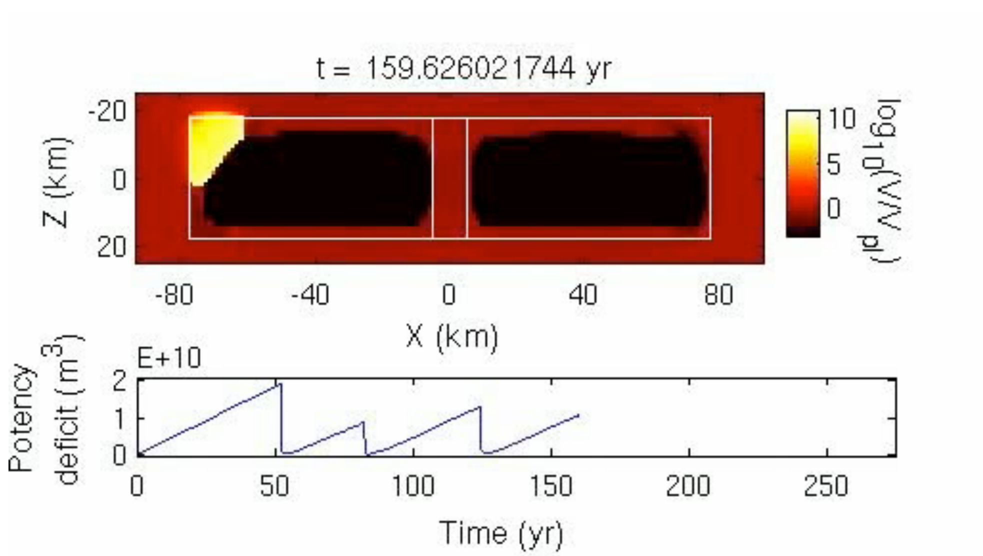


Model of a subduction zone fault surface, with velocity-weakening and velocity-strengthening areas



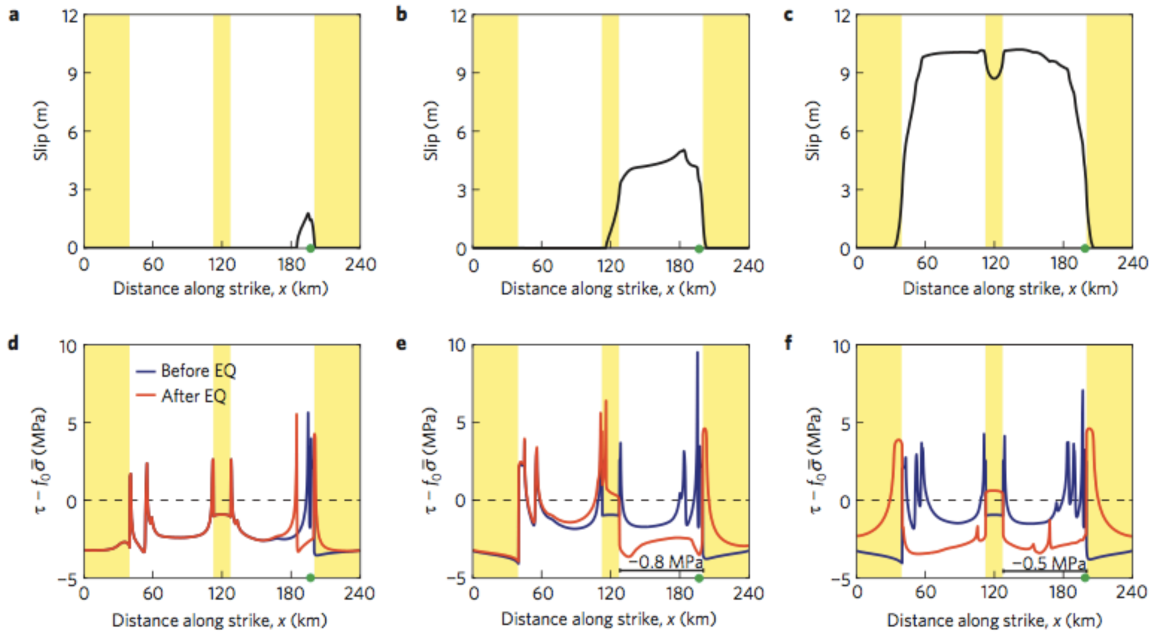

Kaneko et al., 2010

Movie showing modeled earthquakes and interseismic creep over many earthquake cycles




"seismic potency" is just seismic moment / shear modulus ( so it's slip times area)

Small and large earthquakes. top row = slip distribution, bottom row = corresponding pre-and post-quake stress

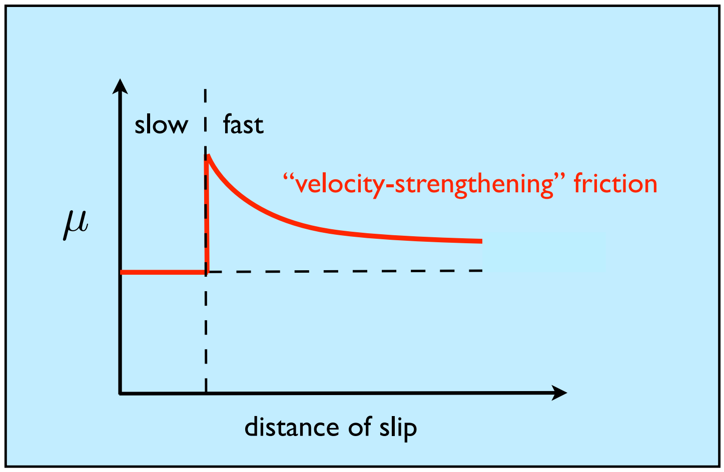


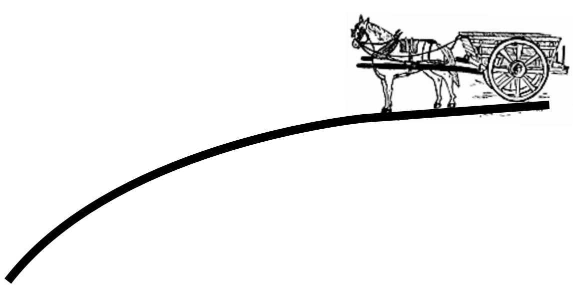

Upshot: by monitoring seismic coupling between earthquakes (via GPS for example) the future large slip patches might be delineated

We still need geologists to tell us whether all the locked fault patches go off at the same time (mega earthquake) or not, because we do not know (a-b) all over the fault.

## $\mu$ increases during sliding

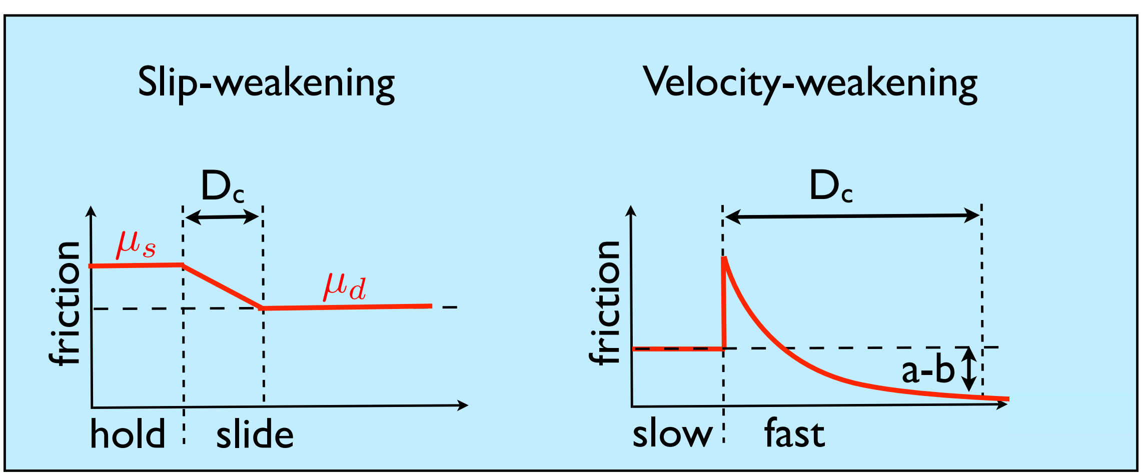
- faster sliding --> stronger fault --> slows sliding
- leads to stable slip: no earthquakes can start
- “velocity-strengthening” friction



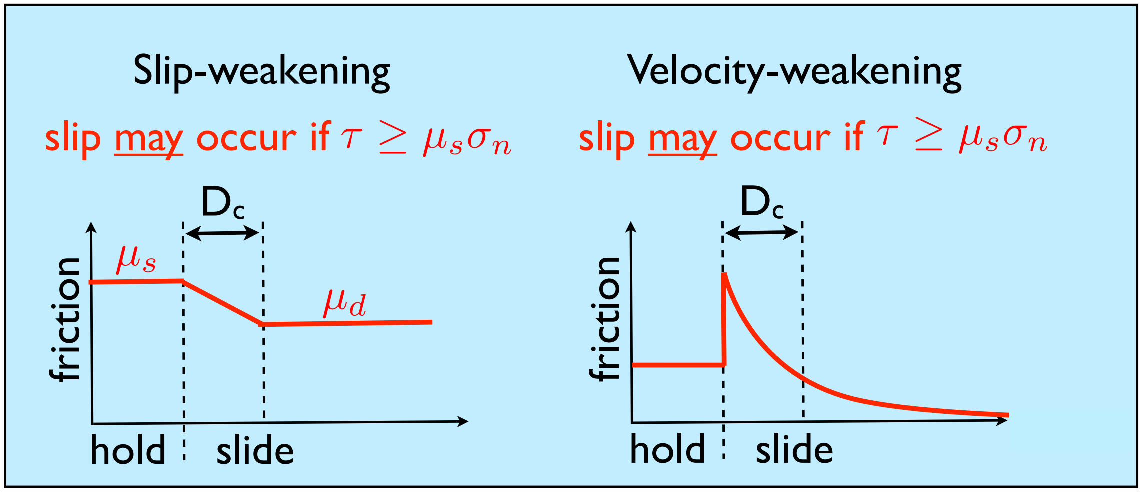



## $\mu$ decreases during sliding:

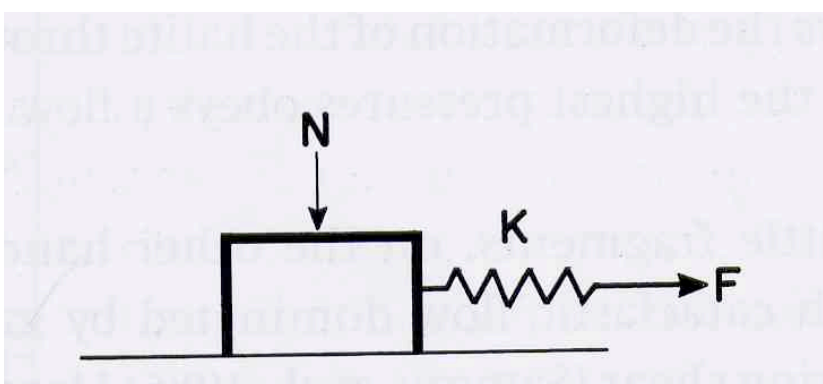
- instability may be possible
- “velocity weakening” or “slip weakening”



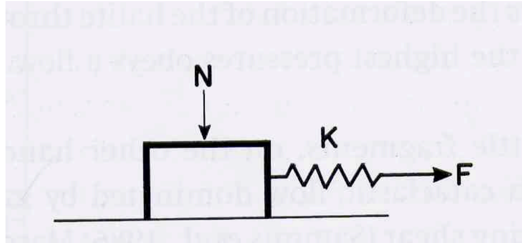
Velocity-weakening or slip-weakening friction:
fault is still not <u>always</u> unstable: there are more required conditions for instability




Spring-slider activity: Friday




Frictional instability and earthquakes




This is a battle between the shear force pulling the block and the friction force resisting it

$$\tau \times A = k \times x = F_{spring}$$
$$\sigma_n \times A \times \mu = N \times \mu = F_{friction}$$
$$F_{spring} + F_{friction} = 0$$

directions these forces are acting?

We will see that sometimes the block slides smoothly and at other times it repeatedly gets stuck and slides suddenly (like a fault).

You will learn what controls whether there are "earthquakes" or not in this system.