From last time...

Friction is independent of the size of areas in contact

Amonton's First Law

Friction is proportional to normal stress

Amonton's Second Law

One correction and one clarification:

(1) "Friction" refers to frictional force - that is, $\mu\sigma_n$, so we know Amonton's second law already

(2) Area in Amonton's first law is the macroscopic area, not just the area of the asperities!

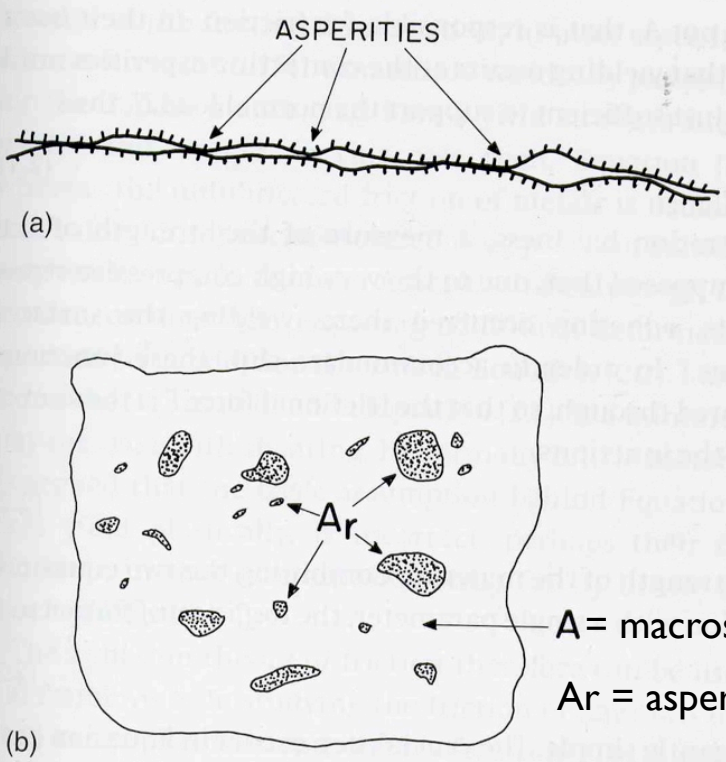
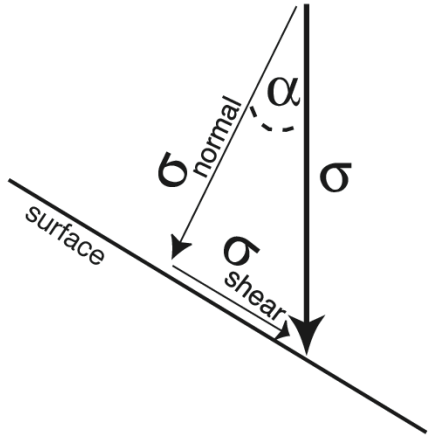


Fig. 2.1. Schematic diagram, in section and plan view, of contacting surface. The stippled regions in plan view represent the areas of asperity contact, which together comprise the real contact area A_r.

A = macroscopic contact area

Ar = asperity contact area

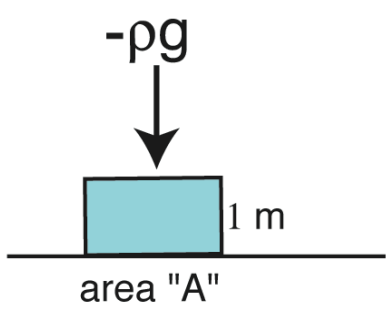
shear stress and normal stress

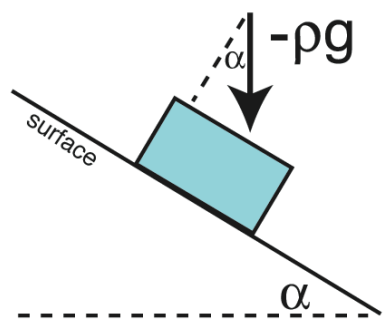


$$\sigma_{shear} = \sigma \sin(\alpha)$$

$$\sigma_{normal} = \sigma \cos(\alpha)$$

friction





$F = -\rho * V * g / A$

$\sigma = F/A = -\rho * g * 1$

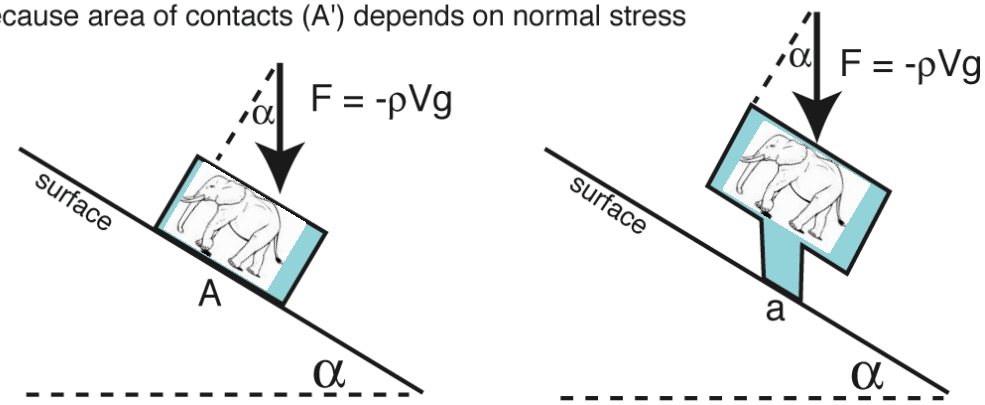
shear stress =

normal stress =

Sliding occurs if $\sigma_{shear} = \sigma_{normal} * \mu$

$\mu = \tan(\alpha)$

Amonton's First Law
friction force is insensitive to **macroscopic** area
because area of contacts (A') depends on normal stress



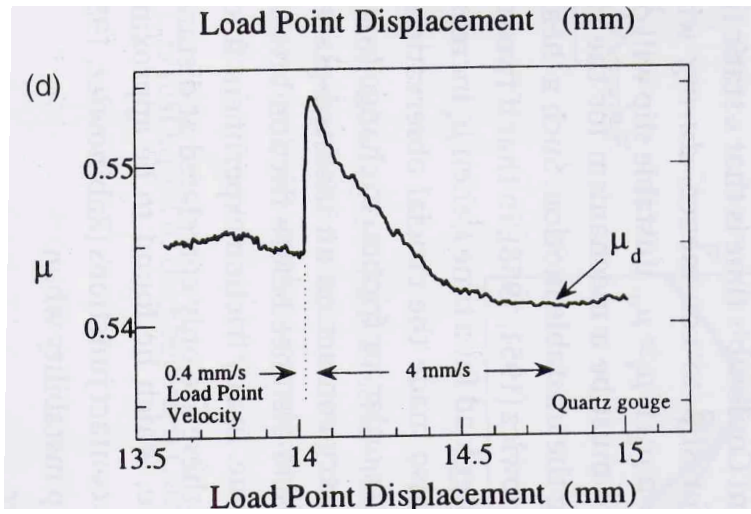
Same contact area Ar for both cases.

If macroscopic contact area is small, normal stress = N/area is larger, asperities squash, and Ar is a larger % of macroscopic contact area

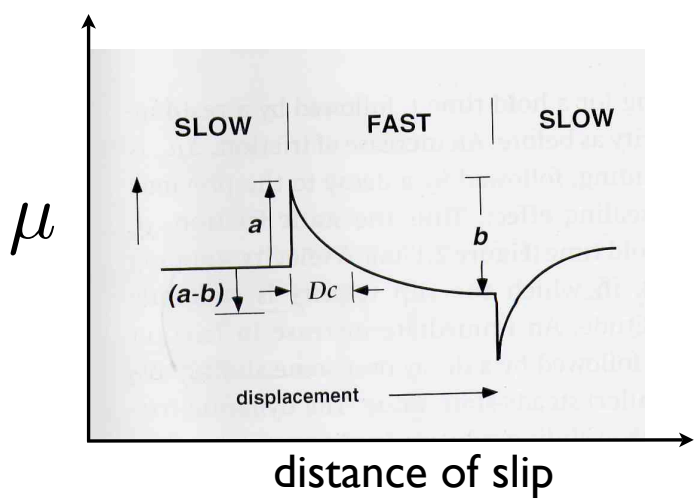
From last time...

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

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



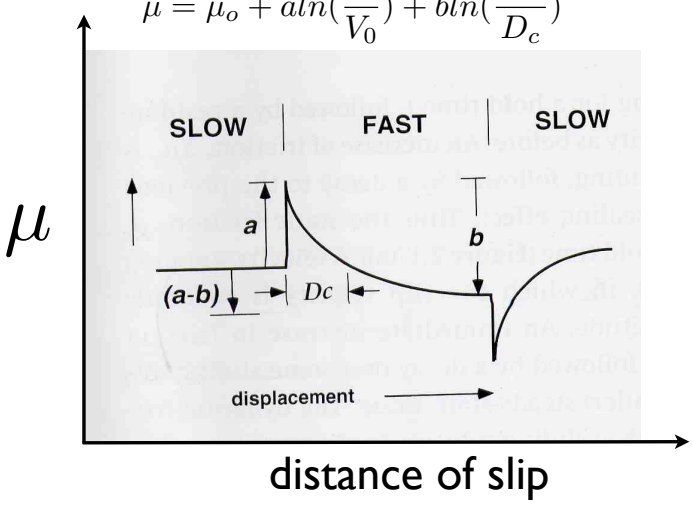
Rate- and state- dependent friction



$$\mu = \mu_o + aln(\frac{V}{V_0}) + bln(\frac{V_o\theta}{D_c})$$

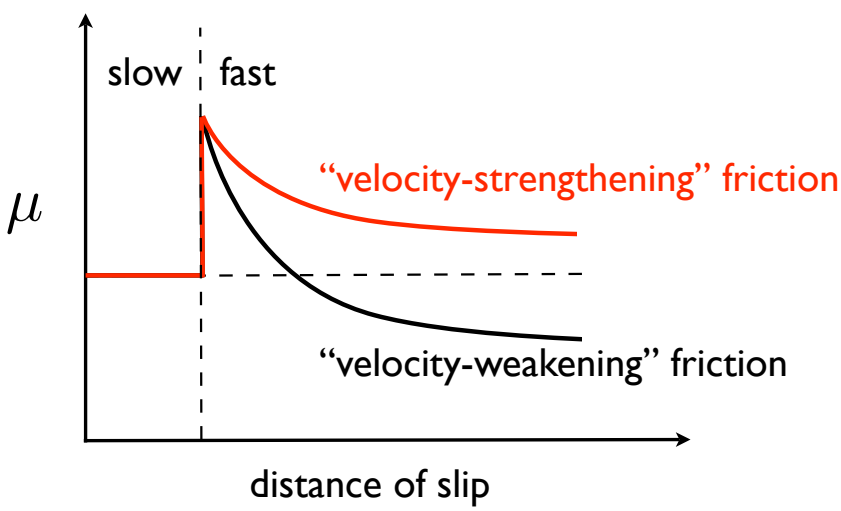
(Dieterich 1981; Ruina 1983)

$$\mu = \mu_o + aln(\frac{V}{V_0}) + bln(\frac{V_o\theta}{D_c})$$



If we assume that the value of the state variable (asperity contact age) is $\theta = \frac{D_c}{V}$
(after a steady state, new sliding velocity is reached)

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



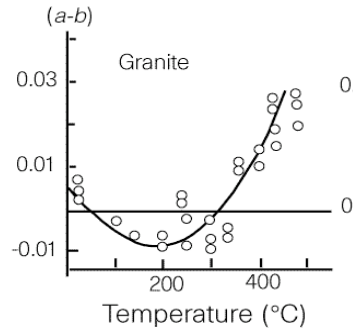
$$\mu = \mu_o + (a-b)ln(\frac{V}{V_o})$$

↓

if positive then _____

if negative then _____

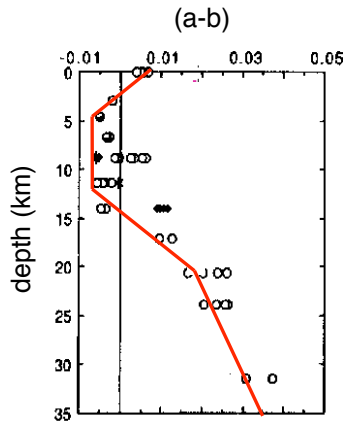
Effect of temperature on friction



(*a* - *b*) vs. temperature for granite (Scholz, 1998 and 2003)

Laboratory experiments show that stable frictional sliding is promoted at temperatures higher than about 300°C for most crustal rocks.

How (a-b) varies with depth



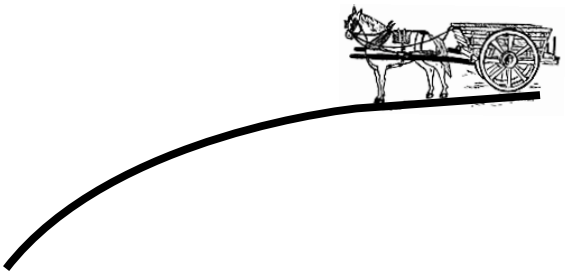
(Blanpied et al, 1991)

T < 300-350°C
a-b<0
Sliding can be unstable

T > 300-350°C
a-b>0
Sliding is stable

μ has NOTHING to do with stability!
Only the **change** in μ with sliding velocity matters.

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



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

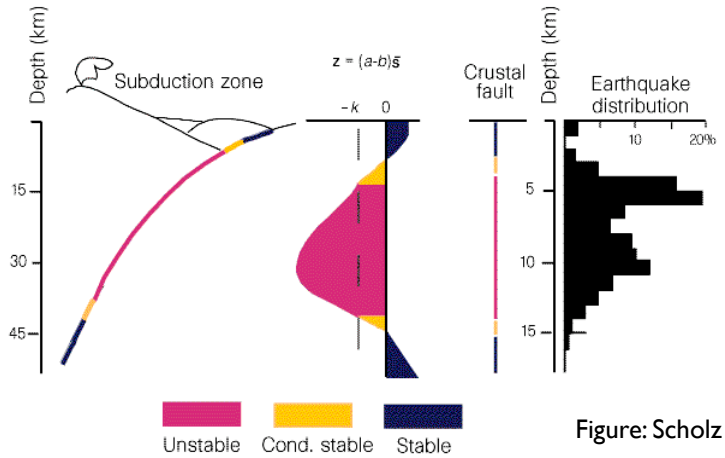


Figure: Scholz 1998

Why velocity-strengthening friction?

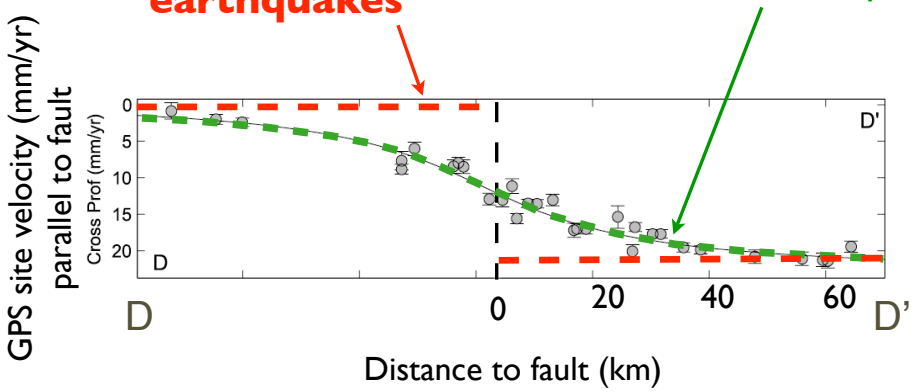
• shallow: granular gouge. particles must move around each other to allow relative motion of two sides of the fault. This requires volume increase with increased sliding rate, which requires energy input.

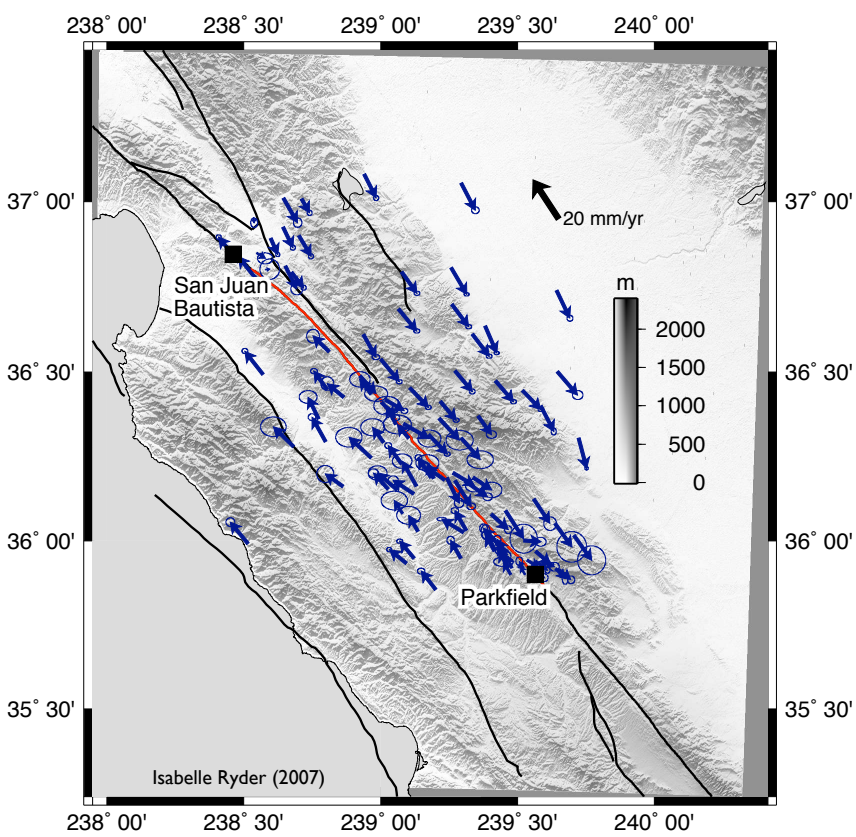
• deep: Big a. Asperities deform viscously to some extent before breaking, and with viscous flow, higher shear stress is required for a higher slip velocity (strain rate across the fault)

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

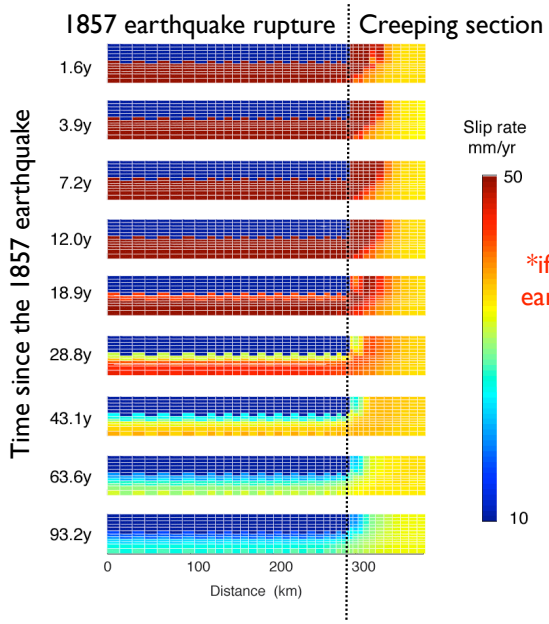
creeping fault: strain and stress are both constant. Aseismic creep and **no earthquakes**

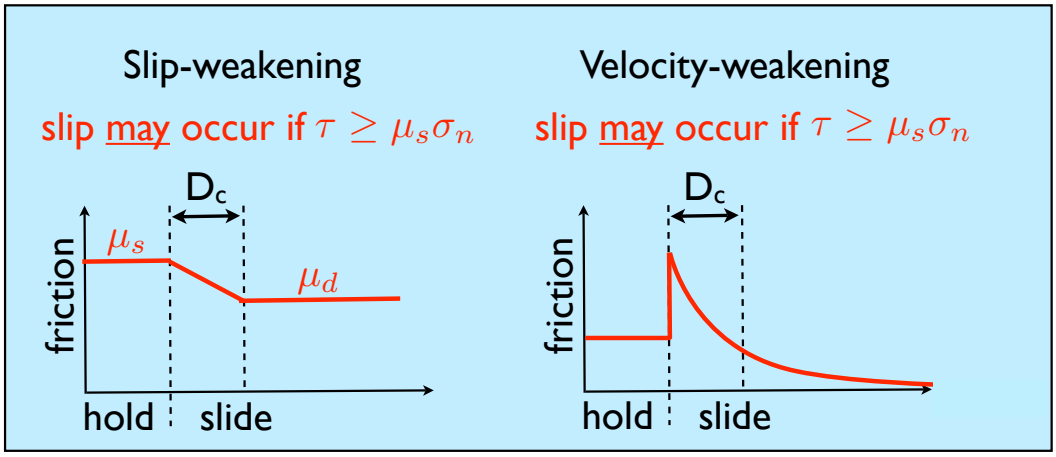
ordinary fault: crust warps around the fault (arctangent profile). strain and elastic stress build up between earthquakes





Creeping section of the San Andreas Fault has velocity-strengthening friction



*if the fault is "kicked" by an earthquake nearby, creep and speed up or slow down.

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