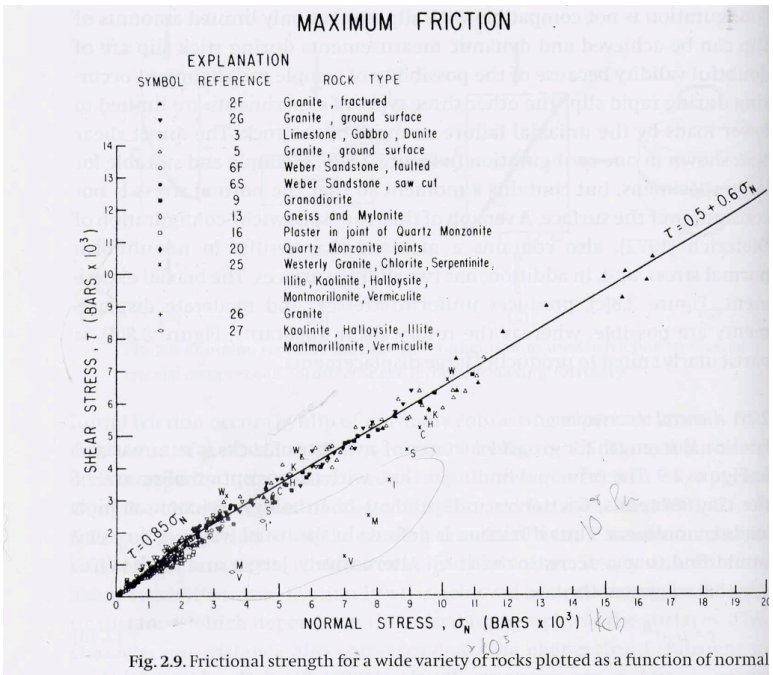


Fig. 2.9. Frictional strength for a wide variety of rocks plotted as a function of normal load. The lettered data points refer to clay minerals as indicated in the key. (From Byerlee, 1978.)

$$\tau = \mu_s \sigma_n$$

Byerlee's Law (1978)

Does rock type matter?

This works at T less than 350-400° C

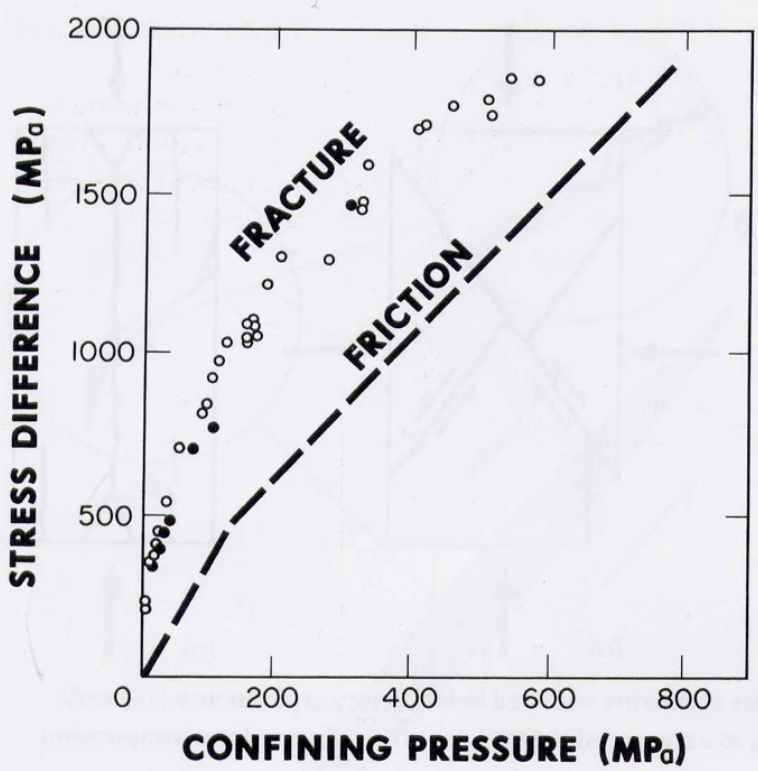


Fig. 1.13. The strength of Westerly granite as a function of confining pressure. Also shown, for reference, is the frictional strength for sliding on an optimally oriented plane. Data sources are: open circles, Brace *et al.* (1966) and Byerlee (1967a); closed circles, Hadley (1975); friction, Byerlee (1978). Stress difference is $\sigma_1 - \sigma_3$.

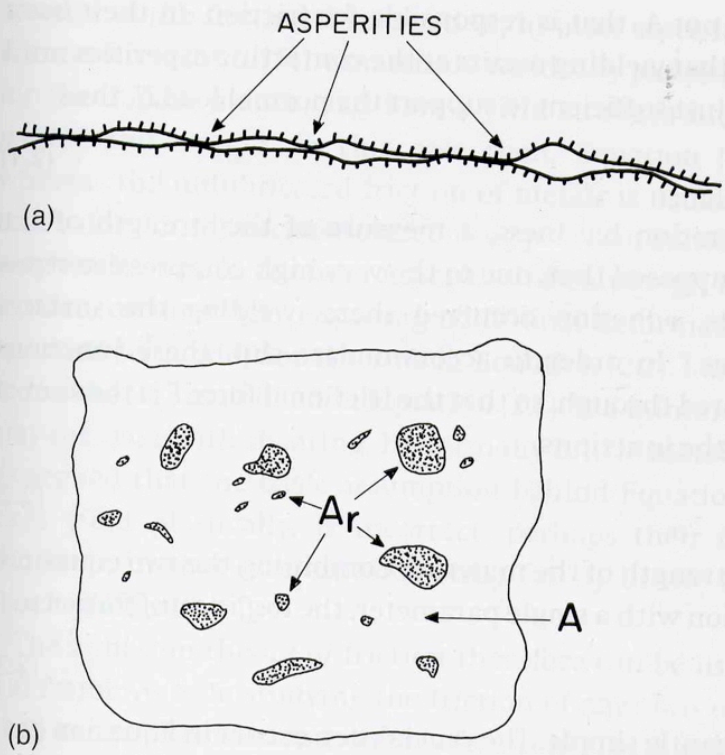


Fig. 2.1. Schematic diagram, in section and plan view, of contacting surface. The stippled regions in plan view represent the areas of asperity contact, which together comprise the real contact area A_r.

Friction is independent of the size of areas in contact

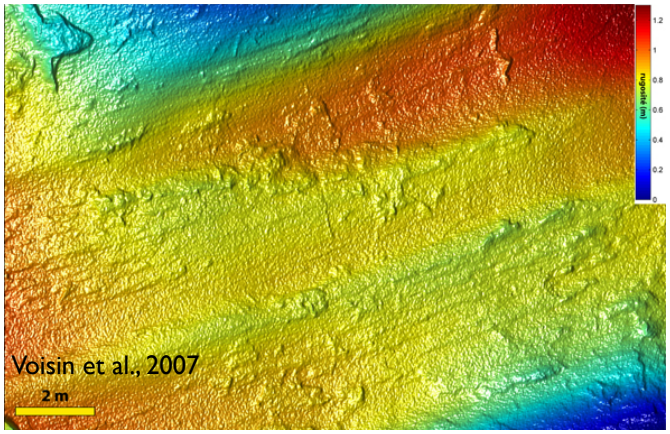
Amonton's First Law

Friction is proportional to normal stress

Amonton's Second Law

- **Asperities can strengthen (and friction can increase) with "hold" time**
- 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

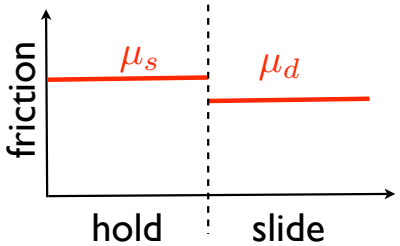
High-precision Lidar scan (topography) of an exposed fault surface



Asperities at a wide array of spatial scales

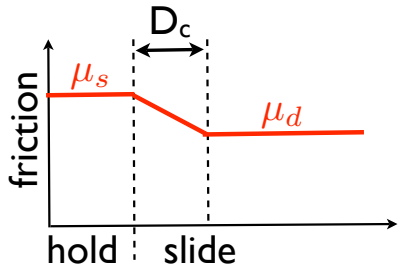
"smoother" profile in the slip direction

Some ideas about static vs. dynamic friction



slip occurs if $\tau \geq \mu_s \sigma_n$

$$\Delta\tau = (\mu_s - \mu_d)\sigma_n$$

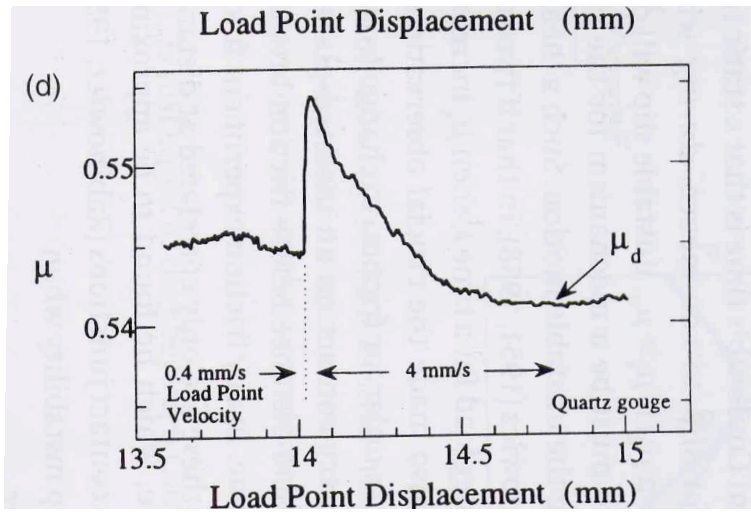


slip <u>may</u> occur.

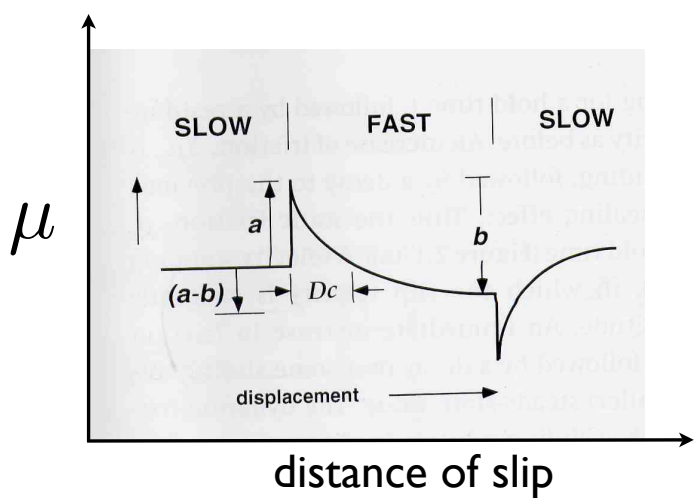
It depends on the "stiffness" of the fault, which is a function of the shear modulus and the size of the fault patch where $\tau \geq \mu_s \sigma_n$

$$\Delta\tau = (\mu_s - \mu_d)\sigma_n$$

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



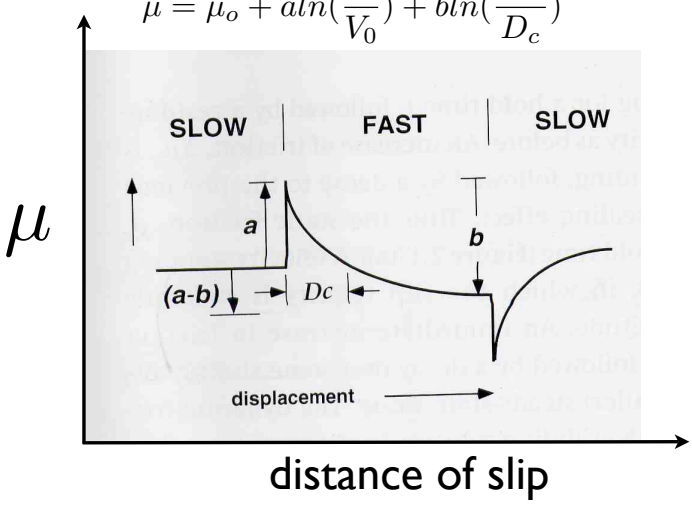
Rate- and state- dependent friction



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

(Dieterich 1981; Ruina 1983)

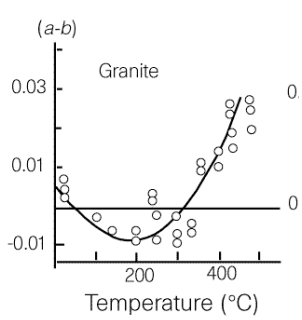
$$\mu = \mu_o + aln(\frac{V}{V_0}) + bln(\frac{V_o\theta}{D_c})$$



If we assume that during slow sliding the value of the state variable was $\theta_o = \frac{D_c}{V_o}$

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

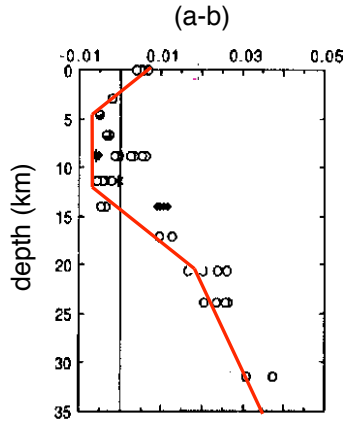
Effect of temperature on friction



(*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.