Amonton’s **First** Law
Frictional force is independent of the size of areas in contact
Amonton (1) is referring to the macroscopic area (not the area of the actual asperities)

Amonton’s **Second** Law
Frictional force is proportional to normal force (“load”)
Amonton (2) also works for stress (force/area)

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

Bigger stress ($F/a$) on the right. Same friction force is resisting sliding in both cases.

**Same contact area $A_r$ for both cases.**
If macroscopic contact area is small, normal stress = $N/area$ is larger, asperities squash, and $A_r$ is a larger % of macroscopic contact area.
• 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 as the age of the asperities

\[
\mu = \mu_o + a\ln\left(\frac{V}{V_0}\right) + b\ln\left(\frac{V_0\theta}{D_c}\right)
\]

In this example, “fast” happens to be $e$ times the speed of “slow” (e is 2.718...)

$\theta$ 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: $\mu = \mu_o + (a - b)\ln\left(\frac{V}{V_o}\right)$
\[ \mu = \mu_o + (a - b) \ln \left( \frac{V}{V_o} \right) \]

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

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

Subduction zone fault earthquake cycle

**Interseismic:**
- **Locked**
- **Shortening**
- **Uplift**

**Coseismic:**
- **Extension**
- **Subsidence**
- **Rupture**

Isabelle Ryder (2007)
Cascadia interseismic deformation

NE Japan interseismic deformation: SZ fully “locked”

Mazzotti et al., 2000
Subduction zone fault surface, showing locked and creeping areas

- creeping: ISC = 0
- locked: ISC = 1

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.
Computer model results, like real earthquakes, are neither time nor slip predictable.

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

We need geologists to tell us whether all the locked fault patches go off at the same time (mega earthquake) or not.
PAGER map: population exposed to various Mercalli Intensities in the Sendai Japan M 9.1 earthquake

PAGER fatality and damage cost estimates based on intensity map and building information for the region

Alert Information

Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are less than 1% of GDP of Japan. Past events with this alert level have required a national or international level response. Orange alert level for shaking-related fatalities. Significant casualties are likely.

Show graphs as tables

Estimated Fatalities

Estimated Economic Losses

This does not factor in the tsunami.
Distribution of coseismic slip and aftershocks
Most fault slip happened in 1st 100 seconds, though this estimate probably missed a lot (slower slip)

slower slip? (not generating seismic waves)
fault slip estimated from modeling surface waves

usgs (gavin hayes)

predicted tsunami wave size (in feet)

 tsunami: much of crescent city harbor destroyed; 4 people swept into sea, 1 feared dead [la times]

waves at crescent city = 2 m high
Velocity-weakening or slip-weakening friction: fault is still not always unstable
Monday and Wednesday: required conditions for instability

Slip-weakening
slip may occur if $\tau \geq \mu_s \sigma_n$

Velocity-weakening
slip may occur if $\tau \geq \mu_s \sigma_n$