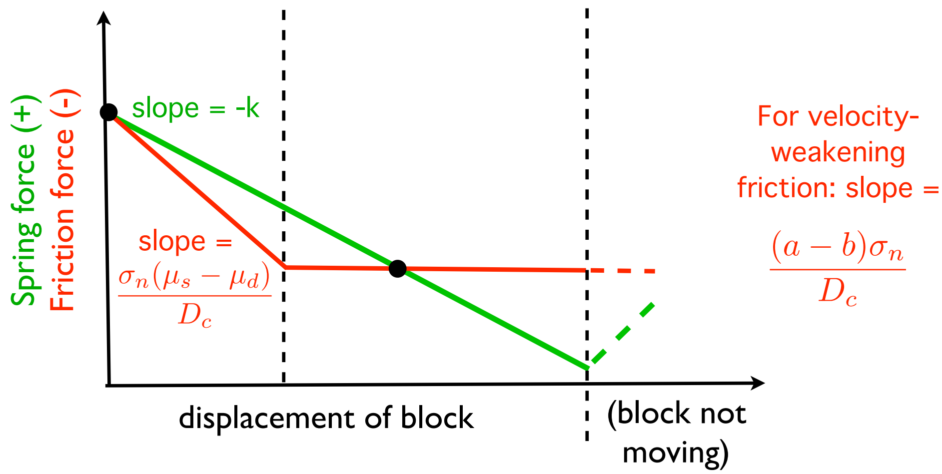


Instability happens if friction decrease during sliding is steeper than elastic force decrease...	Instability if $k < \left\| \frac{\sigma_n (b-a)}{D_c} \right\|$

(think in terms of absolute values - i.e. both quantities with the same sign)

Instability happens if friction decrease during sliding is steeper than elastic force decrease...	Instability if $k < \frac{\sigma_n (b-a)}{D_c}$

Friday, what happened in the “stiff spring” experiment?

Instability happens if friction decrease during sliding is steeper than elastic force decrease...

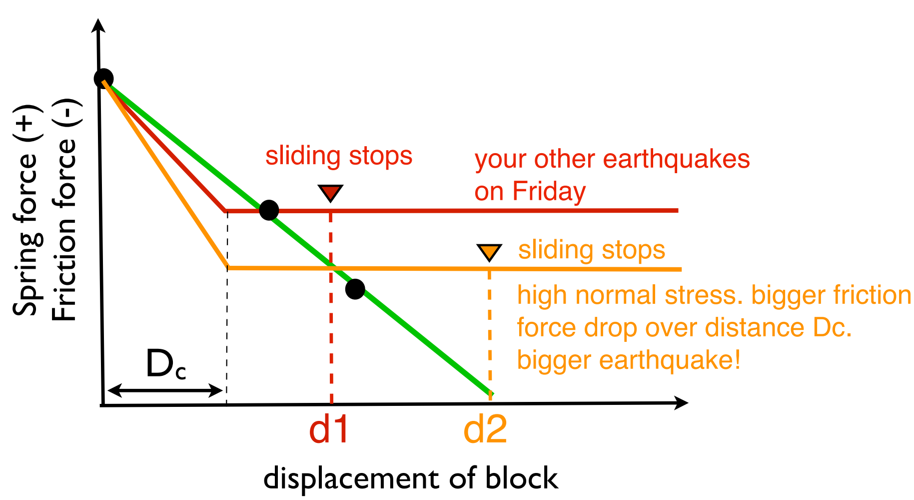
Instability if

$$k < \frac{\sigma_n(b-a)}{D_c}$$

- stiff spring?
- high normal stress?
- weak spring?
- low normal stress?

What about those big earthquakes you made by adding weight to the block?

- high normal stress (added a weight)
- no change to the spring stiffness (same old spring)



What does this mean in the Earth?

$$k < \frac{\sigma_n(b-a)}{D_c}$$

D_c and (a-b) : from lab experiments

σ_n : from (approx.) $\rho g h$

k: spring: k related block slip to elastic force decrease of the spring.

Earth: k relates fault slip to elastic shear force decrease of the rock

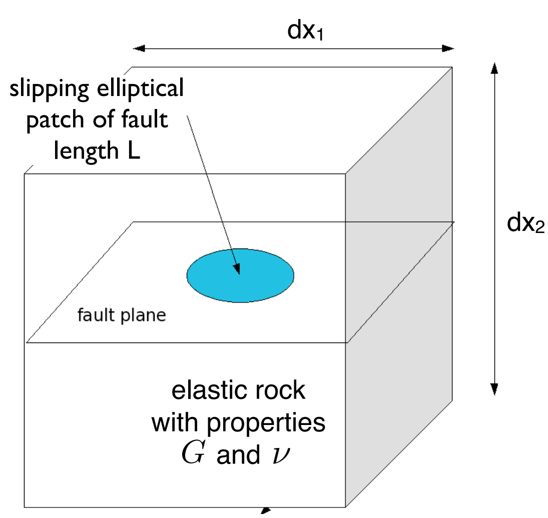
In the Earth, we use an equation for the stiffness k of a small, elliptical crack which comes from elasticity theory (and is proven by experiments)

k relates slip (offset) to the shear stress change

Equation for stiffness k for a small, elliptical crack is:

$$k = \frac{G}{(1-\nu)L}$$

G = shear modulus
ν = Poisson's ratio
L = length of slipping area



Earthquake machine: k is the spring stiffness

Earth: k is the elastic force due to offset along crack (length L)

$$k < \frac{\sigma_n(b-a)}{D_c}$$

$$\frac{G}{(1-\nu)L} < \frac{\sigma_n(b-a)}{D_c}$$

k = crack stiffness
G = shear modulus
ν = Poisson's ratio
L = length of slipping area
$(b-a)$ = friction weakening parameter
σ_n = normal stress
D_c = friction weakening distance

$$L > \frac{D_c G}{(1-\nu)(b-a)\sigma_n}$$

This tells us that the slipping patch of fault must be bigger than a critical size to go unstable, *even* for a velocity weakening fault

The slipping patch of fault must be bigger than a critical size to go unstable

Determine the minimum earthquake size (magnitude and moment) assuming: G=30 GPa, normal stress = 150 MPa, b-a = 0.01, ν= 0.25, and Dc = 10^{-4} m.

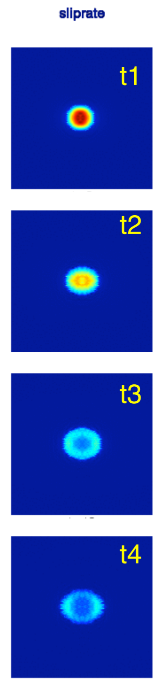
$$L > \frac{D_c G}{(1-\nu)(b-a)\sigma_n}$$

$\log M_o = 1.5(M_w + 6.0333)$

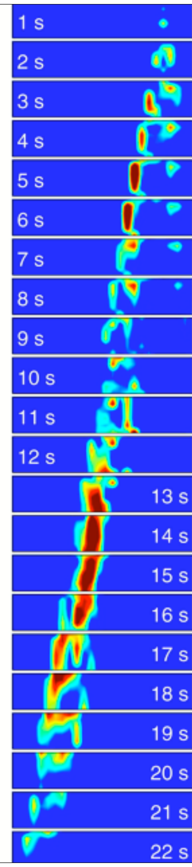
$M_w = \log M_o/1.5 - 6.0333$

$M_o = AsG$

Get L and then get moment and moment magnitude.
Assume offset (slip) is 0.01 times L.



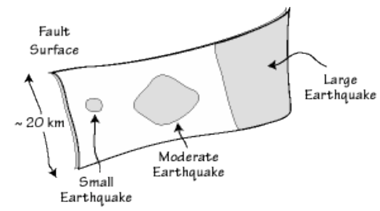
vs.



Madariaga,
Wald and Heaton 1994

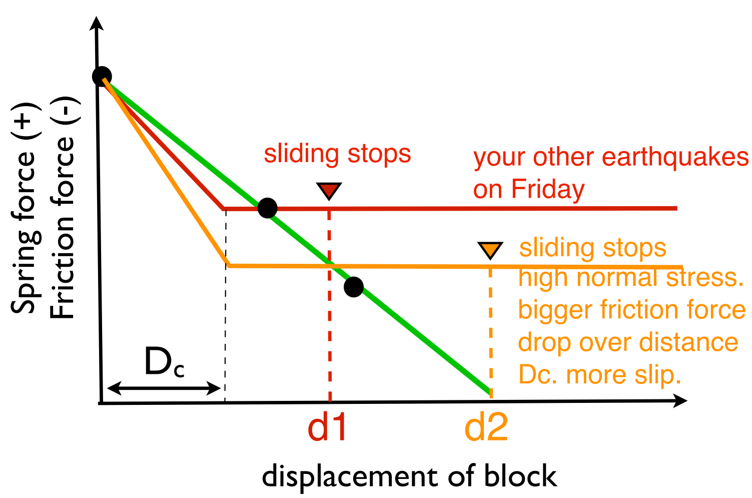
We now know what it takes to start an earthquake.

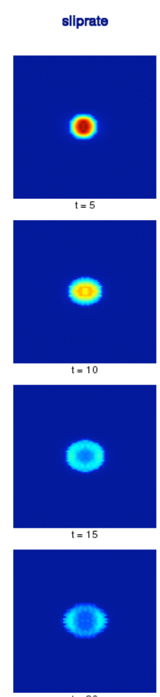
What does it take to make a large earthquake?



They all start small at the hypocenter...

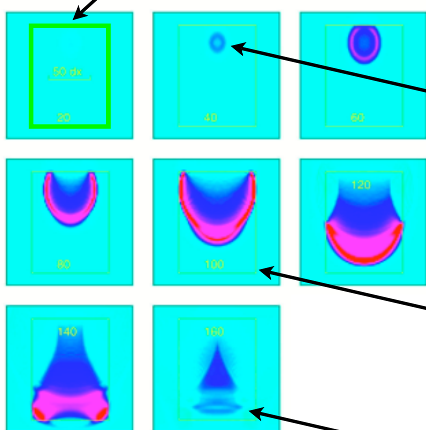
Large normal stress gives the most slip at a particular spot





In a large earthquake, the slipping patch grows: the rupture propagates into previously unbroken parts of the fault

set model up to keep slip inside the green box. How?



start earthquake in model on a patch where...

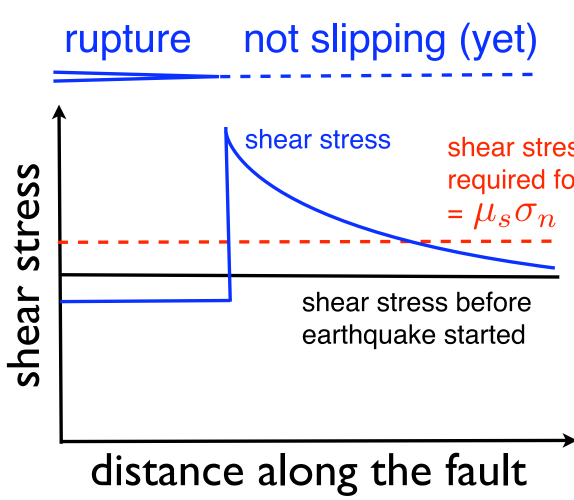
earthquake rupture is growing. slip has already stopped at the source.

slip stays inside the green box

slip fizzles out.

from a numerical model
Madariaga et al.

Good conditions for rupture propagation



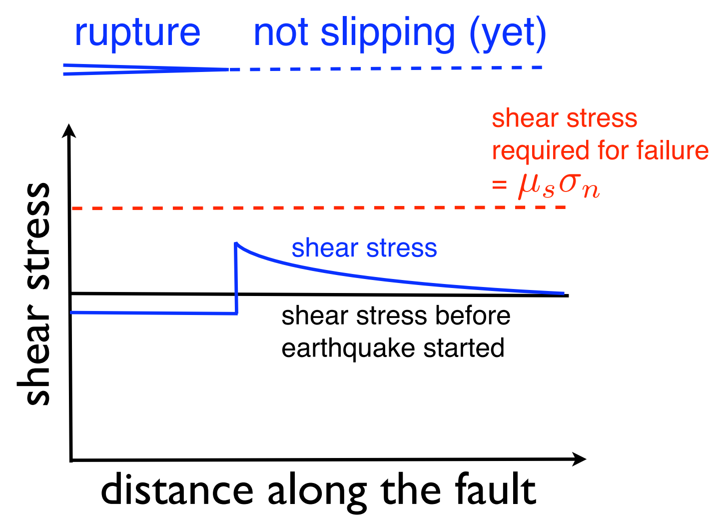
shear stress on unbroken fault next to the rupture increases!

the shear stress increase is proportional to the earthquake stress drop* and (1/ the square root of distance to the rupture tip)

neighboring parts of the fault can be driven to failure by this domino effect if they are already close to failure

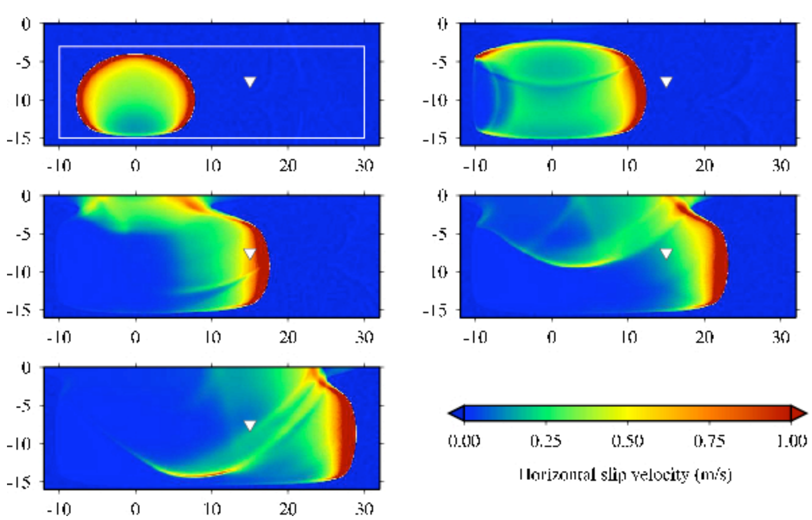
*biggest for high normal stress and velocity weakening (big frictional force drop with slipping)

Bad conditions for rupture propagation

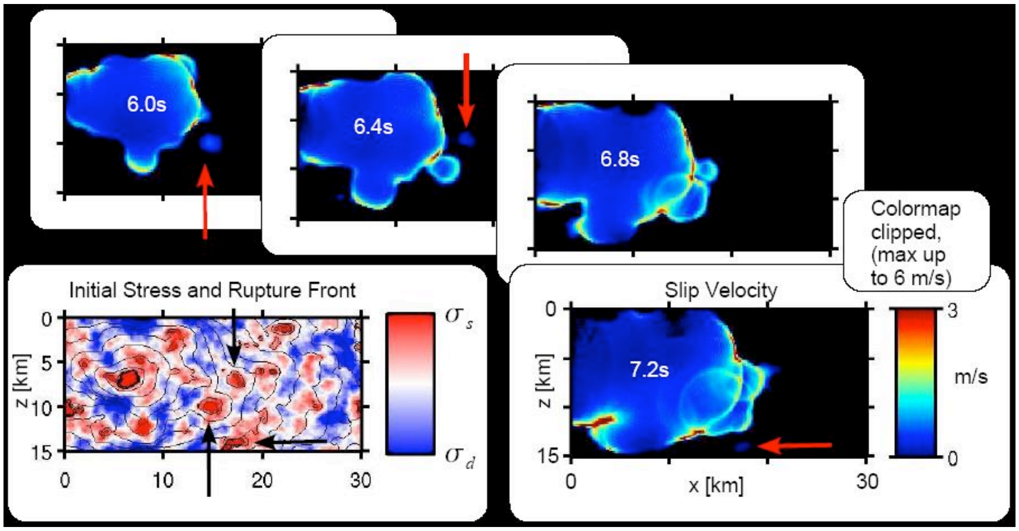


Neighboring parts of the fault can be driven to failure by this domino effect
if they are already close to failure

Two ways for the fault to be close to failure:



Stress is heterogeneous on real faults



Rupture propagation model from J. Ampuero et al.

• Long, continuous fault (no need to jump from segment to segment)
• Shear stress near the Coulomb threshold along this fault
• Large normal stress and velocity weakening friction --> big frictional force drop and large "kick" to adjacent parts of the fault