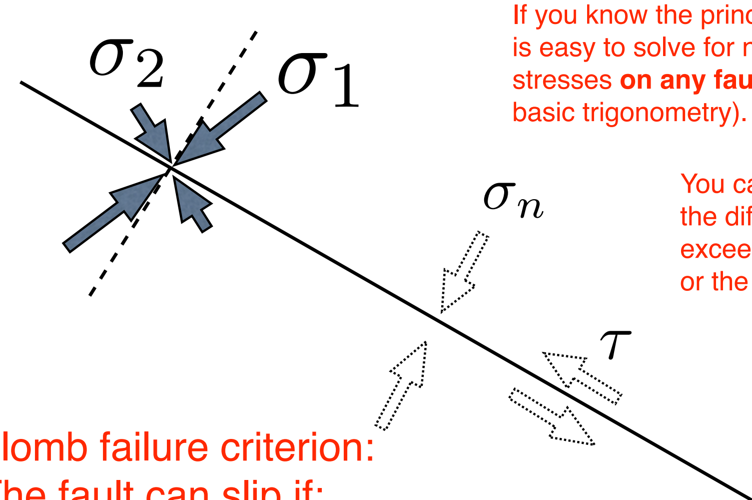
$$\sigma = \begin{pmatrix} \sigma_1 & 0 \\ 0 & \sigma_2 \end{pmatrix}$$



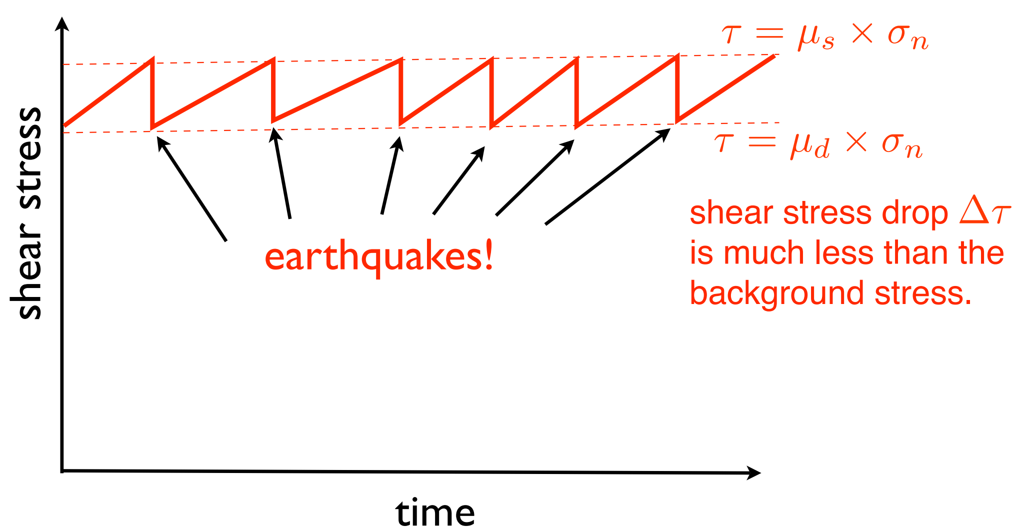
If you know the principal stresses it is easy to solve for normal and shear stresses **on any fault plane** (using basic trigonometry).

You can very easily estimate the differential stress. It can't exceed a few hundred MPa or the rock will break.

Coulomb failure criterion:
The fault can slip if:

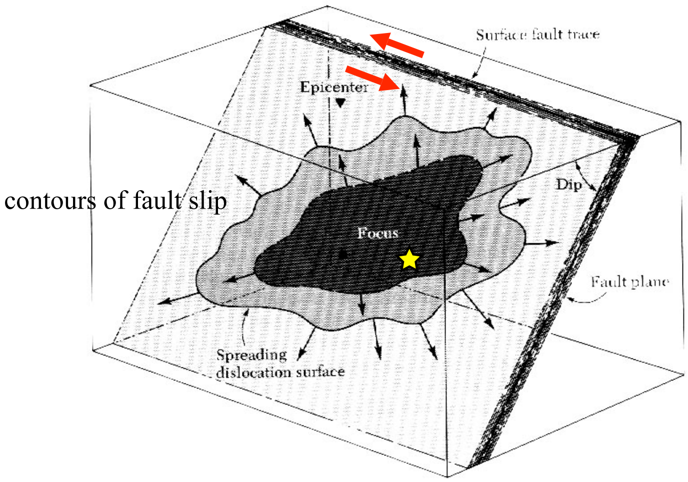
$$\tau = \mu \sigma_n$$

For many faults, earthquake shear stress drop is much smaller than "background" shear stress



Fault friction is actually more complicated than this because it depends on slip speed and the presence of water in the fault zone!

Let's back up and talk a little about the earthquake source

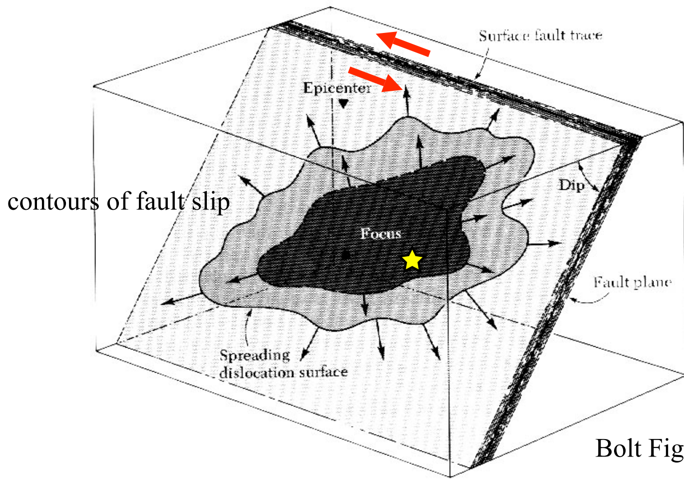


Bolt Figure 4.9

- Two slides of fault start to slip at the hypocenter
- Slip spreads out over some area
- Seismic waves radiate from wherever fault is slipping
  - Disturbance of rock travels far, but rock does not move far
  - Size of waves depends on how much slip happens over how large an area
  - Damage depends on size of waves

• The rupture grows at about the S-wave velocity (2 to 3 km per second)

• Rock on either side of the fault moves at about 1 m/sec (and just for a few seconds in any place)



Bolt Figure 4.9

• The rupture grows at about the S-wave velocity (2 to 3 km per second)

then

• Crustal blocks on either side of the fault "realize" that they are no longer attached (because the fault is unstuck) and they begin to slide past each other

• coyote runs off cliff

then

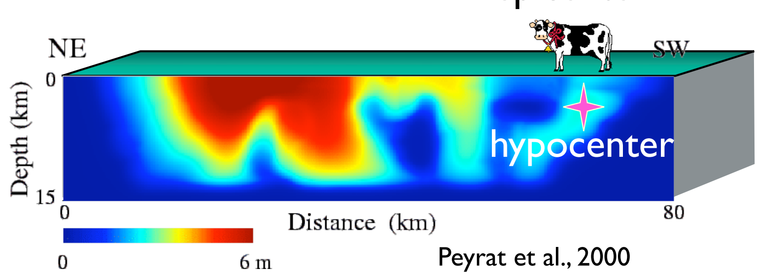
• coyote falls

1994 M = 7.4 Landers, California earthquake

Total rupture time: 20-25 seconds. Fault is slipping only where you see the colors.

When it's all over... splotchy slip

1994 M = 7.4 Landers, California earthquake



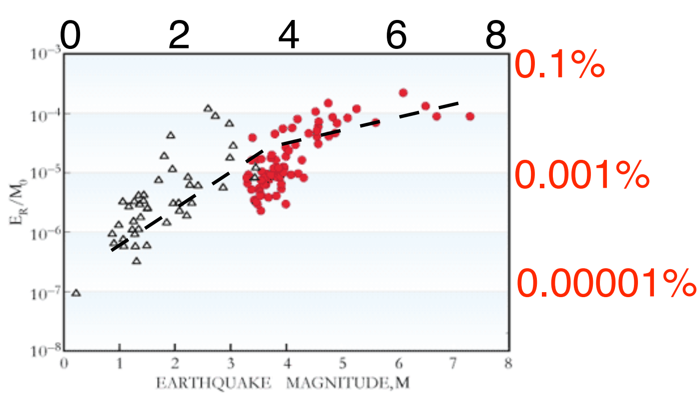
rupture begins at the hypocenter and travels away
("unilateral" = one-way, "bilateral" = both ways)

Seismic moment M_o = rupture area x slip x G

(slip varies with position so $M_o = \int_A Gs\ dA$)

- units: s (m) x A (m^2) x G (N/m^2) = N m
- moment is defined in physics as force x distance
- values are **big**. 2.3 x 10^{20} N m for the 1999 Izmit M 7.4 earthquake
- we have recipes to convert M_o to something that looks like the Richter magnitude (log scale, up to 10)

Energy devoted to seismic shaking is just a tiny % of the total energy of the earthquake (seismic moment)



In a large earthquake, proportionally more energy goes to shaking (and the energy is spent on shaking at lower frequencies, as Prof. Bostock will describe later).

Conversion to M_w: Hanks and Kanamori, 1979 (100% empirical)

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

$$M_w = \log M_o/1.5 - 6.0333$$

$$M_o = AsG$$

M_w	Moment	Length	Slip	Area	Duration *of slip*
4	10^{15} N m	1000 m	2 cm	1 km^2	0.2 s
5	3 x 10^{16} N m	3000 m	10 cm	9 km^2	0.4 s
6		10 km	20 cm		
7		68 km	1.5 m		
8			10 m		
9		1000 km	20 m	10^6 km^2	

Magnitude as a function of slip, rupture size, and stress drop

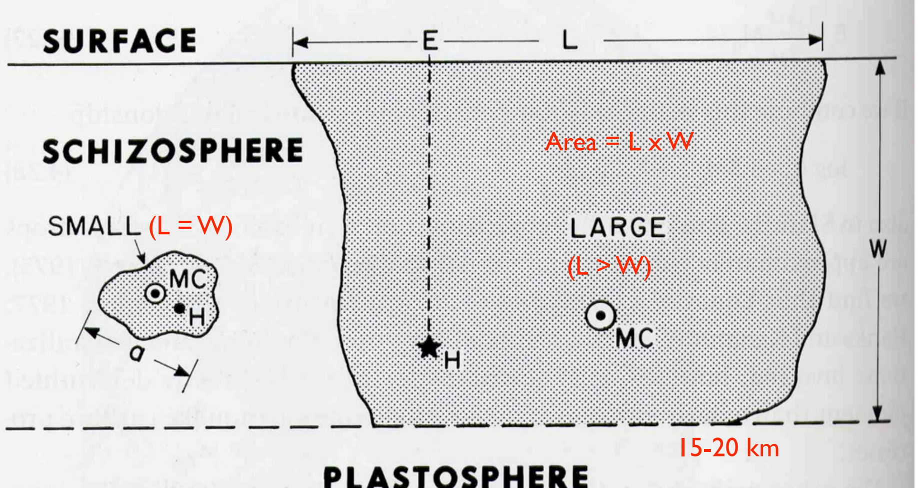
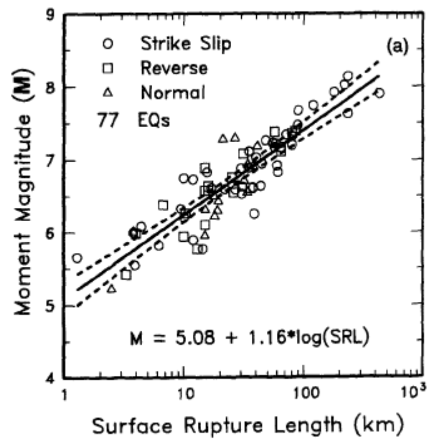


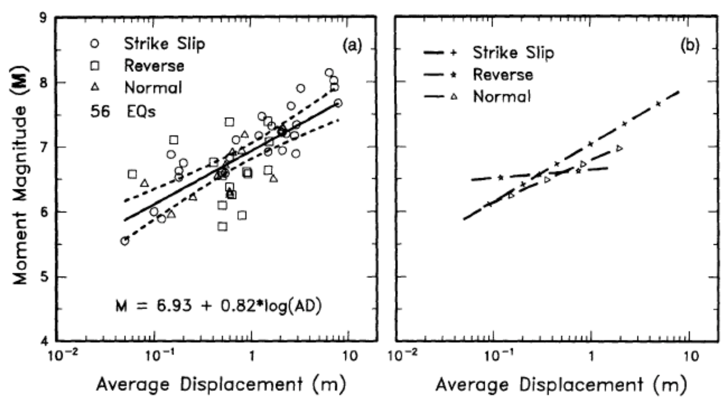
Fig. 4.9. Diagram illustrating the definitions of small and large earthquakes, showing hypocenter (H), epicenter (E), moment centroid (MC), and the dimensions of rupture (*a*, *L*, and *W*).

Moment magnitude versus rupture length



Wells and Coppersmith, 1994

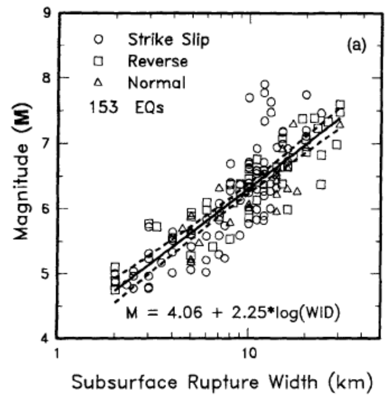
Moment magnitude versus slip



Wells and Coppersmith, 1994

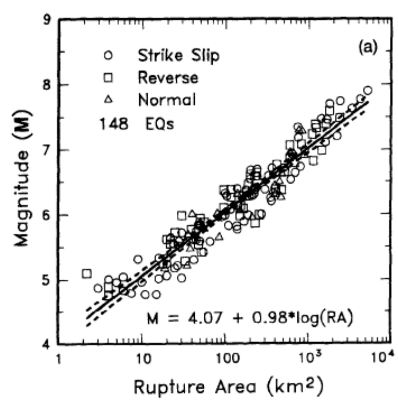
This means that slip scales with rupture length too...
which is good news for paleoseismologists

Moment magnitude versus rupture width



Wells and Coppersmith, 1994

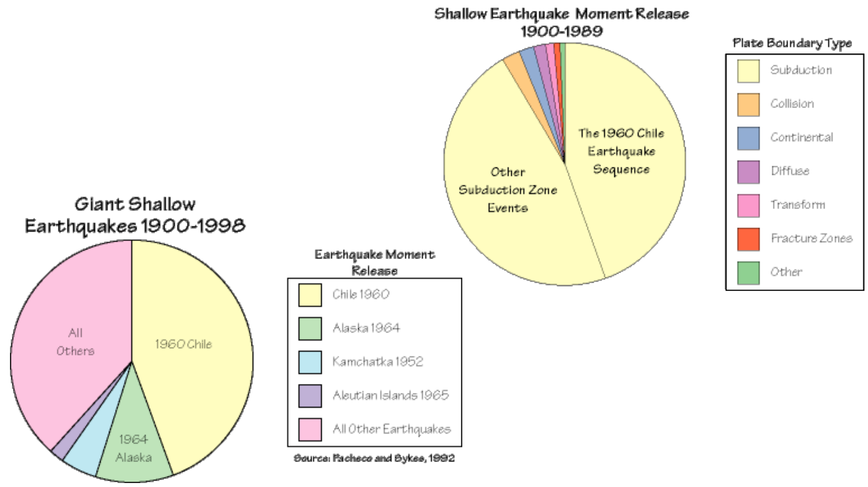
Moment magnitude versus rupture area



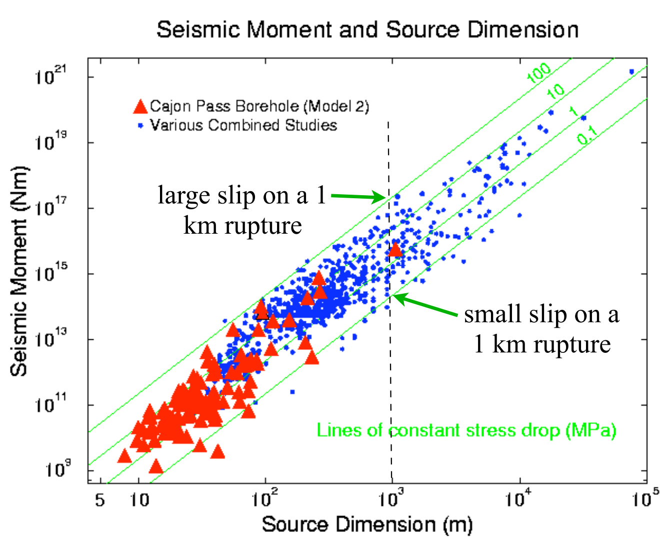
Wells and Coppersmith, 1994

Slip (s) scales with rupture length too, and $M_o = GsA$. Therefore M_o is proportional to L^3 (for small quakes) or L^2W (bigger ones)

Subduction zone earthquakes release most of the Earth's elastic strain energy



Shear stress drop $\Delta\tau$ seems insensitive to magnitude



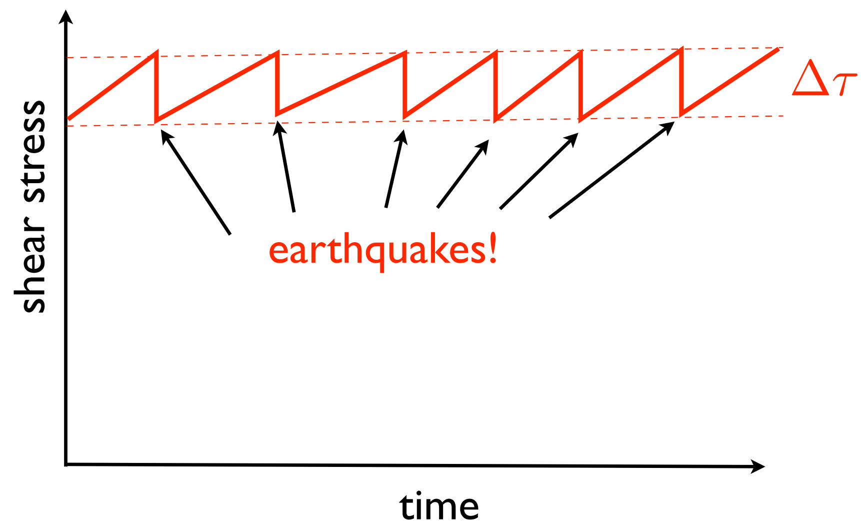
typical $\Delta\tau$ is 1 to 10 MPa

$\Delta\tau$ is proportional to slip/L

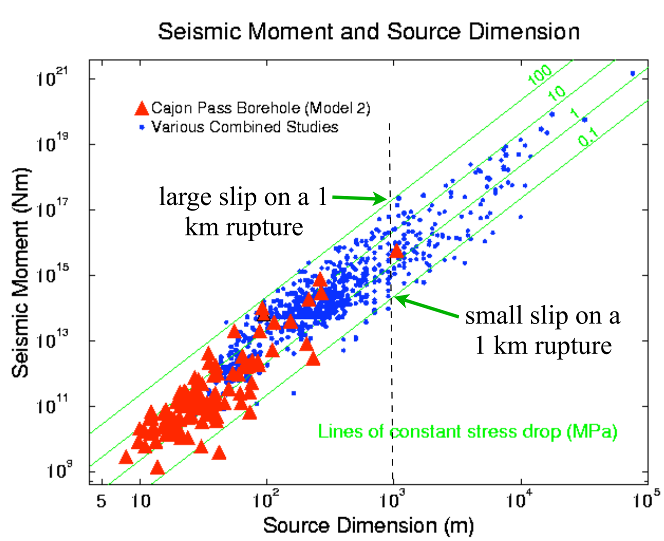
typical $\Delta\tau$ is 1 to 10 MPa

in a large earthquake, this stress drop occurs over a larger area

$\Delta\tau$ can be spatially variable



A range of slip values are possible for a given rupture size - this controls $\Delta\tau$



what is the range of average slip values for a M6 earthquake?

what is the range magnitudes for an earthquake rupture that is about 1 km long?

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

$M_w = \log M_o/1.5 - 6.0333$

$M_o = AsG$