P-wave Shadow Zone

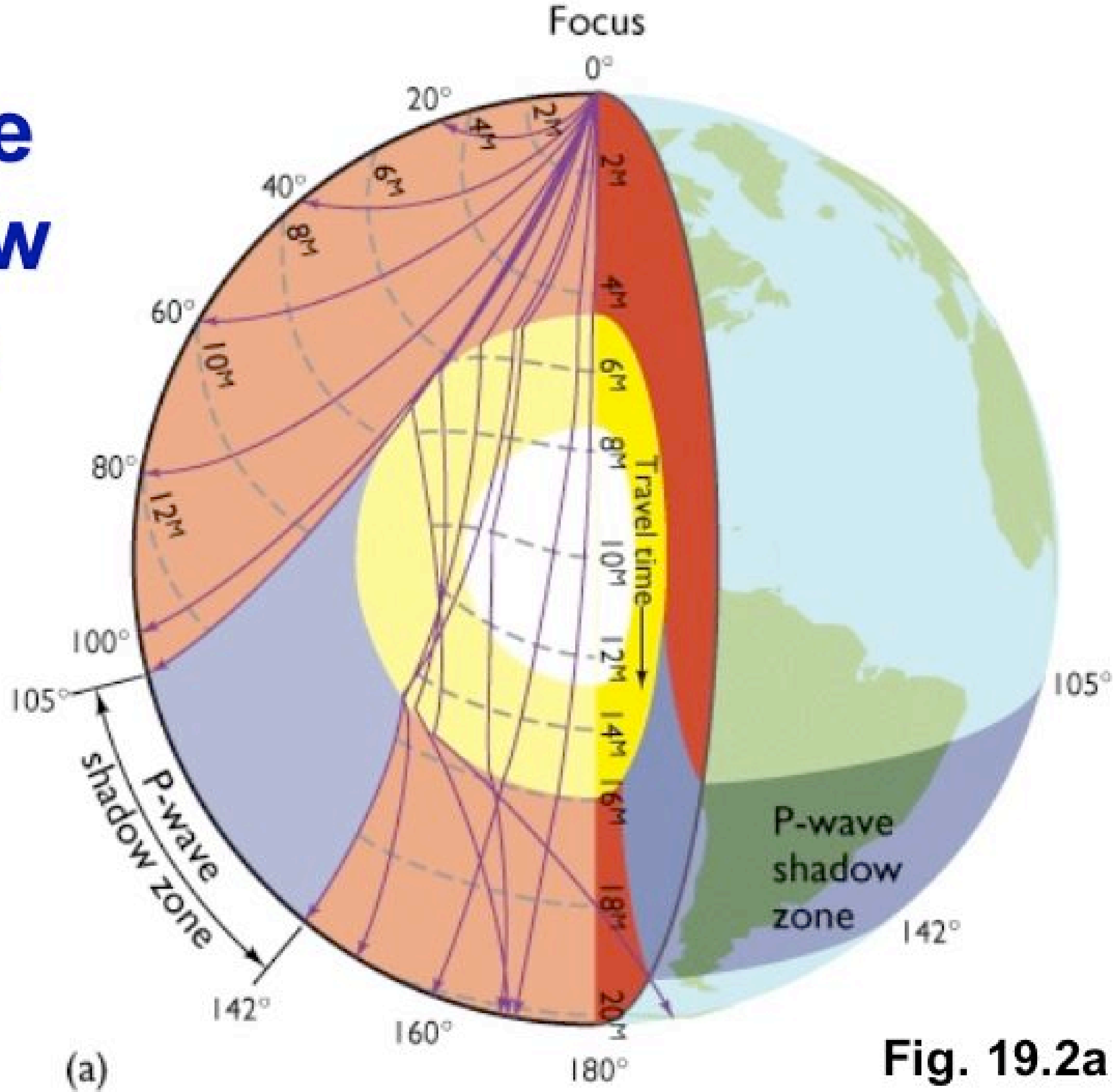


Fig. 19.2a

S-wave Shadow Zone

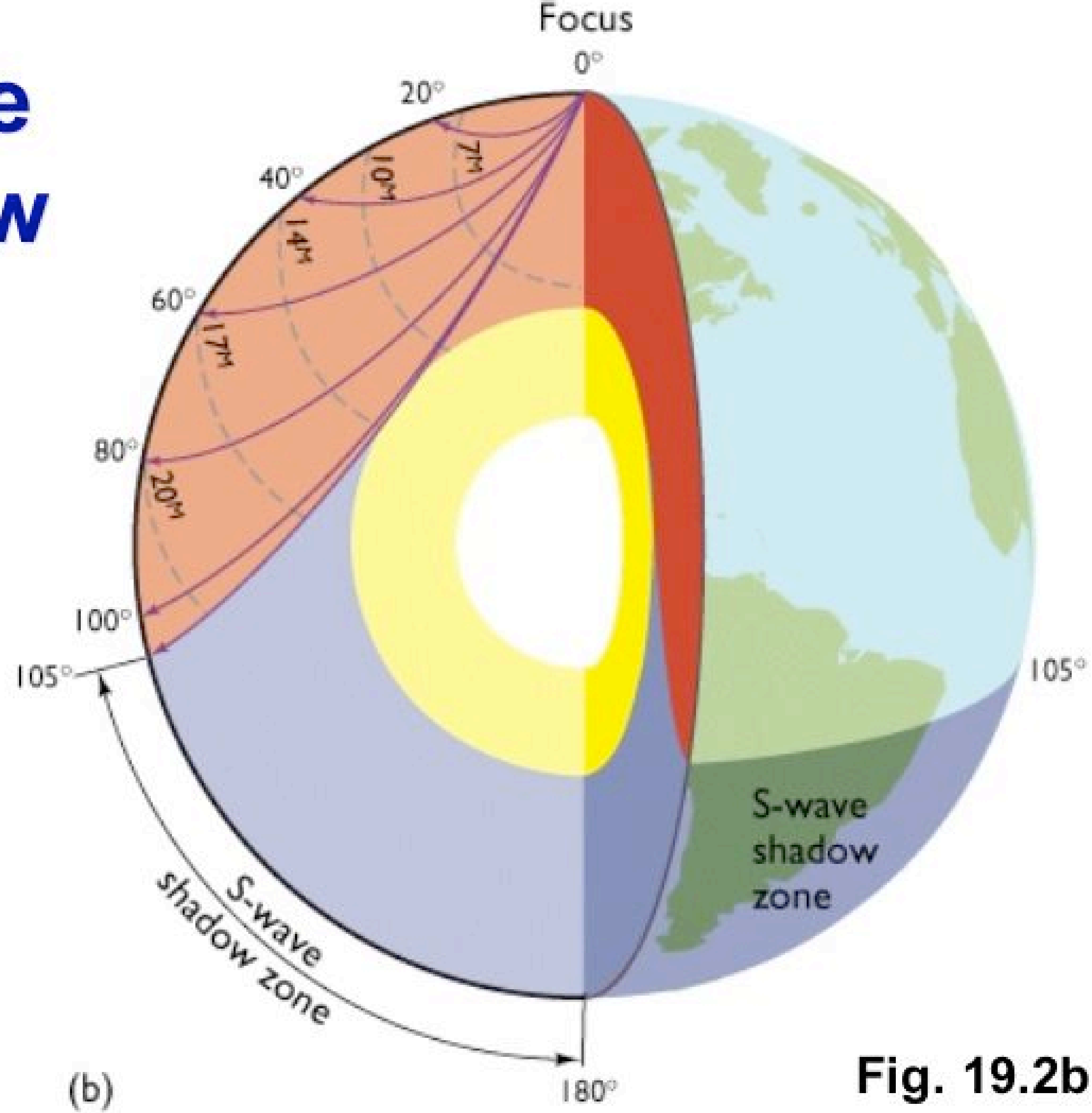


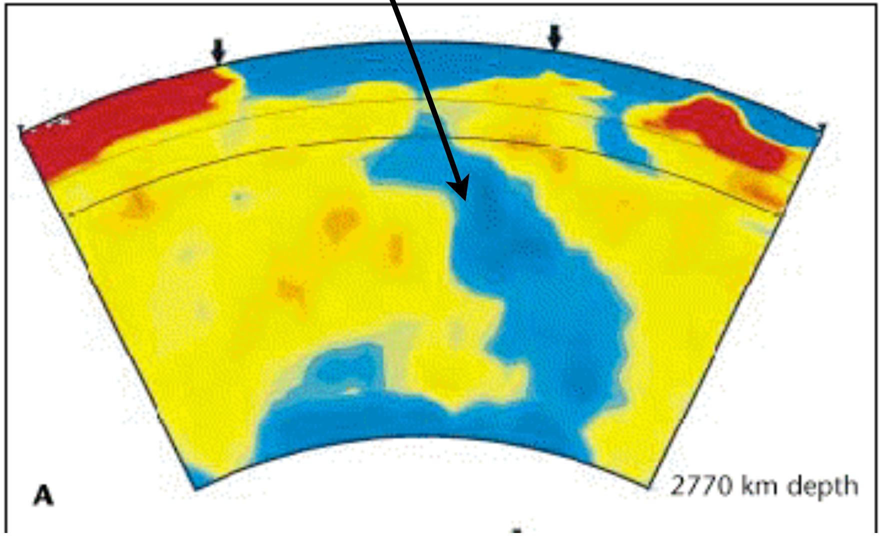
Fig. 19.2b

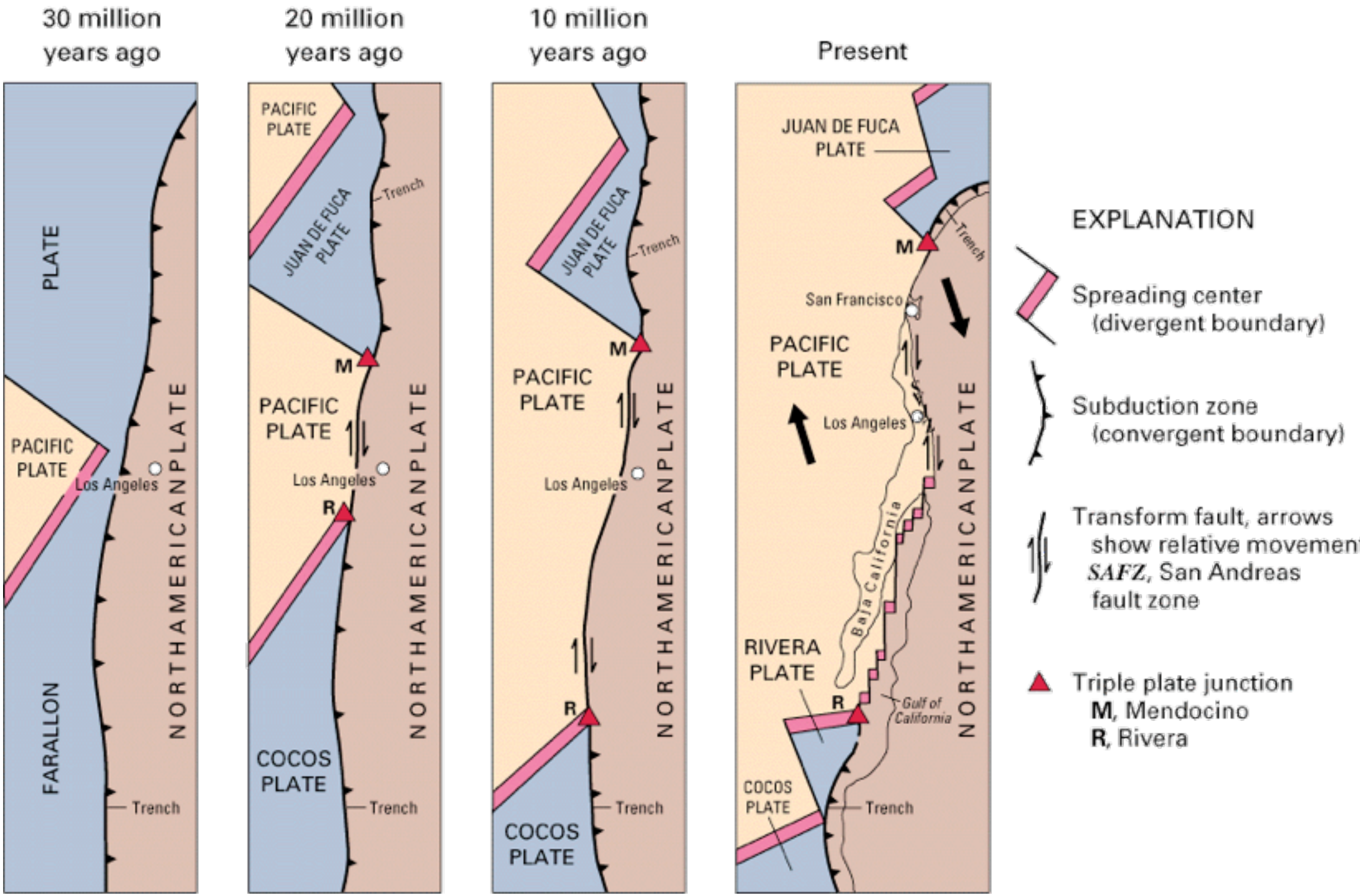
Here is a slice through North America showing the now-subducted Farallon Plate, sinking to the bottom of the mantle.

Red = slow (hot)

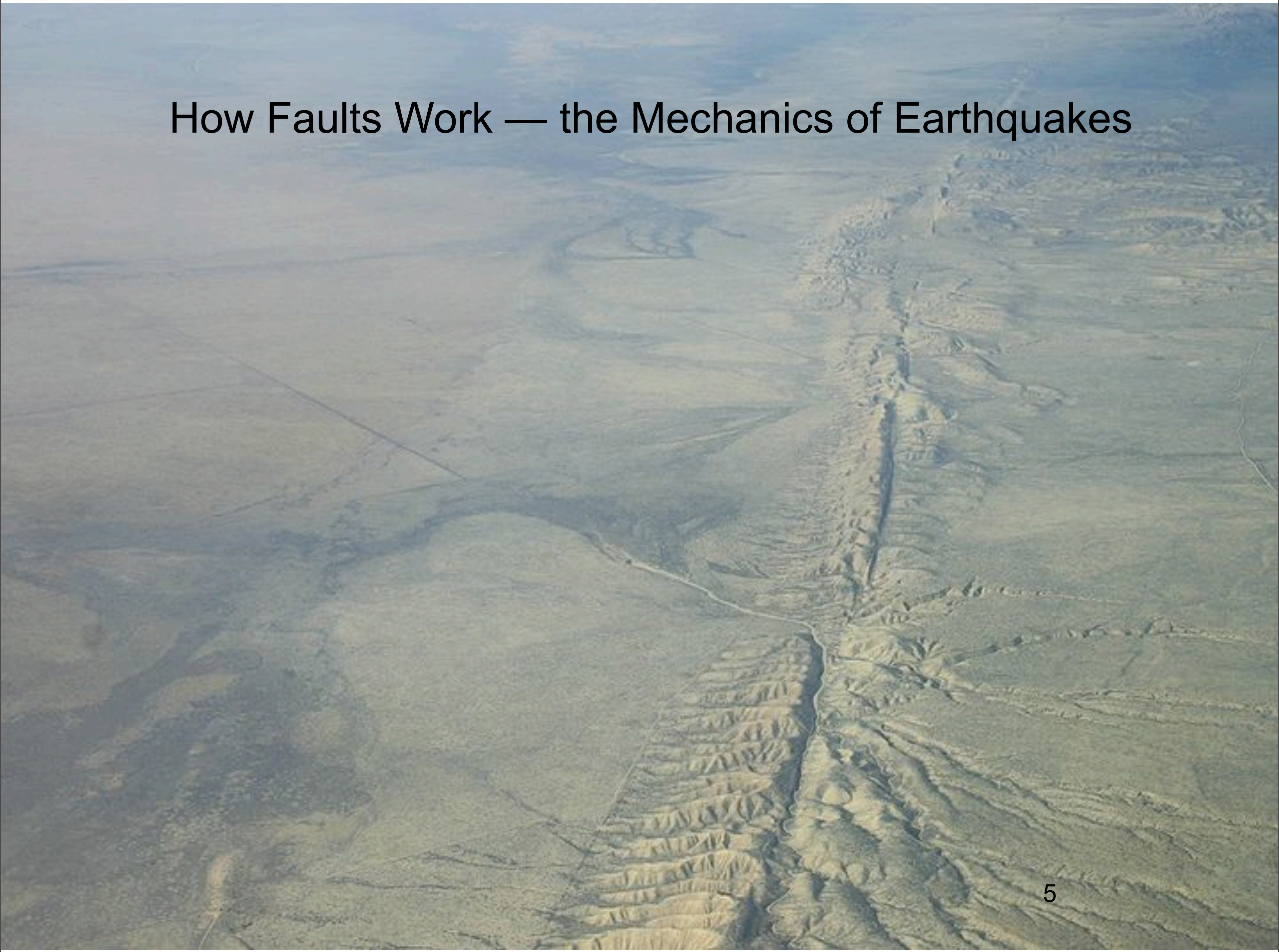
Blue = fast (cold)

Heating reduces rigidity more than it reduces density, so hotter materials have slower seismic velocities

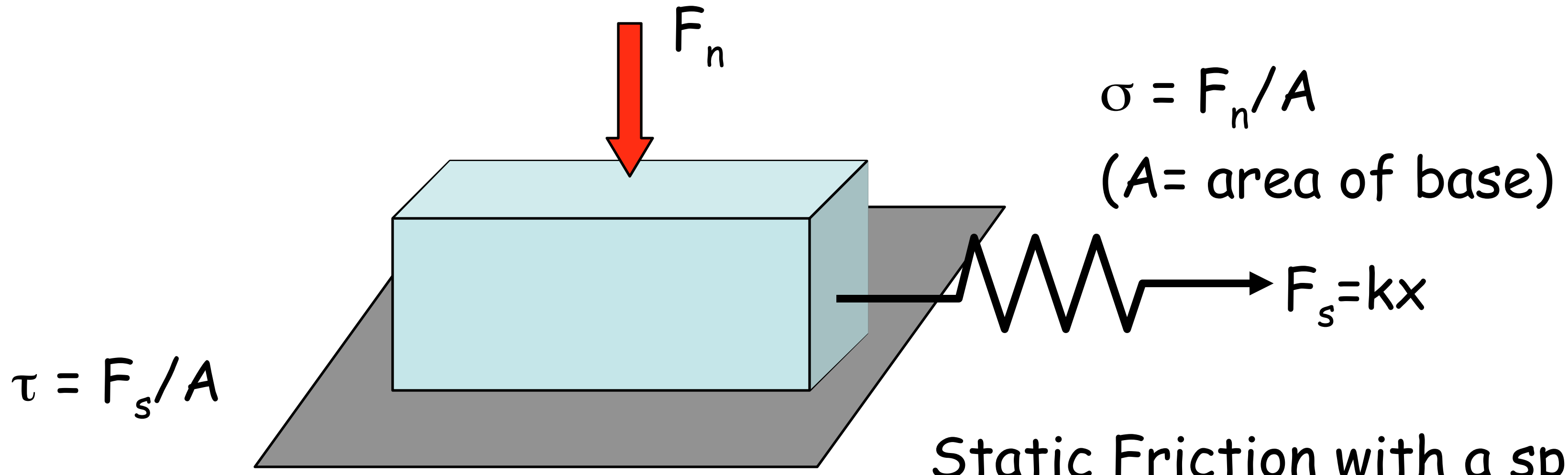



30 million years ago
20 million years ago
10 million years ago
Present
PLATE
FARALLON
PACIFIC PLATE
Los Angeles
Trench
NORTHAMERICANPLATE
JUAN DE FUCA PLATE
M
R
COCOS PLATE
San Francisco
RIVERA PLATE
Baja California
Gulf of California
EXPLANATION
Spreading center (divergent boundary)
Subduction zone (convergent boundary)
Transform fault, arrows show relative movement
SAFZ, San Andreas fault zone
Triple plate junction
M, Mendocino
R, Rivera

How Faults Work — the Mechanics of Earthquakes



Why Earthquakes (stick-slip behavior)?

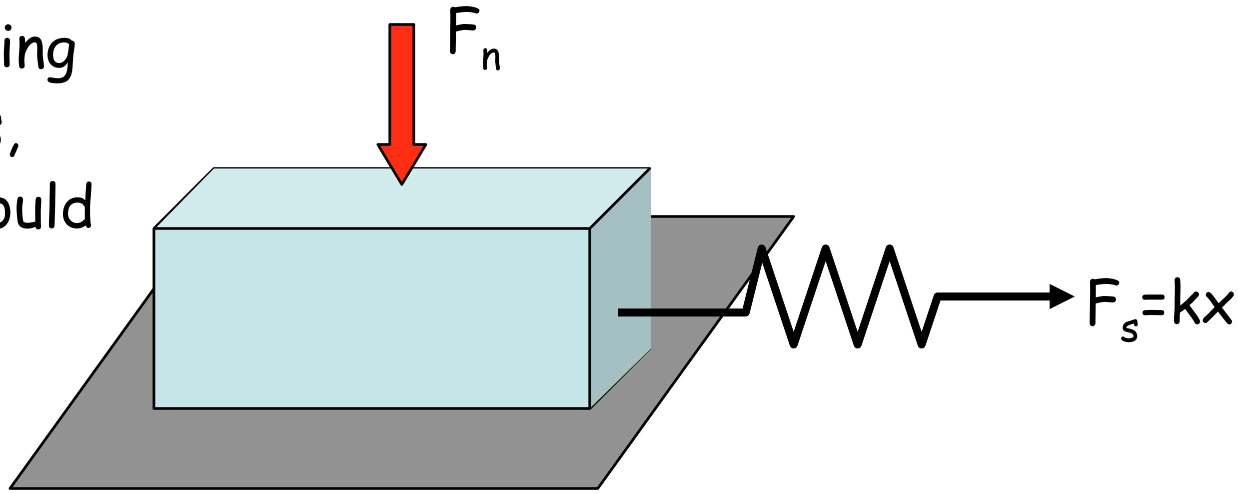


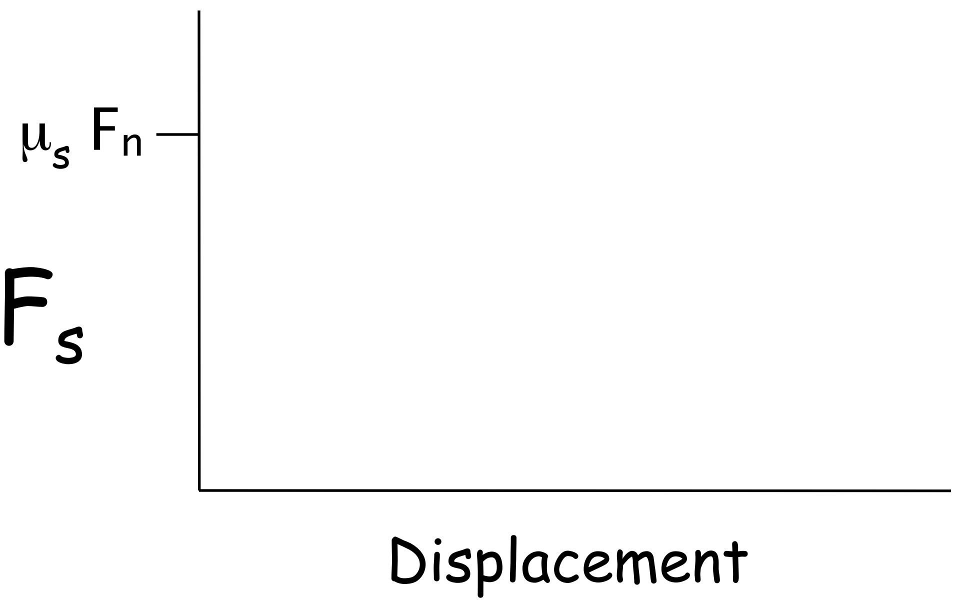
Static Friction with a spring

At time of sliding

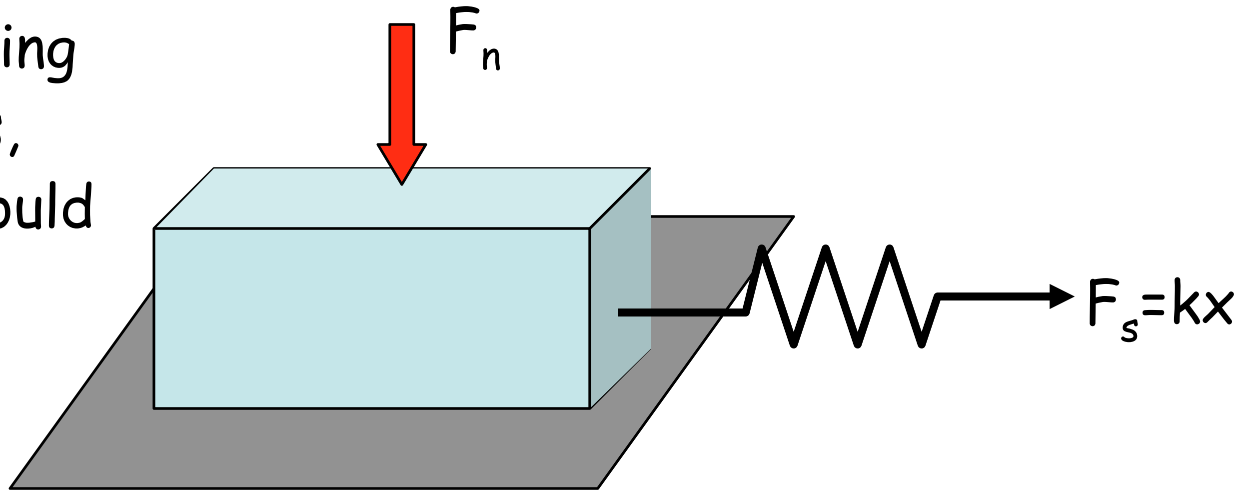
$\tau = \mu_s \sigma$, where μ_s is the static coefficient of friction

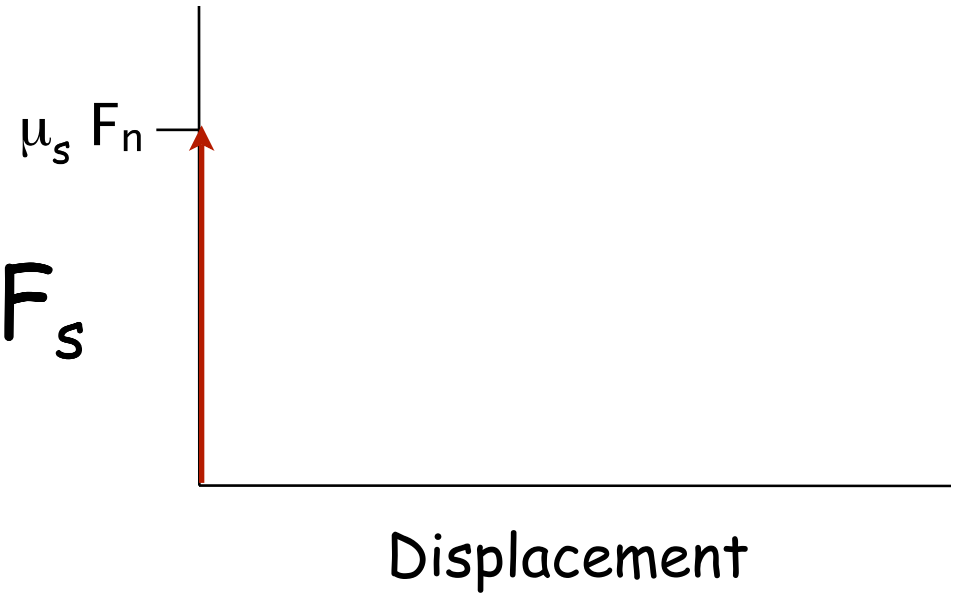
If friction was this simple — and if the applied forces, coming from plate motions, were constant — would we have stick-slip behavior?



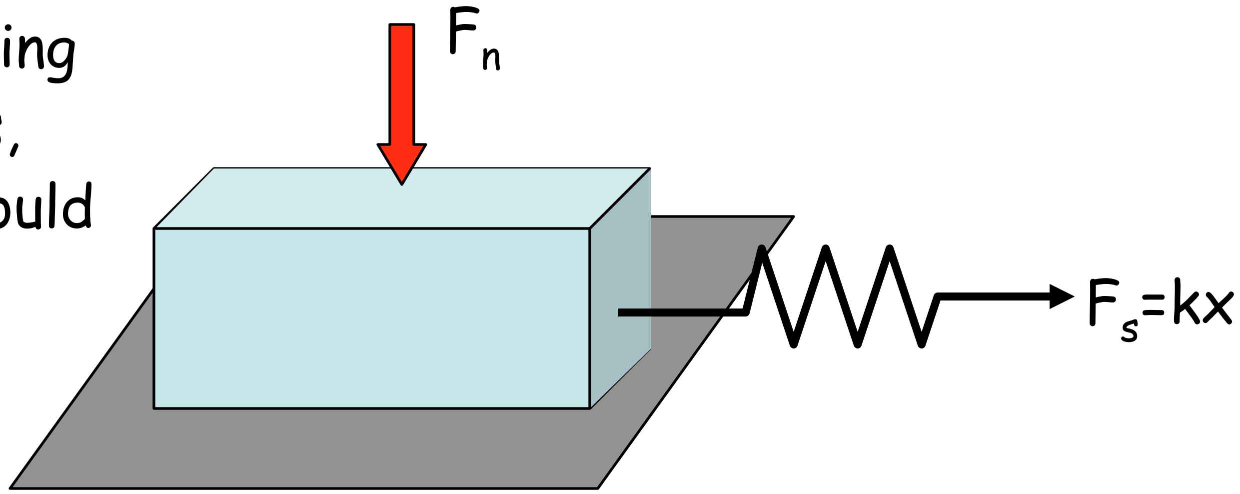


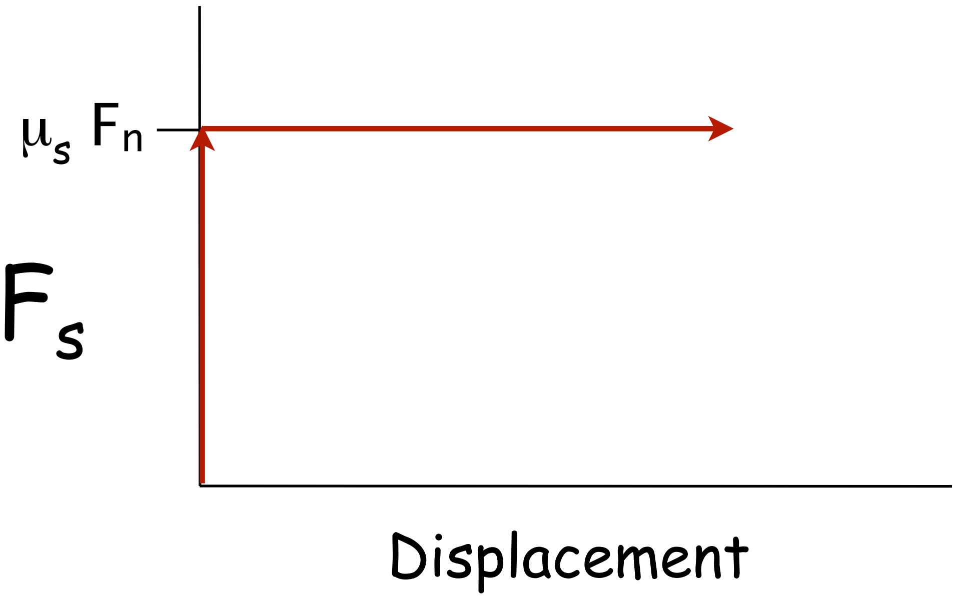
If friction was this simple — and if the applied forces, coming from plate motions, were constant — would we have stick-slip behavior?

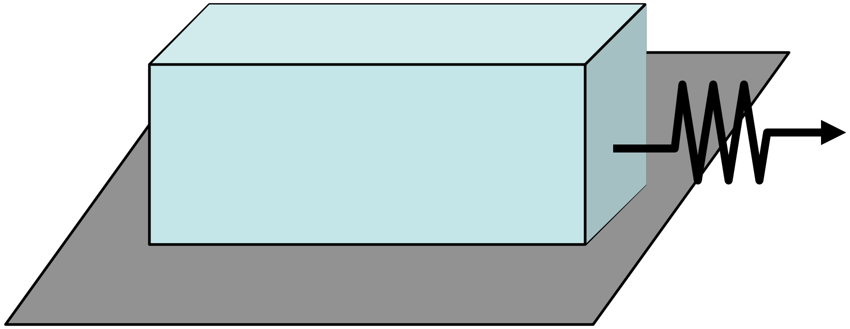




If friction was this simple — and if the applied forces, coming from plate motions, were constant — would we have stick-slip behavior?

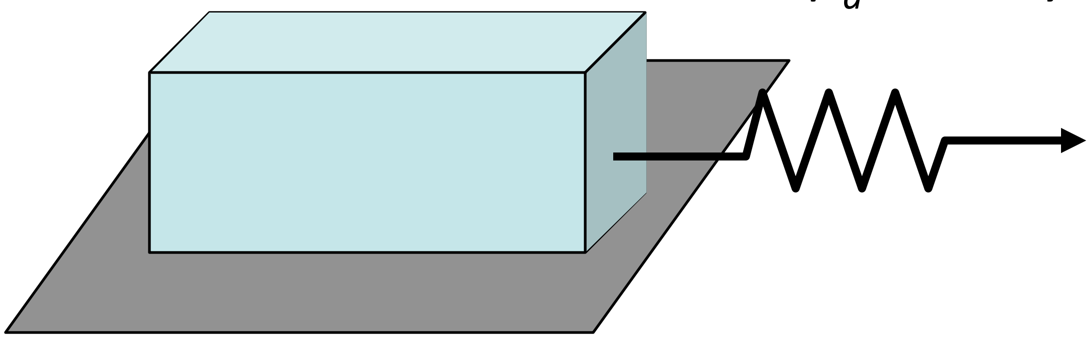




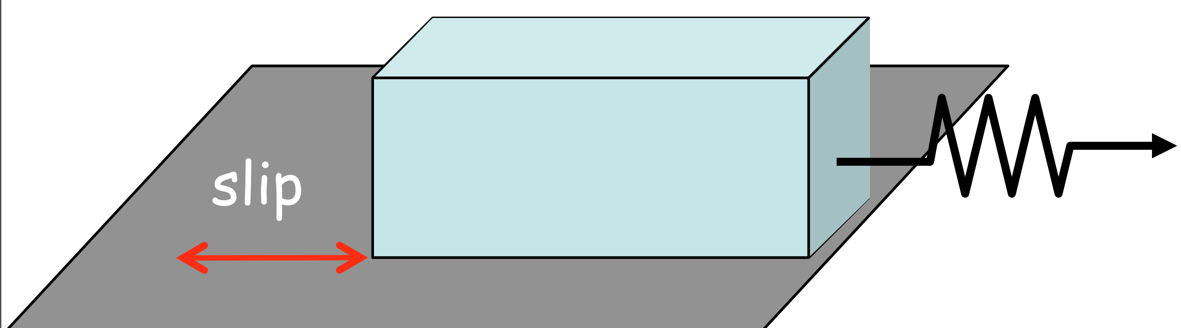


Of course, friction is NOT so simple — the coefficient of friction changes once sliding begins, and if $\mu_d < \mu_s$*, then we should see the idealized stick-slip behavior*

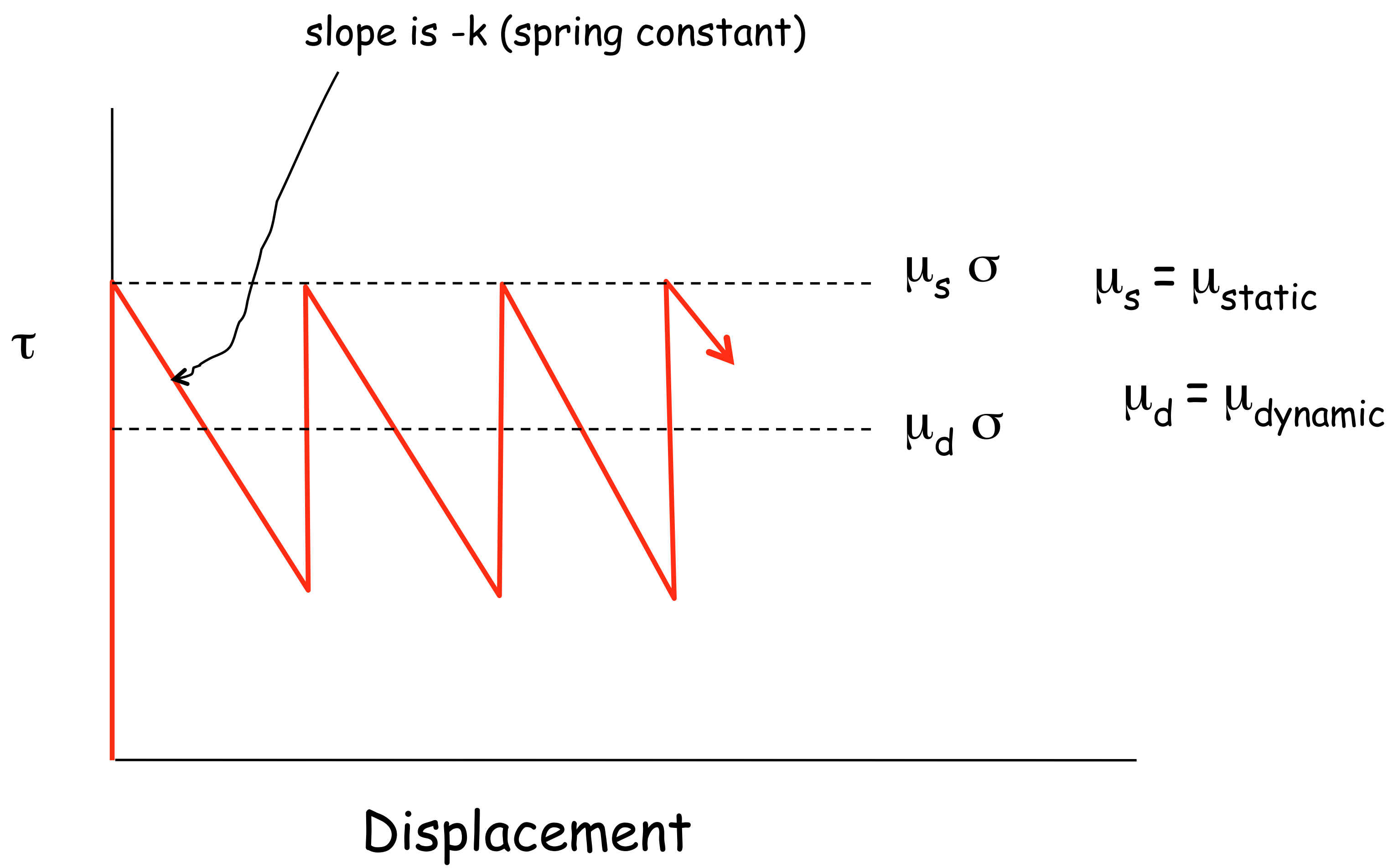
μ_d *is the dynamic coefficient of friction*



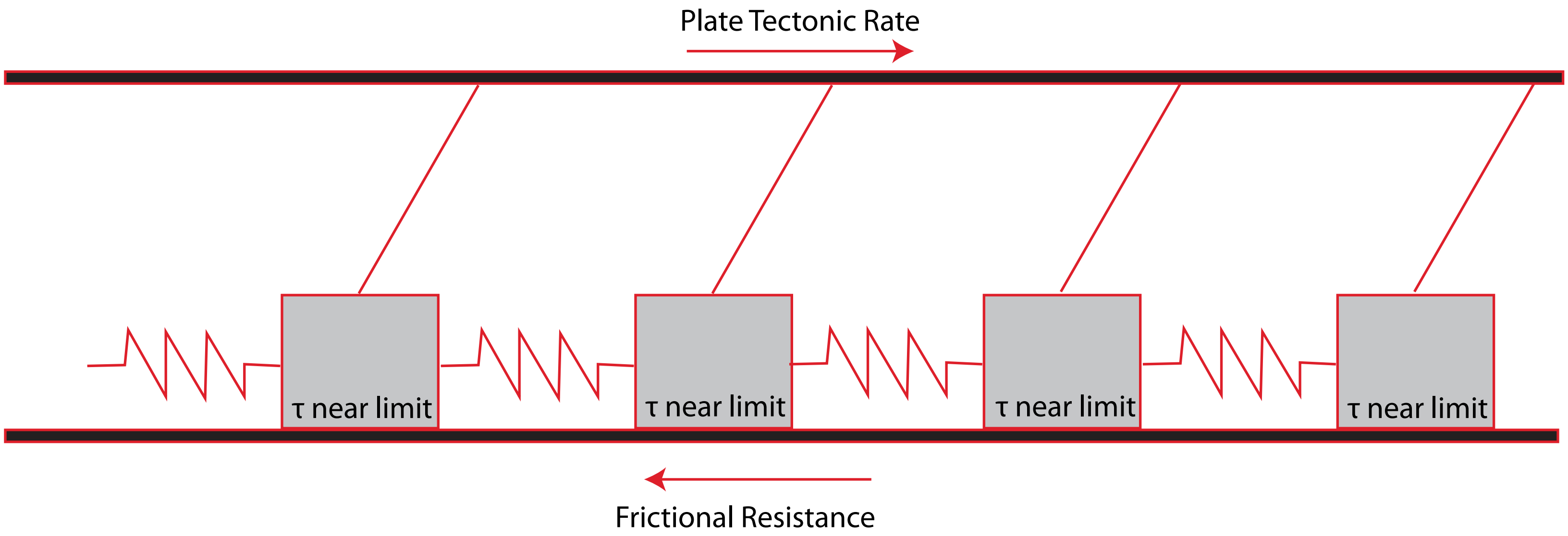
With reduced friction, the block catches up to the spring, lowering the shear stress τ*, bringing slip to an end.*



Idealized Stick-Slip Behavior



EQ Slip Model



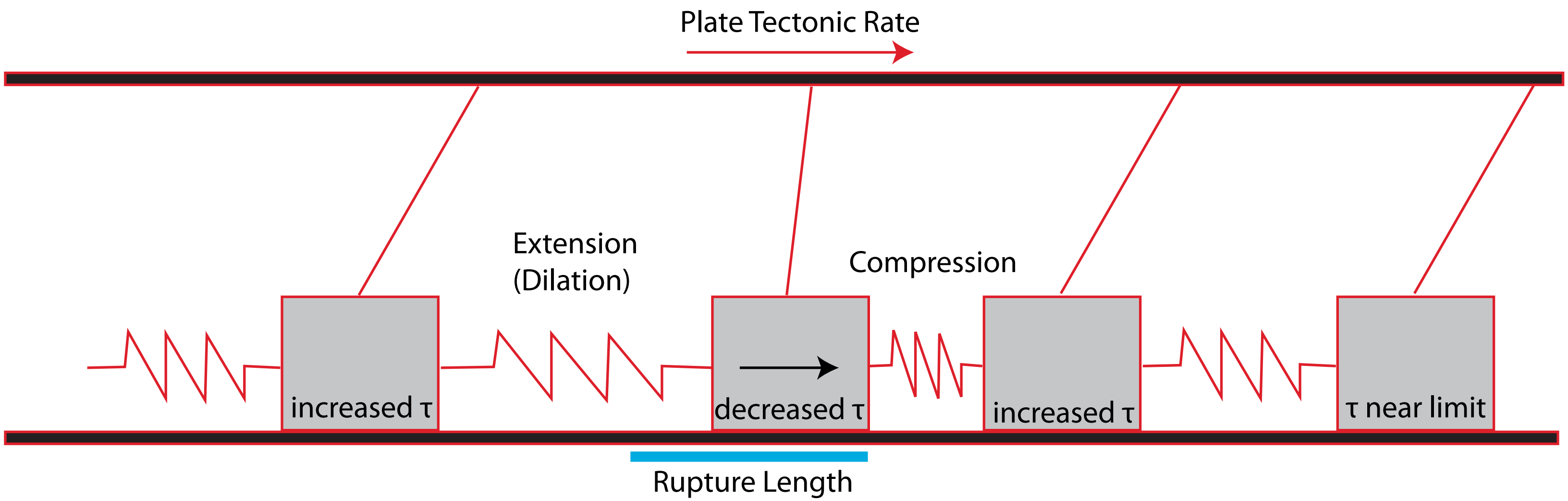
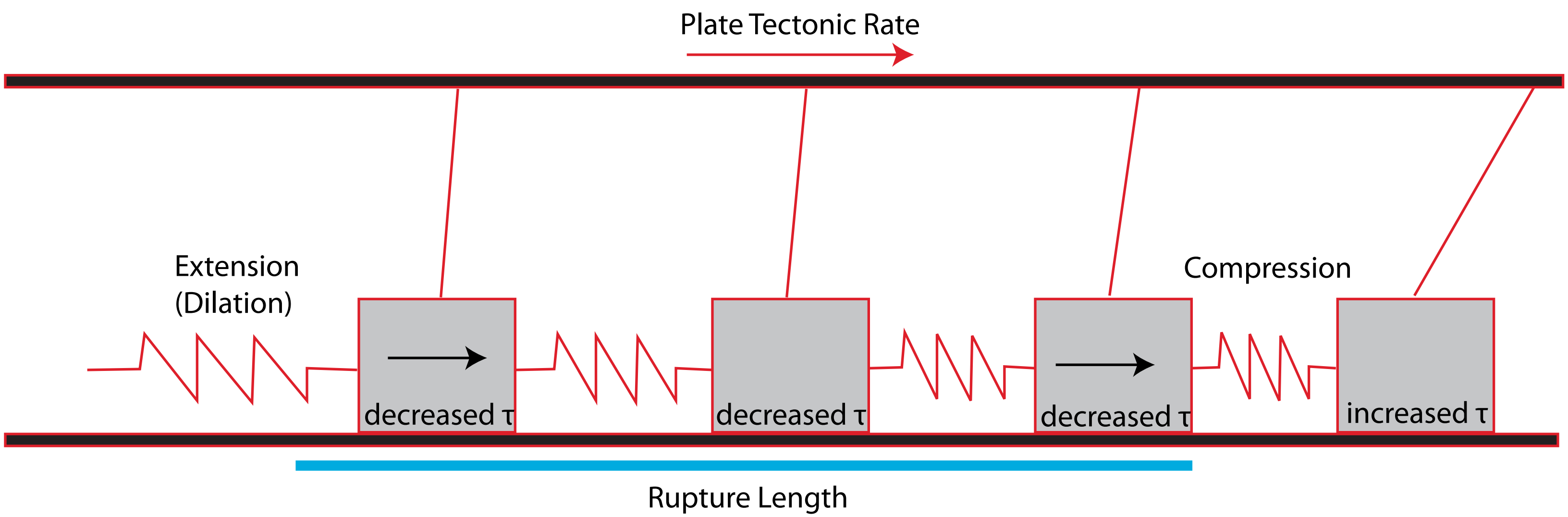


Plate Tectonic Rate
Extension
(Dilation)
Compression
increased τ
decreased τ
increased τ
τ near limit
Rupture Length



As the rupture grows, more energy is released and a larger magnitude earthquake results. If a big segment of the fault is right near the limit, a small rupture can take off and grow into a huge rupture and a huge earthquake

Idealized Stick-Slip Behavior

This is equivalent to the "re-loading" time
if we assume that the tectonic driving forces
are applied at a steady rate

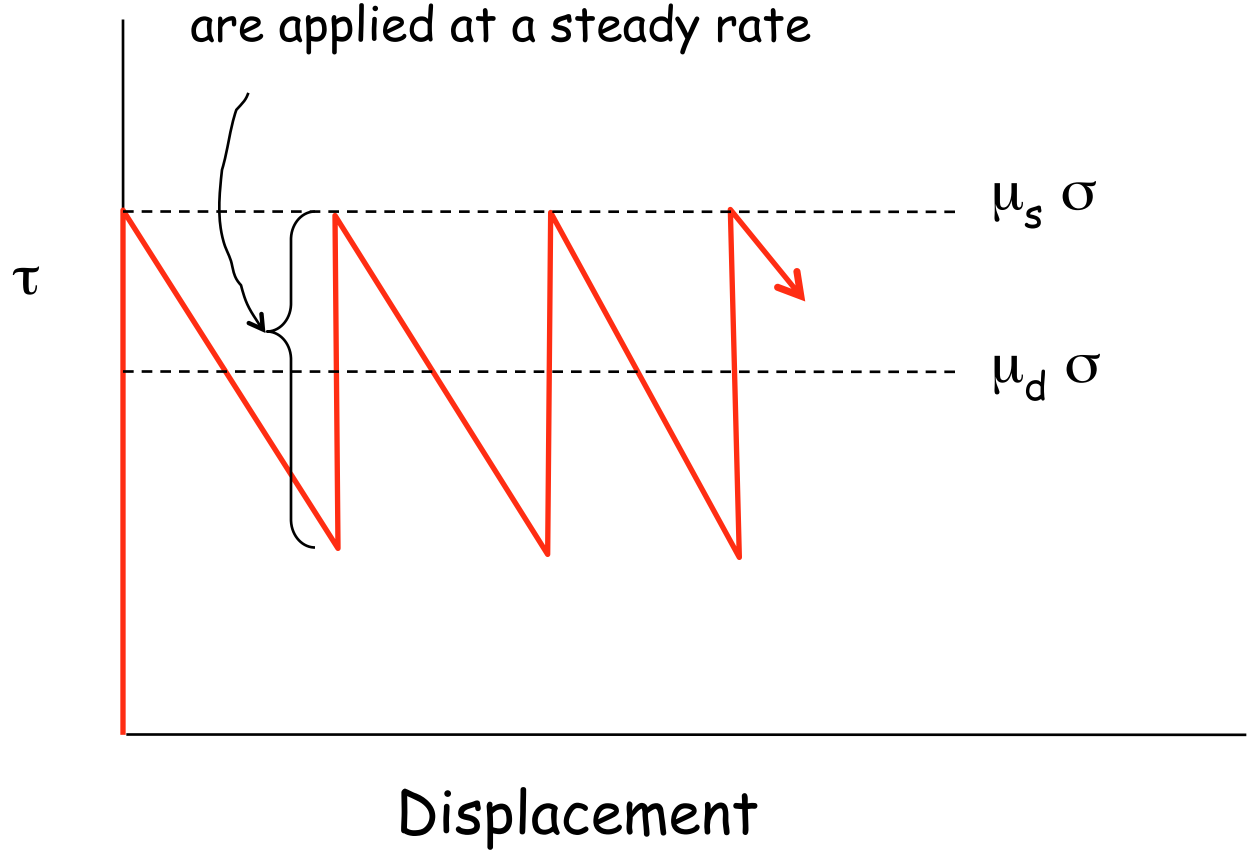
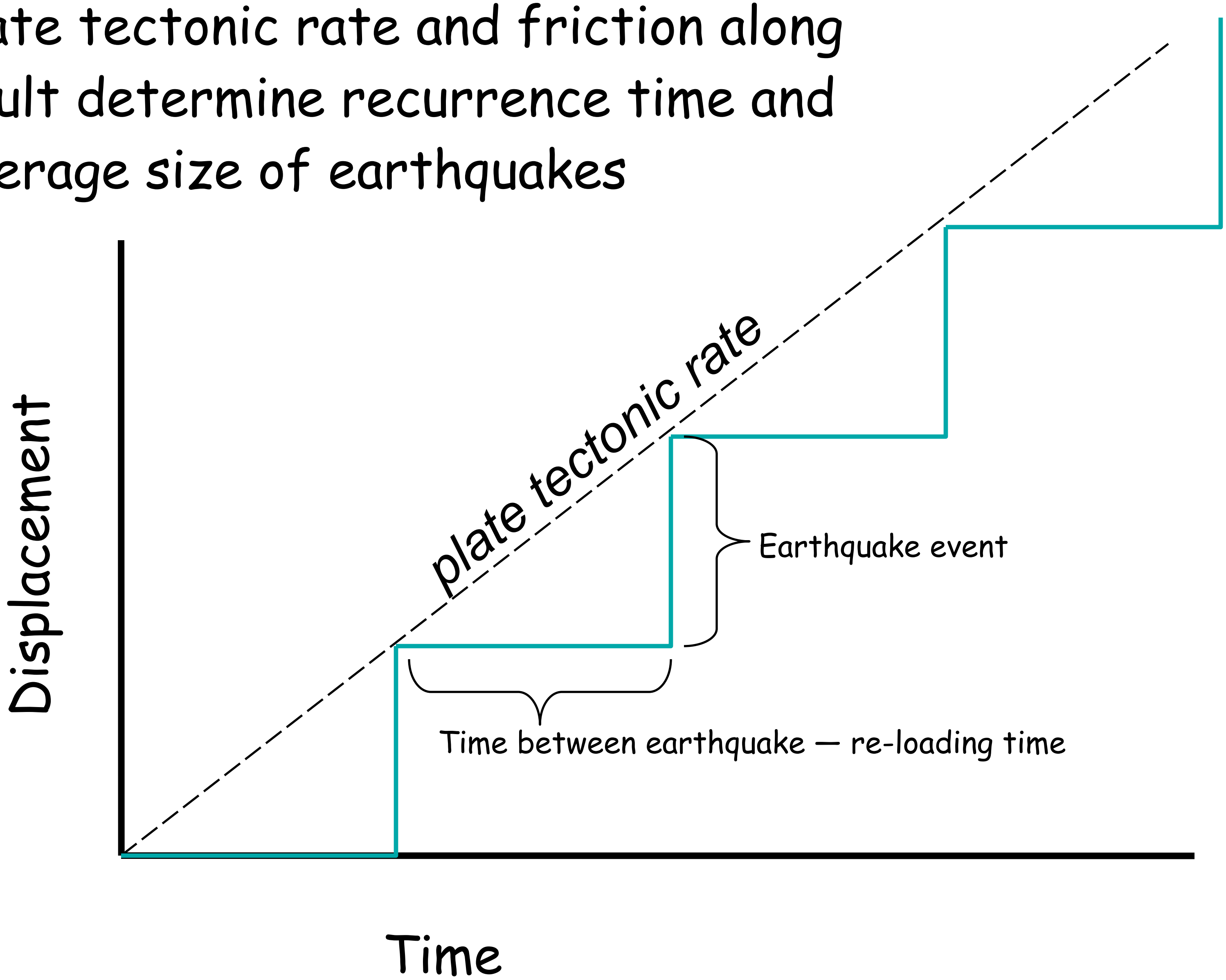
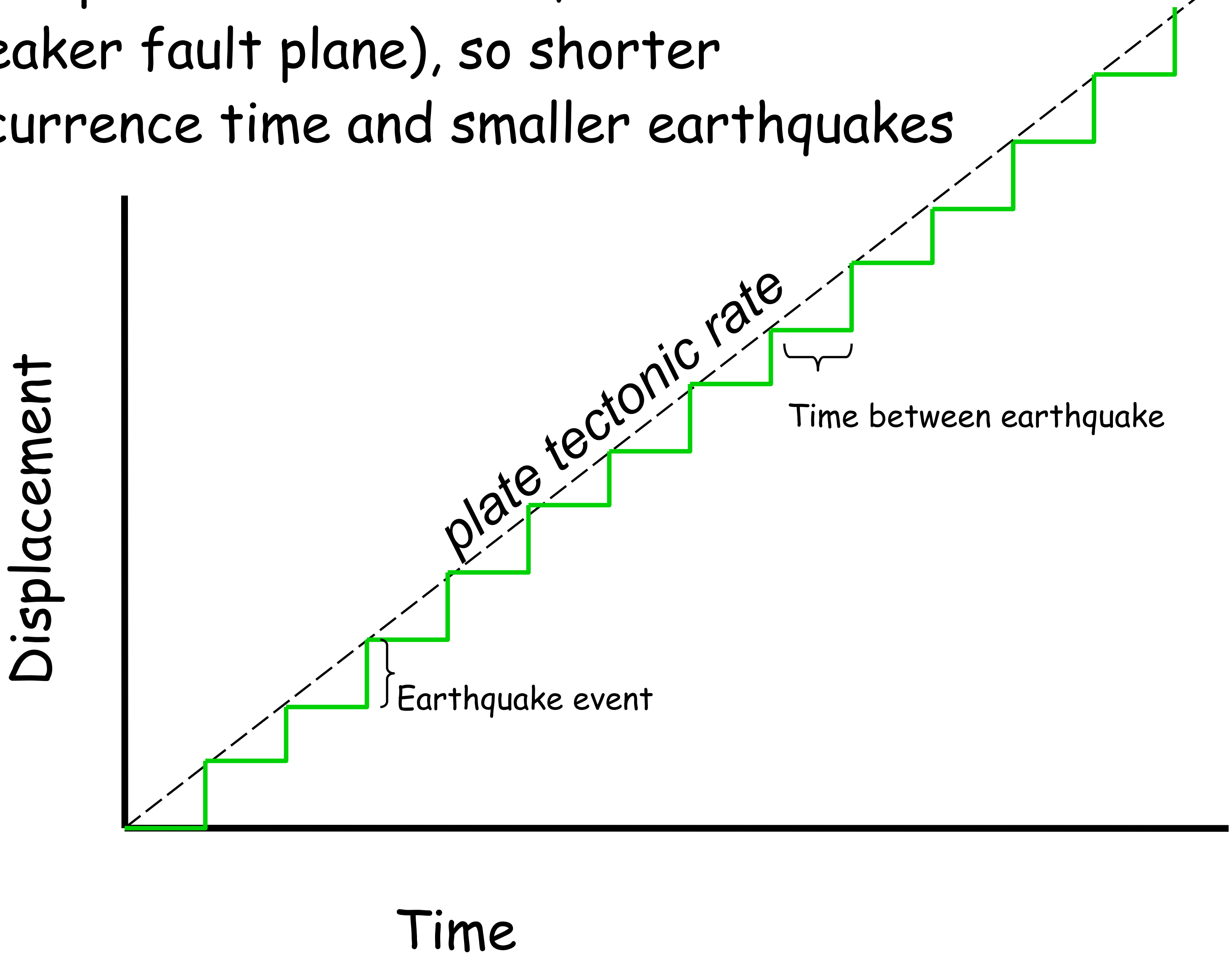


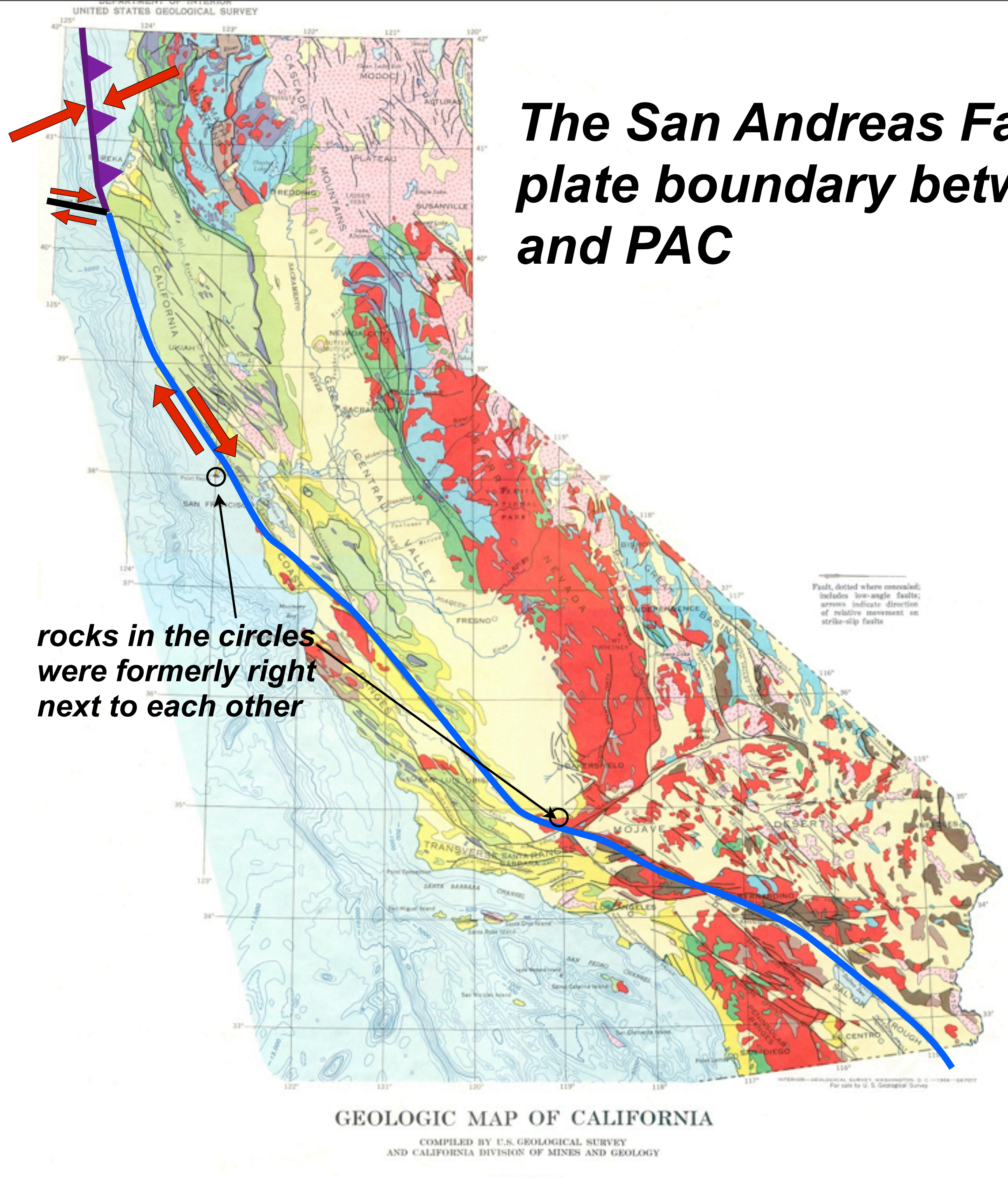
Plate tectonic rate and friction along fault determine recurrence time and average size of earthquakes



Same plate tectonic rate, but low friction (weaker fault plane), so shorter recurrence time and smaller earthquakes

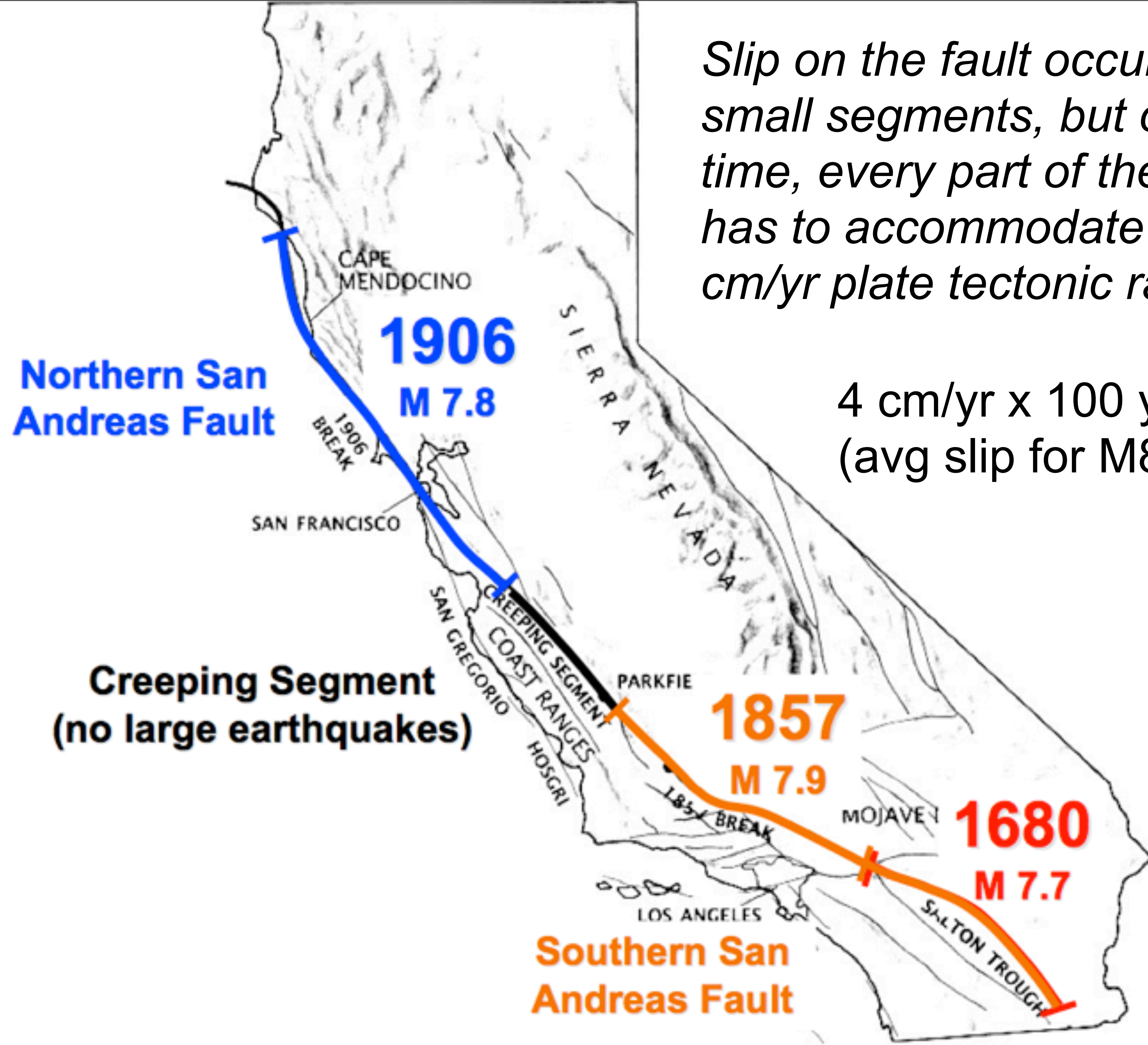


The San Andreas Fault is the plate boundary between NAM and PAC



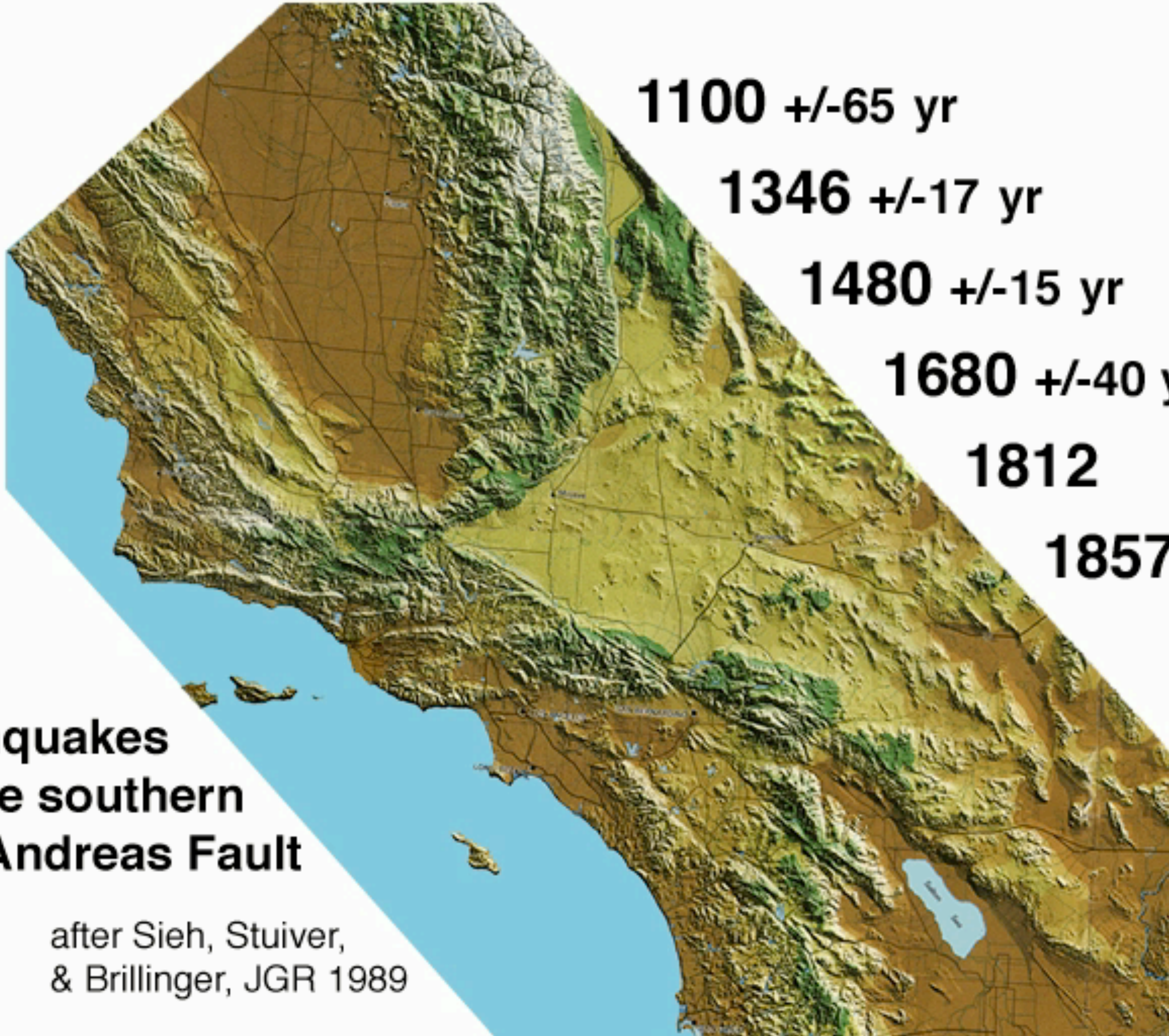
Slip on the fault occurs in small segments, but over time, every part of the fault has to accommodate the 4 cm/yr plate tectonic rate

4 cm/yr x 100 yr = 4 m
(avg slip for M8 EQ)



Characteristics of Earthquake Ruptures

Magnitude	Average Slip	Rupture Length	Rupture Area	Relative Frequency
8	4m	100km	10^4 km^2	N/yr
7	1m	30km	10^3 km^2	10 N/yr
6	40cm	10km	10^2 km^2	10^2 N/yr
5	10cm	3km	10 km^2	10^3 N/yr
4	4cm	1km	1 km^2	10^4 N/yr
3	1cm	300m	10^5 m^2	10^5 N/yr
2	4mm	100m	10^4 m^2	10^6 N/yr
1	1mm	30m	10^3 m^2	10^7 N/yr



1100 +/-65 yr

1346 +/-17 yr

1480 +/-15 yr

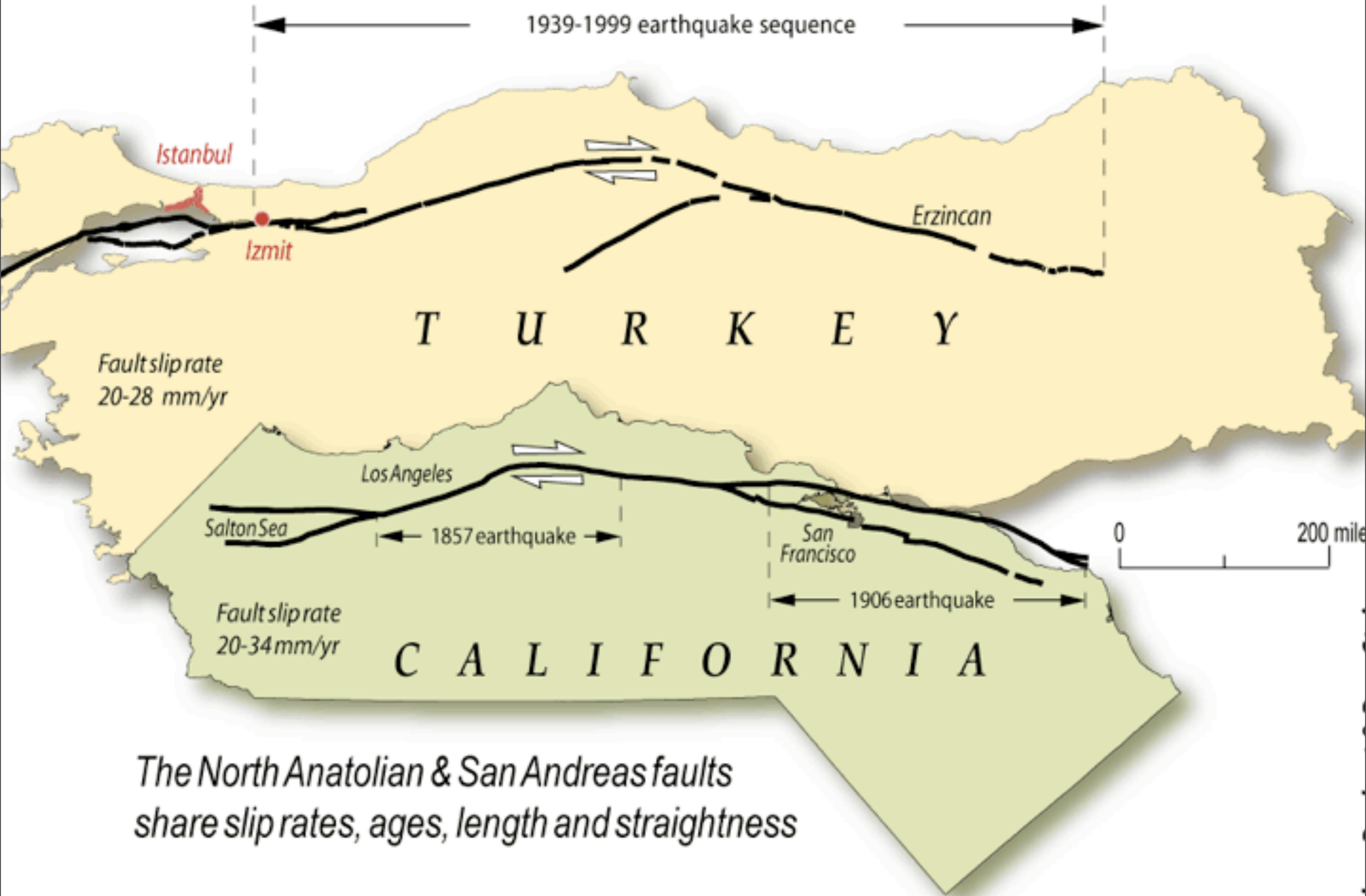
1680 +/-40 yr

1812

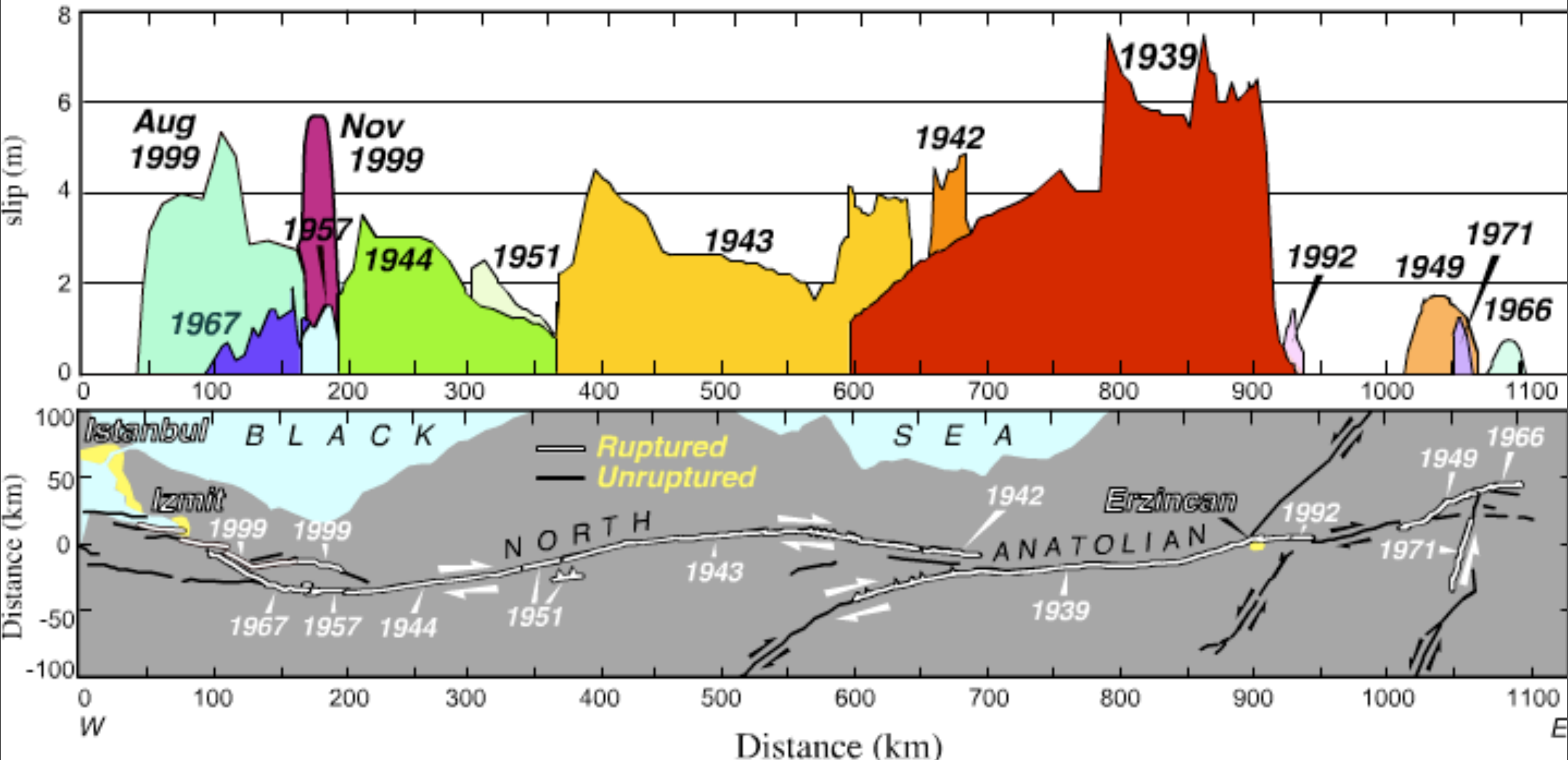
1857

Earthquakes on the southern San Andreas Fault

after Sieh, Stuiver, & Brillinger, JGR 1989



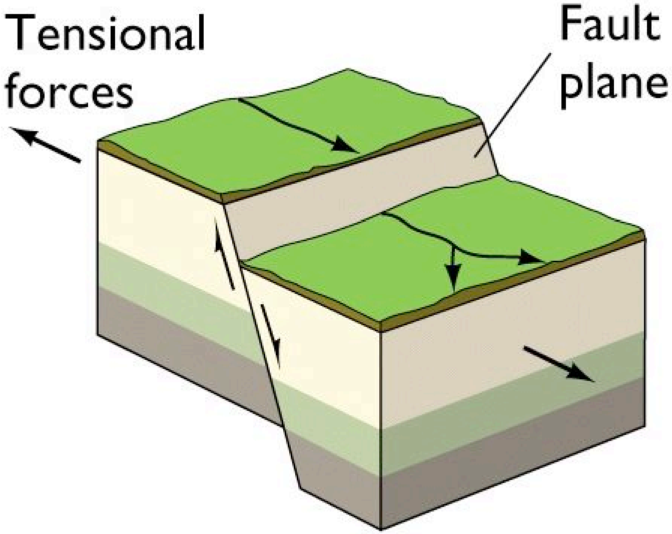
The North Anatolian & San Andreas faults share slip rates, ages, length and straightness



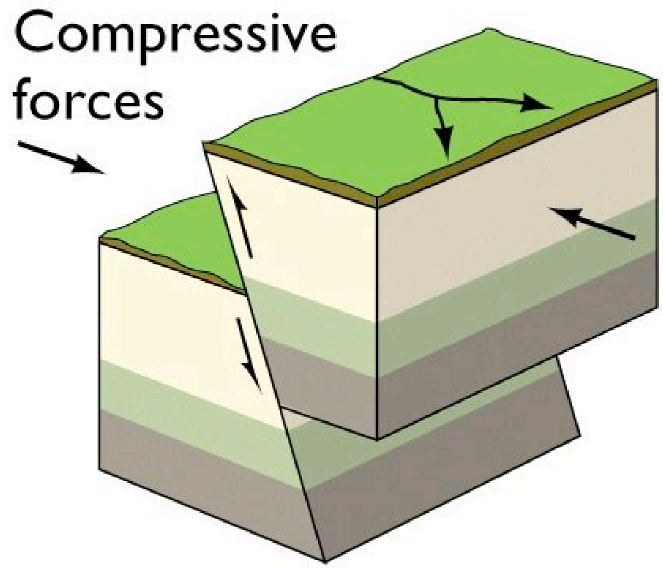
Replay animation

Animation by Rachel Margrett, Ross Stein and Serkan Bozkurt , US Geological Survey
For other animations see our website at: http://quake.wr.usgs.gov/~ross

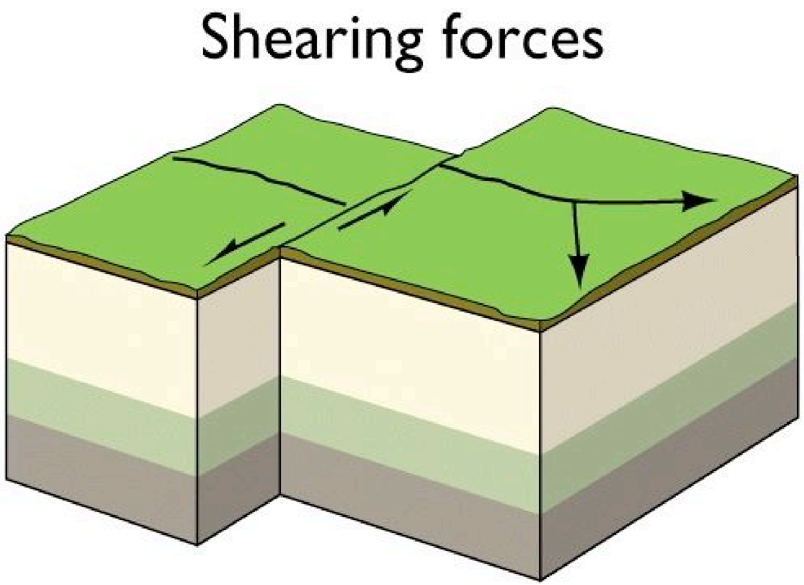
Normal Fault



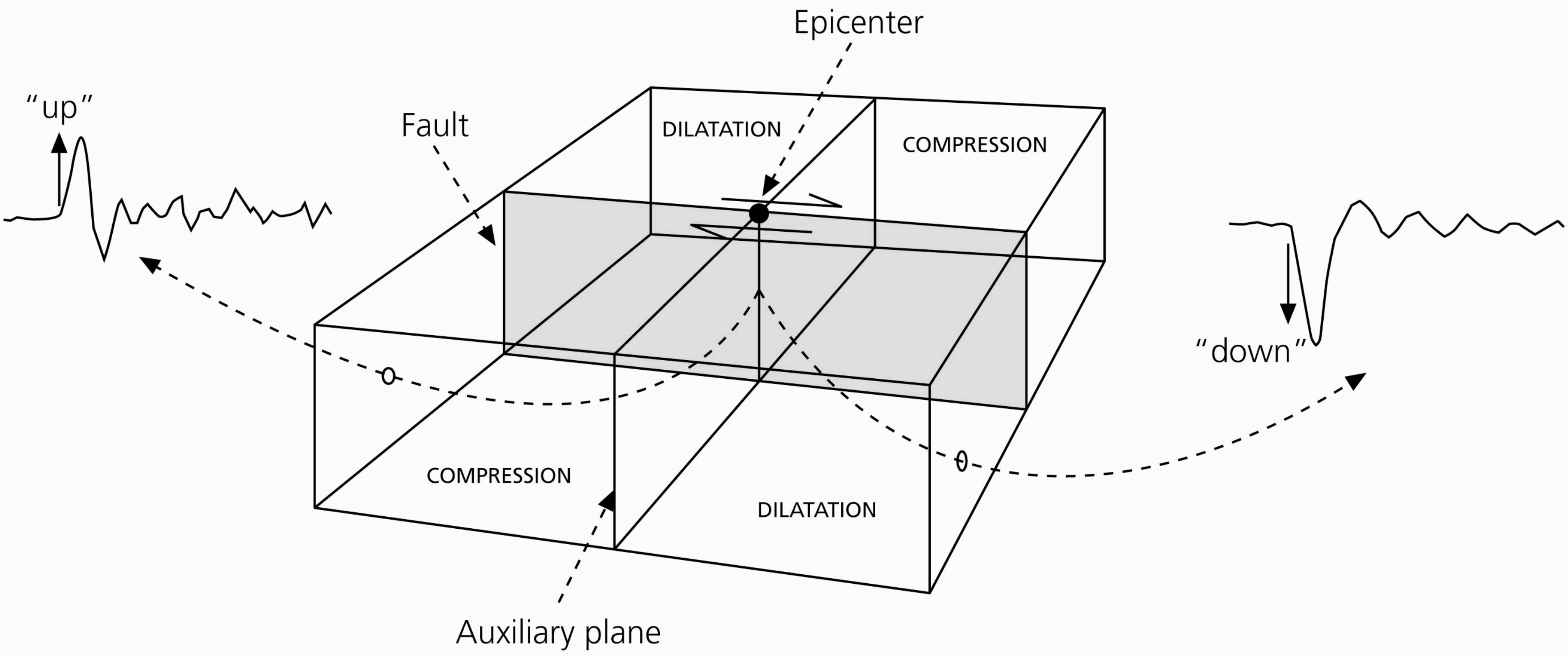
Thrust (reverse) Fault



Strike-slip Fault



First-Motion or Focal Mechanism Solution Provides Orientation of Fault Plane and Sense of Motion



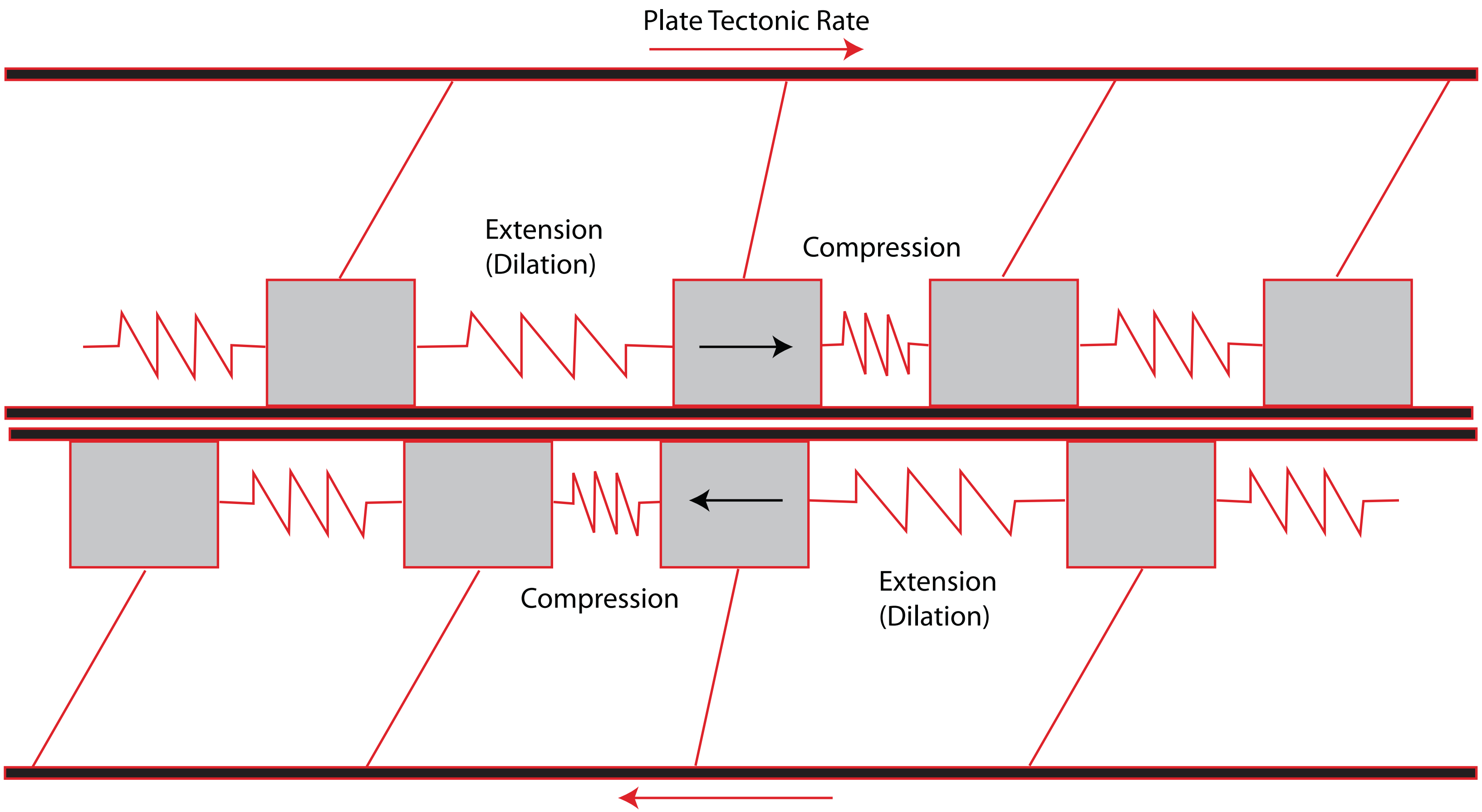
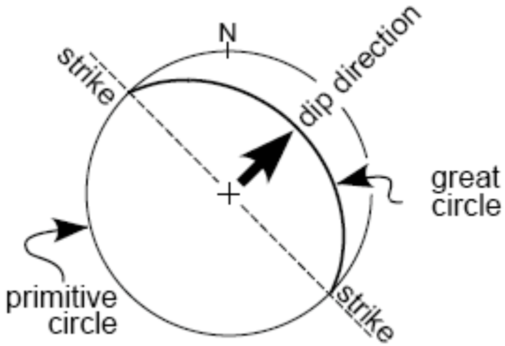
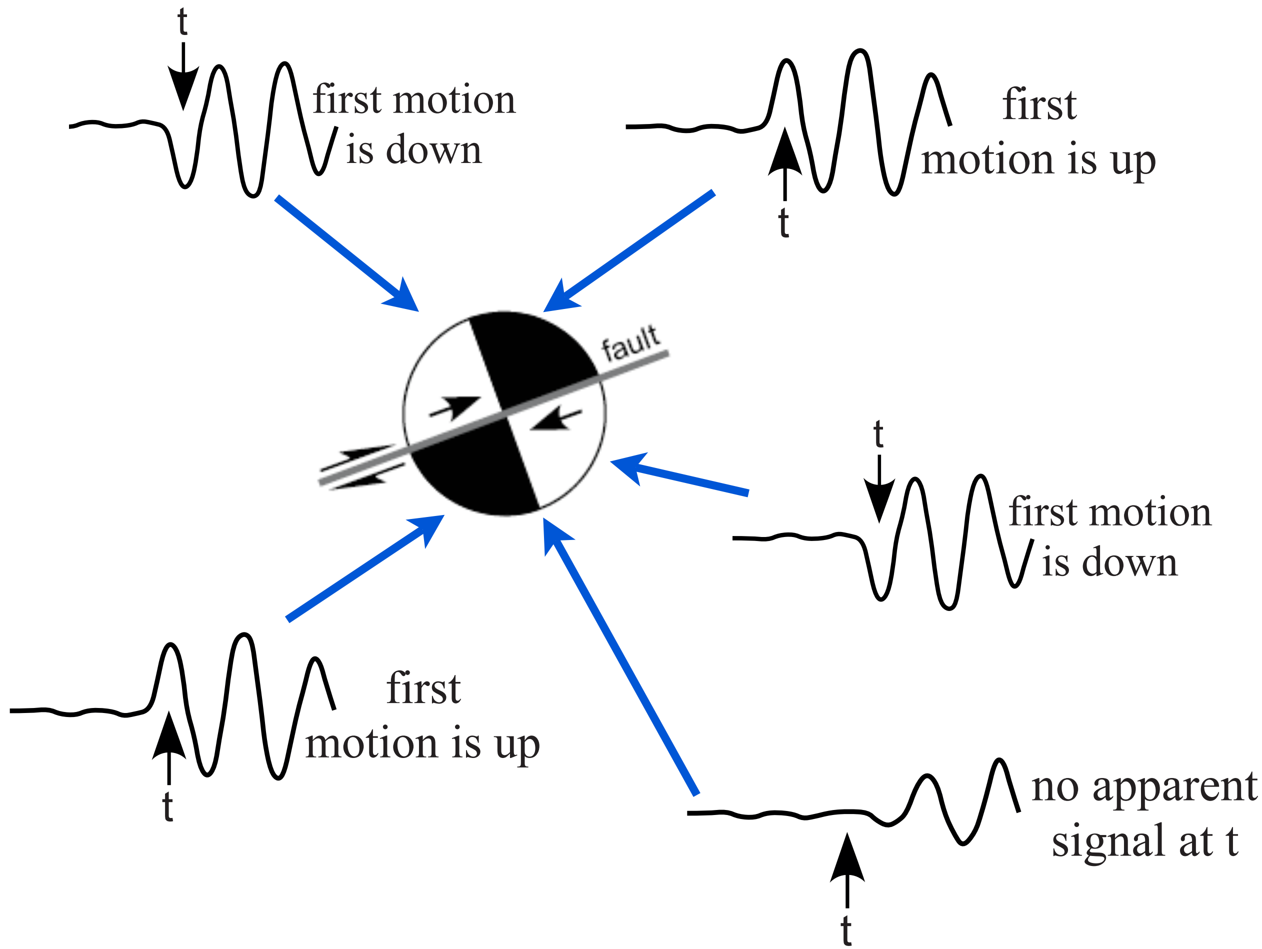
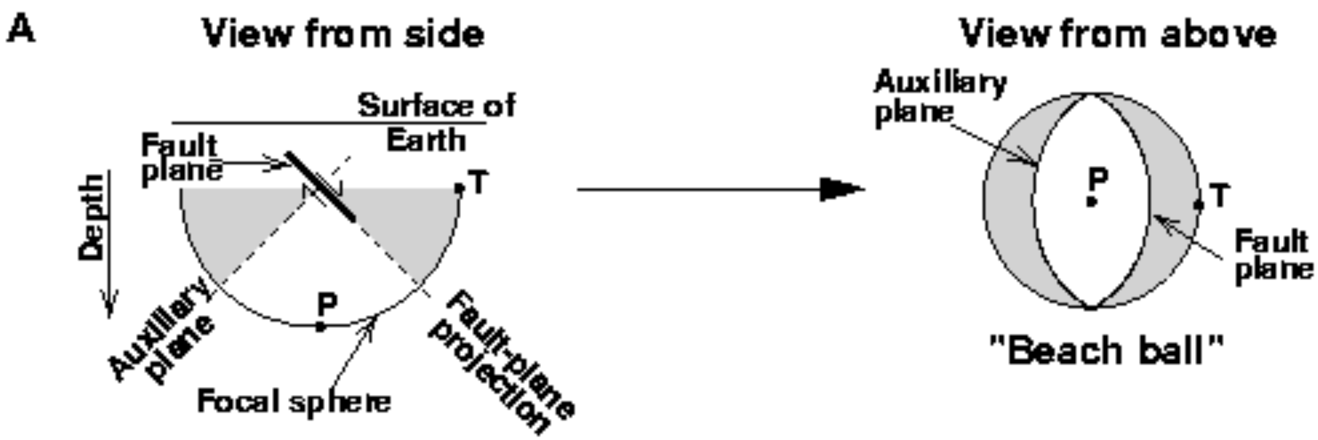


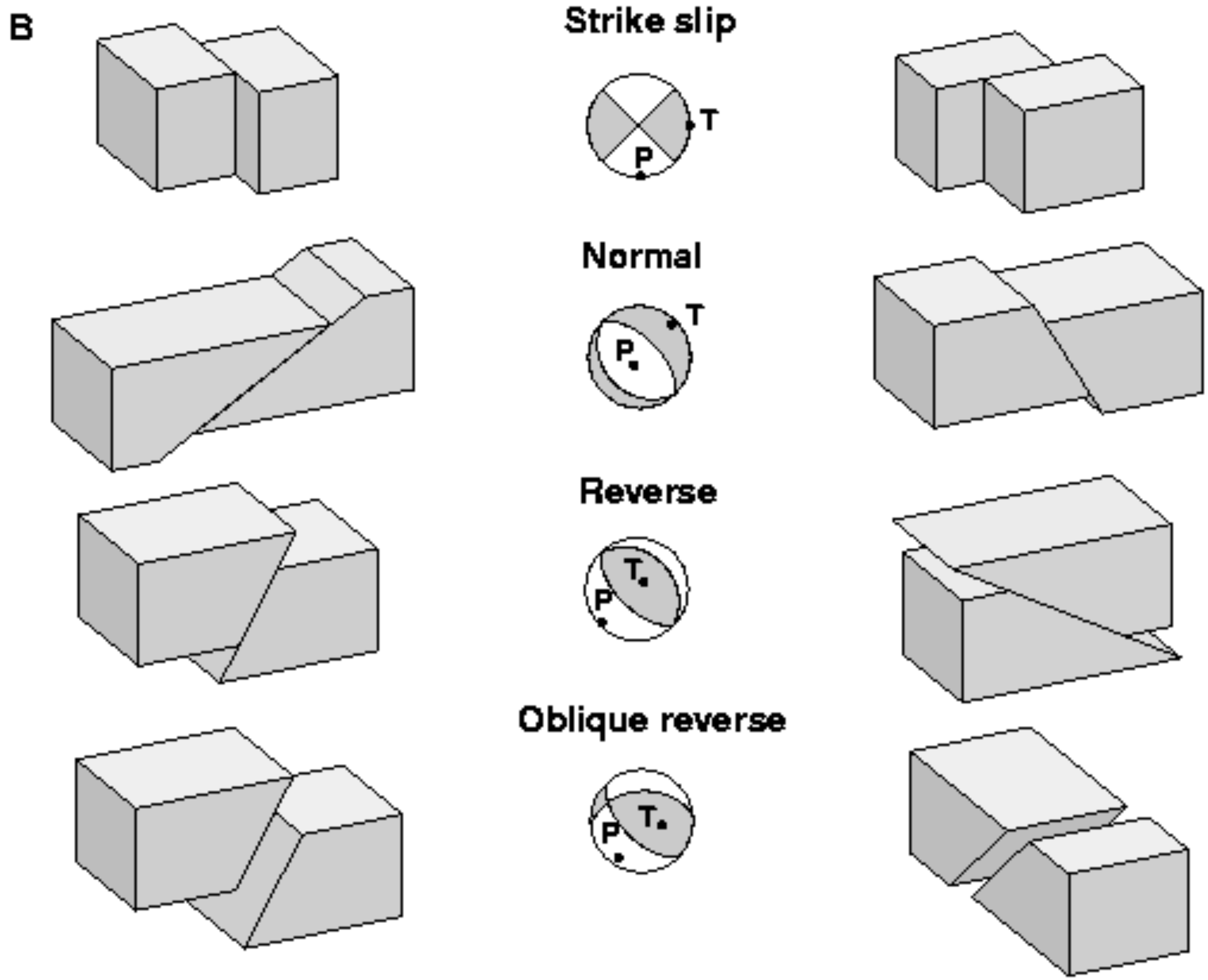
Plate Tectonic Rate
Extension
(Dilation)
Compression
Compression
Extension
(Dilation)


N
strike
dip direction
great circle
primitive circle
strike


t
first motion is down
first motion is up
t
fault
t
first motion is down
first motion is up
t
no apparent signal at t
t

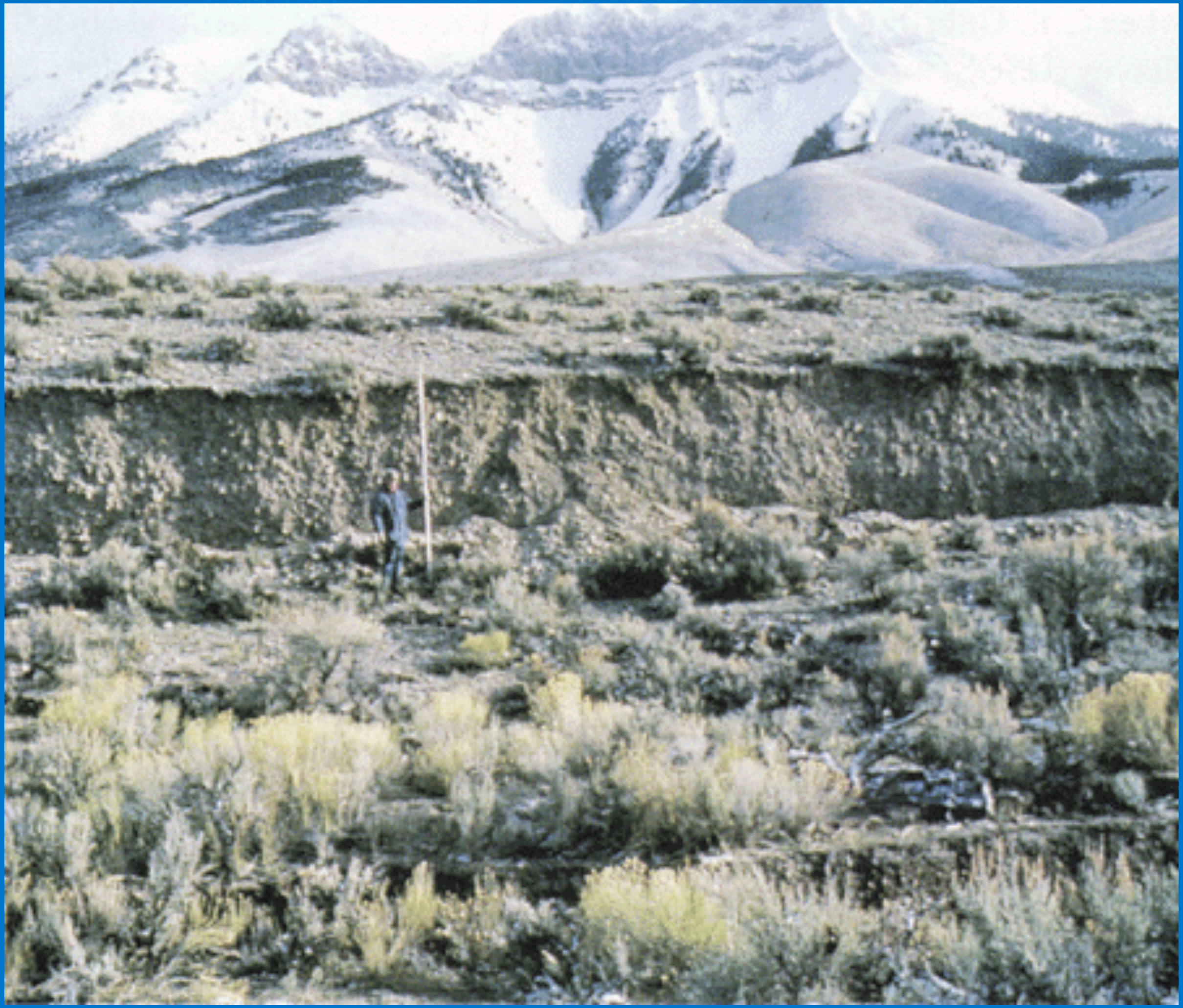
Schematic diagram of a focal mechanism




B
Strike slip
T
P
Normal
T
P
Reverse
T
P
Oblique reverse
T
P

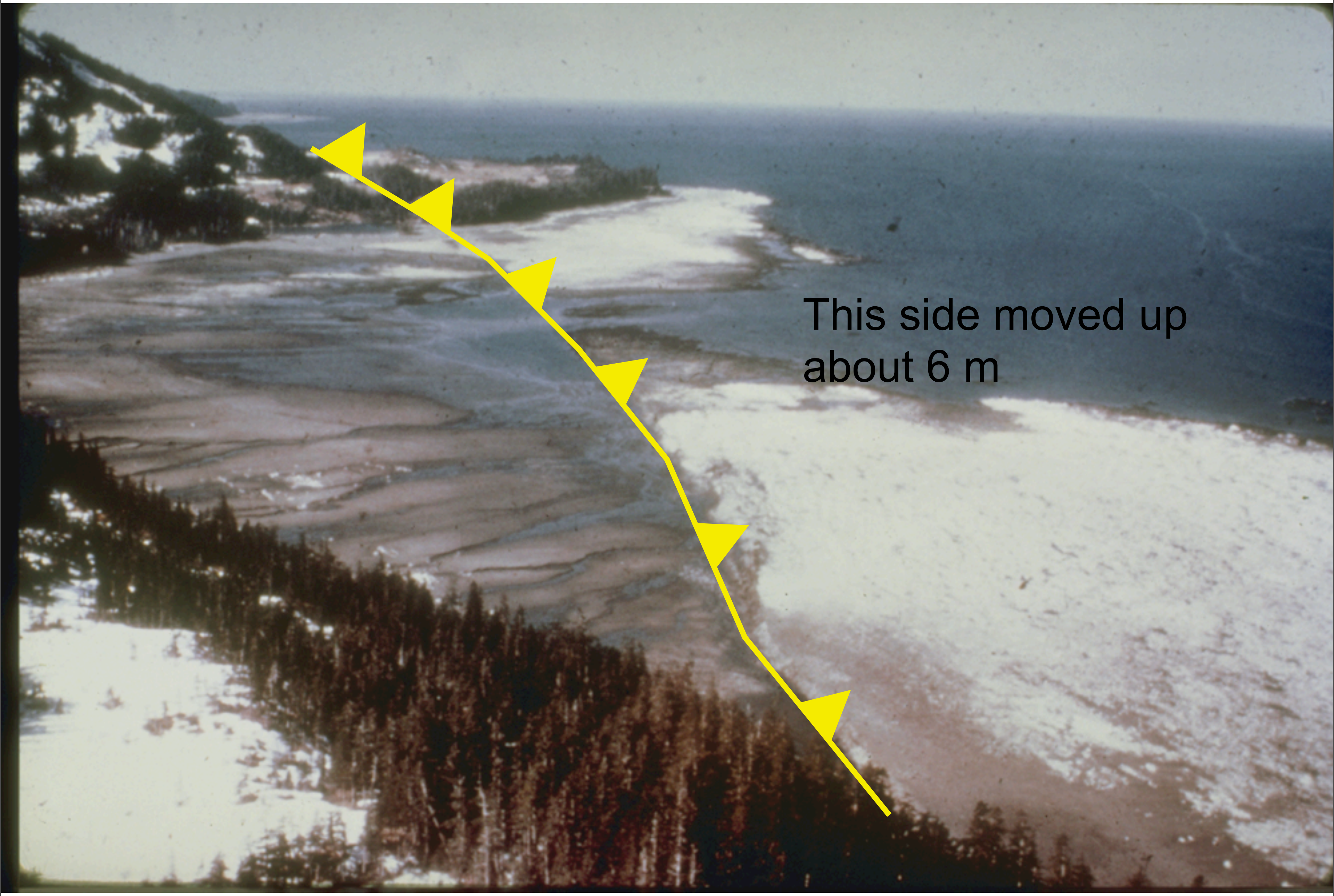
Normal Fault Surface Scarp

Borah Peak, Idaho M 7.3
October 28, 1983



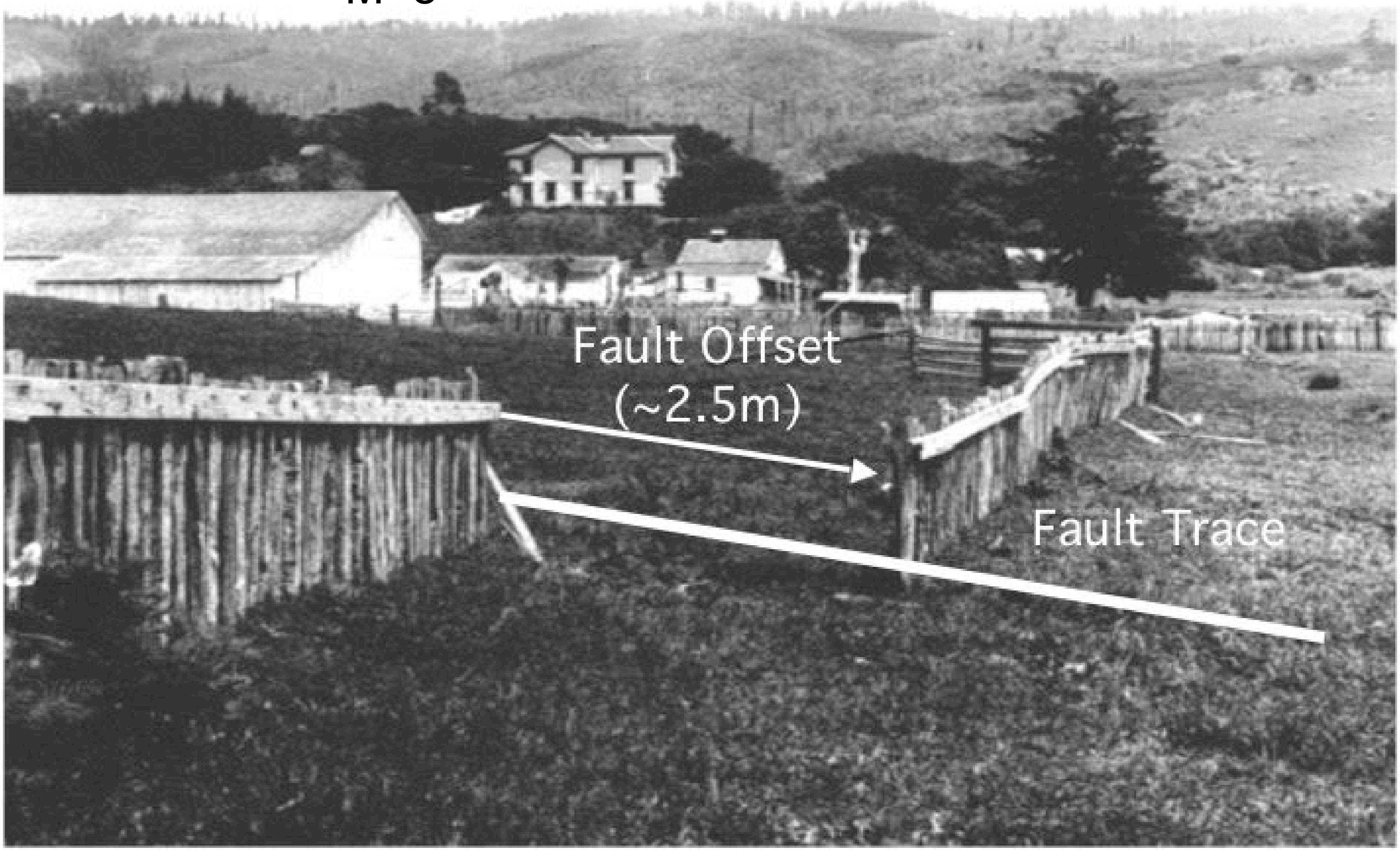
USGS

1964 Alaskan Earthquake (M~9.2)



1906 San Francisco Earthquake

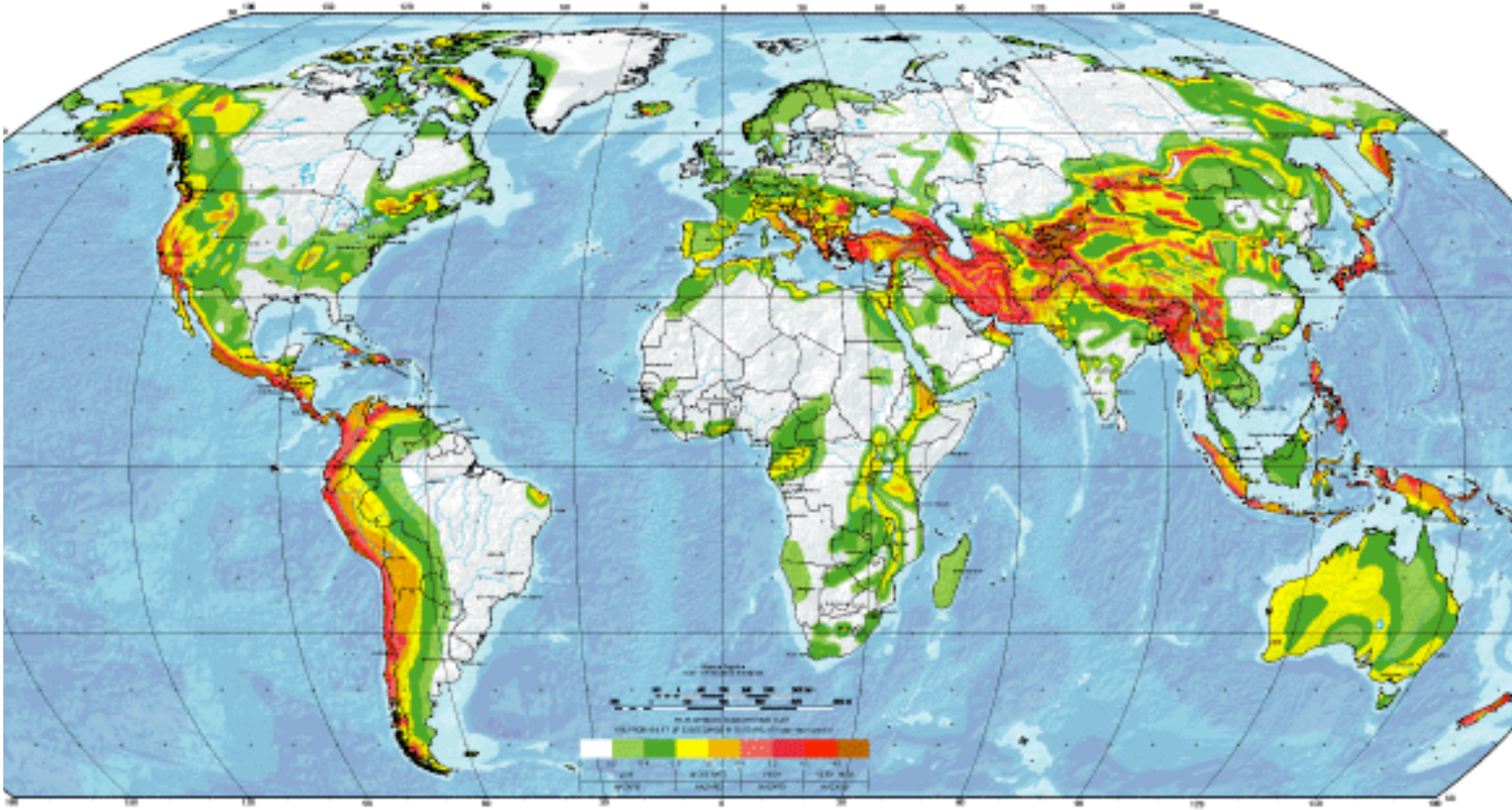
M~8



GLOBAL SEISMIC HAZARD MAP

Produced by the Global Seismic Hazard Assessment Program (GSHAP),
a demonstration project of the UN/International Decade of Natural Disaster Reduction, conducted by the International Lithosphere Program.

Global map assembled by D. Giardini, G. Grünthal, K. Shedlock, and P. Zhang
1999



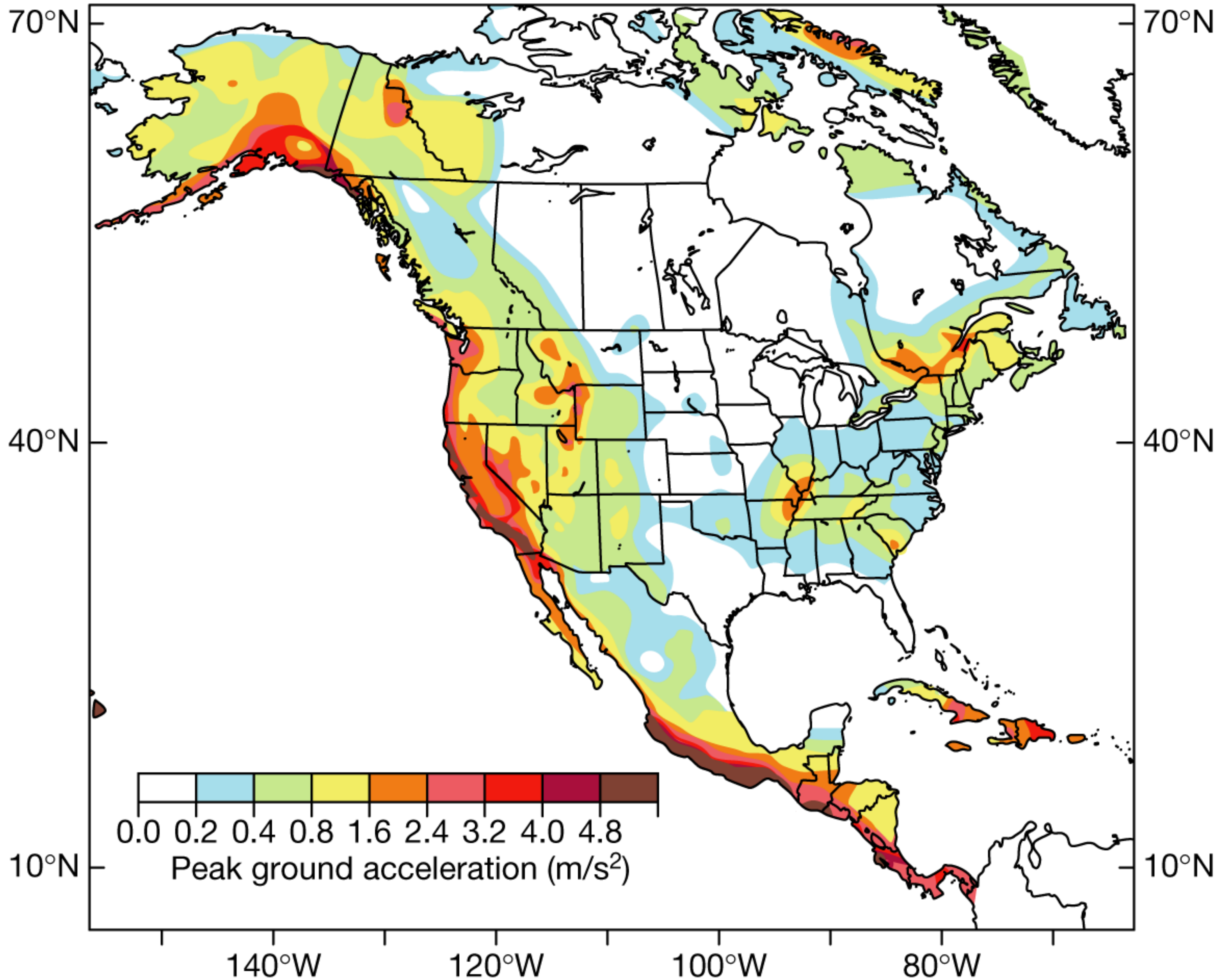

70°N
70°N
40°N
40°N
10°N
10°N
0.0 0.2 0.4 0.8 1.6 2.4 3.2 4.0 4.8
Peak ground acceleration (m/s²)
140°W
120°W
100°W
80°W

Figure 8.30a

What Controls the Level of Shaking?

- **Magnitude**
  - More energy released
- **Distance**
  - Shaking decays with distance
- **Local soils**
  - amplify the shaking

USGS

Earthquake Effects - Ground Shaking

Loma Prieta, CA 1989

USGS

KGO-TV News ABC-7

Earthquake Effects - Ground Shaking

Kobe, Japan 1995

USGS

Figure 8.23b

Figure 8.23c

Earthquake of May 31, 1970, Huaraz, Peru. The magnitude 7.8 earthquake killed 66,794 and caused $250 million in property damage. Several towns were almost totally destroyed. This earthquake, with complicating factors of landslides and floods, was one of the largest disasters ever to occur in the Southern Hemisphere.

Why do buildings/bridges collapse?

Why do buildings/bridges collapse?

1. Ground shaking produces forces that exceed the strength of the structure — or really, the ability of a structure to deform without breaking. So, strong shaking and weak or rigid structures are the problem here. Wood frame houses are good, masonry houses are bad.

Why do buildings/bridges collapse?

1. Ground shaking produces forces that exceed the strength of the structure — or really, the ability of a structure to deform without breaking. So, strong shaking and weak or rigid structures are the problem here. Wood frame houses are good, masonry houses are bad.
2. Seismic wave frequencies match resonant frequencies of buildings, leading to constructive interference

Why do buildings/bridges collapse?

1. Ground shaking produces forces that exceed the strength of the structure — or really, the ability of a structure to deform without breaking. So, strong shaking and weak or rigid structures are the problem here. Wood frame houses are good, masonry houses are bad.
2. Seismic wave frequencies match resonant frequencies of buildings, leading to constructive interference
3. Intensity of shaking increases in weak materials.

Why do buildings/bridges collapse?

1. Ground shaking produces forces that exceed the strength of the structure — or really, the ability of a structure to deform without breaking. So, strong shaking and weak or rigid structures are the problem here. Wood frame houses are good, masonry houses are bad.

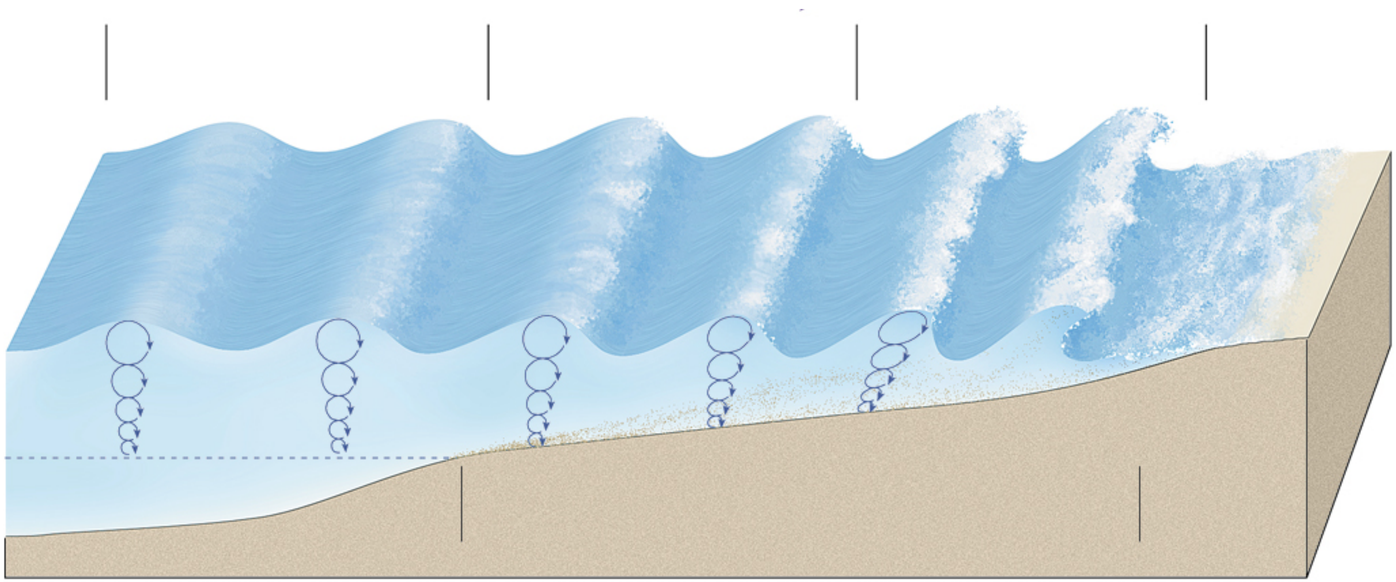
2. Seismic wave frequencies match resonant frequencies of buildings, leading to constructive interference

3. Intensity of shaking increases in weak materials.

4. Strong shaking can liquefy loose, water-saturated deposits, making them behave as fluids; buildings on liquefied materials are in trouble.

The amplitude of seismic waves is also important and this is a function of magnitude, seismic velocity and focusing effects that concentrate seismic energy.

When a waves passes from fast to slow material, the wavelength decreases, and the amplitude increases -- just like a water wave approaching shore.

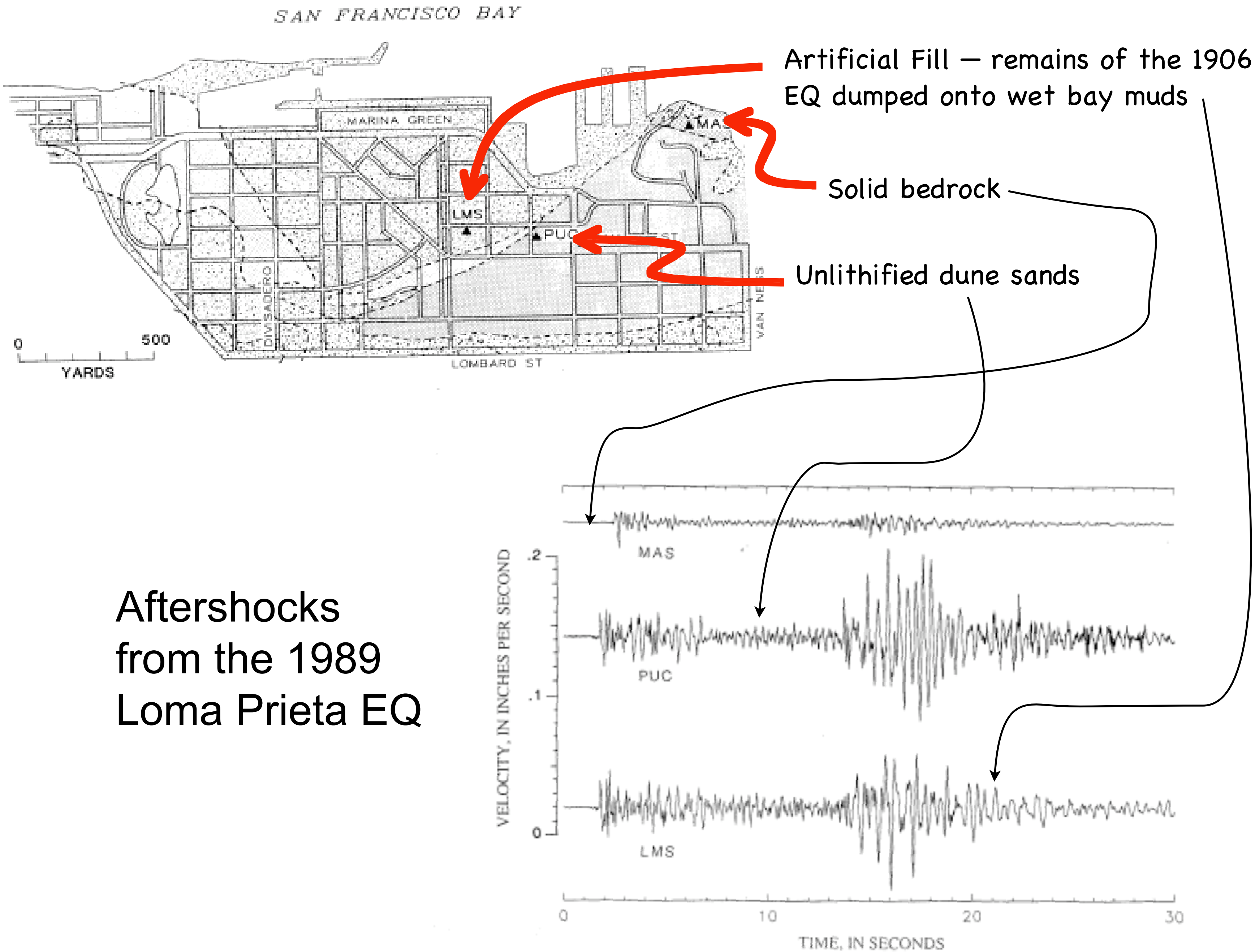


San Francisco

World Series game in progress

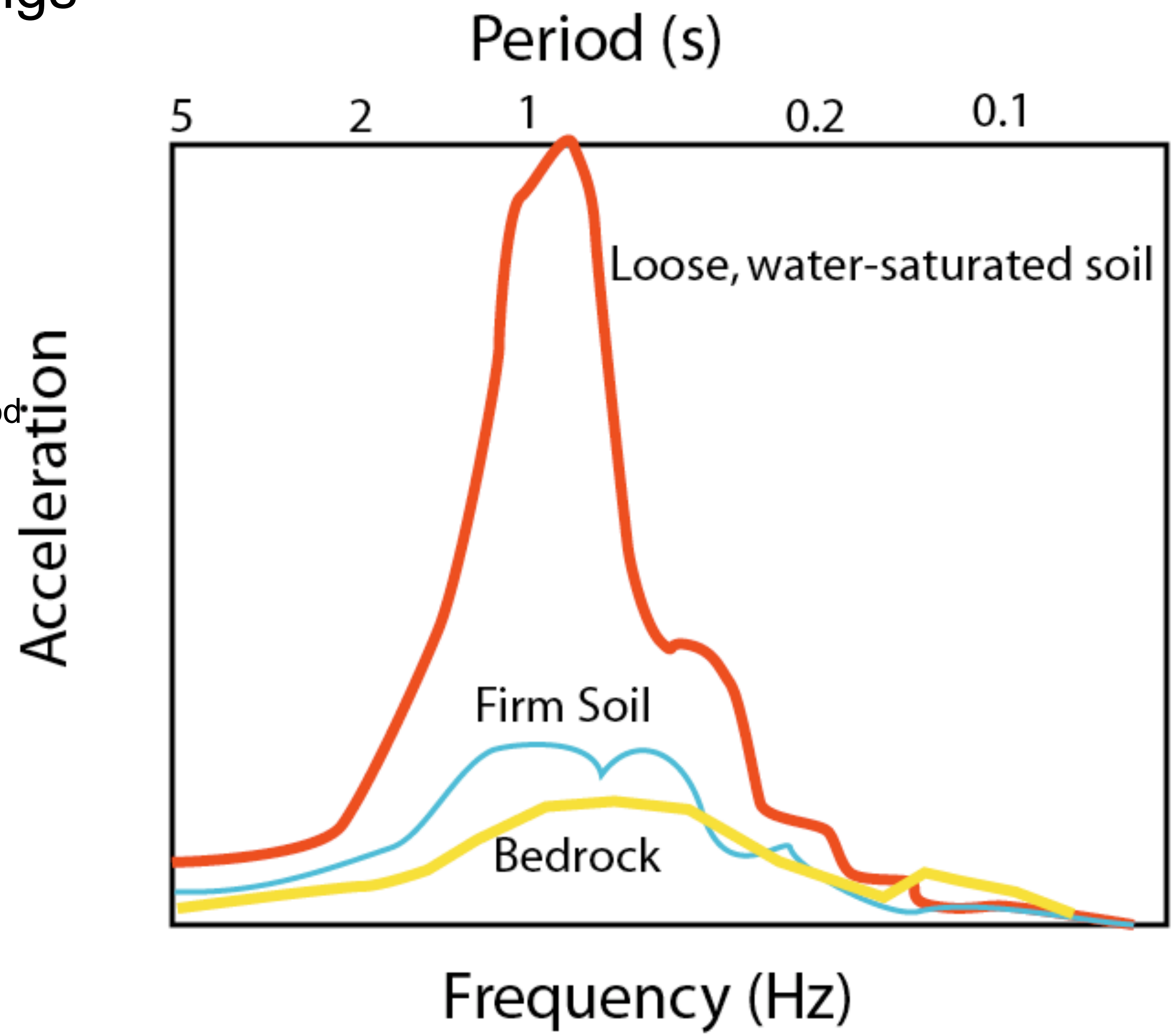
1989 Loma Prieta epicenter M 6.9

Aftershocks from the 1989 Loma Prieta EQ



Higher accelerations mean larger forces acting on buildings

Building Height	Resonant Period
2 story	.2 sec
10 story	1 sec
20 story	2 sec
30 story	3 sec

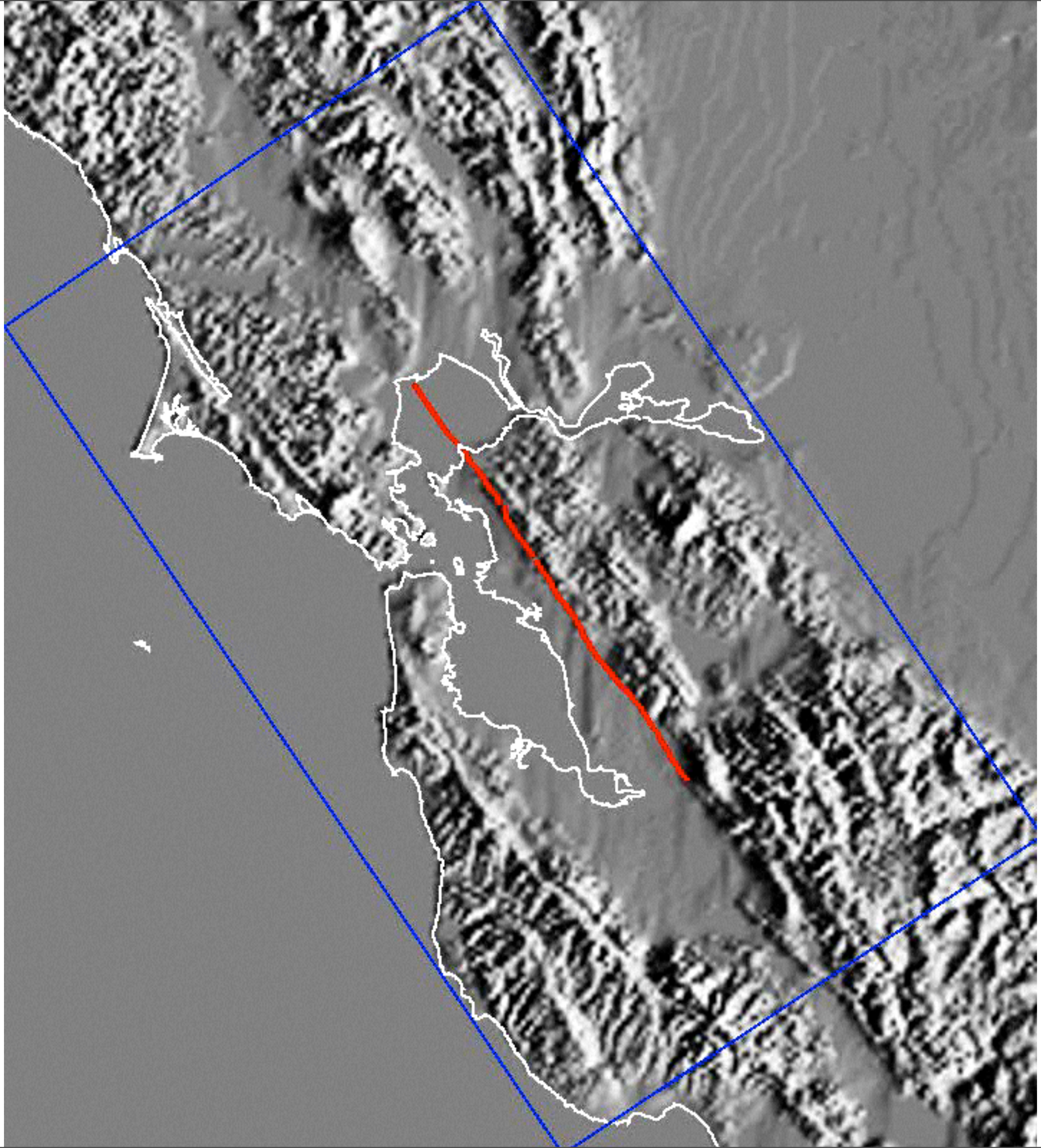



was 11 stories
18 stories
Hotel de Carlo

Focusing

The rupture extent and the surrounding topography and Earth structure can focus seismic energy, subjecting some areas to much greater damage.

Focusing



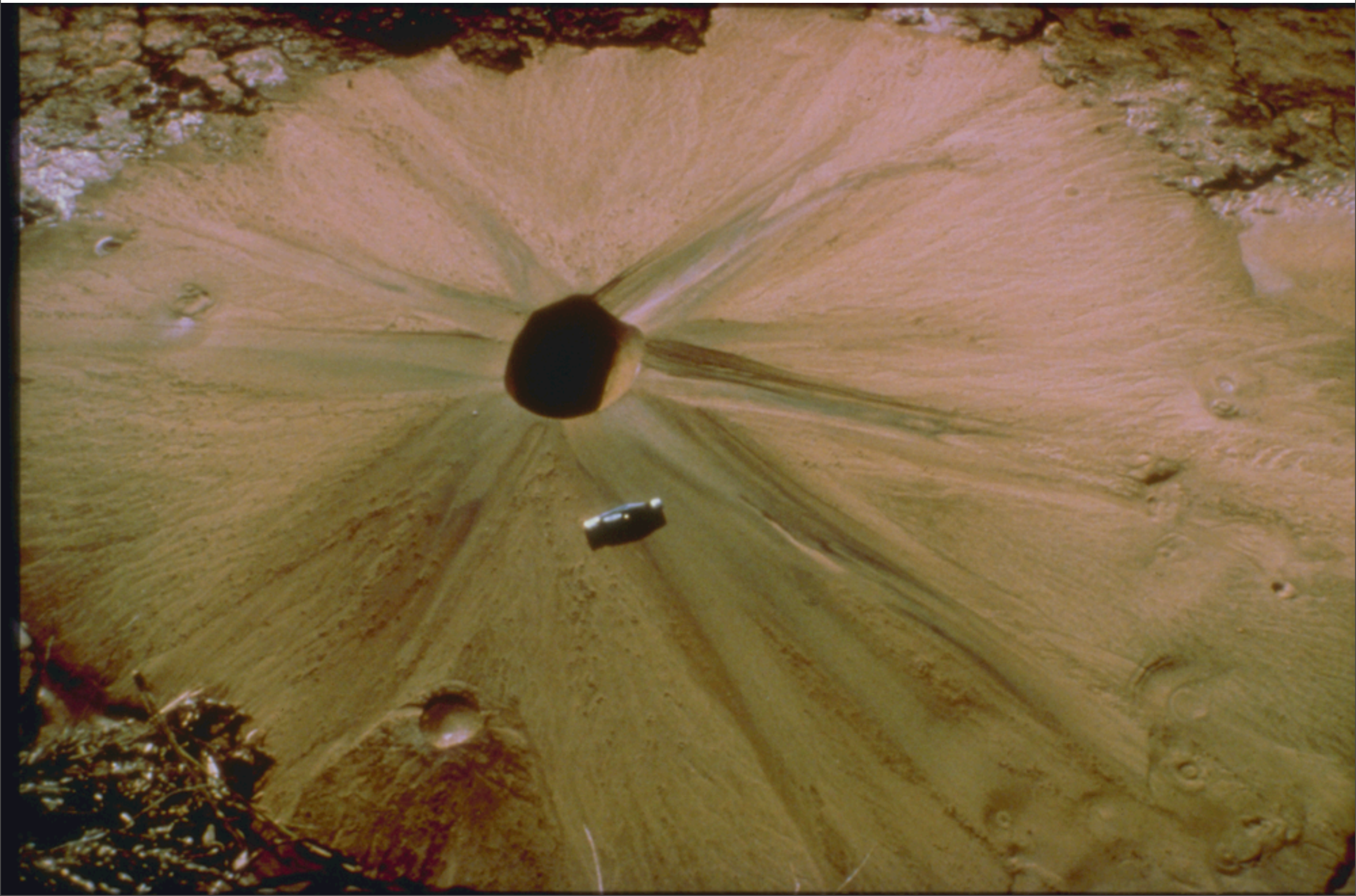
The rupture extent and the surrounding topography and Earth structure can focus seismic energy, subjecting some areas to much greater damage.

Birdseye View of the Ruins of San Francisco.

Supplement to the San Francisco Examiner, May 13, 1906.

Liquefaction

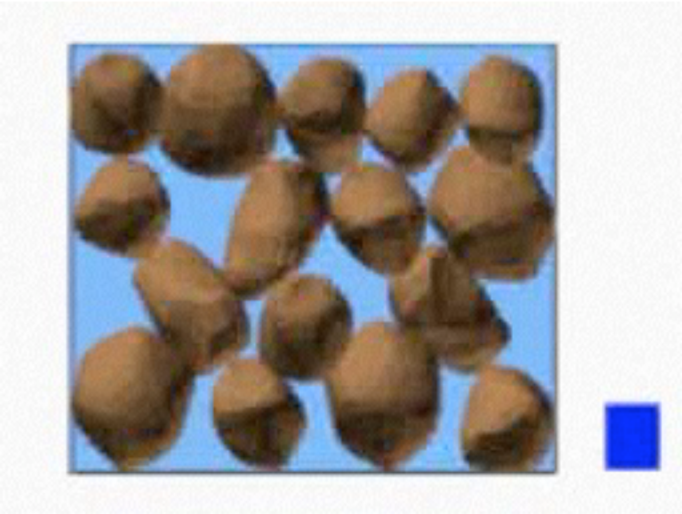
Sand Volcano resulting from liquefaction

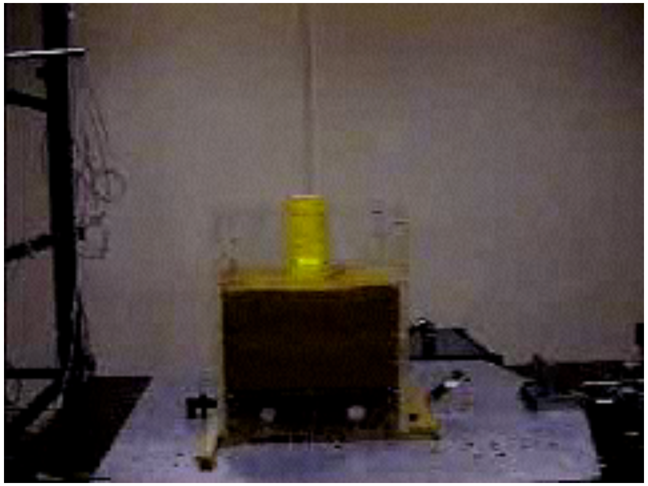


When the sand grains are in contact,their weight is supported from grain to grain, and none of their weight is carried by the water.

But if jostled and shaken quickly, the grains loose contact with one another and their weight is carried by the water, so the water pressure shoots up and keeps the grains apart. At this point, the whole mix of sediment and water is a fluid that has no strength.

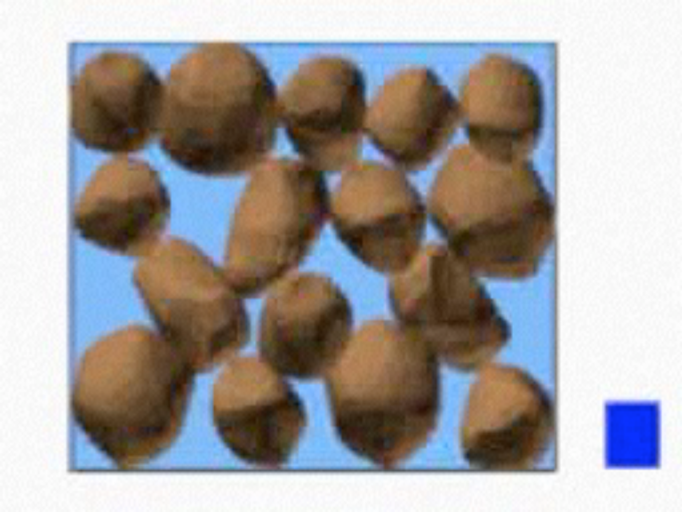
When the sand grains are in contact,their weight is supported from grain to grain, and none of their weight is carried by the water.

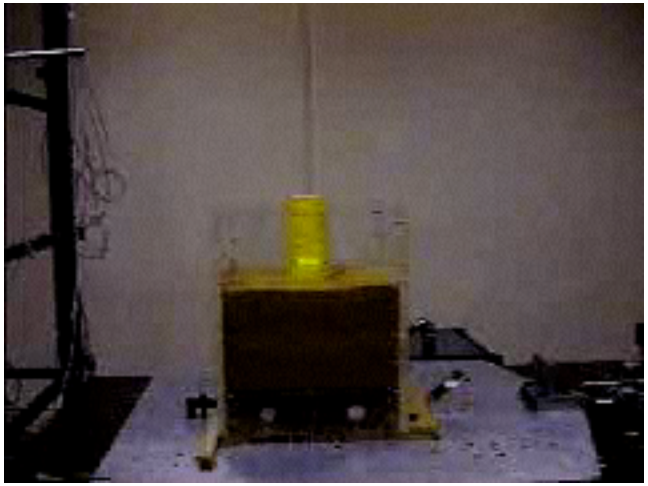




But if jostled and shaken quickly, the grains loose contact with one another and their weight is carried by the water, so the water pressure shoots up and keeps the grains apart. At this point, the whole mix of sediment and water is a fluid that has no strength.

When the sand grains are in contact,their weight is supported from grain to grain, and none of their weight is carried by the water.





But if jostled and shaken quickly, the grains loose contact with one another and their weight is carried by the water, so the water pressure shoots up and keeps the grains apart. At this point, the whole mix of sediment and water is a fluid that has no strength.

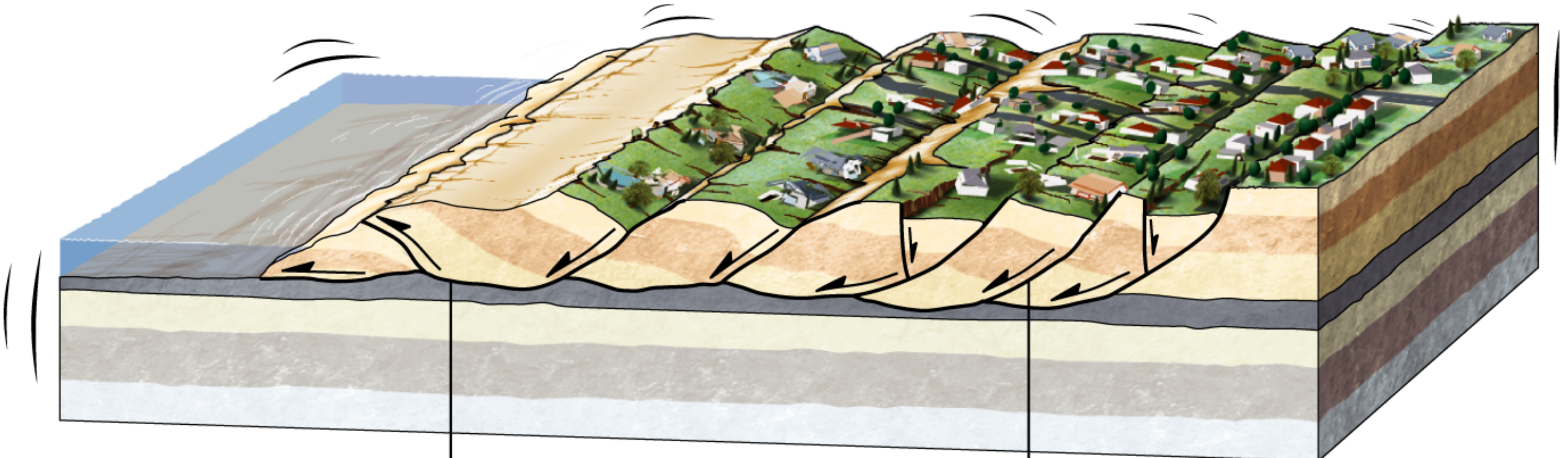
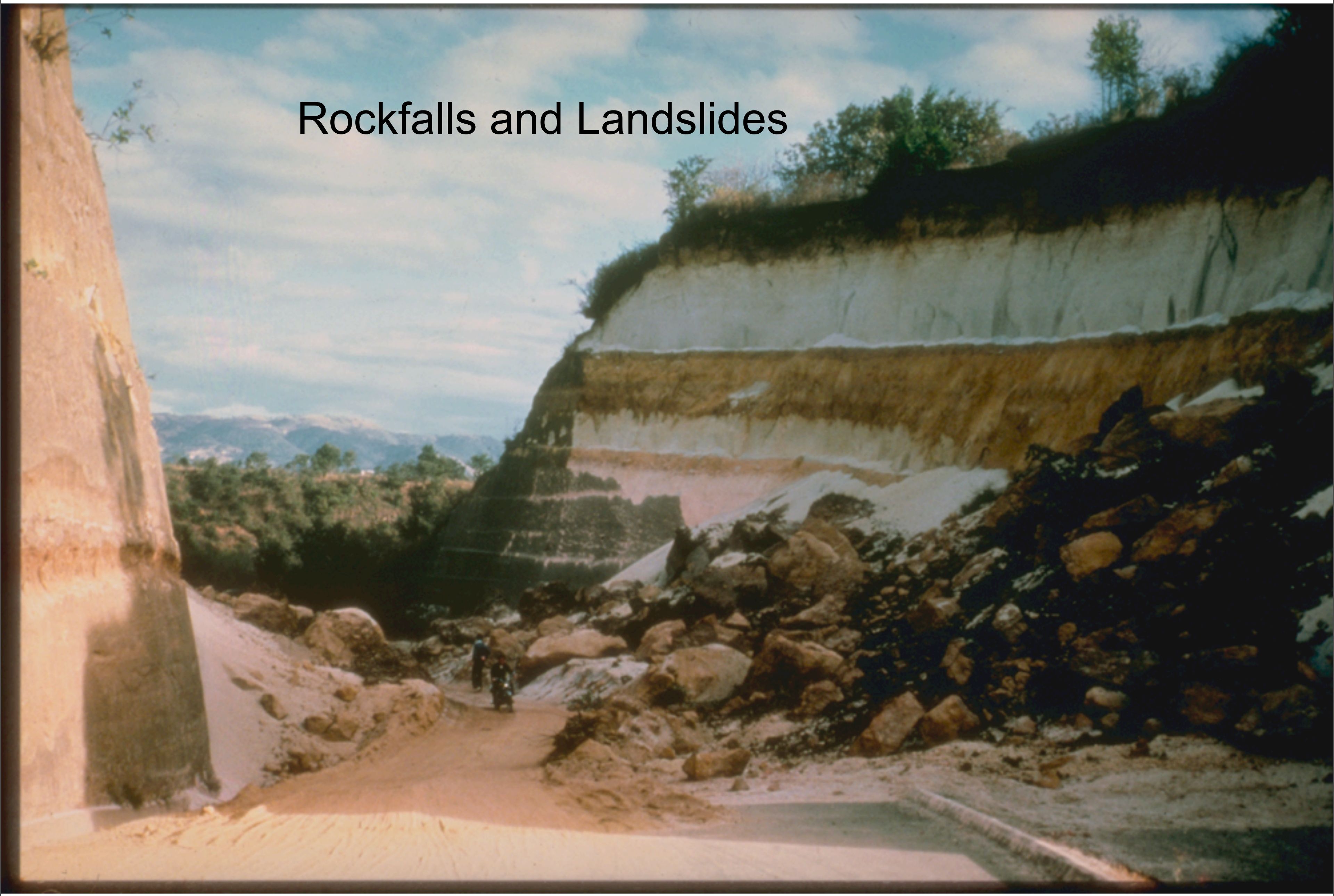


Figure 8.25a

Figure 8.25b


Rockfalls and Landslides

huge landslides from the M 7.9 Denali earthquake

Summary of Seismic Hazards

Building Collapse
- *poor design*
- *strong shaking*
  - *resonance, amplification, topographic focusing*
- *liquefaction*

Infrastructure failure — fires, power, sanitation
Landslides, rockfalls
Tsunami