Earthquakes

Earthquakes

Topics

Where do earthquakes occur?

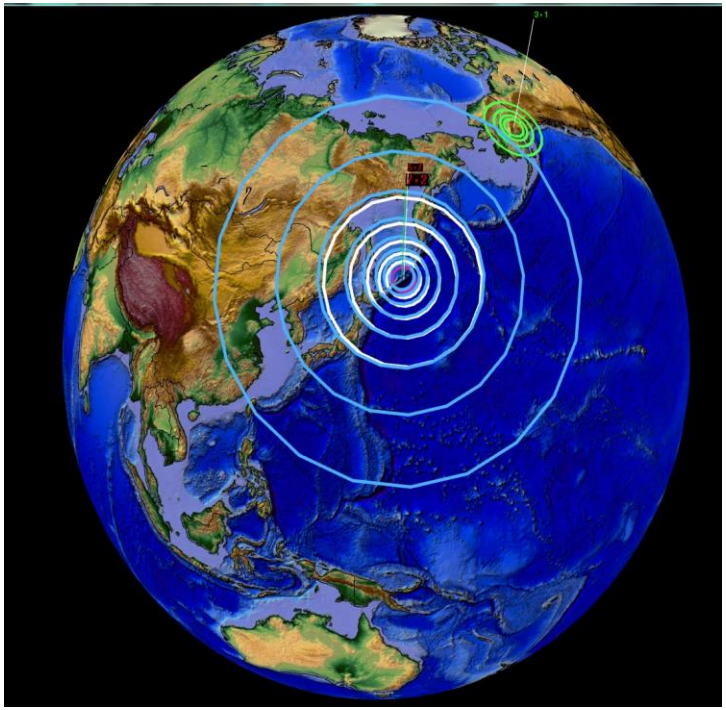
Earthquake Fundamentals

What is an Earthquake?

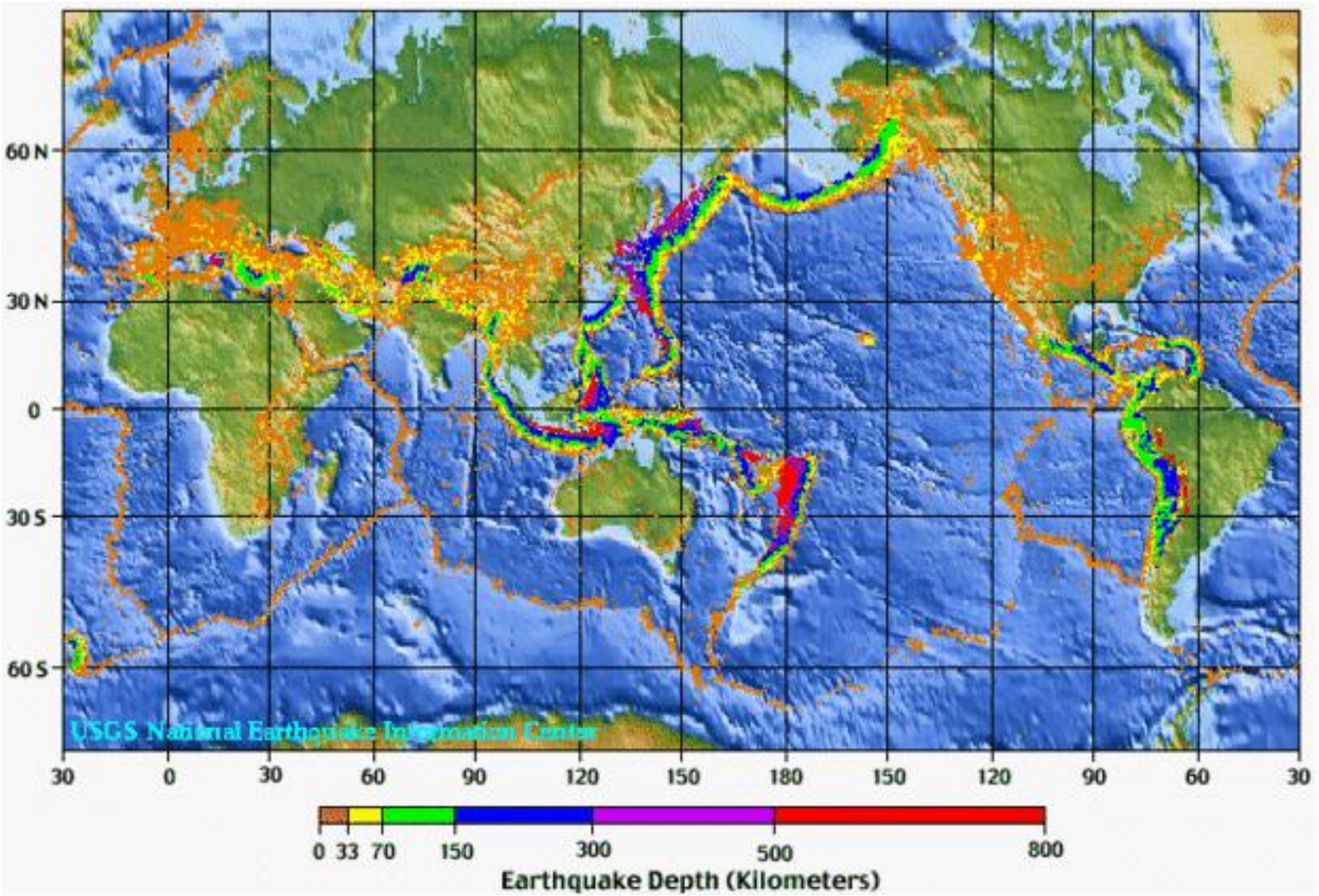
- **Seismic Waves**
- **Locating an Earthquake**
- **Sizes of Earthquakes**

Earthquakes and Plate Tectonics

Earthquake Predicition



Where Do Earthquakes Occur?



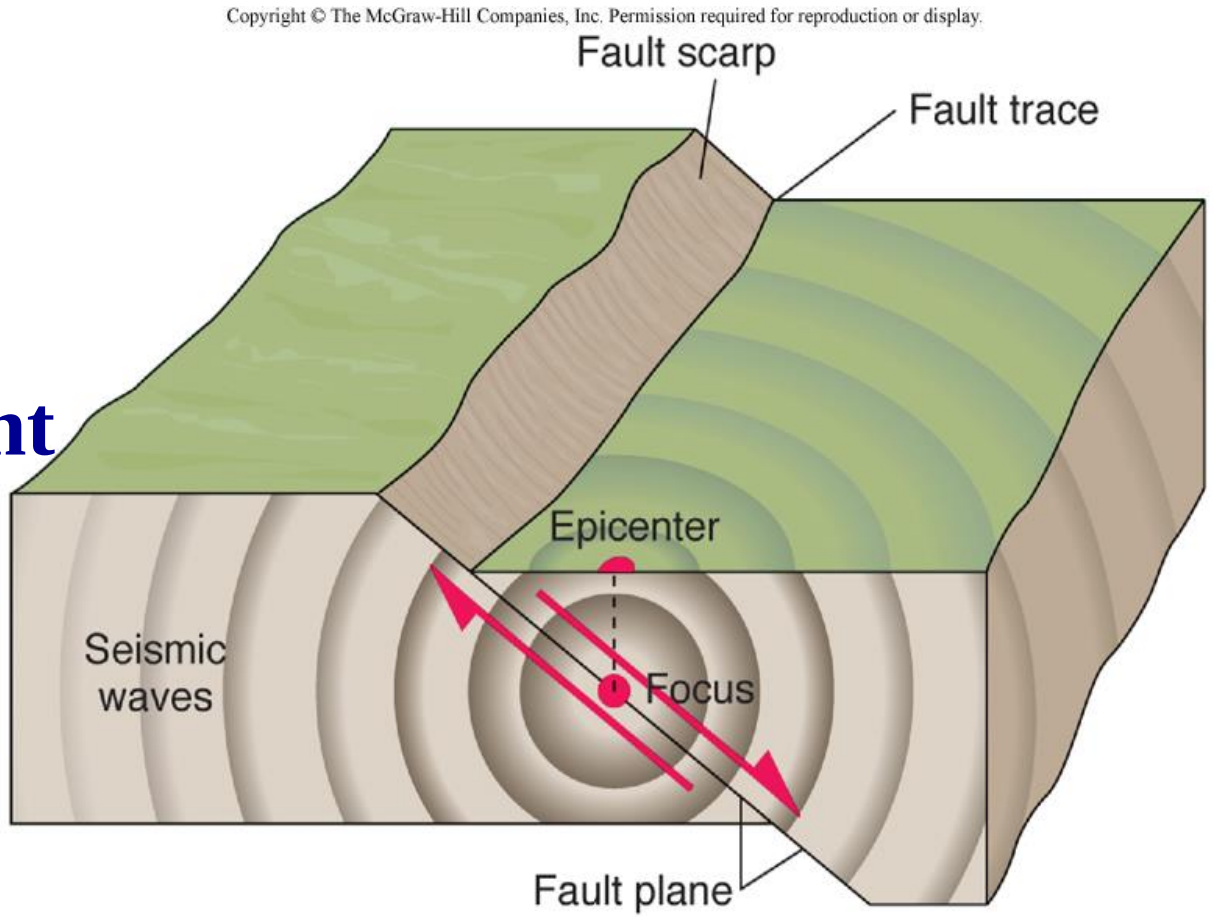
Most earthquakes concentrated at

Mid-ocean ridges; Circum-Pacific belt; Mediterranean-Himalayan belt

What is an Earthquake?

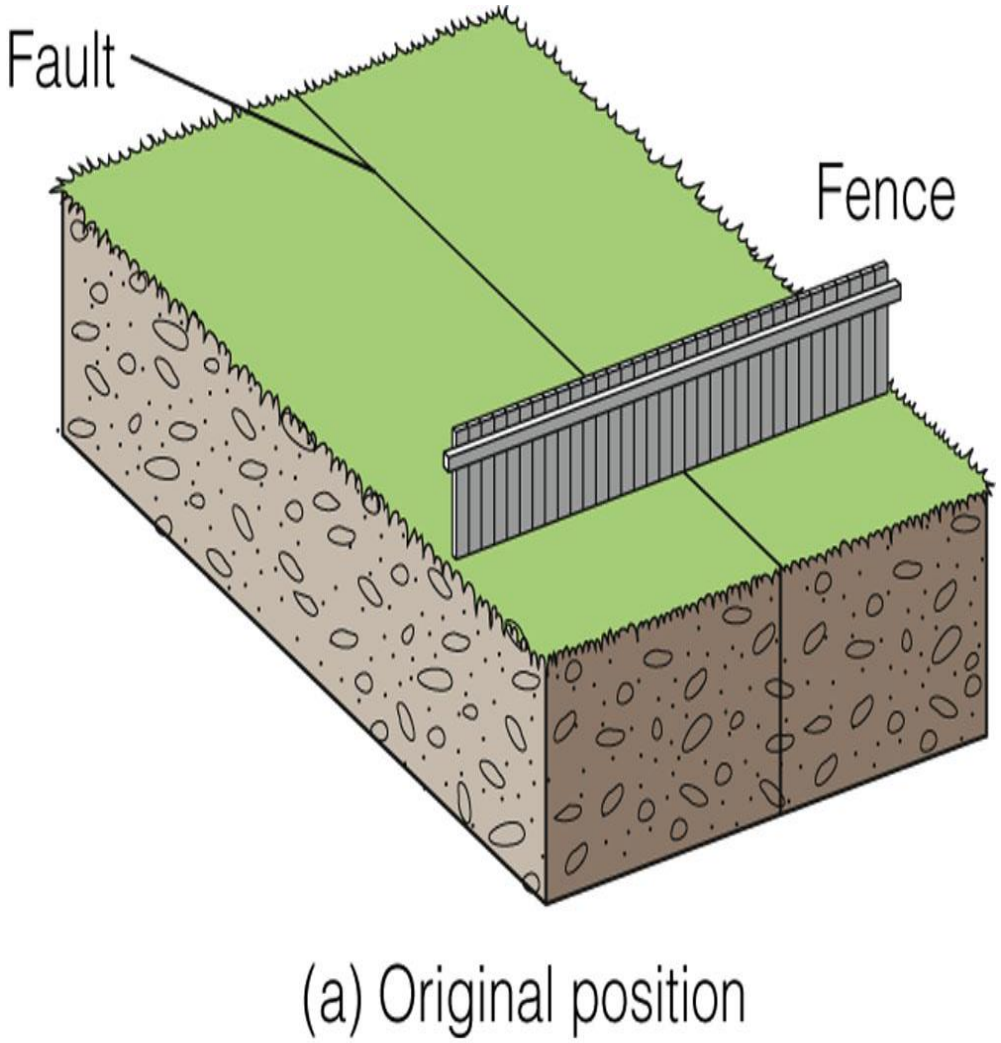
The vibration of the earth produced by rapid release of energy

-- causes by sudden movement along a fault

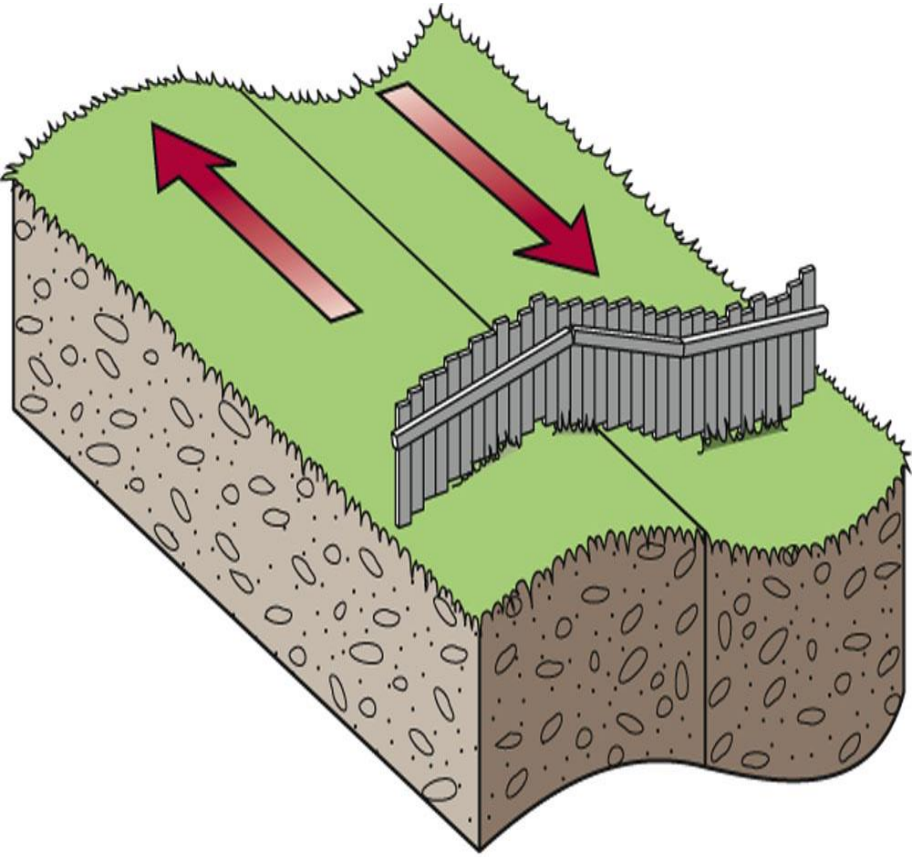


Elastic Rebound Theory:

-- apply stress



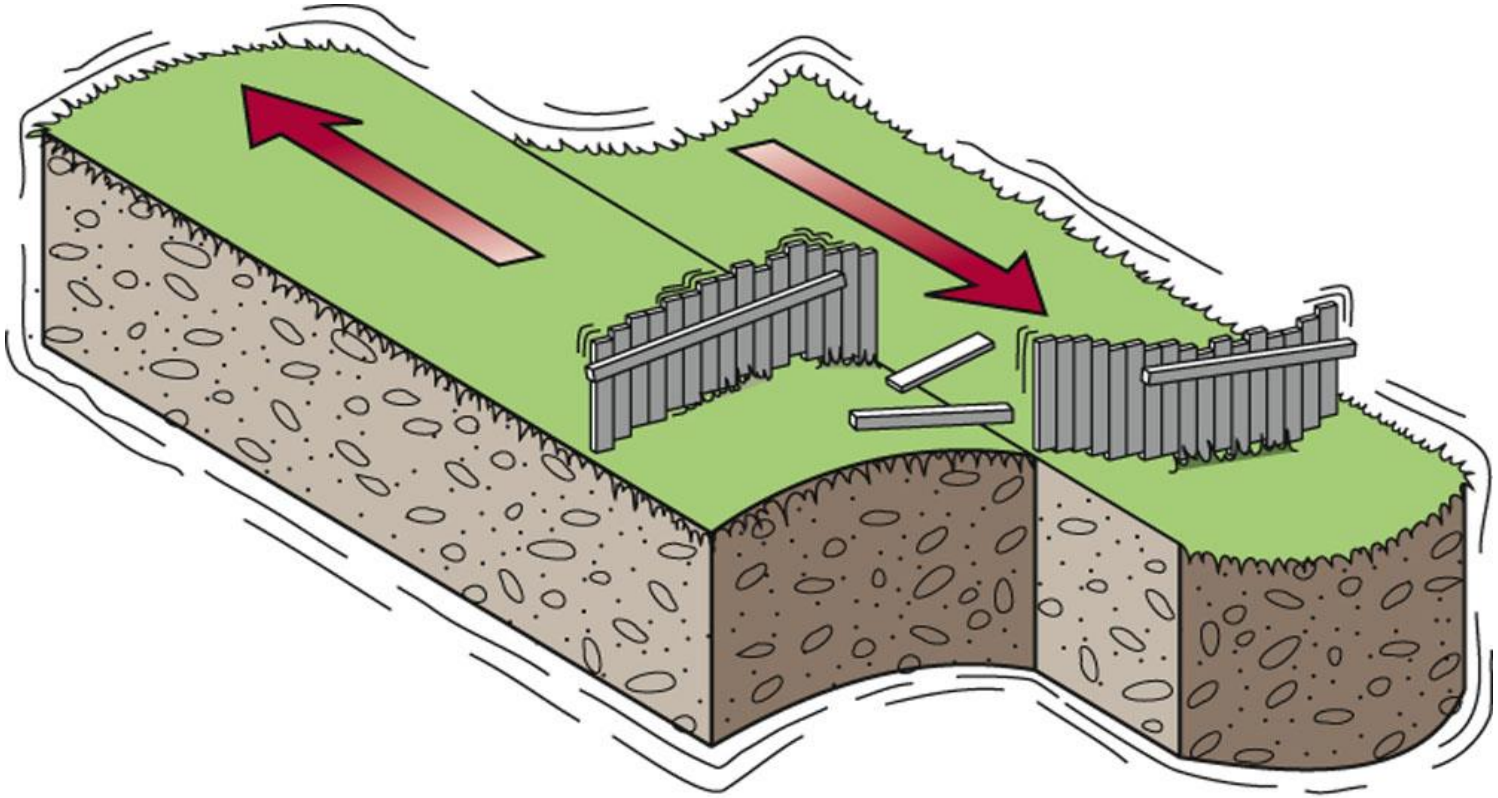
-- build up of strain



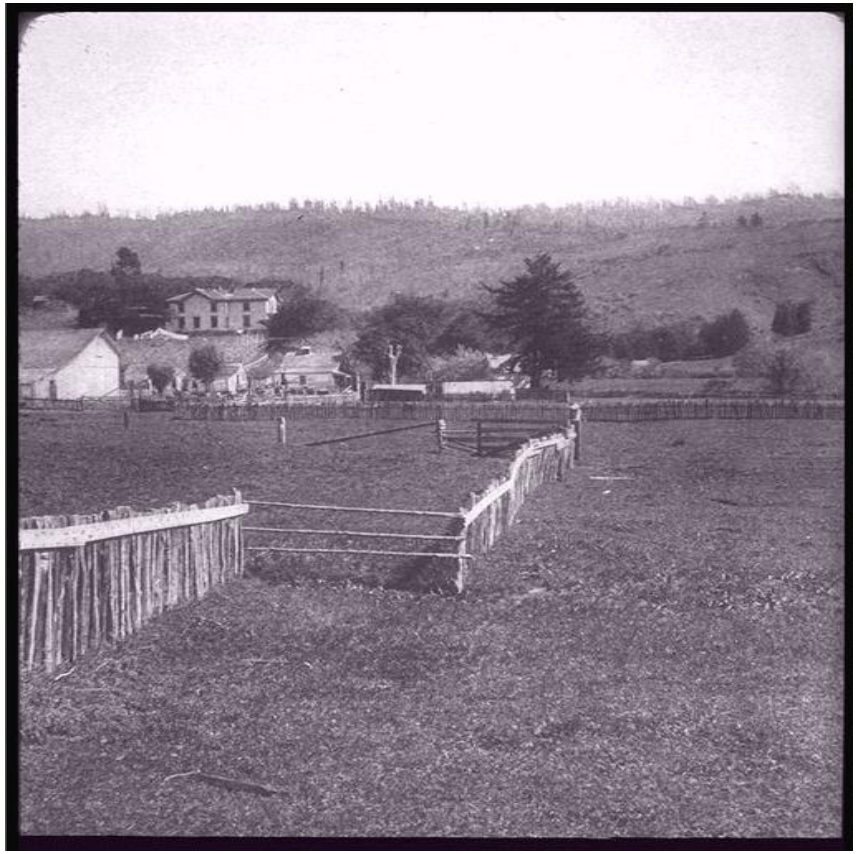
(b) Deformation

Photo by I. J. Witkind, U.S. Geological Survey

-- when forces exceed the elastic limit → rupture
-- release the stored energy/strain
-- sent out waves of energy through the earth



(c) Rupture and release of energy



San Andreas Fault
after 1906 earthquake

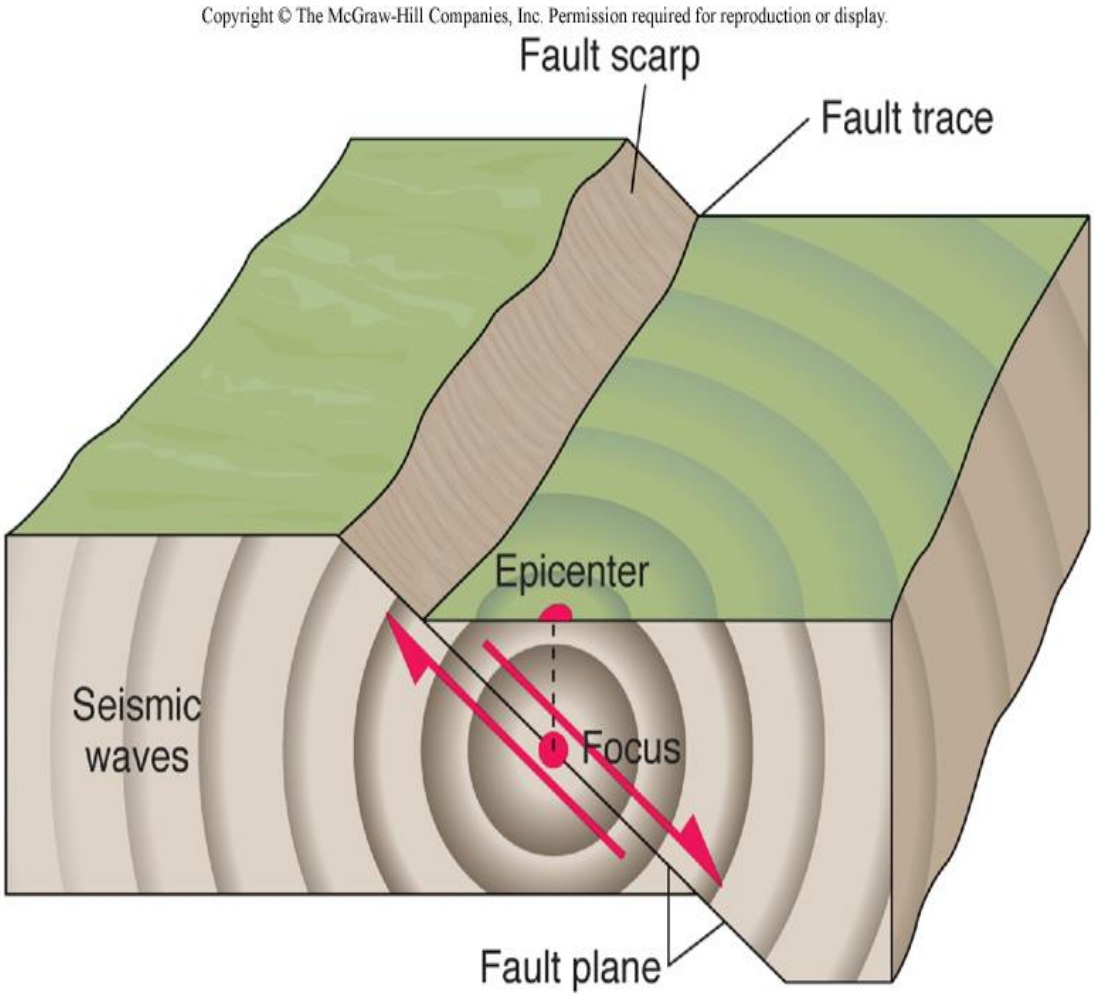
Point Reyes National
Seashore

Seismic Waves

-- Waves of energy produced by an earthquakes

-- point of initiation: "focus"
or “hypocenter”

-- the point on the surface directly above the focus :"epicenter"

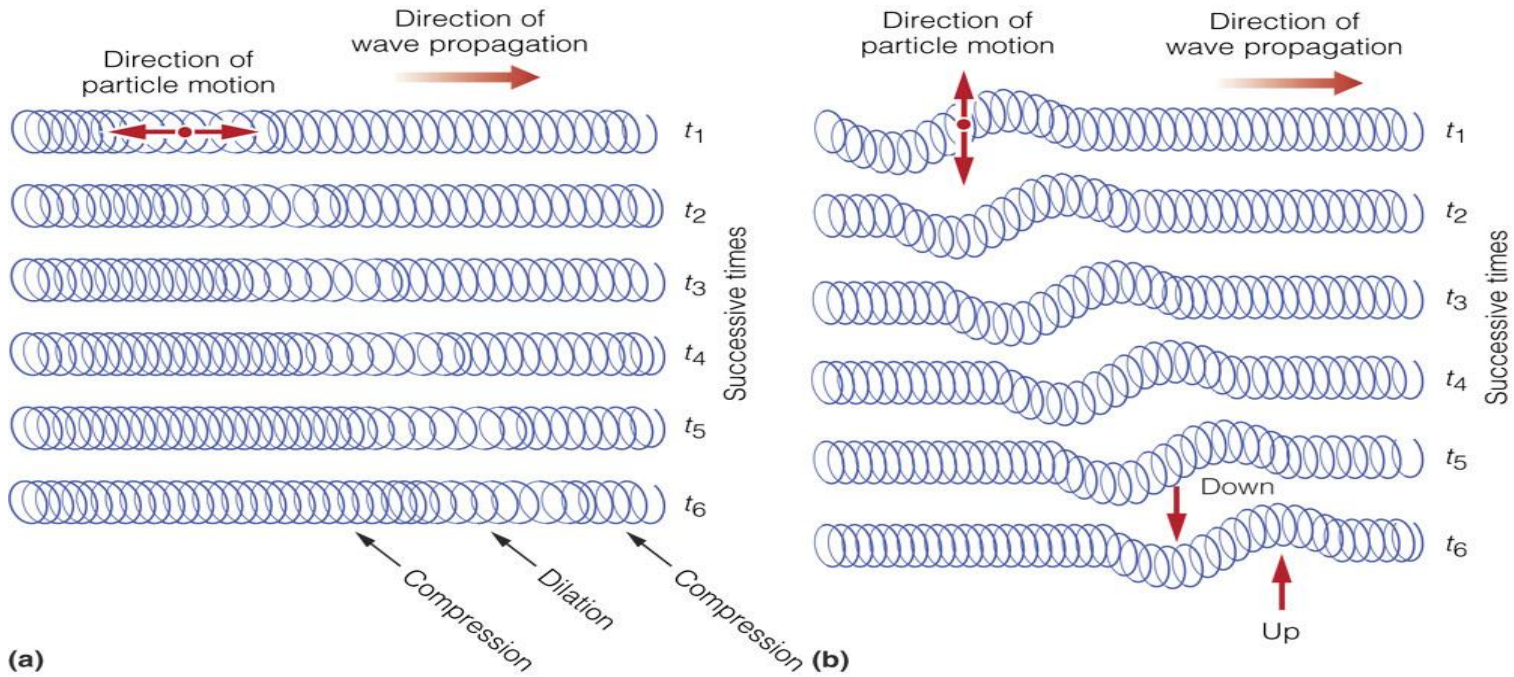


Types of seismic waves

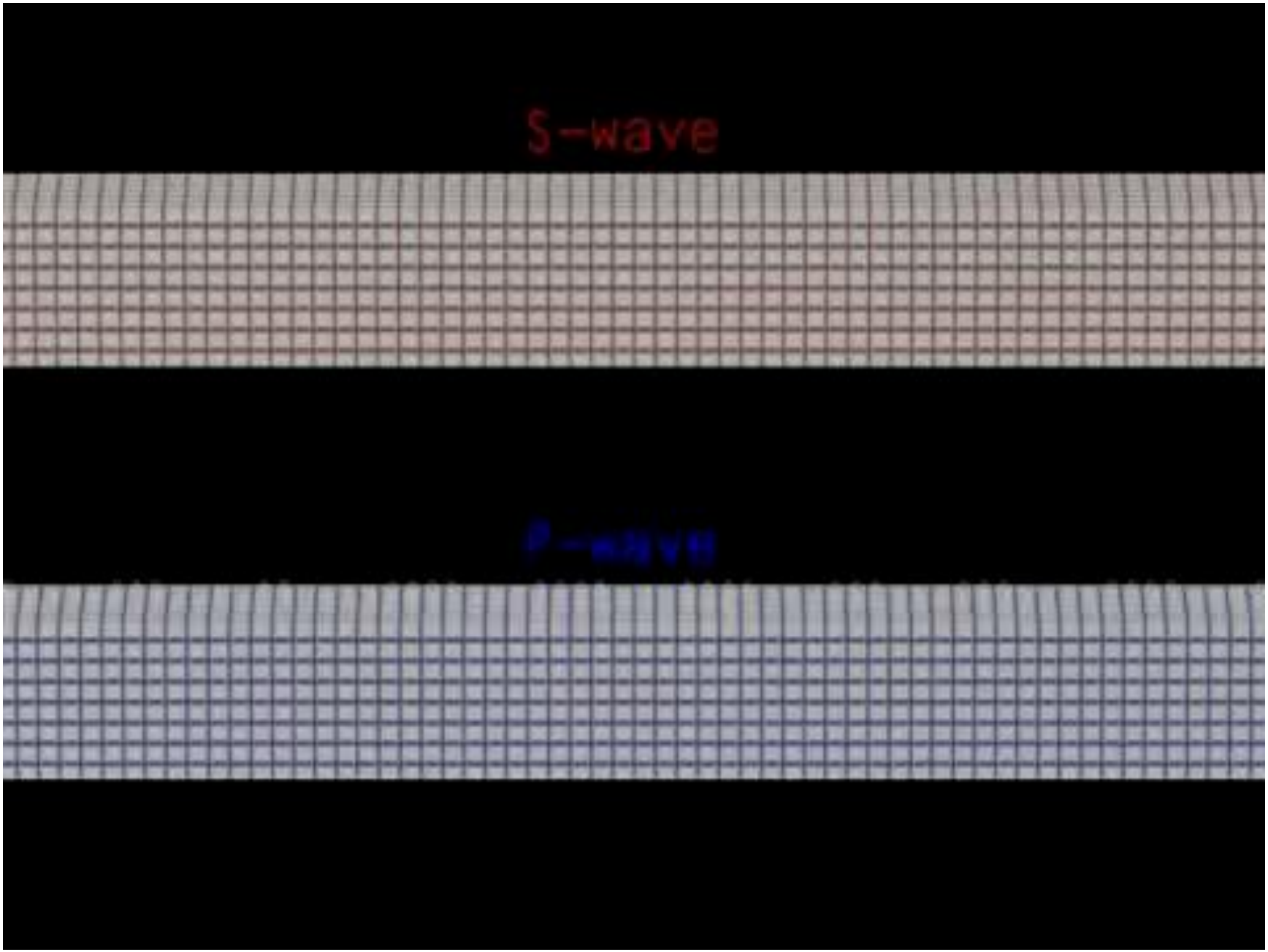
(1) Body waves: travel through the earth's interior

P (primary) waves: direction of wave propagation parallel to the direction of particle motion

S (secondary) waves: direction of wave propagation perpendicular to the direction of particle motion

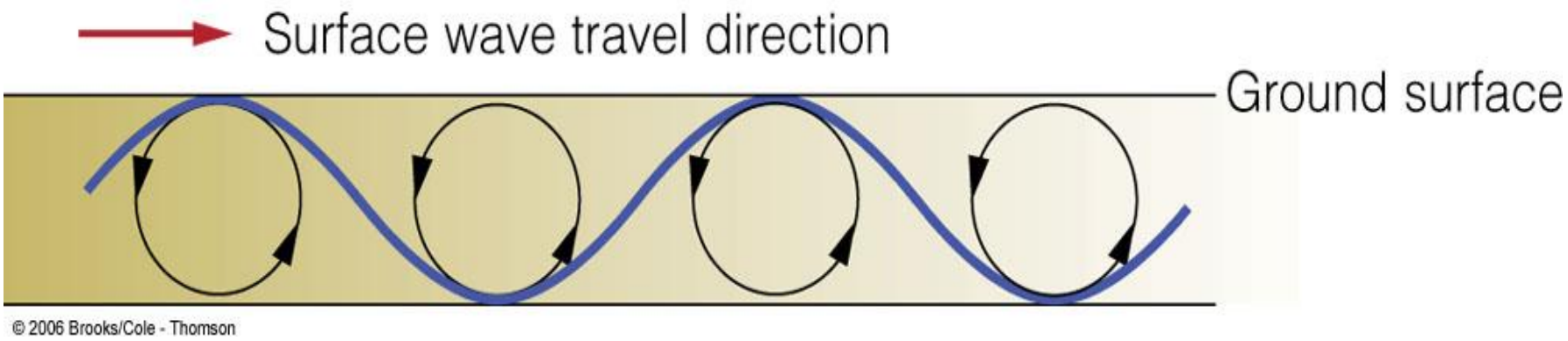


P & S waves



Types of seismic waves

(2) Surface waves: travel on the earth's surface; rolling motion



Which type of earthquake waves cause the most damage during an earthquake?

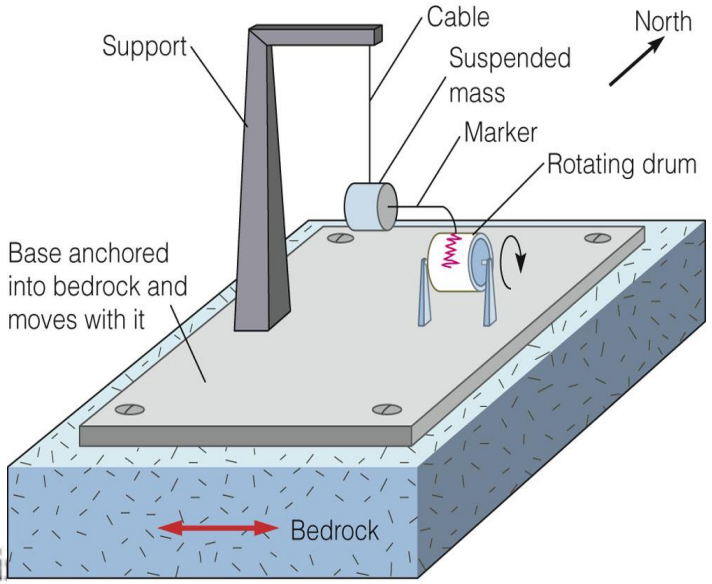
-- Surface waves

Measurement of Ground Vibrations

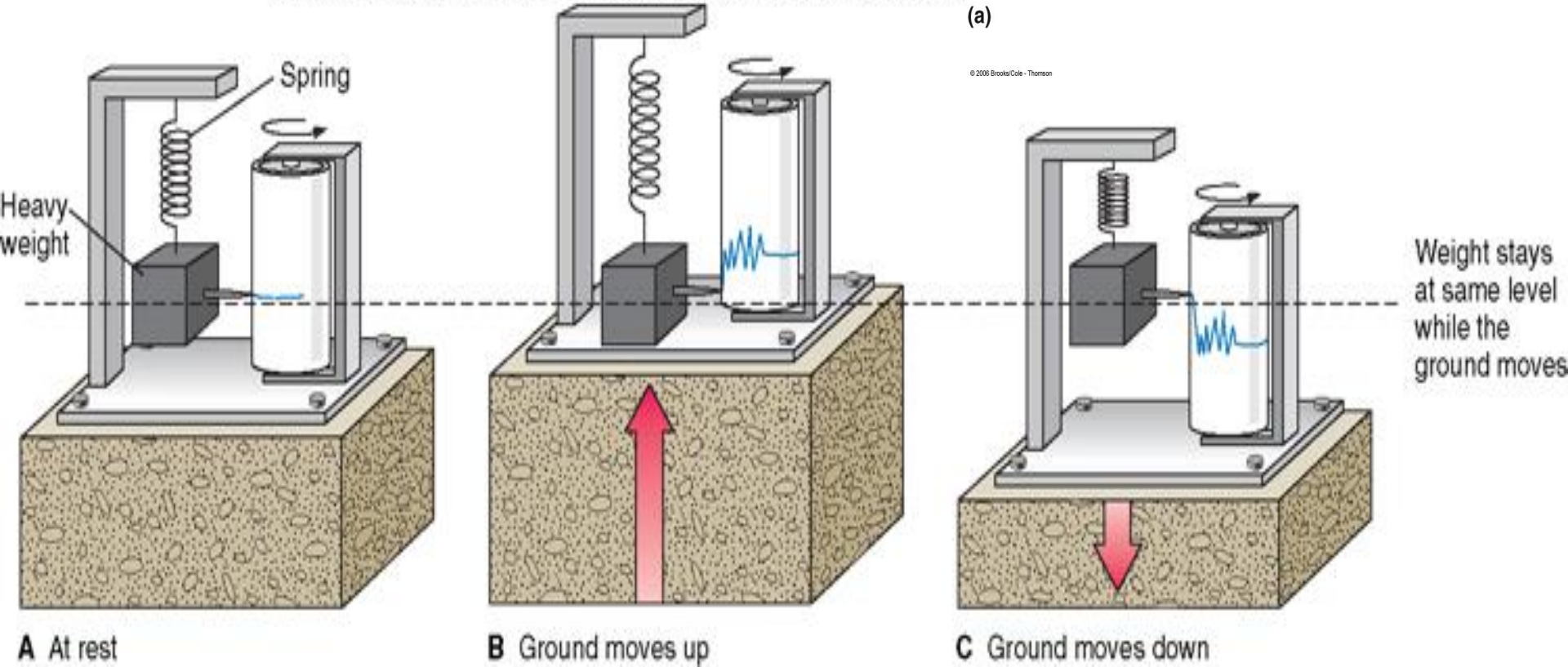
1st prototype instrument by Chang Heng in 132 A.D.

1st modern Seismograph: ~ 1890

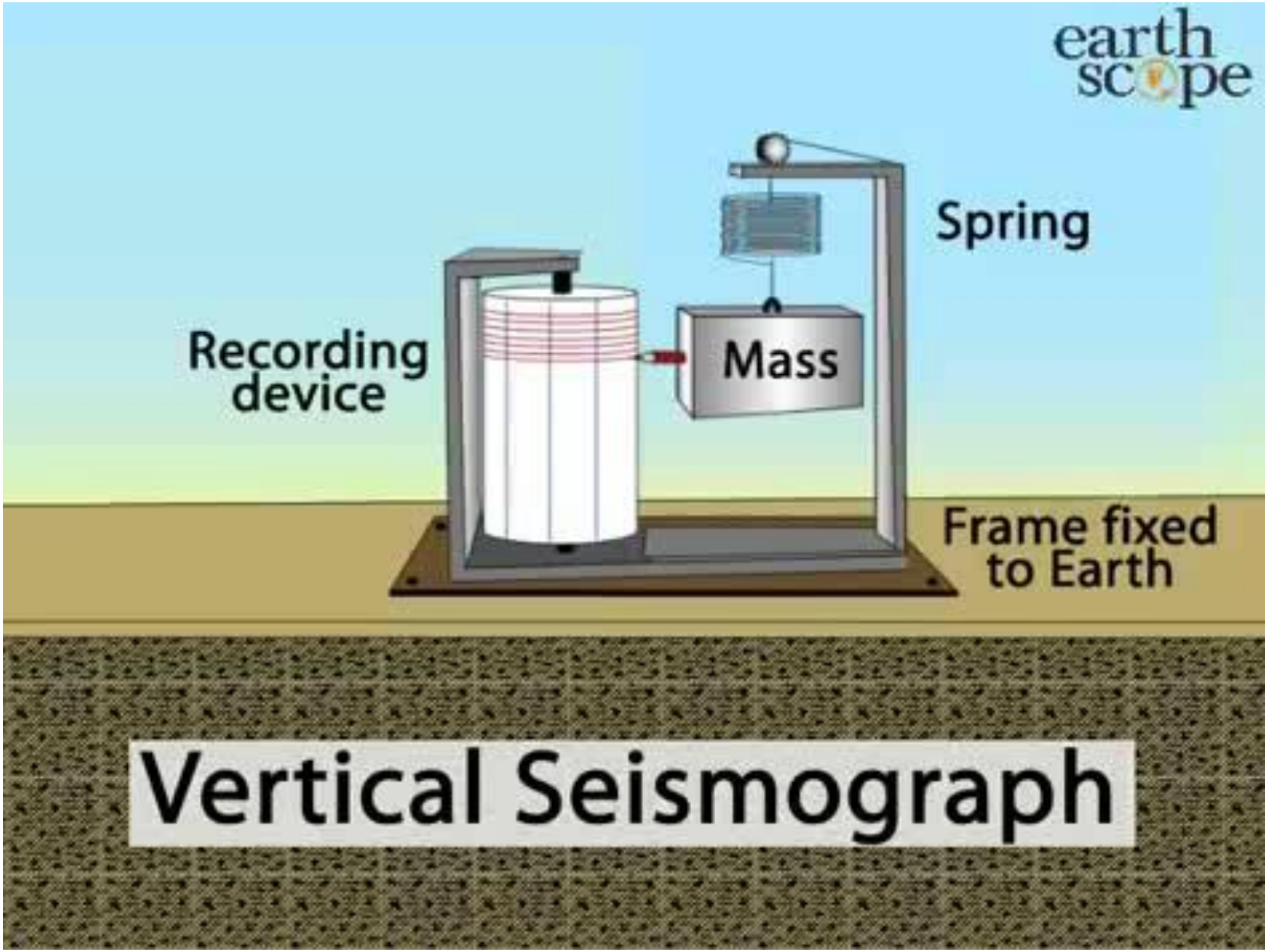
Basic principle: <u>inertia.</u>
Resistance of a large mass
to sudden movement

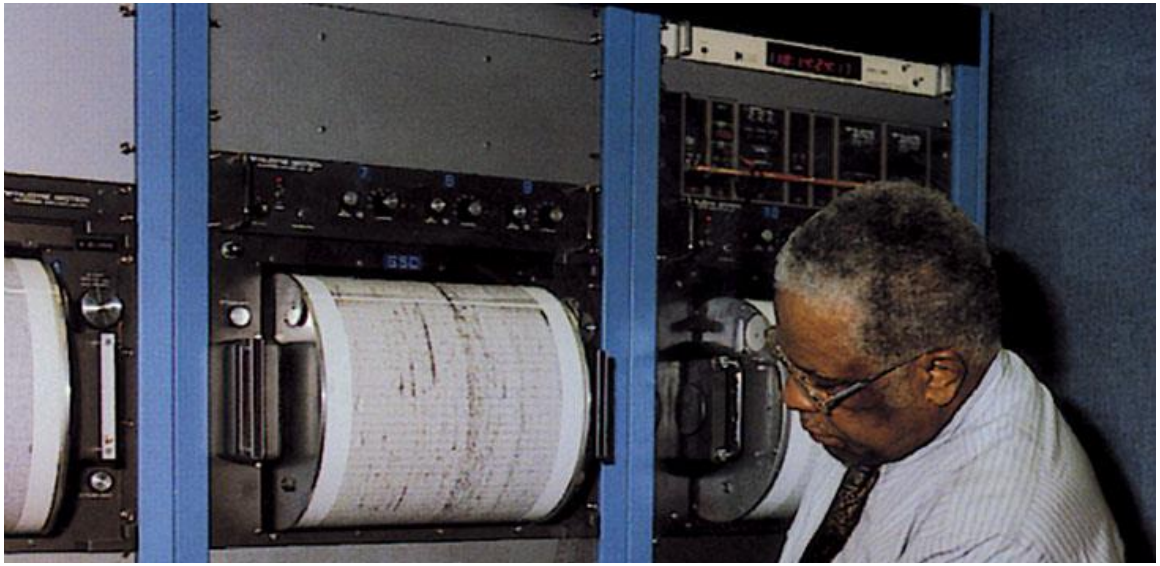


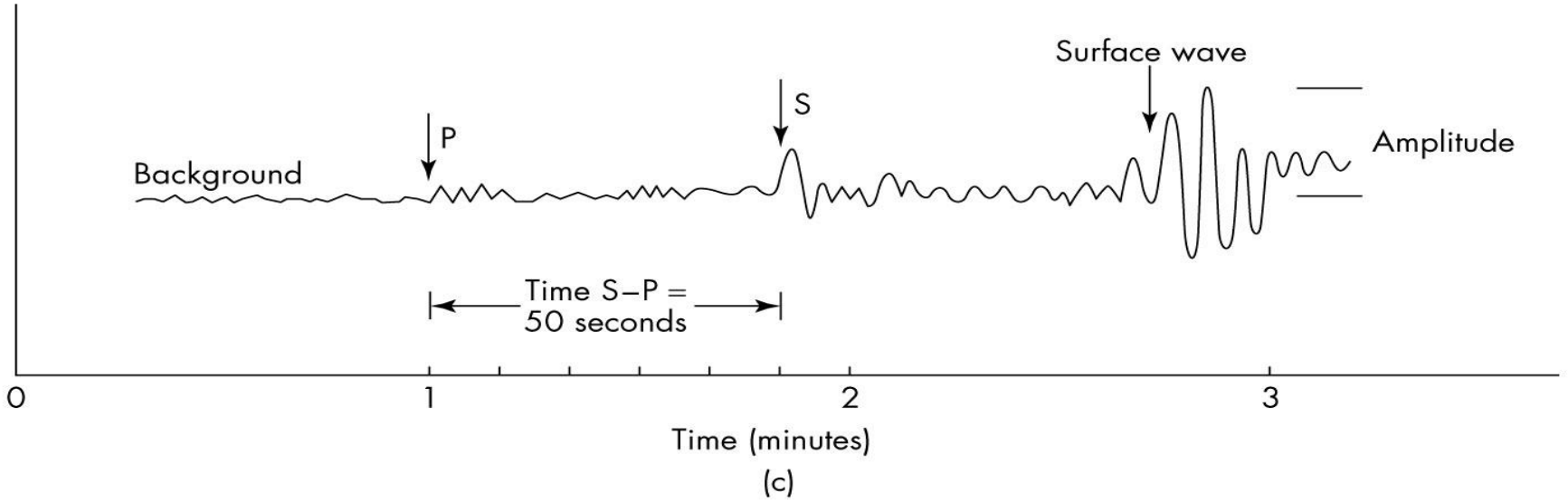
(a)



Animation: How Seismographs Work



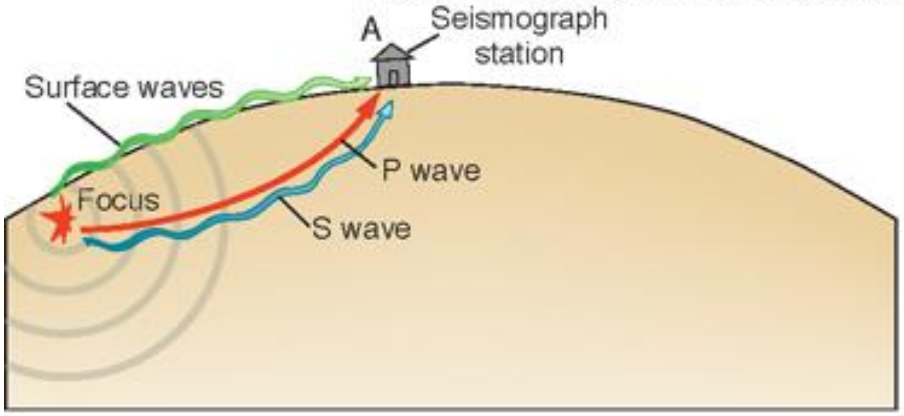




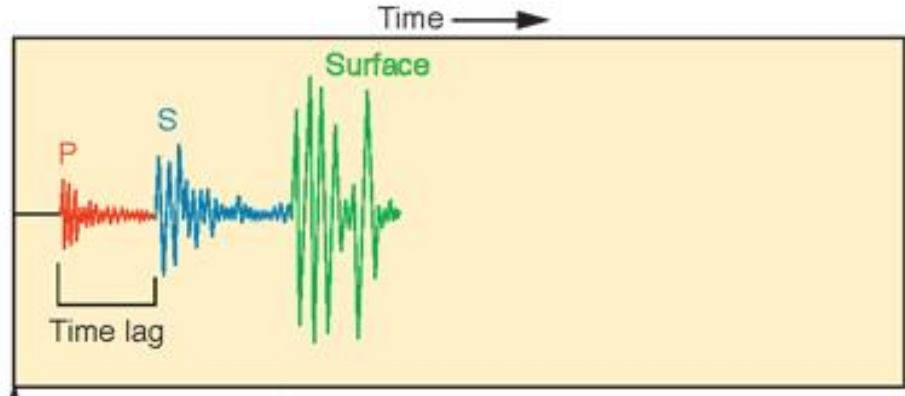
Record of earthquakes: Seismogram

How could you distinguish seismic wave from naturally occurring waves, e.g., sea wave?

Order of arrivals: P - S - Surface waves

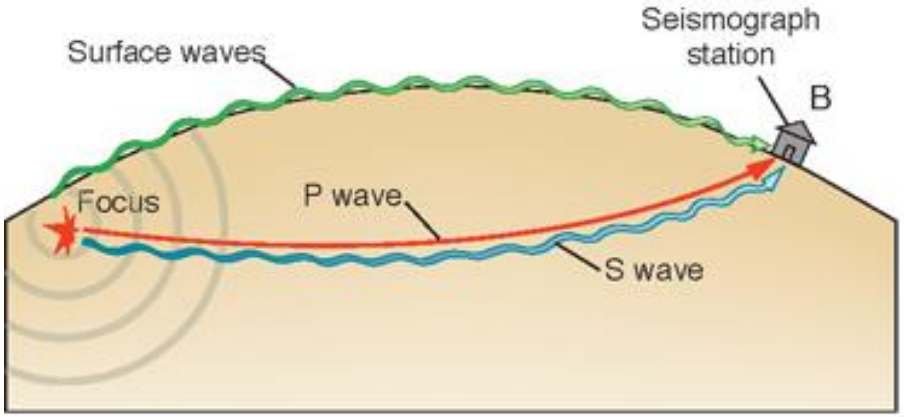


A Station near focus

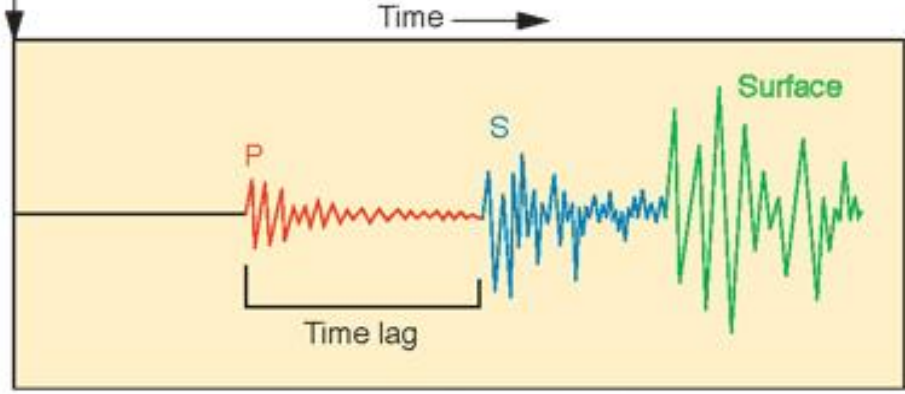


Seismogram from station A

Time of earthquake



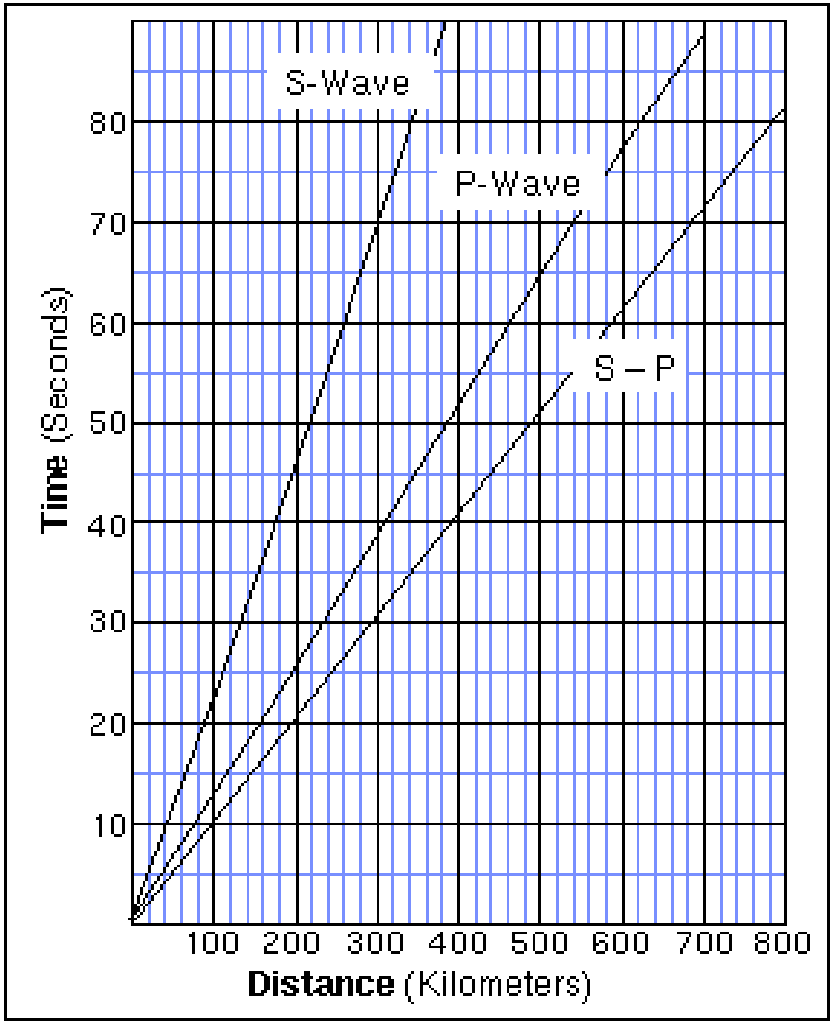
B Station far from focus

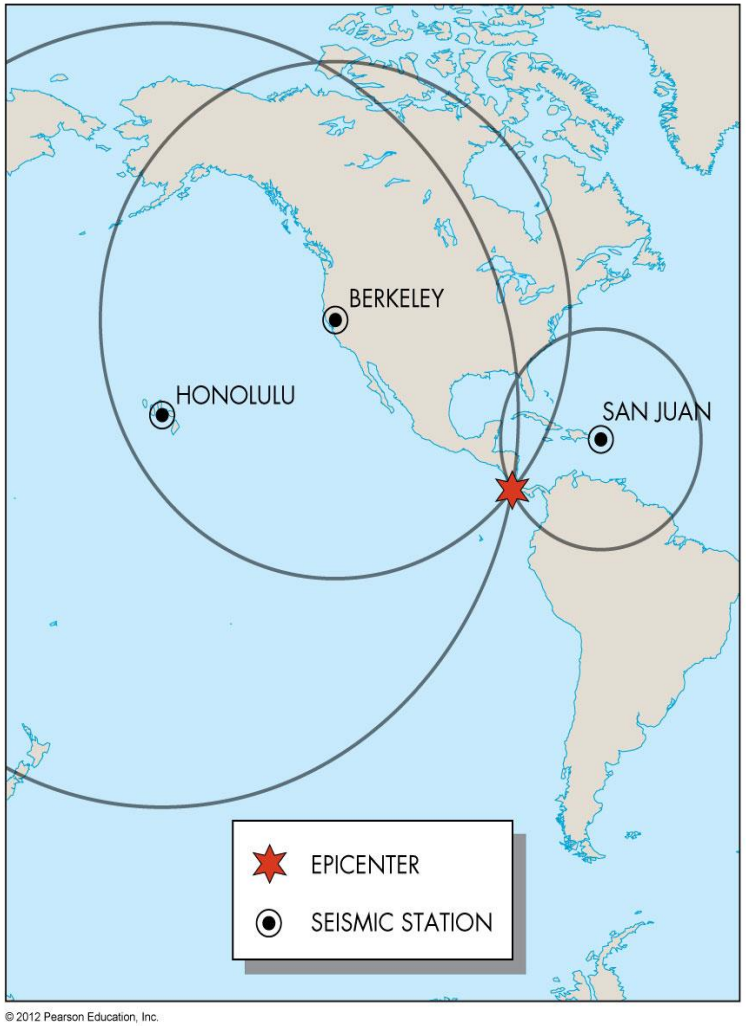


Seismogram from station B

Locating an Earthquake

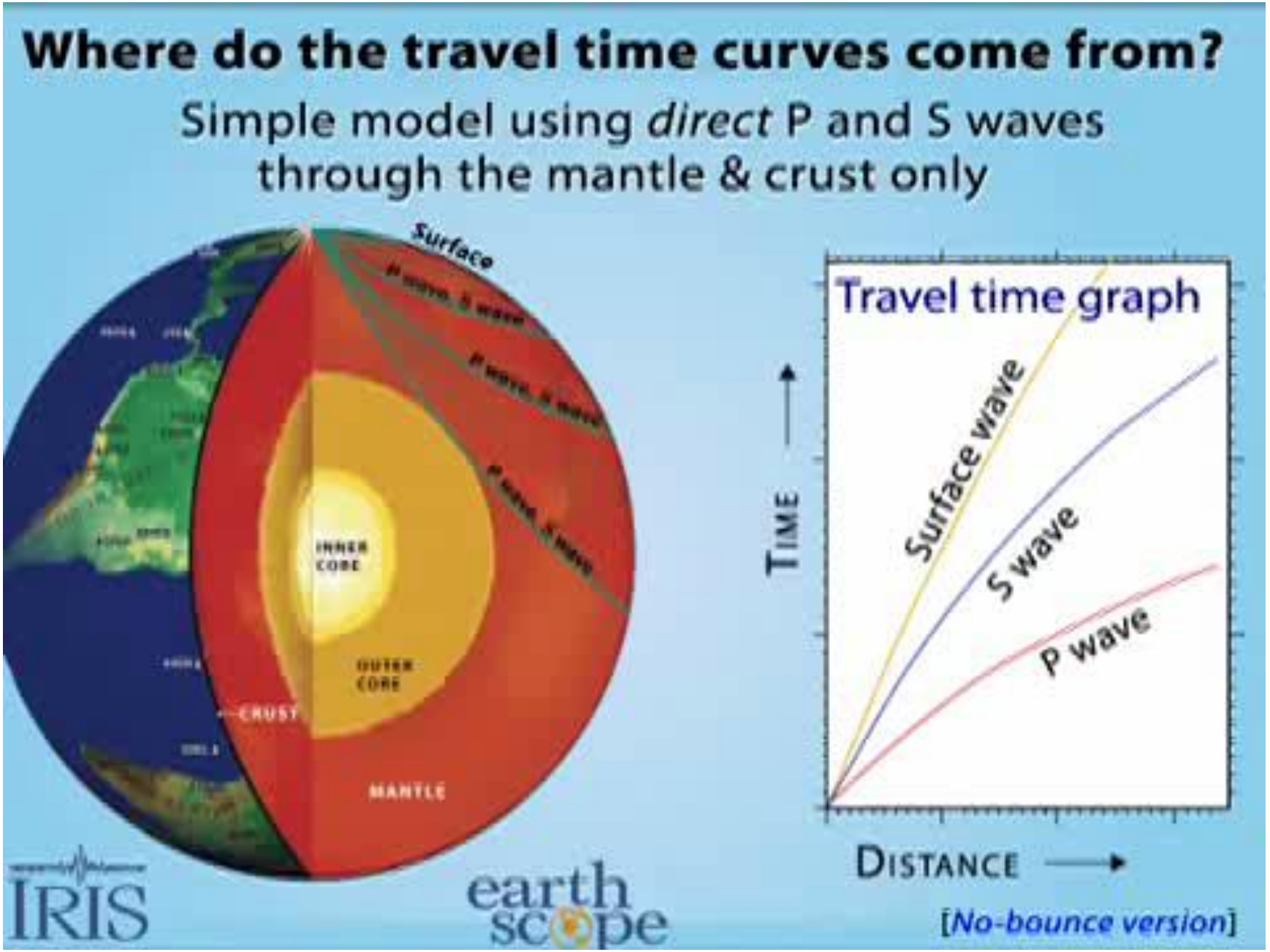
: Use travel time difference between P & S waves





S-P travel time curve

Animation: Creating Travel Time Curve



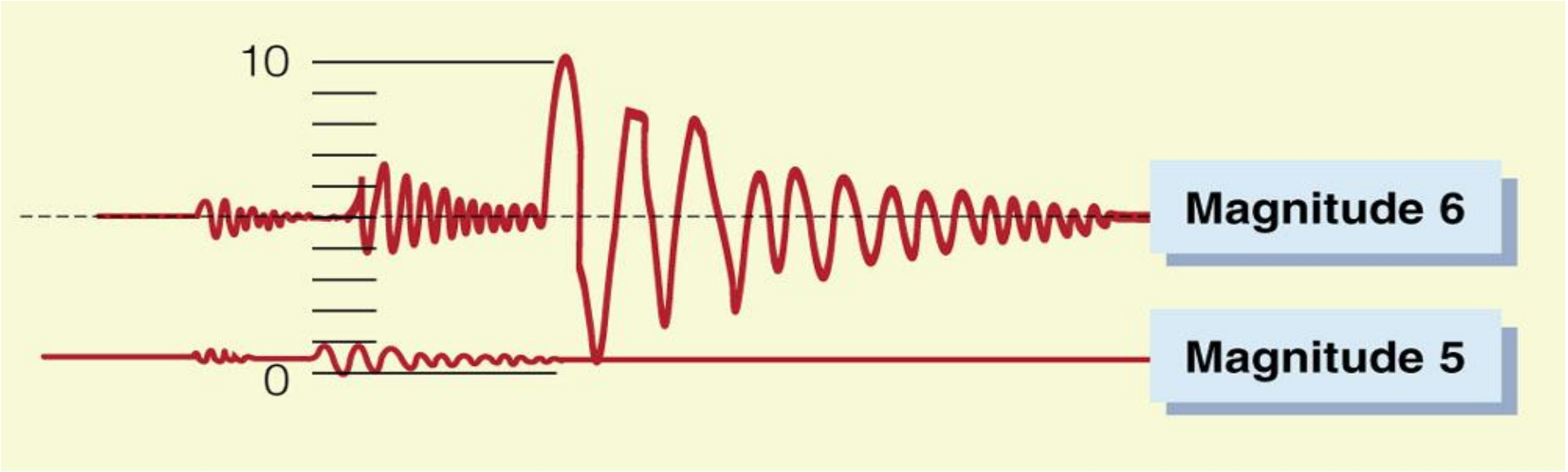
The Sizes of Earthquakes

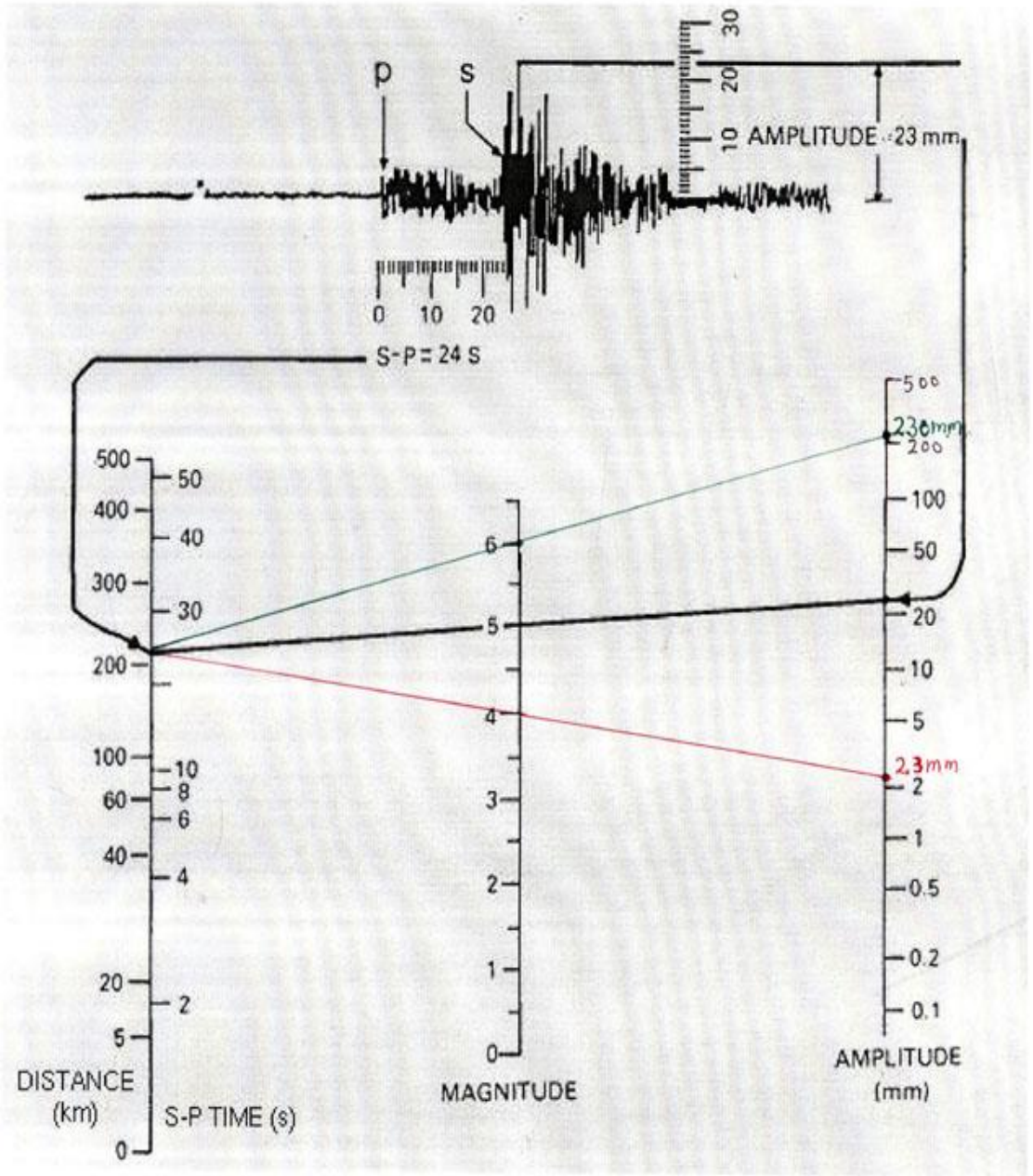
(A) Magnitude: : based on the **size of ground motion** measured by seismograph

Richter Scale: based on amplitude of ground vibration

Log scale:1 unit increase in magnitude

= a 10-fold increase in amplitude of the ground motion





e.g.,

M	Amp.	factor
4	2.3 mm	0.1 x
5	23 mm	1 x
6	230 mm	10 x
7	2300 mm	100 x

Factor of Amplitude

$$= 10^{n}$$

(n = difference in magnitude)

Richter scale is open-ended

(theoretically no maximum value)

However, in practice M ~ 9 is maximum.

Why?

Rocks have finite strength, tend to break after a certain amount of energy is stored in the rocks

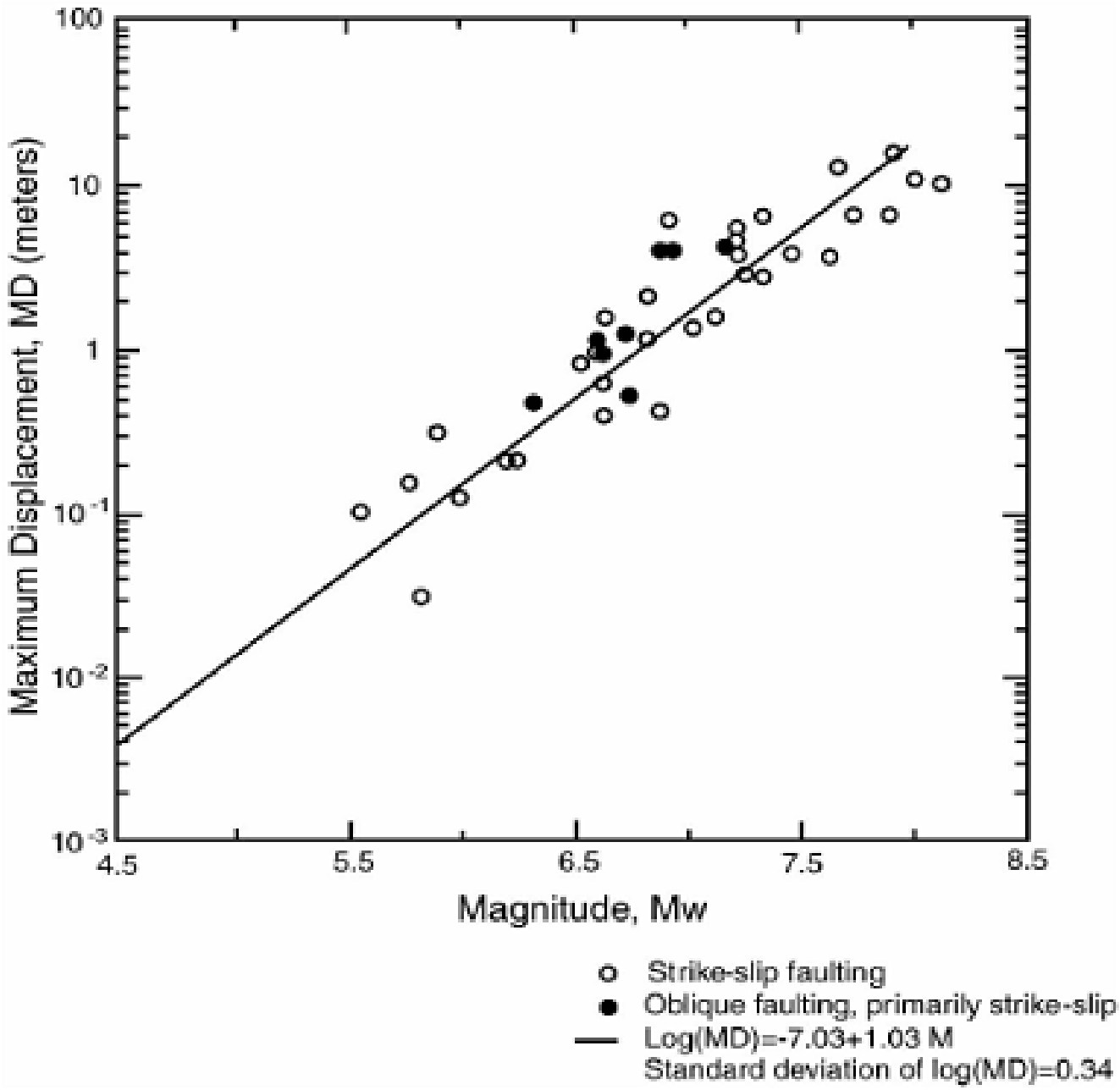
The Sizes of Earthquakes

(A) Magnitude: : based on the **size of ground motion** measured by seismograph

Richter Scale: based on amplitude of ground vibration

Moment Magnitude: based on energy release (reflects in both amplitude and duration of ground motion)

Difference in Magnitude	Difference in Amplitude	Difference in Energy
0.5	~ 3 times (i.e.,$10^{0.5}$)	~ 5.5 times (i.e., $32^{0.5}$)
1	10 times (i.e.,10^{1})	~ 32 times (i.e., 32^{1})
2	100 times (i.e.,10^{2})	~ 1000 times (i.e., 32^{2})



Maximum Surface Fault Displacement vs. Earthquake Moment Magnitude, M_w

The Size of Earthquakes

(B) Intensity- "Modified Mercalli Scale"
: A measure of earthquake damage at a given location; range from I to XII

Intensity depends on:

-- size of EQ

-- strength of structures

-- proximity to the epicenter

-- local geology

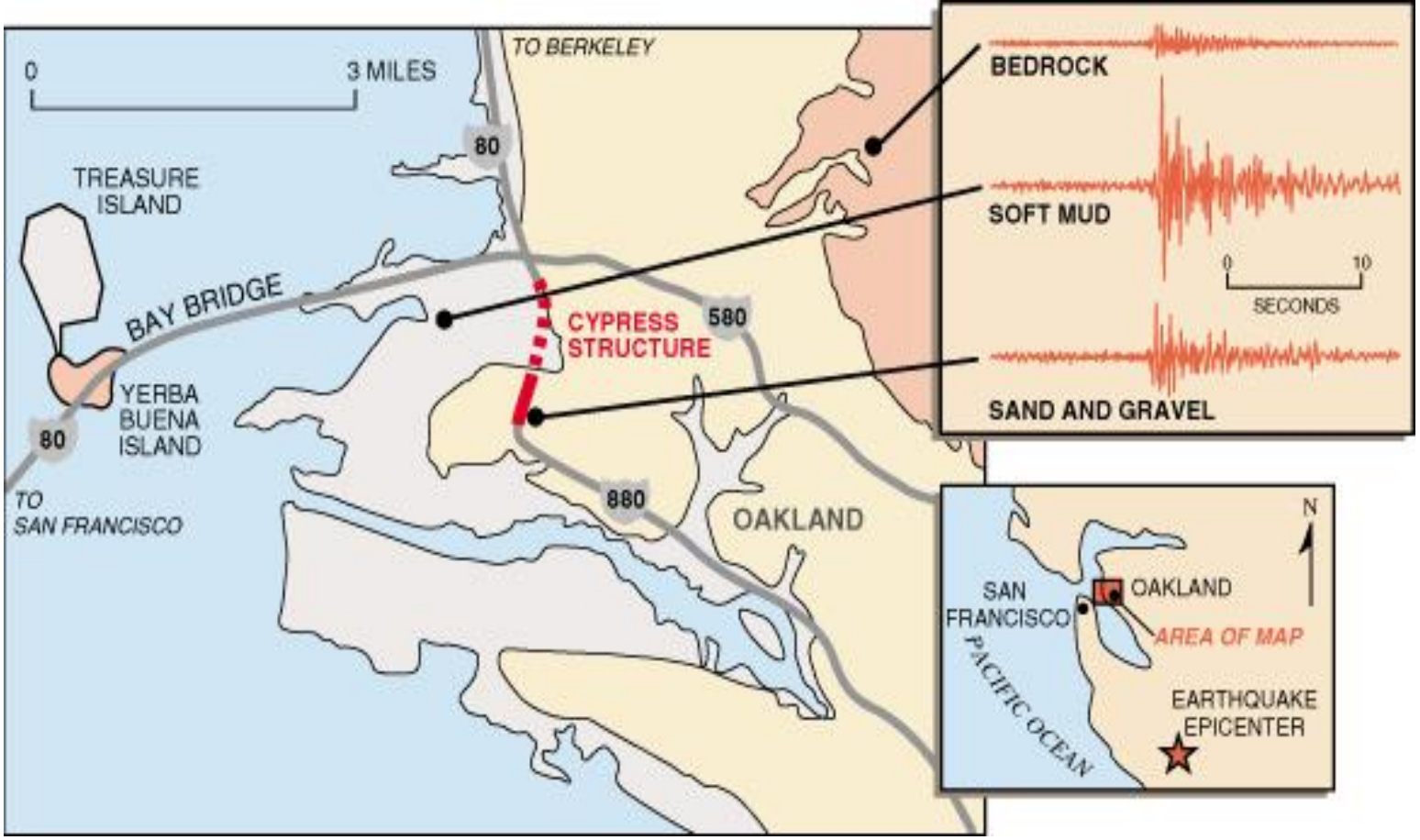
Intensity map, 1971 California earthquake (Mw = 6.7)

The Size of Earthquakes

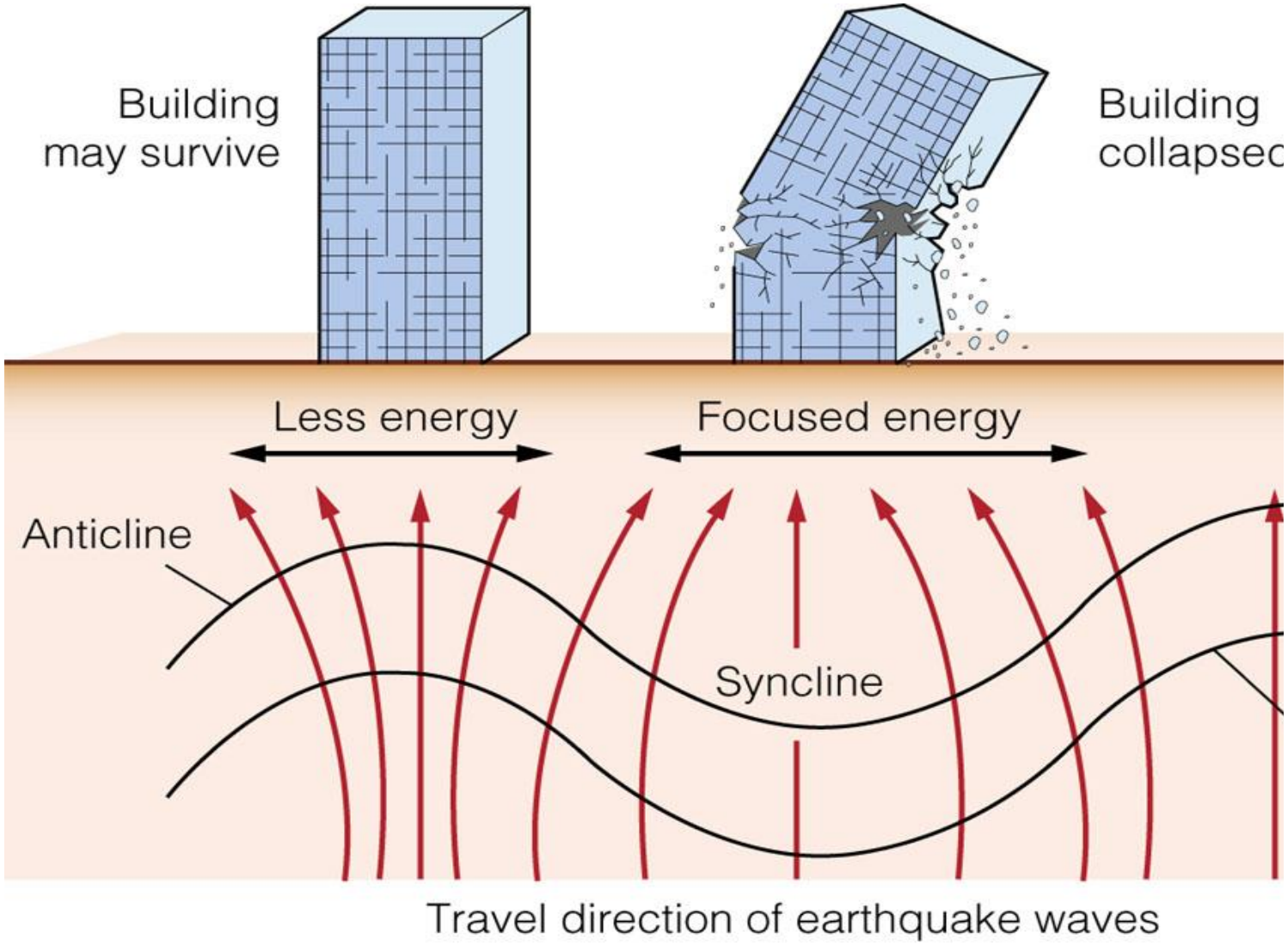
(B) Intensity- "Modified Mercalli Scale"

: A measure of earthquake damage at a given location from I to XII

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felto nly by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.



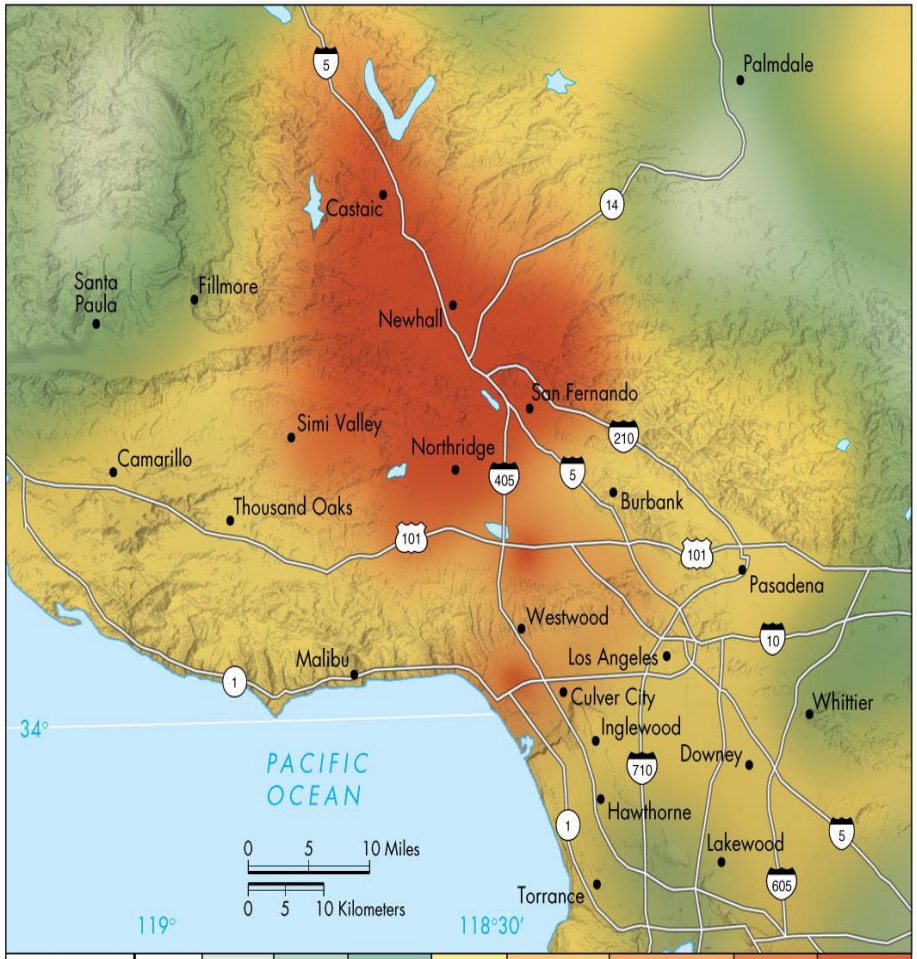
Soft mud amplifies ground vibration the most



Effects of geologic structures on ground shaking

Instrumental Intensity (ShakeMap)

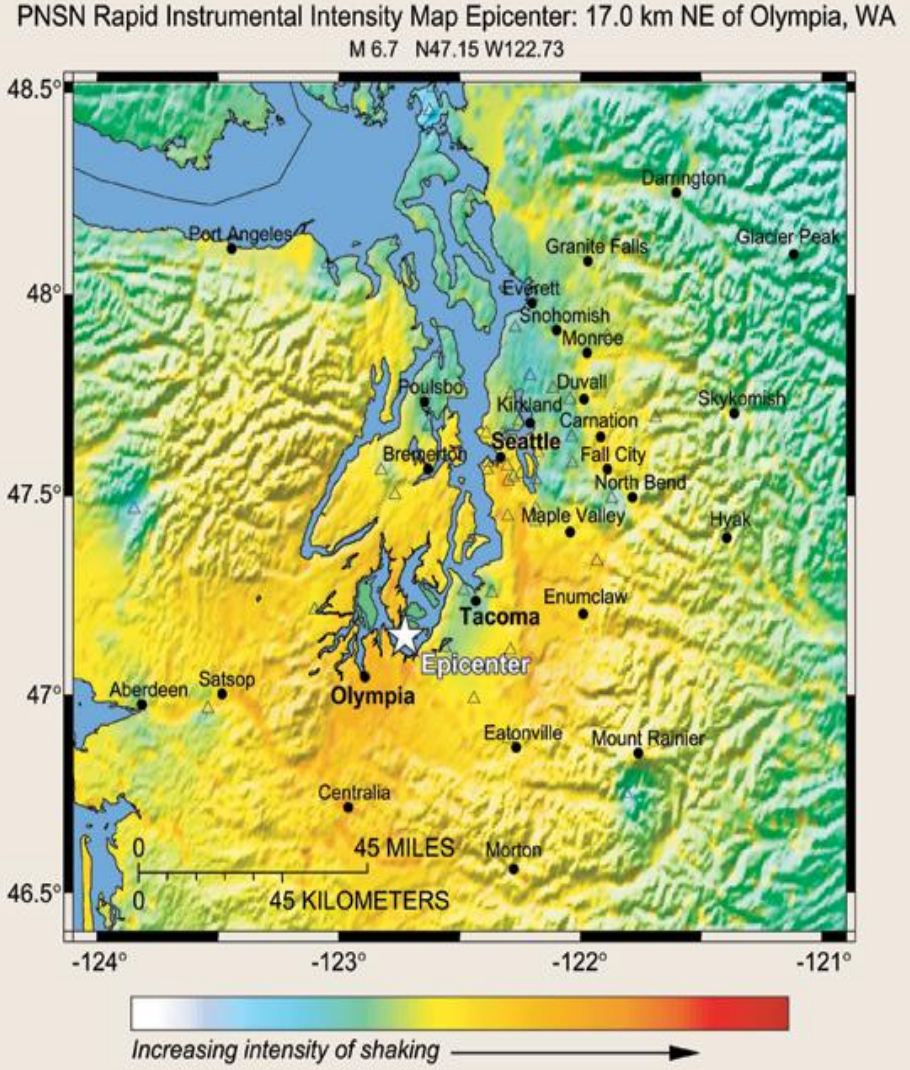
1994 Northridge, CA, Mw = 6.7

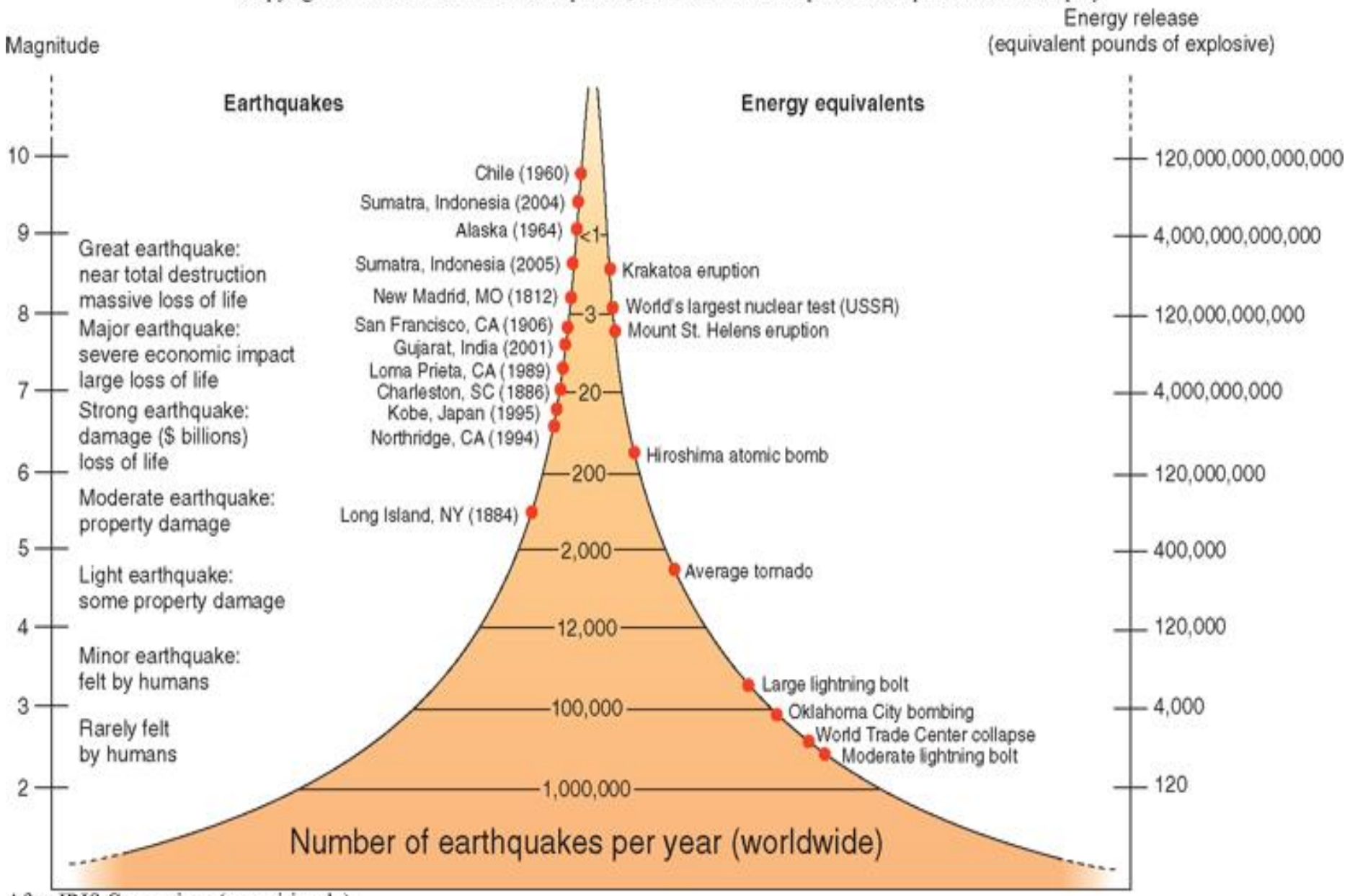


Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	not felt	weak	light	moderate	strong	very strong	severe	violent	extreme
Damage	none	none	none	very light	light	moderate	moderate/heavy	heavy	very heavy

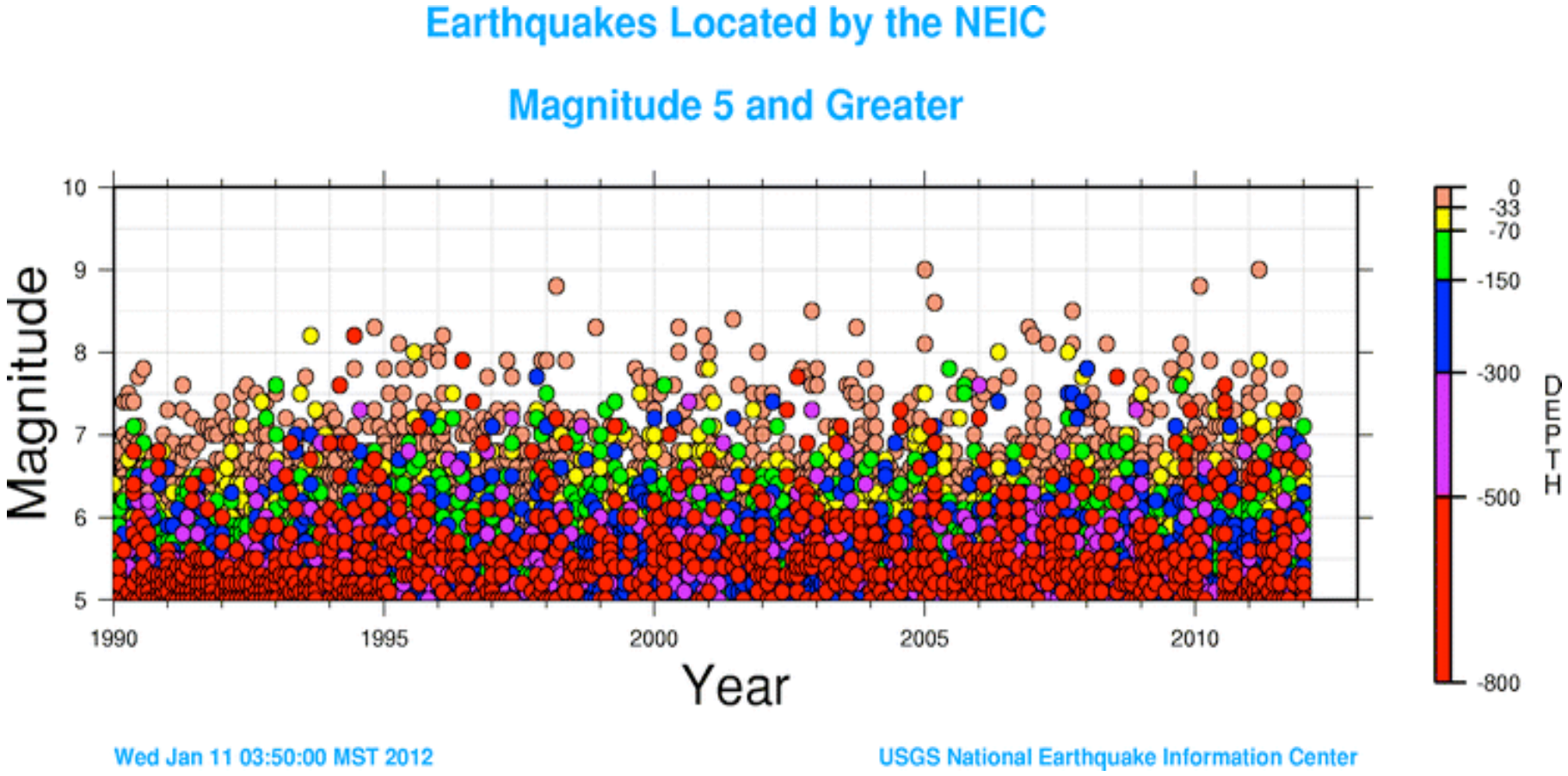
(a)

2001 Nisqually, WA, Mw = 6.7



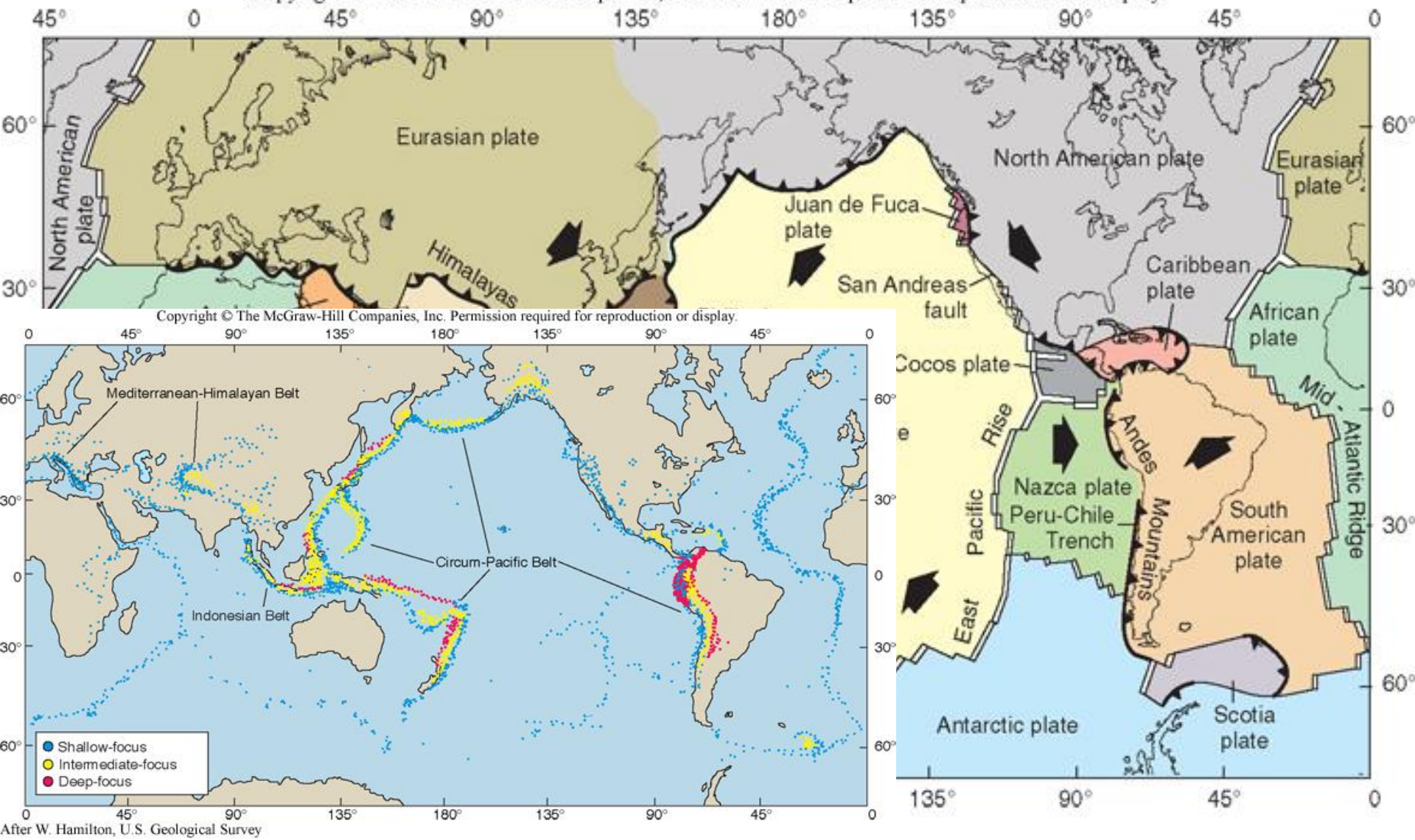


After IRIS Consortium (www.iris.edu)



Frequency and focal depth for earthquakes with magnitude 5 and greater recorded since 1900

Earthquakes and Plate Tectonics

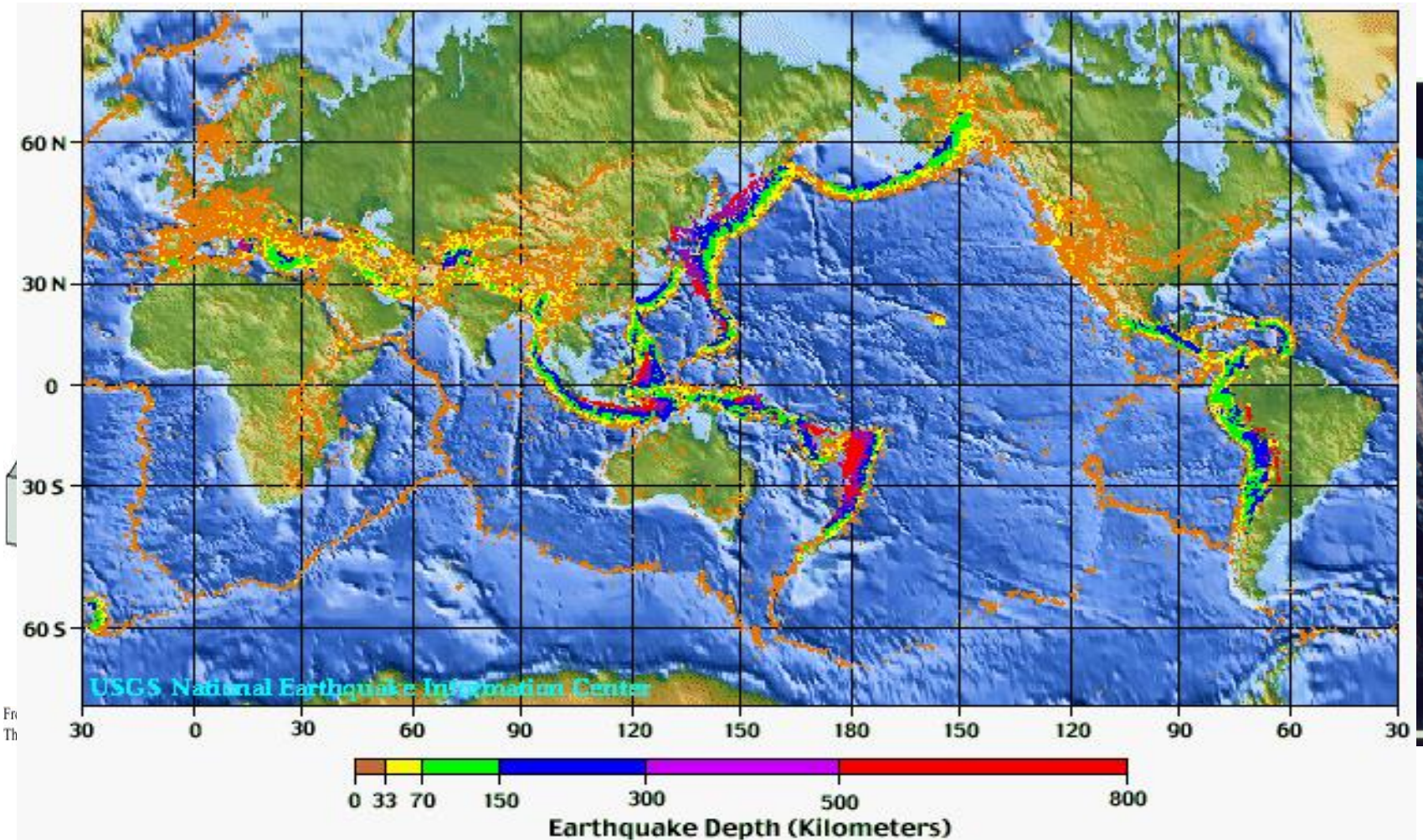


After W. Hamilton, U.S. Geological Survey

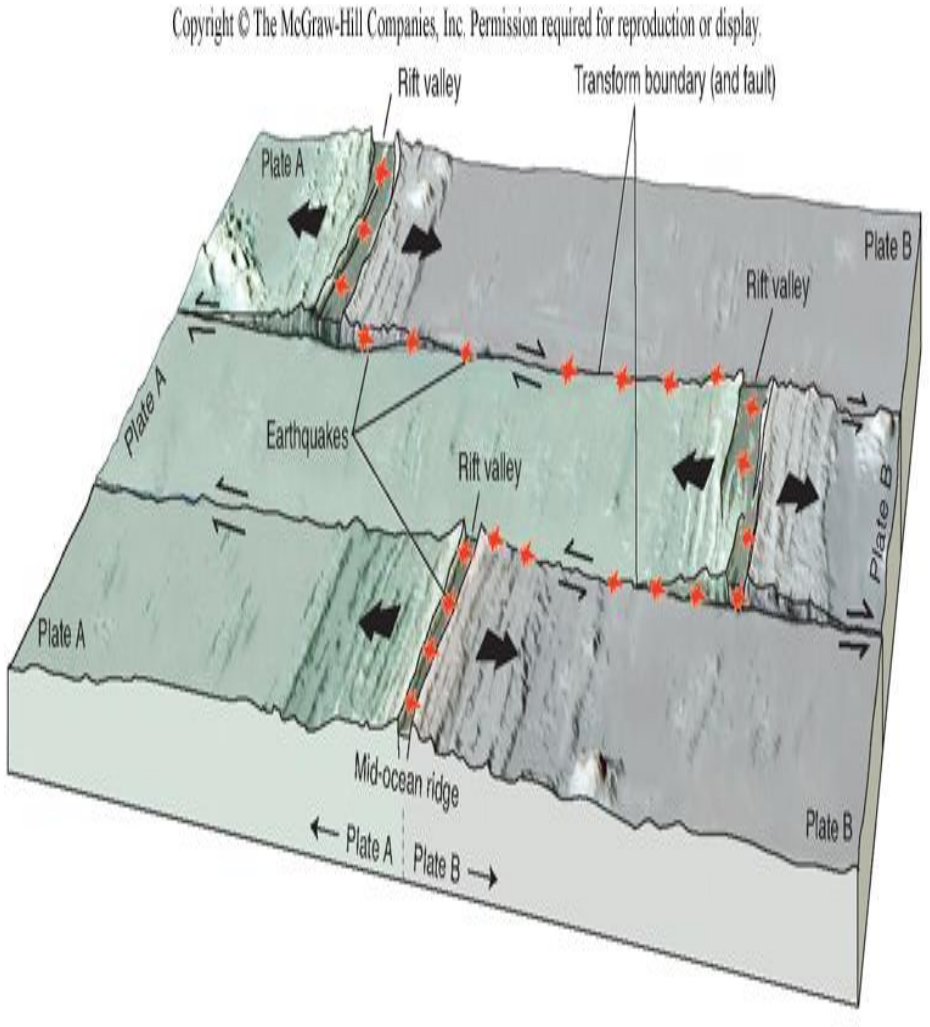
(A) Divergent Boundaries

-- Mid-ocean ridge -- Continental rift

Shallow earthquakes



(B) Transform Boundaries



Shallow earthquakes

(C) Convergent Boundaries

convergent

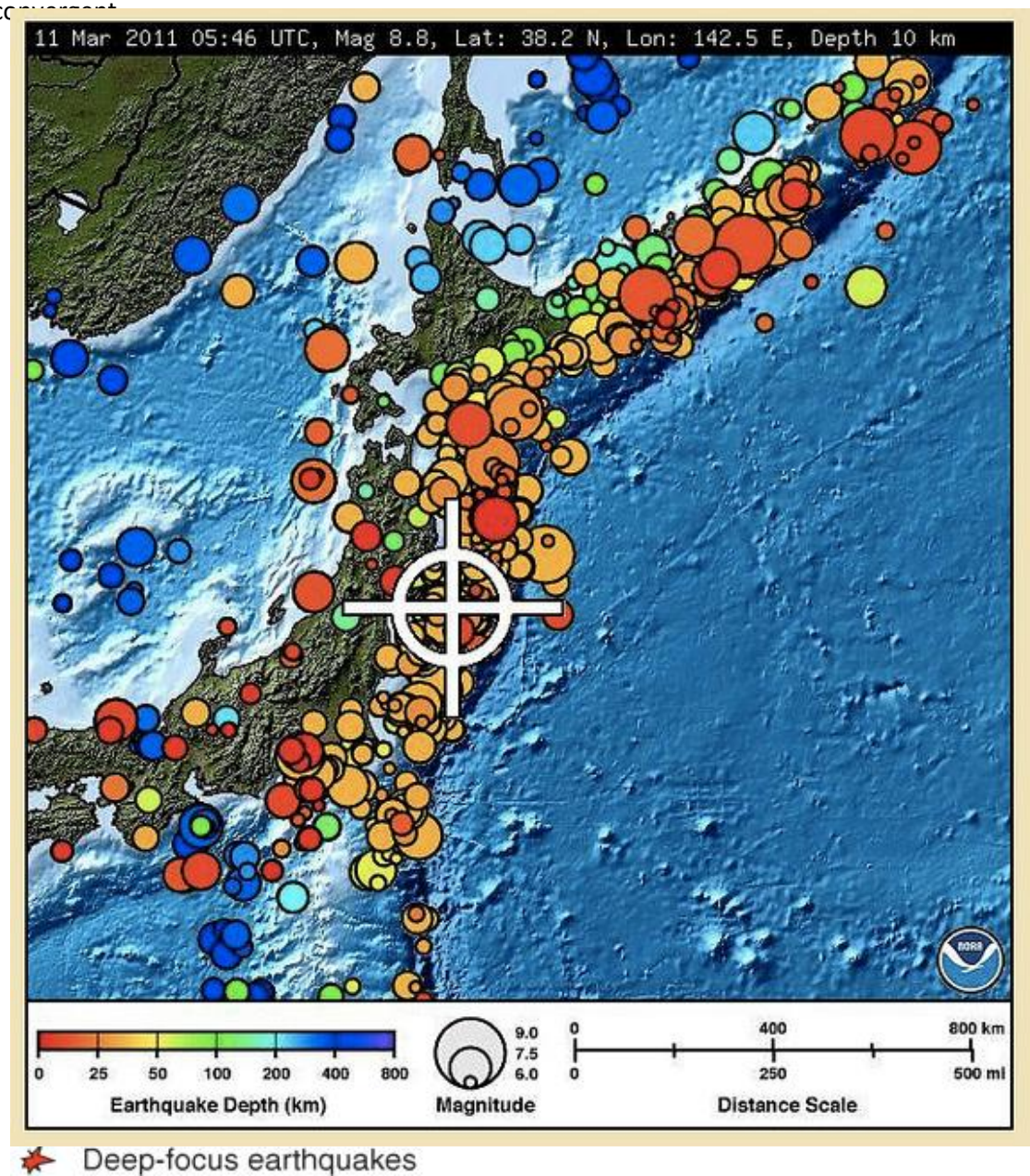
Subduction zones

(Wadati-Benioff zone)

Shallow to deep earthquakes

Deepest:

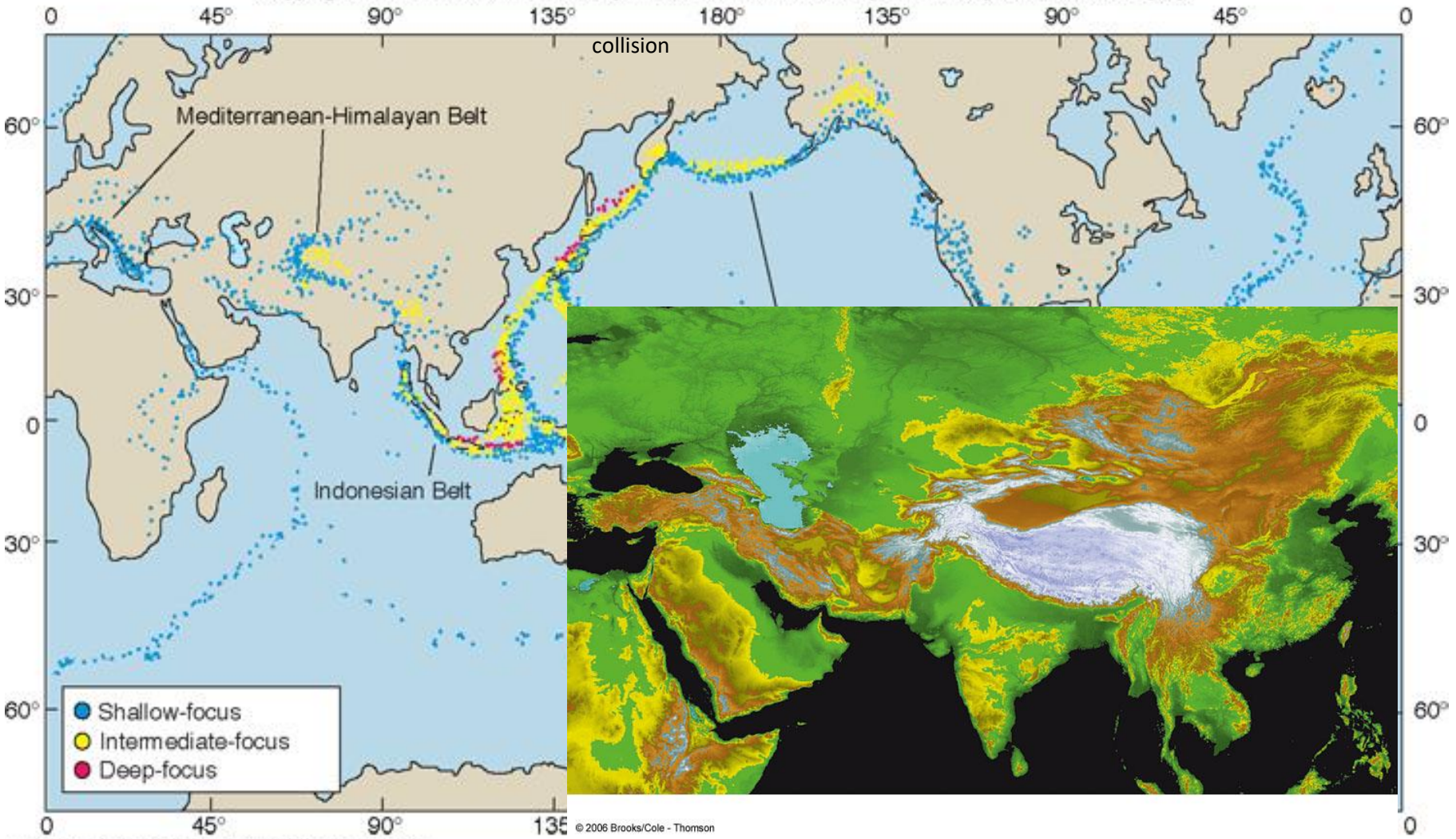
~ 670 KM deep



(C) Convergent Boundaries

Collision zones

Shallow to intermediate earthquakes

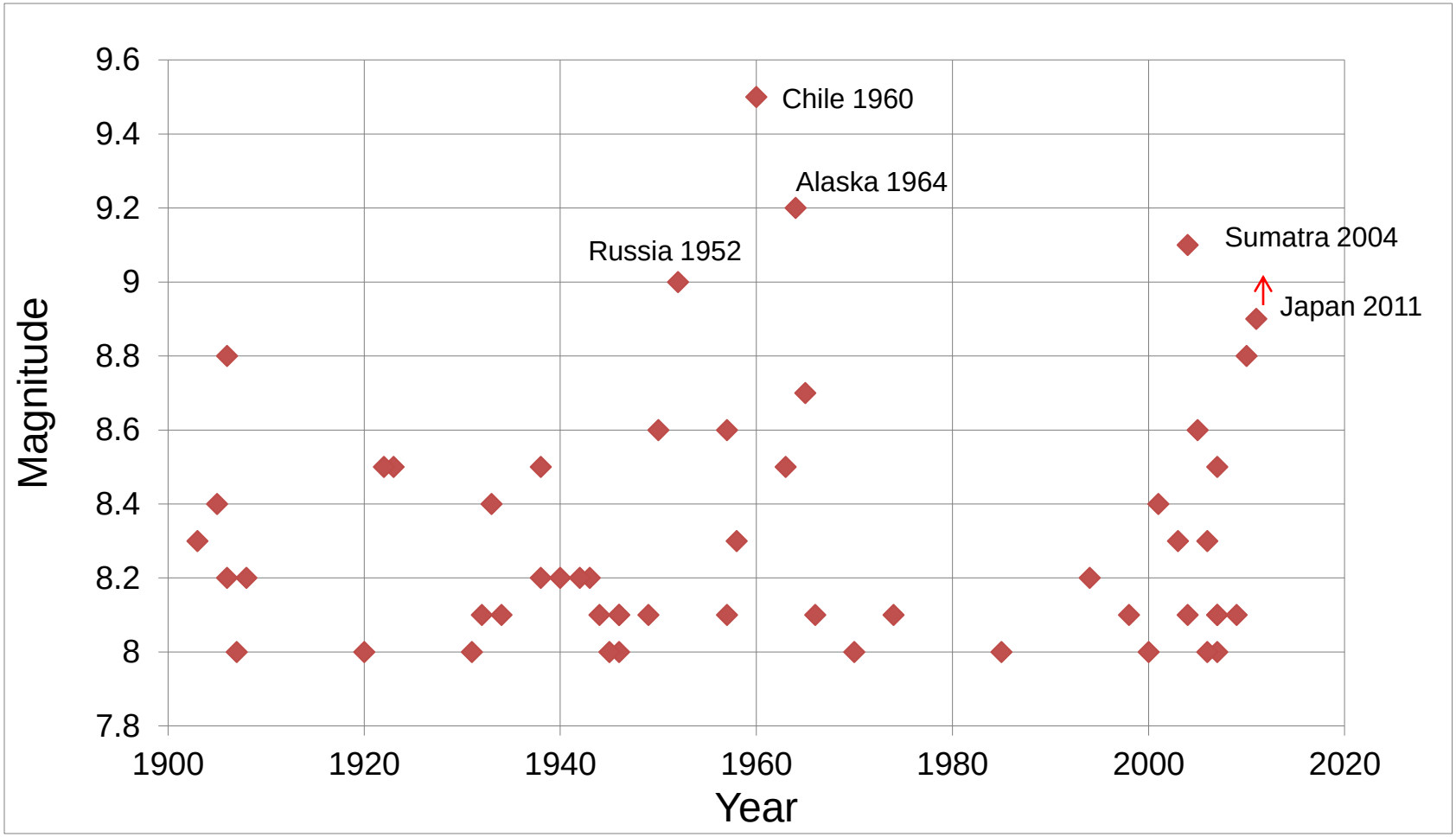


After W. Hamilton, U.S. Geological Survey

Table 4-2 The Largest World Earthquakes Since 1900

Earthquake	Date	Magnitude	Cause
Chile	May 22, 1960	9.5	Subduction zone
Anchorage, Alaska	Mar. 28, 1964	9.2	Subduction zone
Andreanof Is., Alaska	Mar. 9, 1957	9.1	Subduction zone
Northern Sumatra	Dec. 26, 2004	9.0	Subduction zone
Kamchatka	Nov. 4, 1952	9.0	Subduction zone

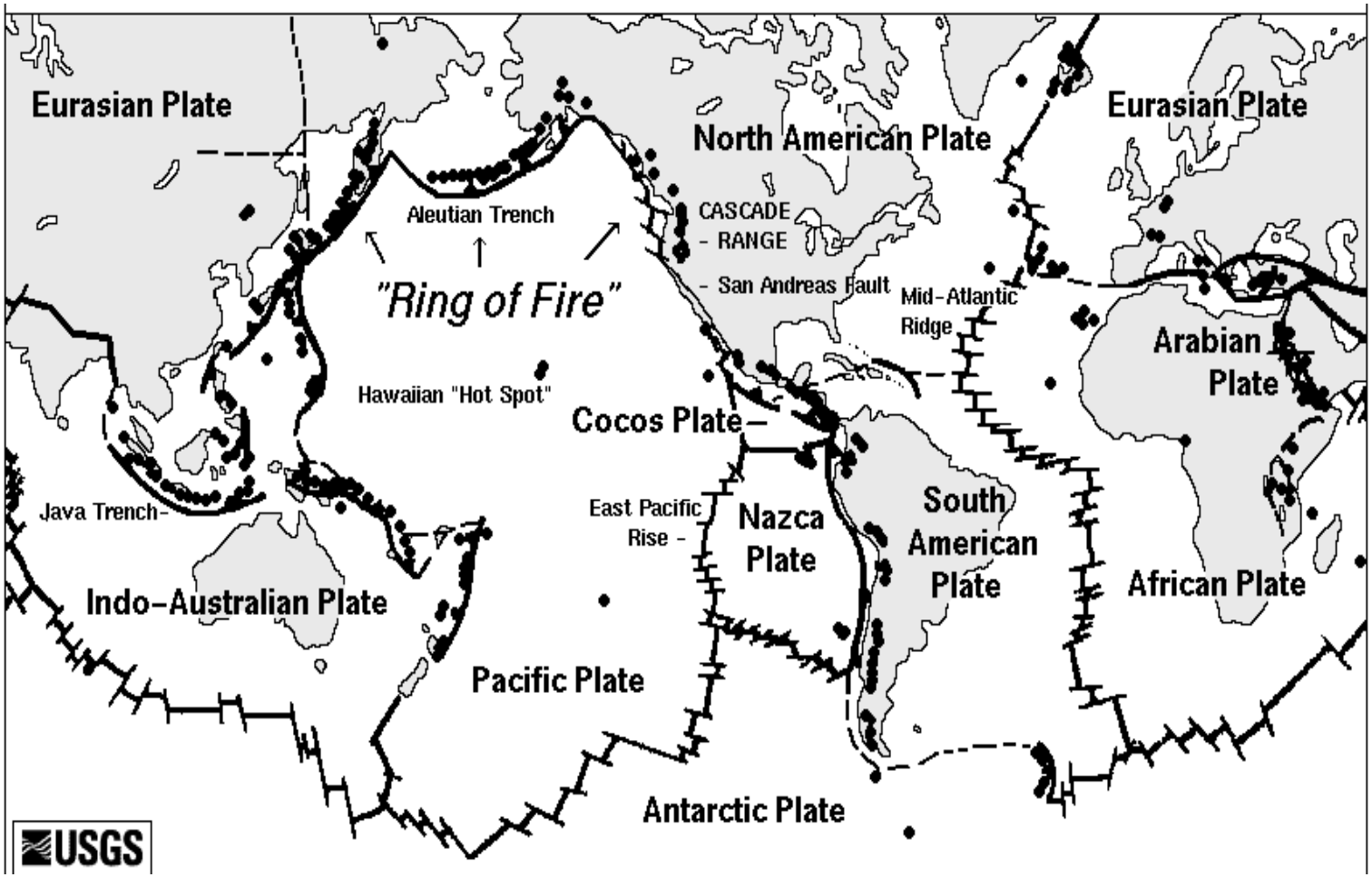
All at subduction zones!



Great (M > 8) earthquakes since 1900 (figure courtesy of IRIS)

Largest EQ ever recorded: 1960 – **Chile (M = 9.5)**

Caused by **subduction of Nazca Plate beneath South American Plate.**



"Recalling 1960 Chile Quake"

“Recalling 1960 Chile Quake”

Deadliest subdcution zone earthquake ever reported
Sumatra, 12/26/2004, Mw = 9.1

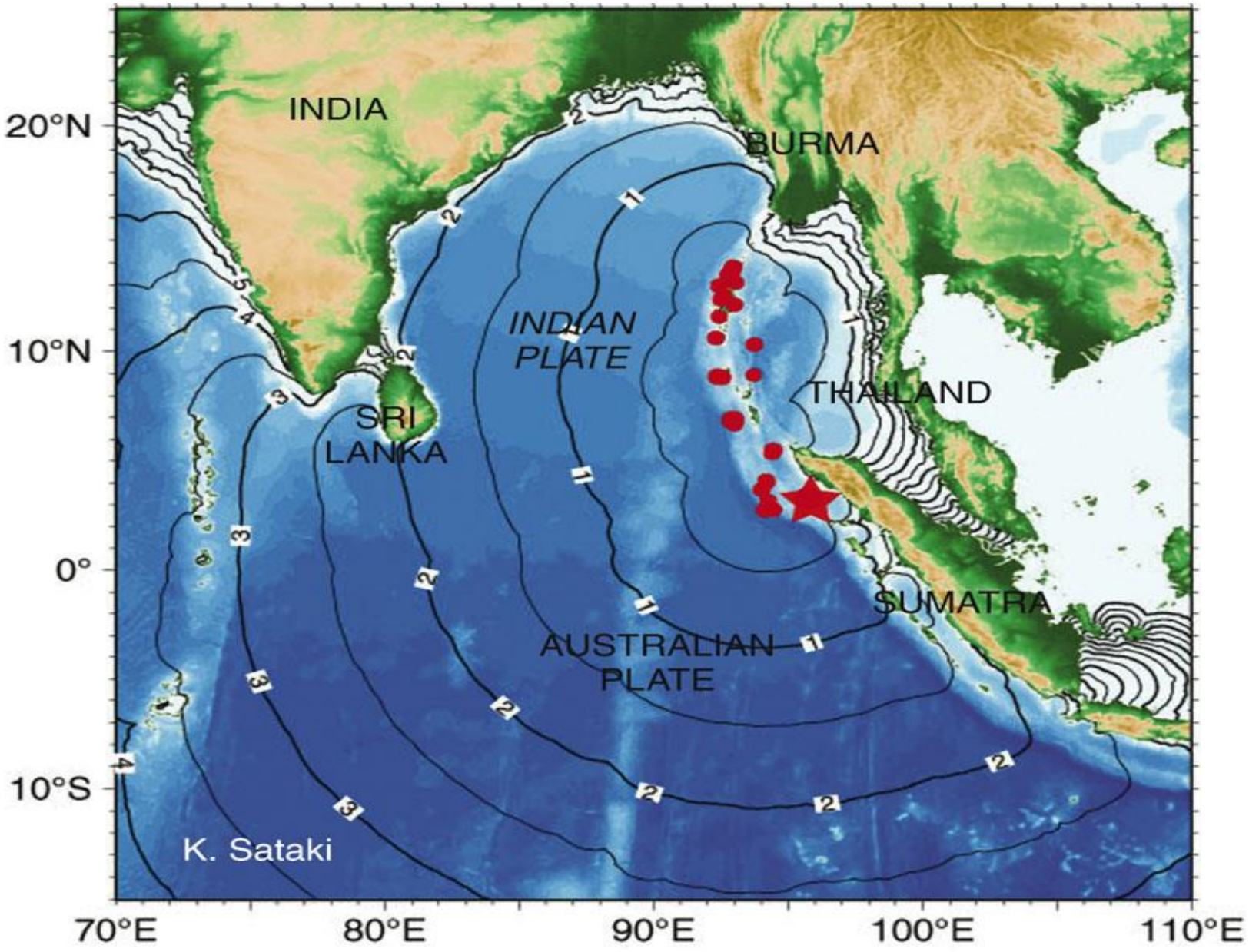
Subduction of

Indian Plate

beneath

Burma Plate

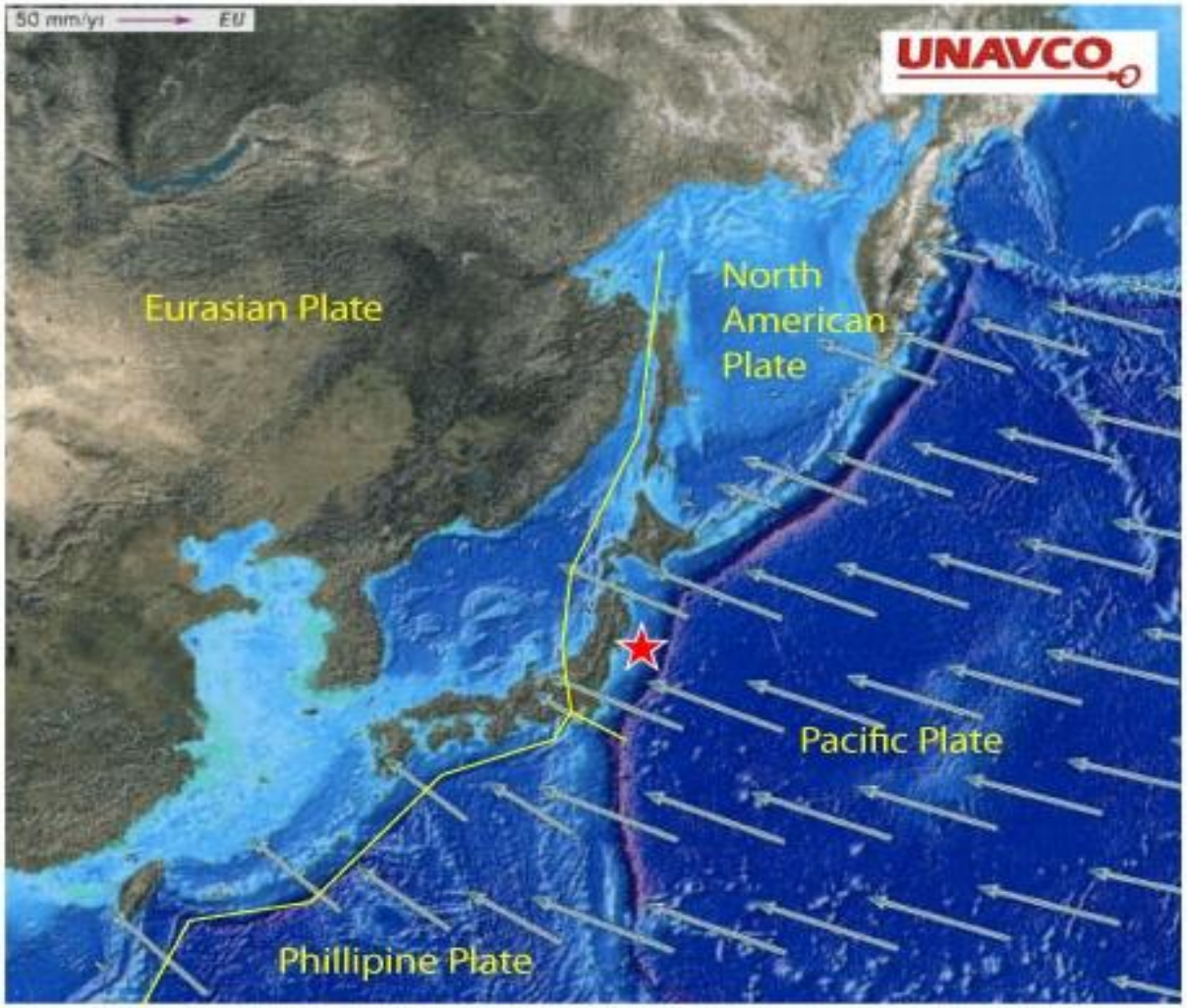
2004 tsunami leveled almost all of the homes in Banda Aceh, Sumatra



Asian Tsunami - CBS News – 20041227

Most costly natural disaster

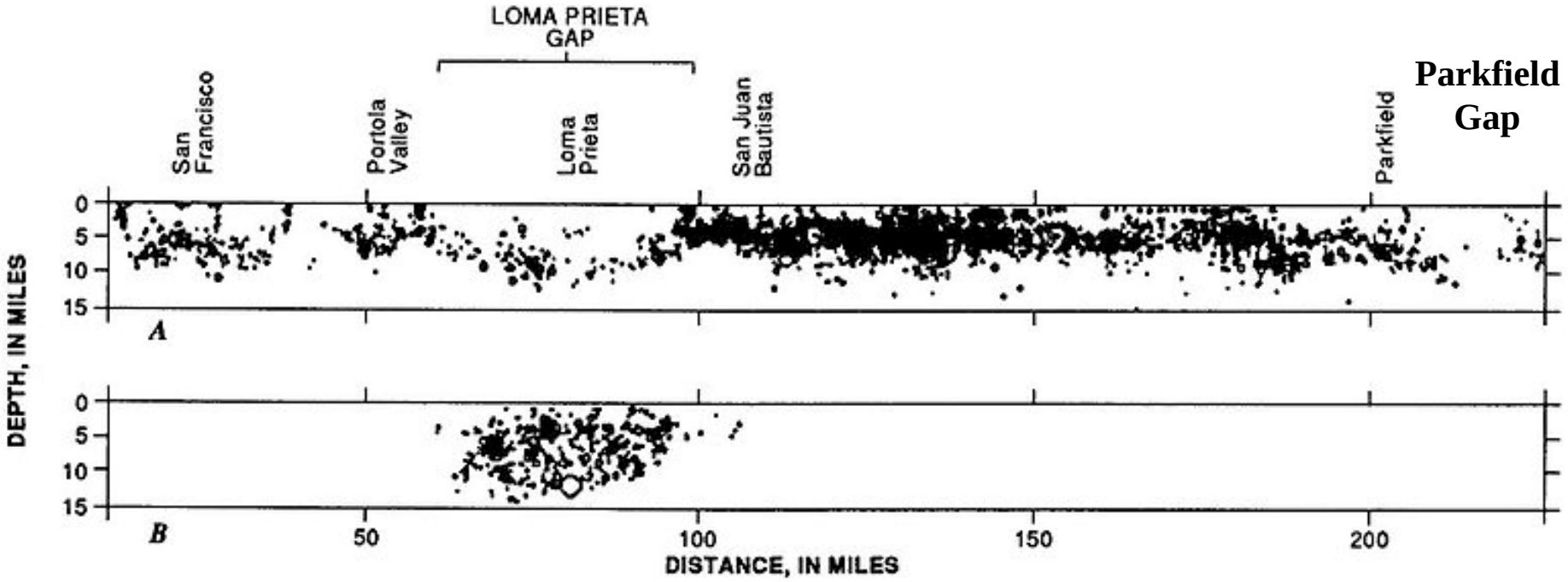
Tohoku, Japan, 3/11/2011 M= 9.0



Subduction of **Pacific Plate** beneath **North American Plate.**

Long-Range Earthquake Prediction

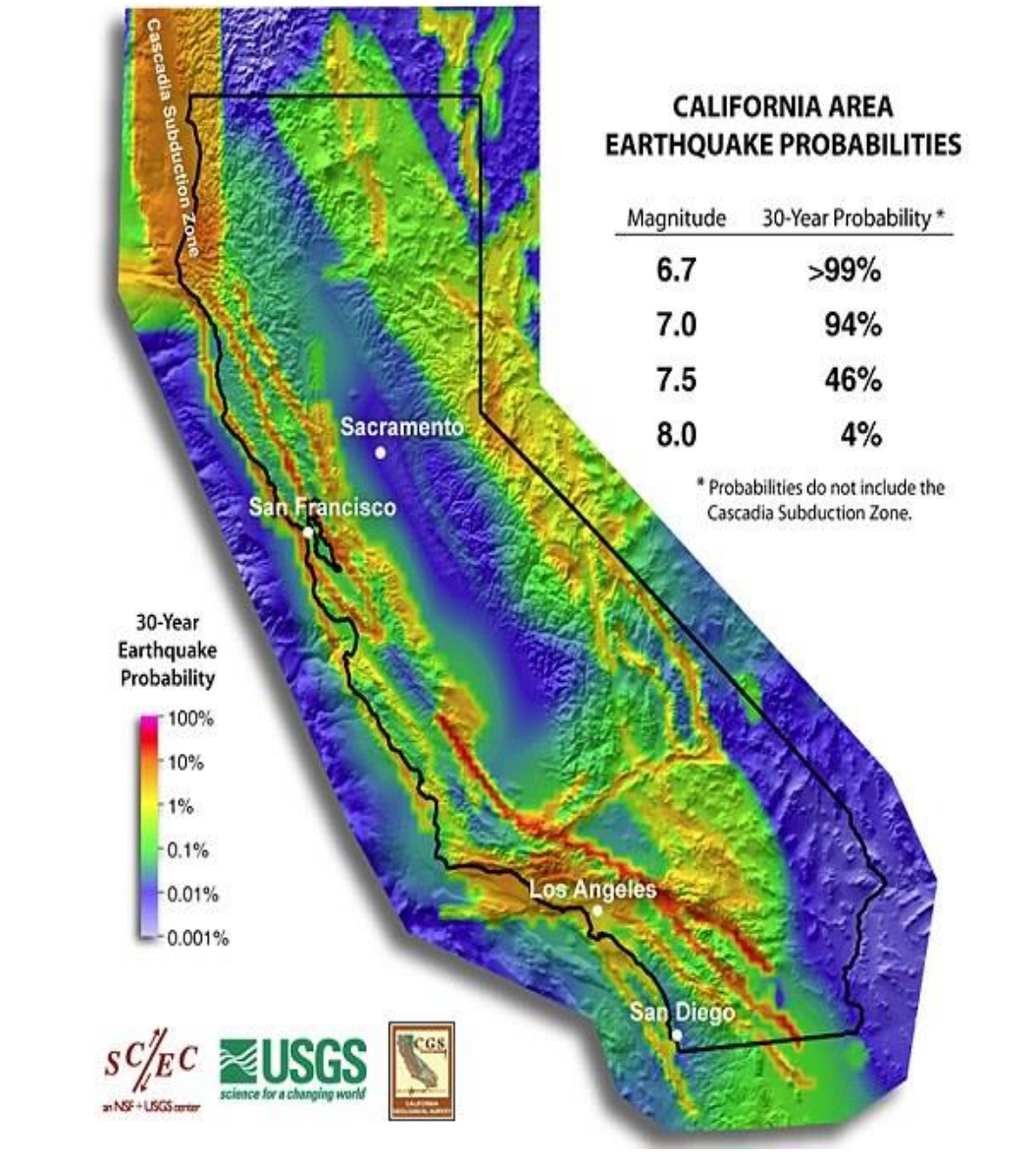
Seismic gap -- seismically active area which has not experienced major EQ for a long time



Seismicity along San Andreas Fault

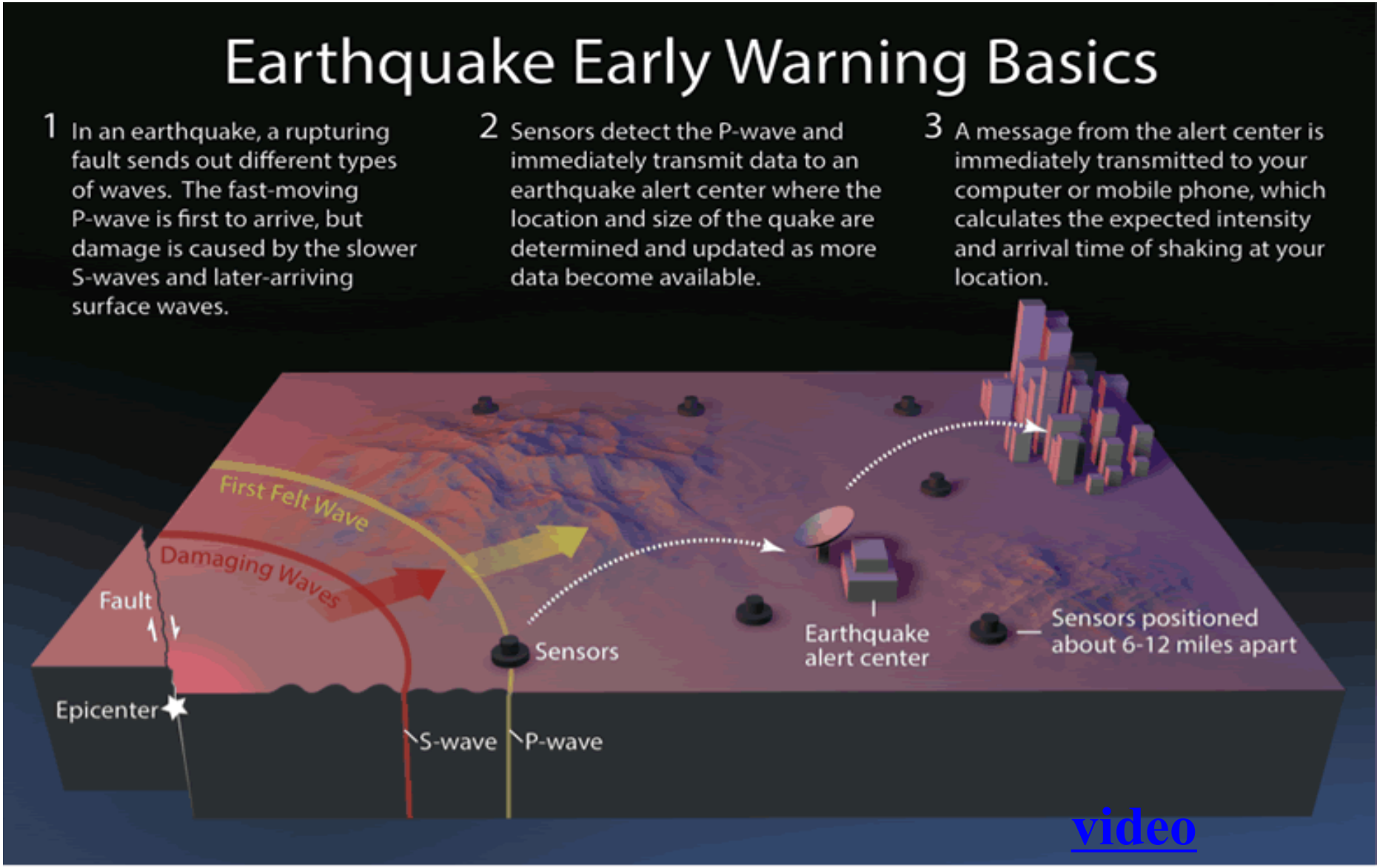
Long-Range Earthquake Warning

UCERF: Map of California Area Earthquake Probabilities



Short Range Earthquake Warning

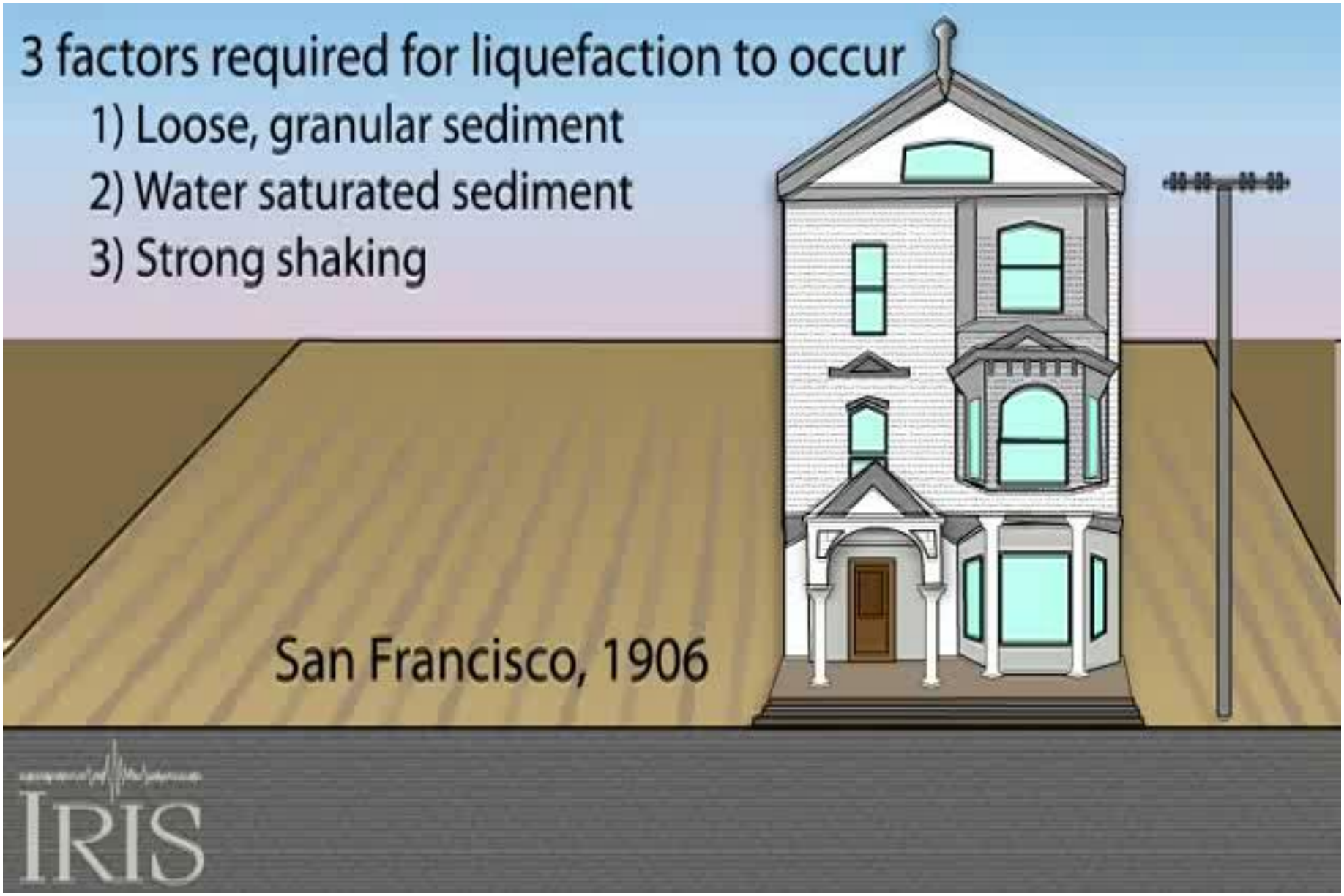
"P-Wave Warning System", or "Shake-Alert"



video

Measuring ‘p-waves’ to warn the public of impending quakes

Animation: Liquefaction, 1906 SF Earthquake



Animation: How will 3 buildings, engineered equally, on different bedrock react to an earthquake?