Earthquakes

Chapter 7

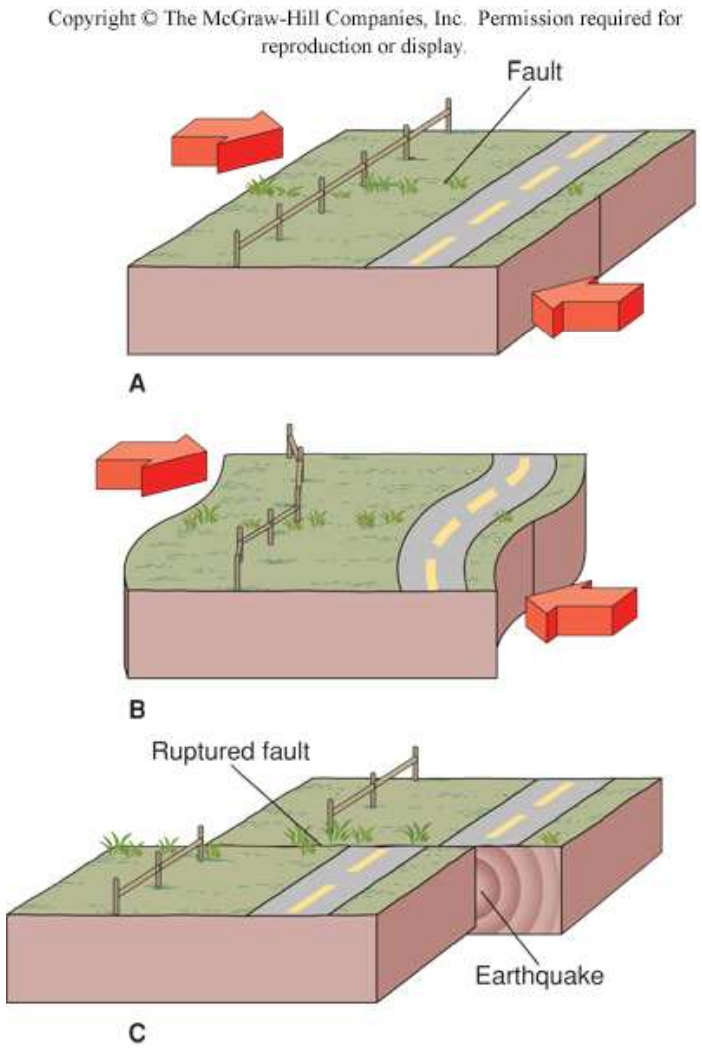
What are Earthquakes?

- The shaking or trembling caused by the sudden release of energy
- Usually associated with faulting or breaking of rocks
- Continuing adjustment of position results in aftershocks

Earthquakes

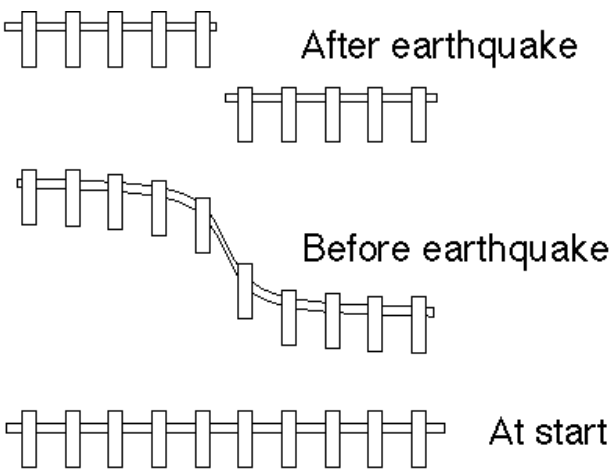
- Tectonic forces within the Earth produce stresses on rocks that eventually exceed their elastic limits, resulting in brittle failure

- Energy is released during earthquakes in the form of *seismic waves*
  - Released from a position along a break between two rock masses (fault)



Elastic rebound theory

- *Elastic rebound theory* - earthquakes are a sudden release of strain progressively stored in rocks that bend until they finally break and move along a *fault*

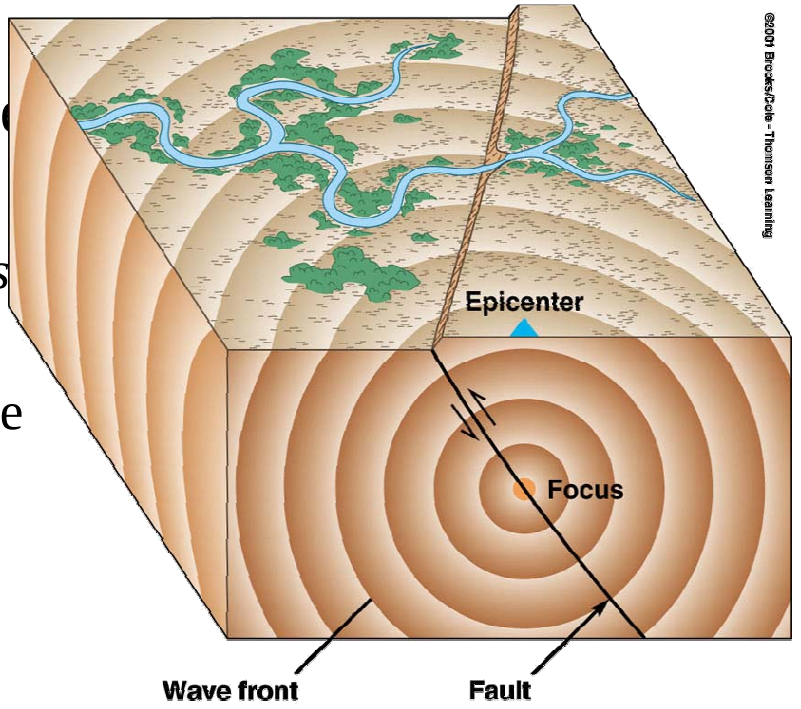


This picture, taken in Marin County, CA (1906) shows a fence that was offset about 8.5 feet along the trace of the fault

Seismic Waves

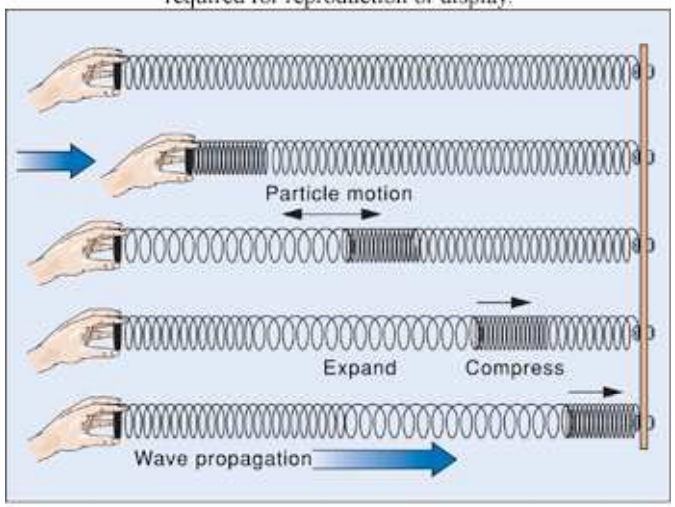
- *Focus* (or *hypocenter*) - the point of initial breakage and movement along a fault, where seismic waves originate
- *Epicenter* - point on Earth's surface directly above the focus

- Two types of seismic waves are produc during earthquakes
  - ***Body waves*** - travel outward from the *focus* all directions through Earth's interior
  - ***Surface waves*** - travel along Earth's surface away from the *epicenter*

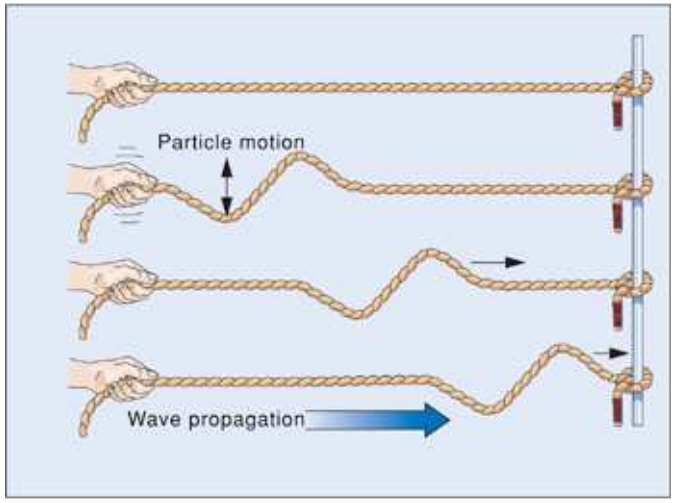


Body Waves

- *P wave* – Primary (compressional) body wave in which rock vibrates back and forth *parallel* to the direction of wave propagation
  - Fast (4 to 7 km/sec) wave that is the first or *primary* wave to arrive at recording station following earthquake
  - Pass through *solids and fluids*
- *S wave* – Secondary (shearing) body wave in which rock vibrates back and forth *perpendicular* to the direction of wave propagation
  - Slower (2 to 5 km/sec) wave that is the *secondary* wave to arrive at recording station following earthquake
  - Pass through *solids only*

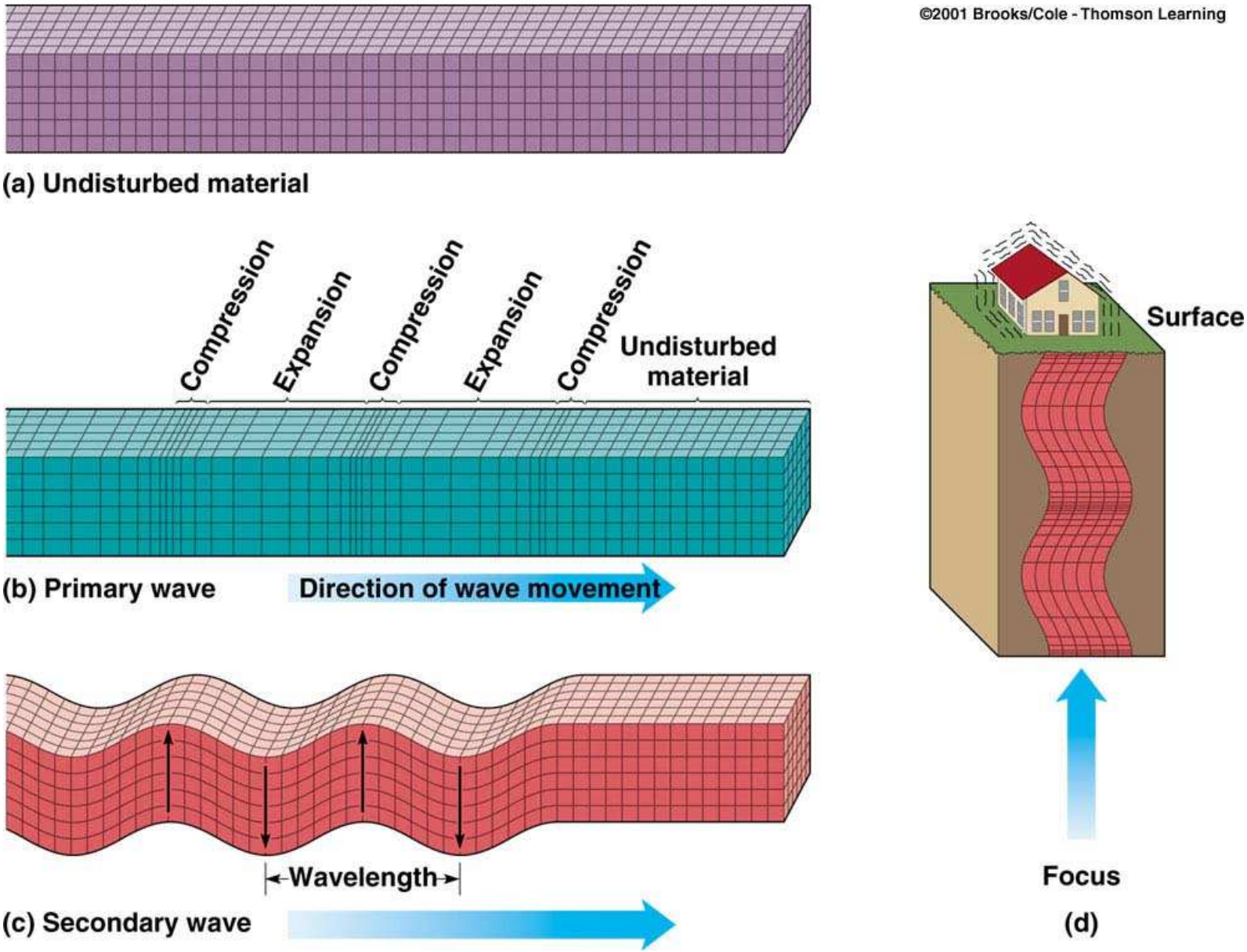


A Primary wave



B Secondary wave

Body Waves: P and S waves

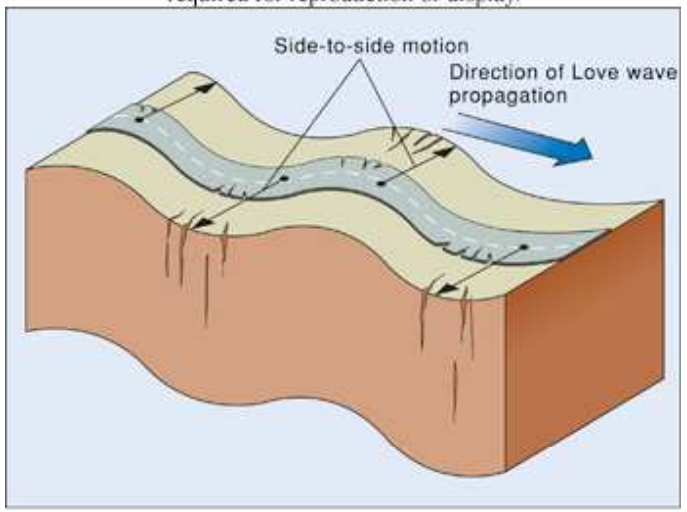


Surface Waves

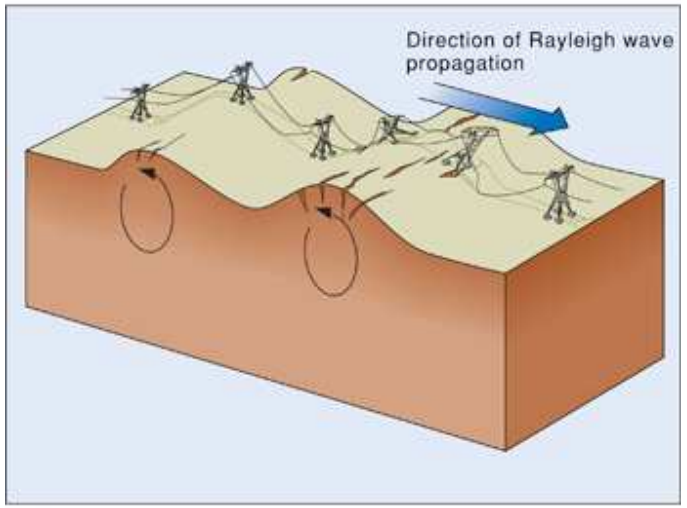
- Slowest type of seismic waves produced by earthquakes

- *Love waves (L-wave)* - side-to-side motion of the ground surface
  - Can't travel through fluids

- *Rayleigh waves (R-wave)* – ground moves in an elliptical path
  - Extremely destructive to buildings

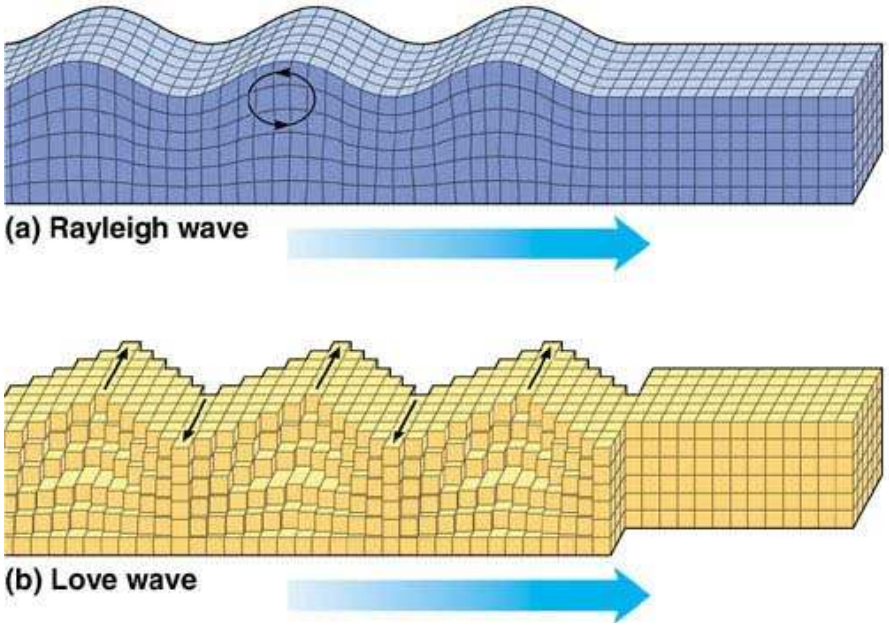


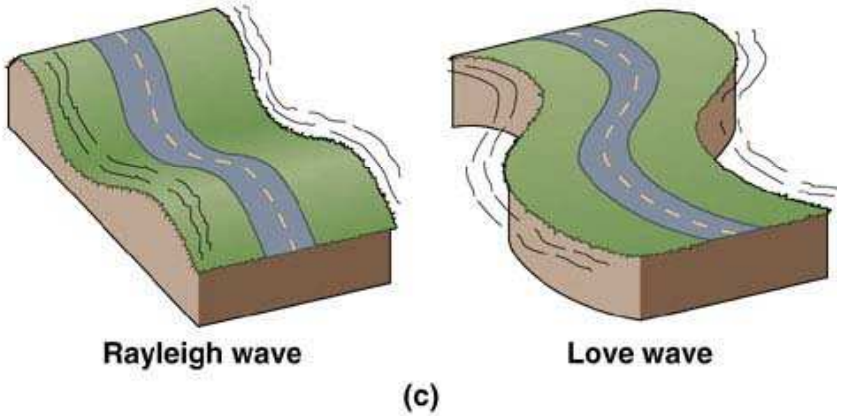
C Love wave



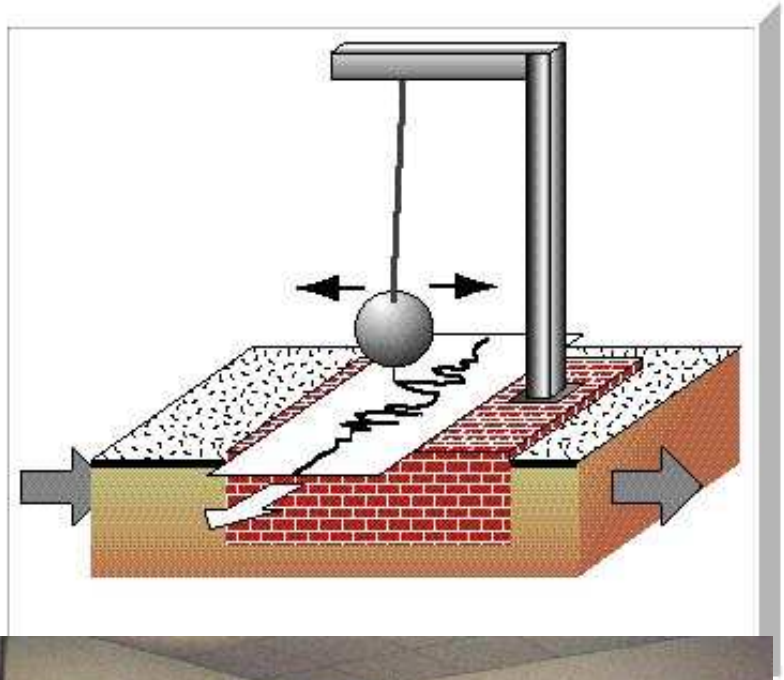
D Rayleigh wave

Surface Waves: R and L waves





Measuring Earthquakes



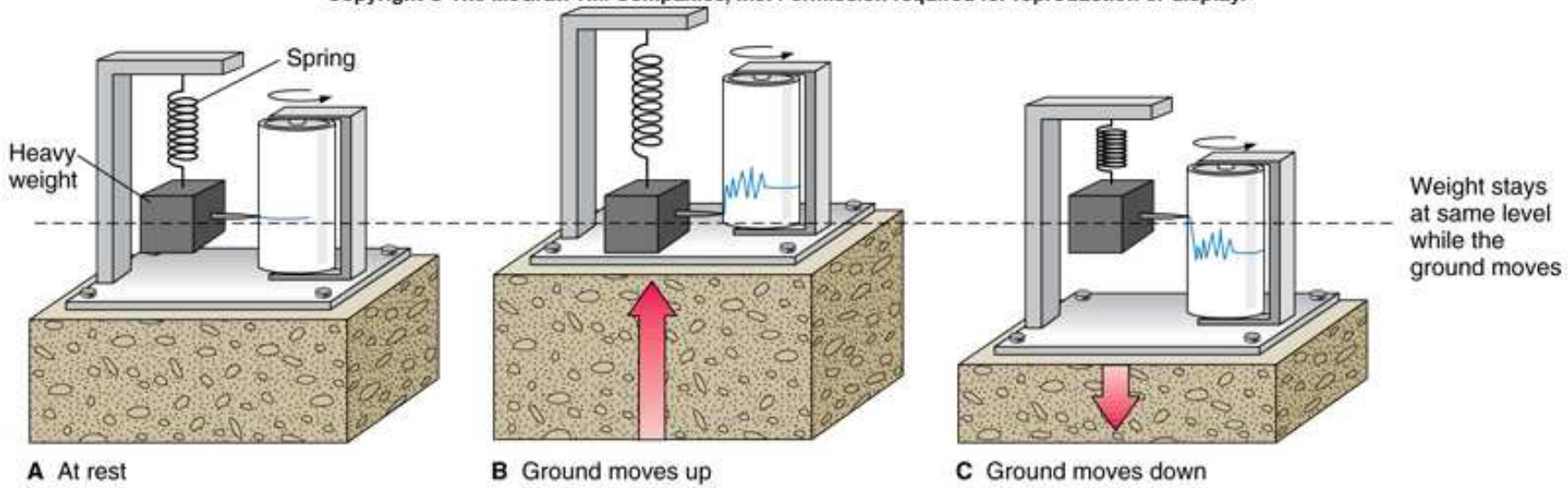
Measuring Earthquakes

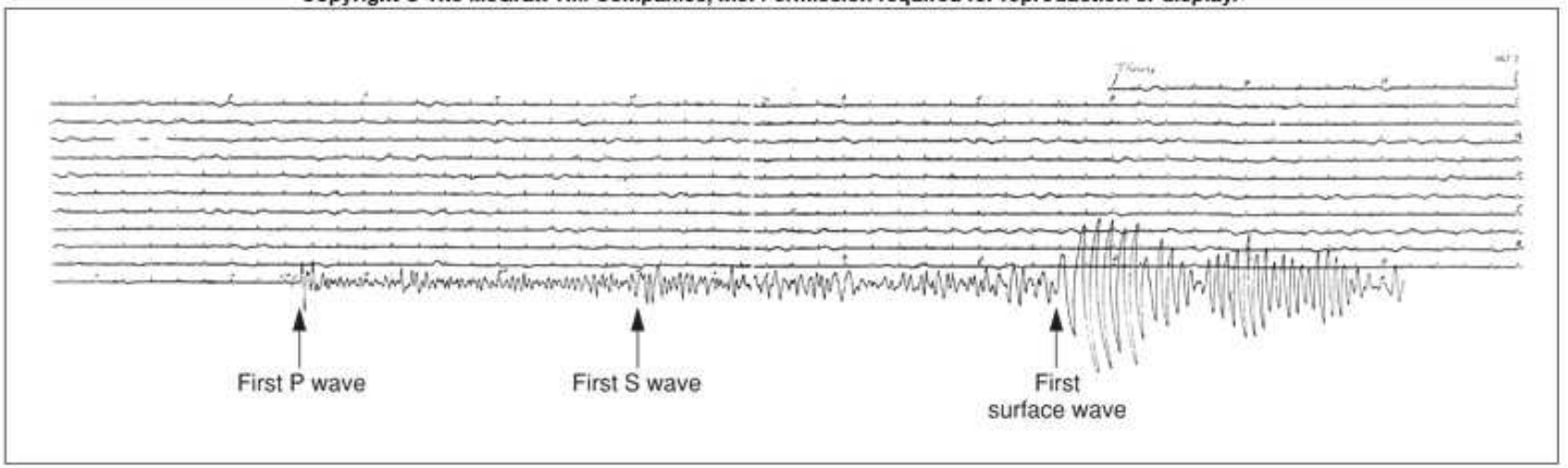
- *Seismometers* - used to measure seismic waves

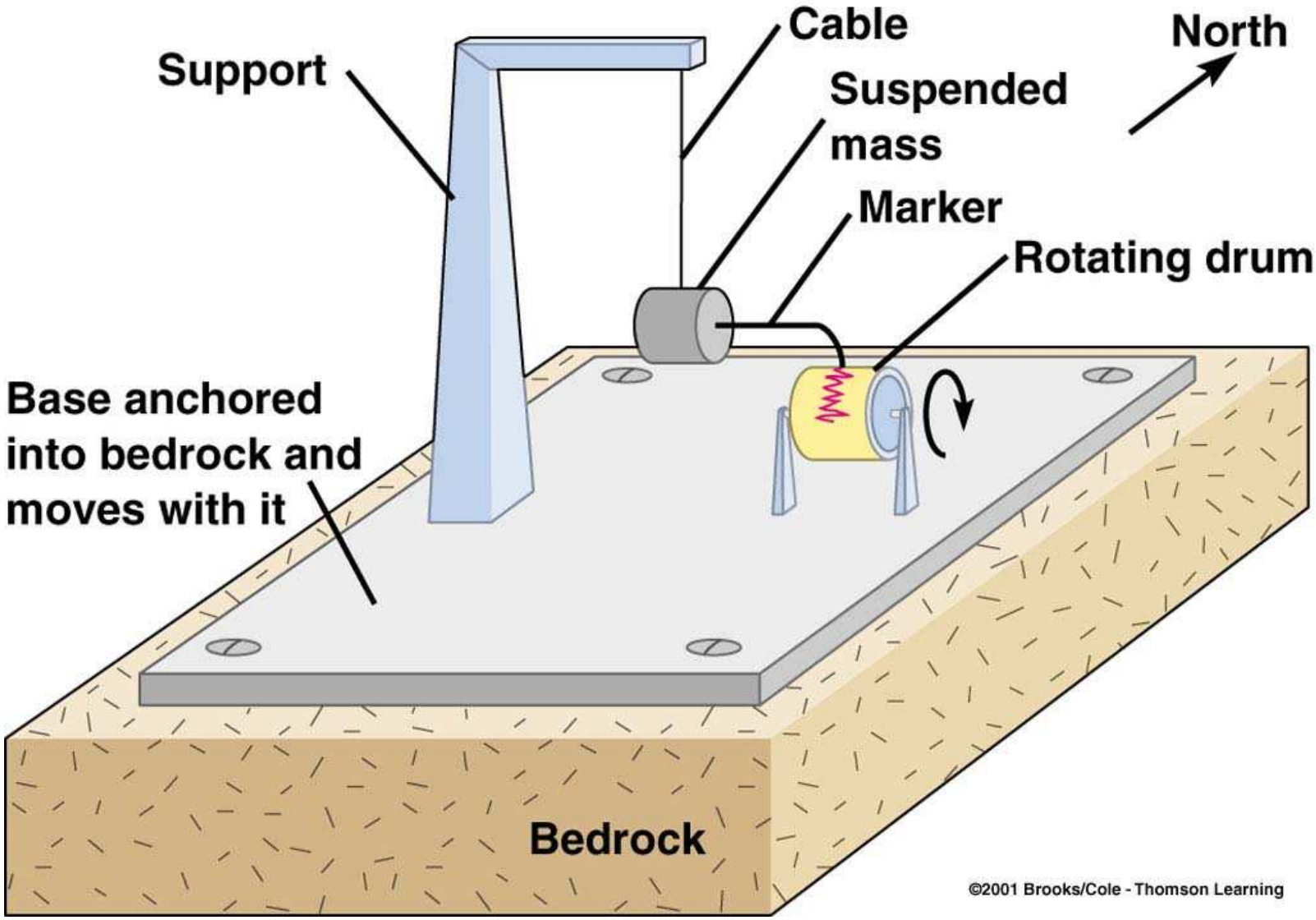
- *Seismographs* - recording devices used to produce a permanent record of the motion detected by seismometers

- *Seismograms* - permanent paper (or digital) records of the earthquake vibrations
  - Used to measure the earthquake strengths

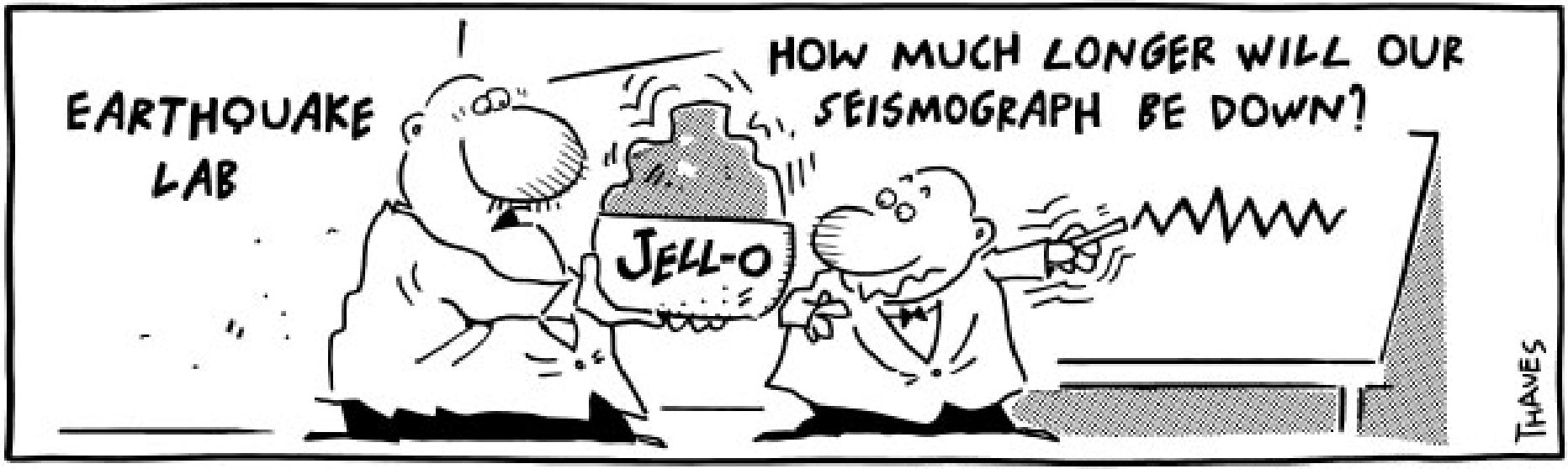
Measuring Earthquakes





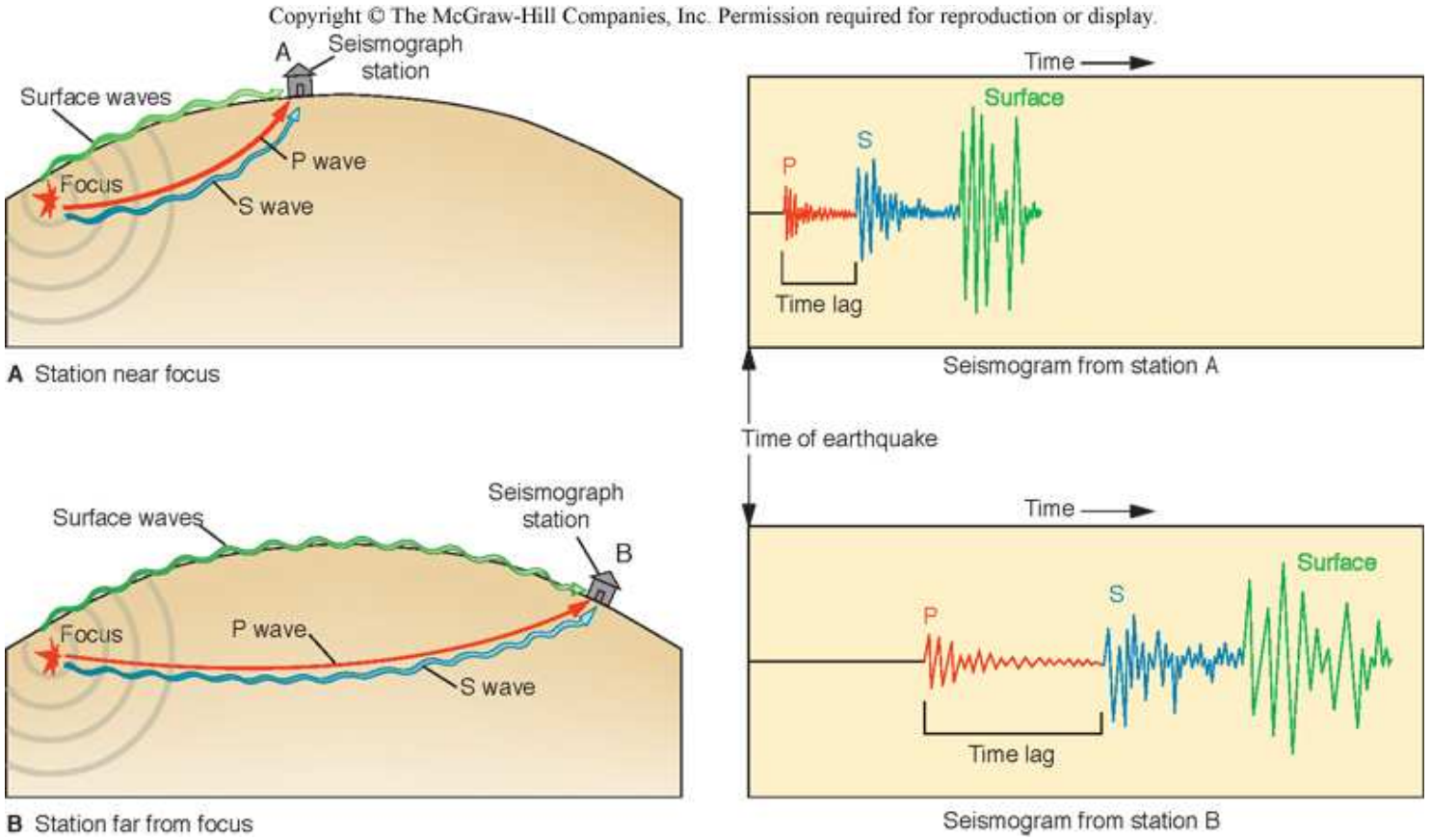

Support
Cable
North
Suspended mass
Marker
Rotating drum
Base anchored into bedrock and moves with it
Bedrock
©2001 Brooks/Cole - Thomson Learning

Frank and Ernest



Locating Earthquakes

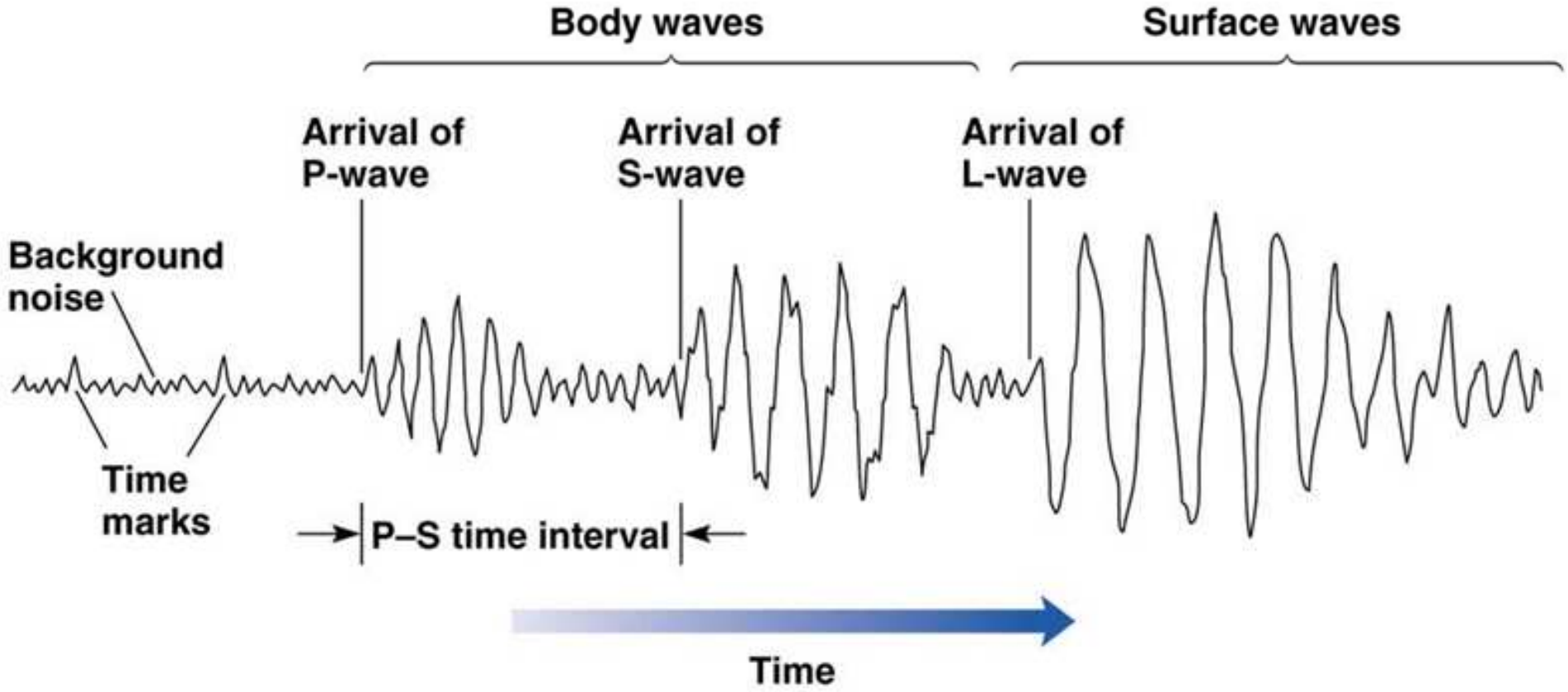
- P- and S-waves leave earthquake focus at the same time
- P-wave gets farther and farther ahead of the S-wave with distance and time from the earthquake
- *Travel-time curve* - used to determine distance to focus



Locating Earthquakes

Travel-time curve

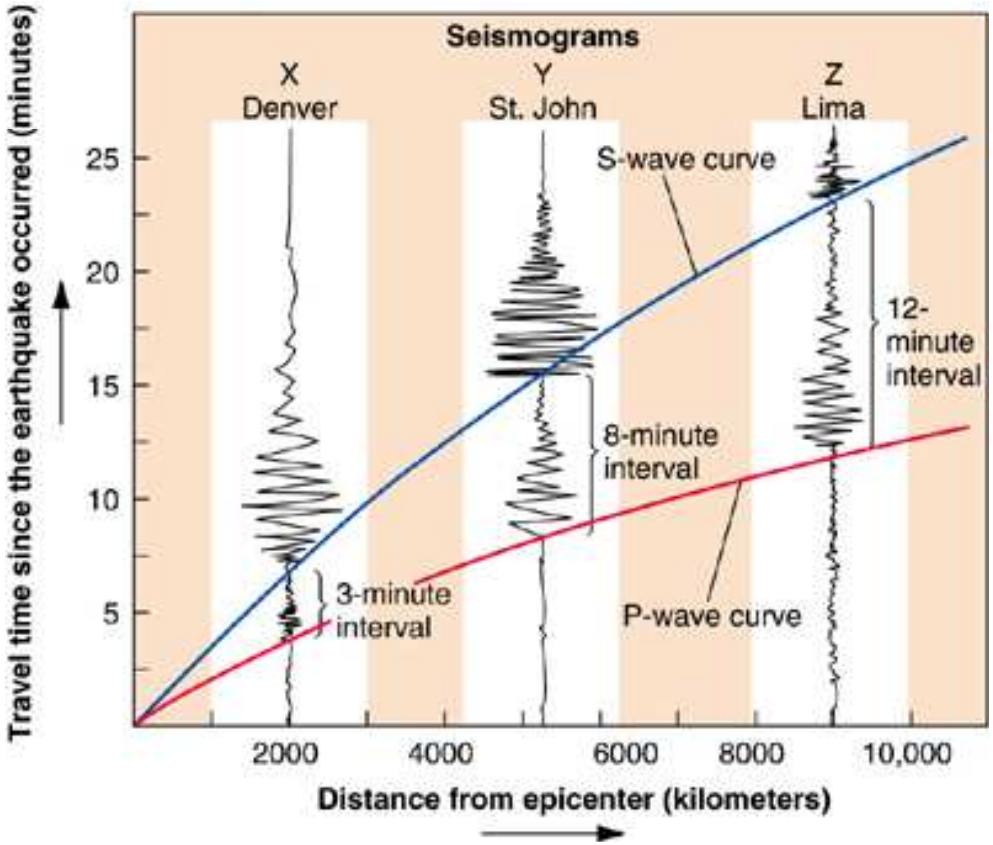
- **P waves arrive first, then S waves, then L and R**
- **Average speeds for all these waves is known**
- **After an earthquake, the difference in arrival times at a seismograph station can be used to calculate the distance from the seismograph to the epicenter.**



Locating Earthquakes

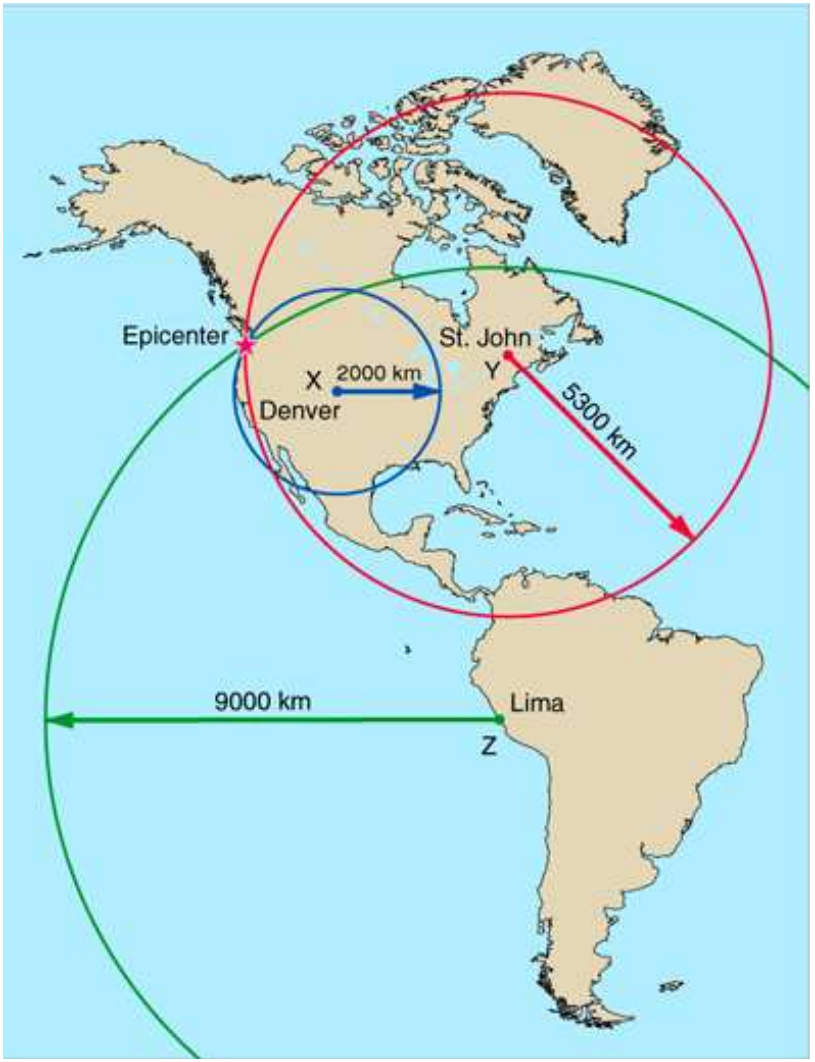
Travel-time graph showing the average travel times for P- and S-waves.

The farther away a seismograph is from the focus of an earthquake, the longer the interval between the arrivals of the P- and S- waves



Locating Earthquakes

- Plotting distances from 3 stations on a map, as circles with radii equal to the distance from the quake, locates earthquake ***epicenter***



- ***Depth of focus*** beneath Earth's surface can also be determined
  - *Shallow focus* *0-70 km deep*
  - *Intermediate focus* *70-350 km deep*
  - *Deep focus* *350-670 km deep*

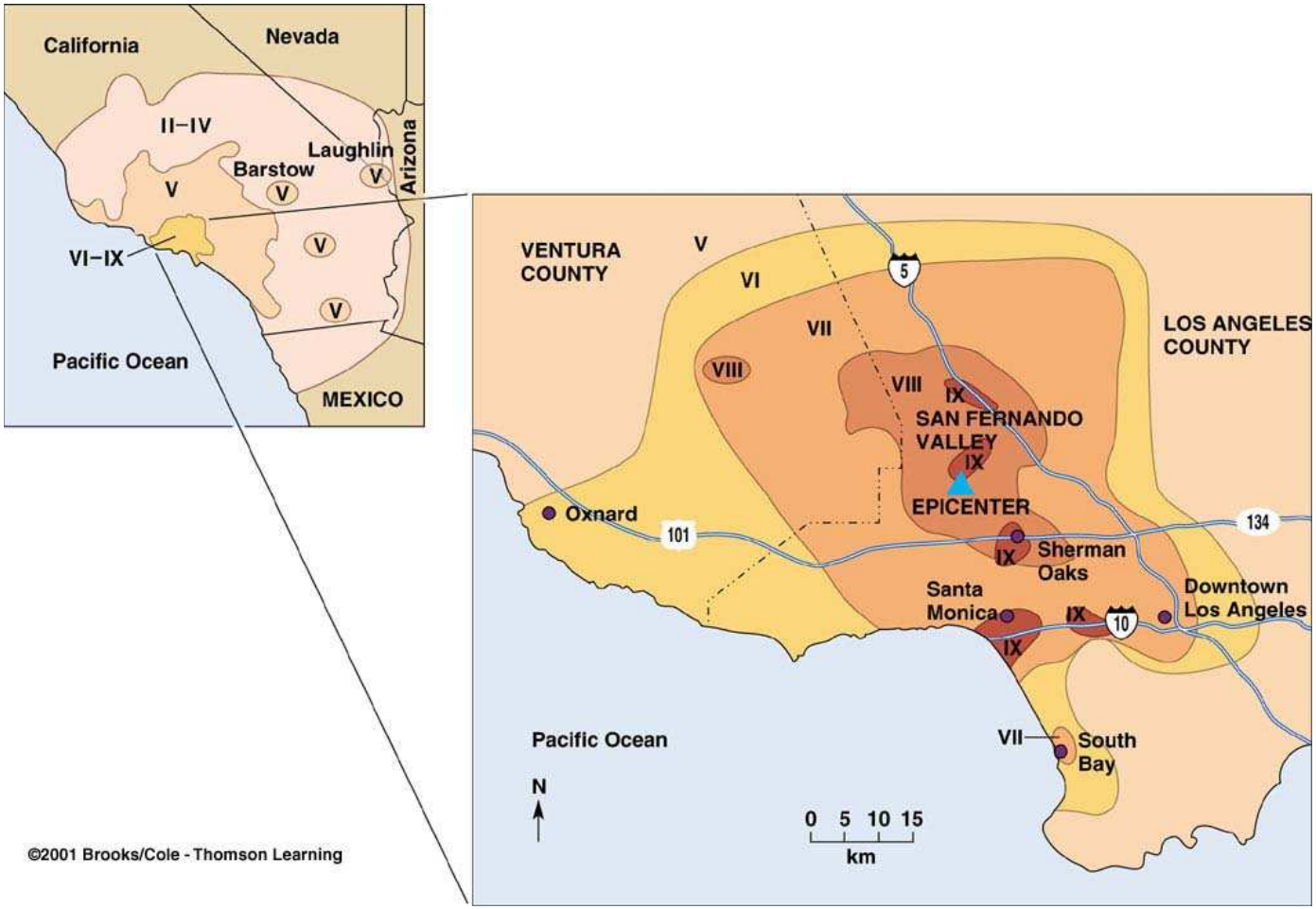
Measuring the “Size” of Earthquakes

- Earthquake “size” measured two ways - *intensity* and *magnitude*

- *Intensity* - a qualitative measure of the *effects* an earthquake produces (on both structures and people)
  - *Modified Mercalli scale (1914):* The **Modified Mercalli scale** is a scale used for measuring the intensity of an earthquake. The scale is a subjective measure of the kind of damage done and people’s reactions to it
  - It quantifies the effects of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale of I through XII, with I denoting a weak earthquake and XII one that causes almost complete destruction.

Modified Mercalli scale

Intensity of an Earthquake



- **Intensity**
  - **Isoseismal lines identify areas of equal intensity**
- **Modified Mercalli Intensity Map**
  - **1994 Northridge, CA earthquake, magnitude 6.7**

Measuring the "Size" of Earthquakes

- *Magnitude* is a measure of the amount of energy released by an earthquake
  - *Richter scale*
  - Developed in 1935 by Charles Richter of the California Institute of Technology
  - The Richter magnitude of an earthquake is determined from the log of the amplitude of waves recorded by seismographs

Richter Magnitudes	Description	Earthquake Effects	Frequency of Occurrence
Less than 2.0	Micro	Microearthquakes, not felt.	About 8,000 per day
2.0-2.9	Minor	Generally not felt, but recorded.	About 1,000 per day
3.0-3.9	Minor	Often felt, but rarely causes damage.	49,000 per year (est.)
4.0-4.9	Light	Noticeable shaking of indoor items, rattling noises. Significant damage unlikely.	6,200 per year (est.)
5.0-5.9	Moderate	Can cause major damage to poorly constructed buildings over small regions. At most slight damage to well-designed buildings.	800 per year
6.0-6.9	Strong	Can be destructive in areas up to about 160 kilometres (100 mi) across in populated areas.	120 per year
7.0-7.9	Major	Can cause serious damage over larger areas.	18 per year
8.0-8.9	Great	Can cause serious damage in areas several hundred miles across.	1 per year
9.0-9.9	Great	Devastating in areas several thousand miles across.	1 per 20 years
10.0+	Epic	Never recorded; see below for equivalent seismic energy yield.	Extremely rare (Unknown)

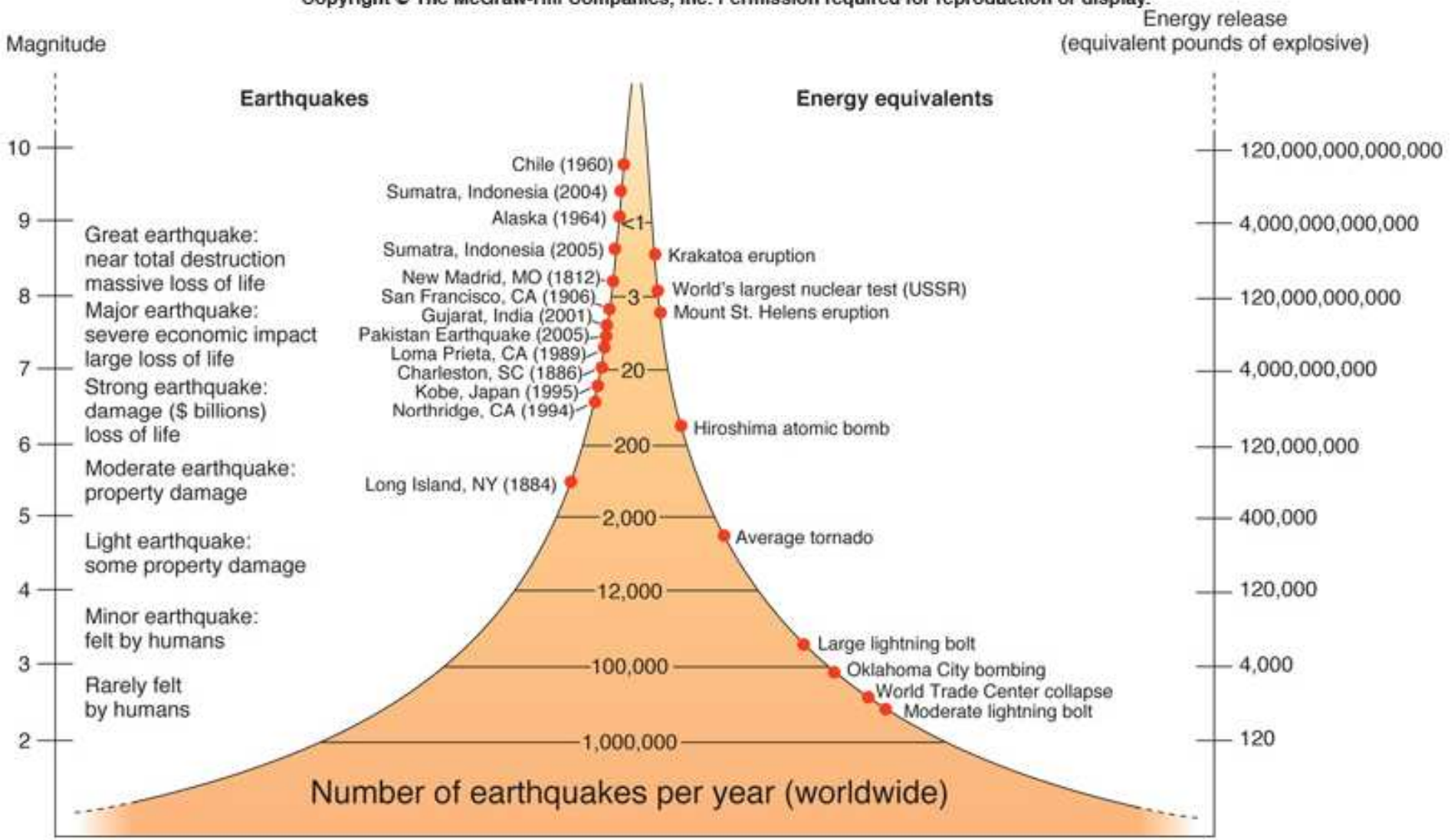


TABLE 7.2 Comparison of Earthquake Magnitude, Description, Intensity, and Expected Annual World Occurrence

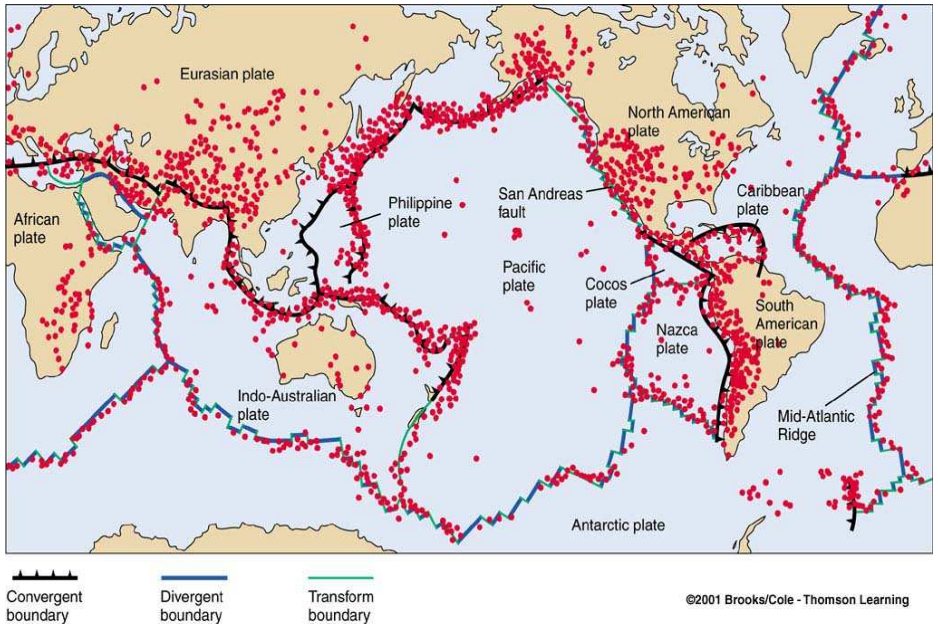
Richter Magnitude	Description	Maximum Expected Mercalli Intensity at Epicenter	Annual Expected Number
2.0	Very minor	I Usually detected only by instruments	600,000
2.0–2.9	Very minor	I–II Felt by some indoors, especially on upper floors	300,000
3.0–3.9	Minor	III Felt indoors	49,000
4.0–4.9	Light	IV–V Felt by most; slight damage	6,200
5.0–5.9	Moderate	VI–VII Felt by all; damage minor to moderate	800
6.0–6.9	Strong	VII–VIII Everyone runs outdoors; moderate to major damage	266
7.0–7.9	Major	IX–X Major damage	18
8.0 or higher	Great	X–XII Major and total damage	1 or 2

Source: U.S. Geological Survey

Where Do Earthquakes Occur and How Often?

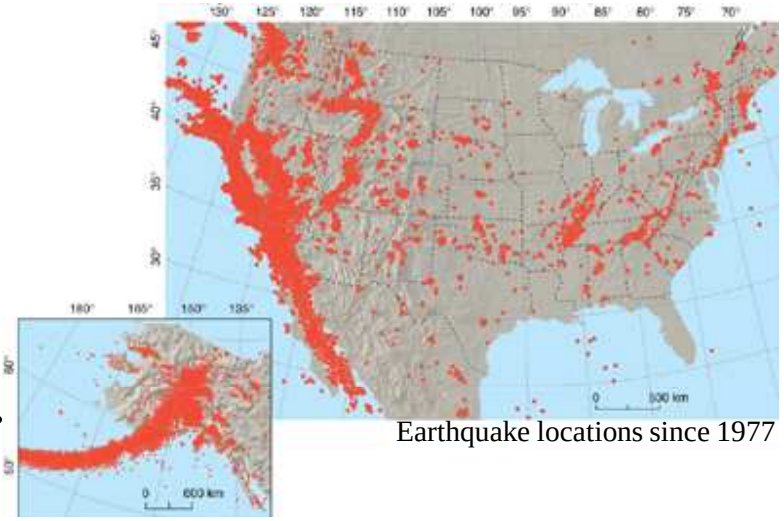
~80% of all earthquakes occur in the circum-Pacific belt

- **most of these result from convergent and transform margin activity**
- **only 5% occur in the interiors of plates**
- **more than 150,000 quakes strong enough to be felt are recorded each year**

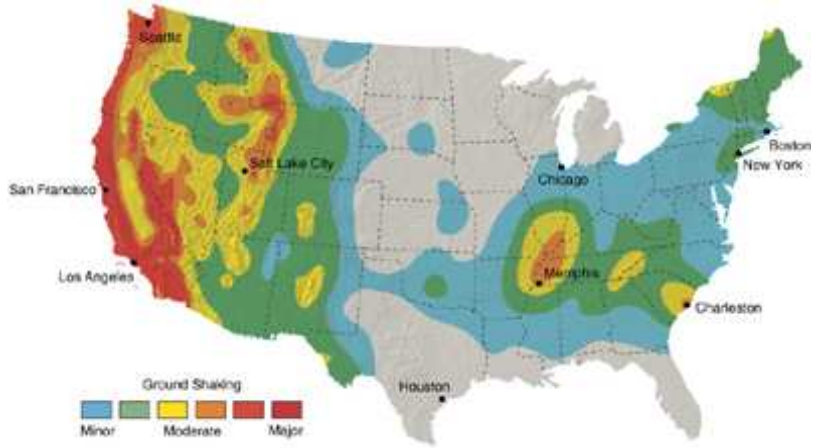


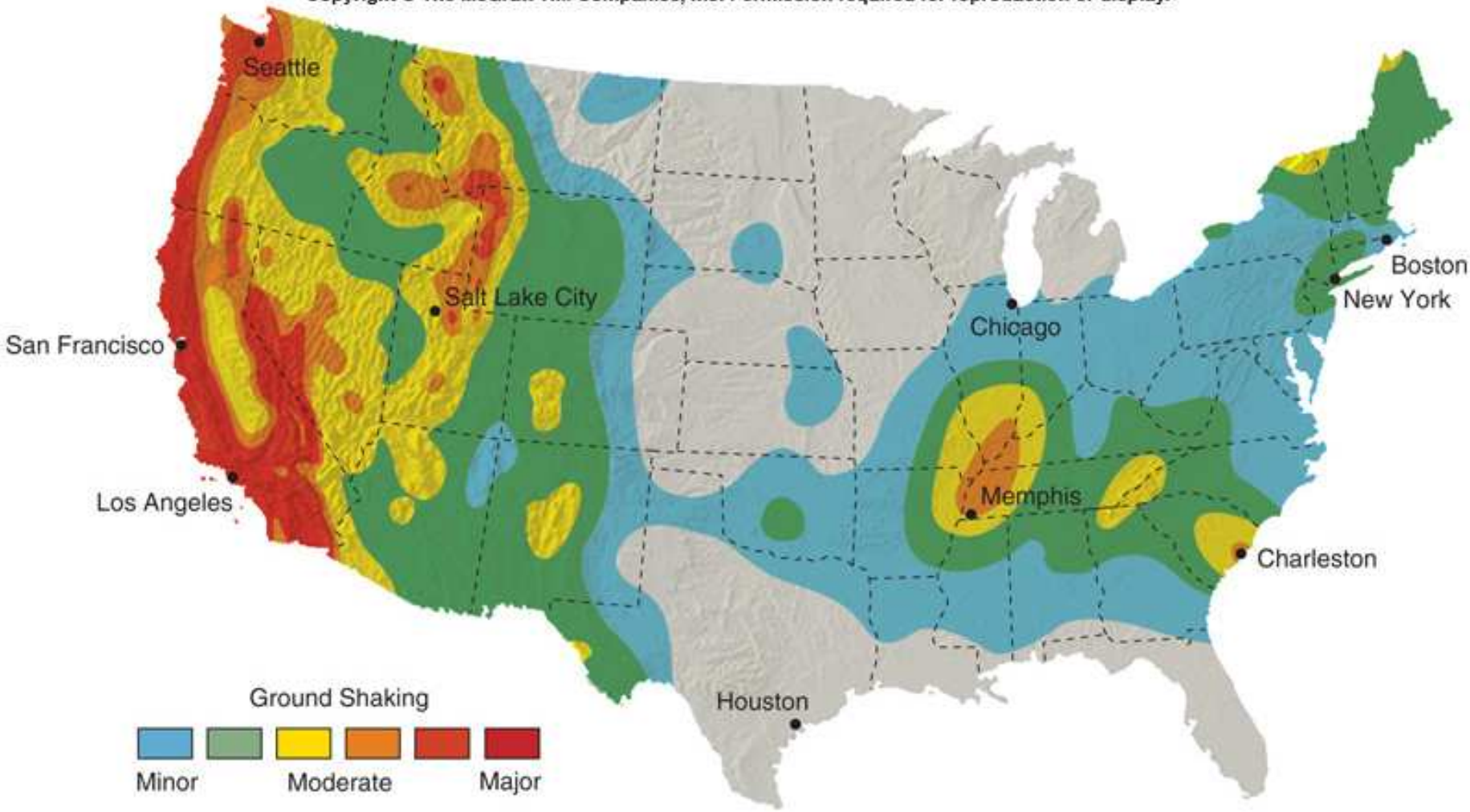
Location and Size of Earthquakes in the U.S.

- Earthquakes occur throughout the U.S., but are much more common in the western states and Alaska
- Largest *seismic risks* or *hazards* exist near the plate boundary along the U.S. Pacific coast (e.g., San Andreas fault), and around New Madrid, Missouri
- Seismic risk determined based on the assumption that large future earthquakes *will occur where they have occurred in the past*

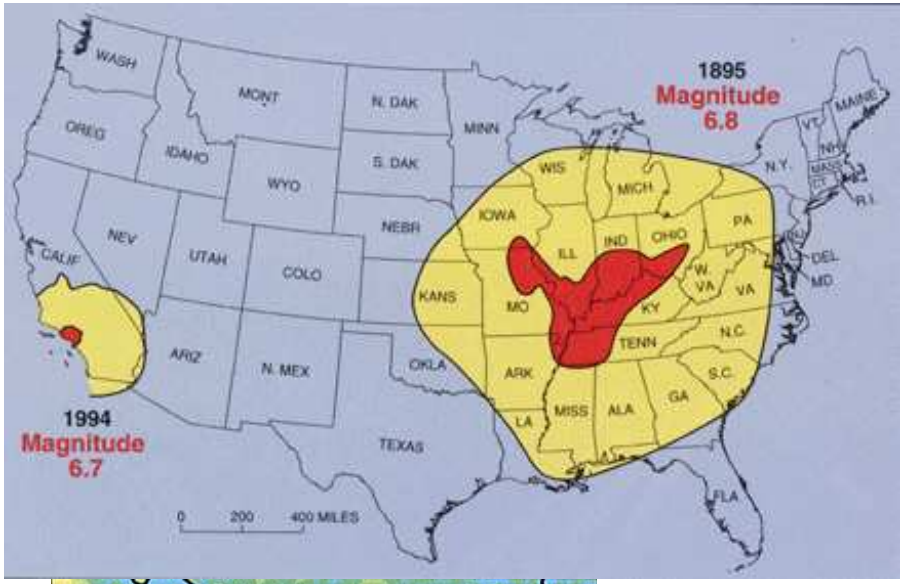


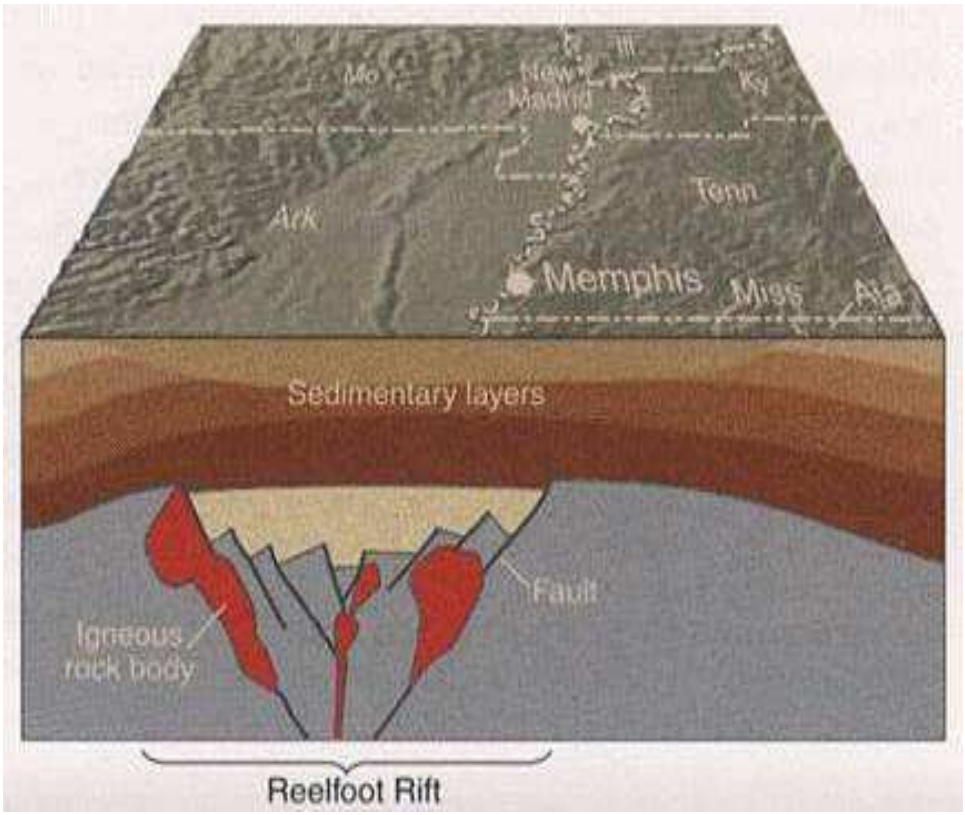
Earthquake locations since 1977

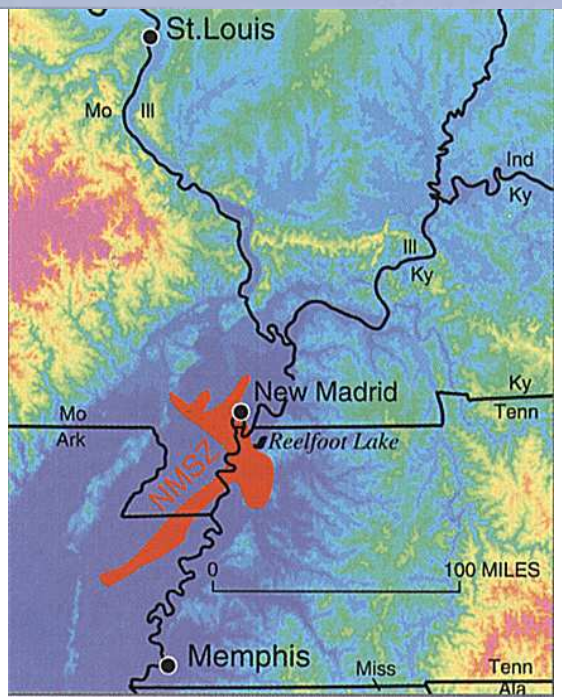


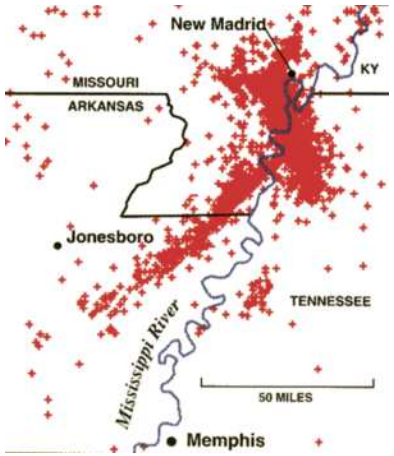


New Madrid Earthquakes, 1811-1812



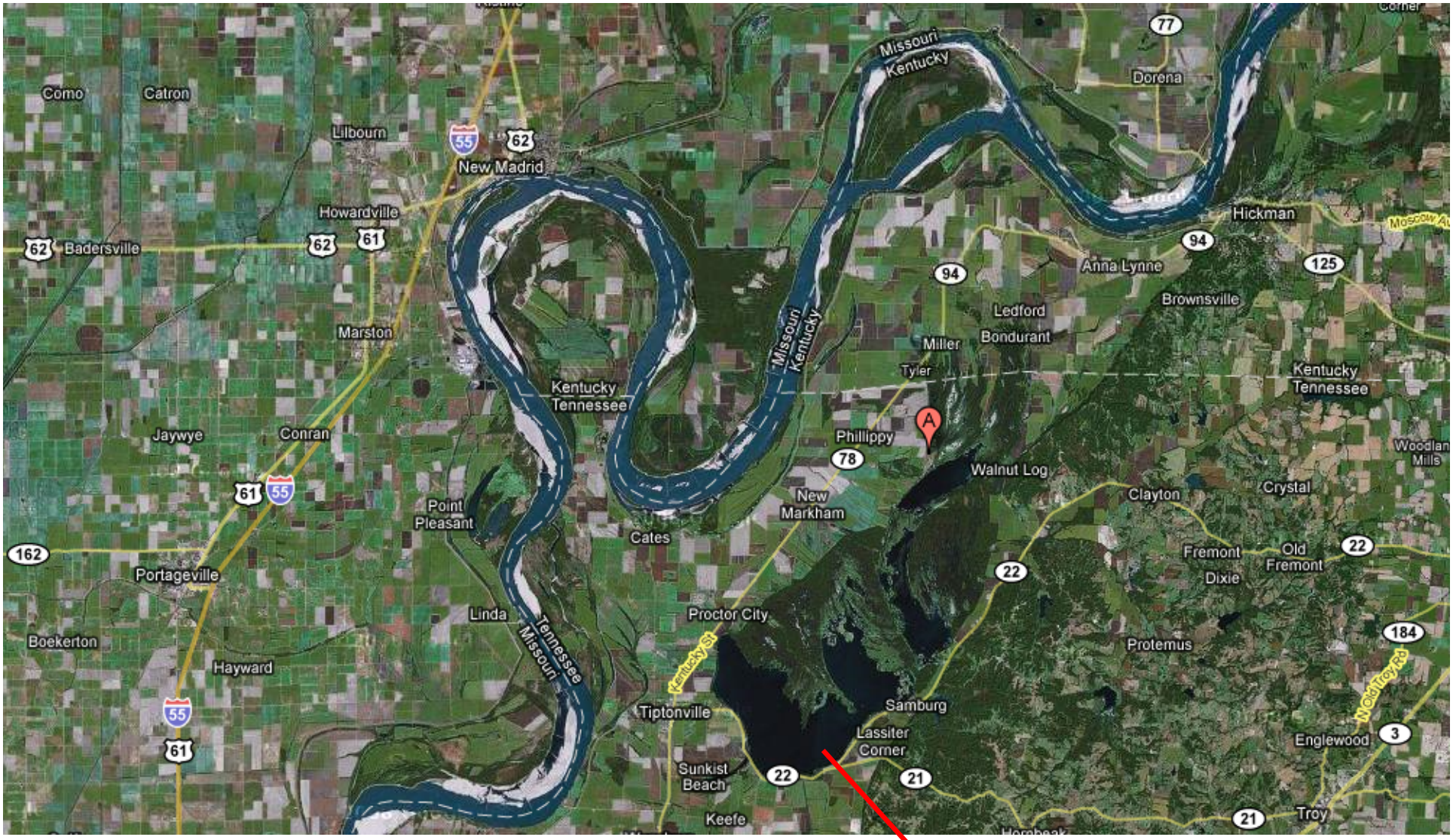






Earthquakes recorded in the New Madrid seismic zone since 1974 (more than 4000)

New Madrid Earthquake, 1895

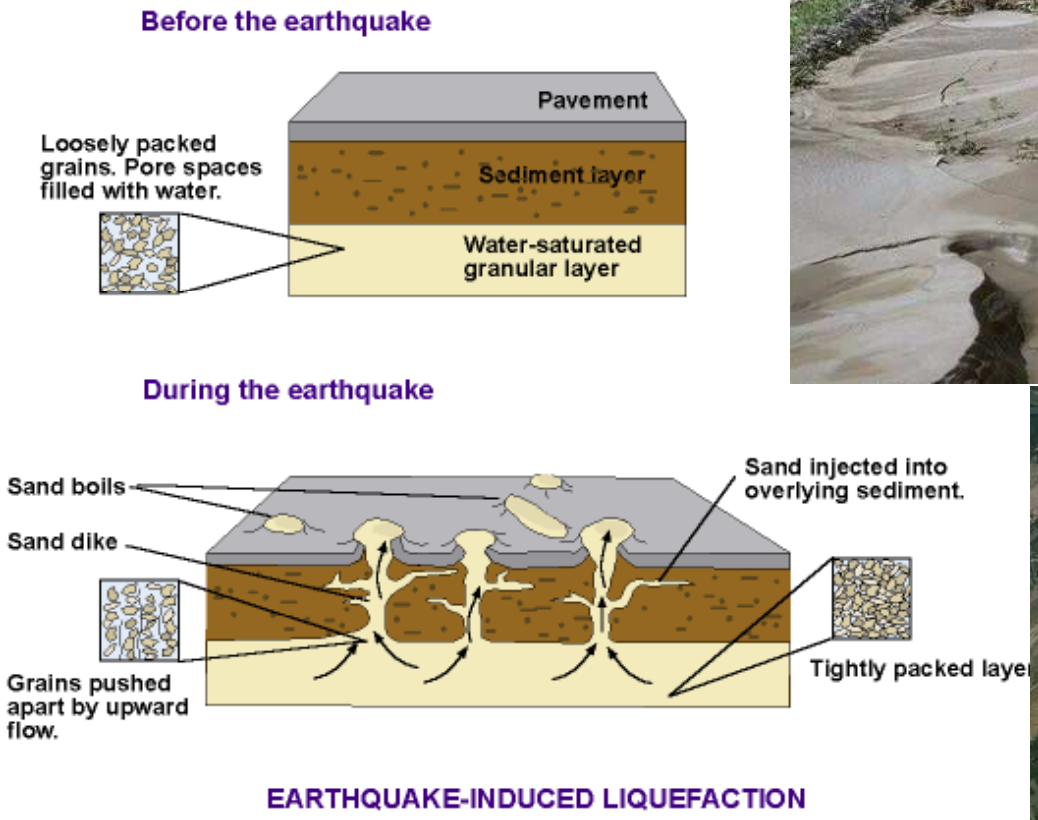


Effects of Earthquakes

- Earthquakes produce several types of effects, all of which can cause loss of property and human life
  - *Ground motion* is the familiar trembling and shaking of the land during an earthquake
    - Can topple buildings and bridges
  - *Fire* is a problem just after earthquakes because of broken gas pipelines and fallen electrical wires
  - *Soil liquefaction* describes the behavior of loose saturated soils, i.e. loose sands, which go from a solid state to have the consistency of a heavy liquid
  - *Landslides* can be triggered by ground shaking, particularly in larger quakes
  - *Permanent displacement of the land surface* can also occur, leaving fractures

Damage Caused by Earthquakes

Soil Liquefaction



Japan, 1964

Damage Caused by Earthquakes: Secondary Effects

Landslides

Damage Caused by Earthquakes: Secondary Effects

Fires

A

San Francisco (1906)

Oakland, CA (1989)

B

F

Anchorage, Alaska (1964) : 200 miles long rupture

Peter Hausler, U.S. Geological Survey

Turkey, 1999

B

D

Gujarat, India (2001)

A

© Reuter/Sankei/Shimbun

Kobe, Japan (1995)

Tsunami

- *Tsunami* (seismic sea waves) - very large sea waves caused by sudden upward or downward movement of the sea floor during submarine earthquakes

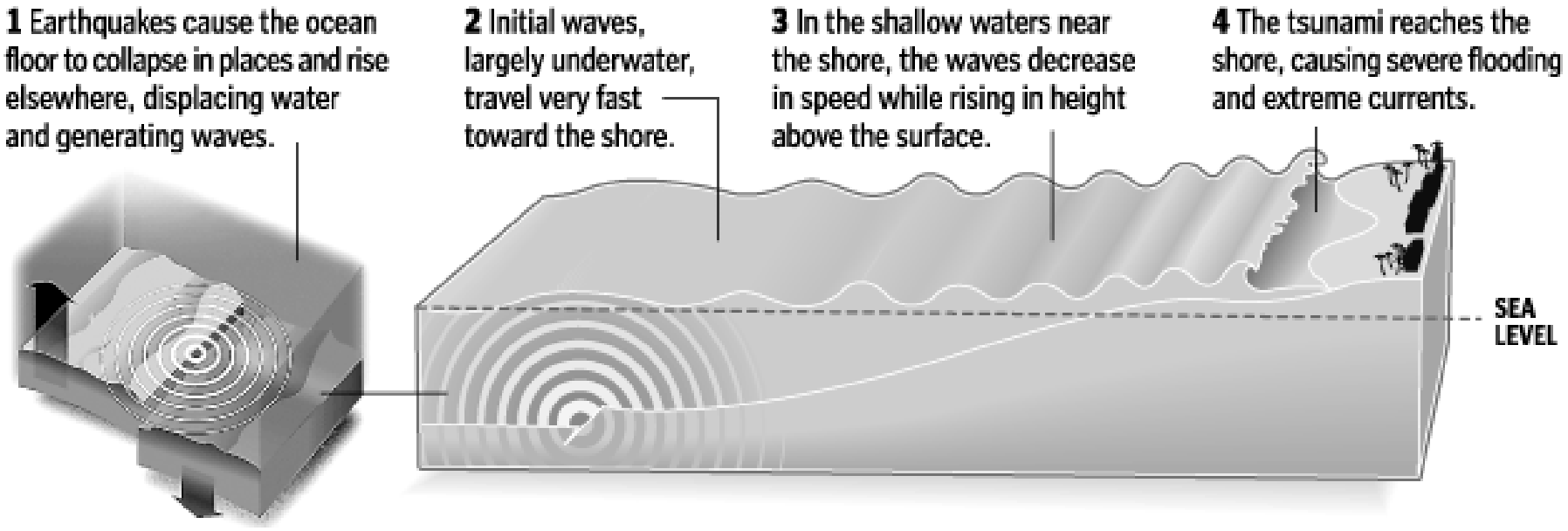
  - generally produced by magnitude 8+ earthquakes (“great” earthquakes - e.g., 9.3 Indonesia, 2004)

  - May also be generated by large *undersea landslides* or *volcanic explosions*

  - Travel across open ocean at speeds of *>700 km/hr*

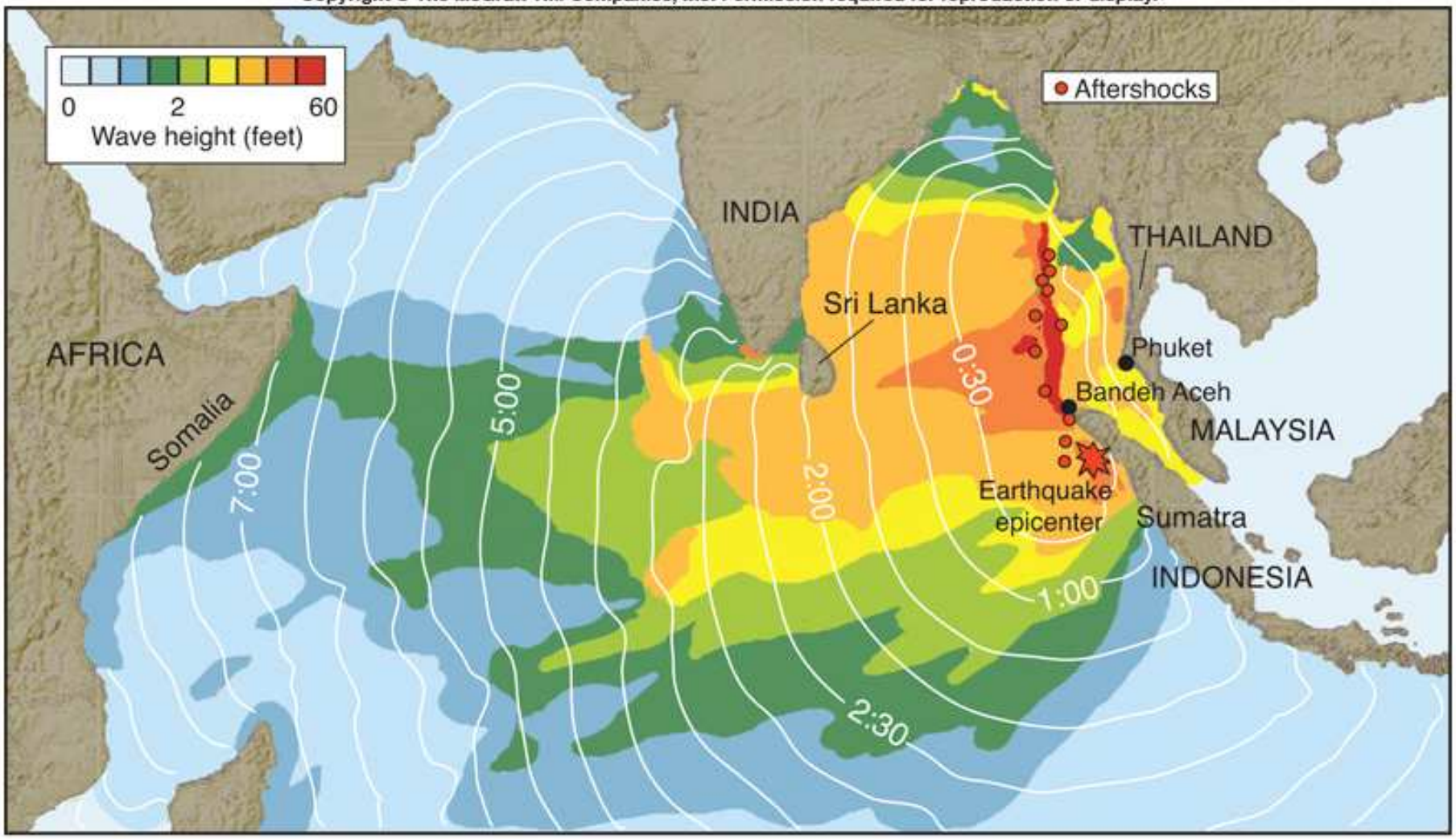
  - Reach great heights in coastal areas with gently sloping seafloor

TSUNAMI - water wave generated by earthquake

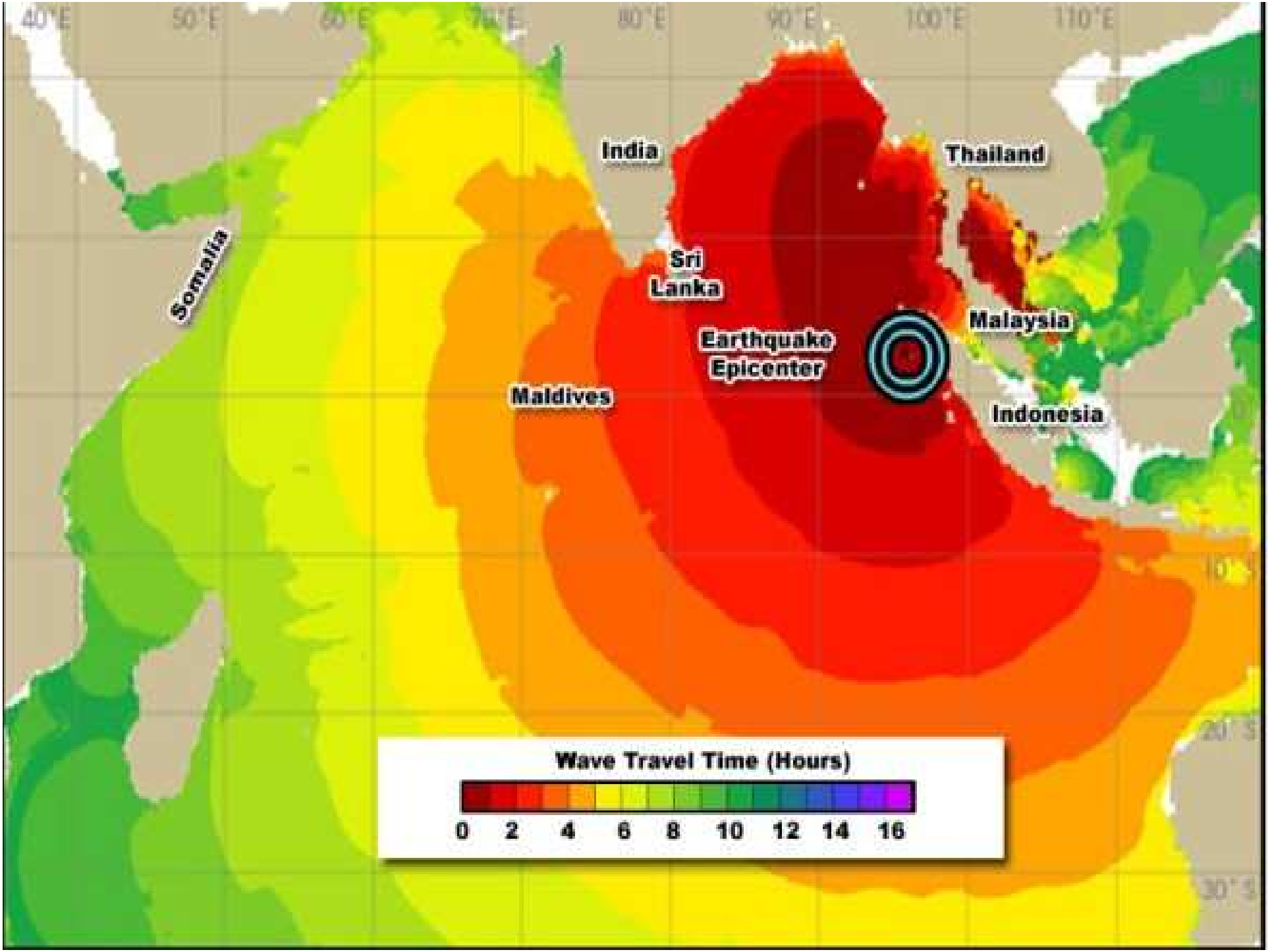


SOURCES: Staff reports, Associated Press

ILLUSTRATION BY THE ASSOCIATED PRESS; GRAPHIC BY THE WASHINGTON POST



A

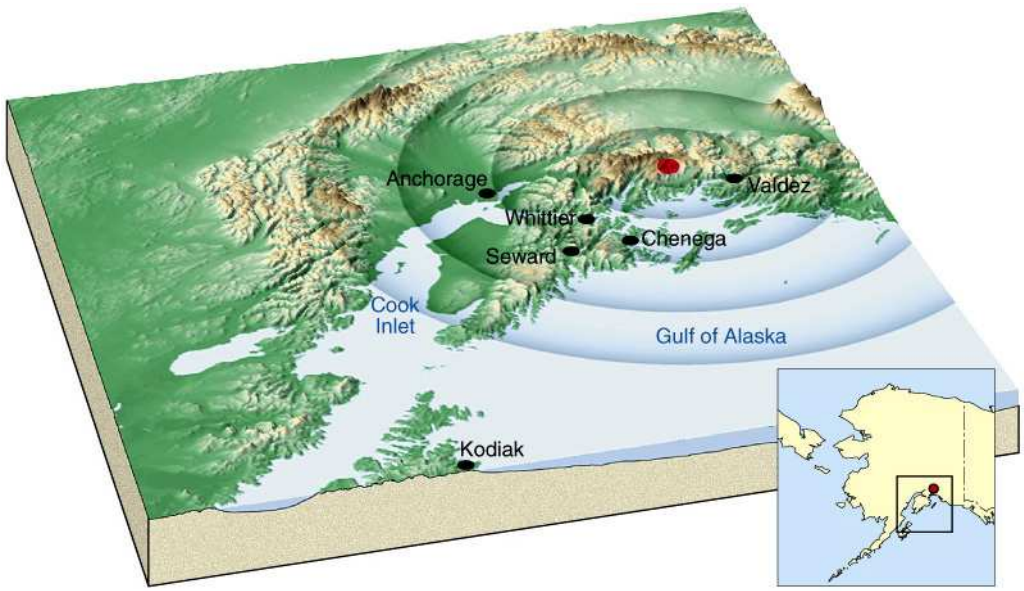

40°E
50°E
80°E
90°E
100°E
110°E
India
Thailand
Somalia
Sri Lanka
Malaysia
Earthquake Epicenter
Maldives
Indonesia
Wave Travel Time (Hours)
0 2 4 6 8 10 12 14 16

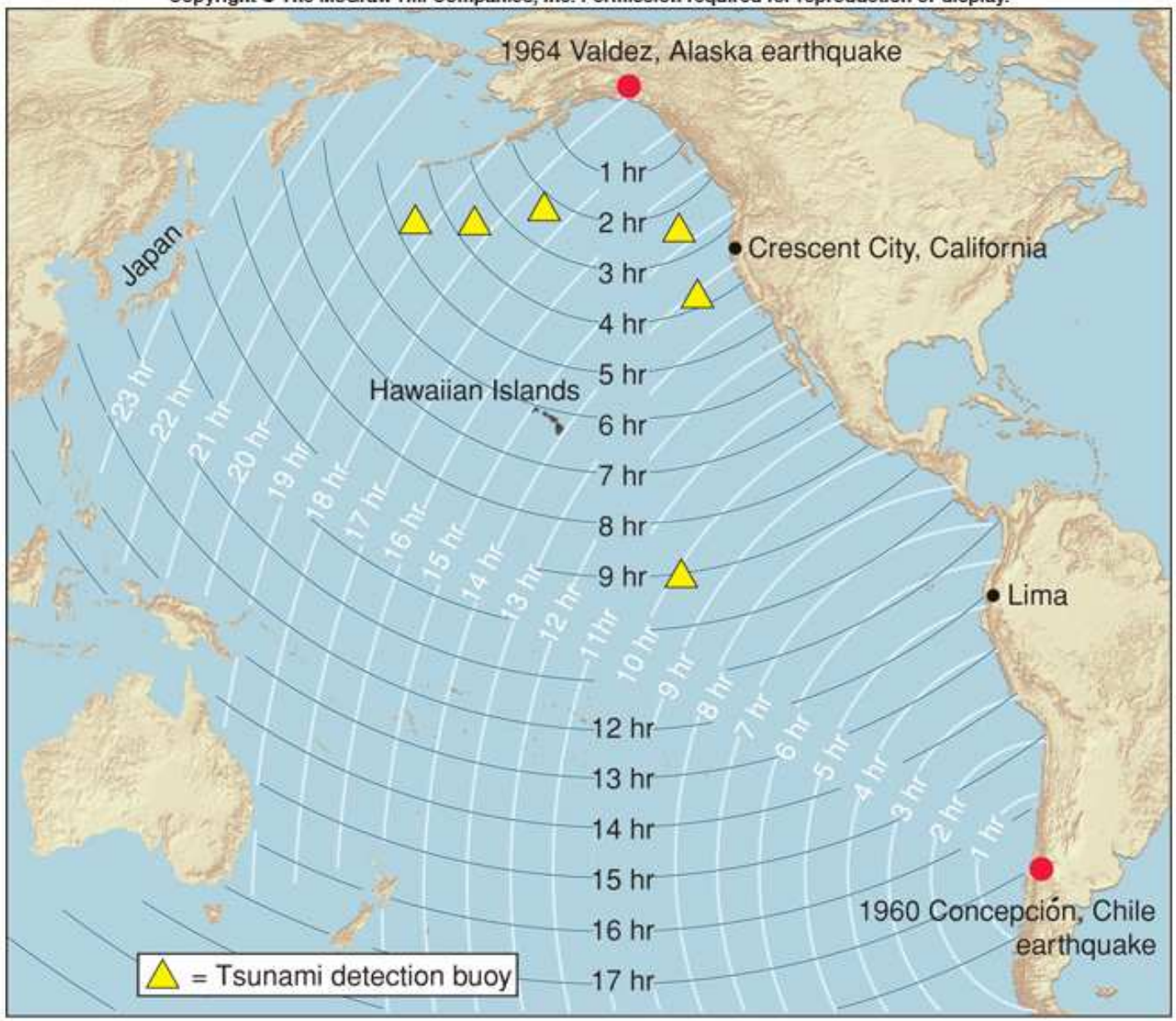
BEFORE - AFTER DECEMBER 26, 2004 EARTHQUAKE-TSUNAMI

BEFORE - AFTER DECEMBER 26, 2004 EARTHQUAKE-TSUNAMI

BEFORE - AFTER DECEMBER 26, 2004 EARTHQUAKE-TSUNAMI

Anchorage, AK 1964





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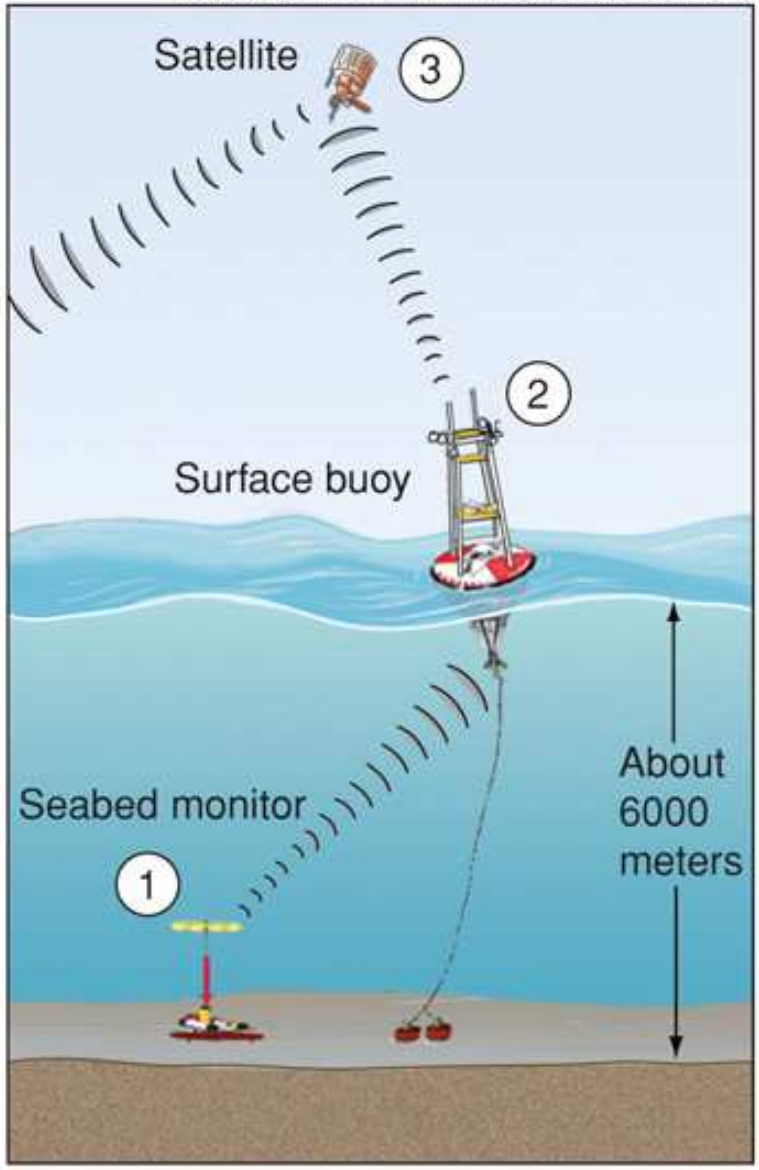


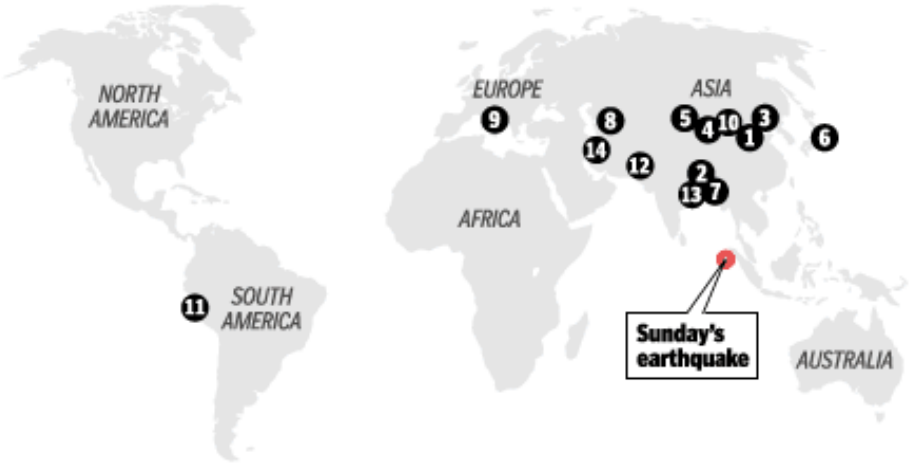
1. Recorder on ocean bottom monitors sea pressure and activity every 15 minutes. An unusual event triggers readings every 15 seconds. Data is transmitted to surface buoy.

2. Surface buoy monitors upper level conditions and relays this as well as data from the seabed monitors to satellite in real-time.

3. Data are then relayed via satellite to ground stations for immediate dissemination to NOAA's Tsunami Warning Centers and Pacific Marine Environmental Laboratory.

B NOAA's DART mooring system (components not to scale)

“CIVILIZATION EXISTS BY GEOLOGICAL CONSENT”



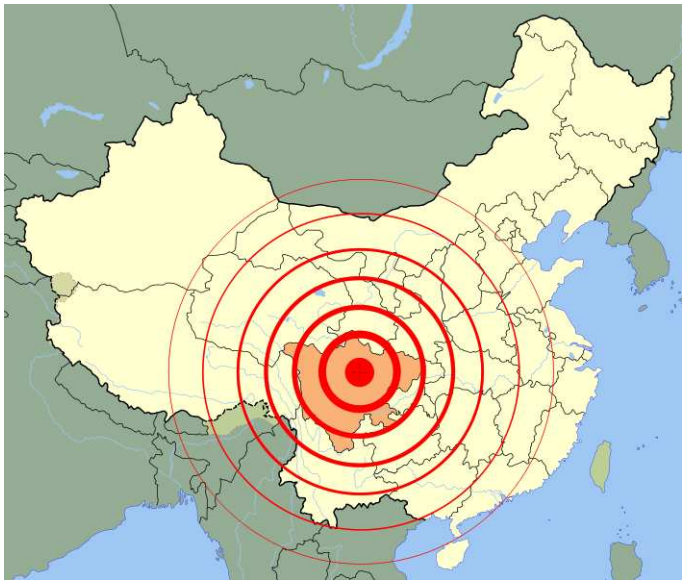
	YEAR	LOCATION	EVENT	ESTIMATED DEATH TOLL
1	1931	Huang He River, China	Flood	3.7 million
2	1970	Bangladesh	Cyclone	300,000
3	1976	Tangshan, China	Earthquake	255,000
4	1920	Gansu, China	Earthquake	200,000
5	1927	Tsinghai, China	Earthquake	200,000
6	1923	Kanto, Japan	Earthquake	143,000
7	1991	Bangladesh	Cyclone	139,000
8	1948	Turkmenistan	Earthquake	110,000
9	1908	Messina, Italy	Earthquake	70,000-100,000
10	1932	Gansu, China	Earthquake	70,000
11	1970	Peru	Earthquake	66,000
12	1935	Quetta, Pakistan	Earthquake	30,000-60,000
13	1942	Bengal, India	Hurricane	40,000
14	1990	Iran	Earthquake	40,000-50,000

SOURCES: U.S. Geological Survey, The World Almanac

THE WASHINGTON POST

2008 Sichuan earthquake (7.9 Magnitude)

- May 12, 2008
- 69,197 are confirmed dead, and 374,176 injured, with 18,222 listed as missing
- The earthquake left about 4.8 million people homeless



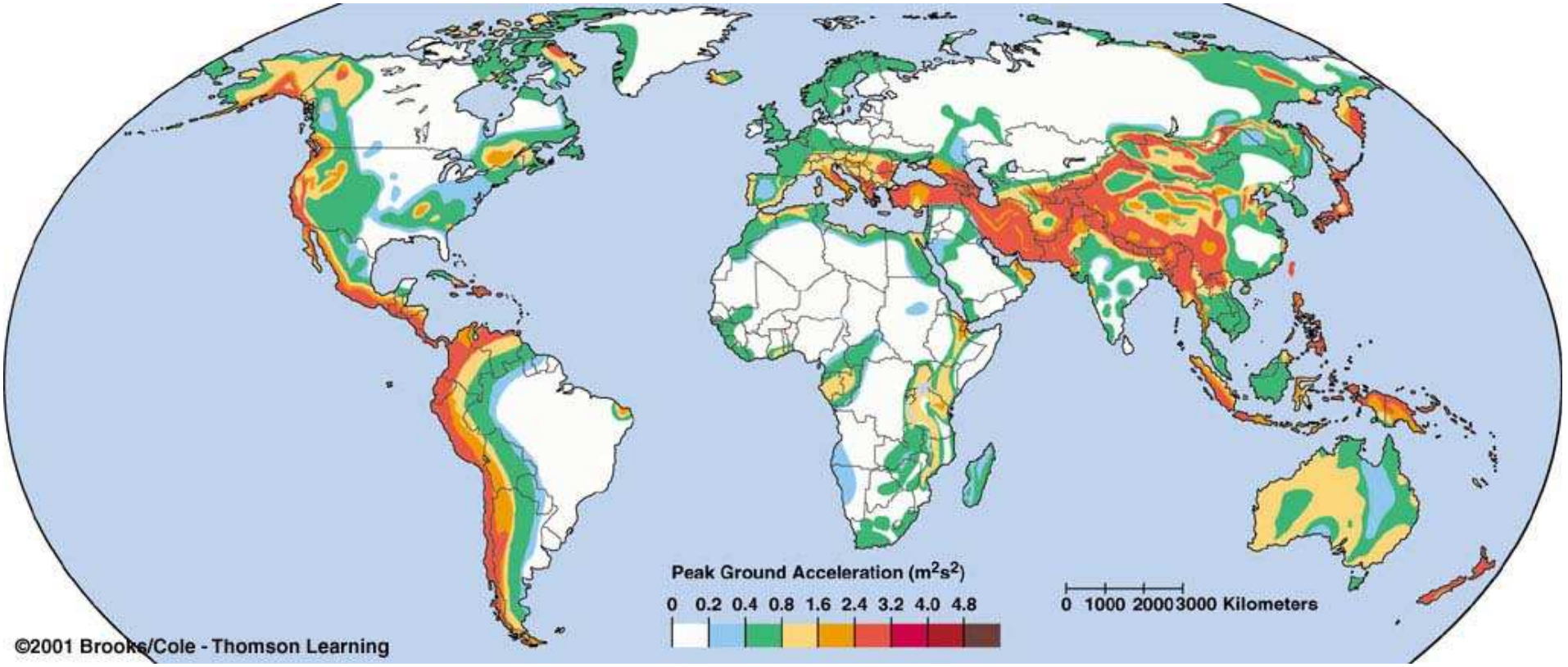
Can Earthquakes be Predicted?

Earthquake Precursors

- changes in elevation or tilting of land surface, fluctuations in groundwater levels
- Rock bending (use of laser light to monitor)

Earthquake Prediction Programs

- include laboratory and field studies of rocks before, during, and after earthquakes
- monitor activity along major faults
- produce risk assessments


Peak Ground Acceleration (m^2s^2)
0 0.2 0.4 0.8 1.6 2.4 3.2 4.0 4.8
0 1000 2000 3000 Kilometers
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Earthquake Prediction and Seismic Risk

- Accurate and consistent short-term earthquake **prediction not yet possible**, three methods assist in determining probability that an earthquake will occur:
  - Measurement of changes in *rock properties*, which may serve as *precursors* to earthquakes
  - Studies of the *slip rate* along fault zones
  - *Paleo-seismology* studies that determine where and when earthquakes have occurred and their size
    - Average intervals between large earthquakes and the time since the last one occurred can also be used to assess the risk (over a given period of time) that a large quake will occur

2008 Sichuan earthquake