# Module 13

# Earthquake

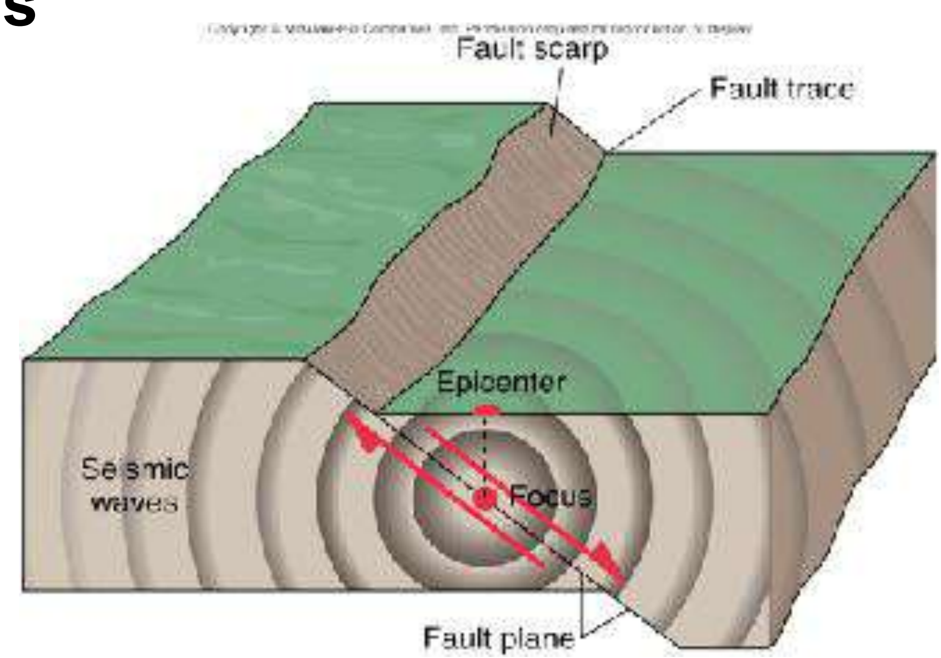
# EARTHQUAKE

Photo credit: USGS

# EARTHQUAKE

## Earthquake

- A series of shock waves generated at a point (**the focus**) within the Earth"s crust or mantle
- The point on the surface of the Earth above the focus is called the **epicenter**
- Three main types of wave motion are generated by an earthquake: P-Waves; S-Waves; dan L-Waves



# EARTHQUAKE

### ***P-Waves***

- High-frequency
- Short-wavelength
- Longitudinal waves
- Can be reflected and refracted
- Travel through the solid and the liquid part of the Earth

### ***S-Waves***

- High-frequency
- Short-wavelength
- Transverse waves
- Can be reflected and refracted
- Travel through the solid part of the Earth at varying velocities.
- Propagated in all directions from the focus

### ***L-Waves***

- Low-frequency
- Long-wavelength
- Transverse vibrations
- Confined to the outer skin of the crust
- Responsible for most of the destructive force of earthquake

# EARTHQUAKE

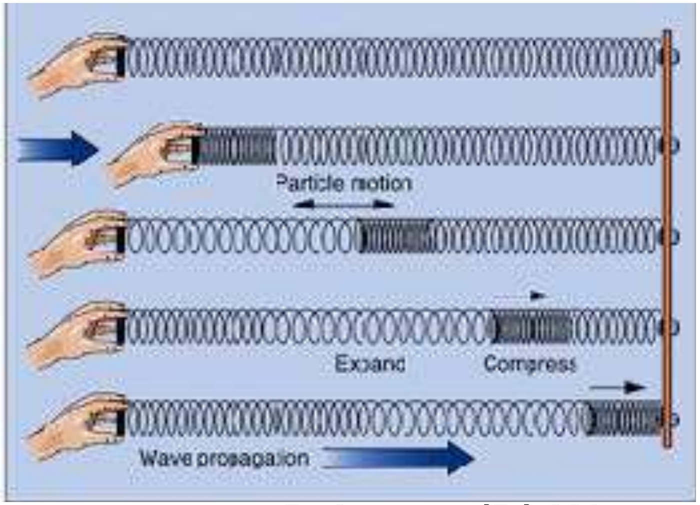
## Seismic Wave Types

- ❑ **Body Waves**
  - ➢ **Primary or Compressional (P-wave)**
  - ➢ **Secondary or Shear (S-wave)**
- ❑ **Surface Waves**
  - ➢ **Rayleigh (large vertical displacements)**
  - ➢ **Love (shear)**

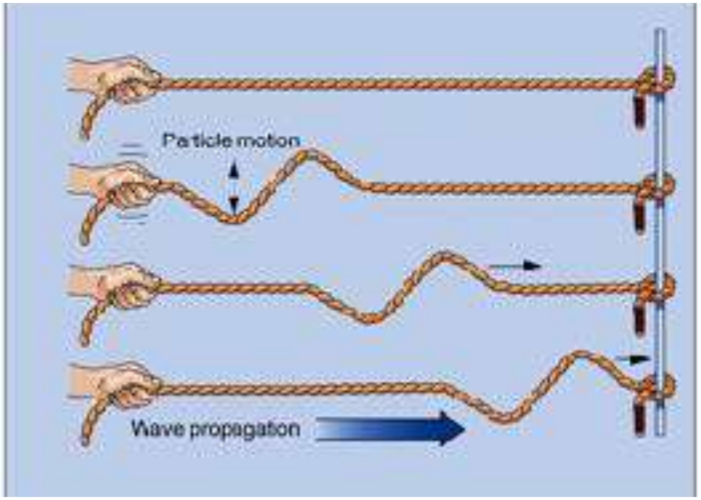
# EARTHQUAKE

## Seismic Wave Types

**Body Waves**

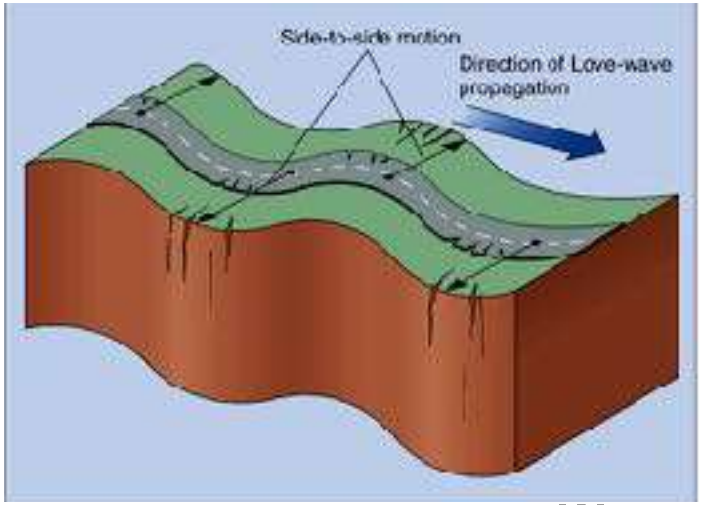



**Primary (P) Wave**

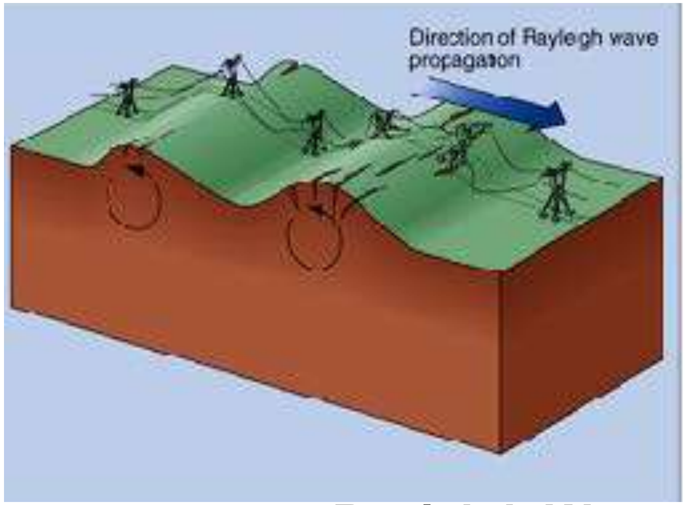



**Secondary (S) Wave**

**Surface Waves**



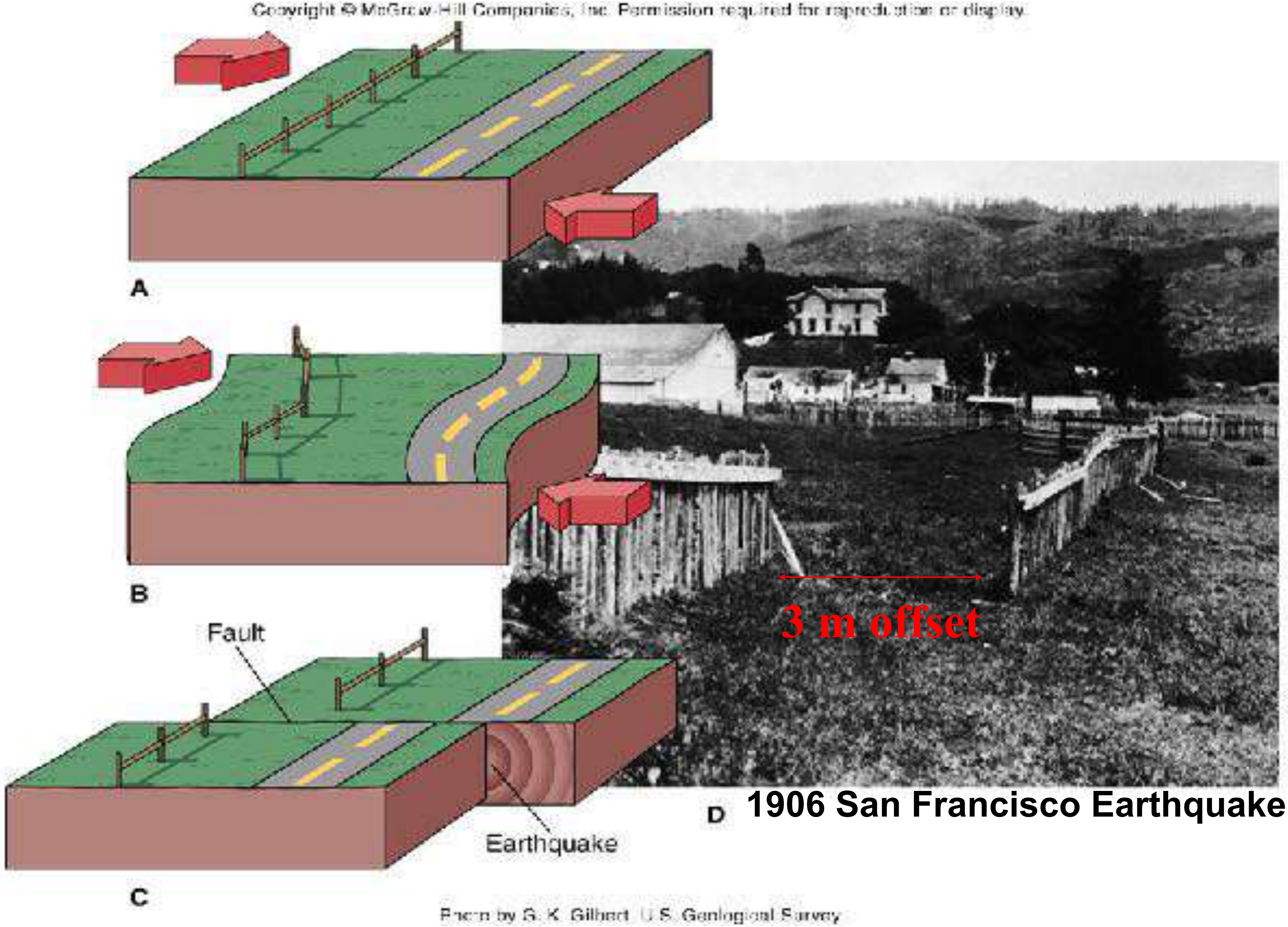

**Love Wave**




**Rayleigh Wave**

# EARTHQUAKE

## Elastic Rebound Theory

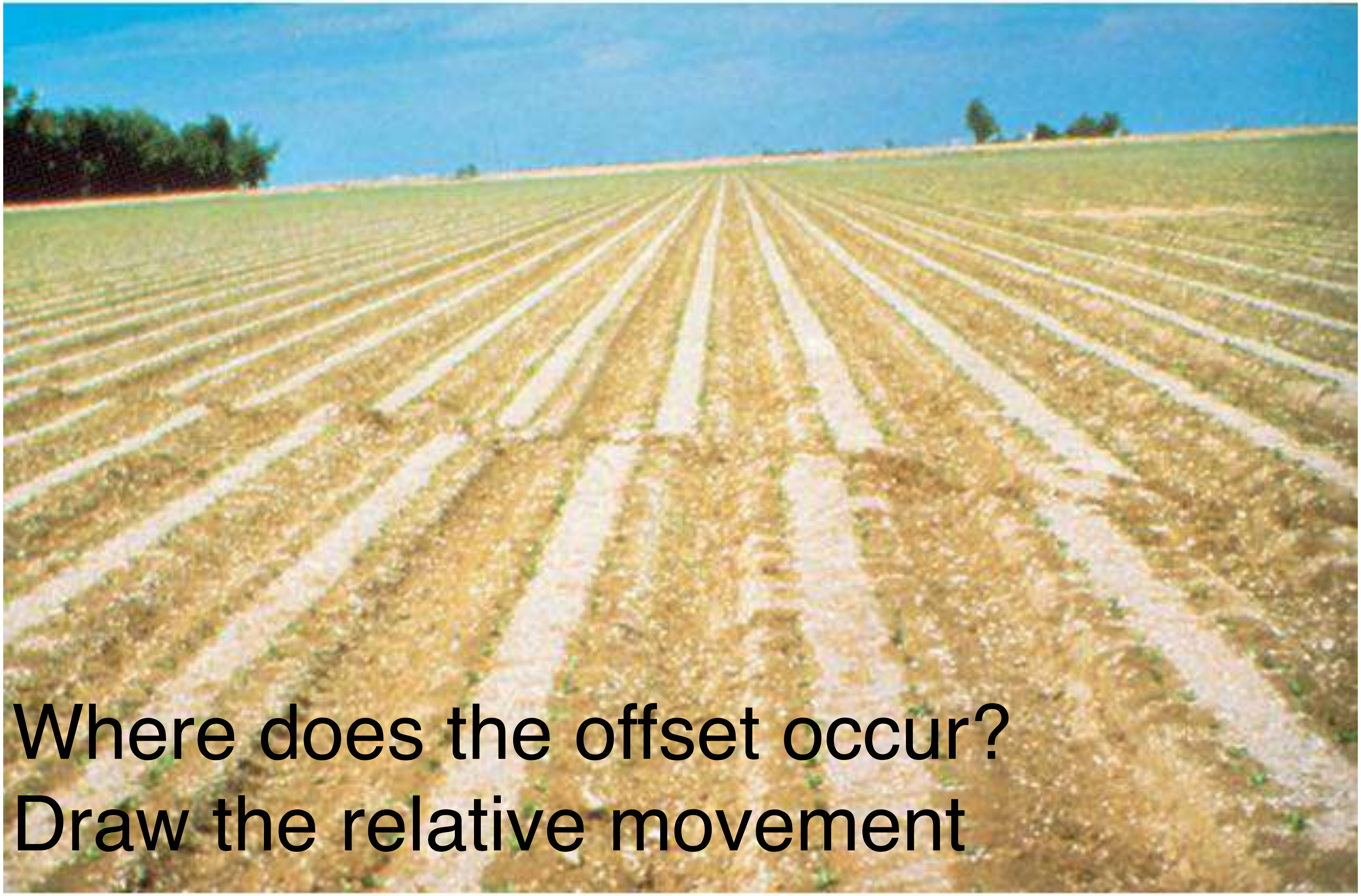



1906 San Francisco Earthquake

# EARTHQUAKE

## Elastic Rebound Theory





Where does the offset occur?
Draw the relative movement



**Offset Lettuce Rows - El Centro, CA**

# EARTHQUAKE

## Equations for velocities

$$V_p = \left[ \frac{k + 4/3\mu}{\rho} \right]^{1/2}$$

$$V_s = \left[ \frac{\mu}{\rho} \right]^{1/2}$$

$\rho$ density

$\mu$ shear modulus (rigidity)

k bulk modulus (rigidity)

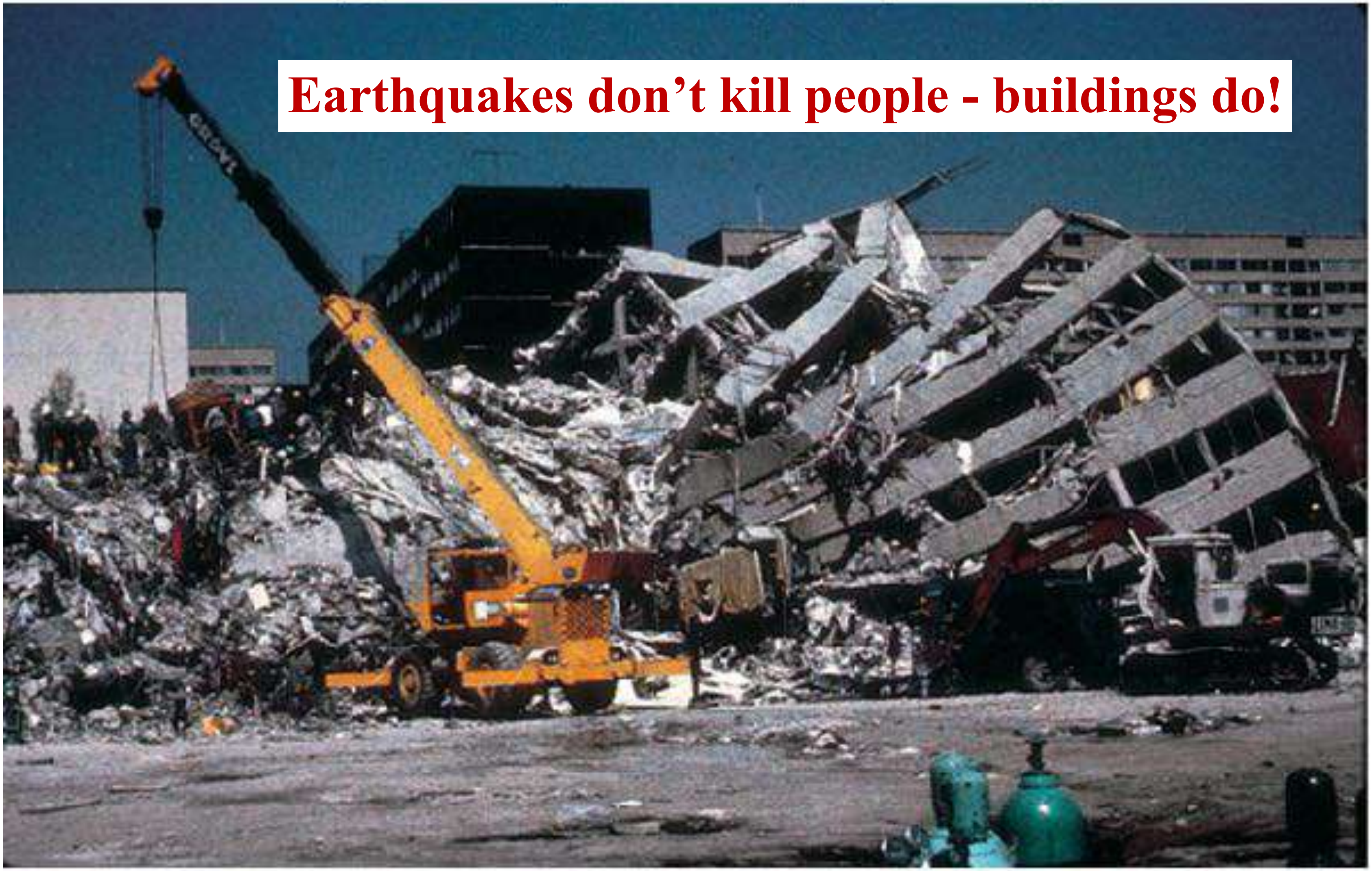
because shear modulus (rigidity) for fluid is zero,
S waves cannot propagate through a fluid

**consequence of equations is that P-waves are 1.7x faster than S-waves**

*can infer physical properties from P and S waves*

# Effects of the Earthquake






B

**Pancaked Building - 1985 Mexico City**

Photo by M. Celebi, U.S. Geological Survey

# Effects of the Earthquake



B

**Soil Liquefaction - 1964 Niigata, Japan**

Photo by National Geophysical Data Center

# Effects of the Earthquake



A

**Surface Displacement - 1964 Alaska**

Photo by U.S. Geological Survey

# Effects of the Earthquake



B

**Ground Rupture, 1906 Olema, CA**

Photo by G. K. Gilbert, U.S. Geological Survey

# *Effects of the Earthquake*



C

**Fence Compression - Gallatin County, MT**

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

# Effects of the Earthquake



D

**Buckled Concrete - 1971 San Fernando, CA**

Photo by David McGeary

# Effects of the Earthquake



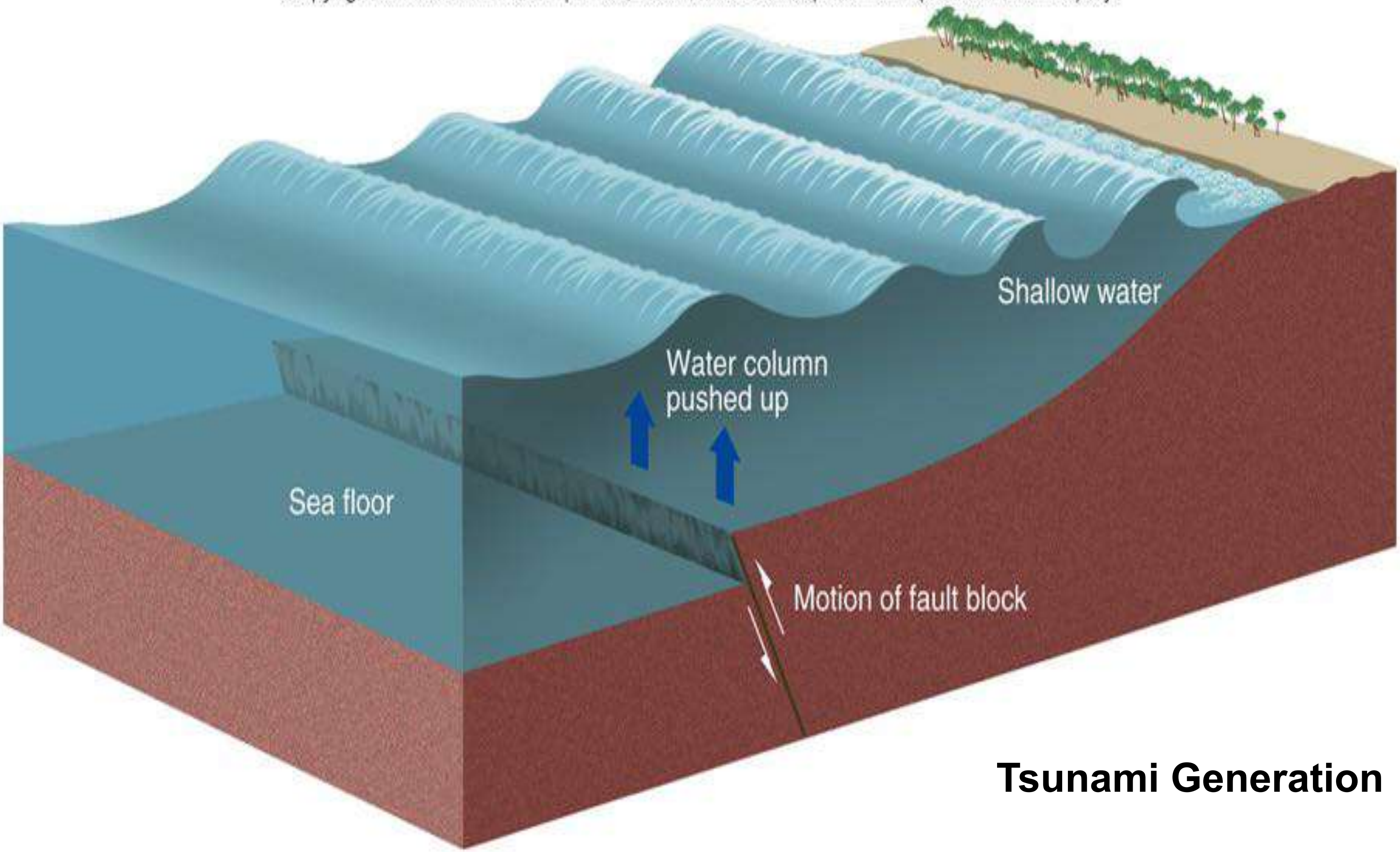

C

**Tsunami Devastation - 1964 Alaska Earthquake**

Photo by National Geophysical Data Center

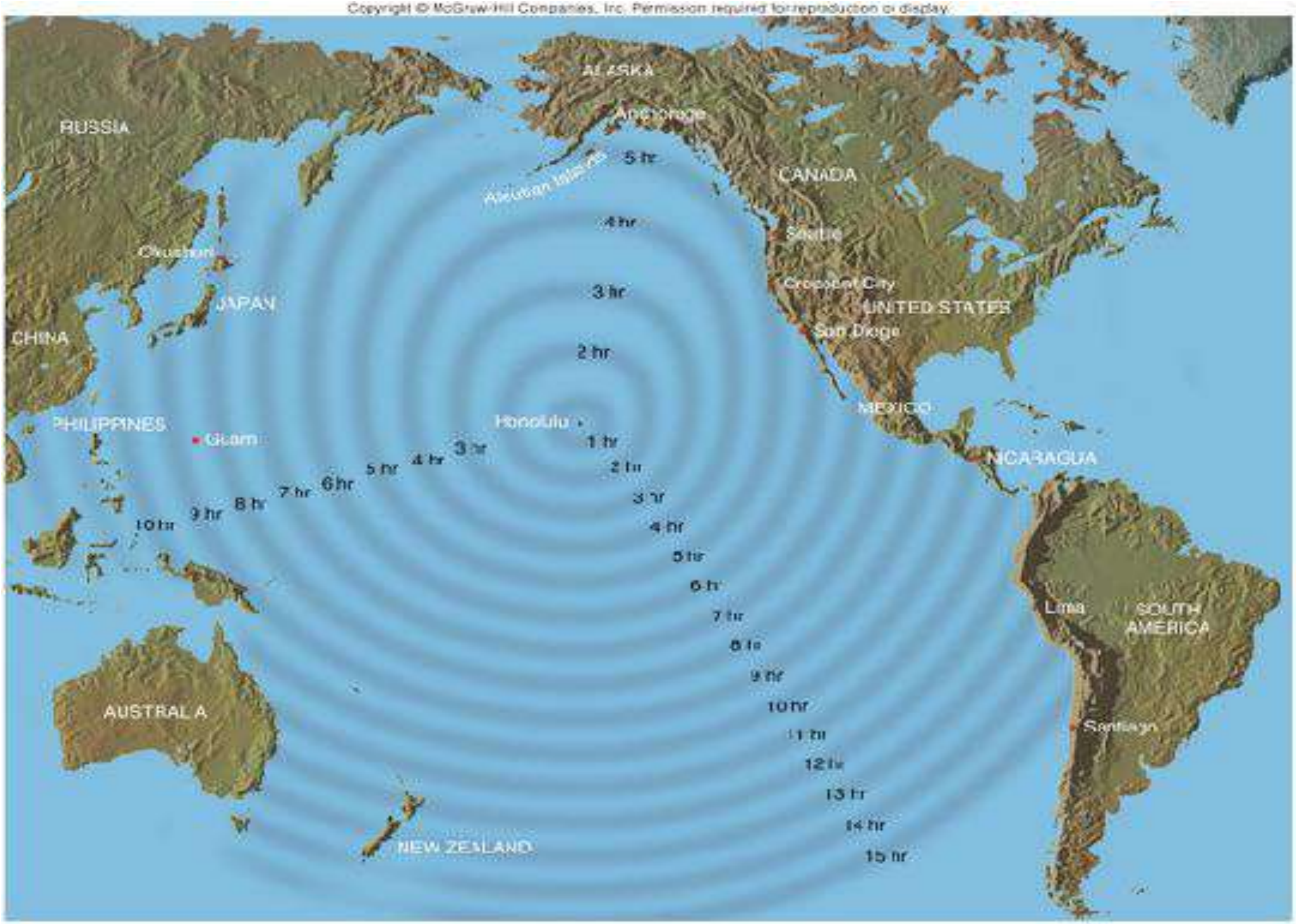
# Effects of the Earthquake






**Tsunami Generation**

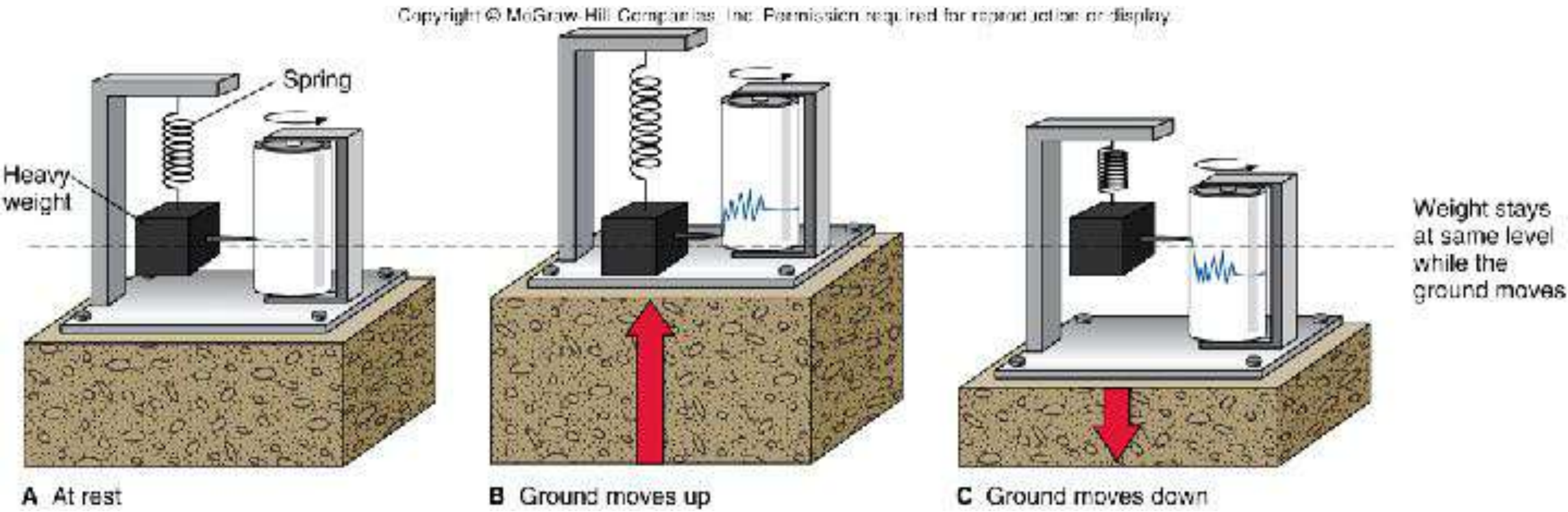
# Effects of the Earthquake




**Tsunami Wave Propagation Times**

# Locating the Earthquake

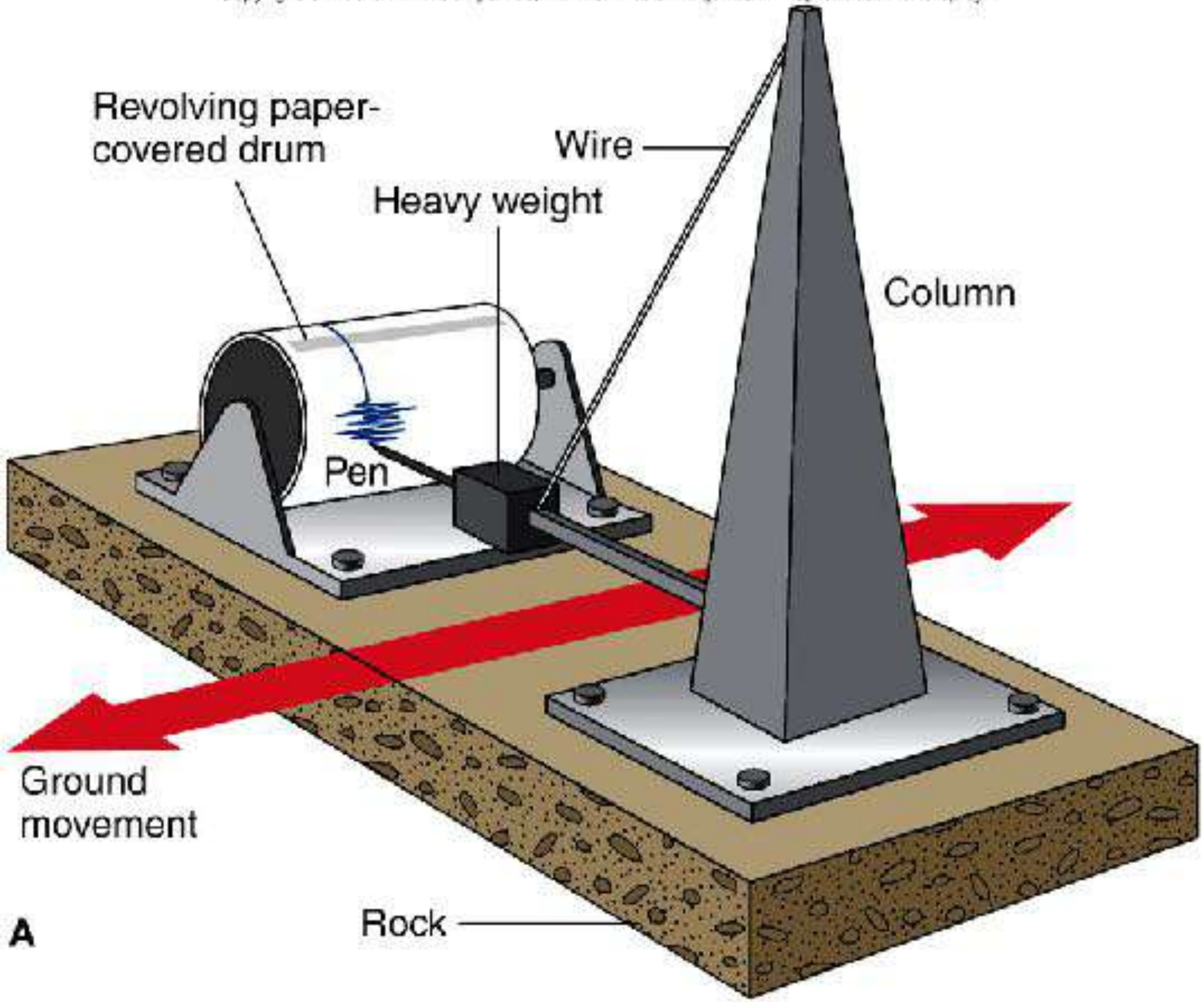
## Vertical Component Seismometer



# Locating the Earthquake

## Horizontal Component Seismometer

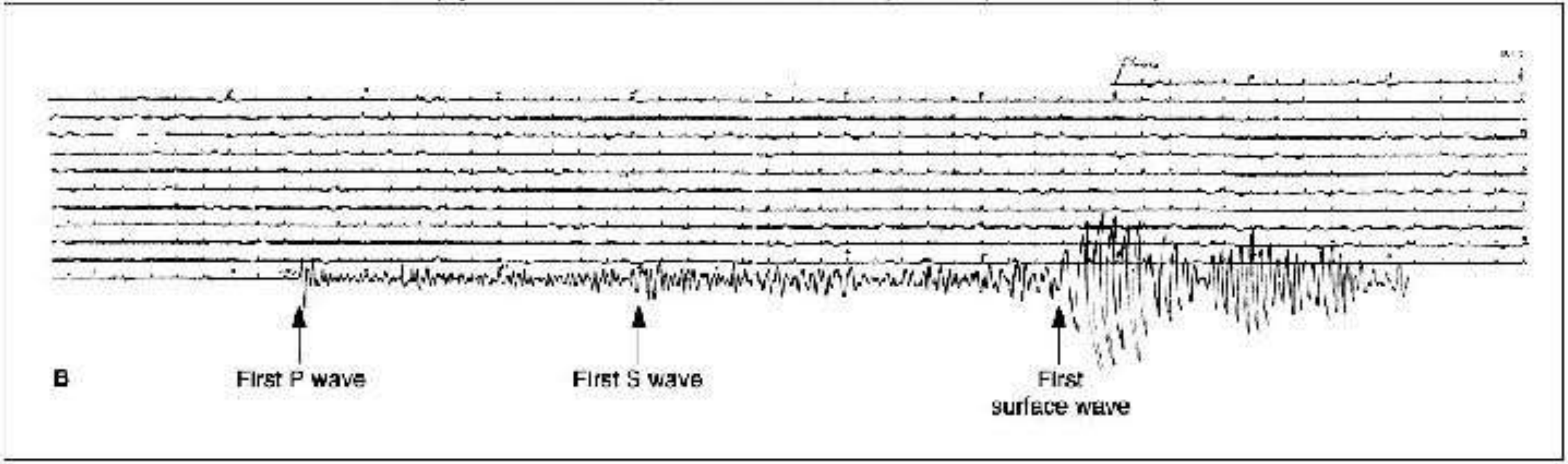




# Locating the Earthquake

## First Arrivals – Seismographic Record

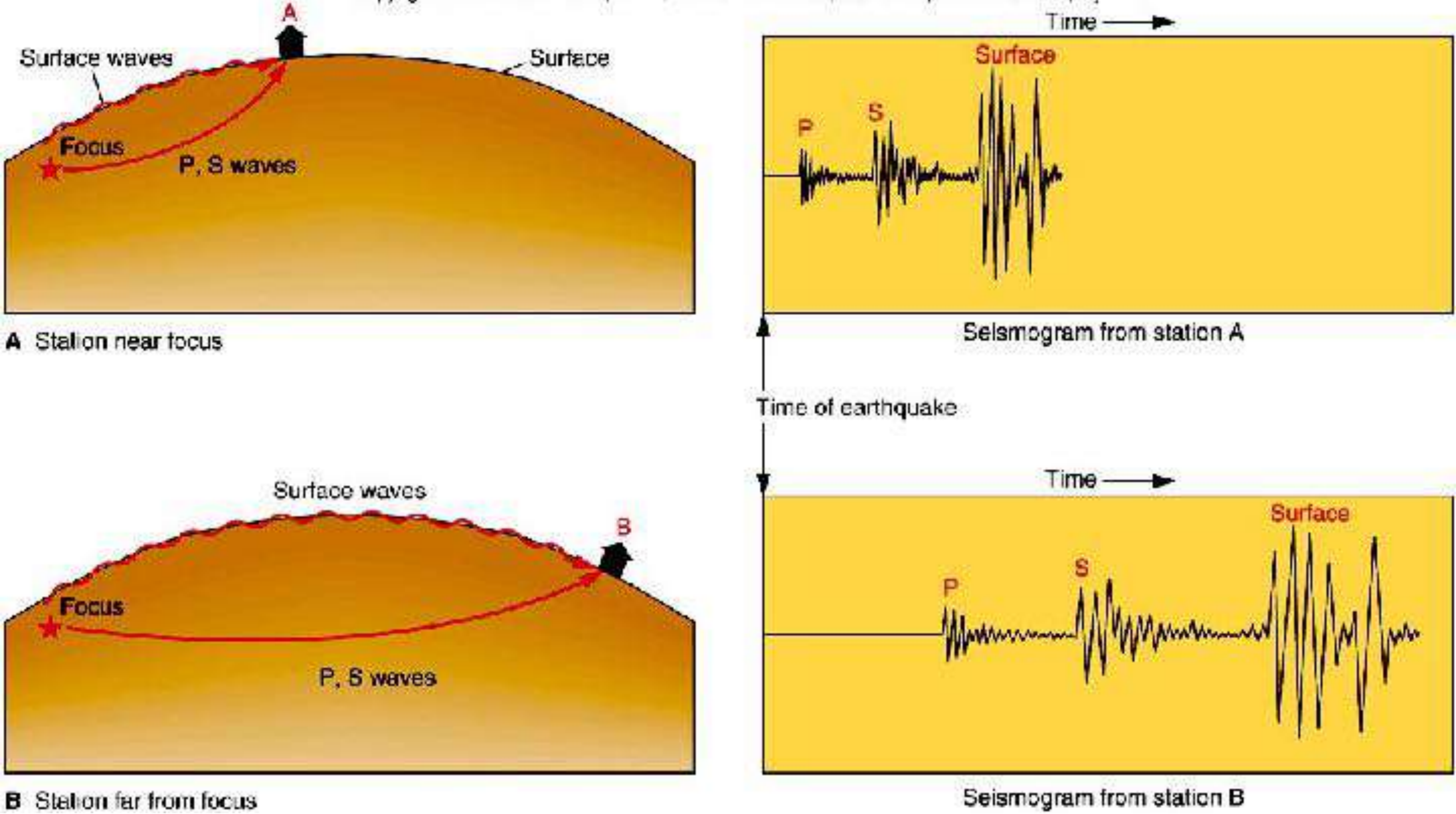




# Locating the Earthquake

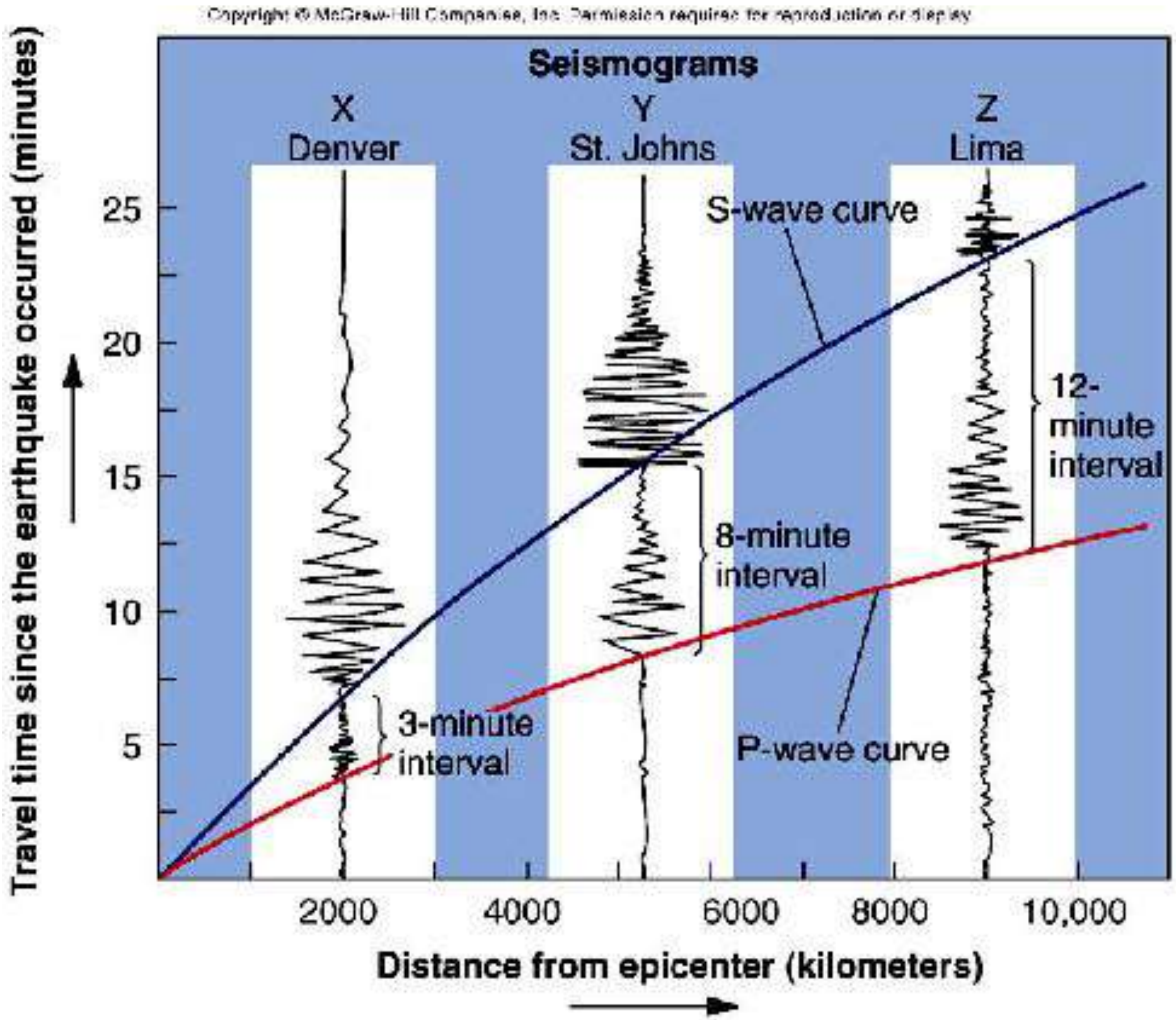
## Distance – Time Ralations





# Locating the Earthquake

## P *vs* S Wave Travel Time Curves



# Locating the Earthquake

## Earthquake Location by Range

# *Measuring the Earthquake*

- 3 distinct methods to measure earthquakes. Two based on energy and one based on intensity.
  - **Richter Magnitude Scale:** originally developed for southern California. Log scale, which has no upper bound. Small earthquakes may yield negative values. Tends to be inaccurate at >7 magnitudes.
  - **Moment Magnitude Scale:** measurement of the amount of work done during the earthquake. Based on rock strength, area of rupture, and displacement during event.
  - **Modified Mercalli Intensity Scale:** based on the damage associated with a particular event at a particular location. Ranges from I (less damage) to XII (most damage).

# Measuring the Earthquake

## Magnitude-Description-Intensity-Frequency Relations



**Table 16.2** 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 |

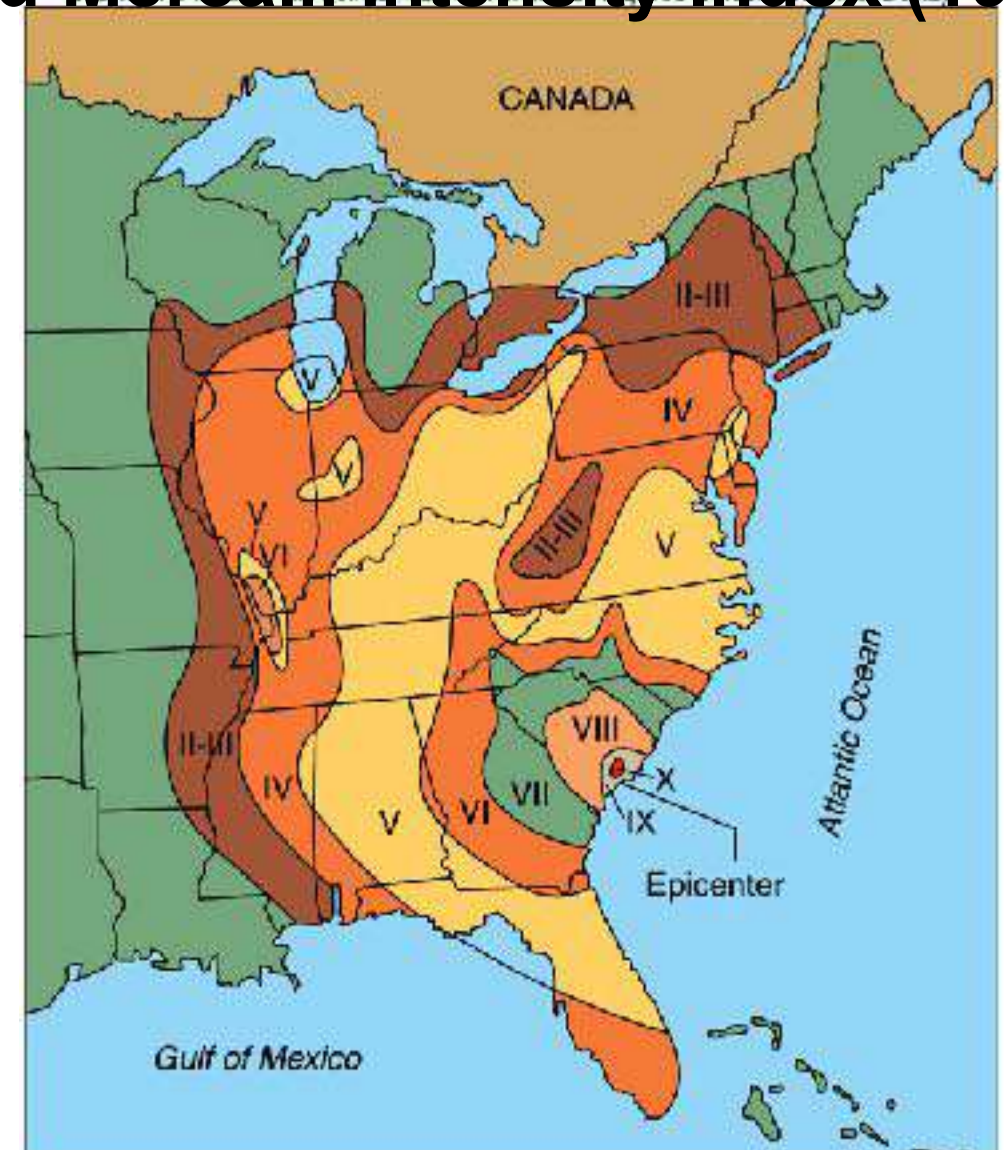
Source: U.S. Geological Survey

# Measuring the Earthquake

## Modified Mercalli Intensity Index (1931

I. Not felt except by a very few under especially favorable circumstances.
II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III. Felt quite noticeably indoors, especially on upper floors of buildings but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster, unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII. Everybody runs outdoors. Damage *negligible* in buildings of good design and construction; *slight* to moderate in well-built ordinary structures; *considerable* in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII. Damage *slight* in specially designed structures *considerable* in ordinary substantial buildings with partial collapse; *great* in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX. Damage *considerable* in specially designed structures; well-designed frame structures thrown out of plumb; *great* in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Considerable landslides from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI. Few if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward into the air.

From Wood and Neumann, 1931, Bulletin Seismological Society of America




1886 Charleston, SC earthquake

# Measuring the Earthquake

## Historical Earthquake Magnitudes



**Table 16.3 Earthquake Magnitudes**

| | | Richter Magnitude | Moment Magnitude |
|---|---|---|---|
| 1811–12 | New Madrid, Missouri area | 7.5, 7.3, 7.8 | 7.7, 7.6, 7.9 |
| 1857 | Fort Tejon, S. Calif. | 7.8 | 7.9 |
| 1872 | Lone Pine, Calif. | 7.8 | 7.6 |
| 1886 | Charleston, South Carolina | 6.7 | 7.0 |
| 1906 | San Francisco, N. Calif. | 8.25 | 7.7 |
| 1915 | Pleasant Valley, Nevada | 7.7 | 7.1 |
| 1933 | Long Beach, S. Calif. | 6.3 | 6.2 |
| 1952 | Kern County, S. Calif. | 7.2 | 7.5 |
| 1954 | Dixie Valley, Nevada | 7.2, 7.1 | 7.3, 6.9 |
| 1957 | Aleutian Islands, Alaska | 8.1 | 8.6 |
| 1958 | Southeastern Alaska | 7.9 | 8.2 |
| 1959 | Hebgen Lake, Montana | 7.7 | 7.3 |
| 1960 | Chile | 8.5 | 9.5 |
| 1964 | Near Anchorage, Alaska | 8.6 | 9.2 |
| 1965 | Aleutian Islands, Alaska | 8.2 | 8.7 |
| 1970 | Peru | 7.75 | 7.9 |
| 1971 | San Fernando Valley, S. Calif. | 6.4 | 6.6 |
| 1975 | Hawaii | 7.2 | 7.5 |
| 1976 | China | 7.8 | 7.6 |
| 1980 | Humboldt County, N. Calif. | 6.9 | 7.2 |
| 1983 | Coalinga, Calif. | 6.7 | 6.2 |
| 1983 | Challis, Idaho | 7.2 | 7.0 |
| 1983 | Adirondack Mountains, New York | 5.1 | 4.9 |
| 1983 | Hawaii | 6.6 | |
| 1985 | Ixtapa, Mexico | | 8.1, 7.5 |
| 1987 | Lawrenceville, Illinois | 5.0 | 5.0 |
| 1987 | Whittier, S. Calif. | 5.9 | 6.0 |
| 1988 | Quebec | 6.0 | |
| 1989 | Loma Prieta, N. Calif. | 7.0 | 7.2 |
| 1989 | Hawaii | 6.1 | 6.4 |
| 1992 | Humboldt County, N. Calif. | 7.1, 6.6, 6.7 | |
| 1992 | Landers, S. Calif. | 7.5, 6.7 | 7.35, 6.4 |
| 1994 | Northridge, S. Calif. | 6.4 | 6.7 |
| 1995 | Kobe, Japan (7.2 on Japanese scale) | 6.8 | 6.9 |
| 1998 | Papua New Guinea | | 7.1 |
| 1999 | Izmit, Turkey | | 7.4 |
| 1999 | Taipei, Taiwan | | 7.6 |
| 2001 | El Salvador | | 7.7 |
| 2001 | Gujarat, India | | 7.7 |
| 2001 | Puget Sound (Nisqually), Washington | | 6.8 |

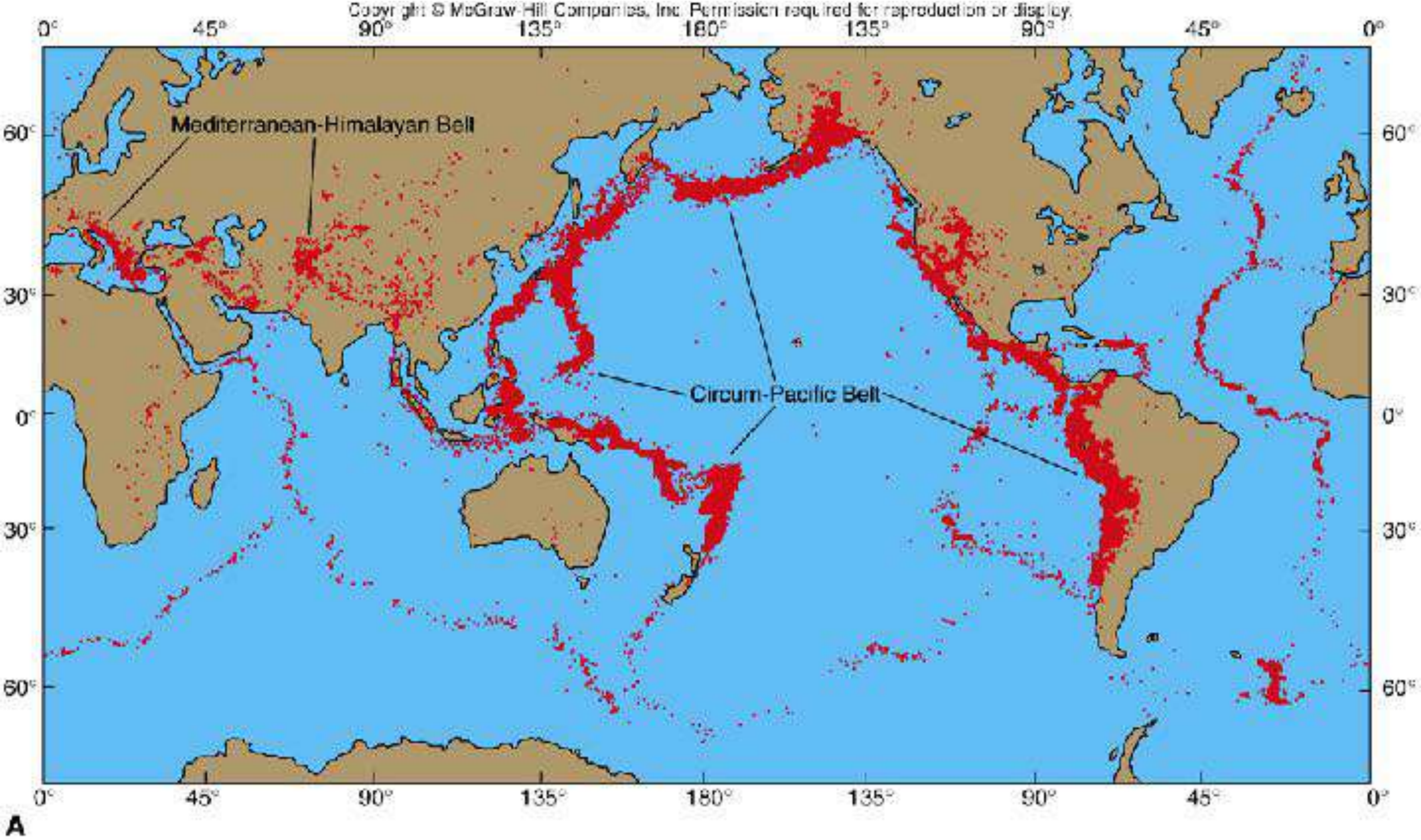
U.S. Geological Survey and other sources

# *Earthquake and Plate Tectonics*

- Earthquakes at Plate Boundaries
- Subduction Angle

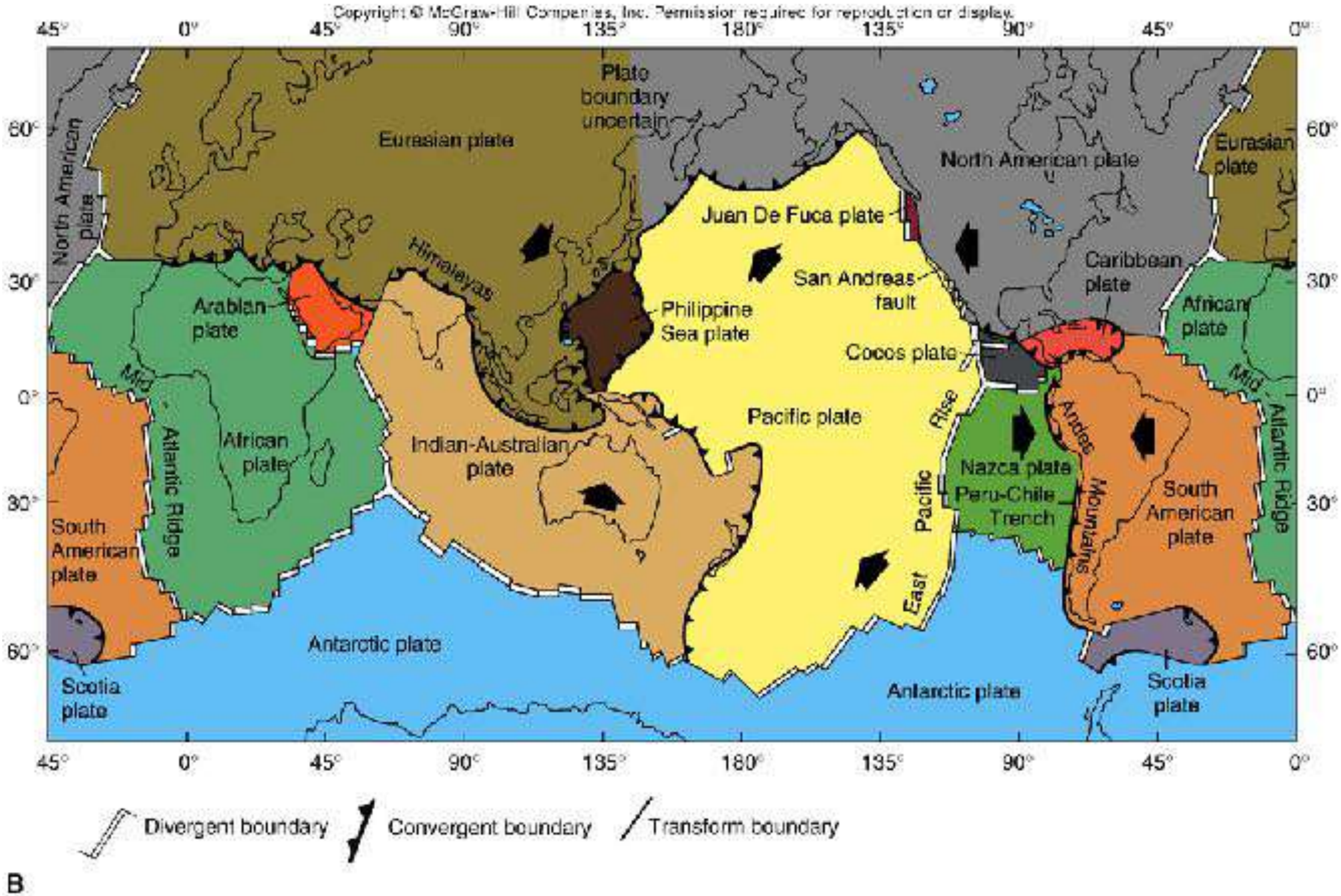
# Earthquake and Plate Tectonics

## Earthquake Distribution



# Earthquake and Plate Tectonics

## Relative plate motion and boundaries

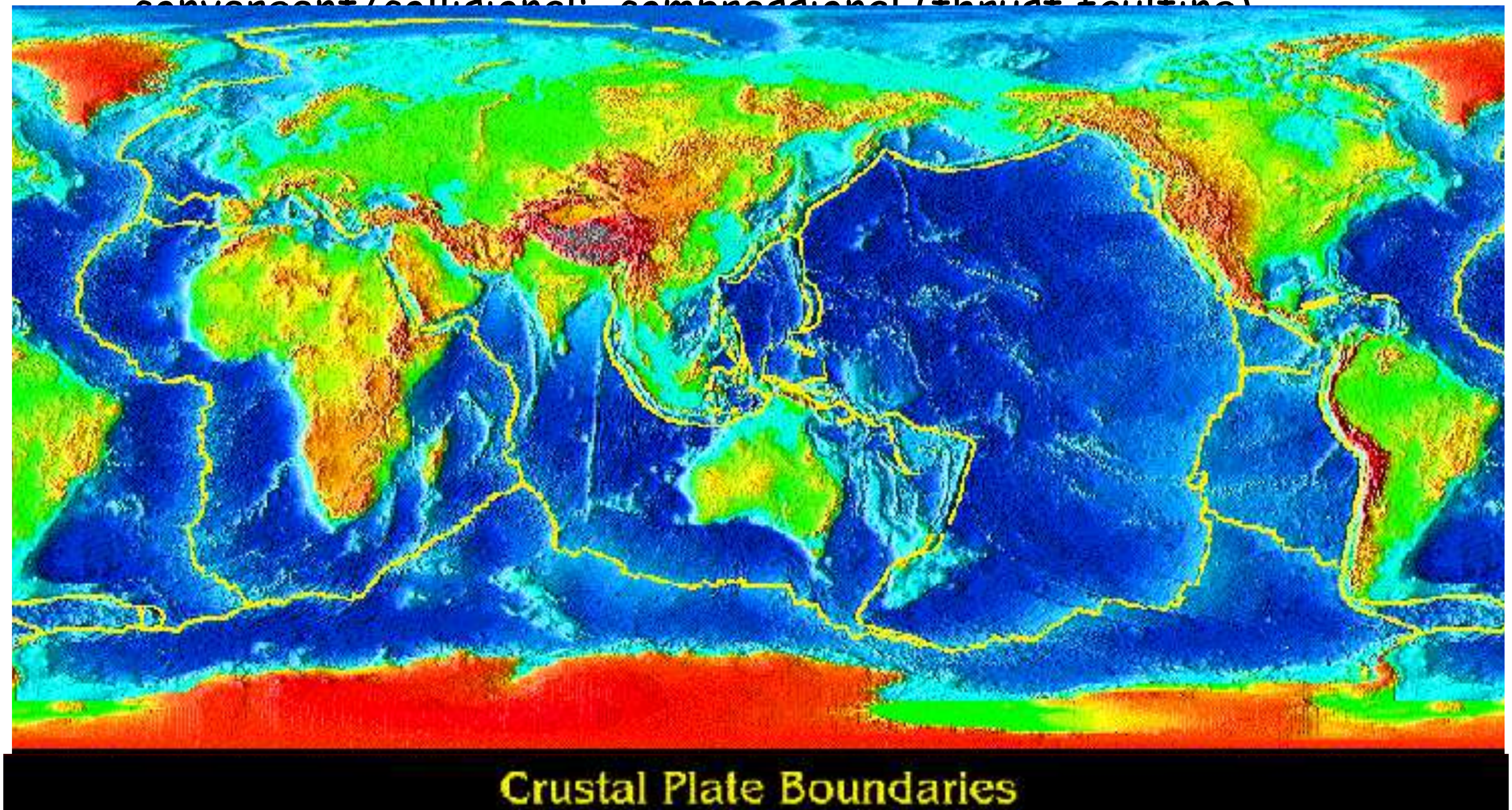


# Earthquake and Plate Tectonics

different types of structures are associated with each boundary type:

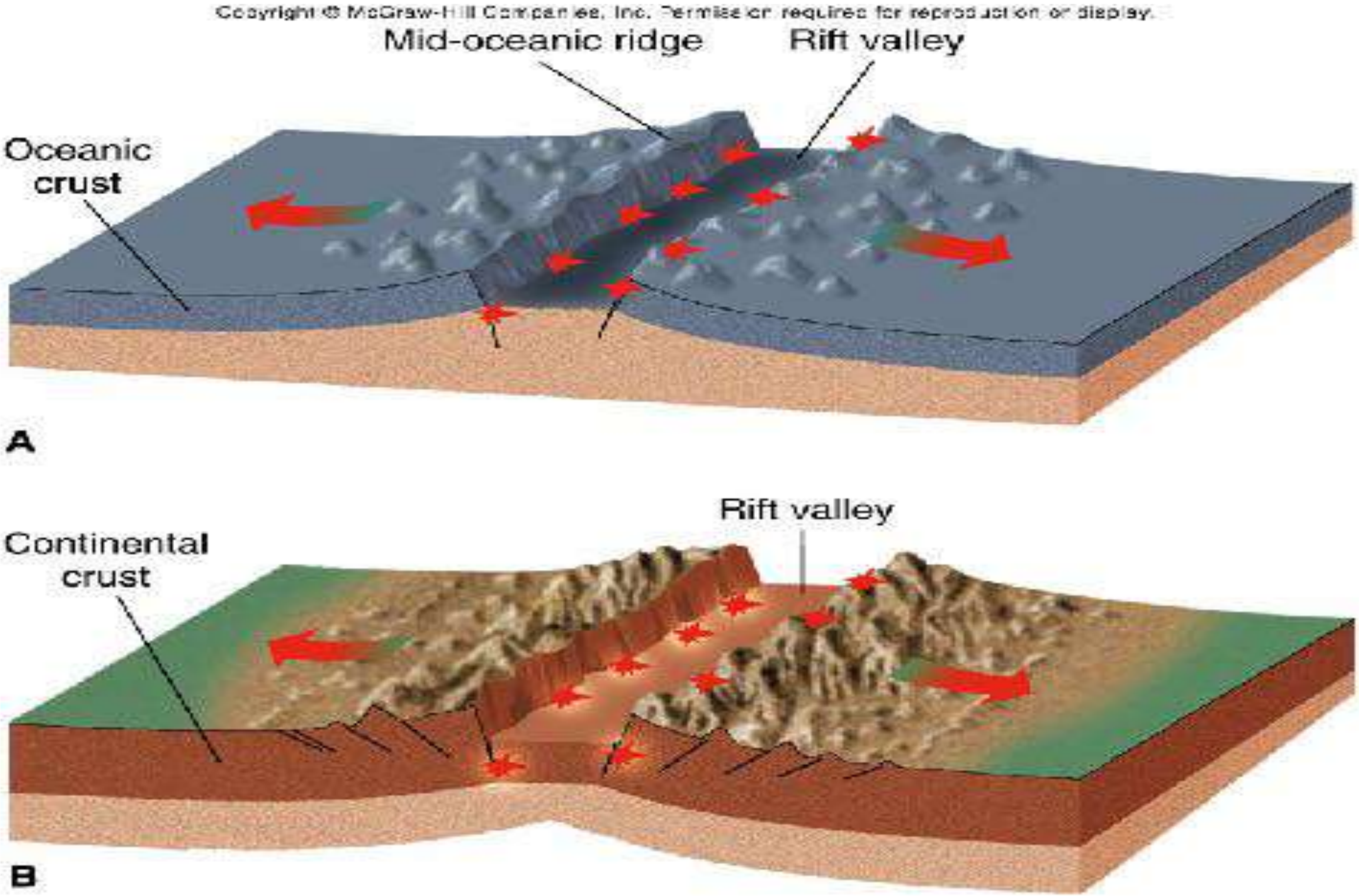
divergent/rifting: extensional (normal faulting)

convergent/collisional: compressional (thrust faulting)



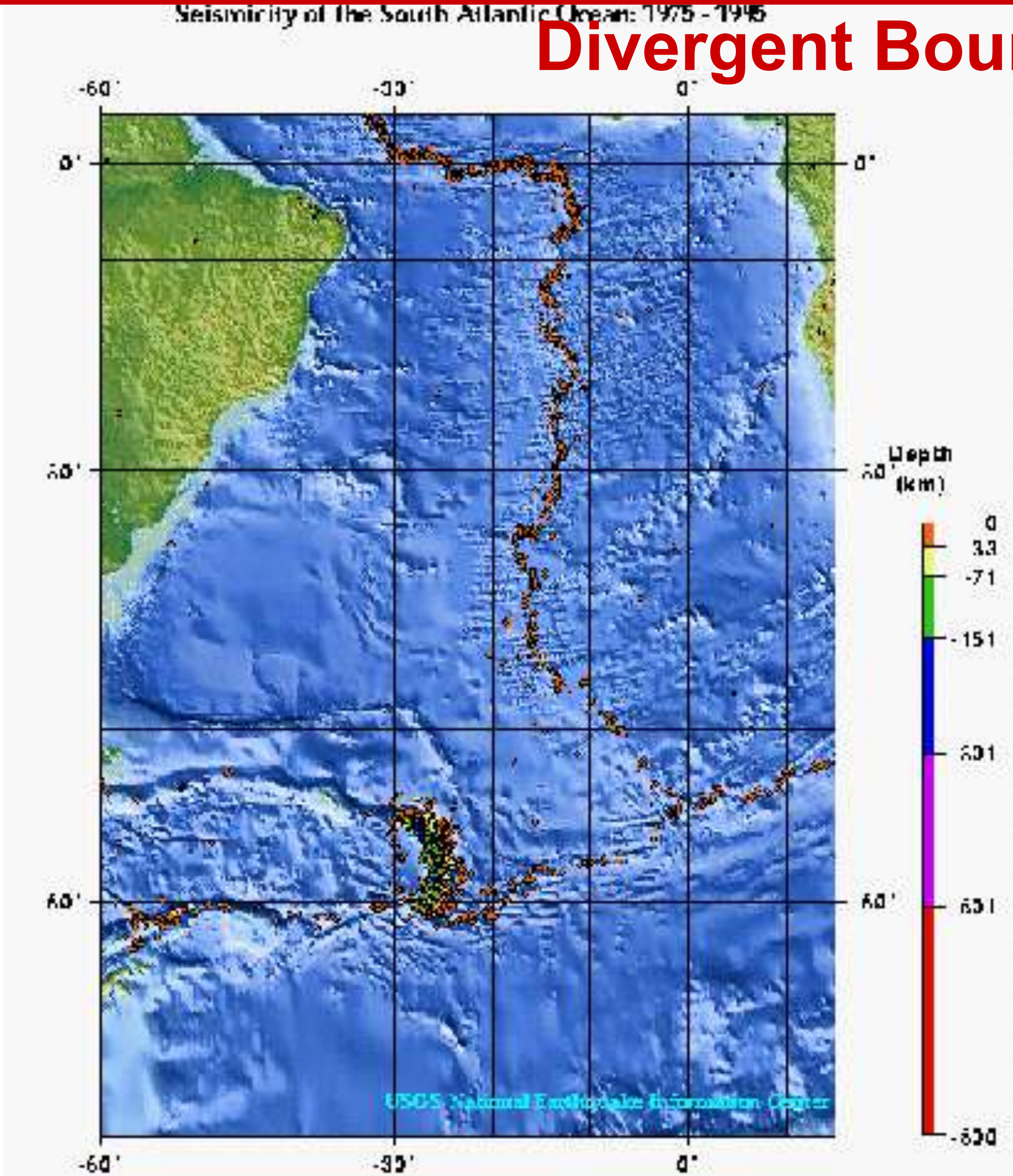
# Earthquake and Plate Tectonics

## Divergent Boundary and Earthquakes



# Earthquake and Plate Tectonics

## Divergent Boundary and Earthquakes



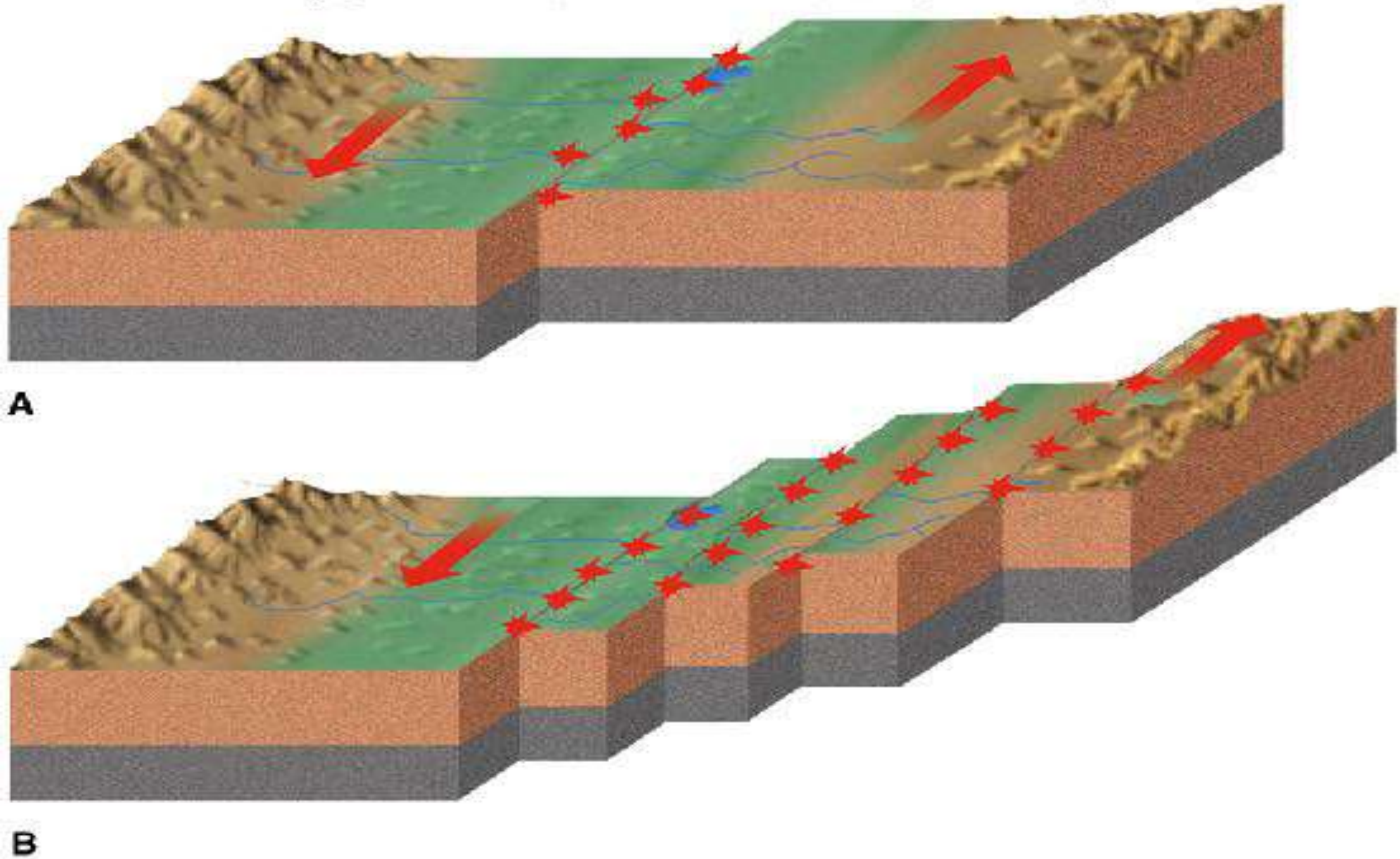

from: http://www.pmel.noaa.gov/vents/coax/coax.html

**Earthquakes along mid-ocean ridge are shallower than those along subduction zone**

# Earthquake and Plate Tectonics

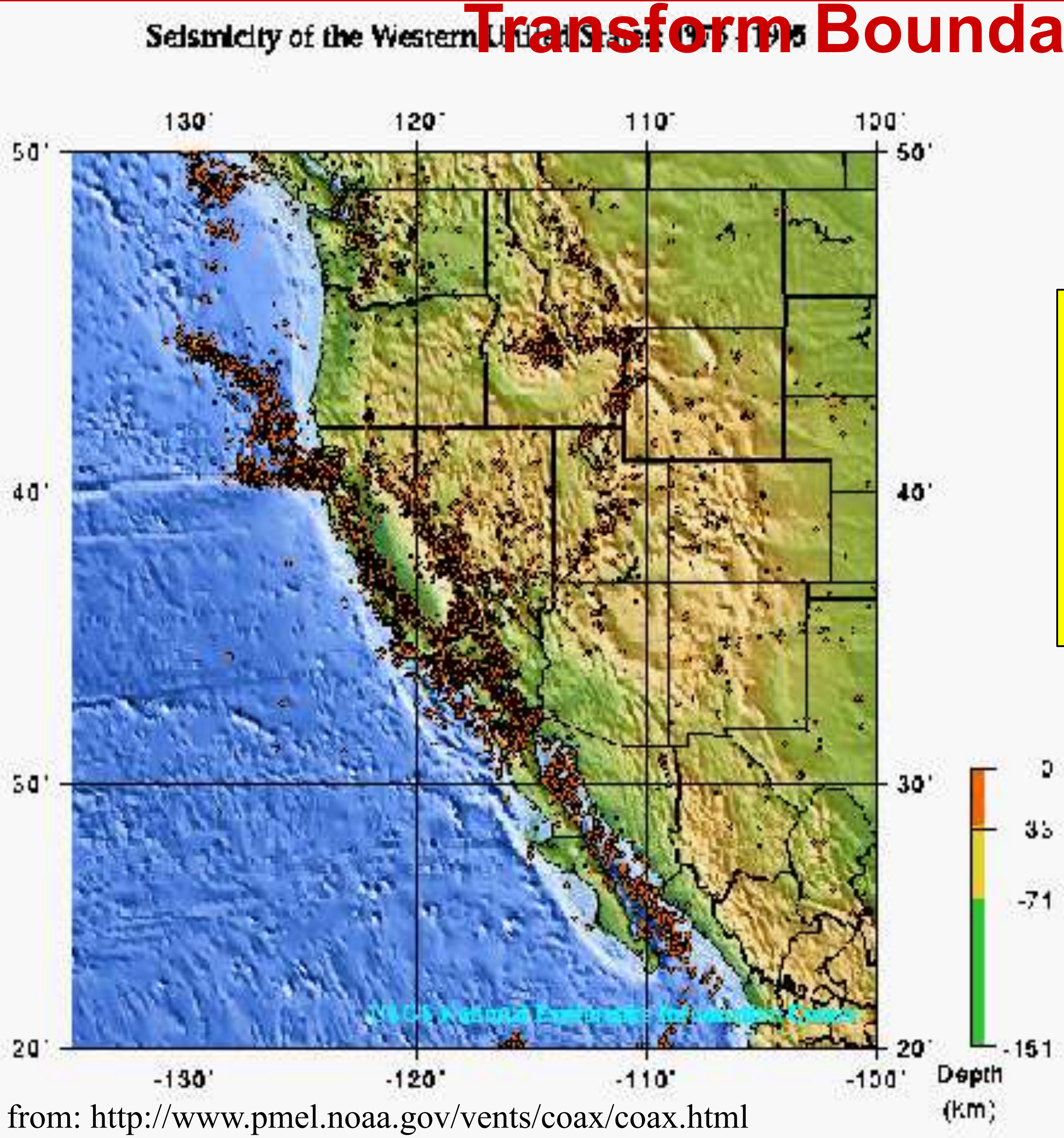
## Transform Boundary and Earthquakes





# *Earthquake and Plate Tectonics*

## Transform Boundary and Earthquakes

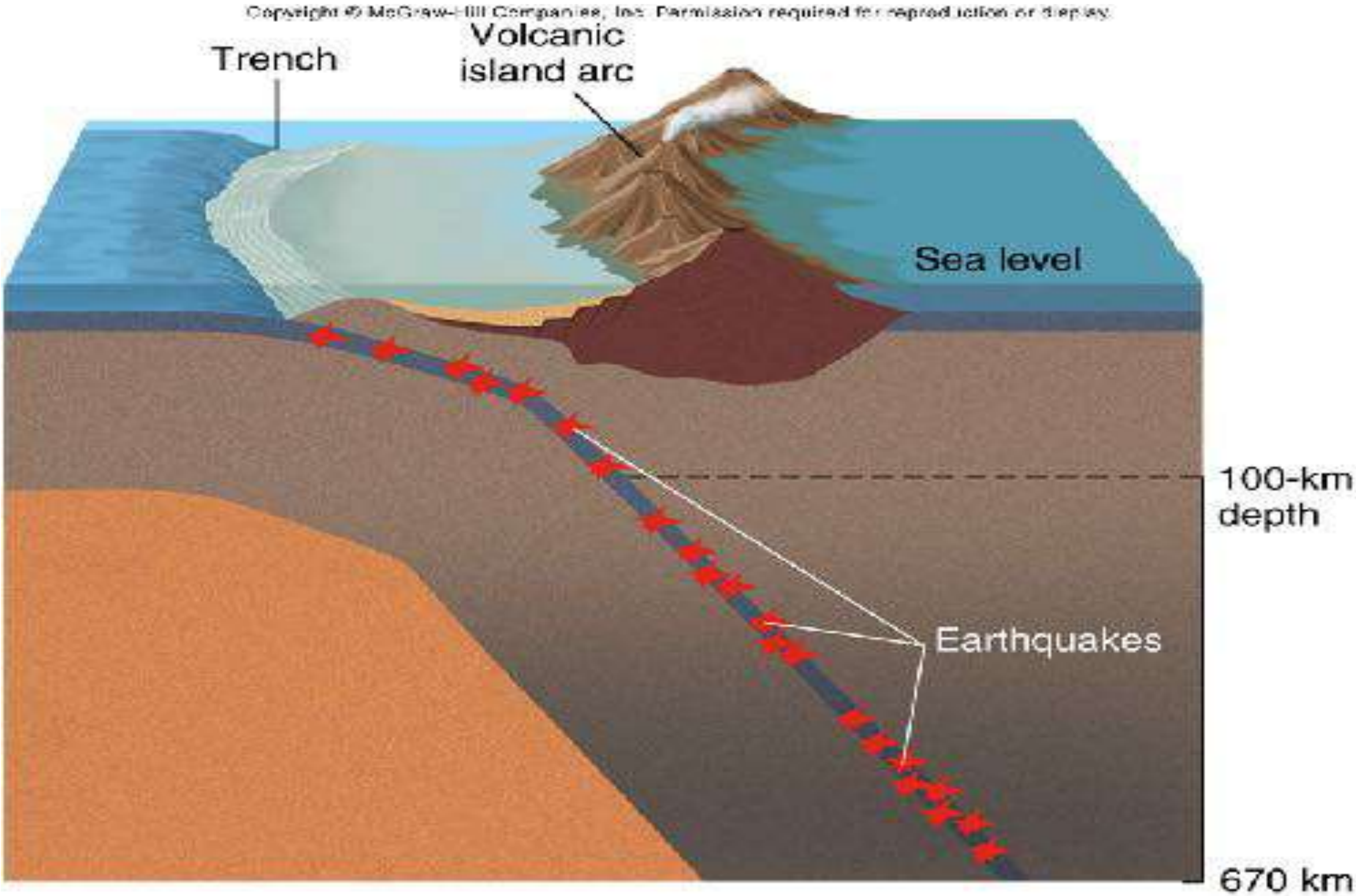



from: http://www.pmel.noaa.gov/vents/coax/coax.html

**The western US is somewhat anomalous**
**Note: absence of deep earthquakes**

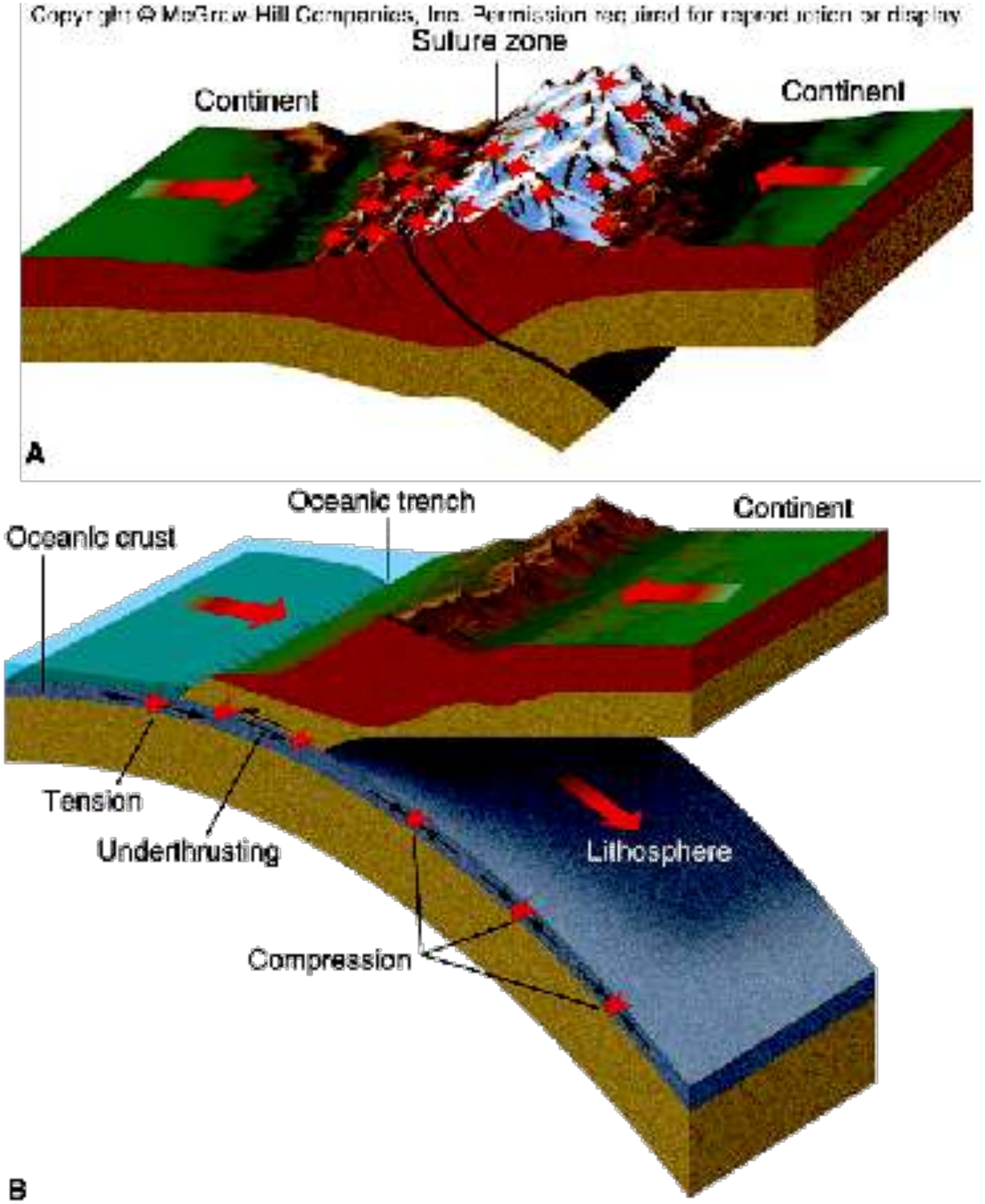
# Earthquake and Plate Tectonics

## Convergent Boundary and Earthquakes



# Earthquake and Plate Tectonics

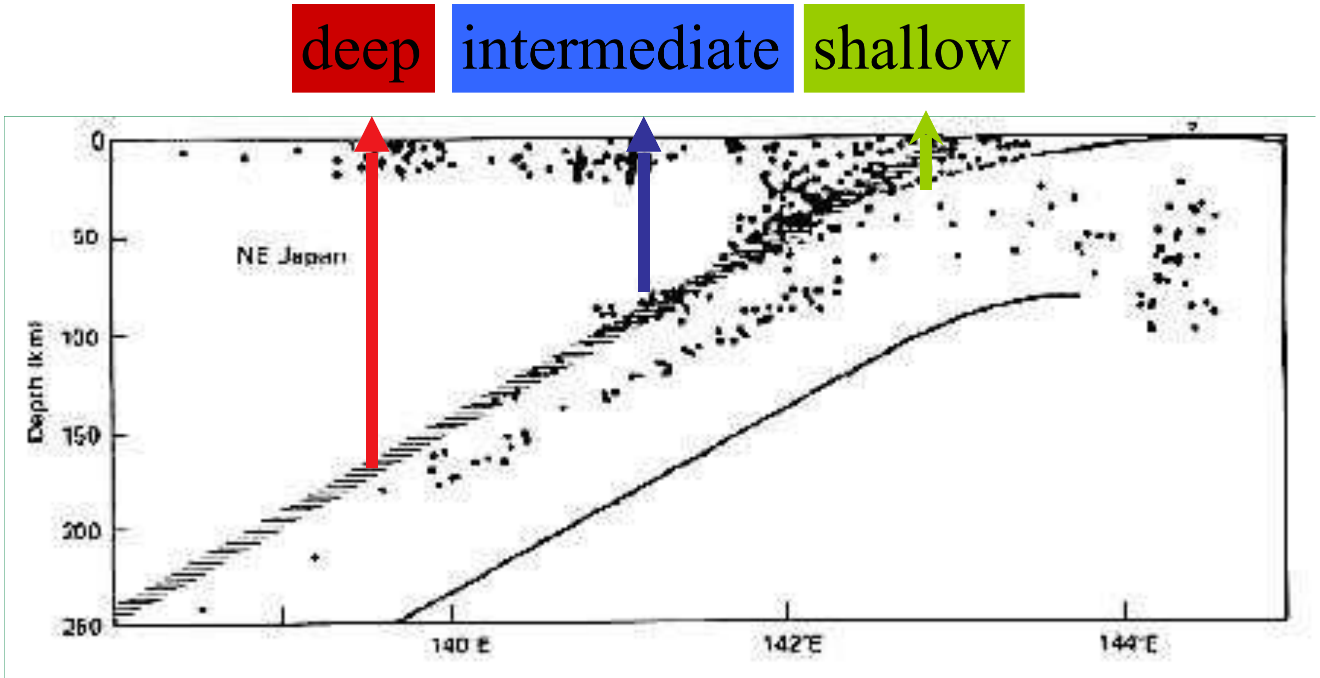
## Shallow vs. Deep Subduction Earthquakes




**Continent-continent collision zones have broad areas of of relatively shallow seismicity**

**Ocean-continent convergent margins have earthquakes foci that extend to great depths. Mechanism tend to change from extension to compression downdip.**

# *Earthquake and Plate Tectonics*

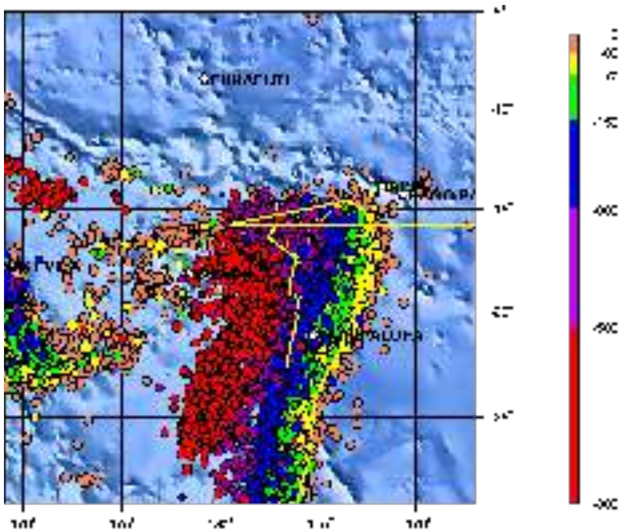



- **Epicenters: location of earthquake rupture projected to surface;**
- **Dip of slab leads to observed seismicity patterns: deeper farther from trench**
- **Location of downgoing slab as it dives into mantle is defined by seismicity.**
- **Earthquakes occur along an inclined belt: the Wadati-Benioff zone reaches maximum depth of ~670 km**

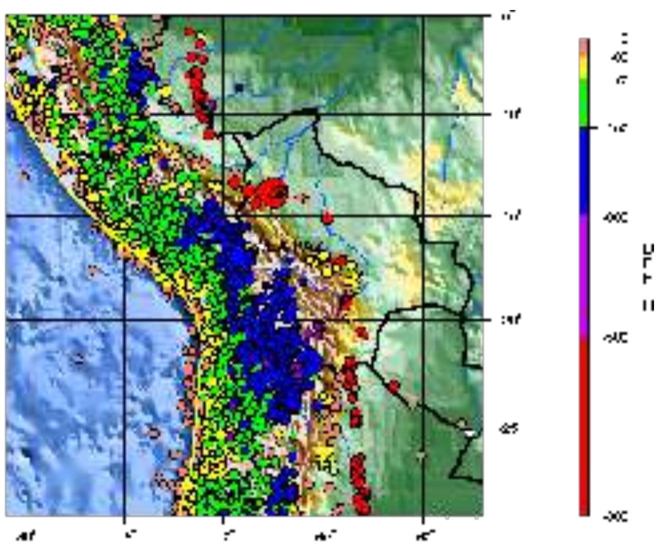
from: http://www.geo.lsa.umich.edu/~crlb/COURSES/270

# Earthquake and Plate Tectonics

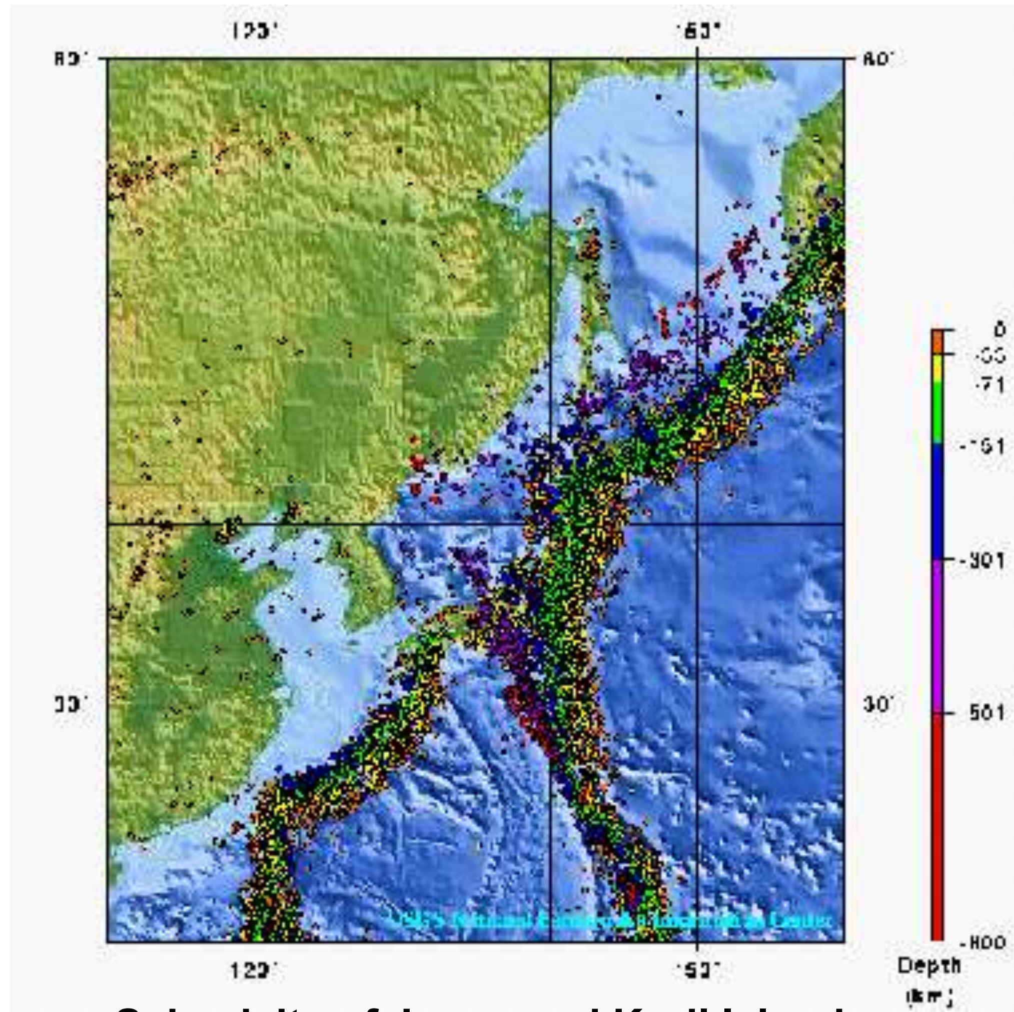
## Seismicity of subduction zones



Seismicity Fiji Islands Region: 1977 - 1997



Seismicity of Peru-Bolivia Border Region: 1977 - 1997

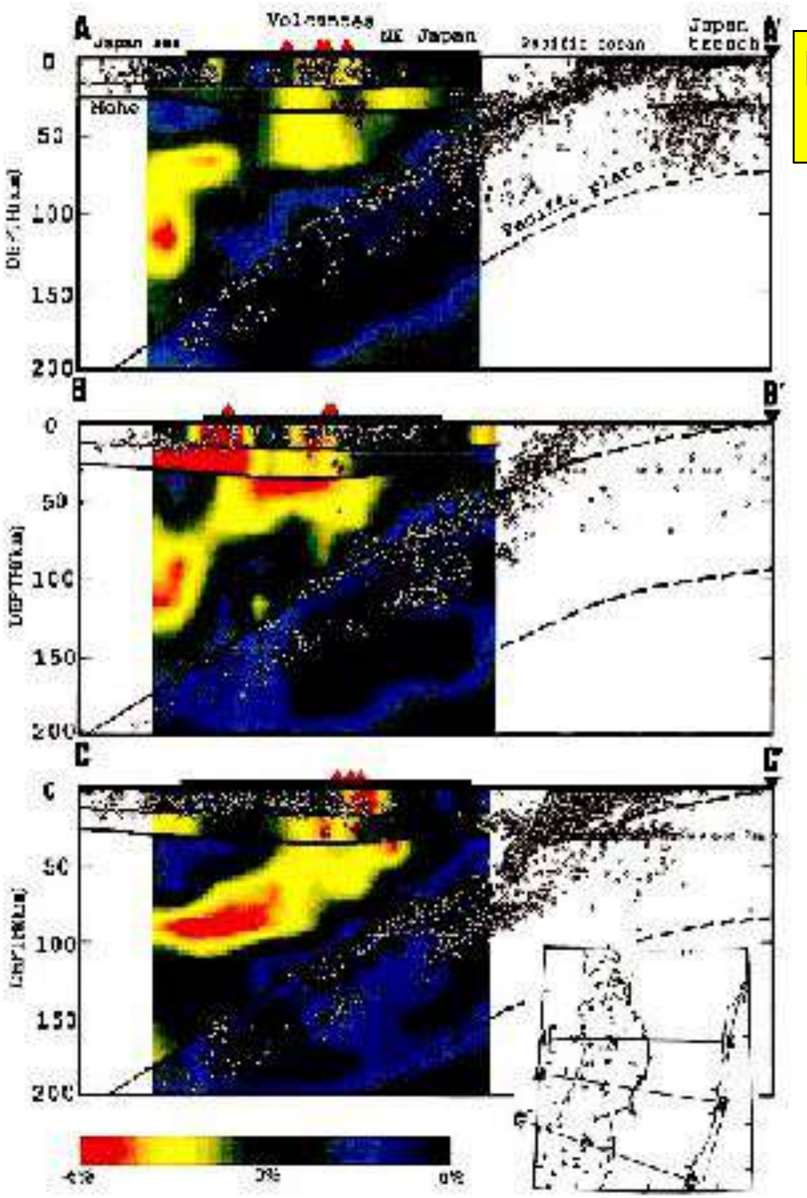



Seismicity of Japan and Kuril Island: 1975 - 1995

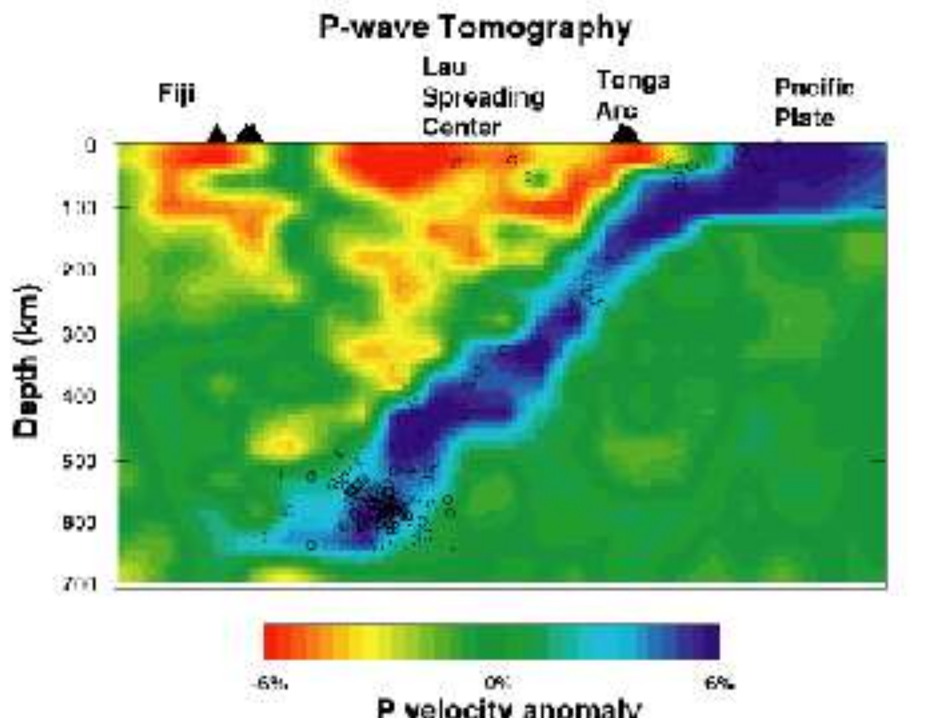
all from: http://www.pmel.noaa.gov/vents/coax/coax.html

# Earthquake and Plate Tectonics

## Tomography (3D seismic)




**blue is fast…
interpreted as slab**

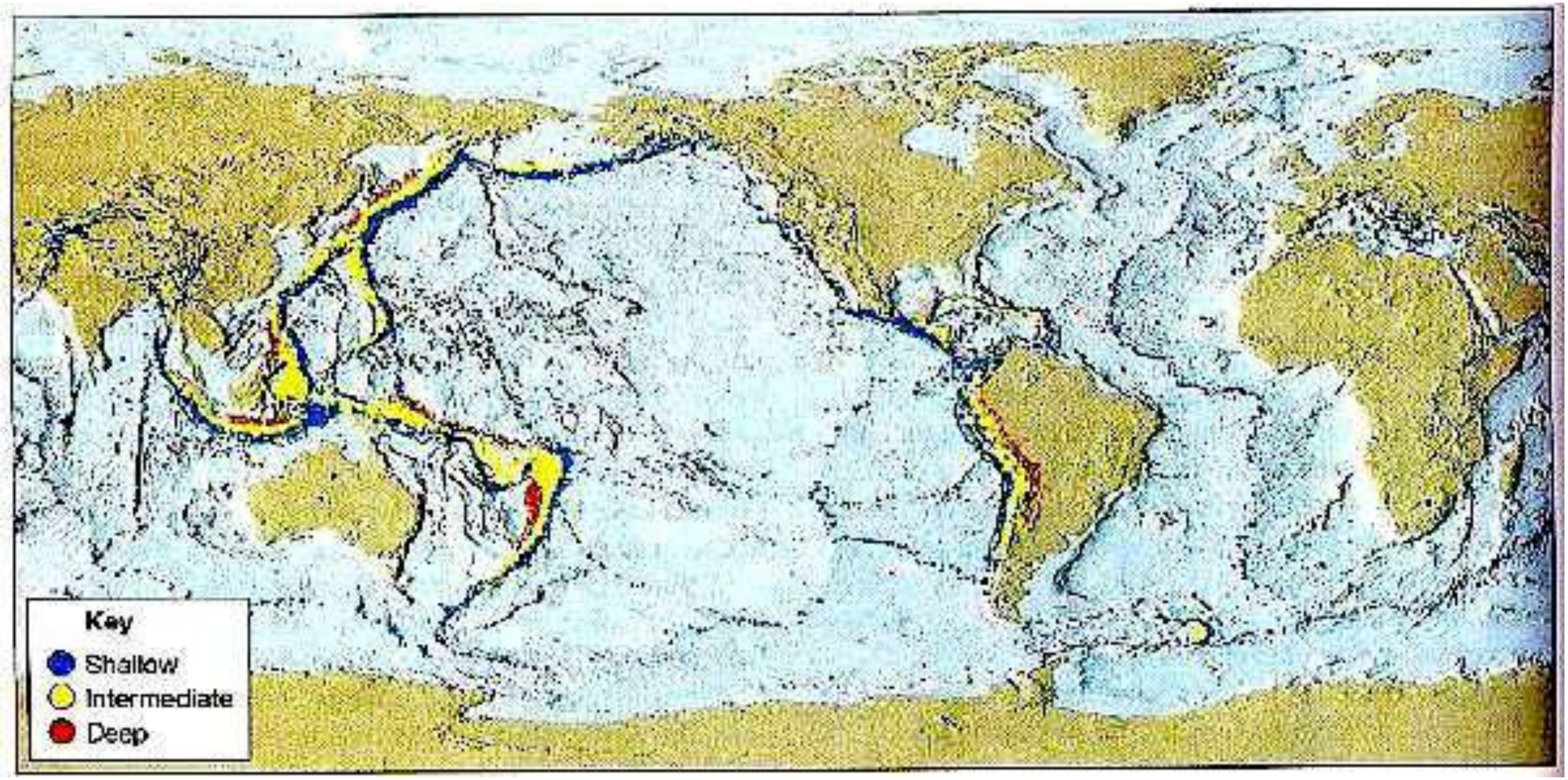



**note continuity of blue slab
to depths on order of 670 km**

**slab is cold and thus can have
earthquakes at greater depths**

from: http://www.pmel.noaa.gov/vents/coax/coax.html

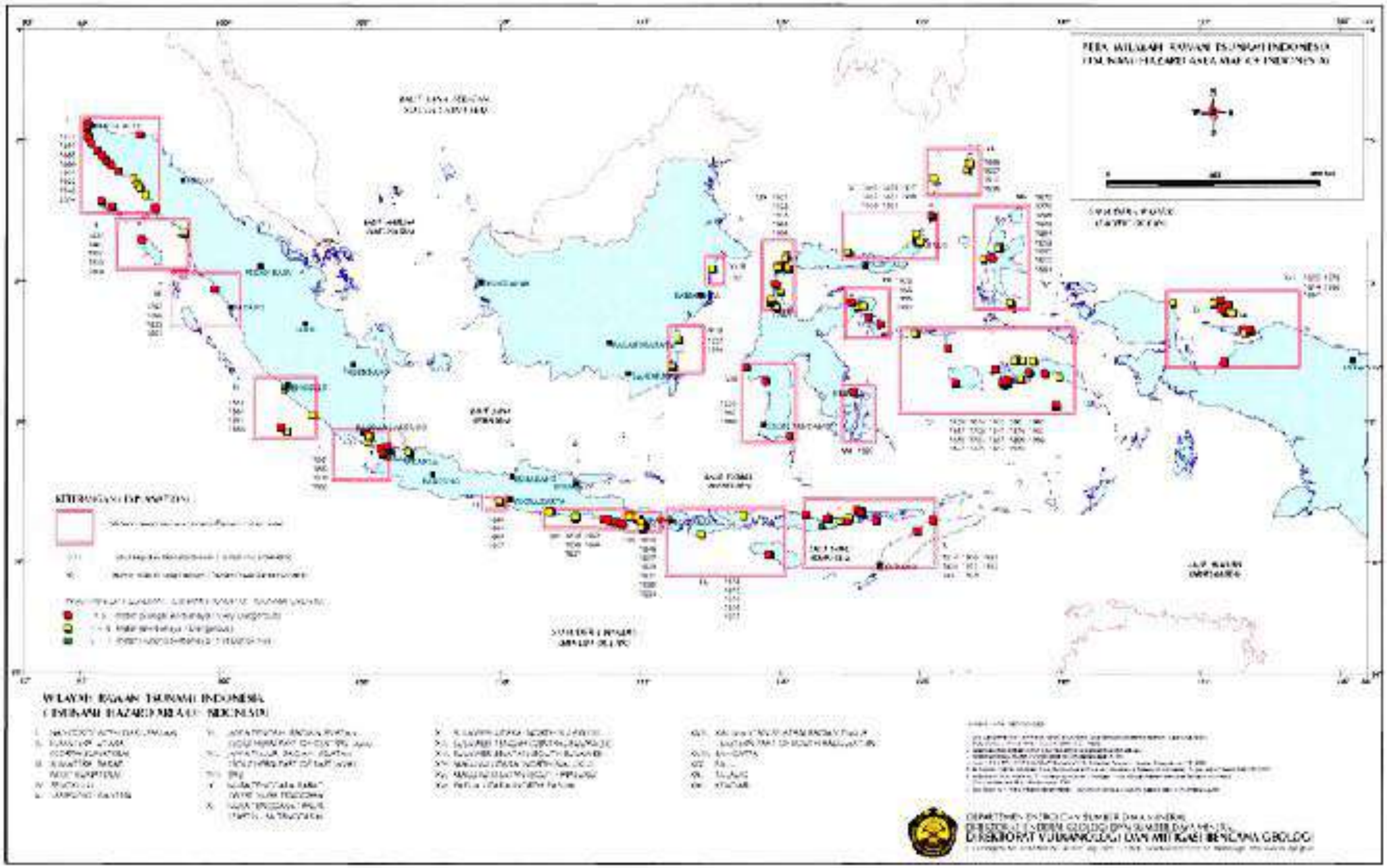
# Earthquake and Plate Tectonics



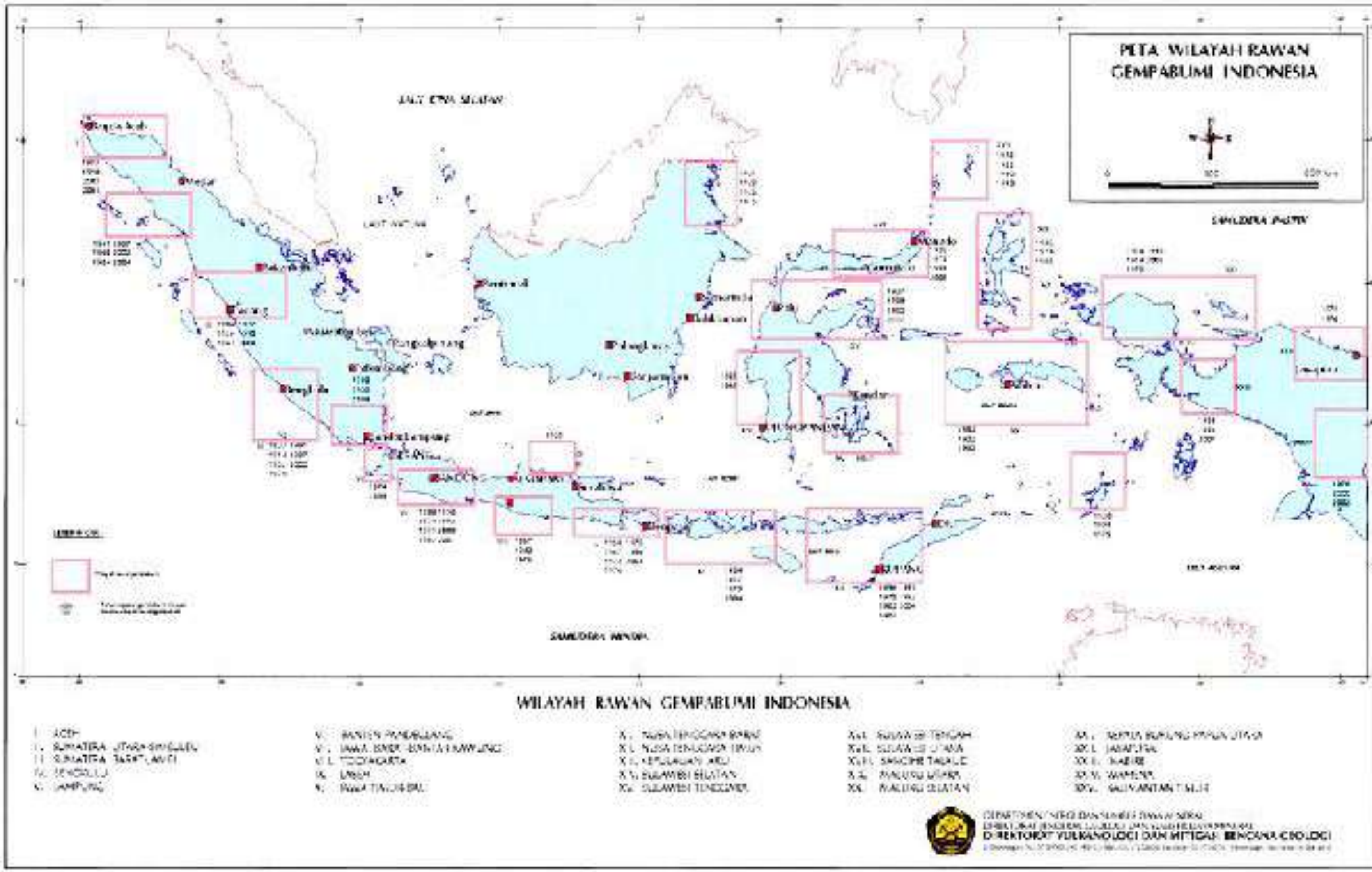

**Seismicity along subduction zones:**
**earthquakes are shallow, intermediate, and deep**
**but have systematic location related to subducting slab**
**shallow adjacent to trench and deep farthest away**

from: http://www.geo.lsa.umich.edu/~crlb/COURSES/270

# Tsunami Hazard Area Map of Indonesia



# Earthquake Hazard Area Map of Indonesia



# Map of Distribution of Active Faults and Destroying Earthquake Epicenters of Indonesia