13 - Earthquakes



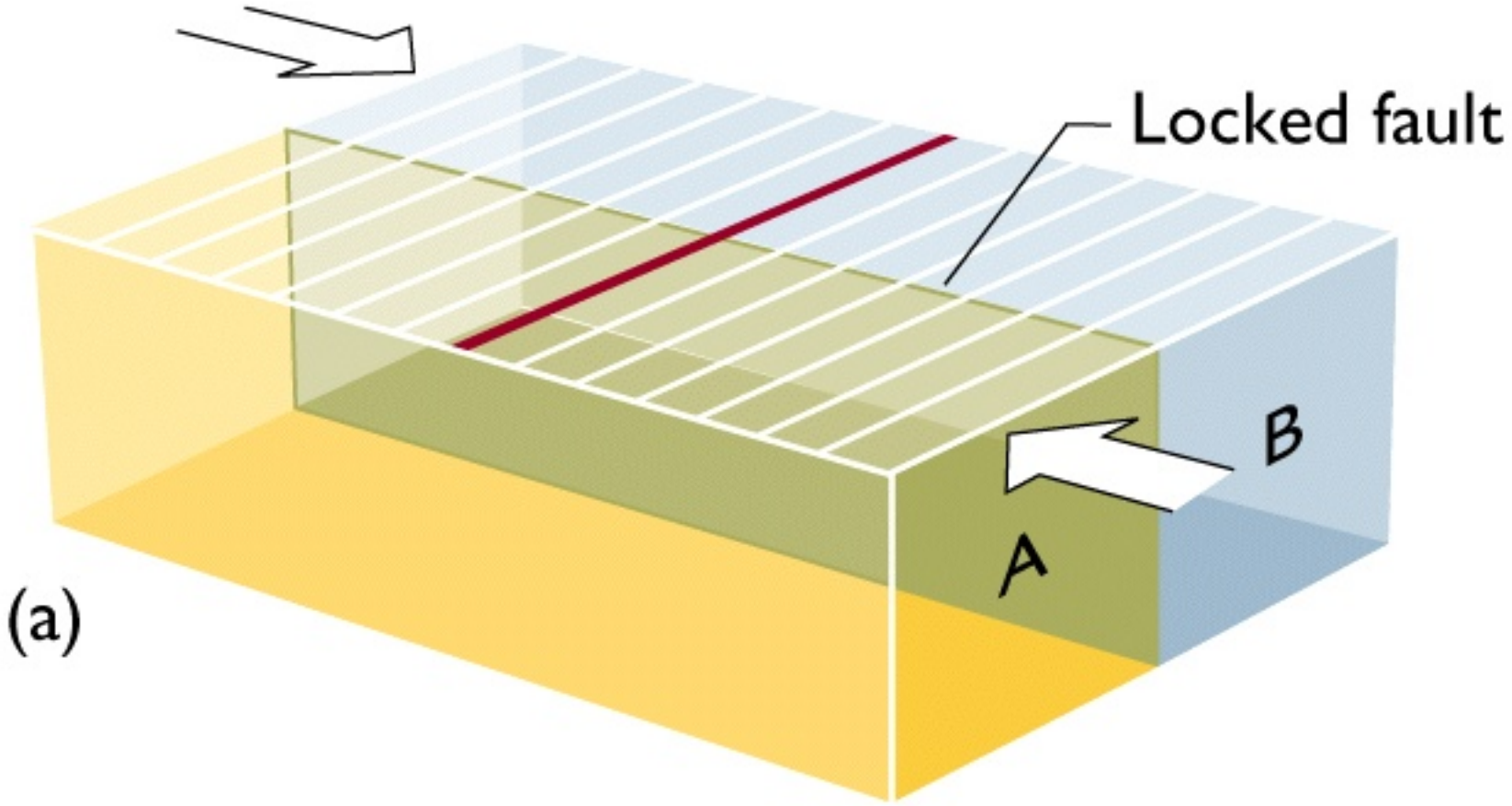
Earthquakes

- *earthquake*: rocks breaking and movement of rock along break
- *fault*: locus of the earthquake movement
- faults come at all scales, mm to separation of lithospheric plates (*e.g.*, San Andreas).

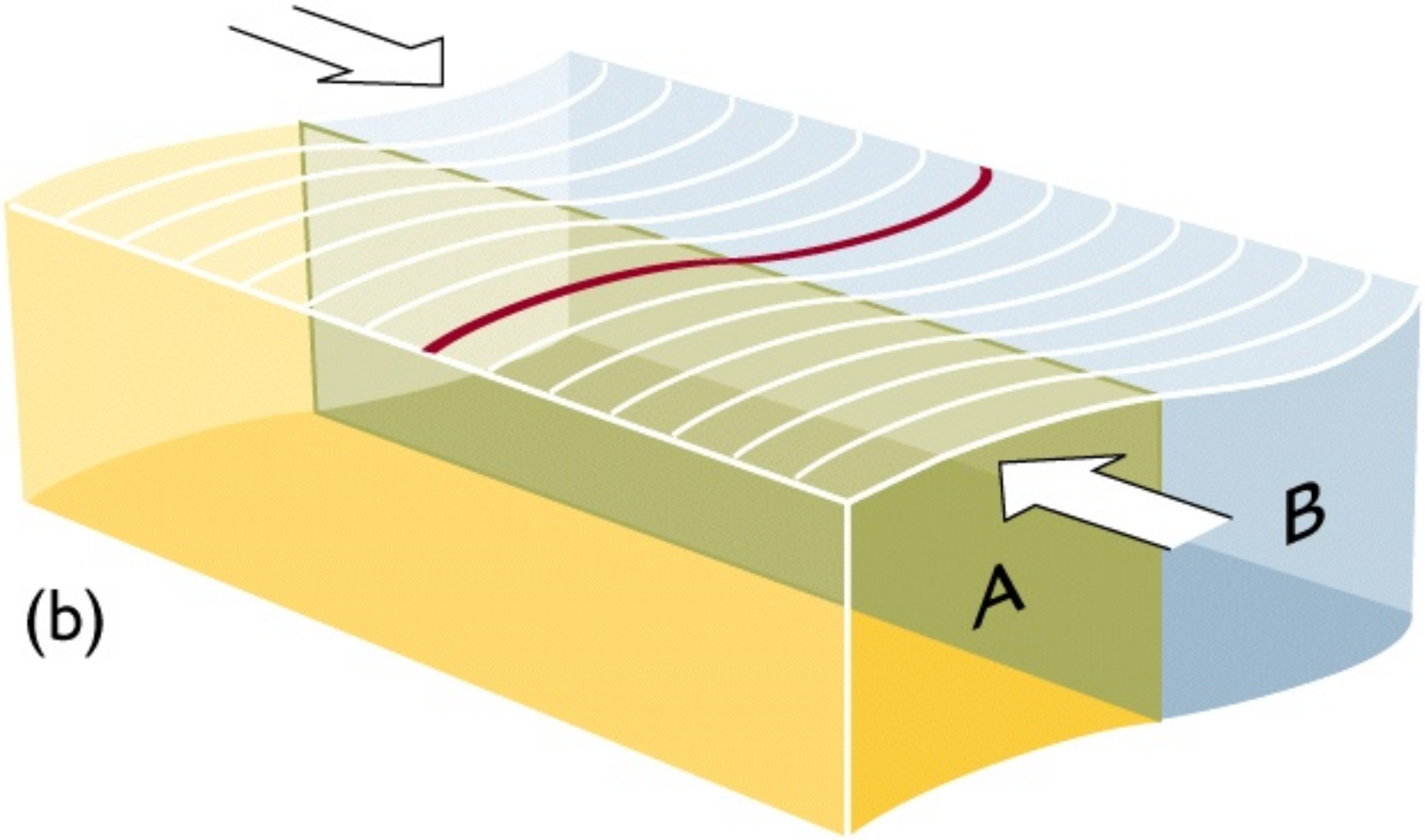
Elastic Rebound Theory

- Stress is applied to rock
- Strain energy builds up for rock does not break at once
- Eventually, rock ruptures and
- Energy is released as heat & SEISMIC WAVES

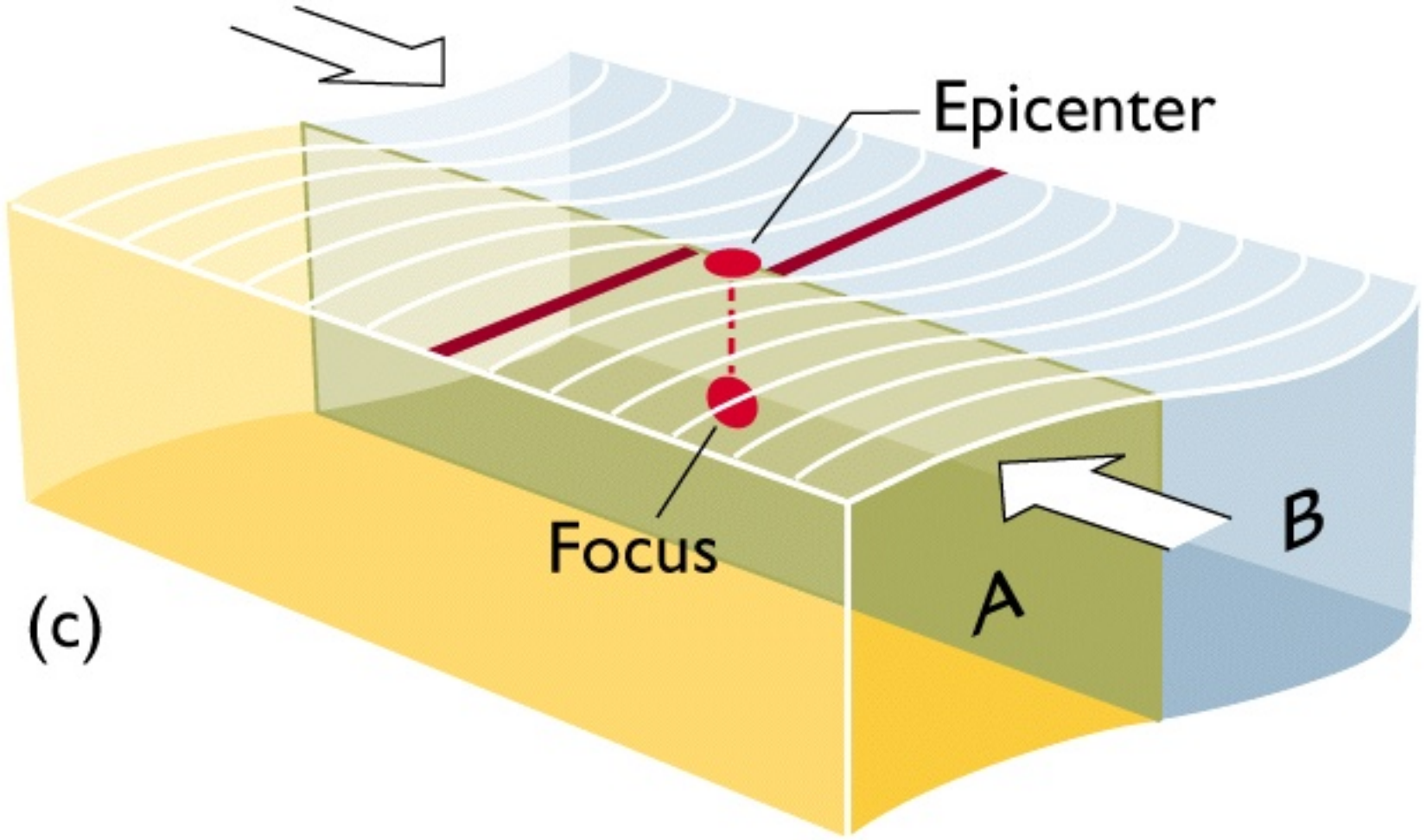
Elastic Rebound Theory



Elastic Rebound Theory



Elastic Rebound Theory



Elastic Rebound Theory

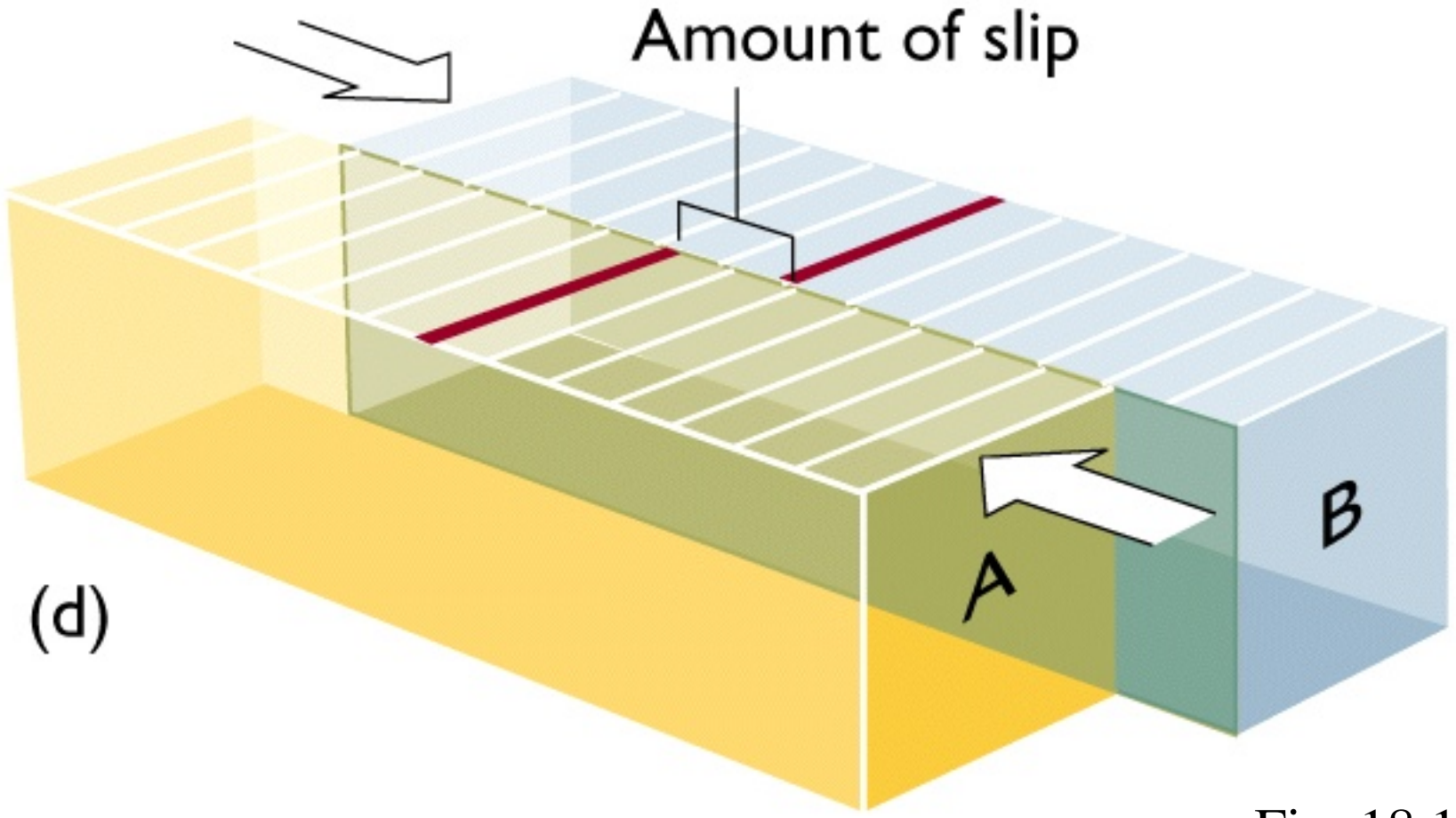


Fig. 18.1d

1906 San Francisco Earthquake

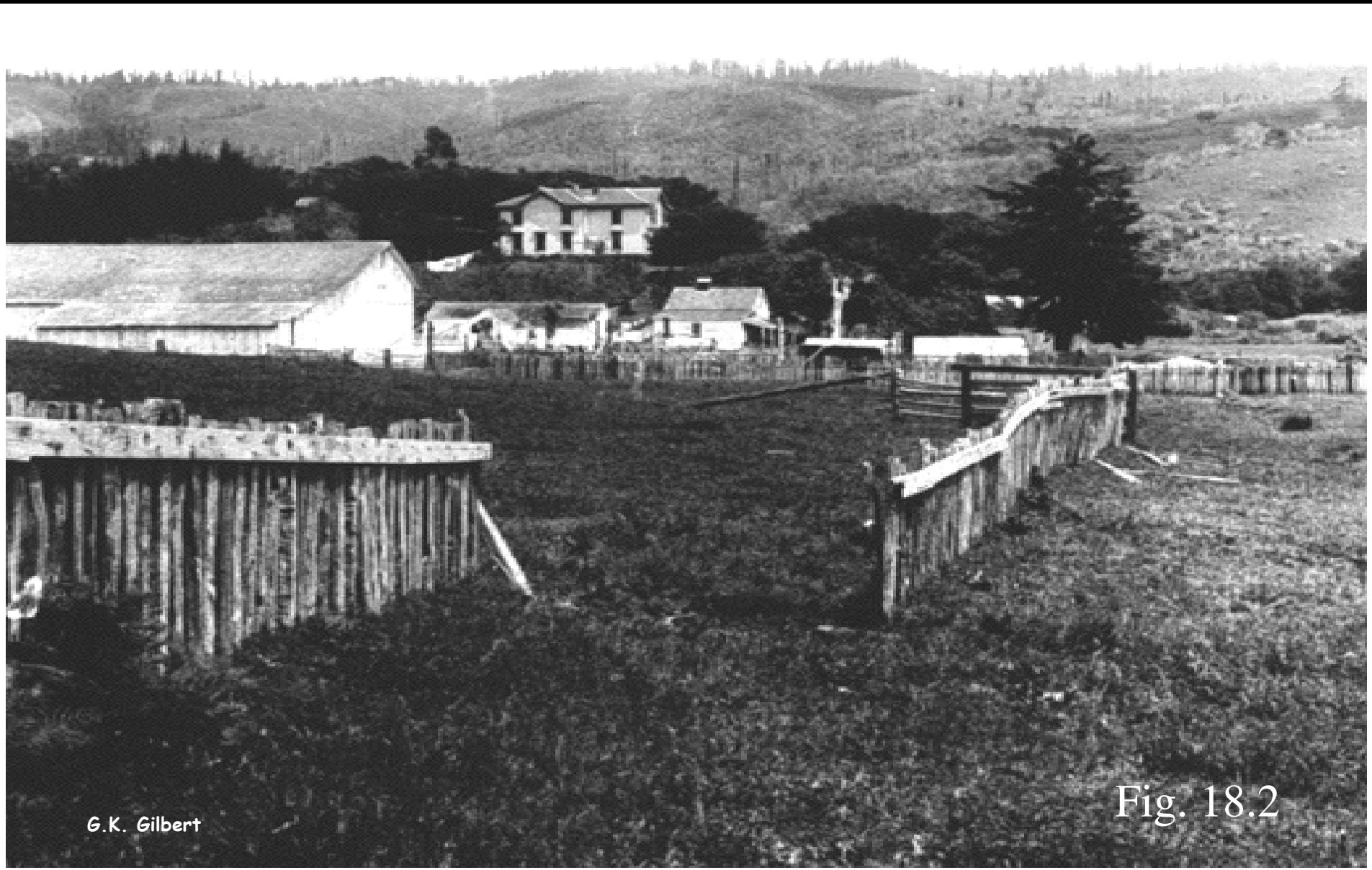


Fig. 18.2

1906 San Francisco Earthquake

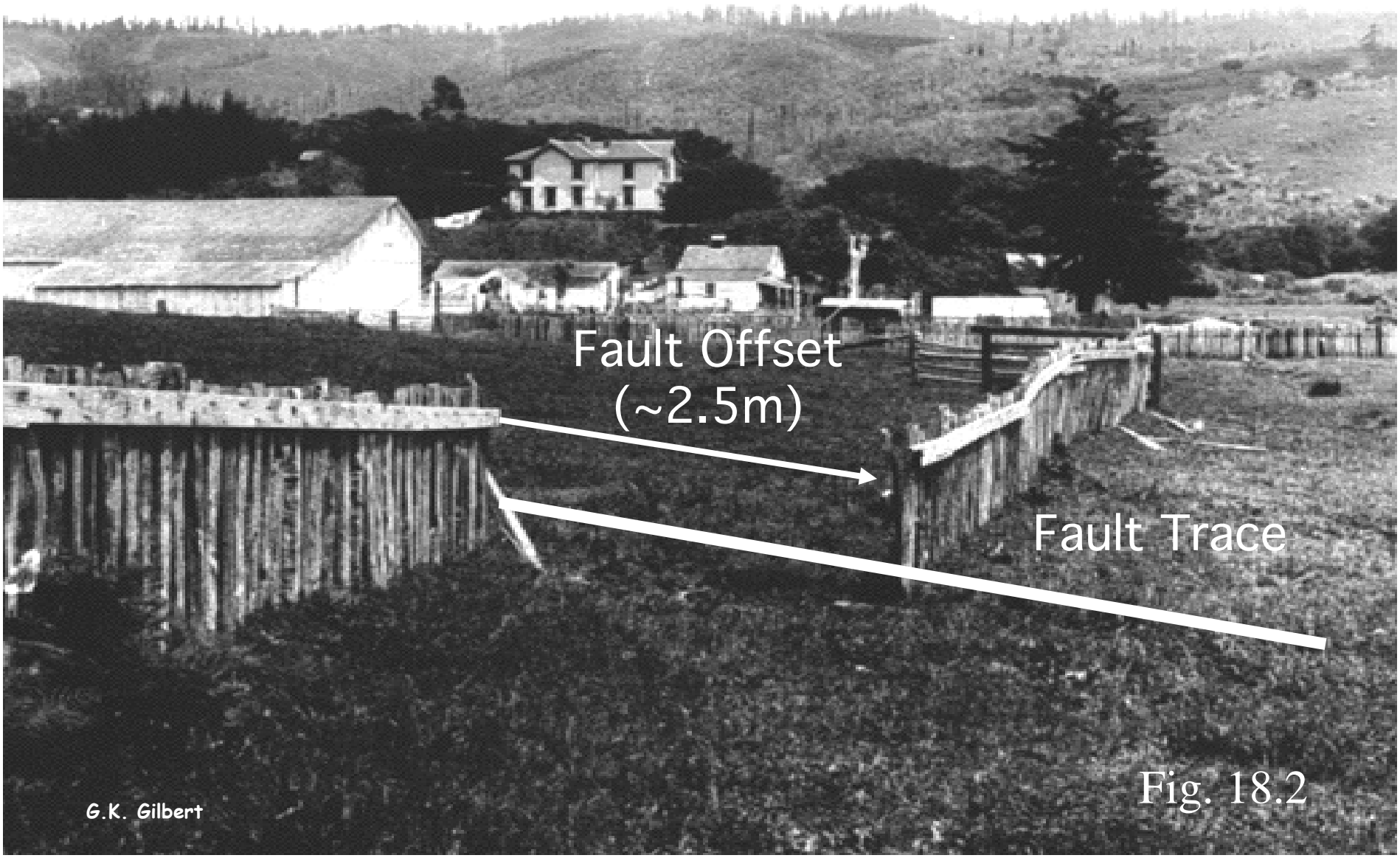


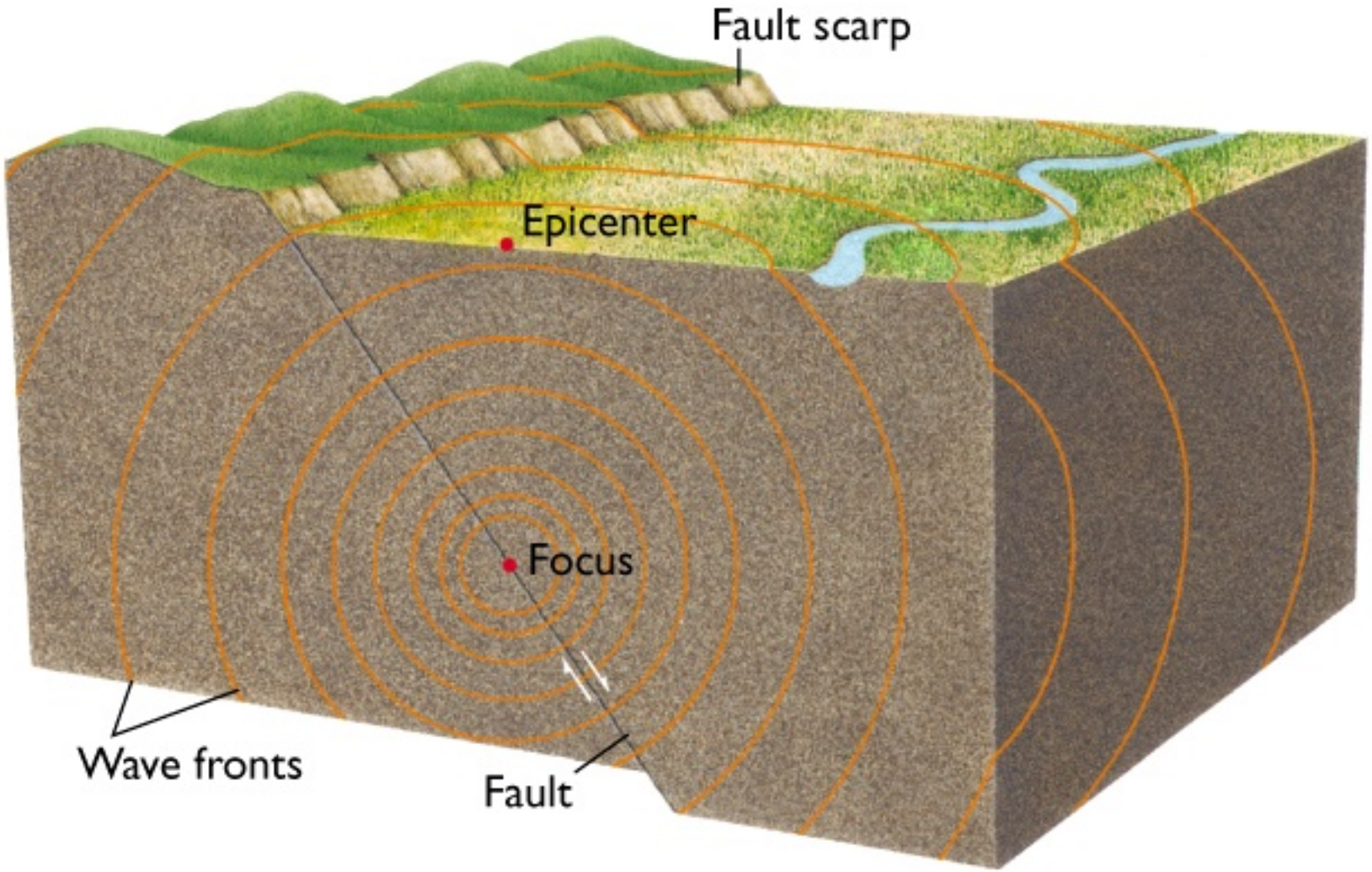
Fig. 18.2

Earthquake terms

focus: site of initial rupture

epicenter: point on surface above the focus

Seismic Waves Radiate from the Focus of an Earthquake



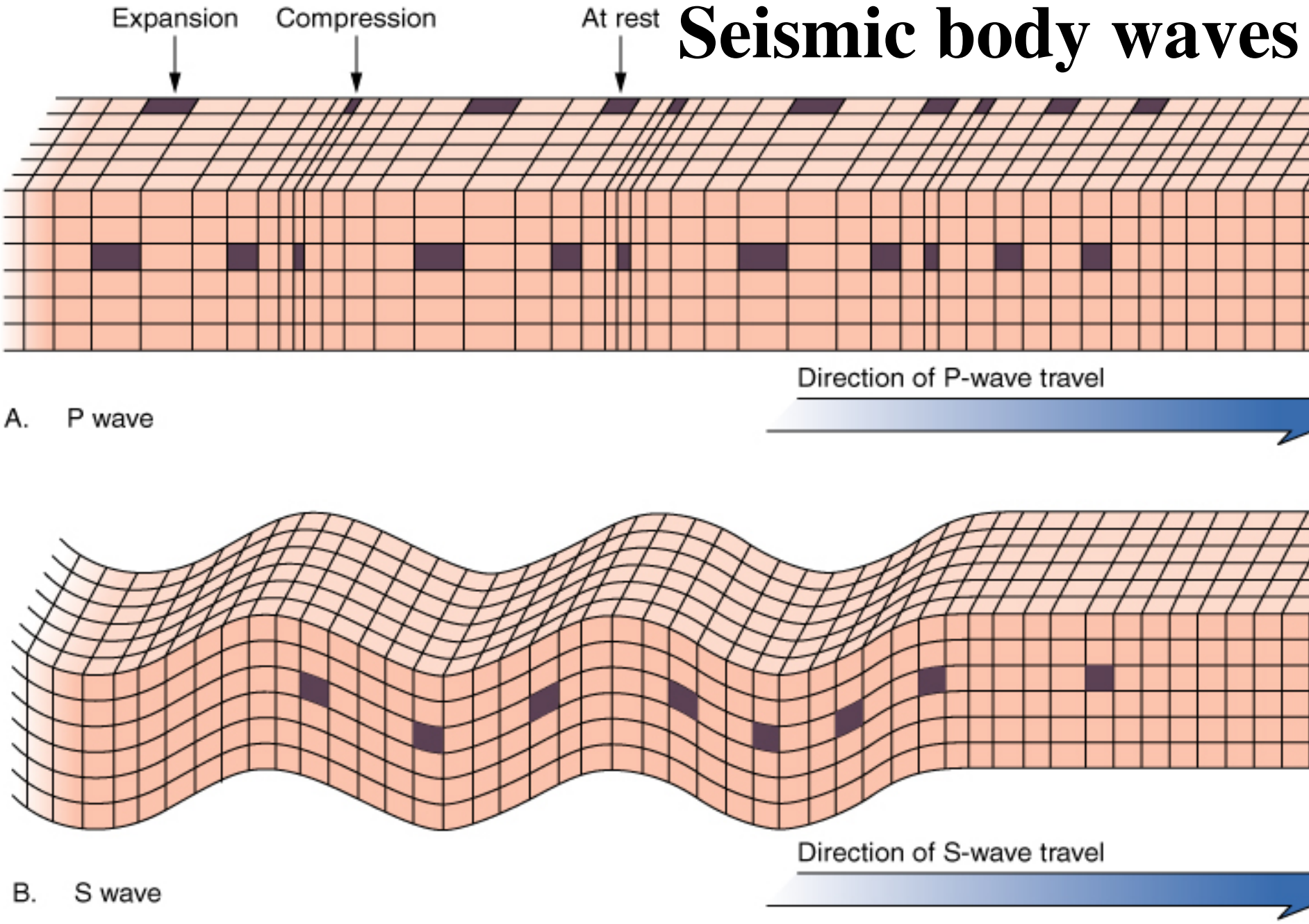
2 KINDS OF SEISMIC WAVES

- BODY WAVES - WAVES THAT MOVE THROUGH THE BODY OF THE EARTH.
- SURFACE WAVES - WAVES THAT MOVE ALONG THE SURFACE OF THE EARTH.

Two kinds of body waves

- *P waves* (compressional) 6–8 km/s. Parallel to direction of movement (slinky), also called primary waves. Similar to sound waves.
- *S waves* (shear) 4–5 km/s. Perpendicular to direction of movement (rope); also called secondary waves. Result from the shear strength of materials. Do not pass through liquids.

Seismic body waves

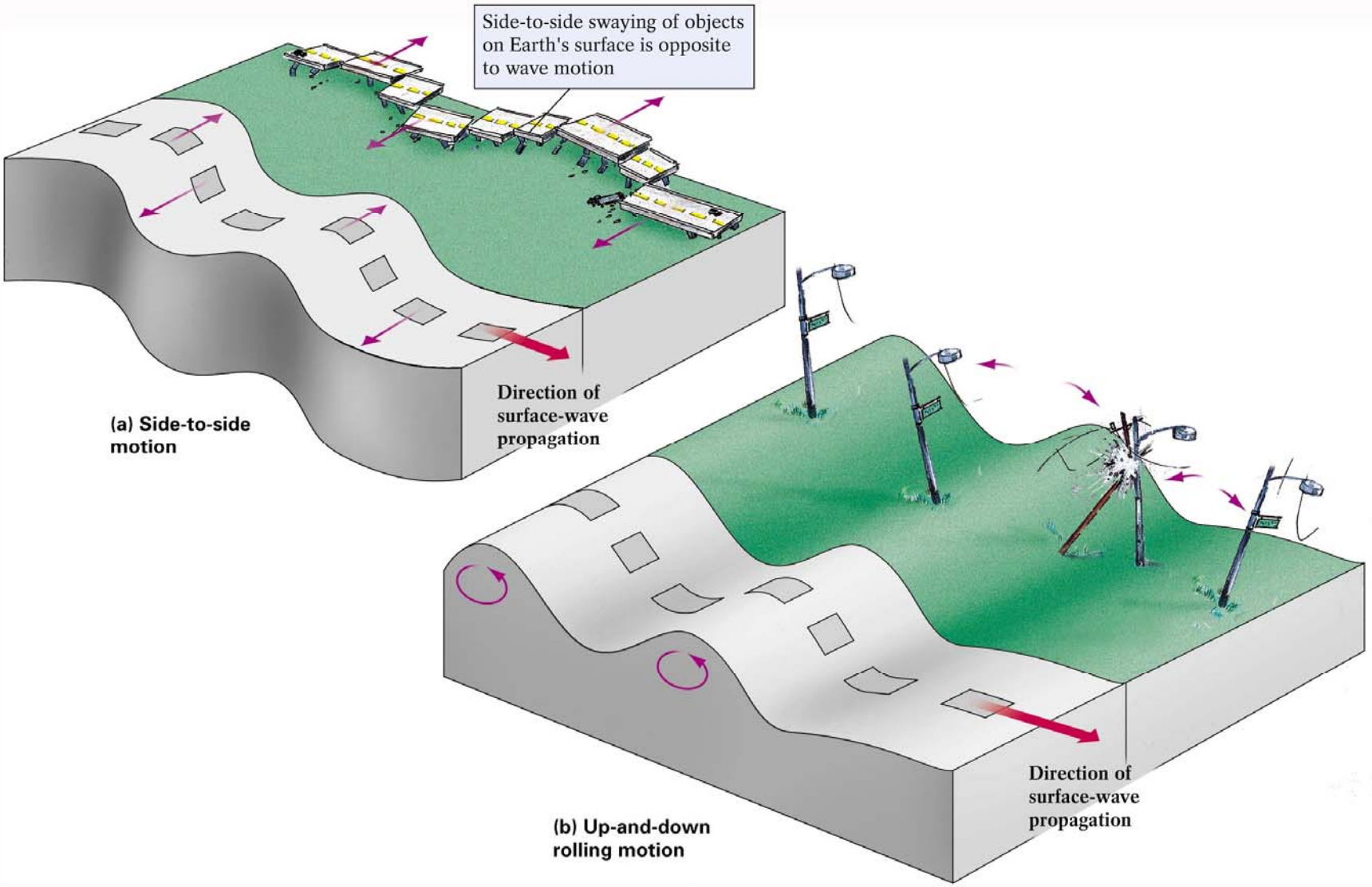


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2 KINDS OF SURFACE WAVES

- LOVE - rolling motion
- RALEIGH - ground shakes sideways

- These waves travel slower than s-waves and are formed as p- and s-wave energy hits the surface.


Side-to-side swaying of objects on Earth's surface is opposite to wave motion
Direction of surface-wave propagation
(a) Side-to-side motion
(b) Up-and-down rolling motion
Direction of surface-wave propagation

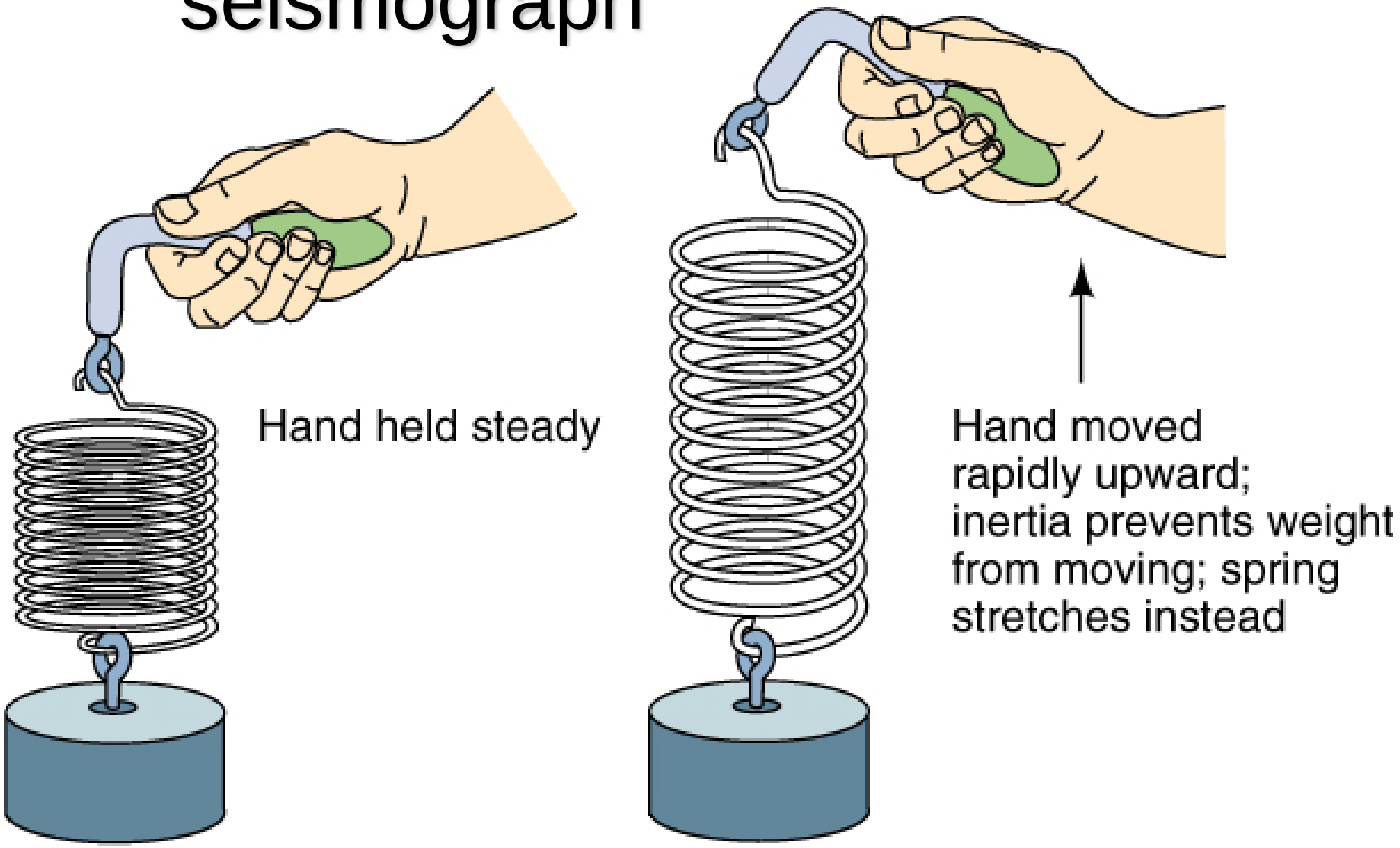
Seismology

- Study of the propagation of mechanical energy through the Earth; released by earthquakes and explosions.
- When energy is released in this fashion, waves of motion (like the effect of a pebble tossed into a pond) are set up in the rocks surrounding the source of the energy (the focus).

Seismic waves

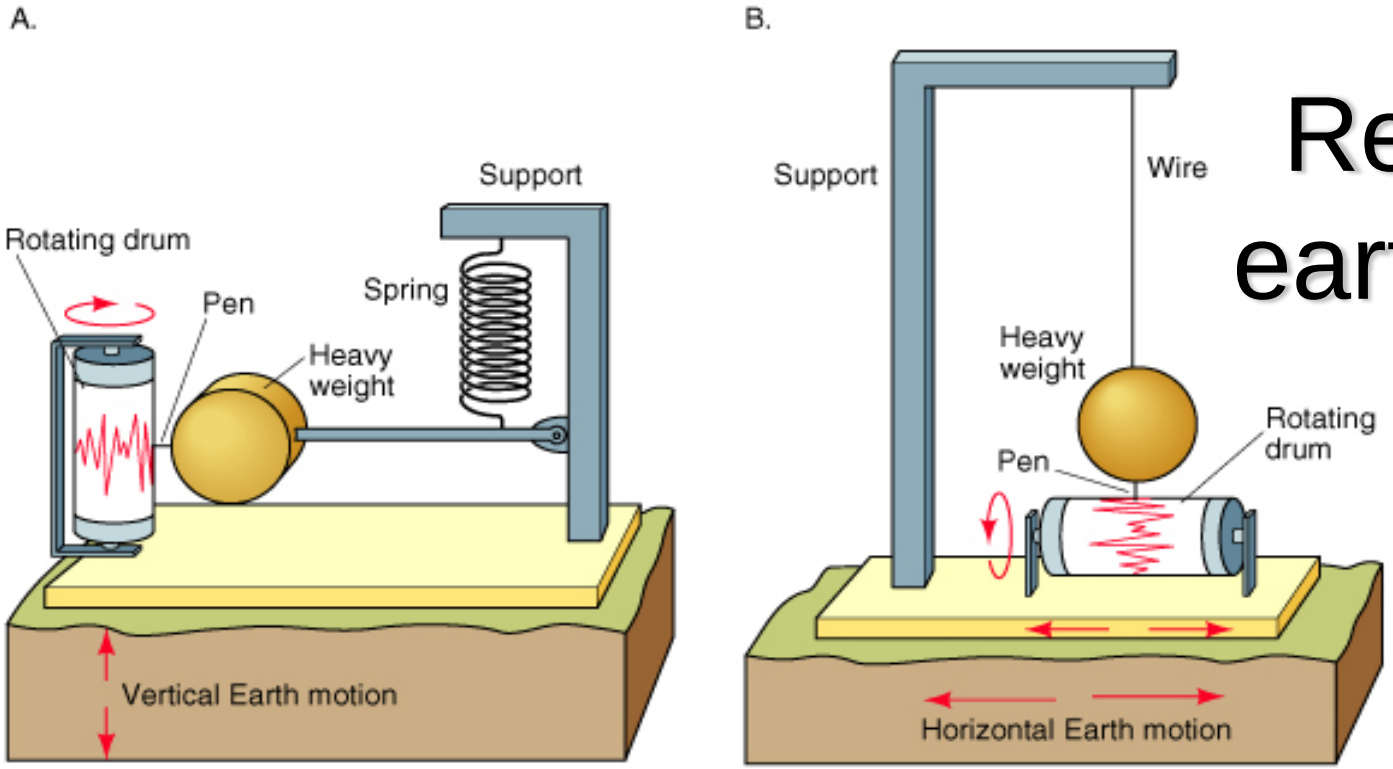
- Waves are started because of initial tension or compression in the rock.
- Instruments used to measure these waves are called seismographs.

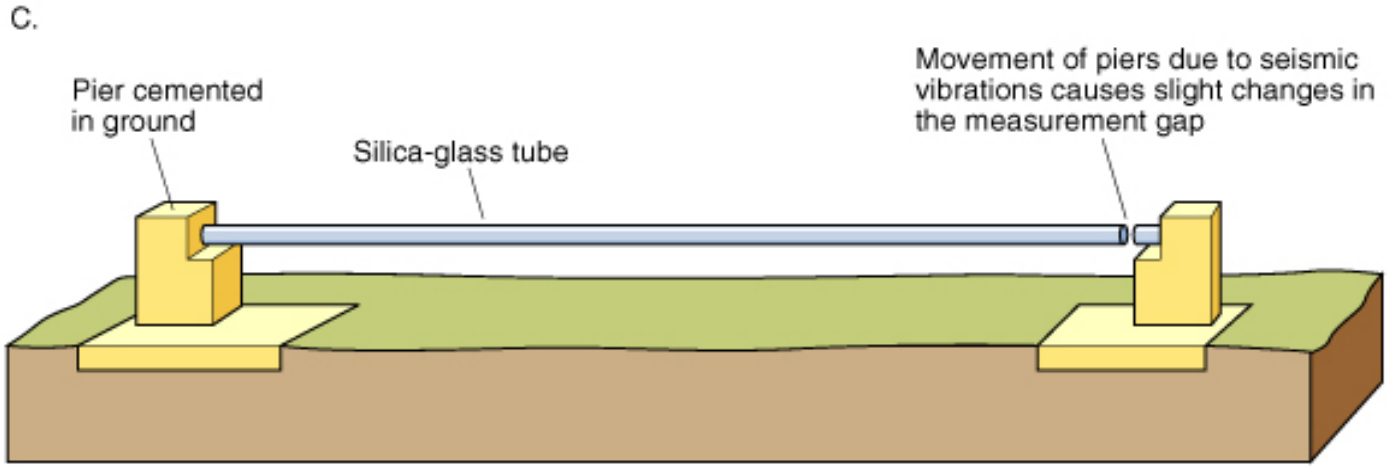
The principle of the inertial seismograph



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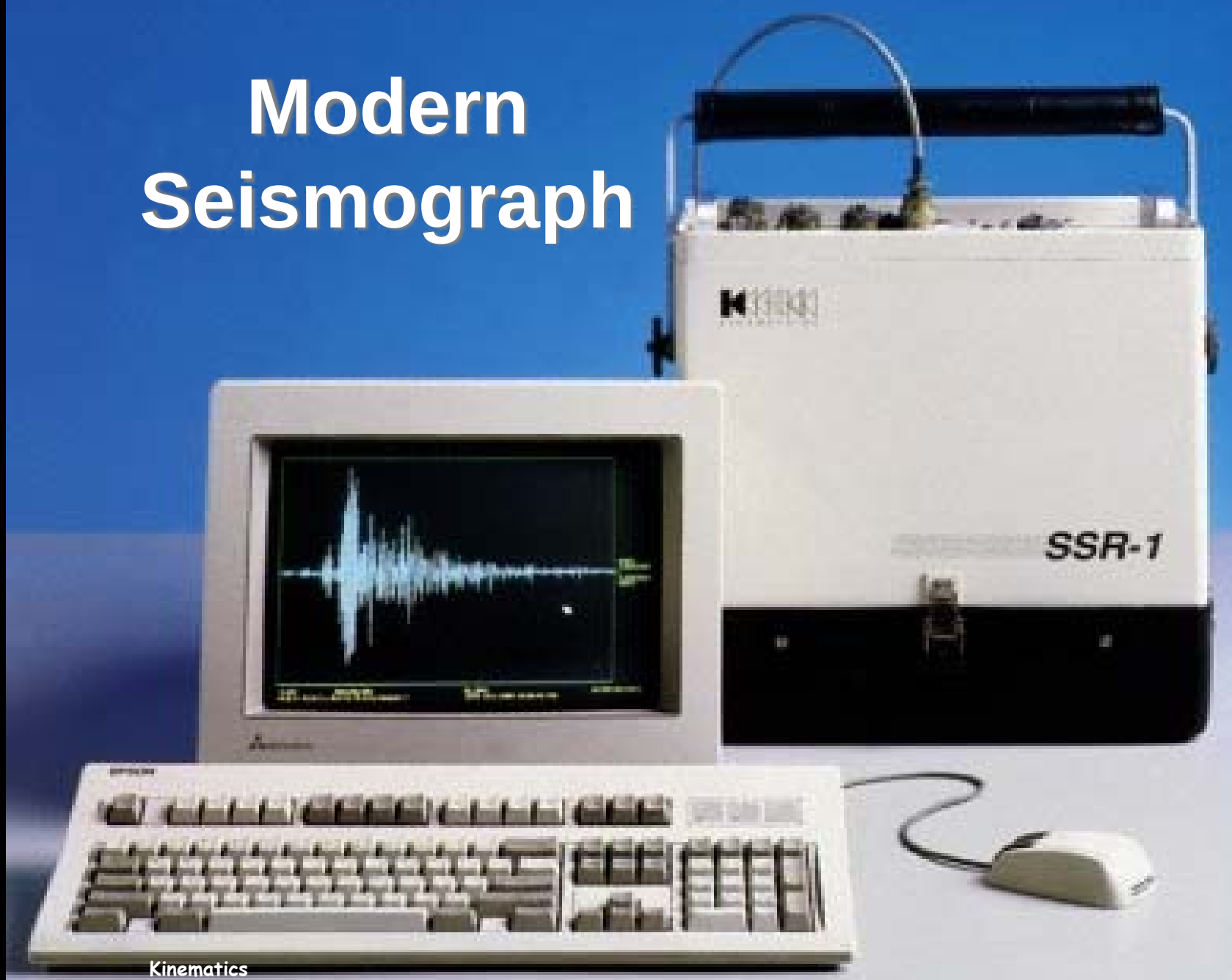
Recording earthquakes



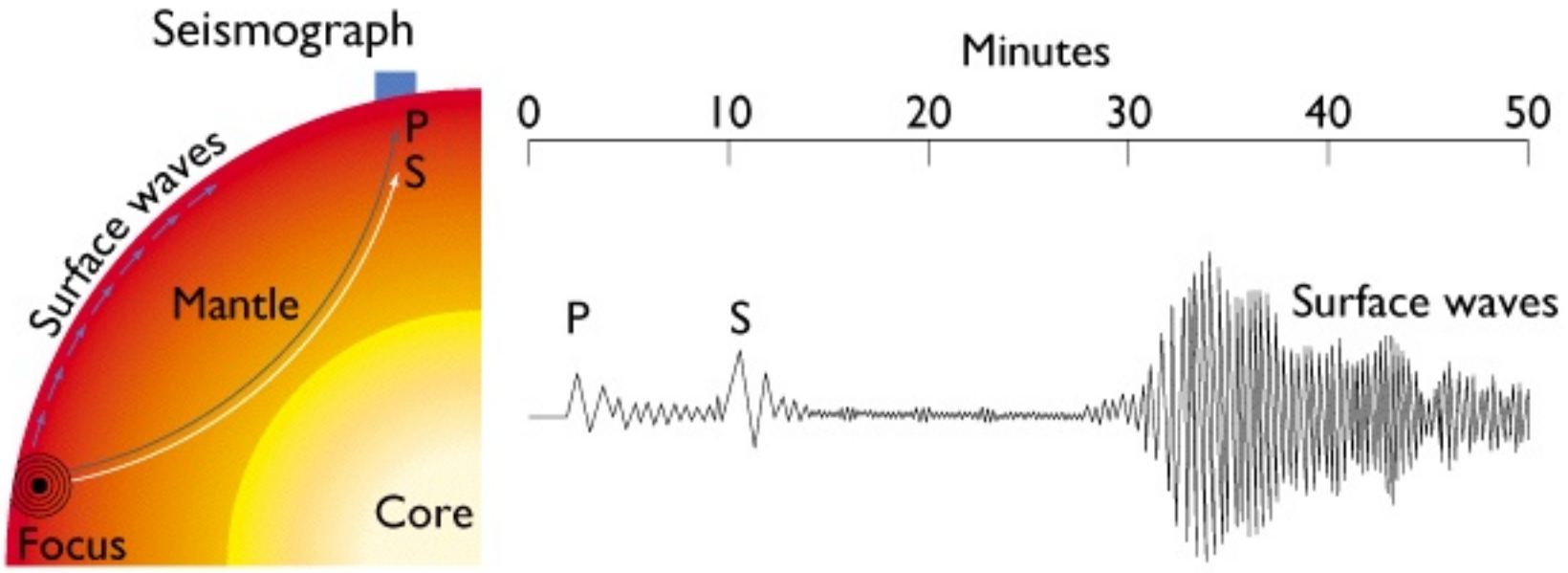


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Modern Seismograph



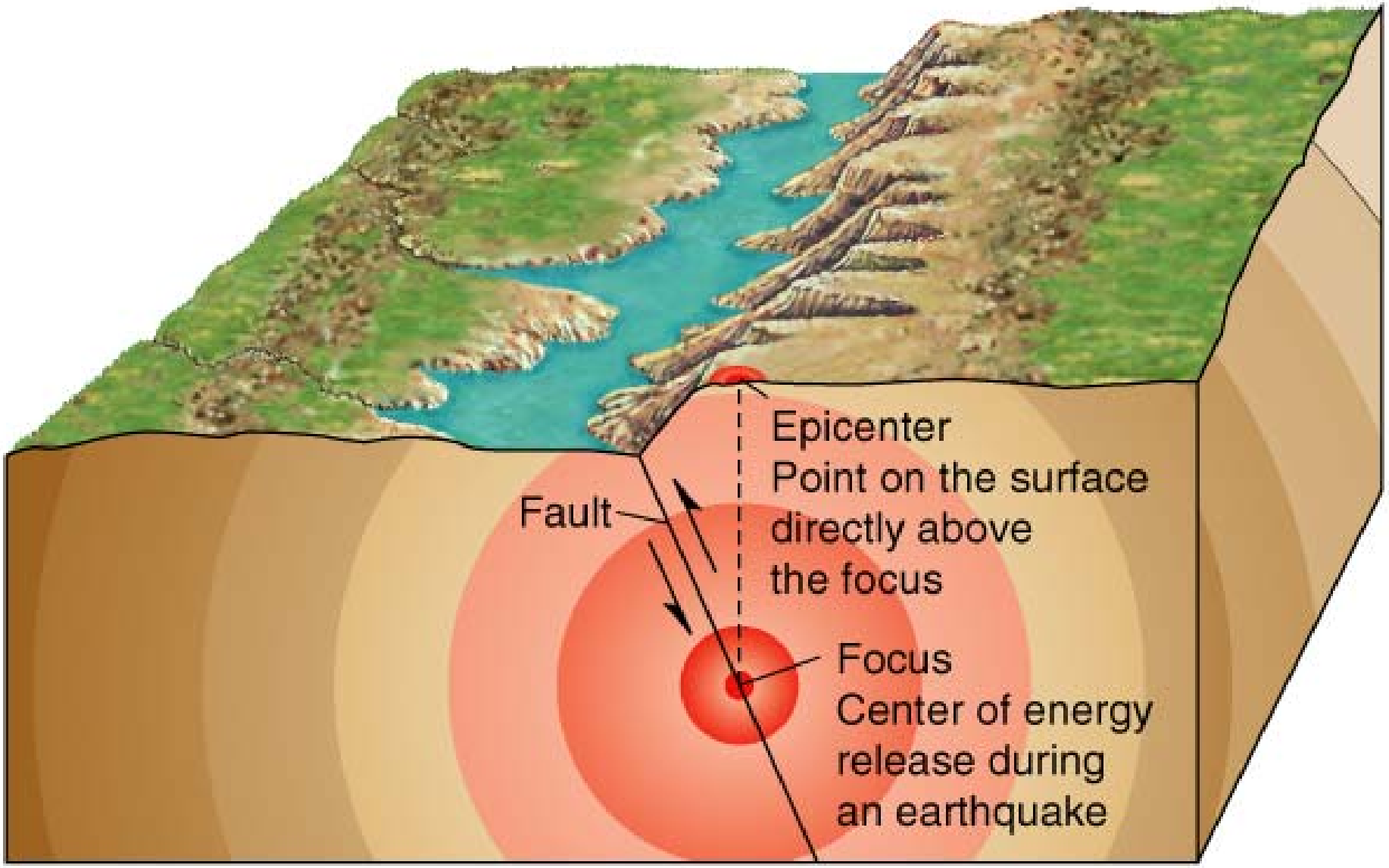
Seismograph Record and Pathway of Three Types of Seismic Waves



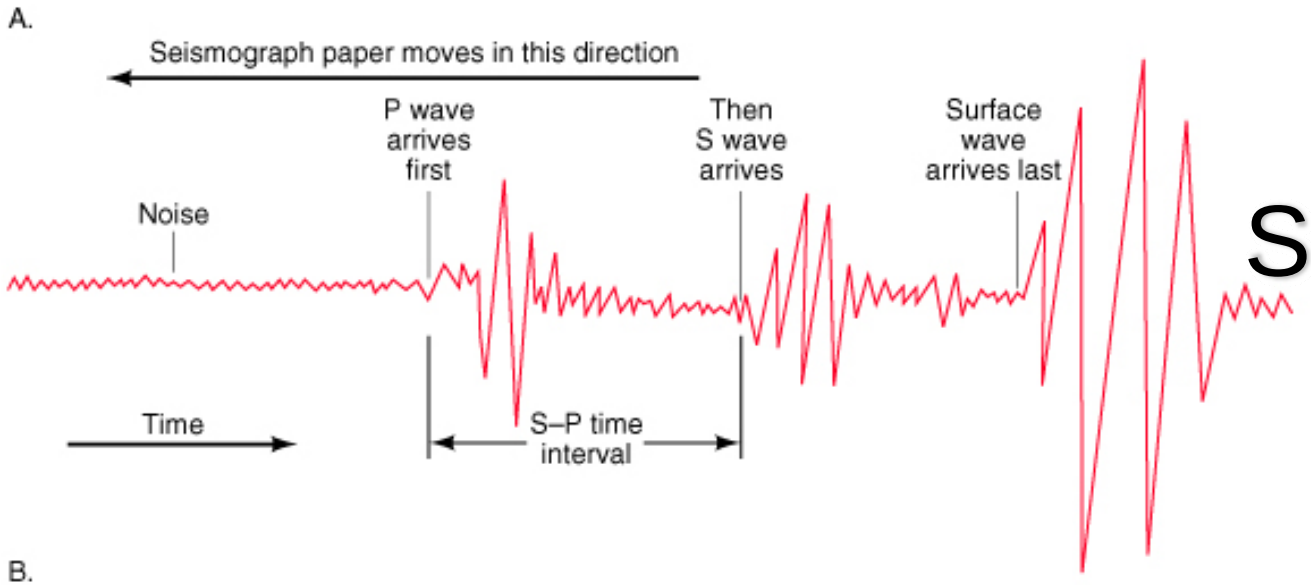
Locating an epicenter

- The difference between the arrival times of the P and S waves at a recording station is a function of the distance from the epicenter.
- Therefore, you need three stations to determine the location of an epicenter - triangluation.

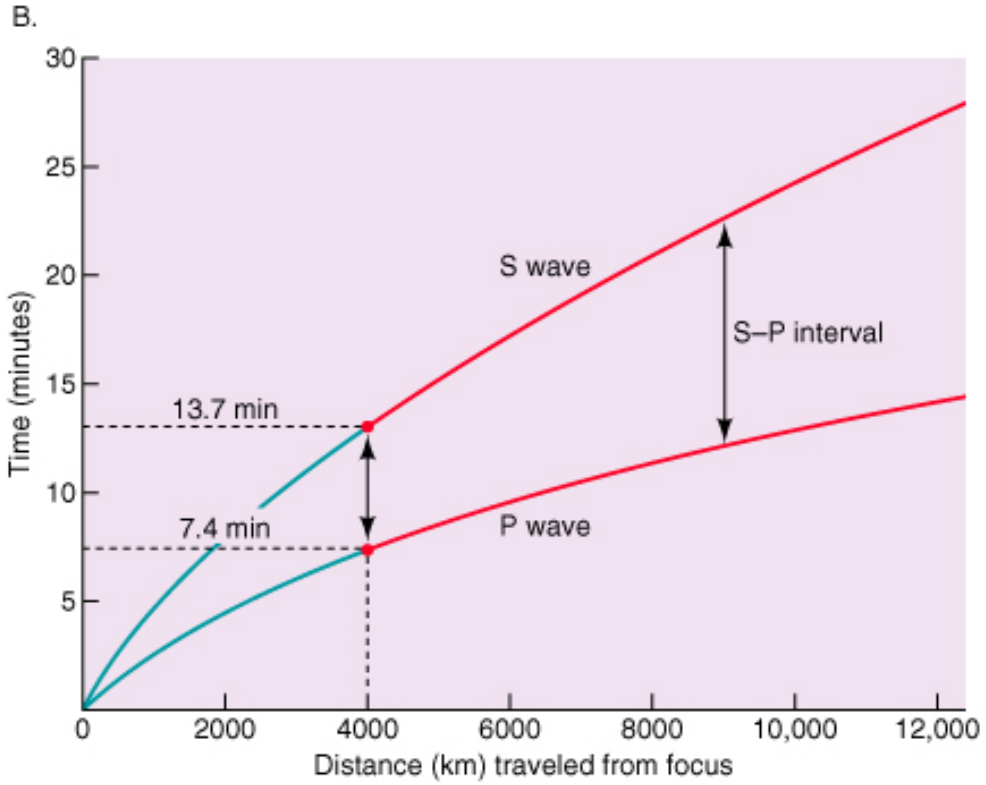
Locating an earthquake



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Typical Seismograph record



Average travel-time curves

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Seismic Travel-time Curve

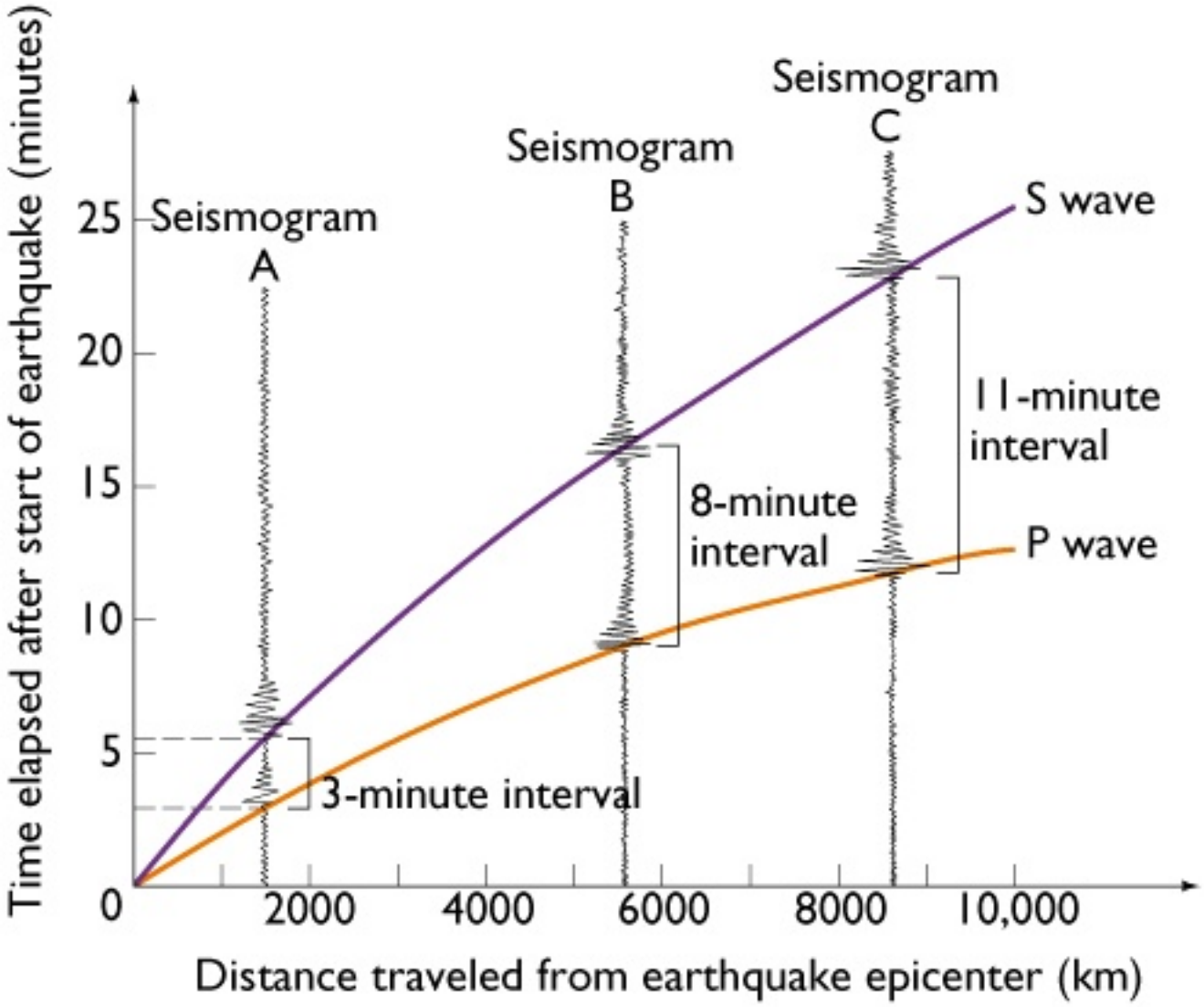
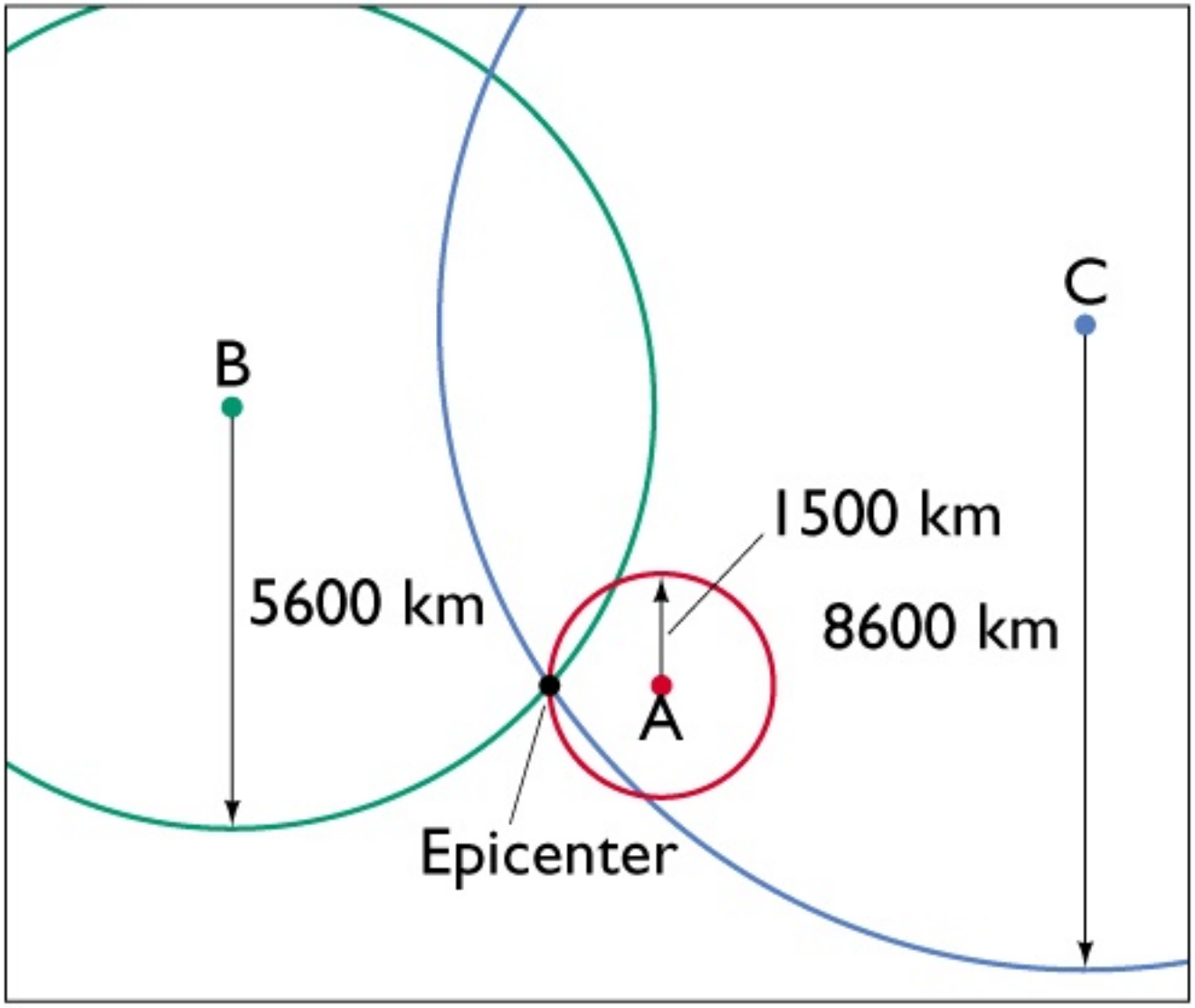


Fig. 18.9b

Locating the Epicenter





Global Positioning System (GPS) to Monitor Ground Motion

Measuring the force of earthquakes

1. *Surface displacement*

- 1964 Alaska earthquake displaced some parts of the seafloor by ~ 50 ft.
- 1906 San Francisco earthquake moved the ground ~8.5 ft.

2. *Size of area displaced*

Alaska — 70,000 sq. miles

Measuring the force of earthquakes

3. *Duration of shaking*

   Up to tens of seconds

4. *Intensity scales (Modified Mercalli)*

   Based on damage and human perception

5. *Magnitude scales (Richter Scale)*

   Based on amount of energy released

Modified Mercalli Intensity Scale

I	Not felt
II	Felt only by persons at rest
III–IV	Felt by persons indoors only
V–VI	Felt by all; some damage to plaster, chimneys
VII	People run outdoors, damage to poorly built structures
VIII	Well-built structures slightly damaged; poorly built structures suffer major damage
IX	Buildings shifted off foundations
X	Some well-built structures destroyed
XI	Few masonry structures remain standing; bridges destroyed
XII	Damage total; waves seen on ground; objects thrown into air

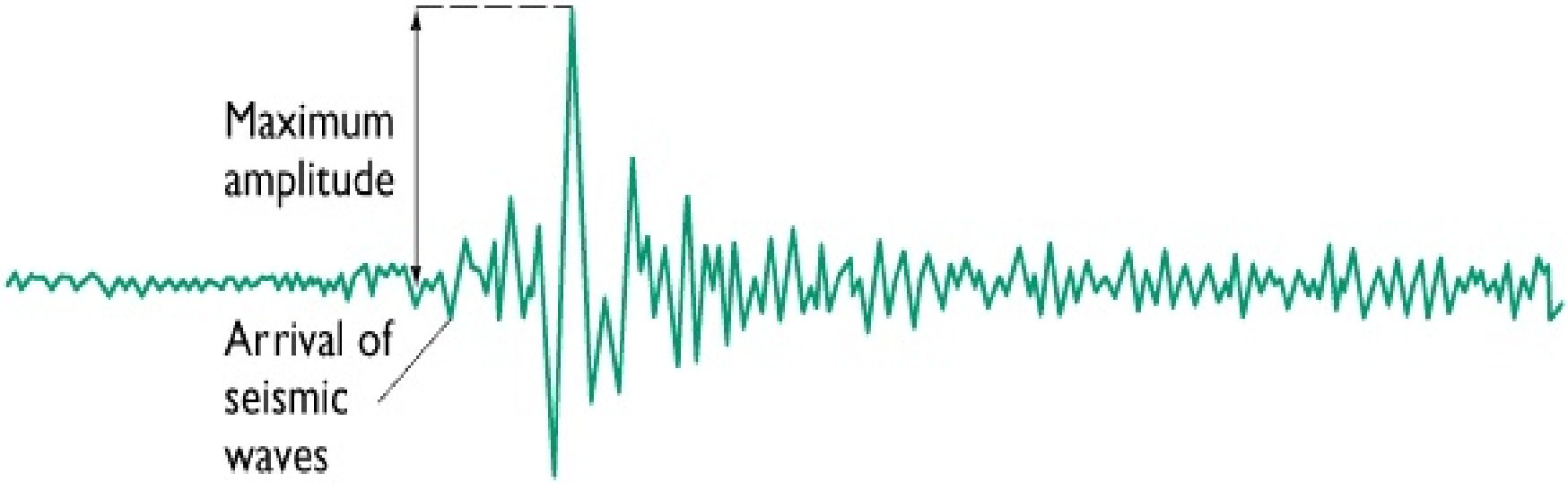
Richter Scale

- Richter scale: amount of energy (ground shaking) received 100 km from epicenter
- Largest quake ever recorded = 8.9 (rocks not strong enough for more).
- Earthquakes less than Mag. 2 are not felt by people.
- Scale is *logarithmic*:

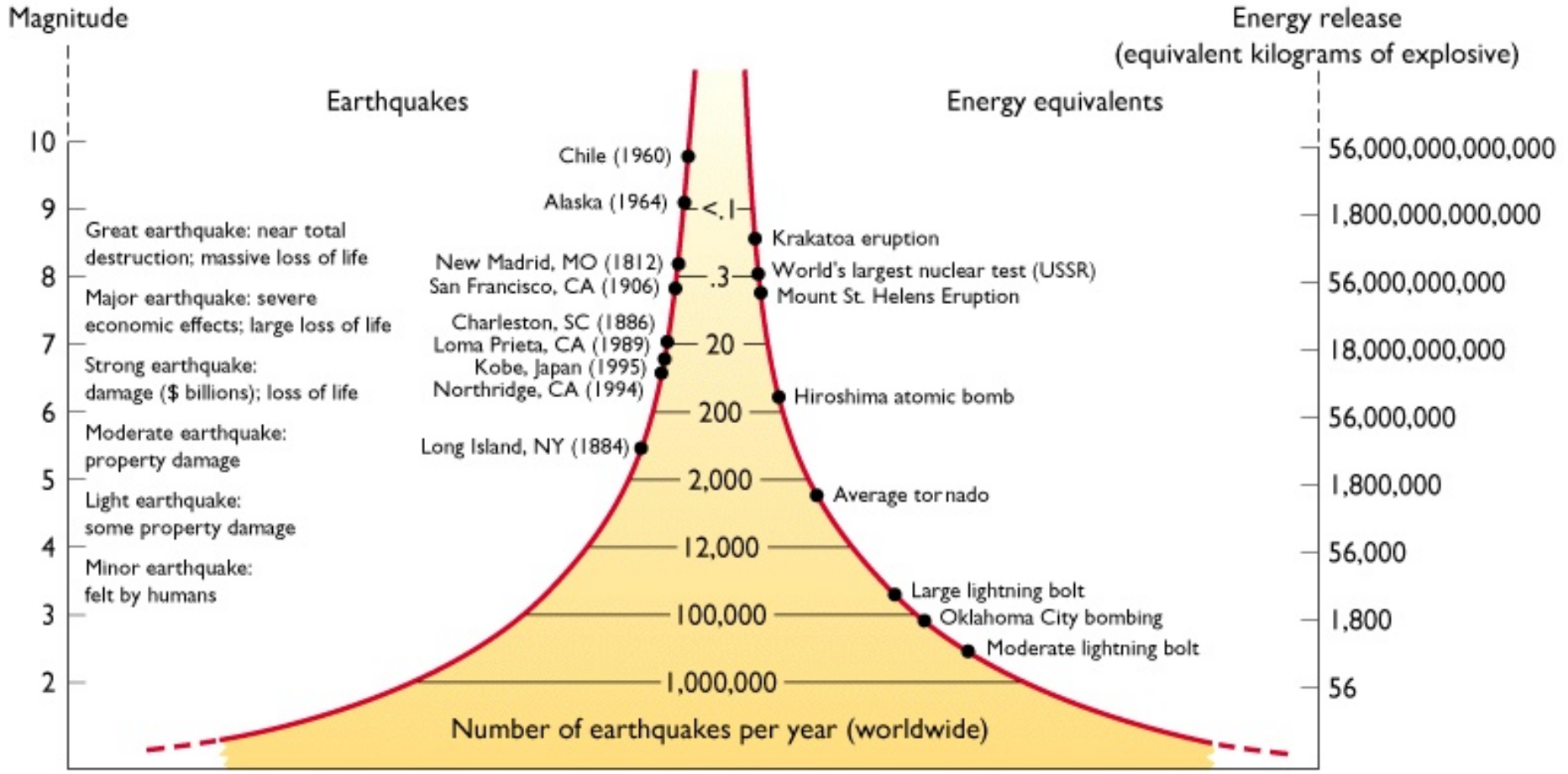
  Increase 1 unit = 10 times greater shaking

  Increase 1 unit = 30 times greater energy

Maximum Amplitude of Ground Shaking Determines Richter Magnitude



Richter Magnitude Versus Energy



6. Moment Magnitude Scale

- New approach for indicates what happened at earthquake source rather than amount of ground shaking - based on amount of energy released
  - Product of :
  - Slip along fault
  - Area of fault break
  - Rock rigidity

Forcasting vs. Predicting Earthquakes

- Forecast means to guess only at the place and magnitude of an earthquake
- Predict means to guess at the place, magnitude and time of an event

Earthquake prediction

Long term—imprecise (within 5 years)

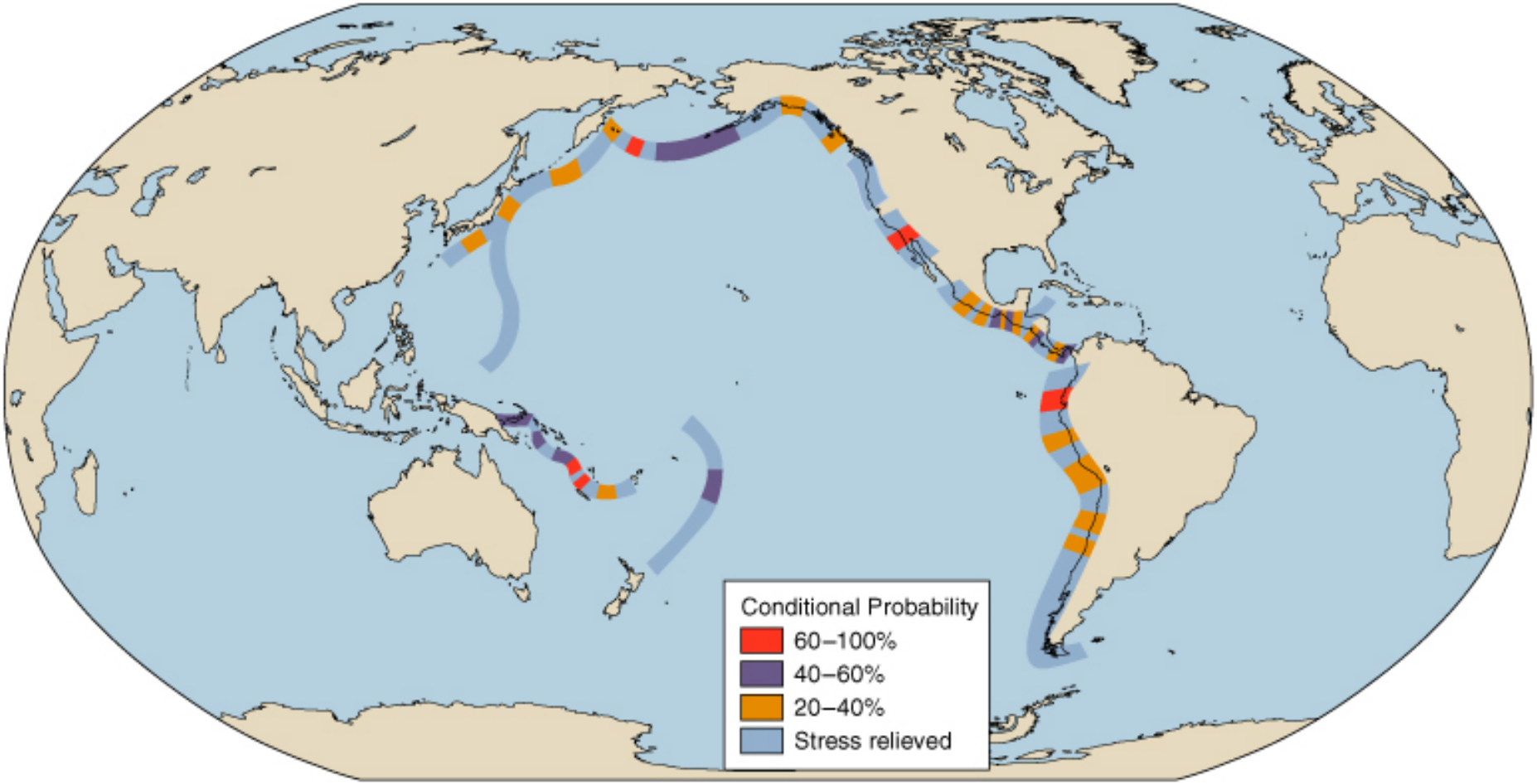
Short term—precise (very difficult)

We can't stop earthquakes, so we have to be prepared for them.

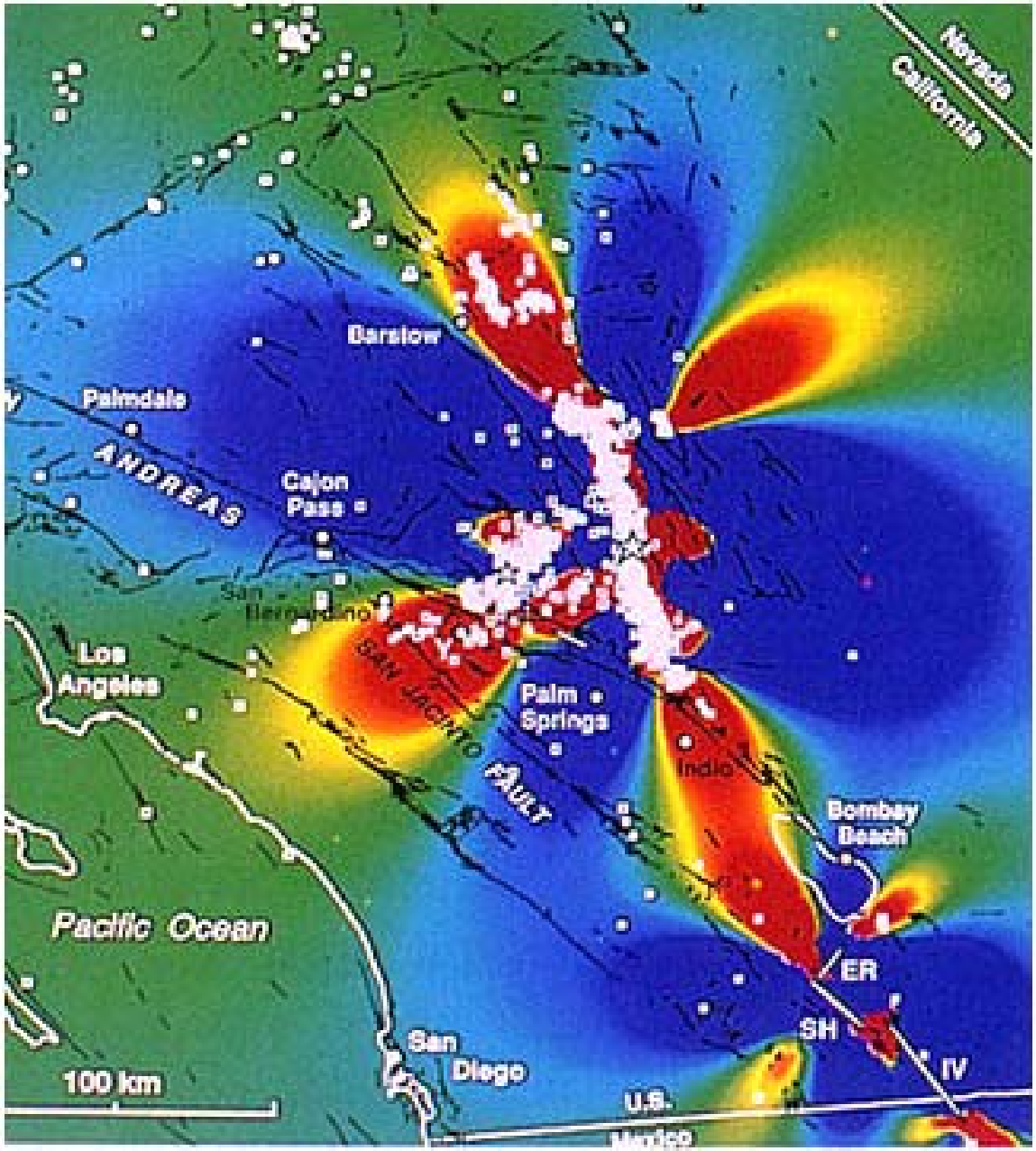
SHORT TERM CLUES

- Changes in speed of P-waves
- Change in tilt due to rx. dilation
- Unusual animal behavior
- Changes in water level in wells
- Foreshocks
- Seismic gaps - long term clue

Seismic Gaps in the circum-Pacific Belt

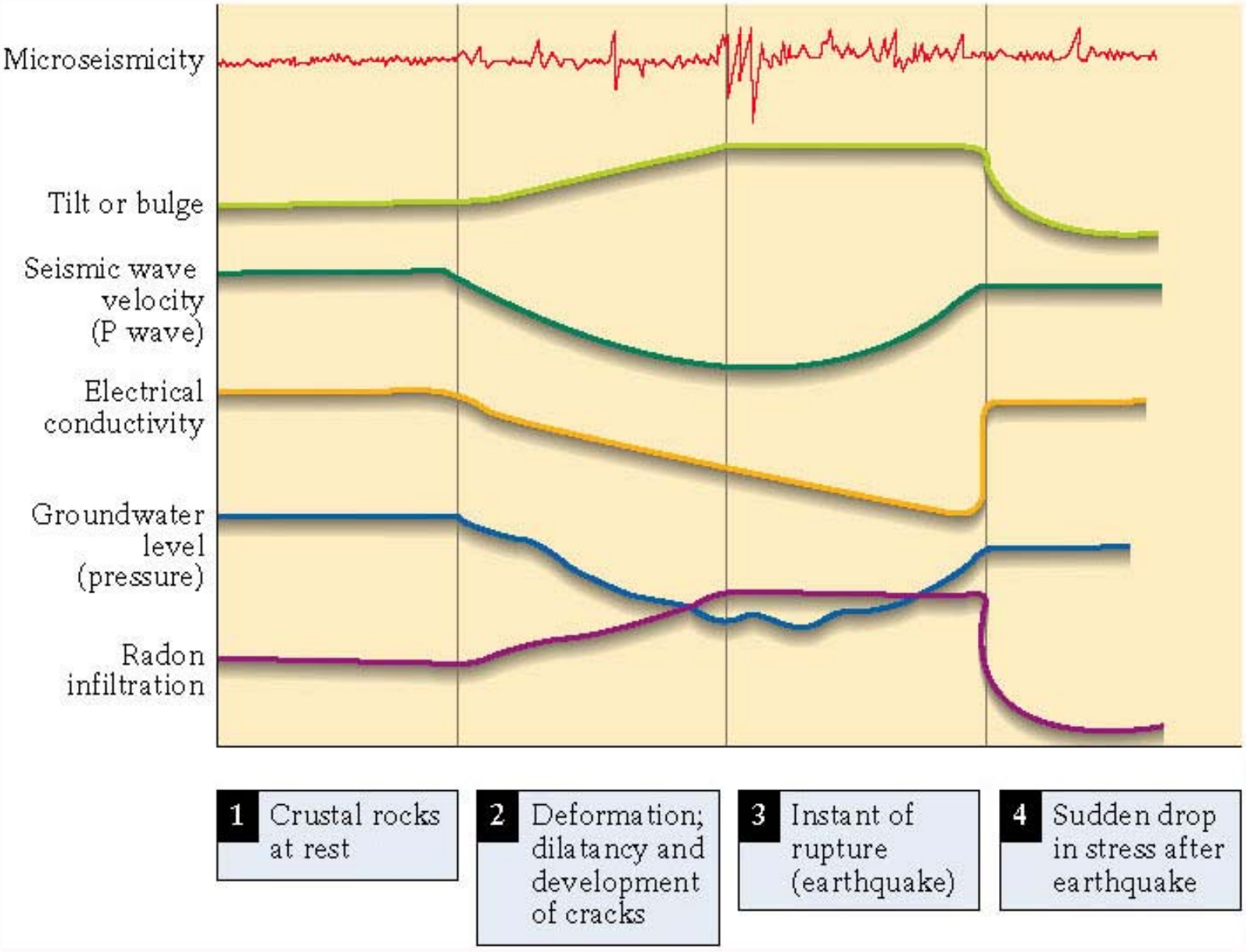


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Stress Changes Caused by Regional Earthquakes in Southern California (1979-1992)

Dilatancy of Highly Stressed Rocks



Damage due to earthquakes

1. DIRECT DAMAGE
   a. *Ground movement* "Earthquakes don't kill people,buildings kill people."
   b. *Ground Cracks*

2. INDIRECT DAMAGE
   a. *Fire*
   b. *Tidal waves* (tsunami)

generate speeds up to 500–800 km/hr in open ocean; only ~ 1m high but get larger when water gets shallow.

Damage due to earthquakes

Indirect con't

c. All kinds of mass wasting

Liquifaction – sudden loss of strength of water-saturated sediment

Buildings sink intact

d. *Flood* Dam break; rivers change course

Effects of the 1994 Northridge, CA, Earthquake



1994 Chronmo Sohn/Sohn/Photo Researchers, Inc

Effects of the 1995 Kobe, Japan, Earthquake



Fig. 18.18

Reuters/Corbis-Bettmann

Generation of a Tsunami

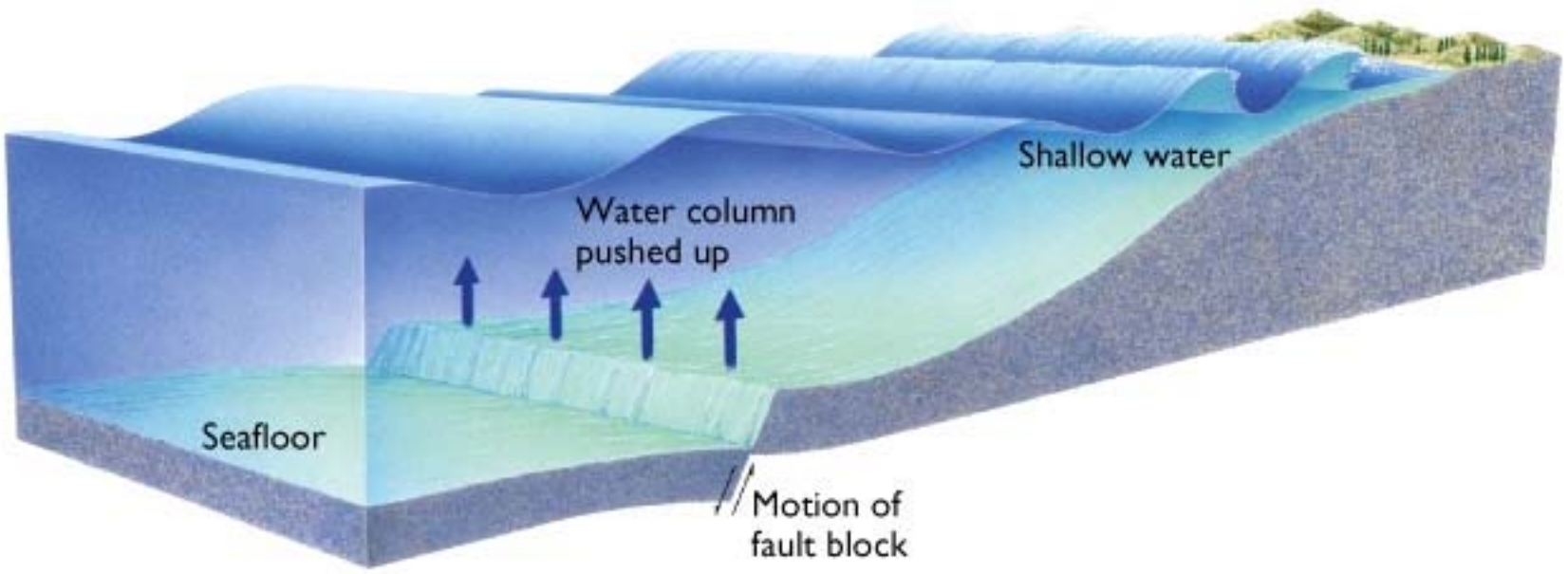


Fig. 18.19

Computer simulation of tsunami radiation caused by a magnitude 7.7 earthquake in the Aleutian Islands

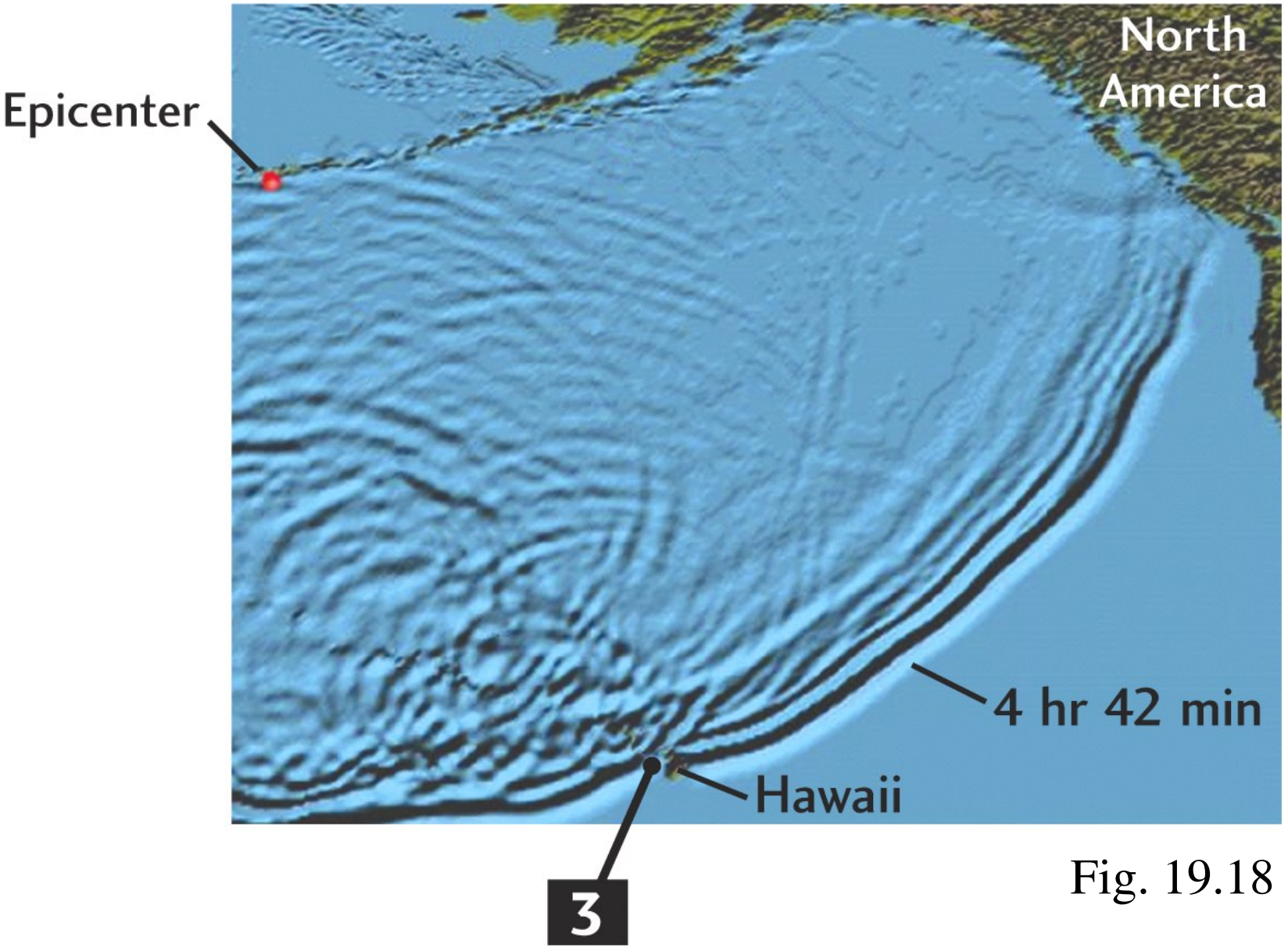
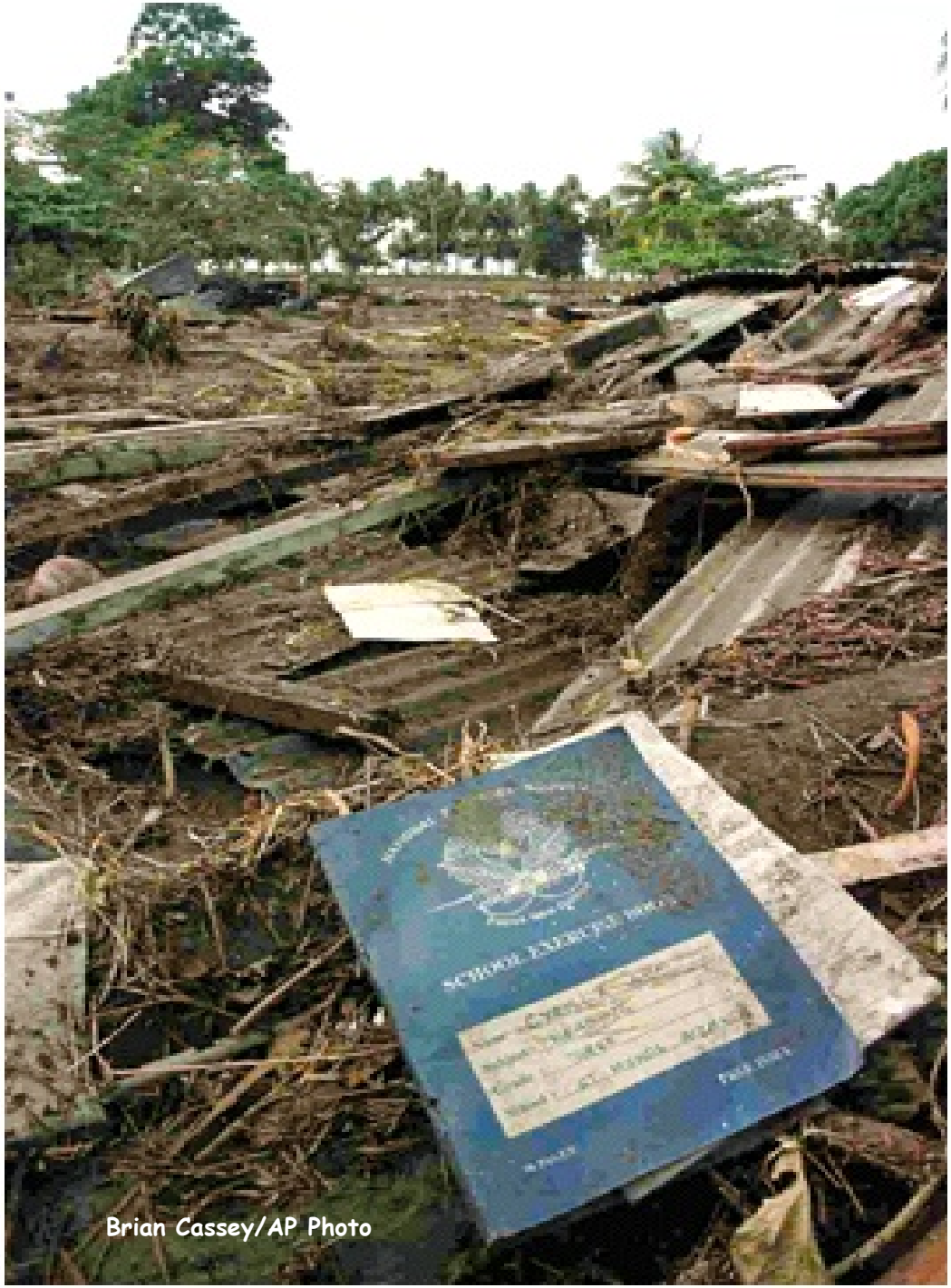


Fig. 19.18



Destruction Caused by 1998 Tsunami, Papua New Guinea

Fig. 18.20

Tsunami Barrier in Taro, Japan

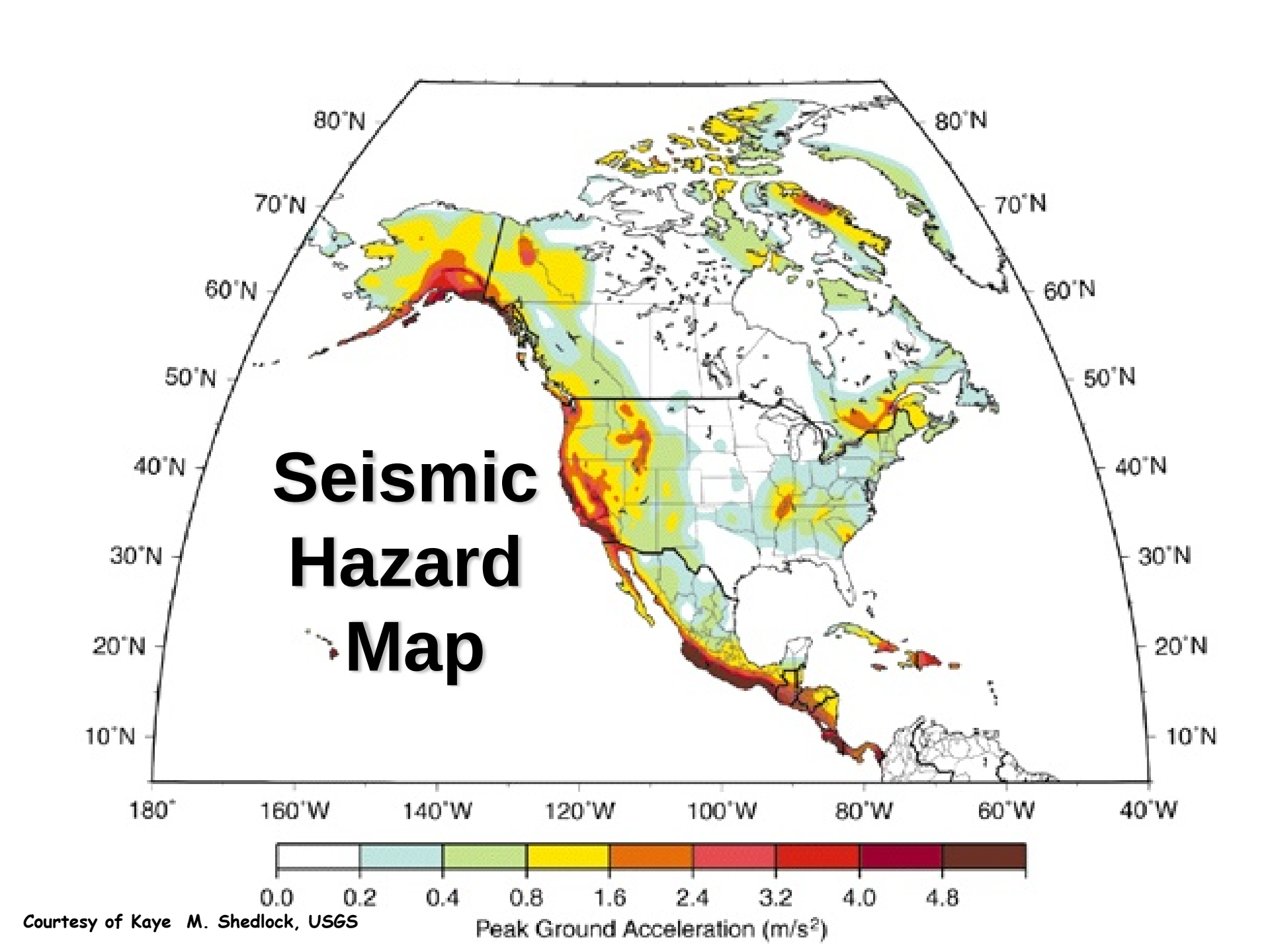


Courtesy of Taro, Japan



New Housing Built Along the 1906 Trace of the San Andreas Fault

Fig. 18.22

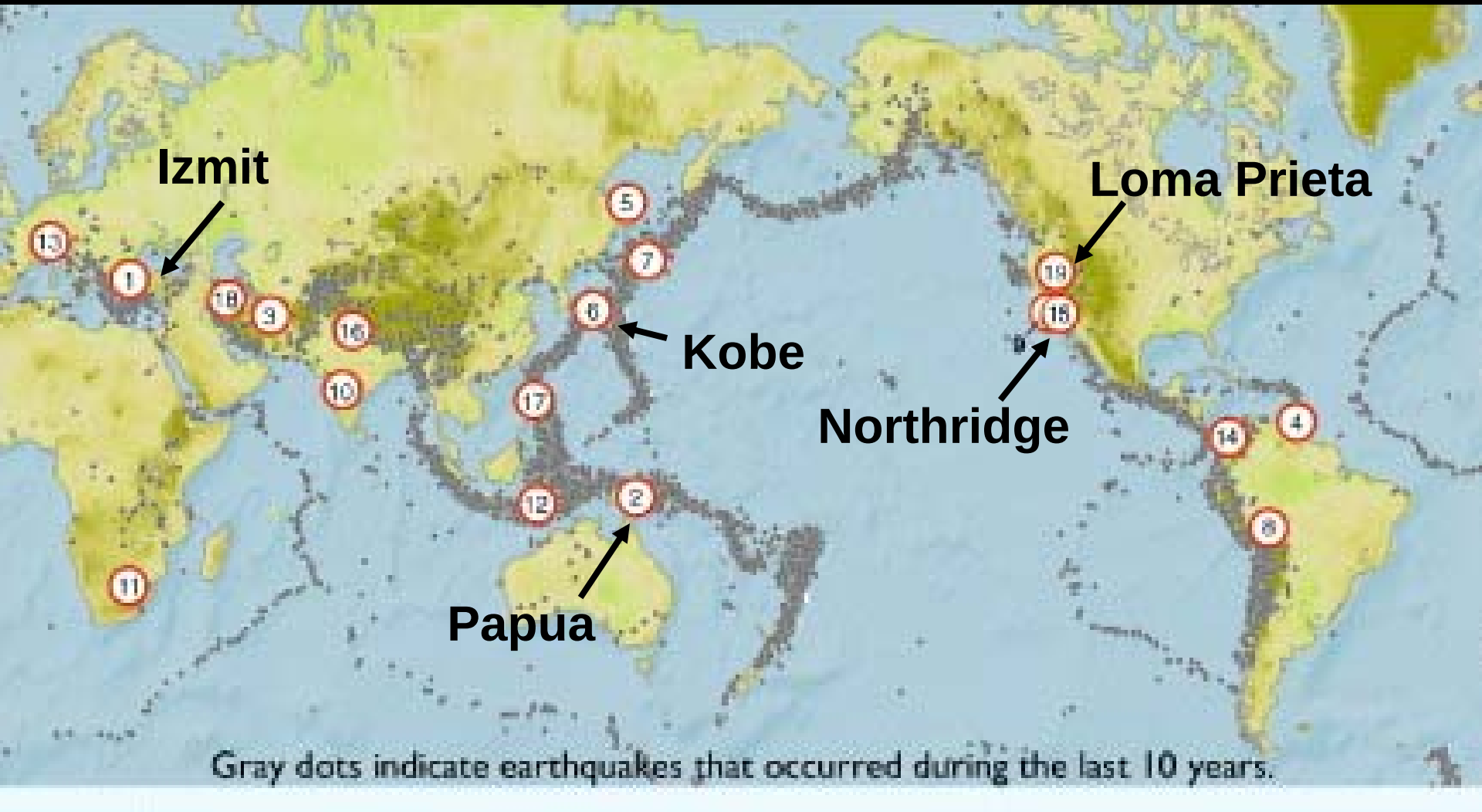


Courtesy of Kaye M. Shedlock, USGS

Demonstrating Earthquake Safety in Japan



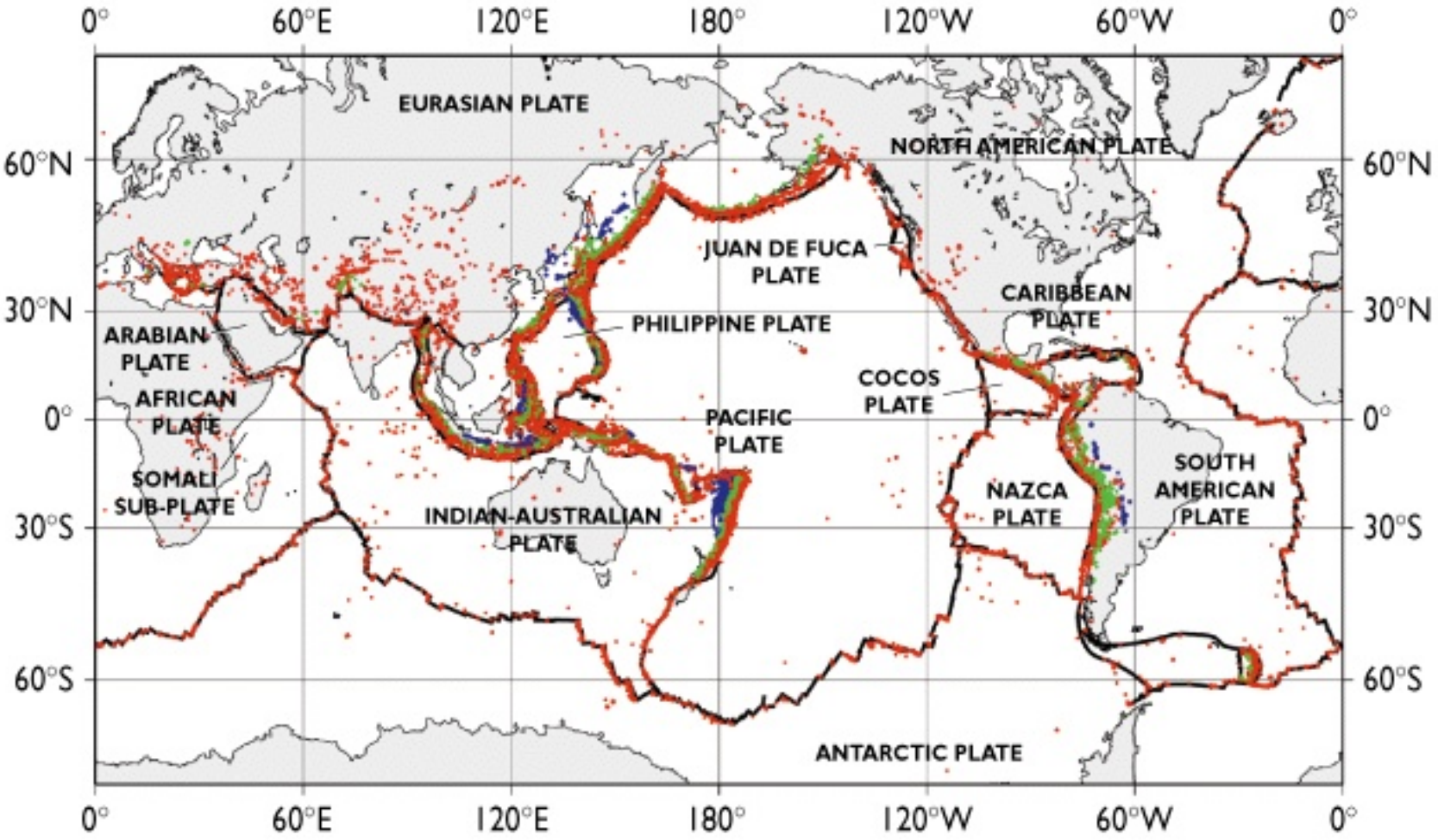
Recent Earthquakes of Special Interest



Distribution of earthquakes

- *Not random*
- Focused around plate margins in long linear belts
- Also see in volcanic regions
- And in plate interiors

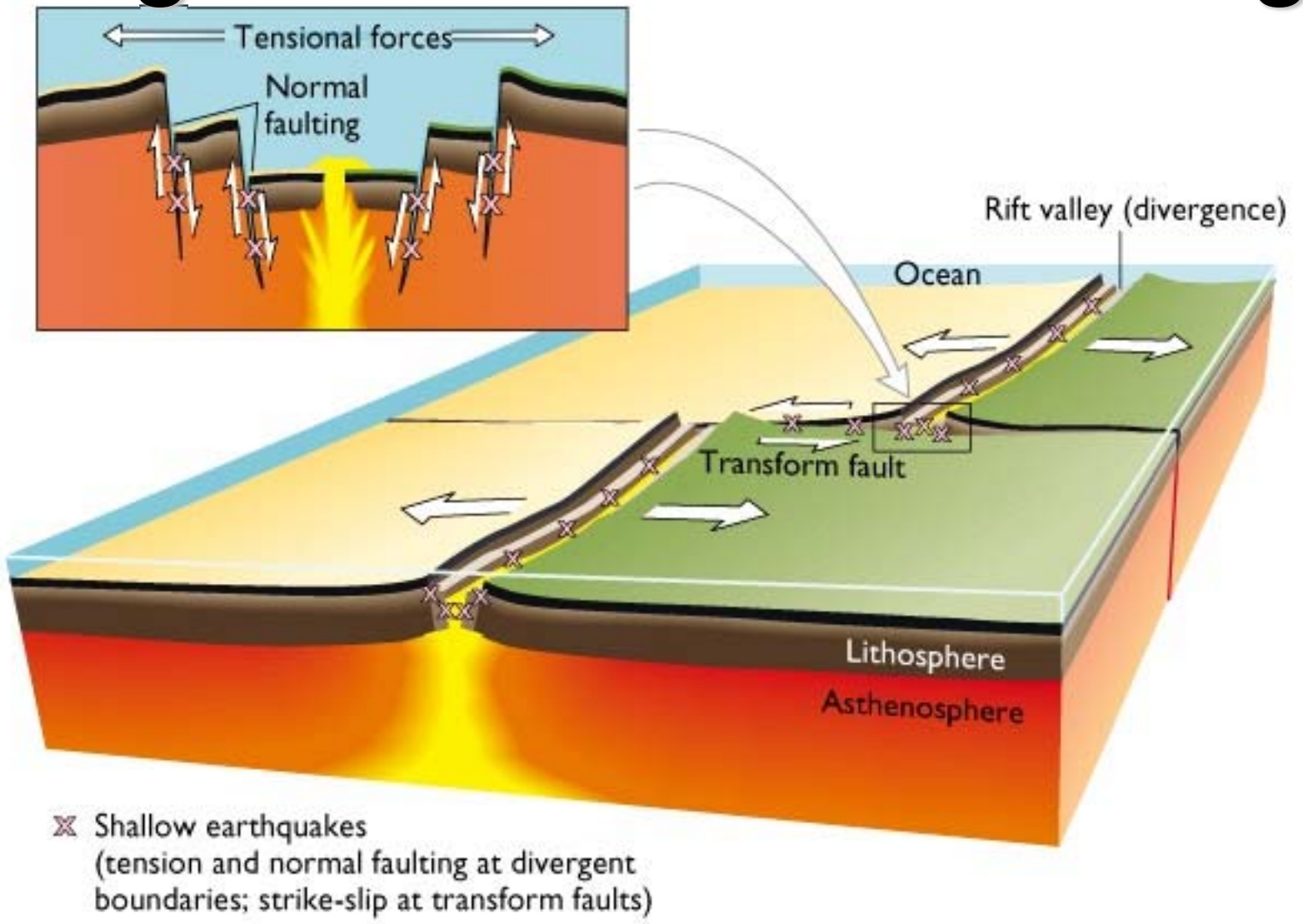
World Seismicity, 1963–2000



Earthquakes & Plate Margins

- Divergent Margins - low magnitude & shallow focus (<100 km) earthquakes (eq) -> normal faulting
- Transform Margins - shallow focus & intermediate magnitude -> strike-slip faulting

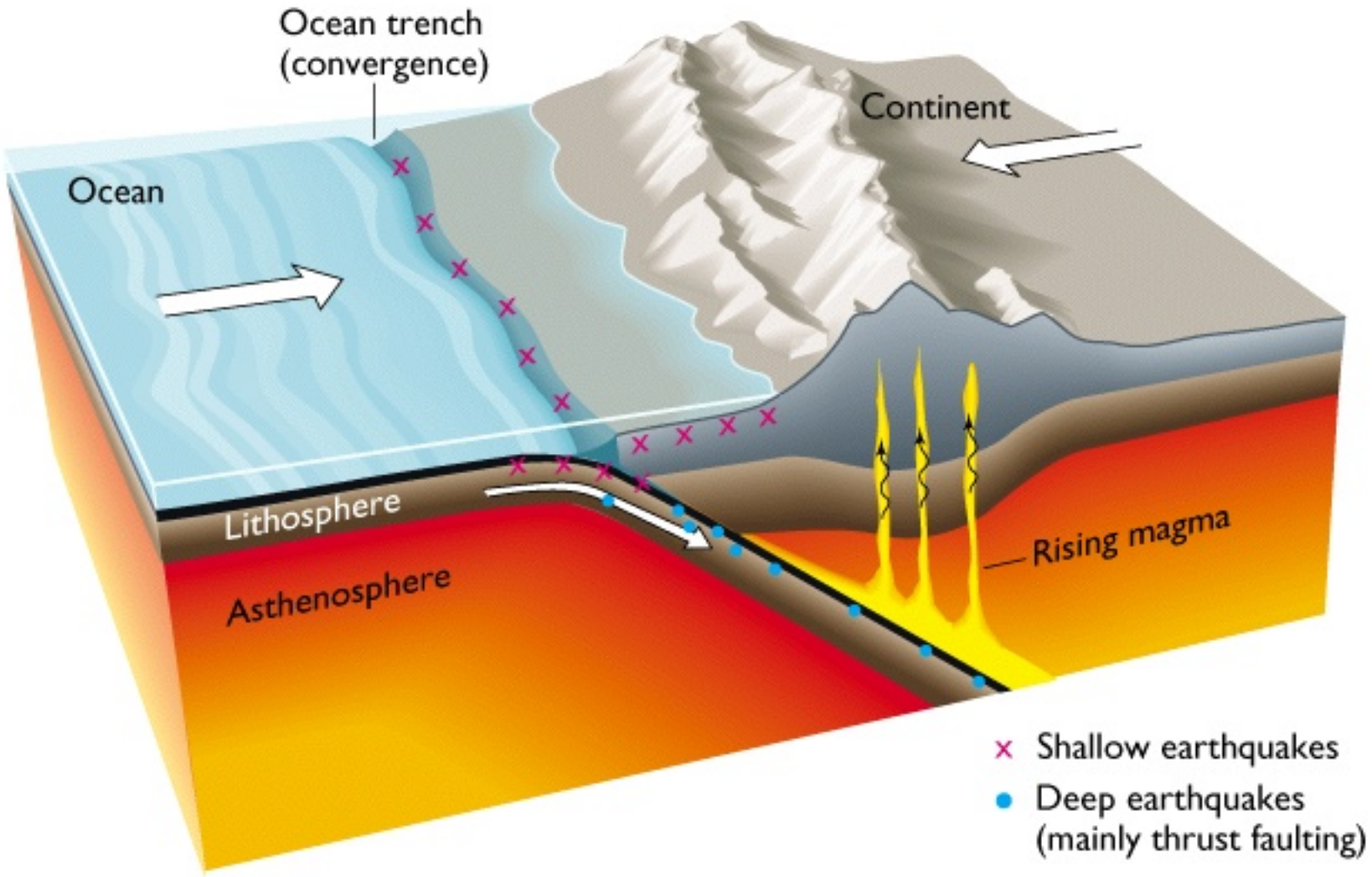
Earthquakes Associated with Divergent and Transform Margins

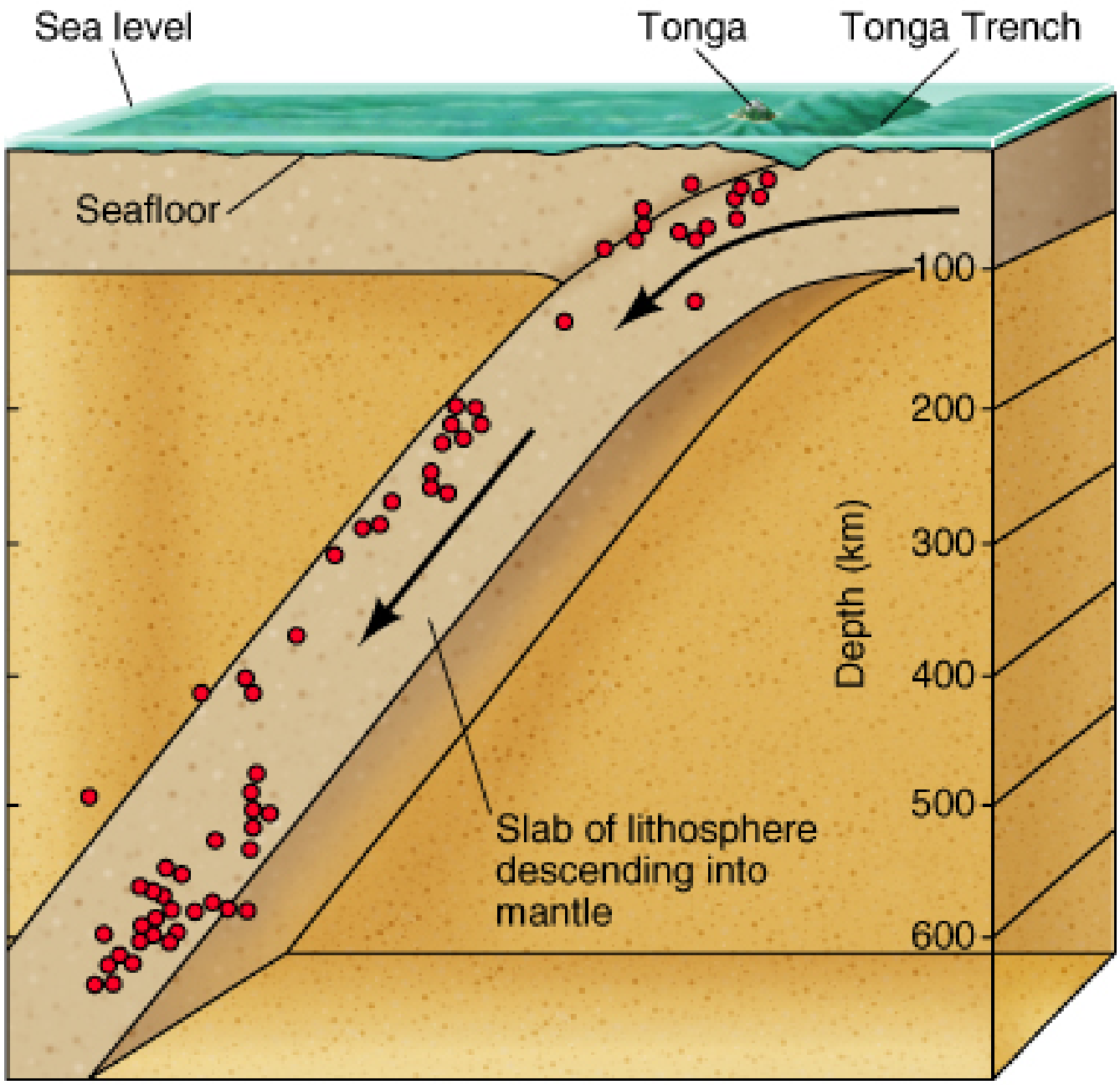


Earthquakes & Plate Margins con't

- Convergent subduction margins - shallow to deep (700 km) & high magnitude eq. -> thrust & reversed faulting
- Convergent collision margins - shallow to intermediate focus (300 km)& high magnitude eq. -> reversed & thrust faulting

Earthquakes Associated with Convergent Plate Margins





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Benioff Zone beneath the Tonga Trench