Earthquakes and Earth's Interior

Summary

- Abrupt movements of faults that release elastically stored energy cause earthquakes – Elastic Rebound.
- Earthquake vibrations are measured with seismometers.
- Energy released at an earthquake's focus radiates outward as body waves, which are of two kinds: P waves (Primary waves, which are compressional) and S waves (Secondary waves, which are shear waves).
- Earthquake energy also causes Earth's surface to vibrate. These vibrations travel laterally as surface waves.
- The focus and epicenter of an earthquake can be located by measuring the differences in travel times between P and S waves.
- The amount of energy released during an earthquake can vary by very large amounts. The standard measure of earthquake size is the magnitude scale. The magnitude scale is logarithmic in order to span seismic activity from small local tremors (magnitude M=0) to great earthquakes (magnitude M>8).
- Seismologists also quantify earthquake size with the seismic moment, whose definition relates directly to fault size and the distance a fault slips during an earthquake.
- Ninety-five percent of all earthquakes originate in the circum-Pacific belt (80%) and the Mediterranean-Himalayan belt (15%). The remaining 5 percent are widely distributed along the mid-ocean ridges and elsewhere.

- Seismic activity outlines the tectonic plates.
- Seismic-wave first-motion studies are used to determine the fault orientation and the direction of fault slip.
- Earthquake forecasting is a long-term estimate of future earthquake activity. Based largely on the records of past earthquakes and present plate motions, earthquake forecasting helps policymakers develop land-use policies that decrease overall seismic hazard to lives and property.
- Earthquake prediction is a short-term estimate of future earthquake activity. Earthquake prediction relies on earthquake precursors, which must be observed in time for public officials to take appropriate actions.
- Despite some documented successes, no earthquake precursor, or set of precursors, has been found that can predict future shocks reliably.
- Earthquake prediction is hampered by our ignorance of what causes a particular earthquake to happen when it does. Recent research has established several useful facts that may help overcome this ignorance: 1) the stresses of a large quake may increase stress on neighboring faults, and cause them to slip either soon (in an aftershock) or after years or decades; 2) fault surfaces lose their frictional strength when earthquake slip starts, and 3) the presence of fluid in fault zones tends to lubricate their motion and encourage earthquake activity.

- Seismic body waves can be refracted and reflected just as sound and light waves are. From the study of seismic wave refraction and reflection, scientists infer Earth's internal structure by locating boundaries, or discontinuities, in its composition and physical properties. Pronounced compositional boundaries occur between the crust and mantle and between the mantle and outer core.
- The base of the crust is a pronounced seismic discontinuity called the Mohorovicic discontinuity. Thickness of the continental crust ranges from 20 to 70 km in continental regions but is less than 10 km beneath oceans.
- Within the mantle there are two zones, at depths of 400 and 670 km, where small jumps in seismic wave speed produce seismic-wave reflections. The change at 400 km is probably produced by a polymorphic transition of olivine. The 670-km change might be due to a polymorphic transition, a compositional change, or a combination of both.
- The core has a high density and is inferred to consist of iron plus small amounts of nickel and other elements. The outer core must be molten because it does not transmit S waves. The inner core is solid.
- Seismic tomography reveals geographic variations in seismic wave speed. Lateral variations in mantle wave speed are caused mostly by variations in temperature. Hotter regions have slower wave speed; colder regions have higher wave speed. Seismic wave speed variations agree with the temperature variations expected from plate tectonics and mantle convection.

Earthquakes:

- The earthquake source
  - Behavior of faults – elastic rebound
  - Connections to Plate Tectonics
  - Measuring the size of earthquakes
- Earthquake waves as a tool to probe earth
  - Measuring waves
  - Earth structure

- Hazards
  - Forecasts
  - Prediction
  - Mitigation
- Cascadia Current Events
  - Discovery of new types of earthquakes
    - Slow slip
    - Episodic tremor

Elastic Rebound Theory

- Energy is stored in elastically strained rocks
  - Faults are locked by friction
  - Plate motions cause elastic strain of rock near faults
- When the elastic stress exceeding the friction on a fault, the sudden slip results in an earthquake
  - The more energy released, the stronger the quake.
    - Can have either more distance of slip or larger area of slip

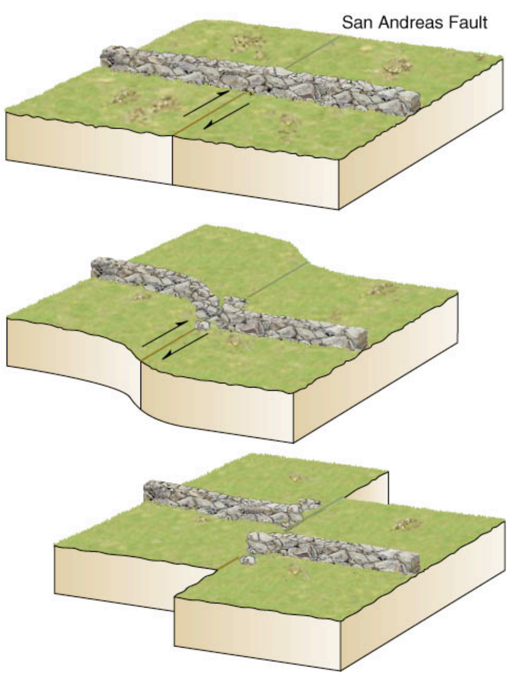


Figure 10.19

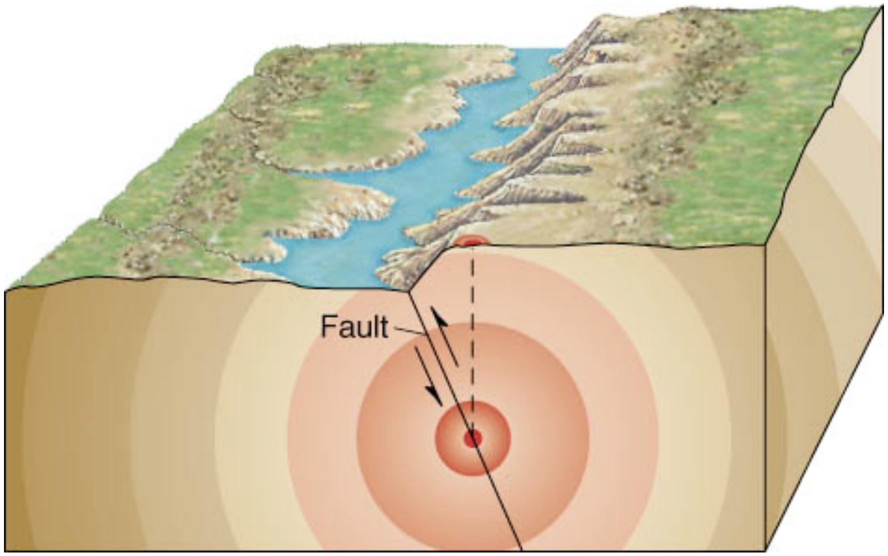
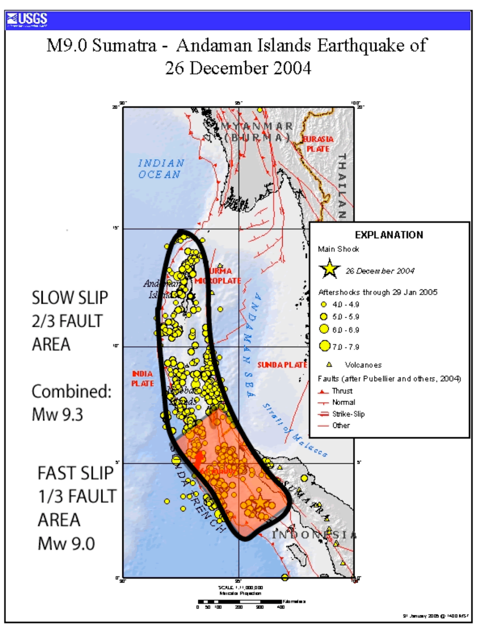


Figure 10.3

Earthquake Focus And Epicenter

- The earthquake ***focus*** is the point where earthquake starts to release the elastic strain of surrounding rock.
- The ***epicenter*** is the point on Earth's surface that lies vertically above the focus of an earthquake.
- Fault slippage begins at the focus and spreads across a fault surface in a ***rupture front***.
- The rupture front travels at roughly 3 kilometers per second for earthquakes in the crust.
- ***Rupture area*** (slip zone) is the whole area of fault that slips during earthquake



Deadliest natural disaster - 225,000 deaths in eleven countries

Second largest earthquake ever observed:

Chile	1960	M=9.5
Sumatra	2004	M=9.3
Alaska	1964	M=9.2

Rupture duration of nearly 10 minutes

Caused planetary vibrations of more than 1 cm

Show tsunami movie

Measuring Earthquakes

- Seismometers
  - Very sensitive – amplitudes of microns far from earthquake
- Accelerometers
  - Measure ***strong motions*** close to fault zone
- GPS
  - Measure total displacements of faults
  - Measure aseismic slip on some faults

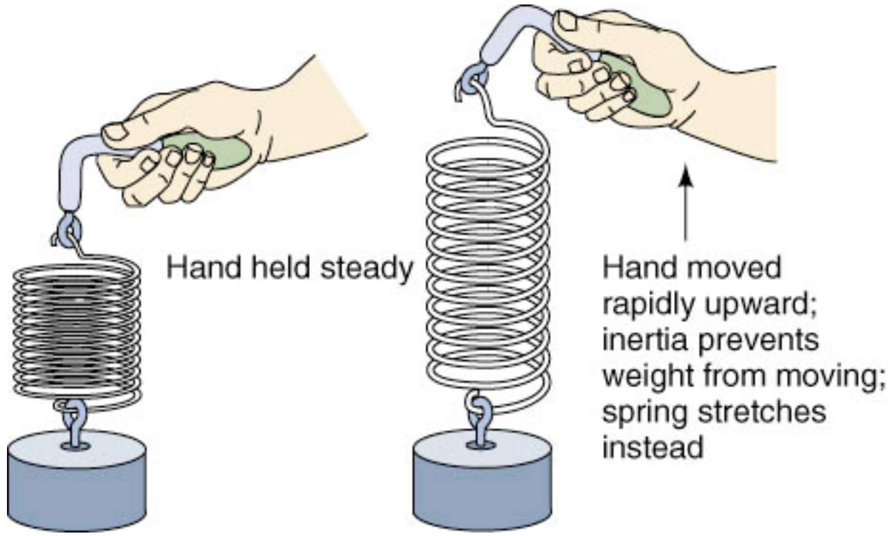


Figure 10.1

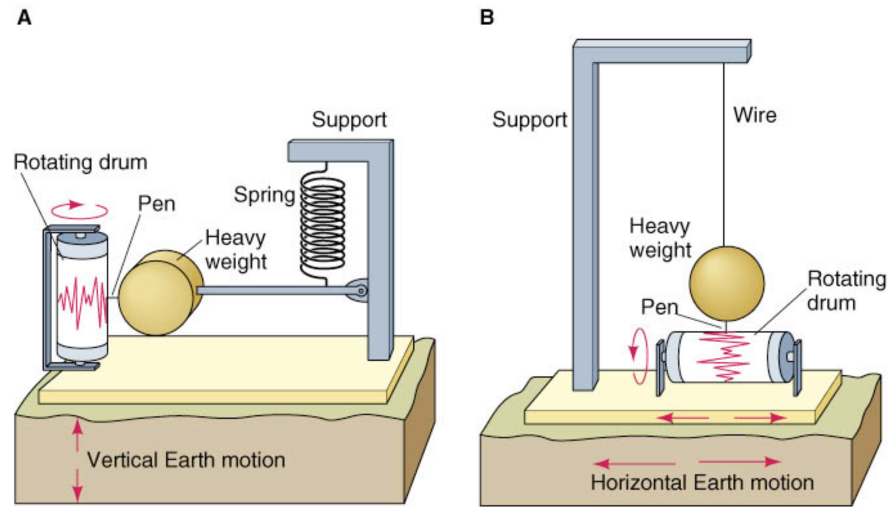


Figure 10.2

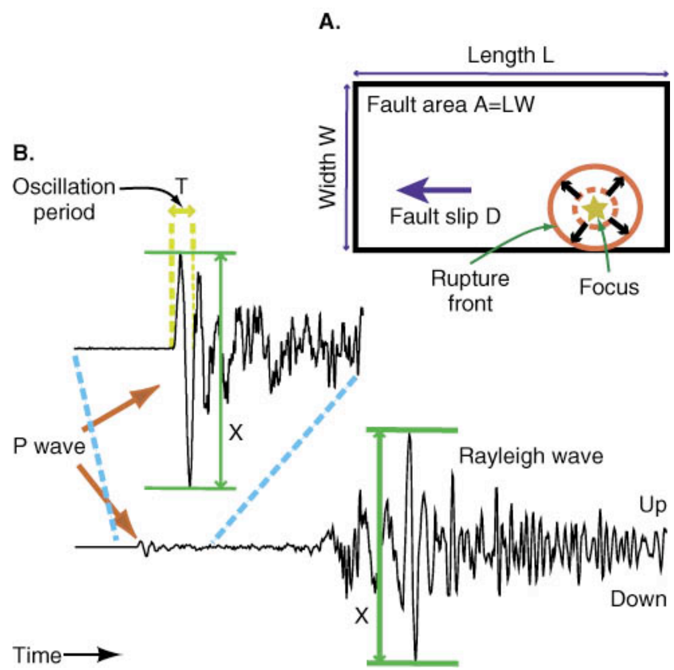


Figure B10.01

Seismic Waves

- Vibrational waves (elastic waves) spread outward initially from the focus of an earthquake, and continue to radiate from elsewhere on the fault as rupture proceeds.

Seismic Waves

- There are two basic families of seismic waves.
  - ***Body waves*** can transmit either:
    - Compressional motion (P waves), or
    - Shear motion (S waves).
  - ***Surface waves*** are vibrations that are trapped near Earth's surface. There are two types of surface waves:
    - Love waves, or
    - Rayleigh waves.

Body Waves

- Body waves travel outward in all directions from their point of origin.
- The first kind of body waves, a ***compressional wave***, deforms rocks largely by change of volume and consists of alternating pulses of contraction and expansion acting in the direction of wave travel.
  - Compressional waves are the first waves to be recorded by a seismometer, so they are called P (for "primary") waves.

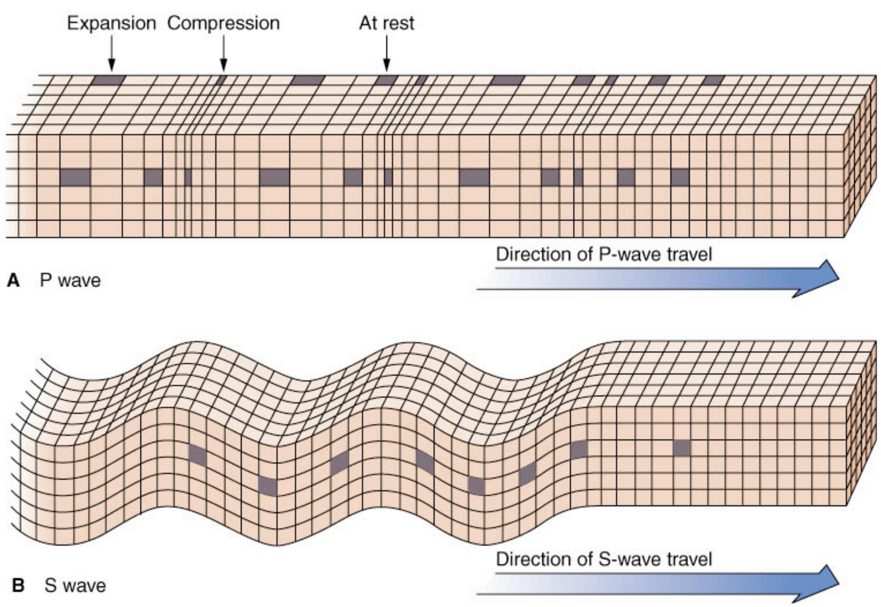


Figure 10.4

Body Waves

- The second kind of body waves is a ***shear wave***.
  - Shear waves deform materials by change of shape,
  - Because shear waves are slower than P waves and reach a seismometer some time after P waves arrives, they are called S (for "secondary") waves.

Body Waves

- Compressional (P) waves can pass through solids, liquid, or gases.
- P waves move more rapidly than other seismic waves:
  - 6 km/s is typical for the crust.
  - 8 km/s is typical for the uppermost mantle.

Body Waves

- Shear (S) waves consist of an alternating series of side-wise movements.
  - Shear waves can travel only within solid matter.
  - A typical speed for a shear wave in the crust is 3.5 km/s, 5 km/s in the uppermost mantle.
- Seismic body waves, like light waves and sound waves, can be reflected and refracted by change in material properties.
- When change in material properties results in a change in wave speed, refraction bends the direction of wave travel.

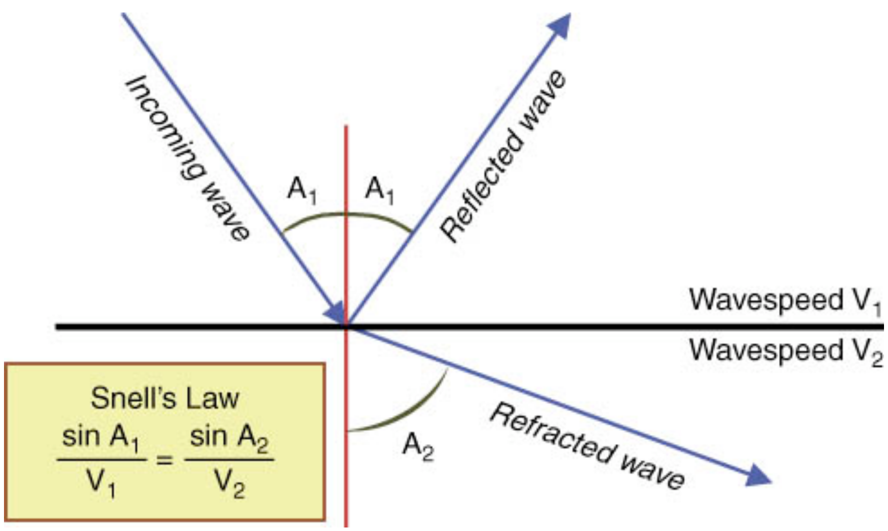


Figure 10.5

Body Waves

- For seismic waves within Earth, the changes in wave speed and wave direction can be either gradual or abrupt, depending on changes in chemical composition, pressure, and mineralogy.
- If Earth had a homogeneous composition and mineralogy, rock density and wave speed would increase steadily with depth as a result of increasing pressure (gradual refraction).
  - Measurements reveal that the seismic waves are refracted and reflected by several abrupt changes in wave speed.

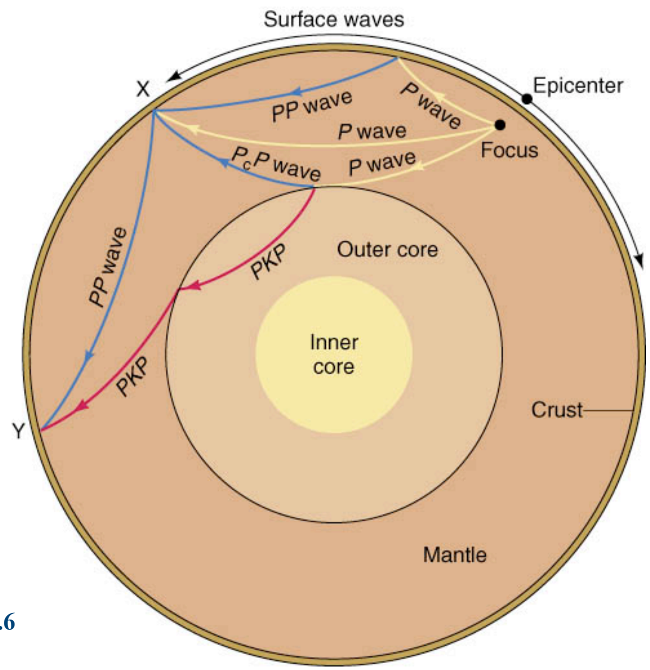


Figure 10.6

Surface Waves

- Surface waves travel more slowly than P waves and S waves, but are often the largest vibrational signals in a seismogram.
- Love waves consist entirely of shear wave vibrations in the horizontal plane, analogous to an S wave that travels horizontally.
- Rayleigh waves combine shear and compressional vibration types, and involve motion in both the vertical and horizontal directions.

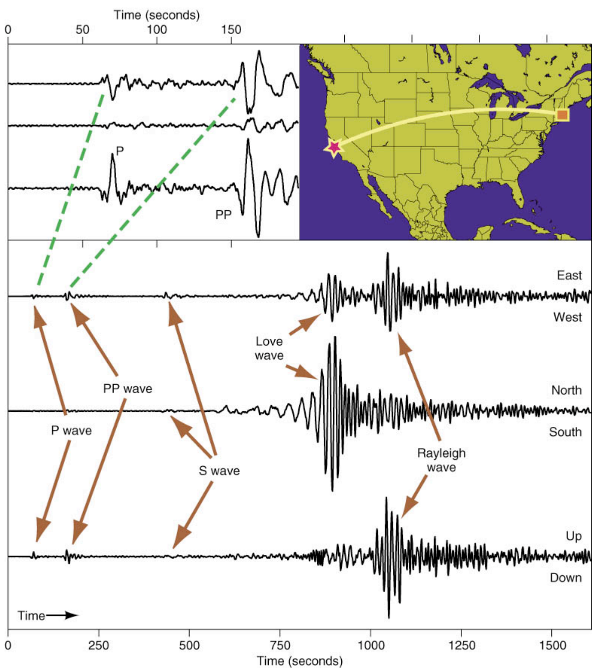


Figure 10.7

Surface Waves

- The longer the wave length of a surface wave, the deeper the wave motion penetrates Earth. Surface waves of different wave lengths develop different velocities. This behavior is called ***Dispersion***

Determining The Epicenter Location

- An earthquake's epicenter can be calculated from the arrival times of the P and S waves at a seismometer.
  - The farther a seismometer is away from an epicenter, the greatest the time difference between the arrival of the P and S waves.

Determining The Epicenter

- The epicenter can be determined when data from three or more seismometers are available.
  - It lies where the circles intersect (radius = calculated distance to the epicenter).
- The depth of an earthquake focus below an epicenter can also be determined, using P-S time intervals.

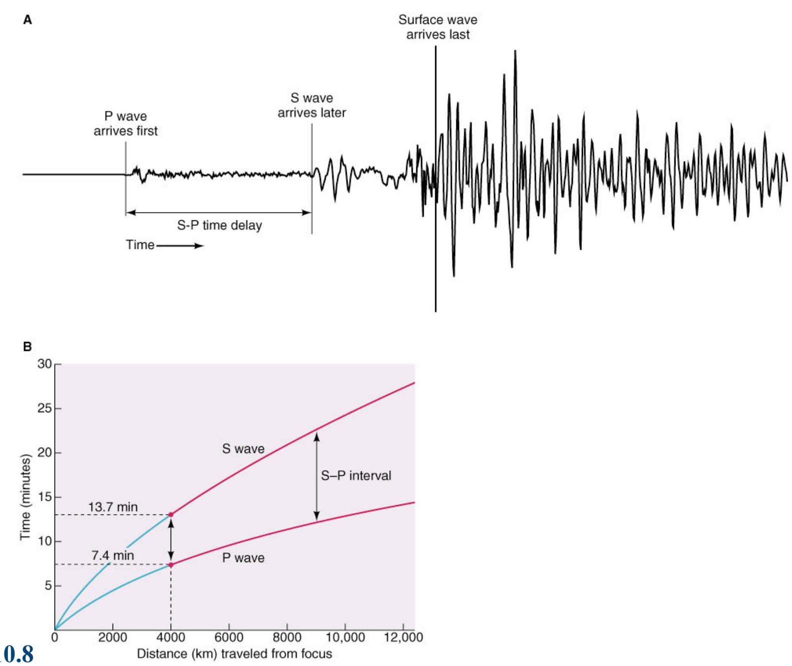


Figure 10.8

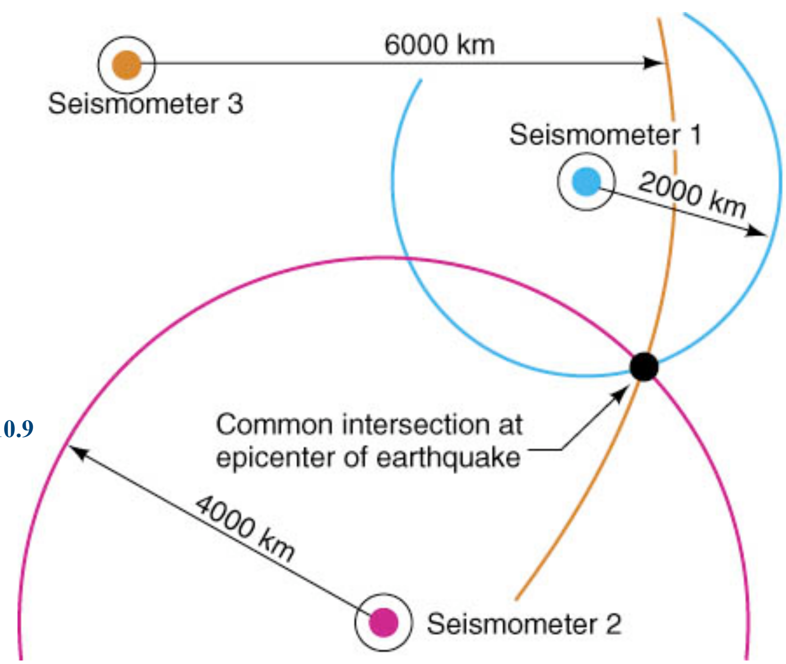


Figure 10.9

Brought in demo seismometer & slinky
Showed Sumatra and Denali video