Earth Science, 12e

Earthquakes and Earth's Interior

Chapter 8

Earthquakes

- General features
  - Vibration of Earth produced by the rapid release of energy
  - Associated with movements along faults
    - Explained by the plate tectonics theory
    - Mechanism for earthquakes was first explained by H. Reid
      - Rocks "spring back" – a phenomenon called elastic rebound
      - Vibrations (earthquakes) occur as rock elastically returns to its original shape

Elastic rebound

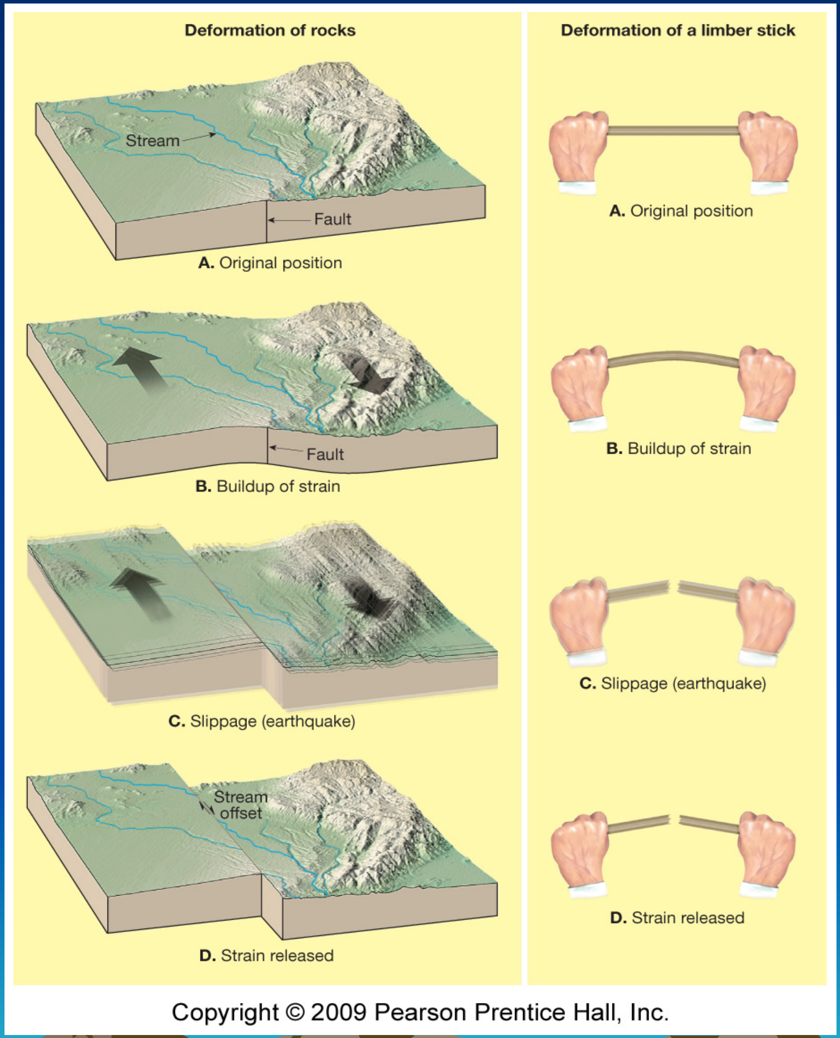


Figure 8.5

Earthquakes

- General features
  - Earthquakes are often preceded by foreshocks and followed by aftershocks

Earthquakes

- Earthquake waves
  - Study of earthquake waves is called seismology
  - Earthquake recording instrument (seismograph)
    - Records movement of Earth
    - Record is called a seismogram
  - Types of earthquake waves
    - Surface waves
      - Complex motion
      - Slowest velocity of all waves

Seismograph

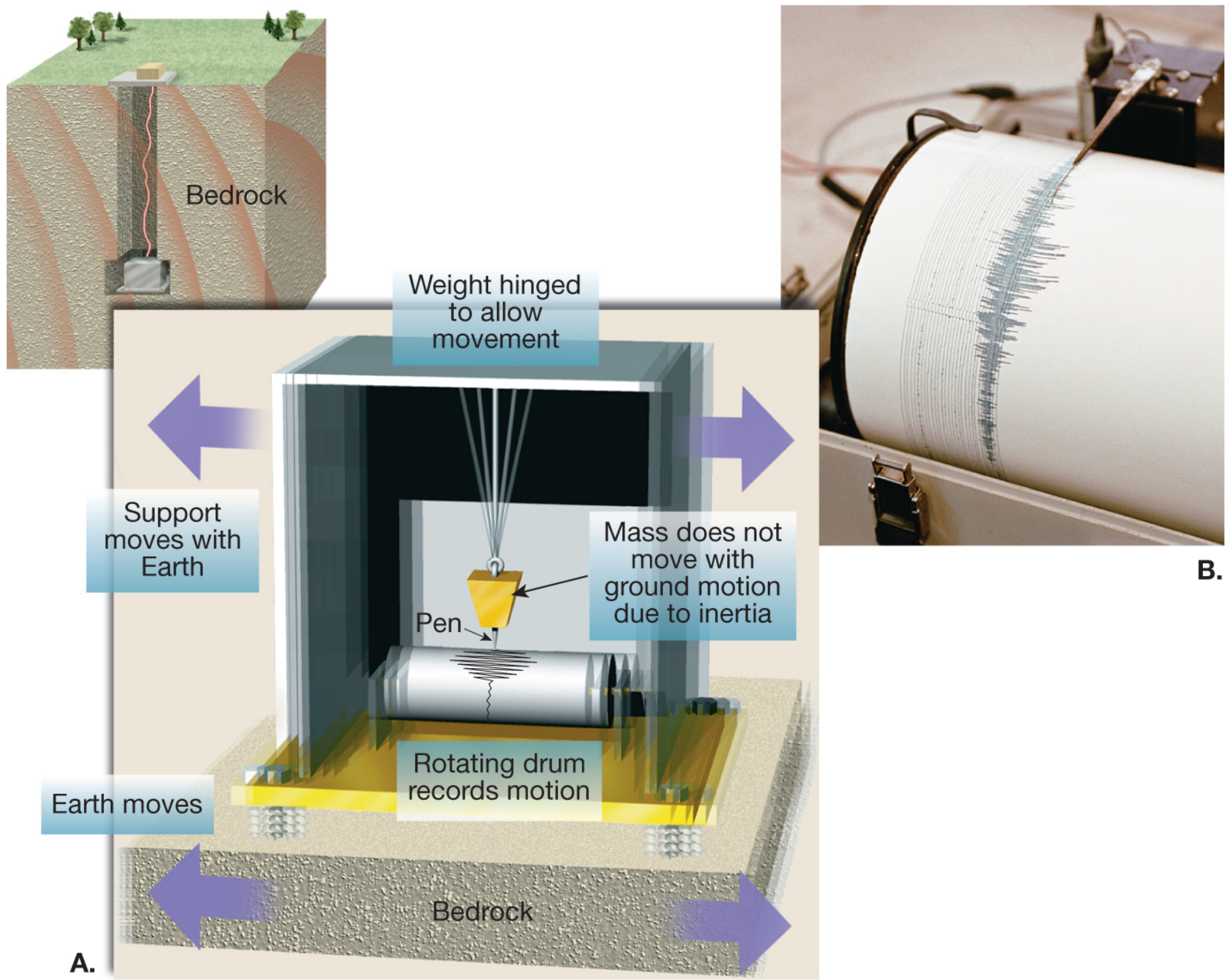


Figure 8.7

A seismogram records wave amplitude vs. time

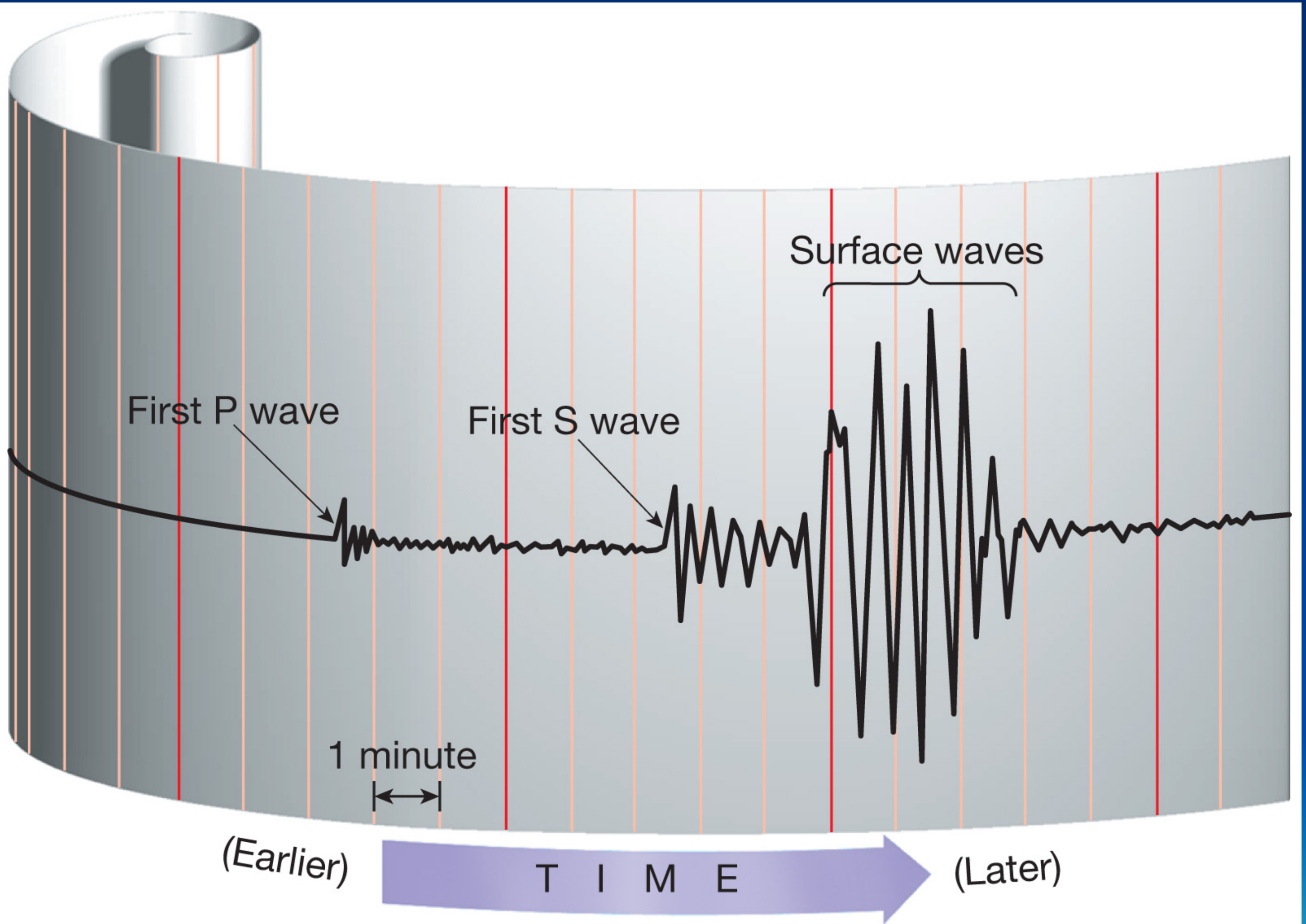
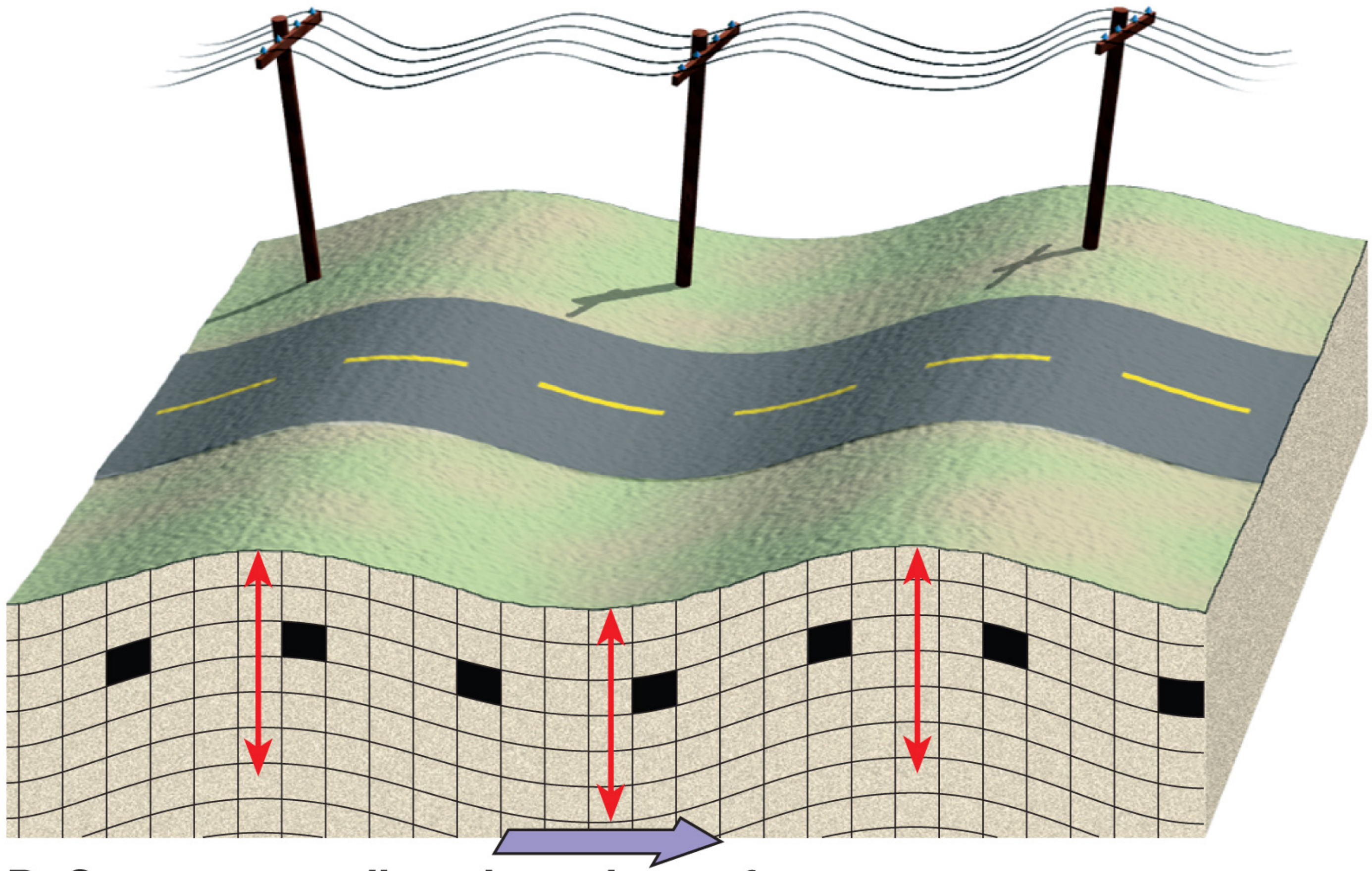


Figure 8.8

Surface waves



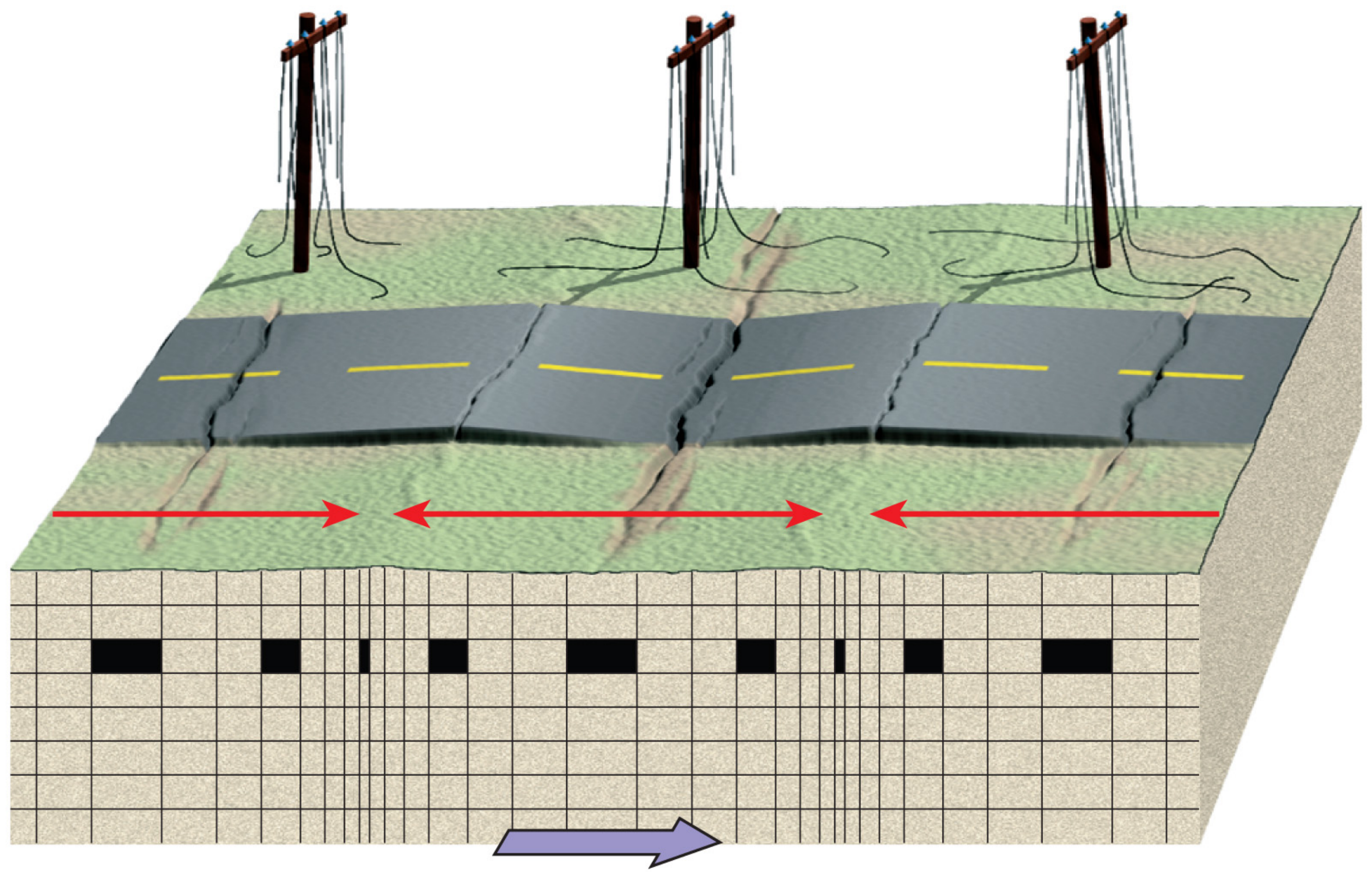
D. S waves traveling along the surface

Figure 8.9 D

Earthquakes

- Earthquake waves
  - Types of earthquake waves
    - Body waves
      - Primary (P) waves
        - Push–pull (compressional) motion
        - Travel through solids, liquids, and gases
        - Greatest velocity of all earthquake waves

Primary (P) waves



B. P waves traveling along the surface

Figure 8.9 B

Earthquakes

- Earthquake waves
  - Types of earthquake waves
    - Body waves
      - Secondary (S) waves
        - “Shake” motion
        - Travel only through solids
        - Slower velocity than P waves

Earthquakes

- Locating an earthquake
  - Focus – the place within Earth where earthquake waves originate
  - Epicenter
    - Point on the surface, directly above the focus
    - Located using the difference in the arrival times between P and S wave recordings, which are related to distance

Earthquake focus and epicenter

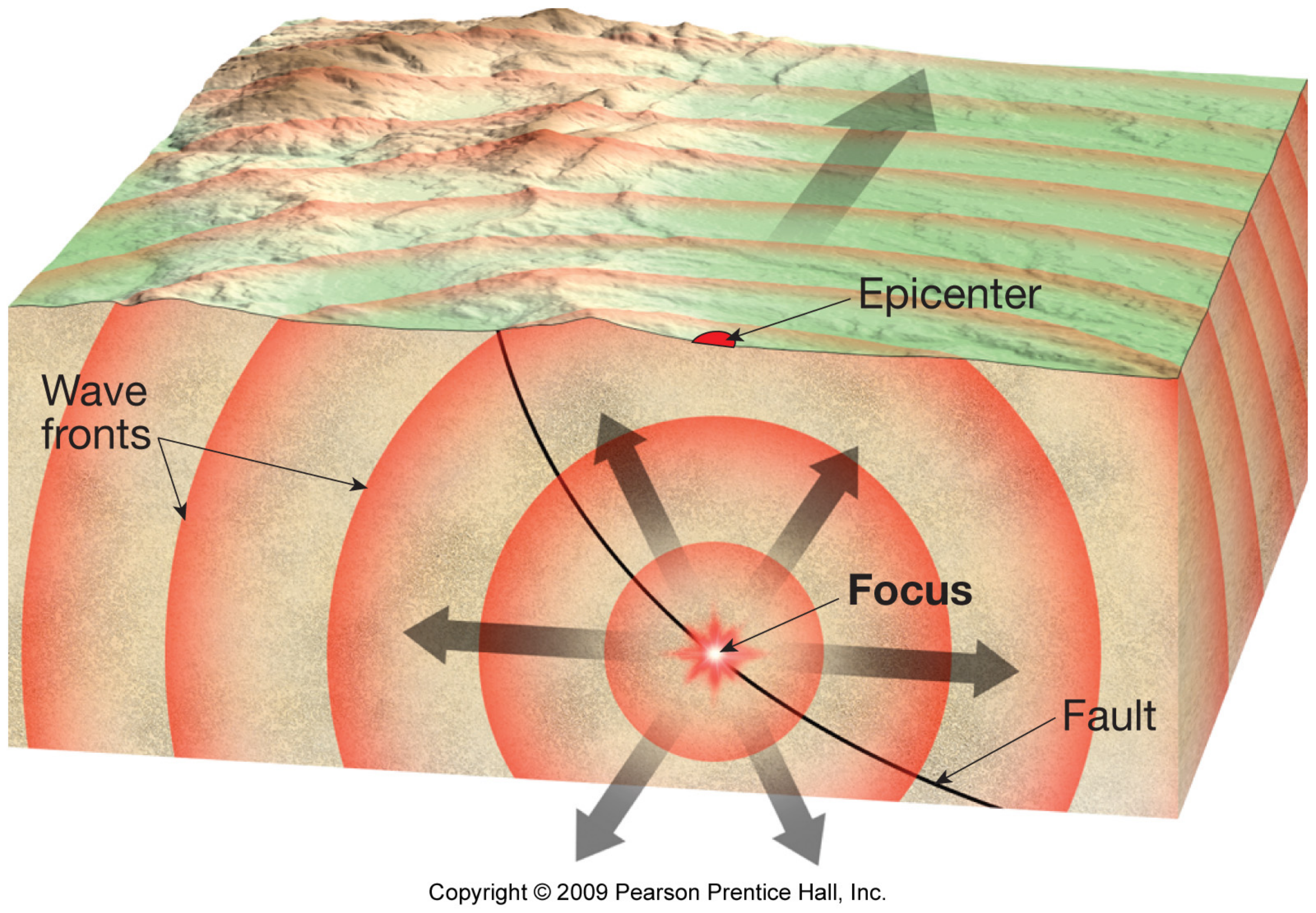
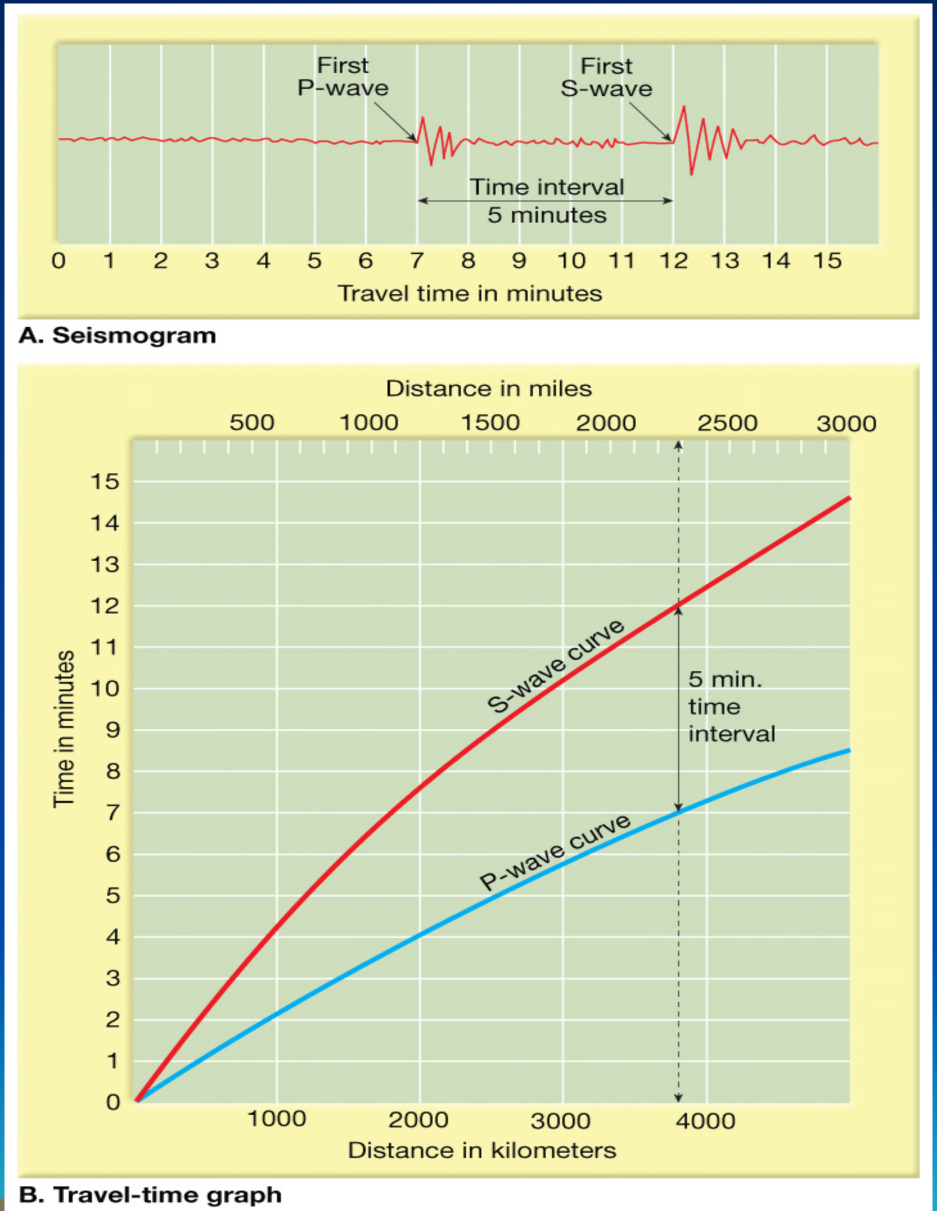


Figure 8.2

Earthquakes

- Locating an earthquake
  - Epicenter
    - Three station recordings are needed to locate an epicenter
      - Circle equal to the epicenter distance is drawn around each station
      - Point where three circles intersect is the epicenter



A travel-time graph

Figure 8.10

The epicenter is located using three or more seismic stations

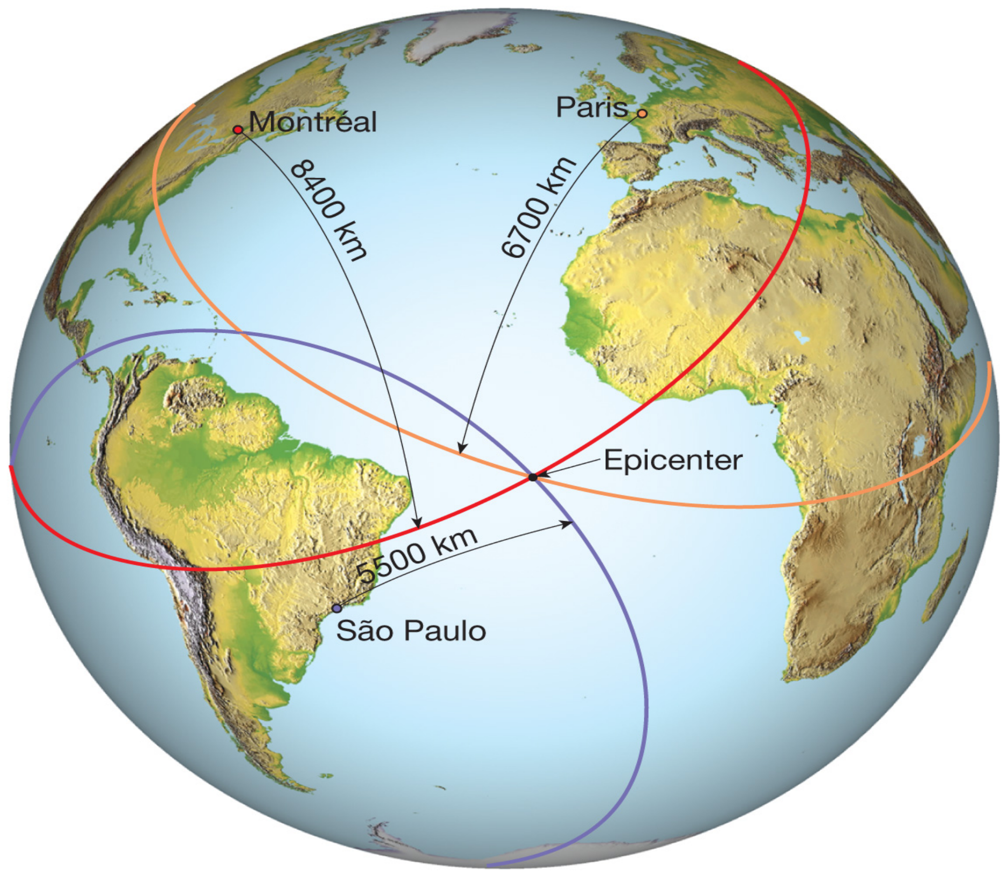


Figure 8.11

Earthquakes

- Locating an earthquake
  - Earthquake zones are closely correlated with plate boundaries
    - Circum-Pacific belt
    - Oceanic ridge system

Magnitude 5 or greater earthquakes over 10 years

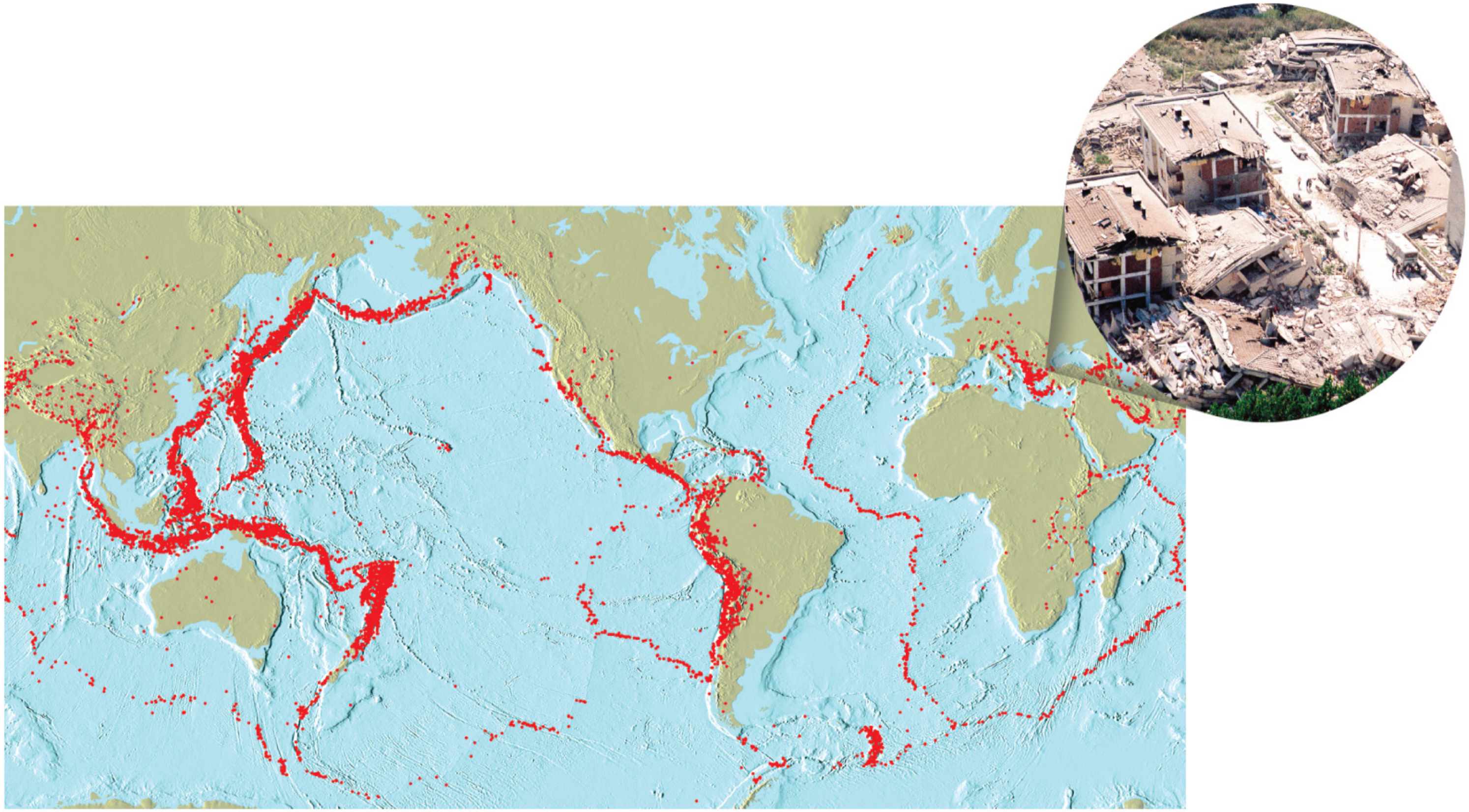


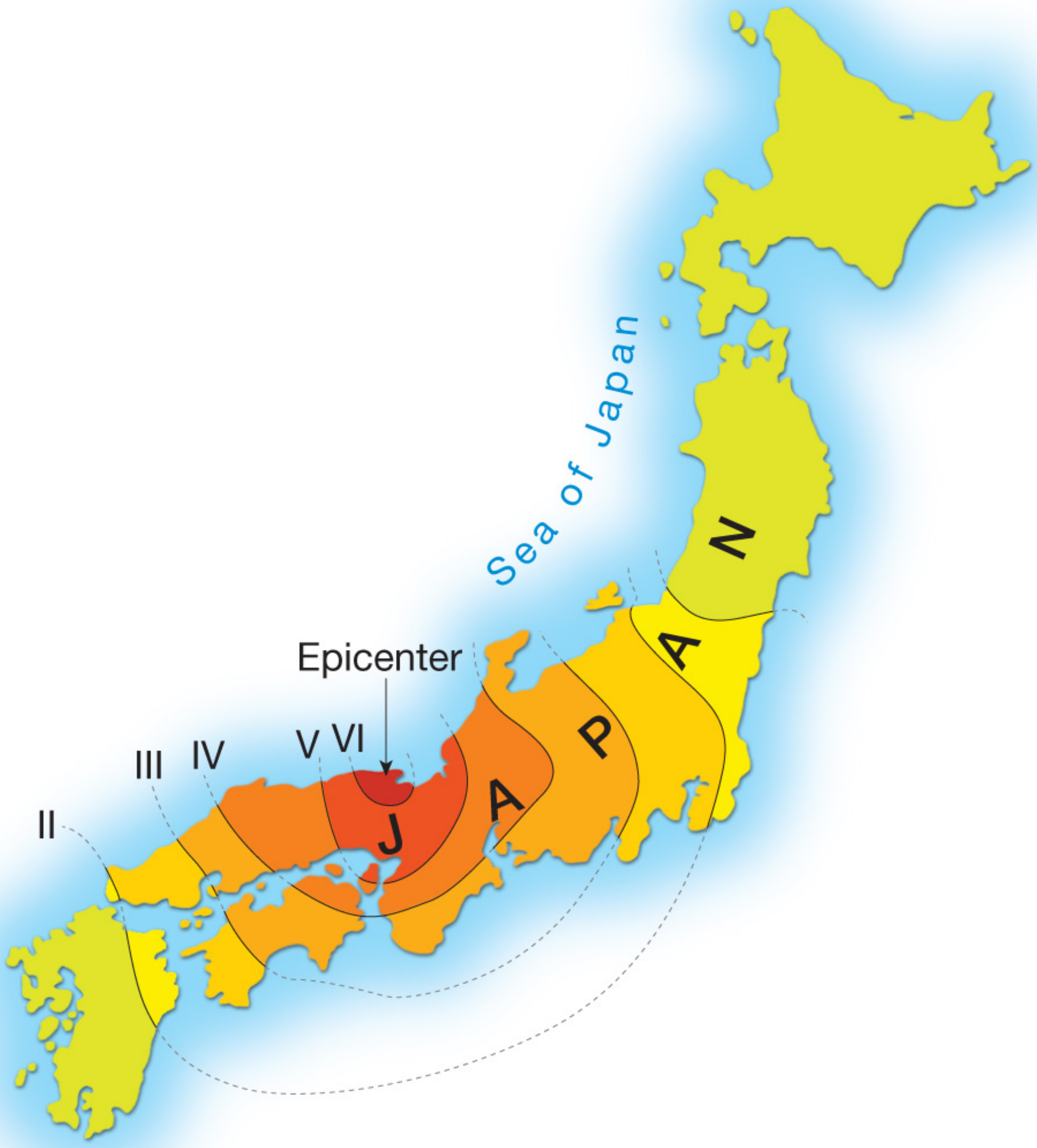
Figure 8.12

Earthquakes

- Earthquake intensity and magnitude
  - Intensity
    - A measure of the degree of earthquake shaking at a given locale based on the amount of damage
    - Most often measured by the Modified Mercalli Intensity Scale
  - Magnitude
    - Concept introduced by Charles Richter in 1935

TABLE 8.1 Modified Mercalli Intensity Scale

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.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake.
IV	During the day felt indoors by many, outdoors by few. Sensation like heavy truck striking building.
V	Felt by nearly everyone, many awakened. Disturbances of trees, poles, and other tall objects sometimes noticed.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; 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.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. (Fall of chimneys, factory stacks, columns, monuments, walls.)
IX	Damage considerable in specially designed structures. Buildings shifted off foundations. Ground cracked conspicuously.
X	Some well-built wooden structures destroyed. Most masonry and frame structures destroyed. Ground badly cracked.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground.
XII	Damage total. Waves seen on ground surfaces. Objects thrown upward into air.

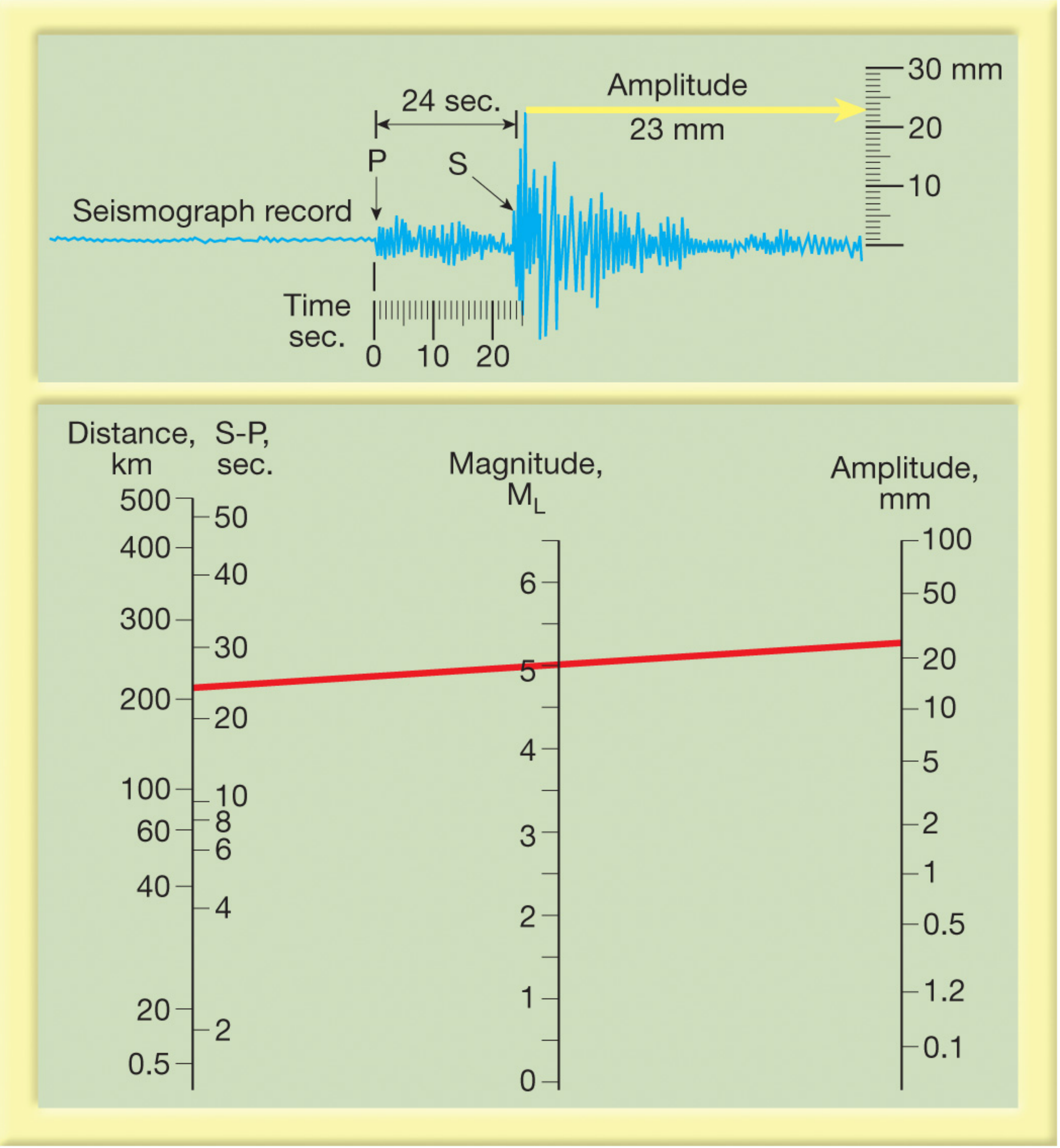

Sea of Japan
Epicenter
II
III
IV
V
VI
JAPAN

Earthquakes

- Earthquake intensity and magnitude
  - Magnitude
    - Often measured using the Richter scale
      - Based on the amplitude of the largest seismic wave
      - Each unit of Richter magnitude equates to roughly a 32-fold energy increase
      - Does not estimate adequately the size of very large earthquakes

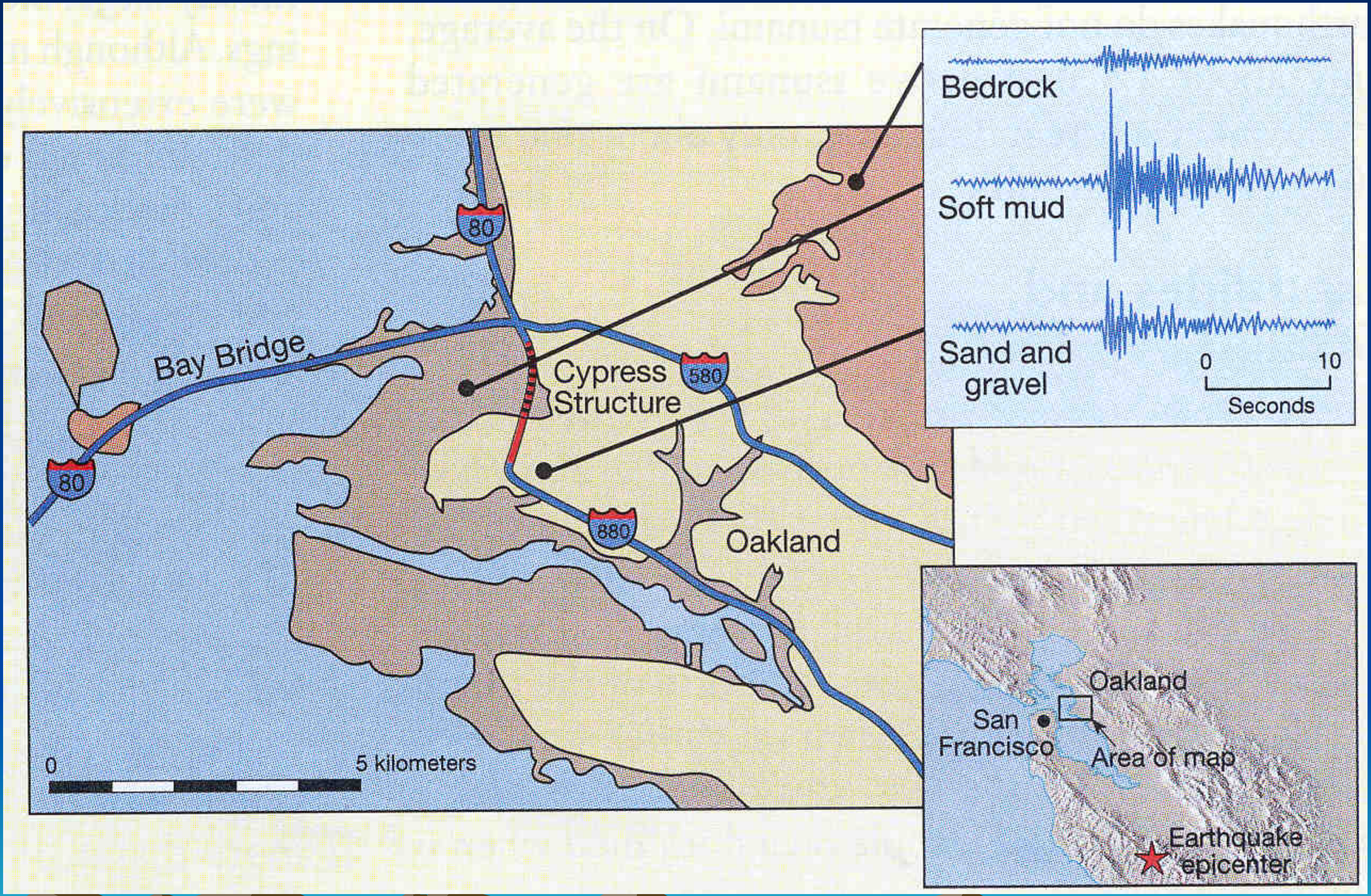
Earthquakes

- Earthquake intensity and magnitude
  - Magnitude
    - Moment magnitude scale
      - Measures very large earthquakes
      - Derived from the amount of displacement that occurs along a fault zone


24 sec.
Amplitude
23 mm
30 mm
20
10
P
S
Seismograph record
Time
sec.
0
10
20
Distance,
km
S-P,
sec.
500
400
300
200
100
60
40
20
0.5
50
40
30
20
10
8
6
4
2
Magnitude,
M_L
6
5
4
3
2
1
0
Amplitude,
mm
100
50
20
10
5
2
1
0.5
1.2
0.1

Earthquakes

- Earthquake destruction
  - Factors that determine structural damage
    - Intensity of the earthquake
    - Duration of the vibrations
    - Nature of the material upon which the structure rests
    - The design of the structure



Bedrock
Soft mud
Sand and gravel
0
10
Seconds
80
Bay Bridge
80
Cypress Structure
580
880
Oakland
0
5 kilometers
Oakland
San Francisco
Area of map
Earthquake epicenter

Earthquakes

- Earthquake destruction
  - Destruction results from
    - Ground shaking
    - Liquefaction of the ground
      - Saturated material turns fluid
      - Underground objects may float to surface
    - Tsunami, or seismic sea waves
    - Landslides and ground subsidence
    - Fires

A.

Damage caused by the 1964 earthquake in Alaska

Figure 8.16

Damage from the 1964 Anchorage, Alaska, earthquake

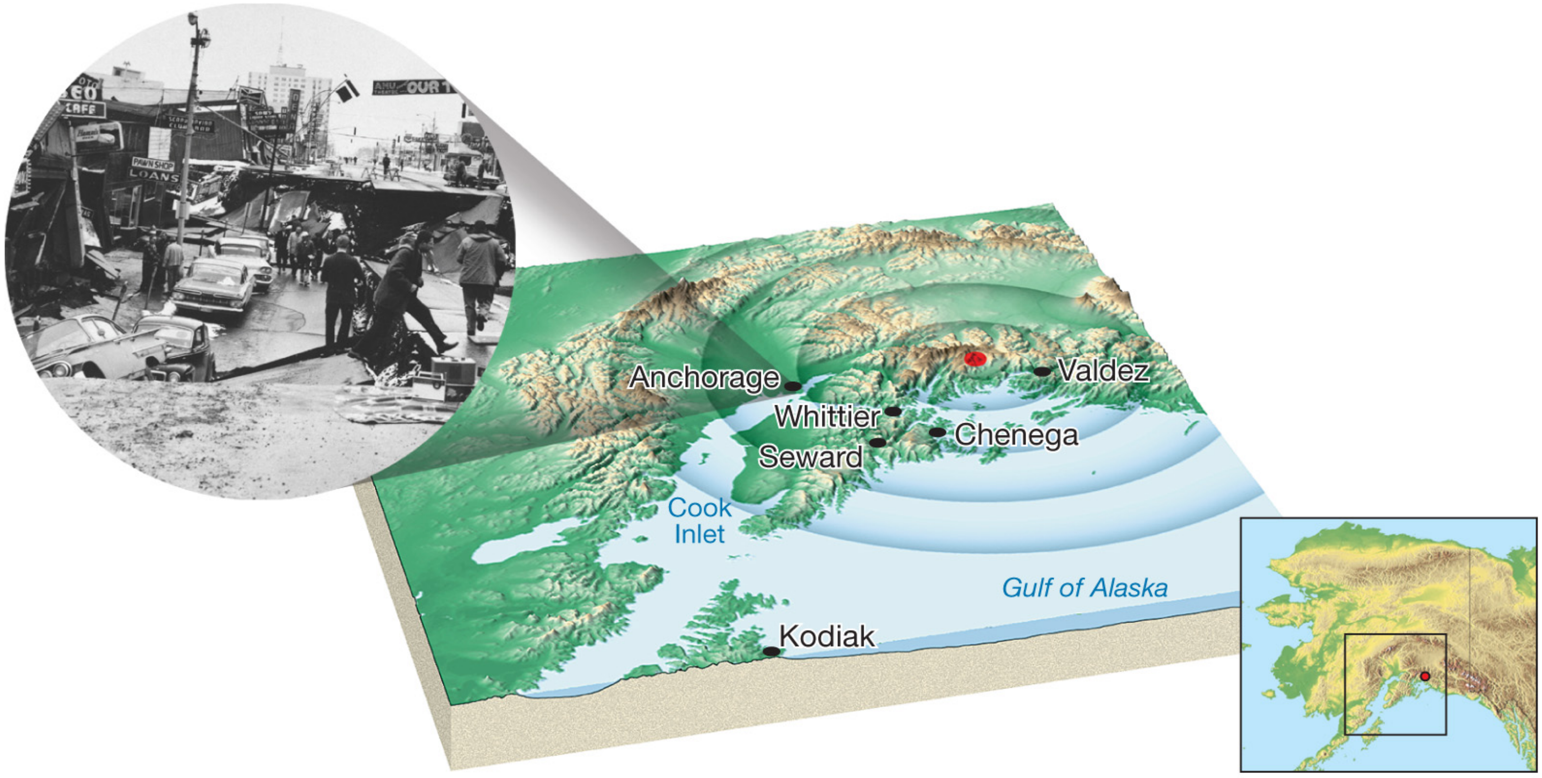
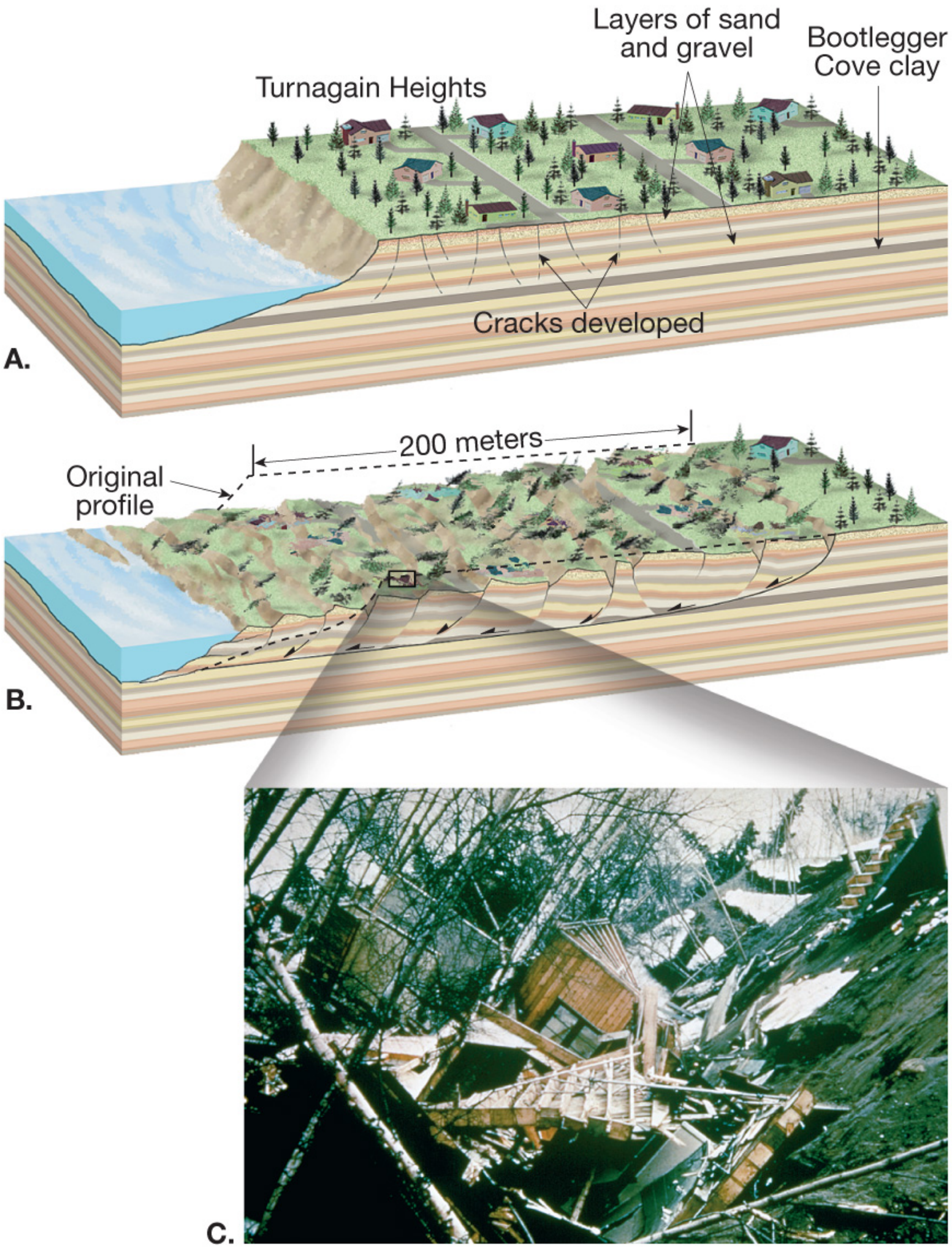


Figure 8.15


Layers of sand and gravel
Bootlegger Cove clay
Turnagain Heights
Cracks developed
A.
200 meters
Original profile
B.
C.

Formation of a tsunami

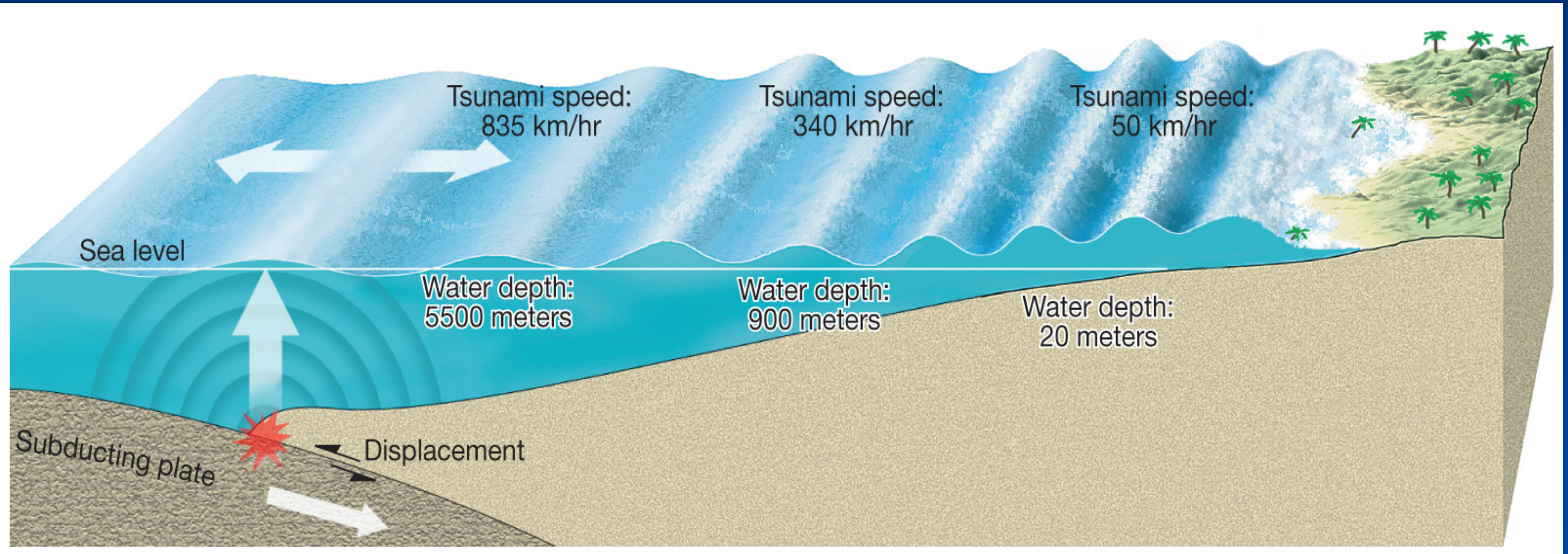


Figure 8.19

Tsunami travel times to Honolulu

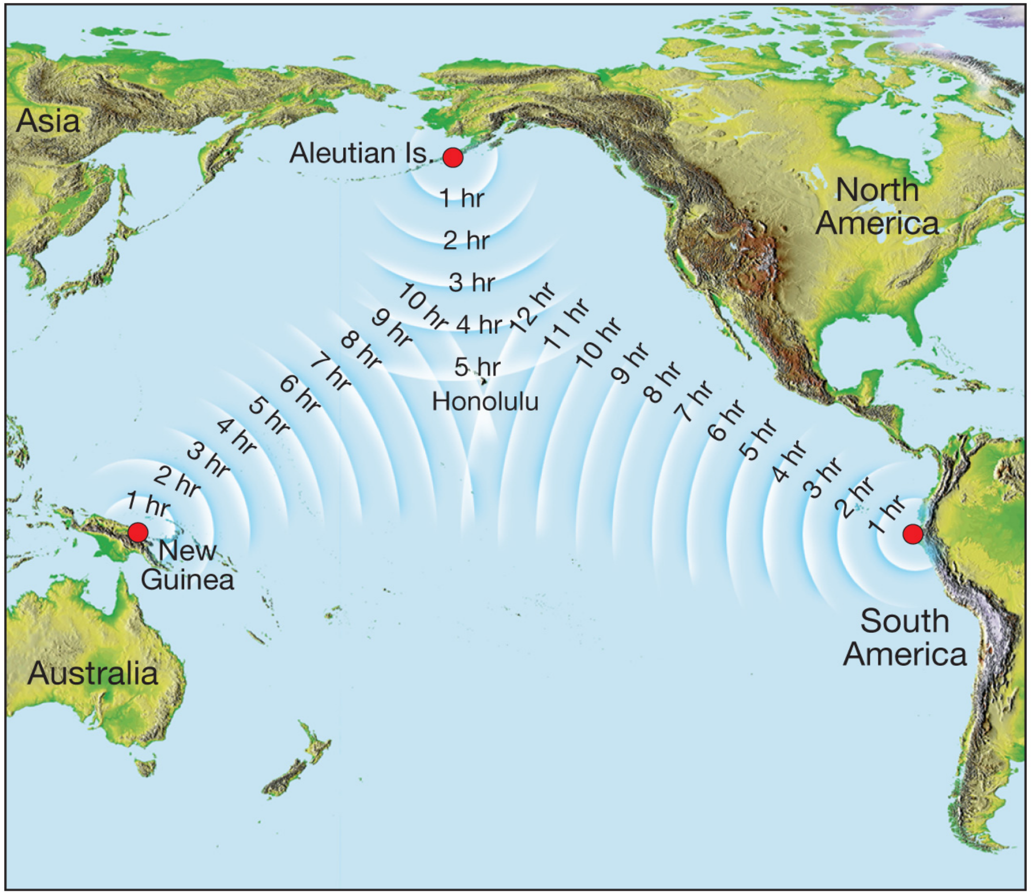
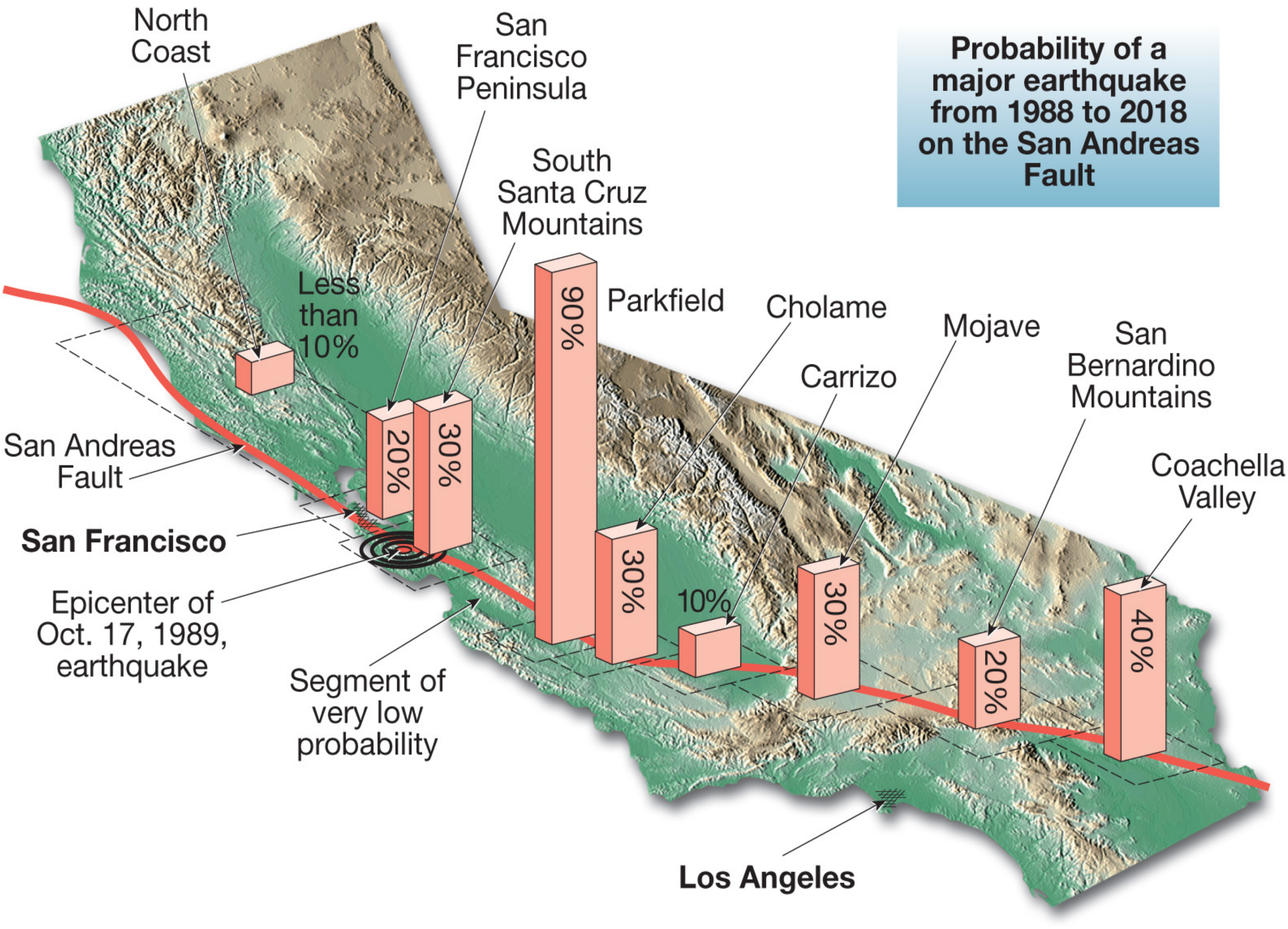


Figure 8.21

Earthquakes

- Earthquake prediction
  - Short-range – no reliable method yet devised for short-range prediction
  - Long-range forecasts
    - Premise is that earthquakes are repetitive
    - Region is given a probability of a quake



Probability of a major earthquake from 1988 to 2018 on the San Andreas Fault
North Coast
San Francisco Peninsula
South Santa Cruz Mountains
Less than 10%
Parkfield
Cholame
Mojave
San Bernardino Mountains
Carrizo
Coachella Valley
90%
20%
30%
30%
10%
30%
20%
40%
San Andreas Fault
San Francisco
Epicenter of Oct. 17, 1989, earthquake
Segment of very low probability
Los Angeles

TABLE 8.3 Some Notable Earthquakes

Year	Location	Deaths(est.)	Magnitude	Comments
1556	Shensi, China	830,000	Unknown	Possibly the greatest natural disaster.
1755	Lisbon, Portugal	70,000	Unknown	Tsunami damage extensive.
*1811–1812	New Madrid, Missouri	Few	Unknown	Three major earthquakes.
*1886	Charleston, South Carolina	60	Unknown	Greatest historical earthquake in the eastern United States.
*1906	San Francisco, California	1,500	8.3	Fires caused extensive damage.
1908	Messina, Italy	120,000	Unknown	
1923	Tokyo, Japan	143,000	7.9	Fire caused extensive destruction.
1960	Southern Chile	5,700	9.5	The largest-magnitude earthquake ever recorded.
*1964	Alaska	131	9.2	Greatest North American earthquake.
1970	Peru	66,000	7.8	Great rockslide.
*1971	San Fernando, California	65	6.5	Damage exceeded $1 billion.
1975	Liaoning Province, China	1,328	7.5	First major earthquake to be predicted.
1976	Tangshan, China	240,000	7.6	Not predicted.
1985	Mexico City	9,500	8.1	Major damage occurred 400 km from epicenter.
1988	Armenia	25,000	6.9	Poor construction practices.
*1989	San Francisco Bay area	62	7.1	Damages exceeded $6 billion.
1990	Iran	50,000	7.3	Landslides and poor construction practices caused great damage.
1993	Latur, India	10,000	6.4	Located in stable continental interior.
*1994	Northridge, California	51	6.7	Damages in excess of $15 billion.
1995	Kobe, Japan	5,472	6.9	Damages estimated to exceed $100 billion.
1999	Izmit, Turkey	17,127	7.4	Nearly 44,000 injured and more than 250,000 displaced.
1999	Chi-Chi, Taiwan	2,300	7.6	Severe destruction; 8,700 injuries.
2001	Bhuj, India	25,000+	7.9	Millions homeless.
2003	Bam, Iran	41,000+	6.6	Ancient city with poor construction.
2004	Indian Ocean	230,000	9.0	Devastating tsunami damage.
2005	Pakistan/Kashmir	83,000	7.6	Many landslides; 4 million homeless.

*U.S. earthquakes.

Source: U.S. National Oceanic and Atmospheric Administration

Earth's layered structure

- Most of our knowledge of Earth's interior comes from the study of P and S earthquake waves
  - Travel times of P and S waves through Earth vary depending on the properties of the materials
  - S waves travel only through solids

Possible seismic paths through the Earth

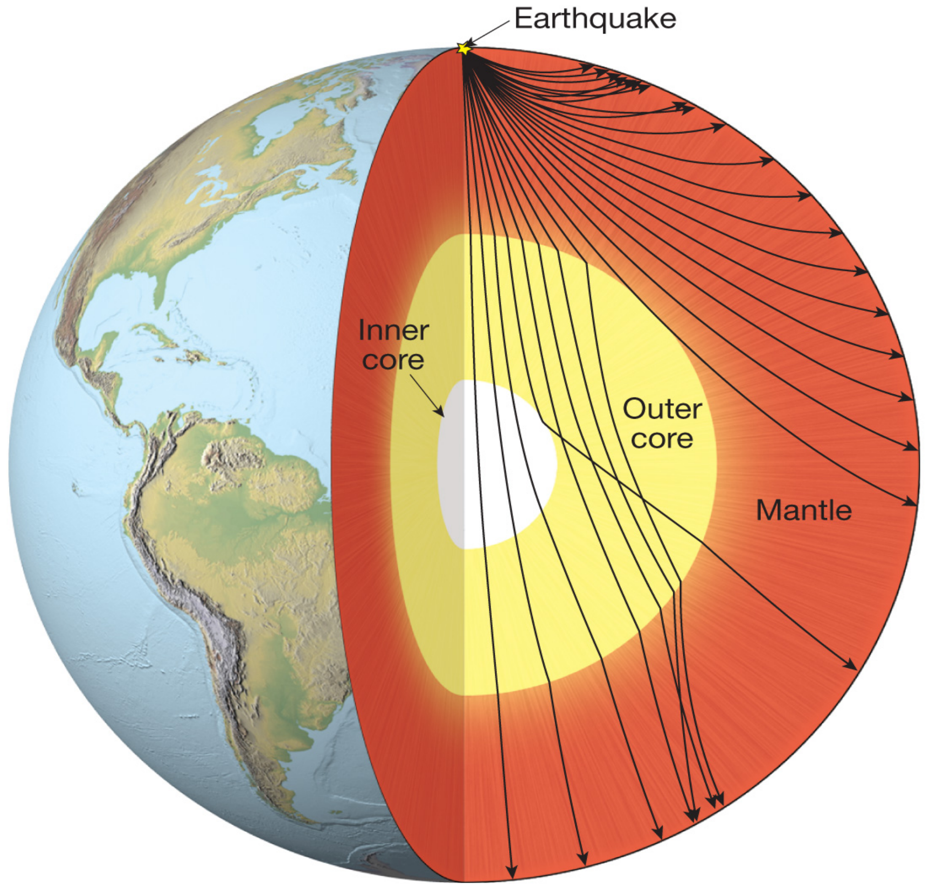


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Figure 8.26

Earth's internal structure

- Layers based on physical properties
  - Crust
    - Thin, rocky outer layer
    - Varies in thickness
      - Roughly 7 km (5 miles) in oceanic regions
      - Continental crust averages 35–40 km (25 miles)
      - Exceeds 70 km (40 miles) in some mountainous regions

Earth's internal structure

- Layers based on physical properties
  - Crust
    - Continental crust
      - Upper crust composed of granitic rocks
      - Lower crust is more akin to basalt
      - Average density is about 2.7 g/cm^3
      - Up to 4 billion years old

Earth's internal structure

- Layers based on physical properties
  - Crust
    - Oceanic Crust
      - Basaltic composition
      - Density about 3.0 g/cm^3
      - Younger (180 million years or less) than the continental crust

Earth's internal structure

- Layers based on physical properties
  - Mantle
    - Below crust to a depth of 2,900 kilometers (1,800 miles)
    - Composition of the uppermost mantle is the igneous rock peridotite (changes at greater depths)

Earth’s internal structure

- Layers based on physical properties
  - Outer Core
    - Below mantle
    - A sphere having a radius of 3,486 km (2,161 miles)
    - Composed of an iron–nickel alloy
    - Average density of nearly 11 g/cm^3

Earth's internal structure

- Layers based on physical properties
  - Lithosphere
    - Crust and uppermost mantle (about 100 km thick)
    - Cool, rigid, solid
  - Asthenosphere
    - Beneath the lithosphere
    - Upper mantle
    - To a depth of about 660 kilometers
    - Soft, weak layer that is easily deformed

Earth's internal structure

- Layers based on physical properties
  - Mesosphere (or lower mantle)
    - 660–2,900 km
    - More rigid layer
    - Rocks are very hot and capable of gradual flow
  - Outer Core
    - Liquid layer
    - 2,270 km (1,410 miles) thick
    - Convective flow of metallic iron within generates Earth's magnetic field

Earth's internal structure

- Layers based on physical properties
  - Inner Core
    - Sphere with a radius of 1,216 km (754 miles)
    - Behaves like a solid

Views of Earth's layered structure

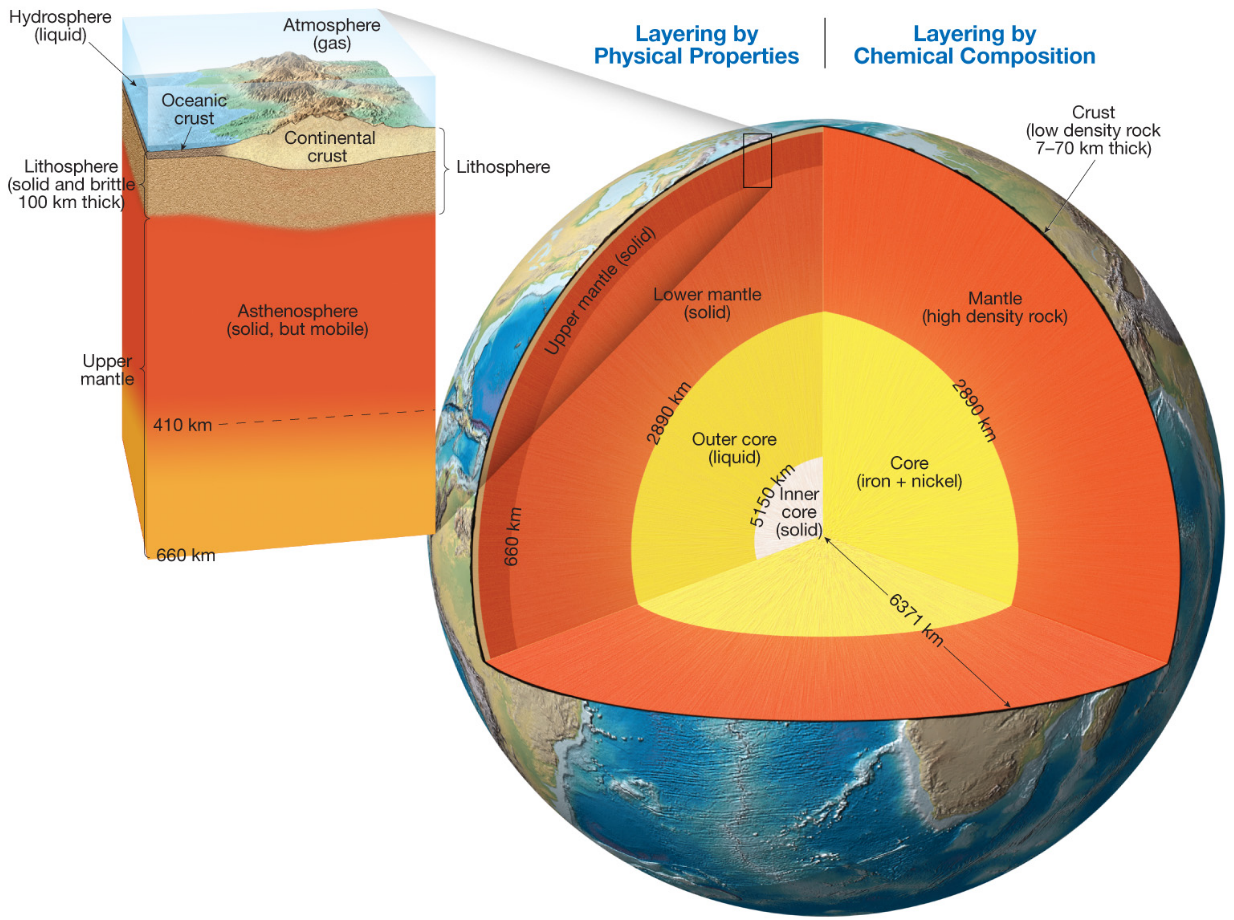


Figure 8.25

Earth's layered structure

- Discovering Earth's major layers
  - Discovered using changes in seismic wave velocity
  - Mohorovicic discontinuity
    - Velocity of seismic waves increases abruptly below 50 km of depth
    - Separates crust from underlying mantle

Earth's layered structure

- Discovering Earth's major layers
  - Shadow zone
    - Absence of P waves from about 105 degrees to 140 degrees around the globe from an earthquake
    - Explained if Earth contained a core composed of materials unlike the overlying mantle

S-wave shadow zones

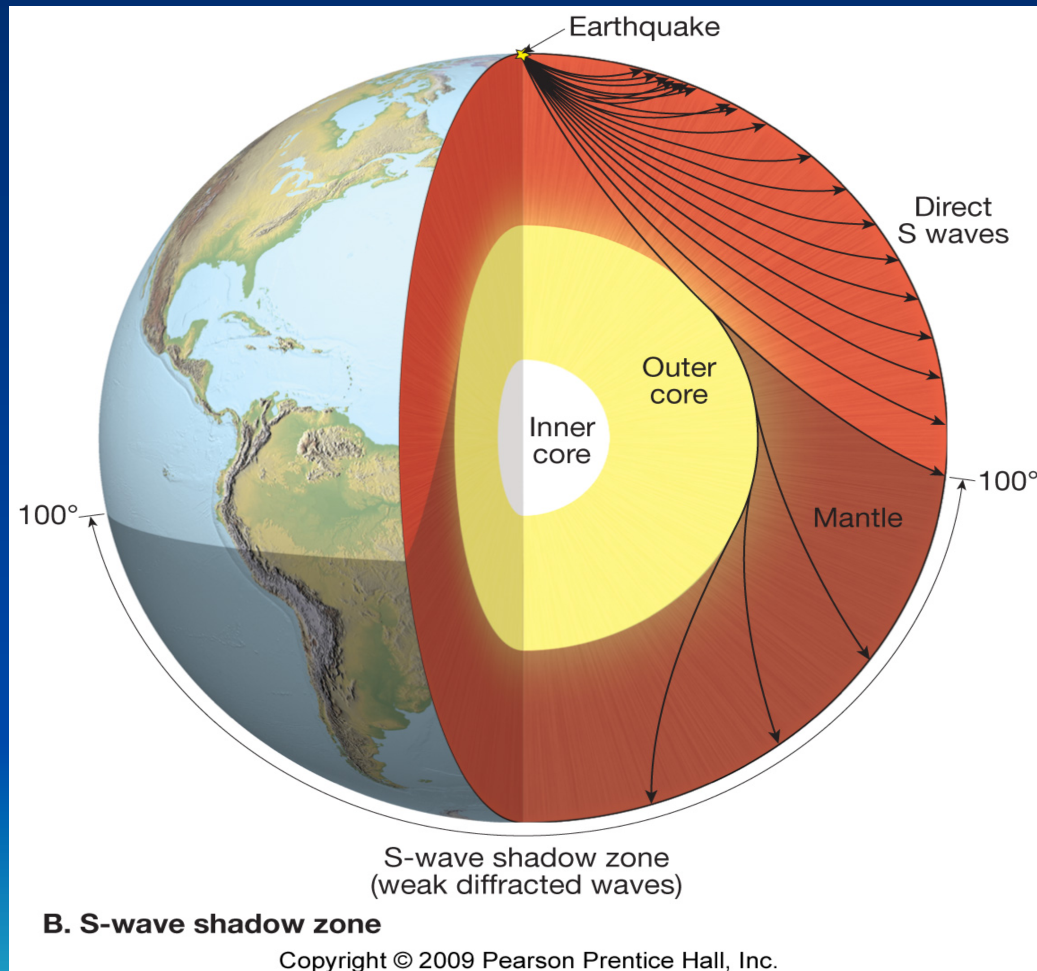
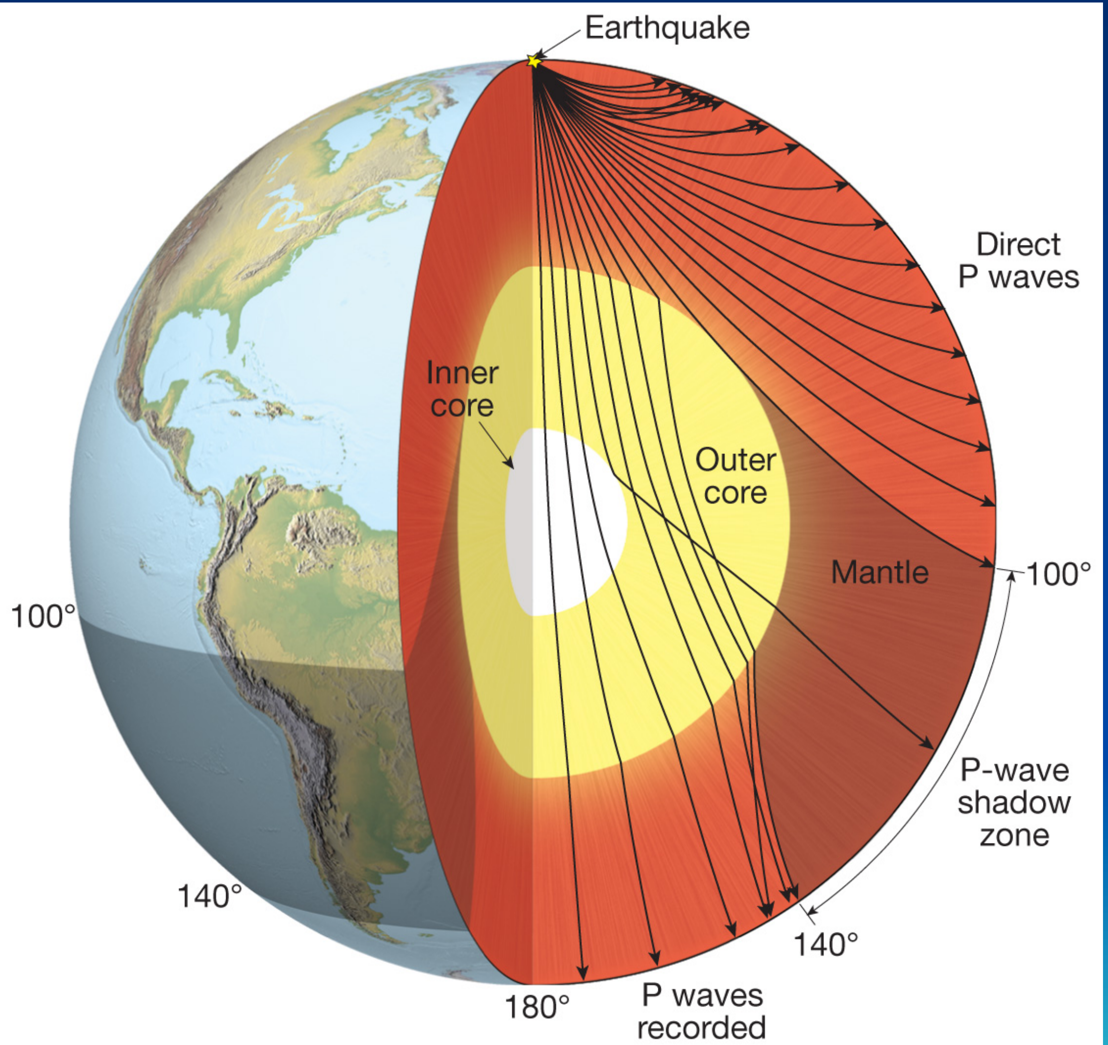


Figure 8.28 B

P-wave shadow zones



A. P-wave shadow zone

Earth's layered structure

- Discovering Earth's major layers
  - Inner core
    - Discovered in 1936 by noting a new region of seismic reflection within the core
    - Size was calculated in the 1960s using echoes from seismic waves generated during underground nuclear tests

End of Chapter 8