Essentials of Geology, 11e

Earthquakes and Earth's Interior
Chapter 14

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What is an earthquake

- **An earthquake is the vibration of Earth produced by the rapid release of energy**
  - **Energy released radiates in all directions from its source, the focus**
  - **Energy is in the form of waves**
  - **Sensitive instruments around the world record the event**

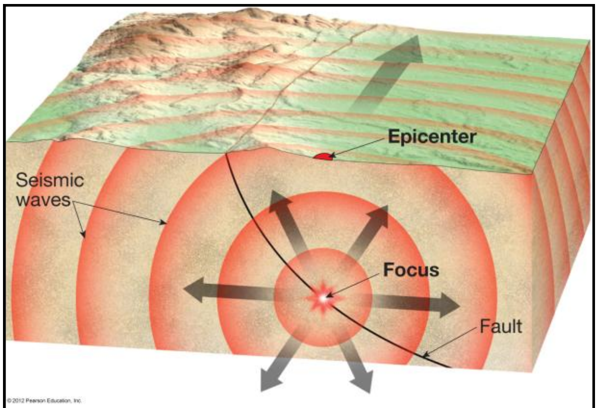


Figure 14.2

230,000 dead after 1/12/10 7.0M earthquake 15 miles from Port-au-Prince, Haiti, 6 miles in depth.

Figure 14.1

What is an earthquake

- **Earthquakes and faults**
  - **Movements that produce earthquakes are usually associated with large fractures in Earth's crust called faults**
  - **Most of the motion along faults can be explained by the plate tectonics theory**

What is an earthquake

- **Elastic rebound**
  - **Mechanism for earthquakes was first explained by H.F. Reid**
    - **Rocks on both sides of an existing fault are deformed by tectonic forces**
    - **Rocks bend and store elastic energy**
    - **Frictional resistance holding the rocks together is overcome**

Elastic Rebound

Earthquake mechanism
- **Slippage at the weakest point (the focus)**
- **Vibrations (earthquakes) occur as the deformed rock "springs back" to its original shape (elastic rebound)**

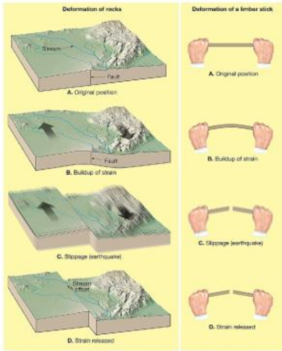


Figure 14.5

What is an earthquake

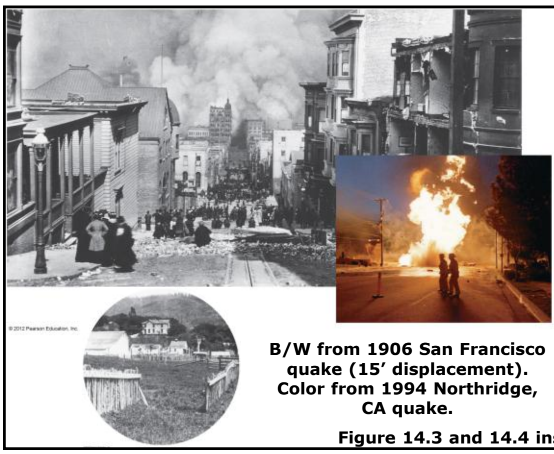
- **Foreshocks and aftershocks**
  - **Adjustments that follow a major earthquake often generate smaller earthquakes called aftershocks**
  - **Small earthquakes, called foreshocks, often precede a major earthquake by days or, in some cases, by as much as several years**

San Andreas: An active earthquake zone

- **San Andreas is the most studied fault system in the world**
- **Displacement occurs along discrete segments 100 to 200 kilometers long**
  - **Some portions exhibit slow, gradual displacement known as fault creep**
  - **Other segments regularly slip producing small earthquakes**

San Andreas: An active earthquake zone

- **Displacements along the San Andreas fault**
  - **Still other segments store elastic energy for hundreds of years before rupturing in great earthquakes**
    - **Process described as stick-slip motion**
    - **Great earthquakes should occur about every 50 to 200 years along these sections**



B/W from 1906 San Francisco quake (15' displacement). Color from 1994 Northridge, CA quake.

Figure 14.3 and 14.4 inset

Seismology

- **The study of earthquake waves, seismology, dates back almost 2000 years to the Chinese**
- **Seismographs, instruments that record seismic waves**
  - **Records the movement of Earth in relation to a stationary mass on a rotating drum or magnetic tape**

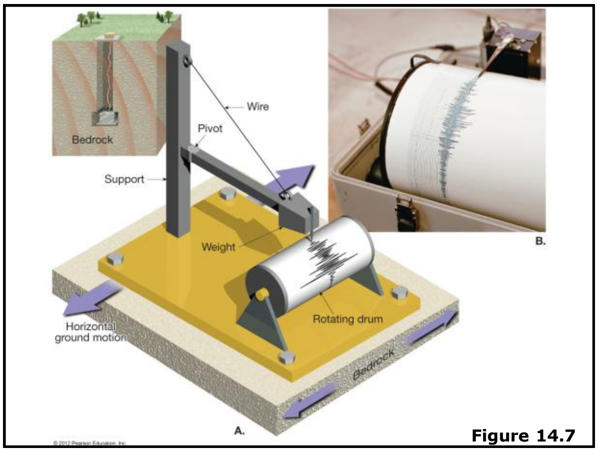


Figure 14.7

Seismology

- **Seismographs**
  - **More than one type of seismograph is needed to record both vertical and horizontal ground motion**
  - **Records obtained are called seismograms**
- **Types of seismic waves**
  - **Body waves- travel in the interior of the Earth**
  - **Surface waves- travel along the outer part of the Earth.**

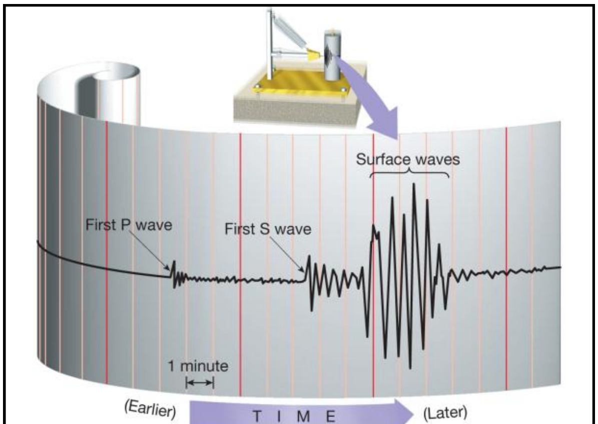
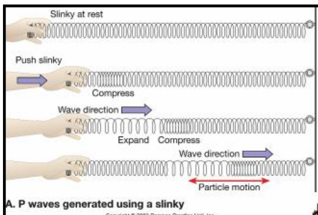


Figure 14.9

Seismology

- **Types of seismic waves**
  - **Body waves**
    - **Travel through Earth's interior**
    - **Two types based on mode of travel**
    - **Primary (P) waves**
      - » **Push-pull (compress and expand) motion, changing the volume of the intervening material**
      - » **Travel through solids, liquids, and gases**
      - » **Generally, in any solid material, P waves travel about 1.7 times faster than S waves**

Primary (P) Waves



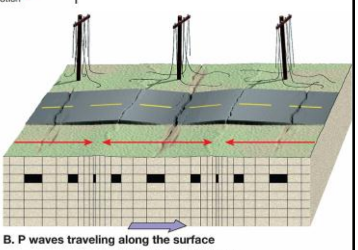
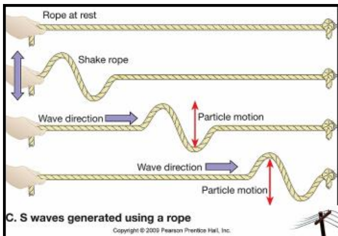


Figure 14.8

Seismology

- **Types of seismic waves**
  - **Body waves**
    - **Secondary (S) waves**
      - **Shaking motion at right angles to their direction of travel**
      - **Travel only through solids**
      - **Slower velocity than P waves**
      - **Slightly greater amplitude than P waves**



Secondary (S) Waves

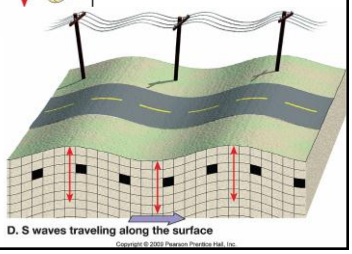
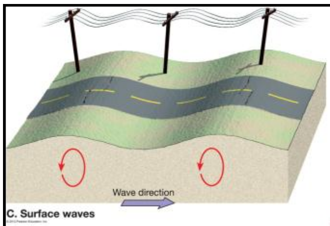


Figure 14.8

Seismology

- **Types of seismic waves**
  - **Surface waves**
    - **Travel along outer part of Earth**
    - **Complex motion**
    - **Cause greatest destruction**
    - **Waves exhibit greatest amplitude and slowest velocity**
    - **Waves have the greatest periods (time interval between crests)**



Complex Surface Waves

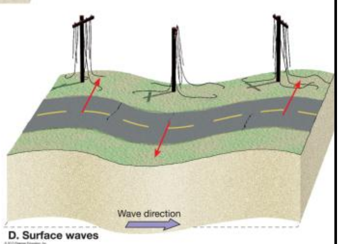


Figure 14.8

Locating the source of earthquakes

- **Terms**
  - **Focus - the place within Earth where earthquake waves originate**
  - **Epicenter – location on the surface directly above the focus**
- **Epicenter is located using the difference in velocities of P and S waves**

Locating the source of earthquakes

- **Locating the epicenter of an earthquake**
  - **Three station recordings are needed to locate an epicenter**
  - **Each station determines the time interval between the arrival of the first P wave and the first S wave at their location**
  - **A travel-time graph is used to determine each station's distance to the epicenter**

A Time-Travel Graph is Used to Find the Distance to the Epicenter

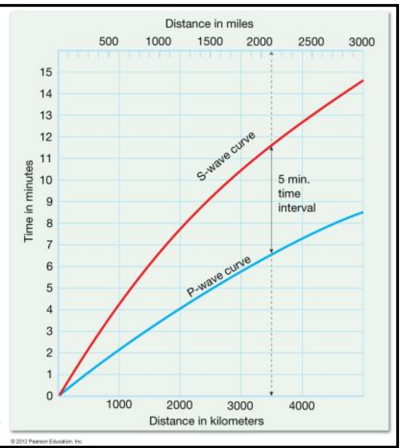


Figure 14.11

Locating the source of earthquakes

- **Locating the epicenter of an earthquake**
  - **A circle with a radius equal to the distance to the epicenter is drawn around each station**
  - **The point where all three circles intersect is the earthquake epicenter**

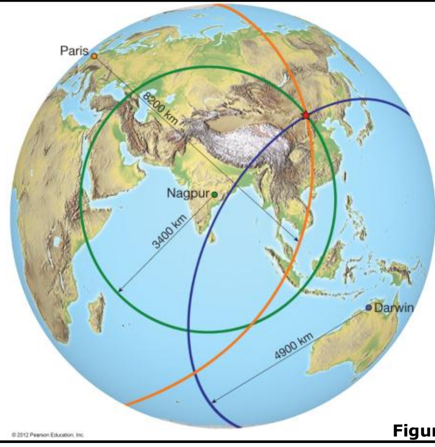


Figure 14.12

Locating the source of earthquakes

- **Earthquake belts**
  - **About 95% of the energy released by earthquakes originates in narrow zones that wind around the globe**
  - **Major earthquake zones include the Circum-Pacific belt, Mediterranean Sea region to the Himalayan complex, and the oceanic ridge system**

Earthquakes of Magnitude 5 or Greater Over a 10 Year Period

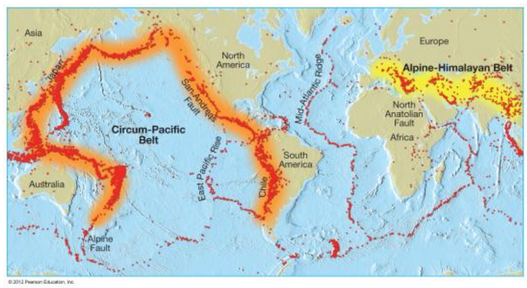


Figure 14.16

Locating the source of earthquakes

- **Earthquake depths**
  - **Earthquakes originate at depths ranging from 5 to nearly 700 kilometers**
  - **Earthquake foci arbitrarily classified-**
    - ***shallow* (surface to 70 km)**
    - ***intermediate* (between 70 and 300 km)**
    - ***deep* (over 300 kilometers)**

Locating the source of earthquakes

- **Earthquake depths**
  - **Definite patterns exist**
    - **Shallow focus occur along the oceanic ridge system**
    - **Almost all deep-focus earthquakes occur in the circum-Pacific belt, particularly in regions situated landward of deep-ocean trenches**

Measuring the size of earthquakes

- **Two measurements that describe the size of an earthquake are**
  - **Intensity** – **a measure of the degree of earthquake shaking at a given locale based on the amount of damage**
  - **Magnitude** – **estimates the amount of energy released at the source of the earthquake**

Measuring the size of earthquakes

- **Intensity scales**
  - **Modified Mercalli Intensity Scale was developed using California buildings as its standard**
  - **The drawback of intensity scales is that destruction may not be a true measure of the earthquakes actual severity**

Measuring the size of earthquakes

- **Magnitude scales**
  - **Richter magnitude - concept introduced by Charles Richter in 1935**
  - **Richter scale**
    - **Based on the amplitude of the largest seismic wave recorded**
    - **Accounts for the decrease in wave amplitude with increased distance**

Measuring the size of earthquakes

- **Magnitude scales**
  - **Richter scale**
    - **Largest magnitude recorded on a Wood-Anderson seismograph was 8.9**
    - **Magnitudes < 2.0 are not felt by humans**
    - **Each unit of Richter magnitude increase corresponds to a tenfold increase in wave amplitude and a 32-fold energy increase**

Measuring the Size of Earthquakes

- **Magnitudes scales**
  - **Other magnitude scales**
    - **Several "Richter-like" magnitude scales have been developed**
    - **Moment magnitude was developed because none of the "Richter-like" magnitude scales adequately estimates the size of very large earthquakes**
      - **Derived from the amount of displacement that occurs along a fault**

Magnitude and Frequency – Inversely Related

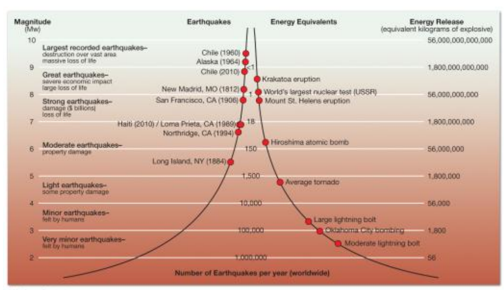


Figure 14.15

Earthquake destruction

- Amount of structural damage attributable to earthquake vibrations depends on:
  - Intensity and duration of the vibrations
  - Nature of the material upon which the structure rests
  - Design of the structure

Earthquake destruction

- Destruction from seismic vibrations
  - Ground shaking
    - Regions within 20 to 50 kilometers of the epicenter will experience about the same intensity of ground shaking
    - However, destruction varies considerably mainly due to the nature of the ground on which the structures are built

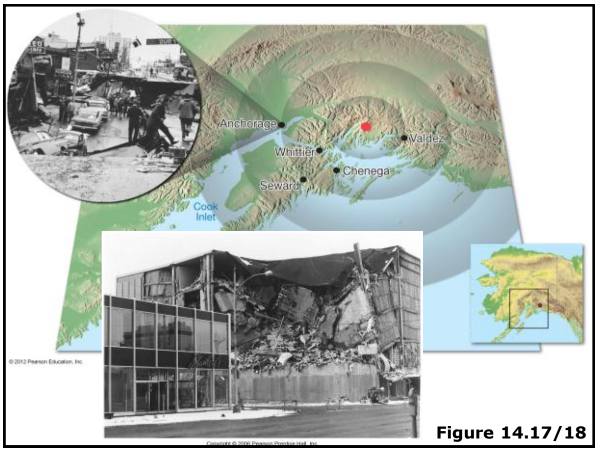


Figure 14.17/18

Earthquake destruction

- Destruction from seismic vibrations
  - Liquefaction of the ground
    - Unconsolidated materials saturated with water turn into a mobile fluid
  - Seiches
    - The rhythmic sloshing of water in lakes, reservoirs, and enclosed basins
    - Waves can weaken reservoir walls and cause destruction

Earthquake destruction

- Tsunamis, or seismic sea waves
  - Destructive waves that are often inappropriately called “tidal waves”
  - Result from:
    - Vertical displacement along a fault located on the ocean floor
    - Large undersea landslide triggered by an earthquake
    - Volcanic eruption
    - Meteor impact

Earthquake destruction

- Tsunamis, or seismic sea waves
    - In the open ocean height is usually less than 1 meter
    - In shallower coastal waters the water piles up to heights that occasionally exceed 30 meters
    - Can be very destructive
- Landslides and ground subsidence
- Fire

Formation of a Tsunami

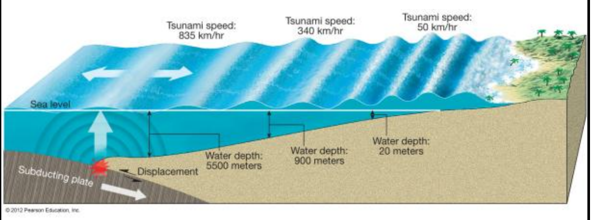


Figure 14.21

12/26/2004: 9.1 Mw Indonesian earthquake tsunami damage.

Over 230,000 dead.

Figure 14.19 A and B

Can earthquakes be predicted?

- **Short-range predictions**
  - **Goal is to provide a warning of the location and magnitude of a large earthquake**
  - **Research has concentrated on monitoring possible precursors –uplift, subsidence, and strain in the rocks**
  - **Currently, no reliable method exists for making short-range earthquake predictions**

Can earthquakes be predicted?

- **Long-range forecasts**
  - **Give the probability of a certain magnitude earthquake occurring on a time scale of 30 to 100 years, or more**
  - **Based on the premise that earthquakes are repetitive or cyclical**
    - **Using historical records or paleoseismology**
  - **Are important because they provide information used to**
    - **Develop the Uniform Building Code**
    - **Assist in land-use planning**

Seismic waves and Earth's structure

- **The abrupt changes in seismic-wave velocities that occur at certain depths:**
  - **Seismologists conclude that Earth is composed of distinct shells**
- **Layers are defined by composition**
  - **Because of density sorting during an early period of partial melting, Earth's interior is not homogeneous**

Seismic waves and Earth's structure

Layers are defined by composition:

- **Three main compositional layers- crust, mantle, core**
- **Crust – the comparatively thin outer skin that ranges from 3 kilometers at the oceanic ridges to 70 kilometers**
  - **Continental crust**
    - **Lighter - Granitic rocks**
  - **Oceanic crust**
    - **Denser - Composed primarily of basalt**

Discovering Earth's composition

- Mantle
  - Solid, rocky (silica-rich) shell
  - Extends to a depth of about 2900 km
  - Composed of rocks like peridotite
- Core
  - Thought to mainly consist of dense iron and nickel
  - Radius of 3486 km
  - Two parts
    - Outer core - liquid
    - Inner core - solid

Seismic waves and Earth's structure

- Layers defined by physical properties
  - With increasing depth, Earth's interior is characterized by gradual increases in temperature, pressure, and density
  - Earth material may behave like a brittle solid, deform in a plastic–like manner, or melt and become liquid
  - Main layers of Earth's interior are based on physical properties and hence mechanical strength

Seismic waves and Earth's structure

Layers defined by physical properties:

- Lithosphere (sphere of rock)
  - Earth's outermost layer
  - Consists of the crust and uppermost mantle
  - Relatively cool, rigid shell
  - Averages about 100 kilometers in thickness, but may be 250 kilometers or more thick beneath the older portions of the continents

Seismic waves and Earth's structure

Layers defined by physical properties:

- Asthenosphere (weak sphere)
  - Beneath the lithosphere, in the upper mantle to a depth of about 600 kilometers
  - Small amount of melting in the upper portion allows the lithosphere to move independently of the asthenosphere

Seismic waves and Earth's structure

Layers defined by physical properties:

- Mesosphere or lower mantle
  - Rigid layer between the depths of 660 kilometers and 2900 kilometers
  - Rocks are very hot and capable of very gradual flow

Seismic waves and Earth's structure

Layers defined by physical properties:

- Outer core
  - Composed mostly of an iron-nickel alloy
  - Liquid layer
  - 2270 kilometers (1410 miles) thick
  - Convective flow within generates Earth's magnetic field

Seismic waves and Earth's structure

Layers defined by physical properties:

- **Inner core**
  - **Sphere with a radius of 3486 kilometers**
  - **Material is stronger than the outer core**
  - **Behaves like a solid**

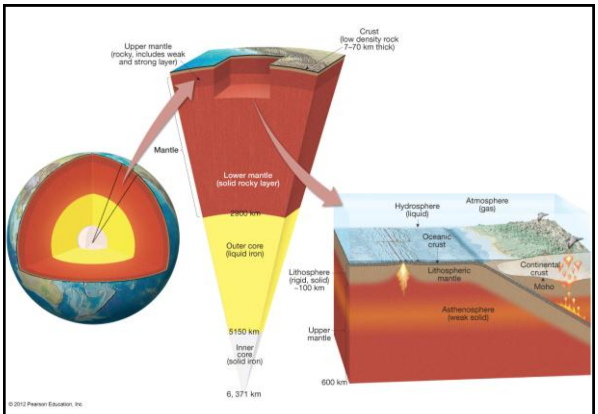


Figure 14.30

Discovering Earth's major boundaries

- **The crust-mantle boundary**
  - **The Moho (Mohorovicic discontinuity)**
  - **Discovered in 1909 by Andriaja Mohorovicic**
  - **Separates crustal materials from underlying mantle**
  - **Identified by a change in the velocity of P waves**

Discovering Earth's major boundaries

- **The core-mantle boundary**
  - **Discovered in 1914 by Beno Gutenberg**
  - **Based on the observation that P waves die out at 105 degrees from the earthquake and reappear at about 140 degrees - this 35 degree wide belt is named the P-wave shadow zone**

P and S wave paths through Earth's interior

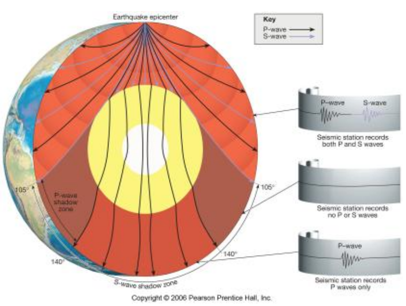


Figure 14.29

Discovering Earth's major boundaries

- **The core-mantle boundary**
  - **Characterized by bending (refracting) of the P waves**
  - **The fact that S waves do not travel through the core**
    - **liquid layer beneath the rocky mantle**

Discovering Earth's major boundaries

- **Discovery of the inner core**
  - **Predicted by Inge Lehmann in 1936**
  - **P waves passing through the inner core show increased velocity suggesting that the inner core is solid**