Prentice Hall

EARTH SCIENCE

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Chapter 8

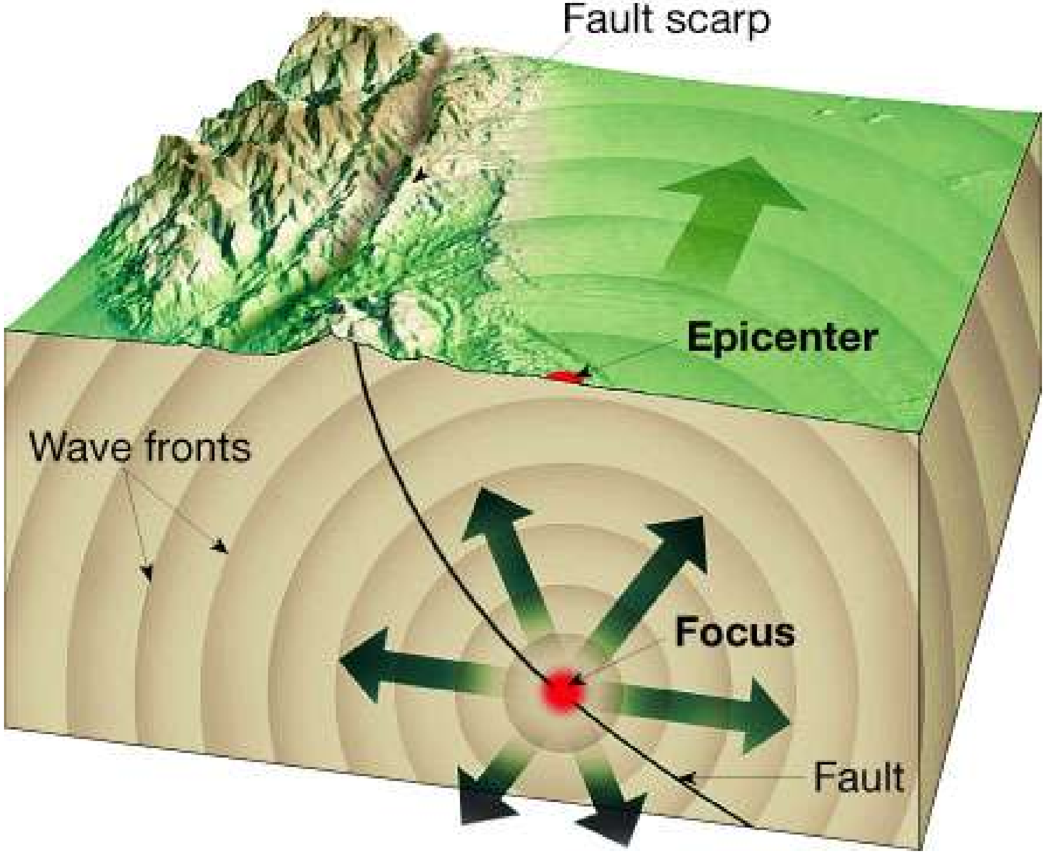
Earthquakes and Earth's Interior

8.1 What Is an Earthquake?

Earthquakes

- An **earthquake** is the vibration of Earth produced by the rapid release of energy
- Focus and Epicenter
  - **Focus** is the point within Earth where the earthquake starts.
  - **Epicenter** is the location on the surface directly above the focus.
- Faults
  - **Faults** are fractures in Earth where movement has occurred.

Focus, Epicenter, and Fault



Slippage Along a Fault

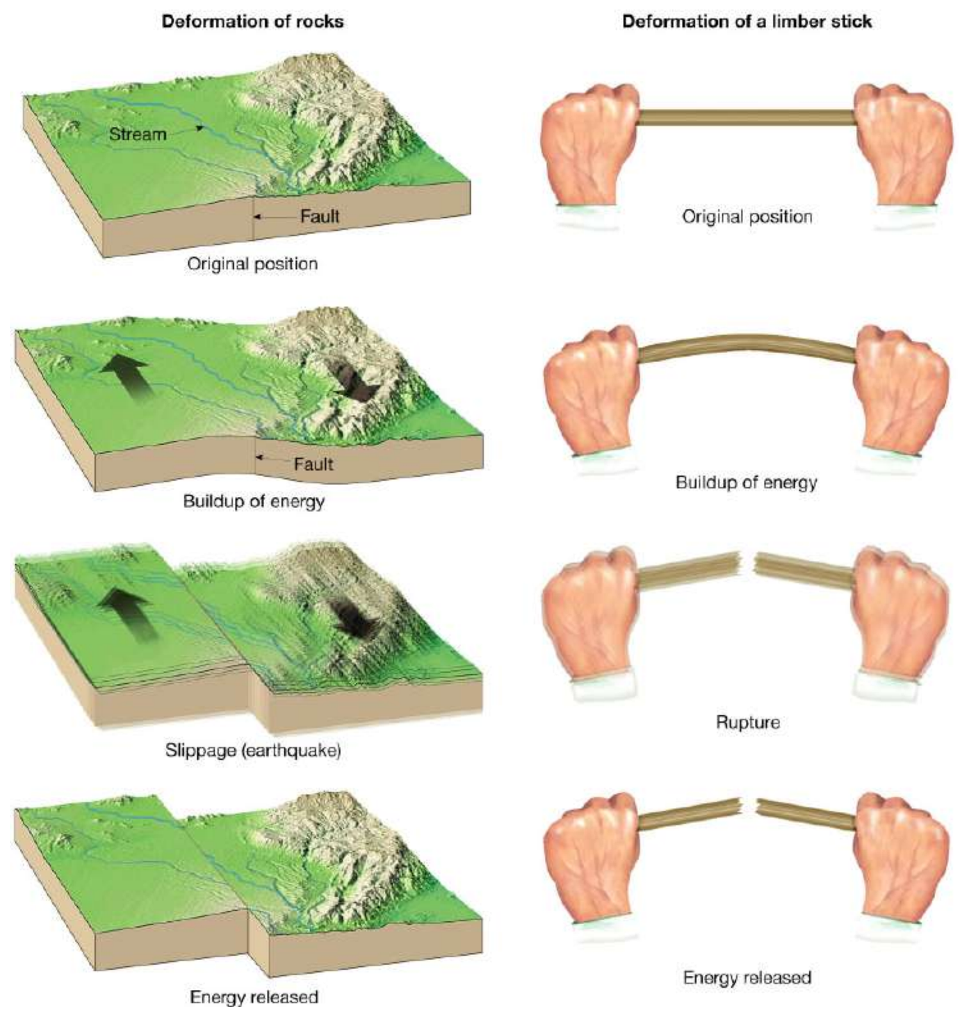
8.1 What Is an Earthquake?

Cause of Earthquakes

◆ Elastic Rebound Hypothesis

- Most earthquakes are produced by the rapid release of elastic energy stored in rock that has been subjected to great forces.
- When the strength of the rock is exceeded, it suddenly breaks, causing the vibrations of an earthquake.

Elastic Rebound Hypothesis



8.1 What Is an Earthquake?

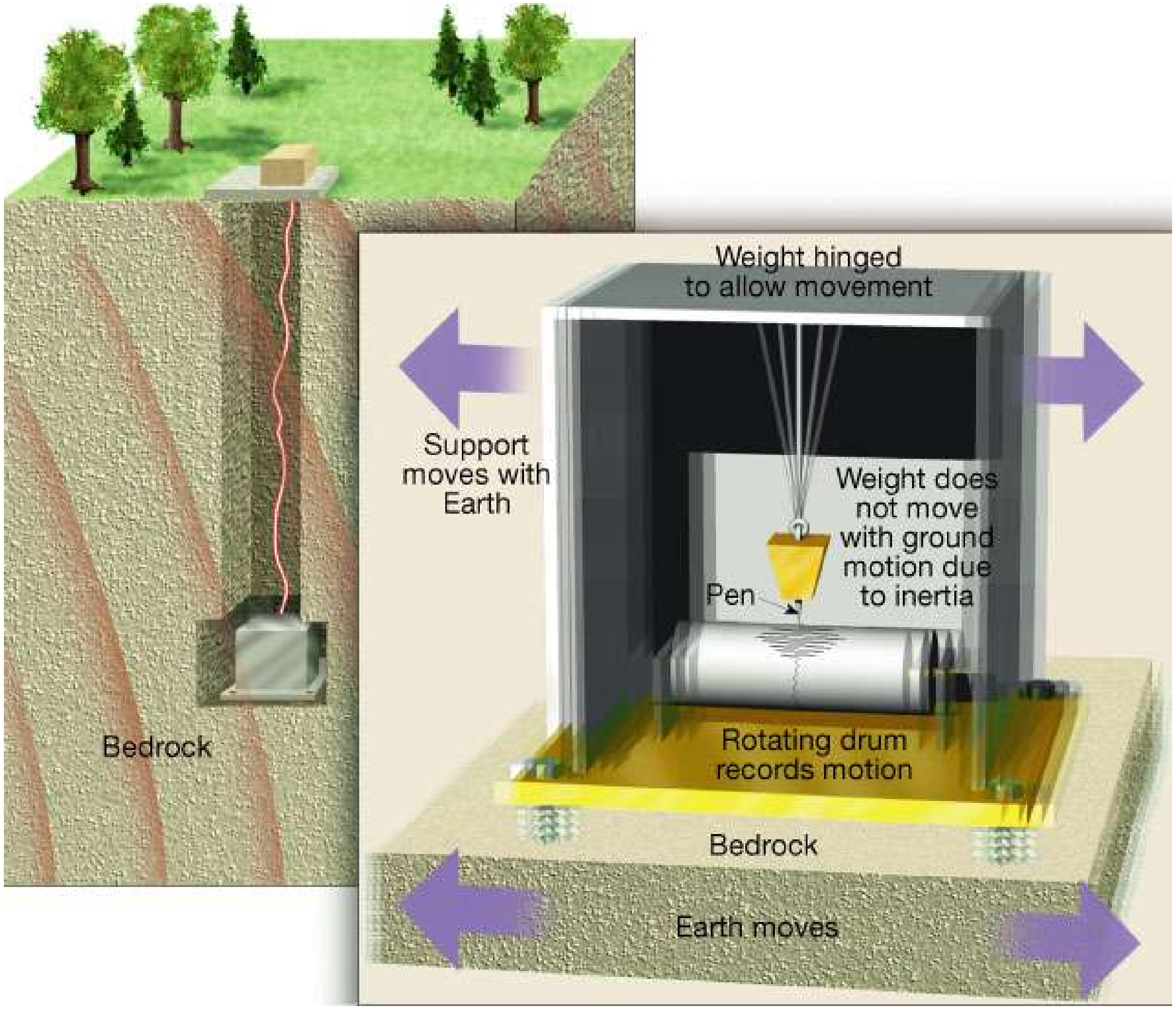
Cause of Earthquakes

- Aftershocks and Foreshocks
  - An **aftershock** is a small earthquake that follows the main earthquake.
  - A **foreshock** is a small earthquake that often precedes a major earthquake.

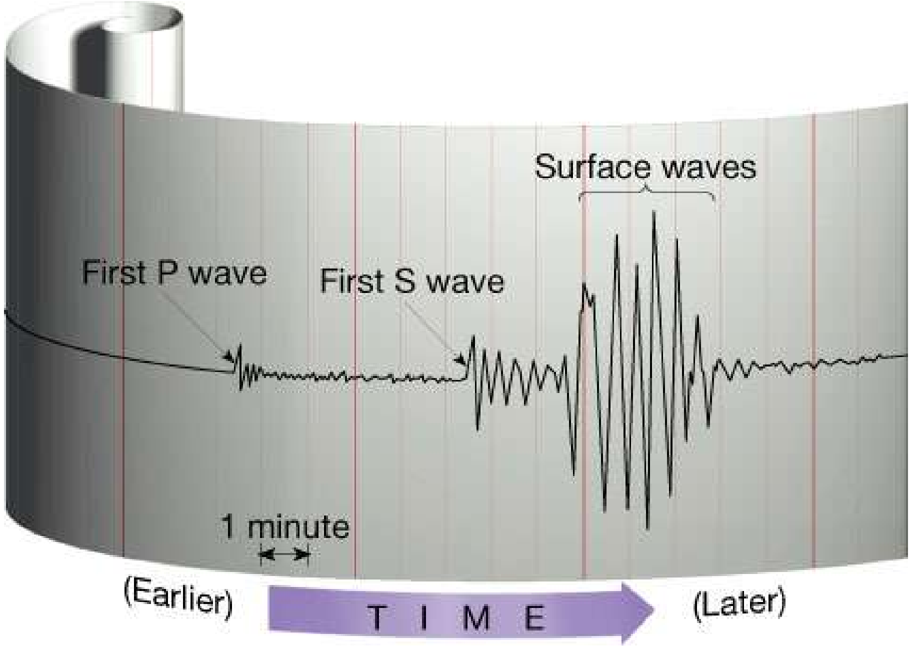
Earthquake Waves

- **Seismographs** are instruments that record earthquake waves.
- **Seismograms** are traces of amplified, electronically recorded ground motion made by seismographs.
- **Surface waves** are seismic waves that travel along Earth’s outer layer.

Seismograph



Seismogram


Surface waves
First P wave
First S wave
1 minute
(Earlier)
T I M E
(Later)

8.2 Measuring Earthquakes

Earthquake Waves

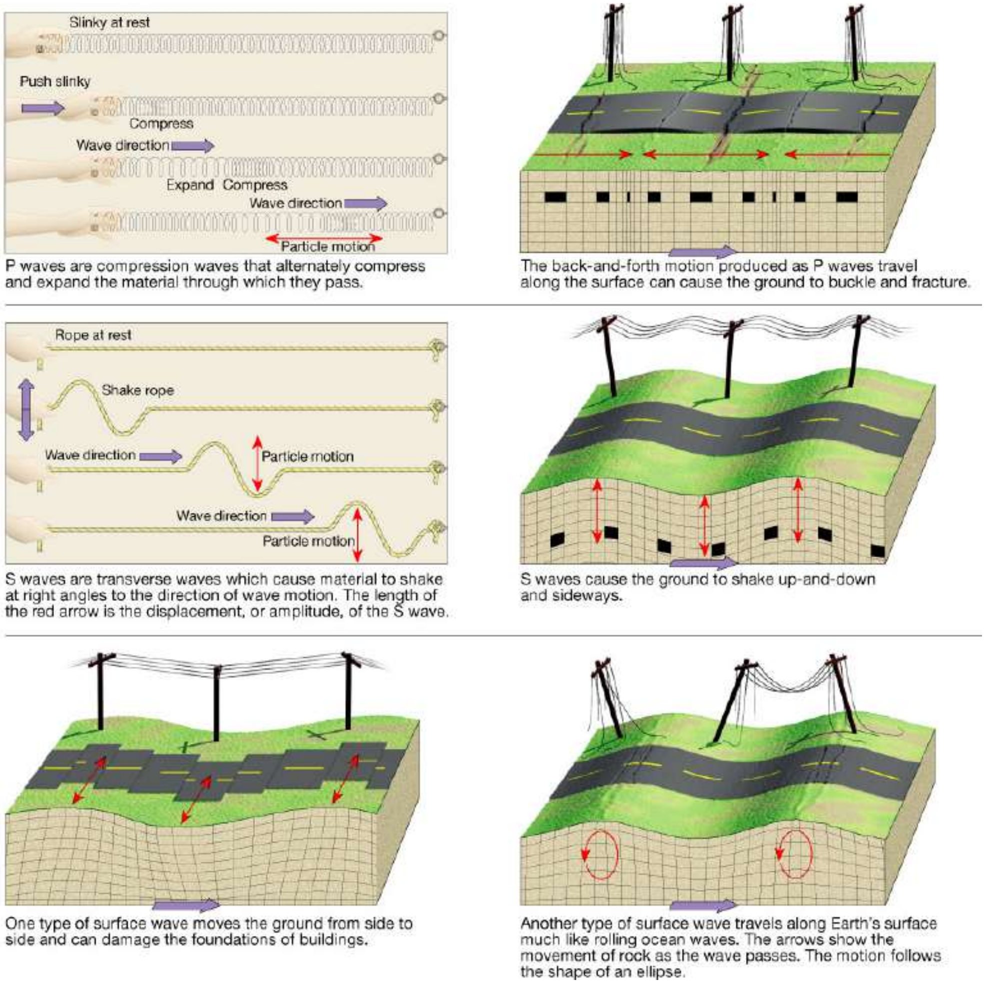
- Body Waves
  - Identified as P waves or S waves
  - **P waves**
    - Are push-pull waves that push (compress) and pull (expand) in the direction that the waves travel
    - Travel through solids, liquids, and gases
    - Have the greatest velocity of all earthquake waves

8.2 Measuring Earthquakes

Earthquake Waves

- Body Waves
  - **S waves**
    - Seismic waves that travel along Earth's outer layer
    - Shake particles at right angles to the direction that they travel
    - Travel only through solids
    - Slower velocity than P waves
- A seismogram shows all three types of seismic waves—surface waves, P waves, and S waves.

Seismic Waves

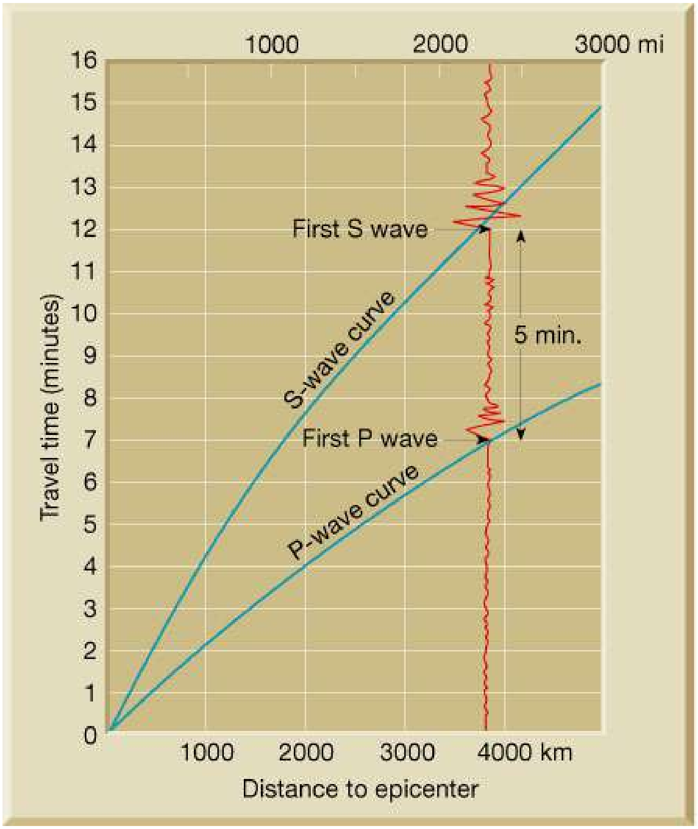


8.2 Measuring Earthquakes

Locating an Earthquake

- Earthquake Distance
  - The epicenter is located using the difference in the arrival times between P and S wave recordings, which are related to distance.
- Earthquake Direction
  - Travel-time graphs from three or more seismographs can be used to find the exact location of an earthquake epicenter.
- Earthquake Zones
  - About 95 percent of the major earthquakes occur in a few narrow zones.

Locating an Earthquake



8.2 Measuring Earthquakes

Measuring Earthquakes

- Historically, scientists have used two different types of measurements to describe the size of an earthquake—intensity and magnitude.
- 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

8.2 Measuring Earthquakes

Measuring Earthquakes

Momentum Magnitude

- Derived from the amount of displacement that occurs along the fault zone
- Moment magnitude is the most widely used measurement for earthquakes because it is the only magnitude scale that estimates the energy released by earthquakes.
- Measures very large earthquakes

Earthquake Magnitudes

Table 1 Earthquake Magnitudes and Expected World Incidence

Moment Magnitudes	Effects Near Epicenter	Estimated Number per Year
< 2.0	Generally not felt, but can be recorded	$> 600{,}000$
2.0–2.9	Potentially perceptible	$> 300{,}000$
3.0–3.9	Rarely felt	$> 100{,}000$
4.0–4.9	Can be strongly felt	13,500
5.0–5.9	Can be damaging shocks	1,400
6.0–6.9	Destructive in populous regions	110
7.0–7.9	Major earthquakes; inflict serious damage	12
8.0 and above	Great earthquakes; destroy communities near epicenter	0–1

Some Notable Earthquakes

Table 2 Some Notable Earthquakes

Year	Location	Deaths (est.)	Magnitude†	Comments
*1886	Charleston, South Carolina	60		Greatest historical earthquake in the eastern United States
*1906	San Francisco, California	1500	7.8	Fires caused extensive damage.
1923	Tokyo, Japan	143,000	7.9	Fire caused extensive destruction.
1960	Southern Chile	5700	9.6	Possibly the largest-magnitude earthquake ever recorded
*1964	Alaska	131	9.2	Greatest North American earthquake
1970	Peru	66,000	7.8	Large rockslide
*1971	San Fernando, California	65	6.5	Damages exceeded $1 billion.
1985	Mexico City	9500	8.1	Major damage occurred 400 km from epicenter.
1988	Armenia	25,000	6.9	Poor construction practices caused great damage.
*1989	Loma Prieta, California	62	6.9	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	57	6.7	Damages exceeded $40 billion.
1995	Kobe, Japan	5472	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	2300	7.6	Severe destruction; 8700 injuries
2001	El Salvador	1000	7.6	Triggered many landslides
2001	Bhuj, India	20,000†	7.9	1 million or more homeless

*U.S. earthquakes
†Widely differing magnitudes have been estimated for some earthquakes. When available, moment magnitudes are used.
SOURCE: U.S. Geological Survey

8.3 Destruction from Earthquakes

Seismic Vibrations

- The damage to buildings and other structures from earthquake waves depends on several factors. These factors include the intensity and duration of the vibrations, the nature of the material on which the structure is built, and the design of the structure.

Earthquake Damage

Seismic Vibrations

- Building Design
  - Factors that determine structural damage
    - Intensity of the earthquake
    - Unreinforced stone or brick buildings are the most serious safety threats
    - Nature of the material upon which the structure rests
    - The design of the structure

8.3 Destruction from Earthquakes

Seismic Vibrations

Liquefaction

- Saturated material turns fluid
- Underground objects may float to surface

Effects of Subsidence Due to Liquefaction

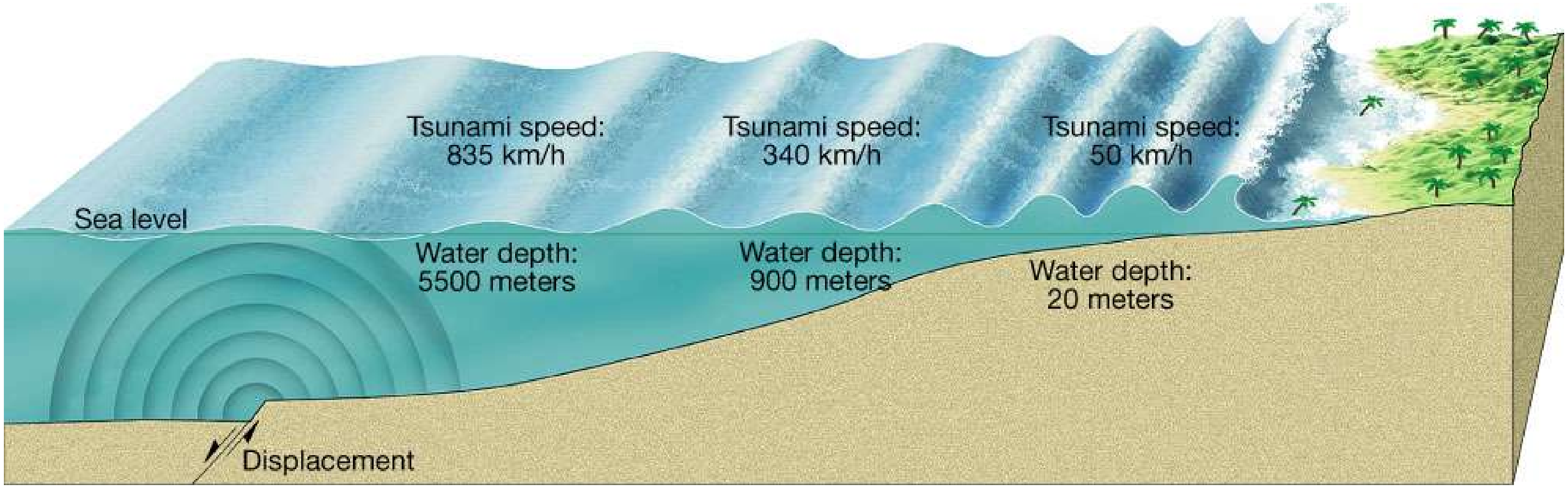
8.3 Destruction from Earthquakes

Tsunamis

Cause of Tsunamis

- A **tsunami** triggered by an earthquake occurs where a slab of the ocean floor is displaced vertically along a fault.
- A tsunami also can occur when the vibration of a quake sets an underwater landslide into motion.
- *Tsunami* is the Japanese word for “seismic sea wave.”

Movement of a Tsunami



8.3 Destruction from Earthquakes

Tsunamis

- Tsunami Warning System
  - Large earthquakes are reported to Hawaii from Pacific seismic stations.
  - Although tsunamis travel quickly, there is sufficient time to evacuate all but the area closest to the epicenter.

Other Dangers

- Landslides
  - With many earthquakes, the greatest damage to structures is from landslides and ground subsidence, or the sinking of the ground triggered by vibrations.
- Fire
  - In the San Francisco earthquake of 1906, most of the destruction was caused by fires that started when gas and electrical lines were cut.

Landslide Damage

8.3 Destruction from Earthquakes

Predicting Earthquakes

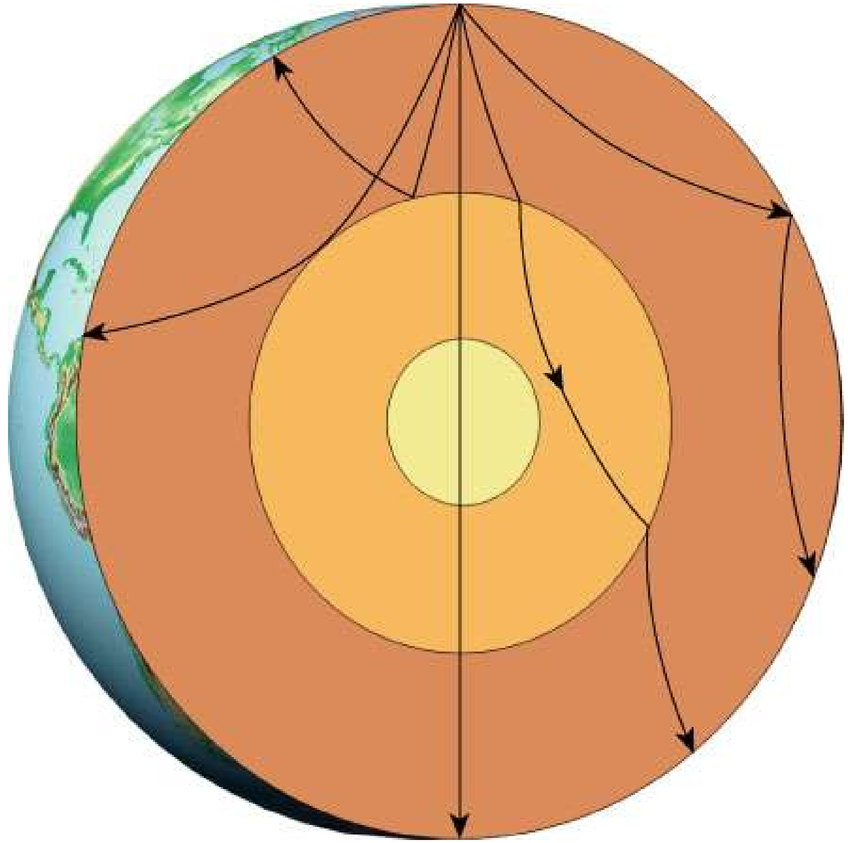
- Short-Range Predictions
  - So far, methods for short-range predictions of earthquakes have not been successful.
- Long-Range Forecasts
  - Scientists don’t yet understand enough about how and where earthquakes will occur to make accurate long-term predictions.
  - A **seismic gap** is an area along a fault where there has not been any earthquake activity for a long period of time.

8.4 Earth's Layered Structure

Layers Defined by Composition

- Earth's interior consists of three major zones defined by their chemical composition—the **crust, mantle,** and **core.**
- Crust
  - Thin, rocky outer layer
  - Varies in thickness
    - Roughly 7 km in oceanic regions
    - Continental crust averages 8–40 km
    - Exceeds 70 km in mountainous regions

Seismic Waves Paths Through the Earth



8.4 Earth's Layered Structure

Layers Defined by Composition

- 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

8.4 Earth’s Layered Structure

Layers Defined by Composition

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

8.4 Earth's Layered Structure

Layers Defined by Composition

- Mantle
  - Below crust to a depth of 2900 kilometers
  - Composition of the uppermost mantle is the igneous rock peridotite (changes at greater depths).

Layers Defined by Composition

- Core
  - Below mantle
  - Sphere with a radius of 3486 kilometers
  - Composed of an iron-nickel alloy
  - Average density of nearly 11 g/cm^3

8.4 Earth's Layered Structure

Layers Defined by 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

8.4 Earth's Layered Structure

Layers Defined by Physical Properties

- Lower Mantle
  - 660–2900 km
  - More rigid layer
  - Rocks are very hot and capable of gradual flow.

8.4 Earth's Layered Structure

Layers Defined by Physical Properties

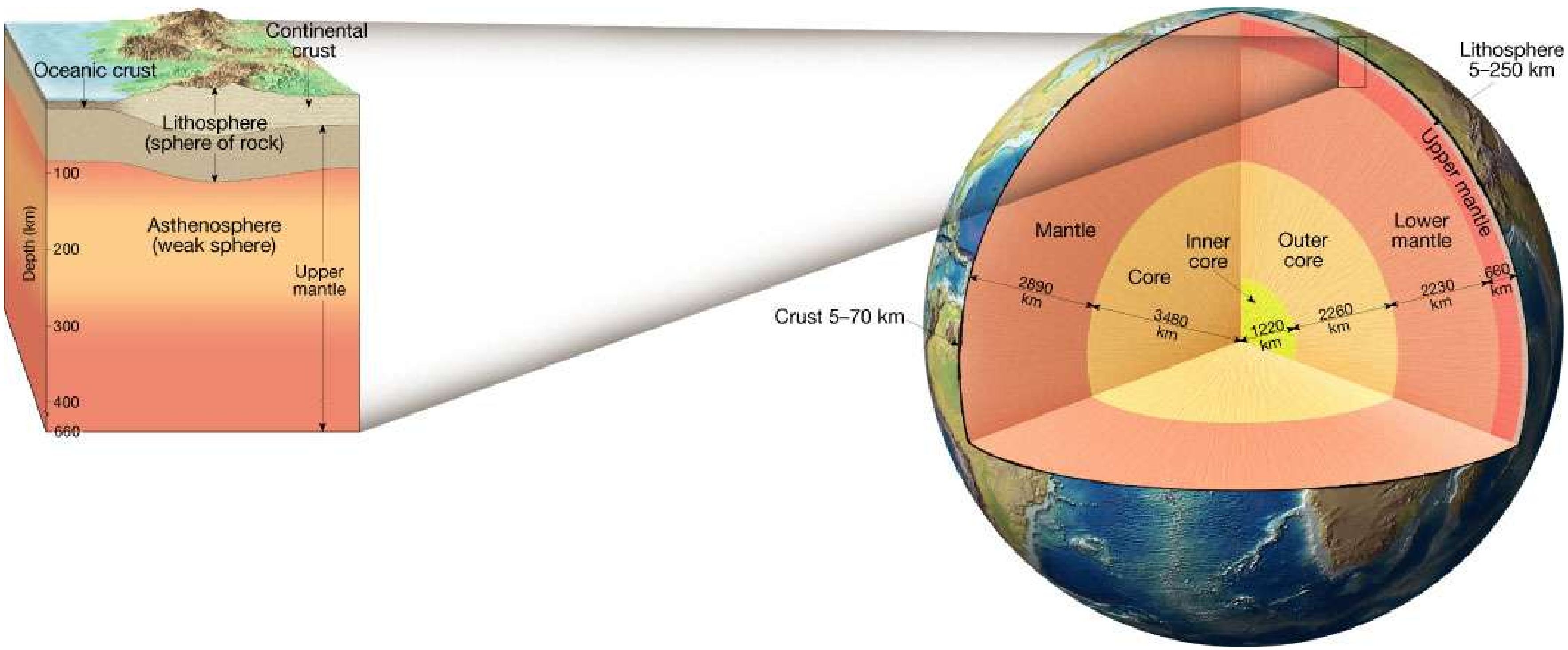
◆ Inner Core

- Sphere with a radius of 1216 km
- Behaves like a solid

◆ Outer Core

- Liquid layer
- 2270 km thick
- Convective flow of metallic iron within generates Earth's magnetic field

Earth's Layered Structure

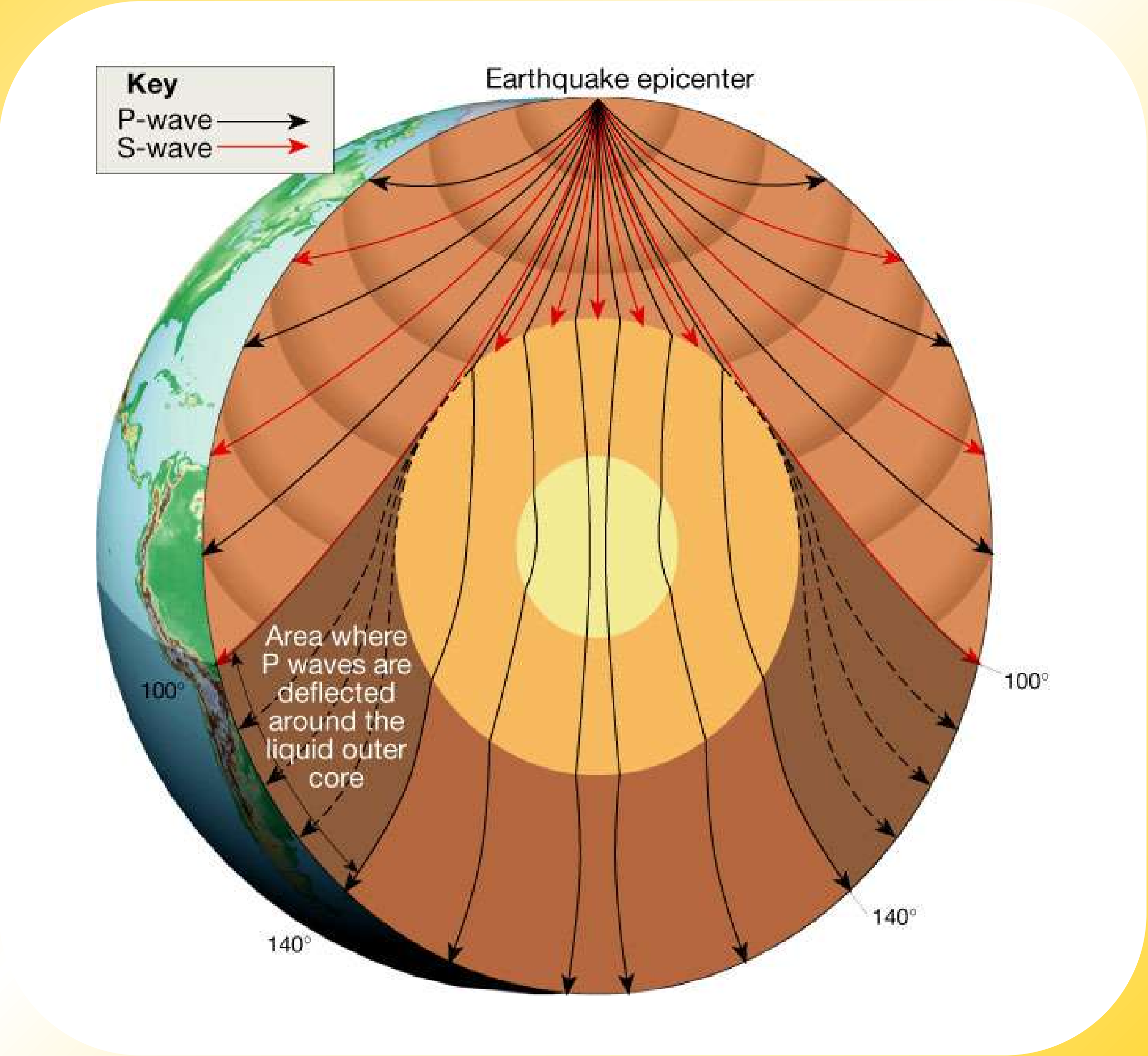


8.4 Earth's Layered Structure

Discovering Earth's Layers

- **Moho**
  - Velocity of seismic waves increases abruptly below 50 km of depth
  - Separates crust from underlying mantle
- Shadow Zone
  - Absence of P waves from about 105 degrees to 140 degrees around the globe from an earthquake
  - Can be explained if Earth contains a core composed of materials unlike the overlying mantle

Earth’s Interior Showing P and S Wave Paths



8.4 Earth's Layered Structure

Discovering Earth's Composition

- Crust
  - Early seismic data and drilling technology indicate that the continental crust is mostly made of lighter, granitic rocks.
- Mantle
  - Composition is more speculative.
  - Some of the lava that reaches Earth's surface comes from asthenosphere within.

8.4 Earth’s Layered Structure

Discovering Earth’s Composition

- Core
  - Earth’s core is thought to be mainly dense iron and nickel, similar to metallic meteorites. The surrounding mantle is believed to be composed of rocks similar to stony meteorites.