Chapter 11: Earthquakes and Earth's Interior

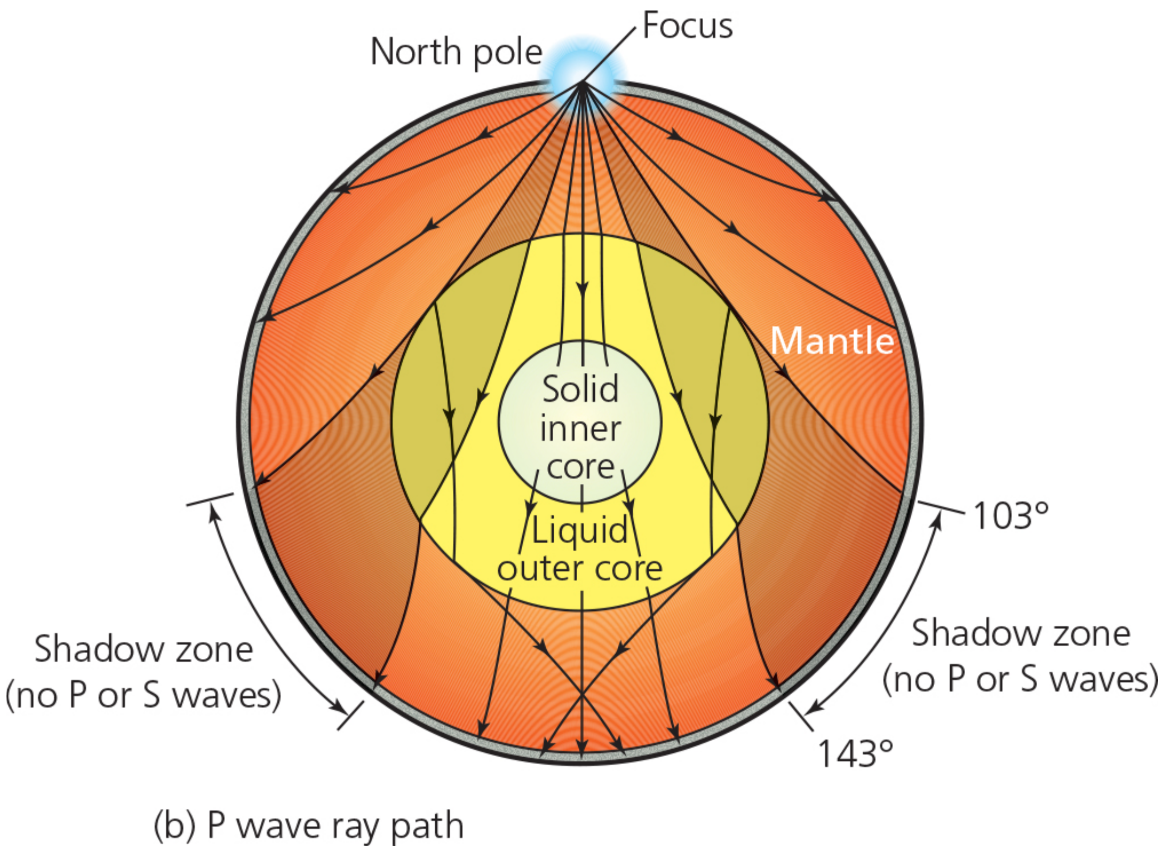


Fig 11.13b

OBJECTIVES

- Describe how geophysicists use geophysical methods and earthquake waves to probe Earth's interior.
- Explain the elastic rebound theory, which provides an explanation for the origin of earthquakes.
- Describe the characteristics of seismic waves and explain the difference between primary waves, secondary waves, and surface waves.
- List the key observations that revealed Earth to possess a layered planetary interior.

OBJECTIVES

- Explain our current understanding of Earth's hidden interior using the evidence provided by Earth's internal heat, its density, and the path of earthquake waves through its interior.
- Describe how it is now possible to produce three-dimensional pictures of Earth's interior and what these pictures indicate about the circulation of materials in the core and mantle.
- Explain how the fate of subducted slabs may be linked to the formation of mantle plumes at the core-mantle boundary.

Earthquakes and Earth's Interior: An Overview

- Our direct knowledge of Earth's interior is limited to the first few tens of kilometers immediately below the surface.

- Earth's layers can be examined indirectly, such as by studying earthquakes, magnetism, gravity, and heat flow and by applying the laws of physics.

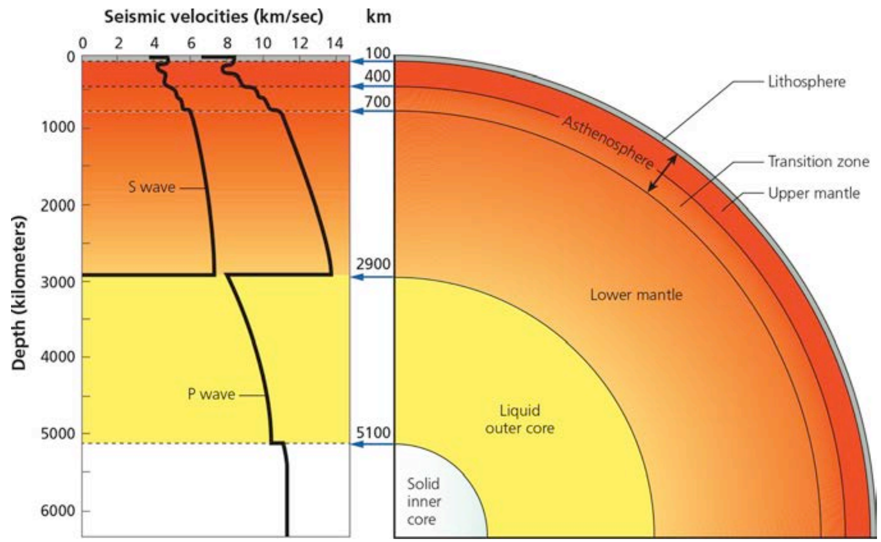
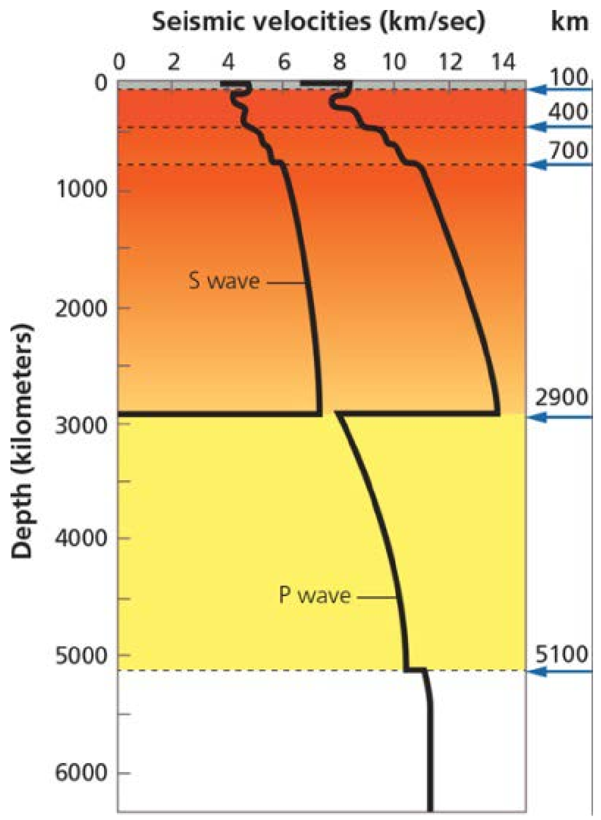


Fig. 11.15

Heat and Density: Clues to Earth's Interior

- Processes in the interior of the planet can be examined only indirectly.
- Geophysicists apply physical laws to learn how Earth's layers are segregated.
- Density is a measure of a material's compaction.
- Density affects the speed of seismic waves.



Earthquakes and Elastic Rebound Theory

- **Elastic Rebound Theory**
  - When rocks along a fault lock together, strain builds on both sides.
  - The sides slowly bend, storing elastic energy.
  - When the strain reaches a threshold, the rocks rupture and jerk past each other.
  - The energy released sends out shock waves, known as **seismic waves**.

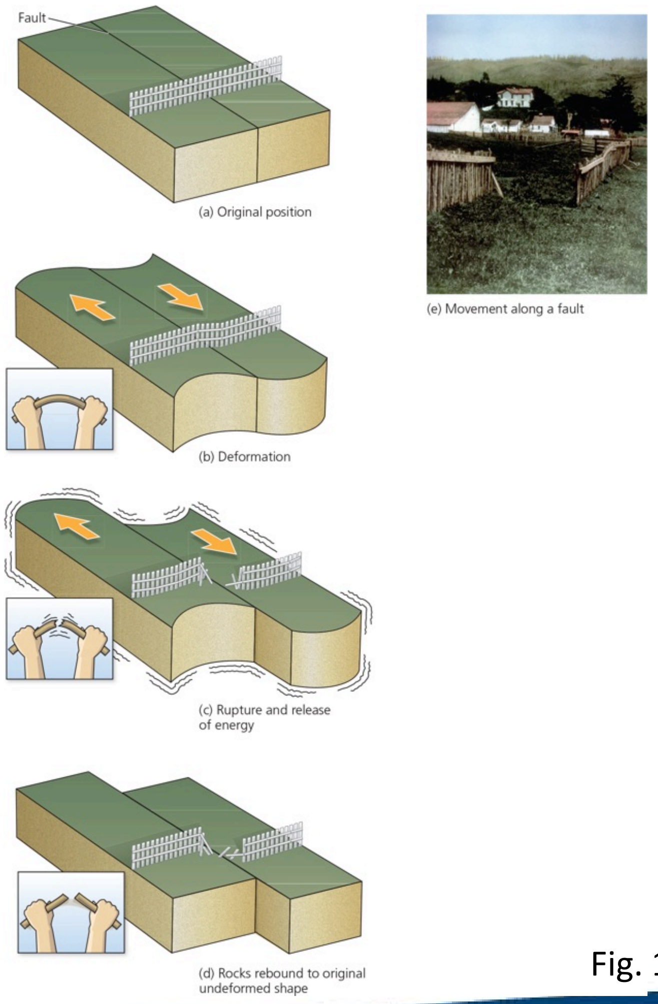


Fig. 11.1

Seismic Waves

- **Surface Waves**
  - Travel along Earth's surface
  - Cause most of the damage associated with earthquakes
  - Produce low-frequency vibrations
  - Travel slowly; take longer to diminish
  - Do not penetrate the interior
- **Body Waves**
  - Travel through Earth's interior
  - Two main types: **primary** and **secondary**

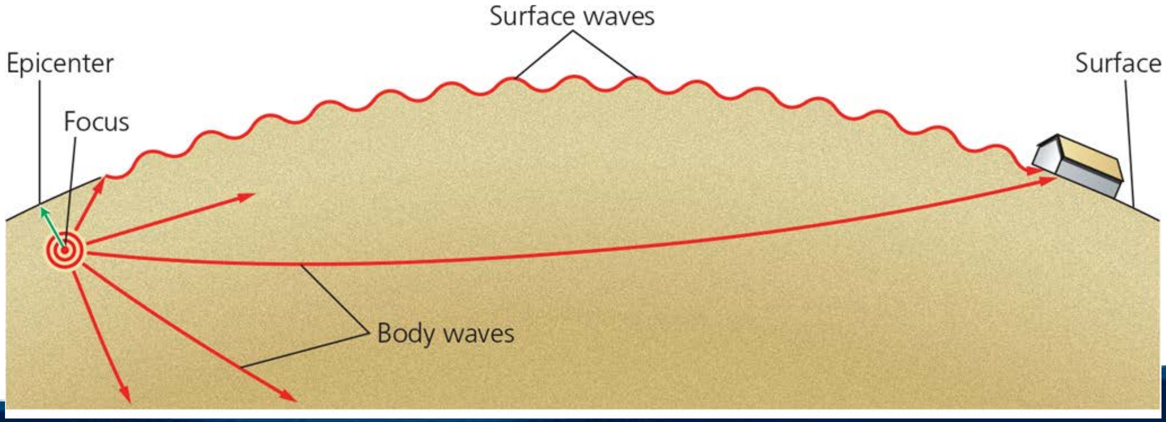
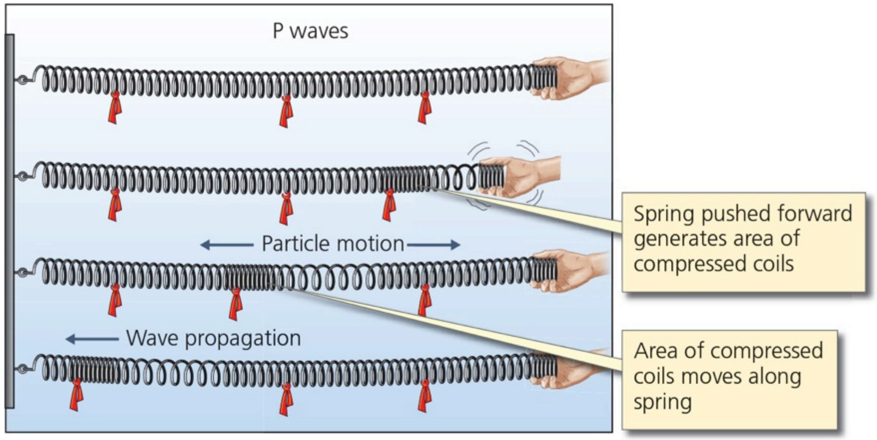


Fig. 11.2

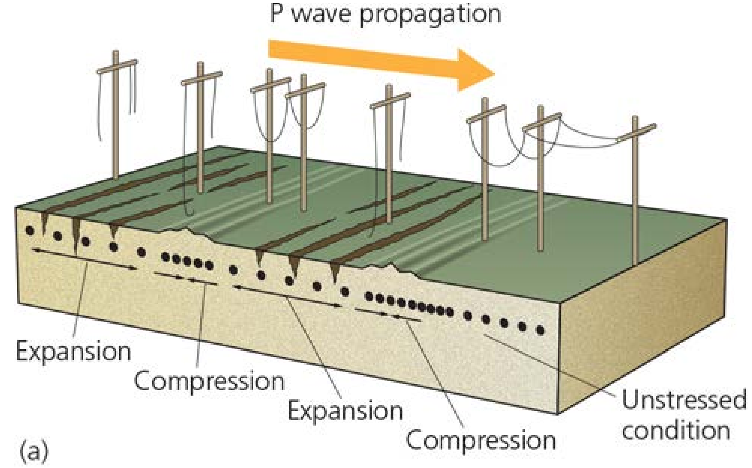
Seismic Waves

- **Primary (P) waves** are generated by sudden compression or extension of the ground at the earthquake site.
  - Travel most rapidly through dense, rigid rocks
  - Are slowed by hot rocks, liquids, and gases
- **Secondary (S) waves** are generated by the sliding motion at an earthquake site.
  - Travel only through solid materials
  - Do not travel through liquids and gases

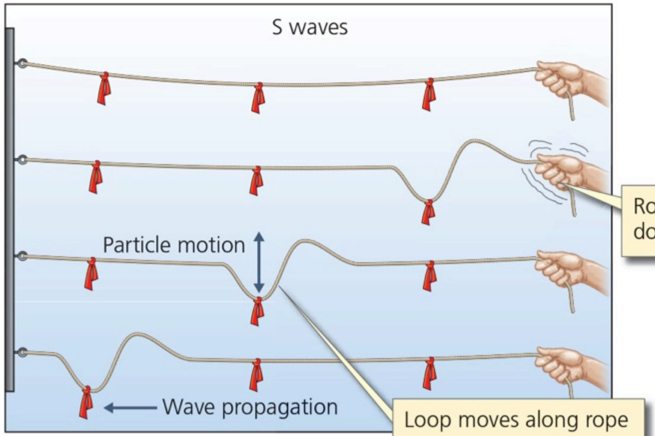
Seismic Waves



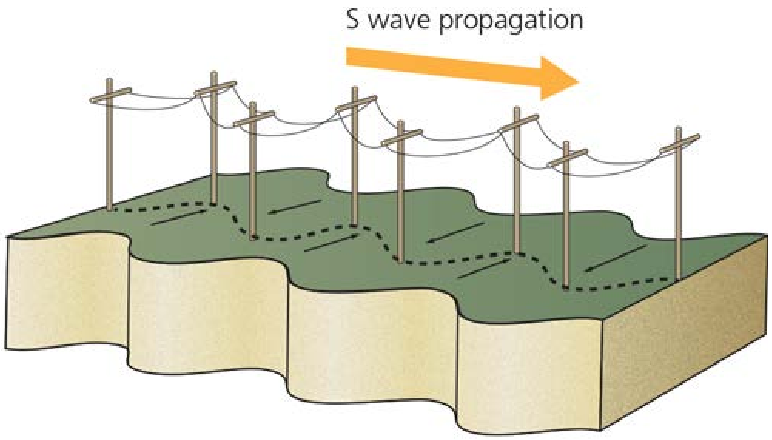
(a) Primary waves



(a)



(b) Secondary waves



(b)

Figs. 11.3, 11.4

Seismic Waves

- Measuring Seismic Waves
  - **Seismometer** (or Seismograph)
    - Mounted directly on bedrock, often buried
    - Produces a **seismogram**
    - Can help determine epicenter and magnitude of earthquakes
  - **Richter Magnitude Scale**
    - Calculated from the amplitude (height) of the largest seismic wave recorded on seismogram

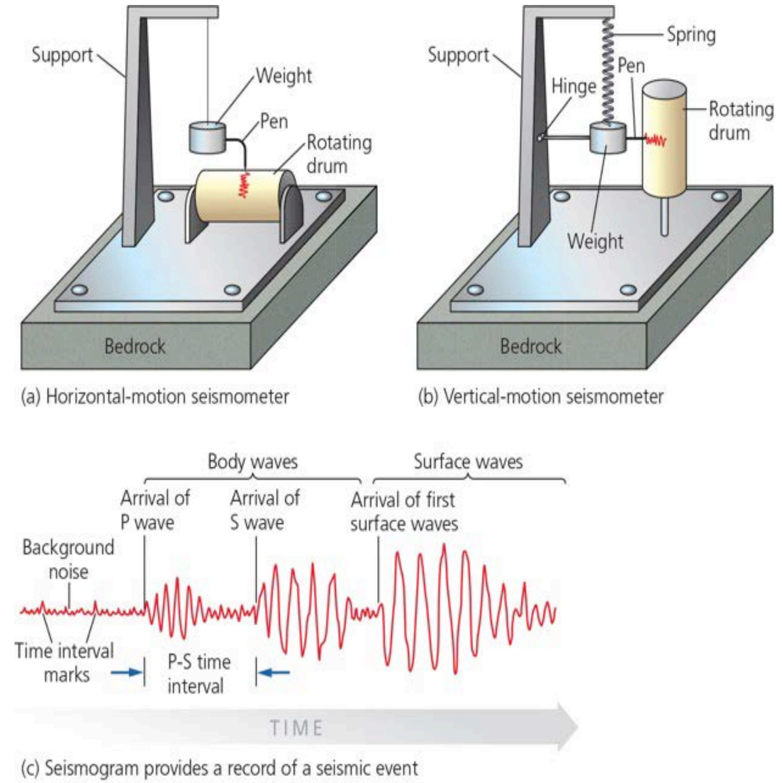


Fig. 11.6

Journey to the Center of the Earth

- **Seismology:** the study of earthquake waves
  - Patterns and speed of waves give insight about the material they travel through.

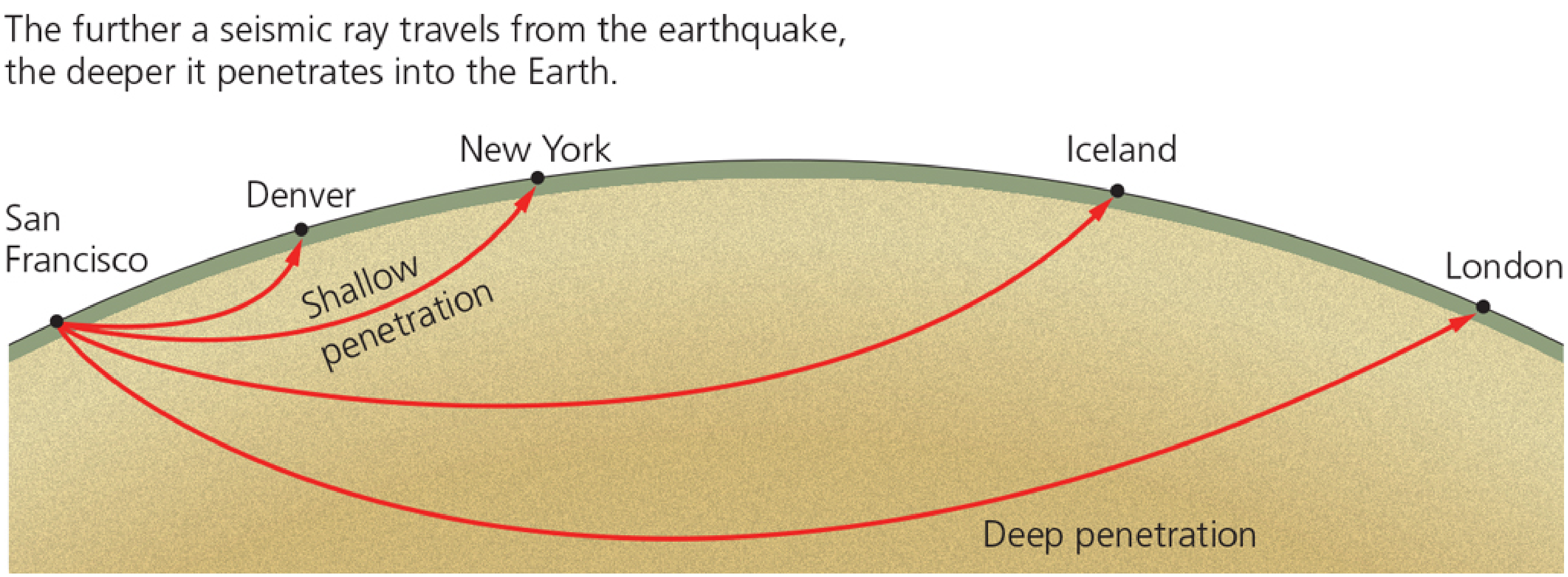


Fig. 11.9

Journey to the Center of the Earth

- **Seismic Discontinuities:** abrupt changes in velocity of seismic waves indicate the presence of distinct layers of material.
  - The Moho
  - The shadow zone
  - Inner and outer cores
- Earth is a layered planet.
  - **Crust:** very thin outer layer
  - **Mantle:** thick, rocky layer between crust and core
  - **Core:** massive metallic center

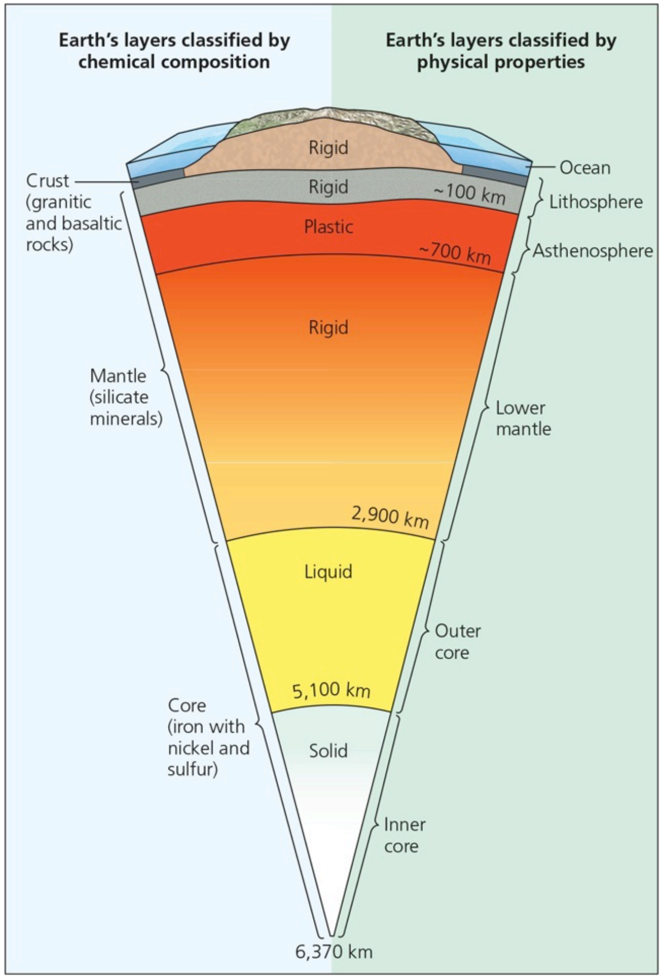


Fig 11.11

Earth's Structure and Composition

- **Crust**
  - Continental crust
    - Mostly granitic and granodioritic
    - Thicker and less dense than oceanic crust
  - Oceanic crust
    - Mostly basaltic
    - Thinner and denser than continental crust
  - The Moho
    - Base of the crust
    - Boundary separating the lower crustal rocks from ultramafic rocks of the uppermost mantle

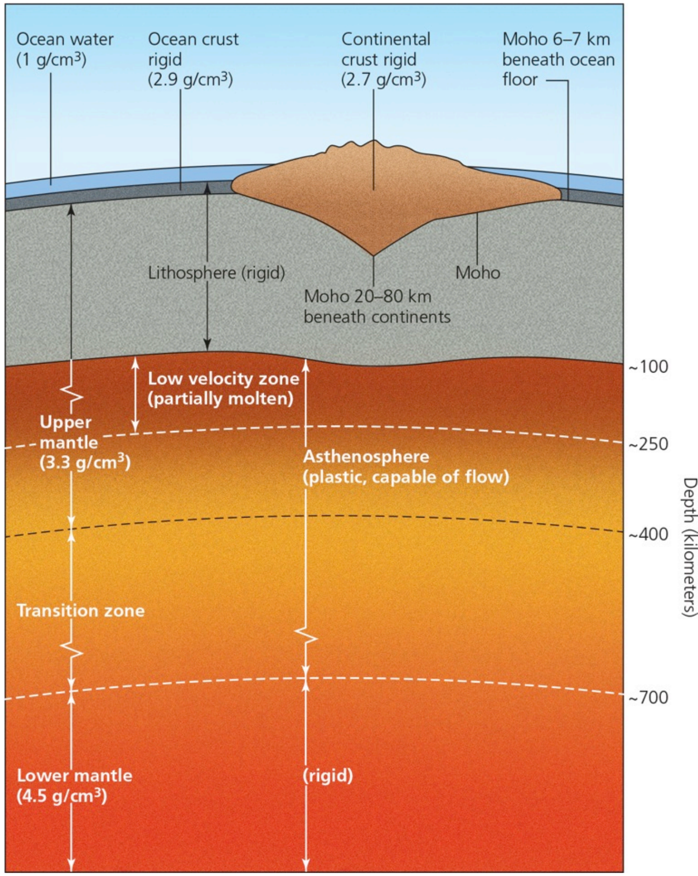
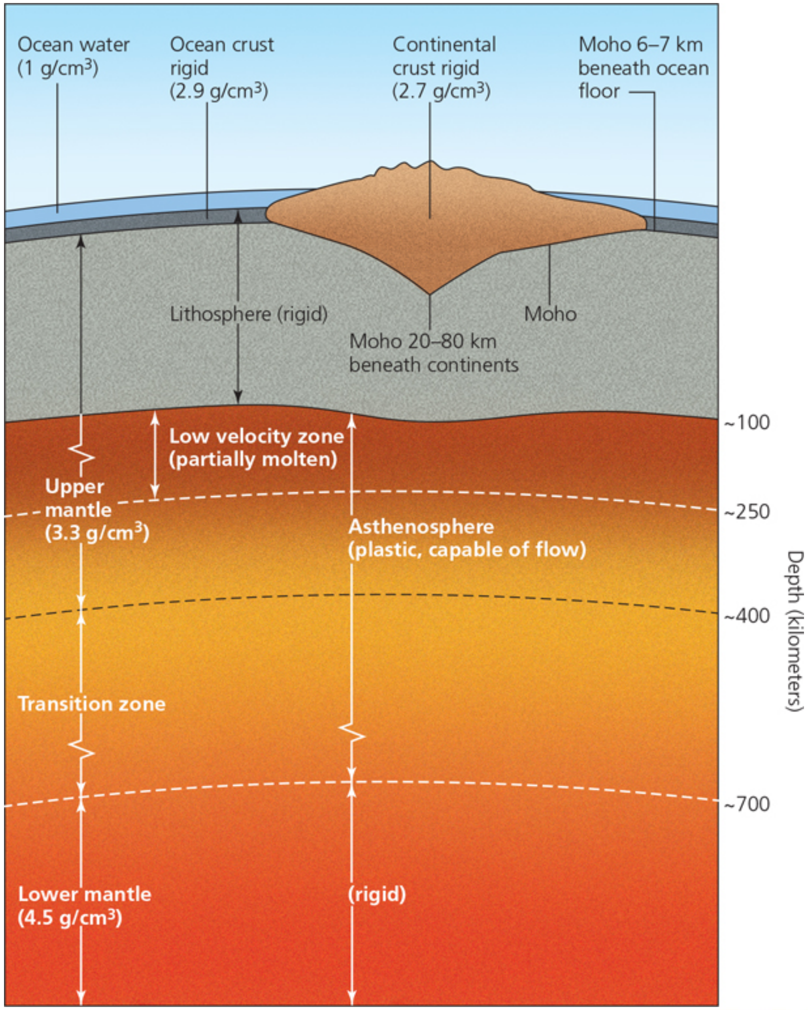


Fig. 11.15

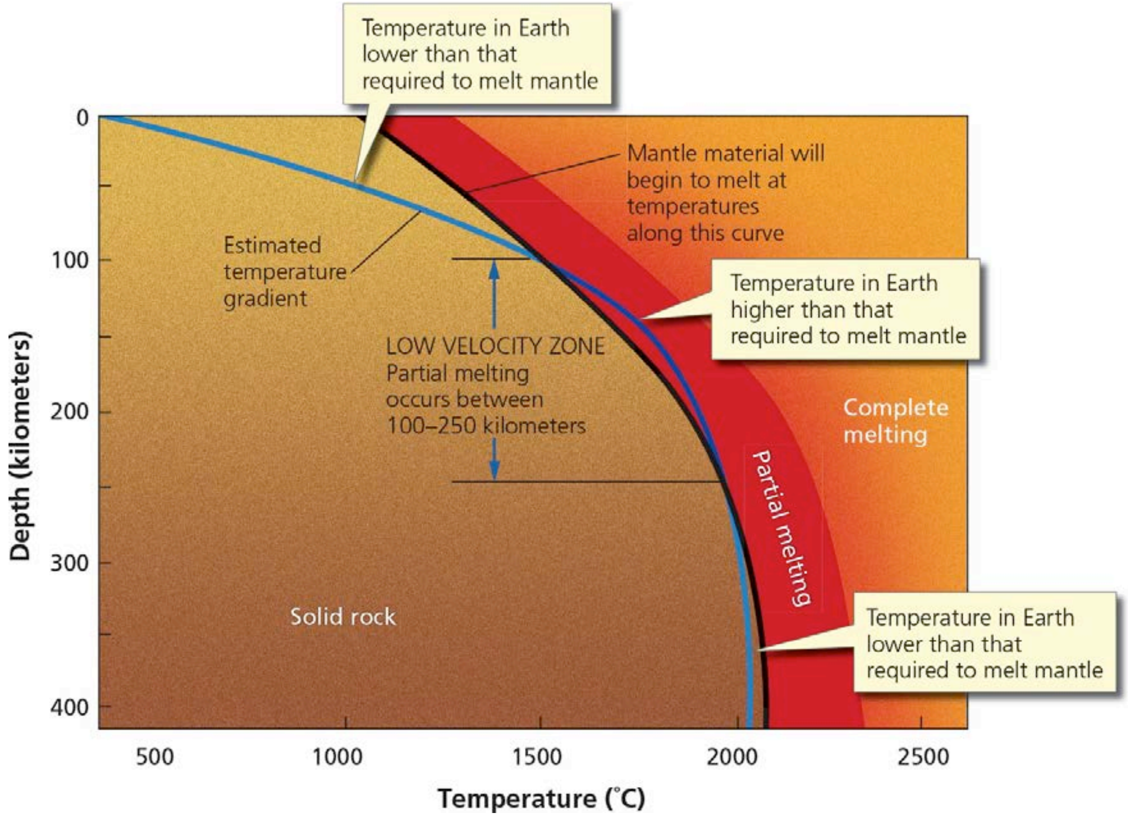
Earth's Structure and Composition



Earth's Structure and Composition

- **Mantle**
  - Between the crust and the core-mantle boundary
  - 83% of Earth's volume (largest of Earth's layers)
  - Composed of ultramafic rocks
    - Uppermost mantle: **peridotite**
  - **Lithosphere:** the crust and upper mantle
  - **Asthenosphere:** the plastic layer beneath the lithosphere

Earth's Structure and Composition



Low-Velocity Zone: Melt is produced in the mantle where the mantle temperature exceeds that needed for melting to begin. The presence of melt in the mantle results in a zone of low seismic velocity within the asthenosphere, known as the low-velocity zone.

Fig. 11.16

Earth’s Structure and Composition

- **Core**
  - Central part of Earth
  - Core-mantle boundary: 2900 kilometers (1800 miles) below the base of the crust
  - About 6950 kilometers (4300 miles) in diameter
  - A seismic discontinuity separates the liquid **outer core** from the solid **inner core.**
  - Mostly iron

Circulation in Earth’s Interior

- Circulation in the liquid outer core helps generate Earth’s magnetic field.

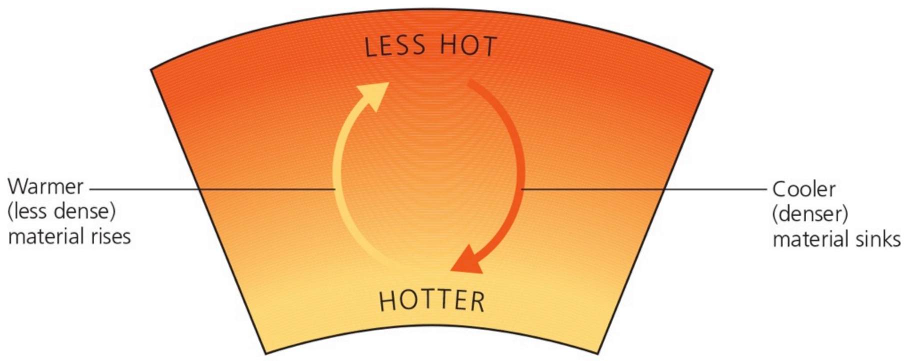
- Circulation in the solid mantle is also thought to cause the motion of Earth’s lithospheric plates.

- There are two forms of circulation:
    - **Thermal Convection:** driven by temperature contrasts
    - **Compositional Convection:** driven by differences in composition

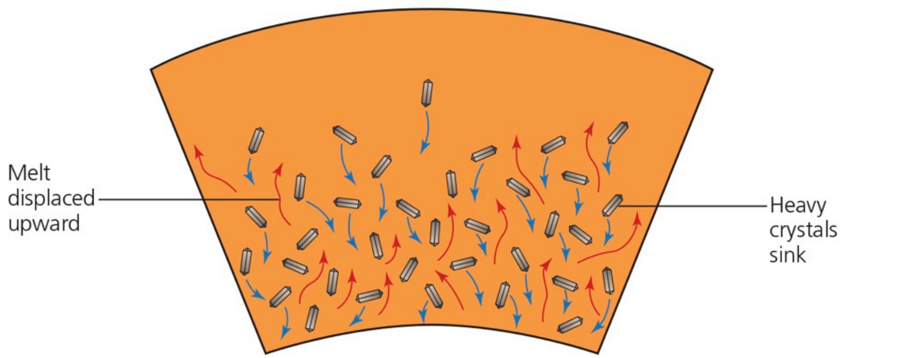
OXFORD
UNIVERSITY PRESS

Circulation in Earth's Interior

- **Thermal Convection**
  - Warm, less-dense material rises; cooler, denser material sinks.
  - Hot material is transferred from the interior toward the exterior of the planet.
  - Segregates material by density.
- **Compositional Convection**
  - Light material rises; heavy material sinks.
  - Convection in outer core affects growth of inner core.



(a) Thermal convection

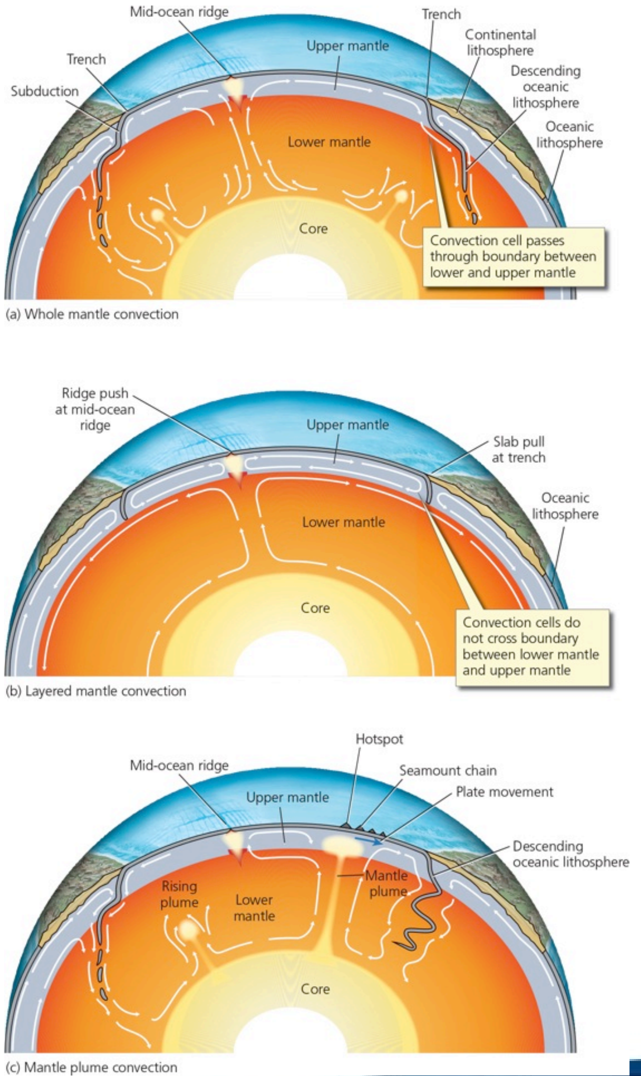


(b) Compositional convection

Fig 11.17

Circulation in Earth’s Interior

- Models of Mantle Convection
  - **Whole Mantle Convection:** Large convection cells extend from the core-mantle boundary to the base of the lithosphere.
  - **Layered Mantle Convection:** More vigorous circulation in the upper mantle because mantle rocks are close to their melting point.
  - **Mantle Plumes:** A narrow, focused column of mantle upwelling and much more diffuse system of return flow.



(a) Whole mantle convection

(b) Layered mantle convection

(c) Mantle plume convection

Fig. 11.19

Circulation in Earth's Interior

- **Seismic Tomography**
  - 3D maps of the mantle
  - Relatively new, computer imaging technique
  - Mimics the CAT (computerized axial tomography) scan procedure
  - Indicates that convective flow in the mantle is more complex than the other models suggest

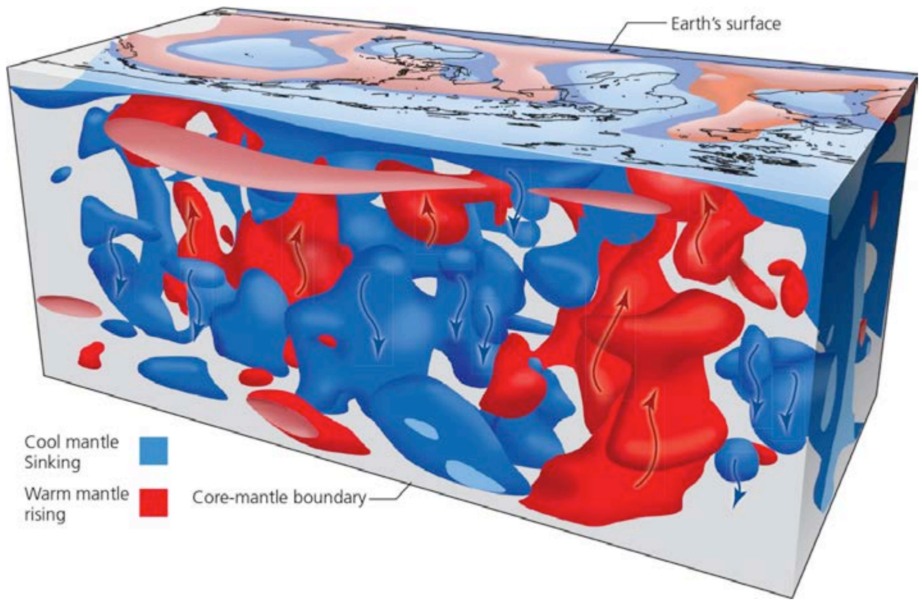


Fig. 11.22

Circulation in Earth's Interior

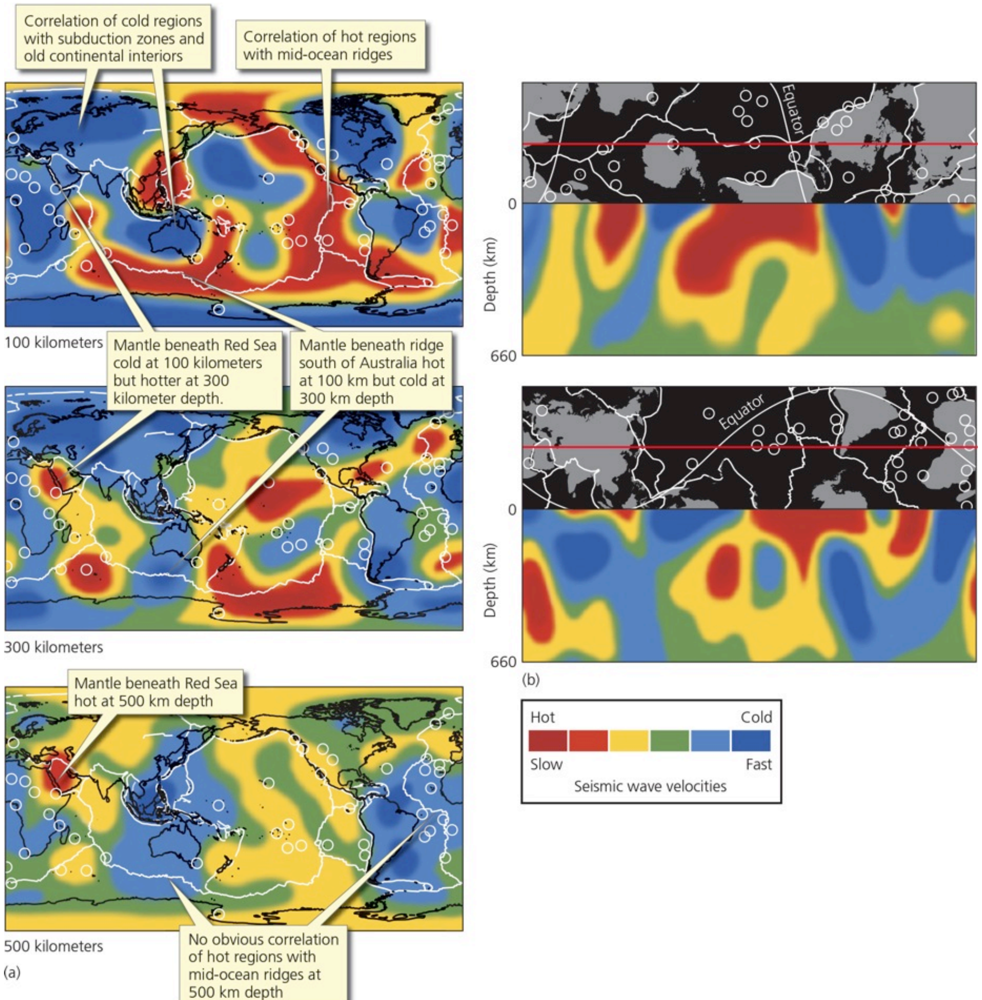


Fig. 11.21

Scans of Earth's Interior: Global maps show tomographic scans of seismic wave velocities in the upper mantle, (a) in map view at depths of 100, 300, and 500 km (60, 190, and 310 miles), and (b) in cross section to a depth of 660 km (410 miles) directly beneath the two lines indicated, one that girdles Earth from pole to pole (top) and the other running a diagonal course across the Pacific Ocean (bottom). Regions in red have low seismic wave velocities, indicating they are hot. Regions in blue have high seismic wave velocities, indicating they are cold.

Plate Tectonics and the Fate of Subducted Slabs

- Vertical slices through Earth's mantle beneath Central America and Japan show the distribution of colder (seismically fast) material (blue) and hotter (seismically slow) material (red) to the core-mantle boundary based on seismic tomography.

- The distribution of colder material suggests that the subducting slabs beneath both areas penetrate the main transition zone and extend to the base of the mantle.

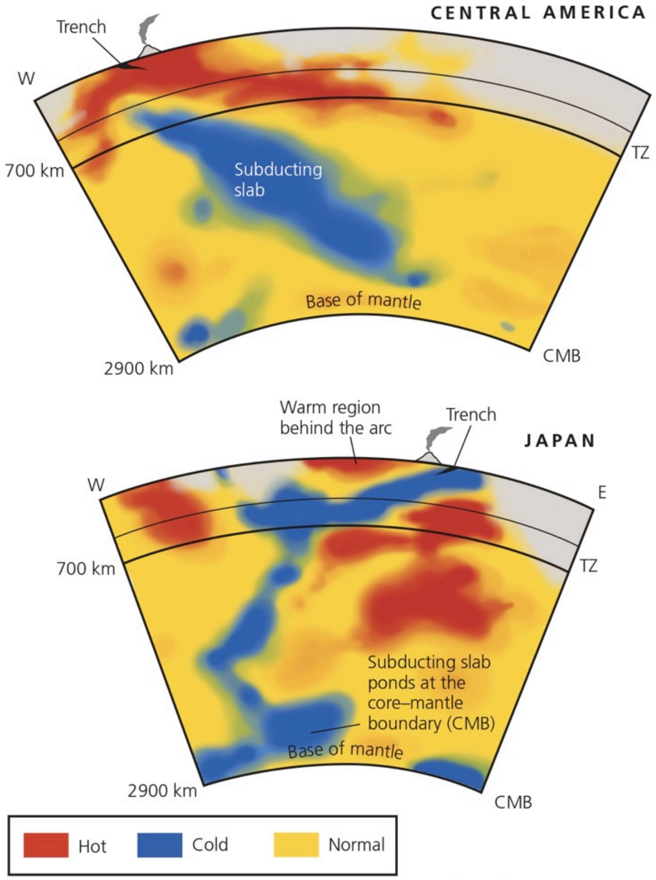


Fig. 11.23

SUMMARY

- Indirect measurement of Earth's density and heat provides information on Earth's internal layers.
- Earthquakes happen when a locked fault breaks and the rocks undergo elastic rebound.
- Seismic waves spread out in all directions from earthquake foci and travel at speeds that vary depending on the properties of the material through which they travel.
- Seismic waves undergo reflection at the boundary between two materials and refraction when they move from one material into another.

SUMMARY

- Seismic discontinuities delineate the boundaries of Earth's layers: the crust, the mantle, and the core.
- Earth is layered in terms of composition and physical properties, which can be inferred via seismic data.
- Material within Earth undergoes thermal convection and compositional convection.
- Convection is thought to generate Earth's magnetic field and to drive plate tectonics.
- Mantle flow appears to be very complex.
- There is seismic evidence that subducted slabs reach the core-mantle boundary