Chapter 8
Earth Systems

Module 24
Mineral Resources and Geology

After reading this module you should be able to

- describe the formation of Earth and the distribution of critical elements on Earth.
- define the theory of plate tectonics and discuss its relevance to the study of the environment.
- describe the rock cycle and discuss its importance in environmental science.

The availability of Earth's resources was determined when the planet was formed

- The distribution of chemicals, minerals, and ores around the world is in part a function of the processes that occurred during the formation of Earth.

The Formation and Structure of Earth

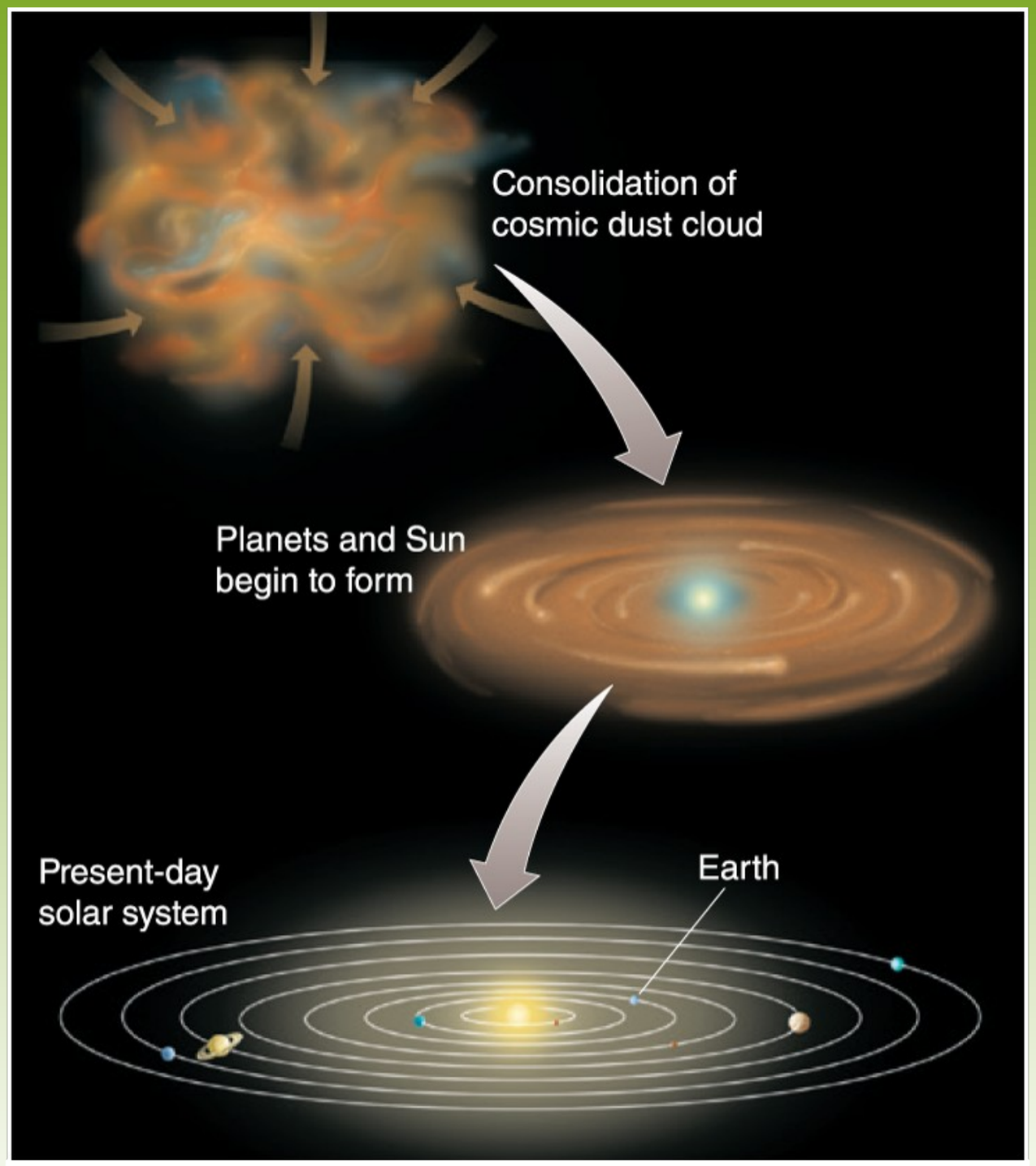

Figure 24.2

Formation of Earth and the solar system.
The processes that formed Earth 4.6 billion years ago determined the distribution and abundance of elements and minerals today.

The Formation and Structure of Earth

- Earth is characterized by distinct vertical zonation.

- **Core** The innermost zone of Earth's interior, composed mostly of iron and nickel. It includes a liquid outer layer and a solid inner layer.

- **Mantle** The layer of Earth above the core, containing magma.

- **Magma** Molten rock.

- **Asthenosphere** The layer of Earth located in the outer part of the mantle, composed of semi-molten rock.

- **Lithosphere** The outermost layer of Earth, including the mantle and crust.

- **Crust** In geology, the chemically distinct outermost layer of the lithosphere.

The Formation and Structure of Earth

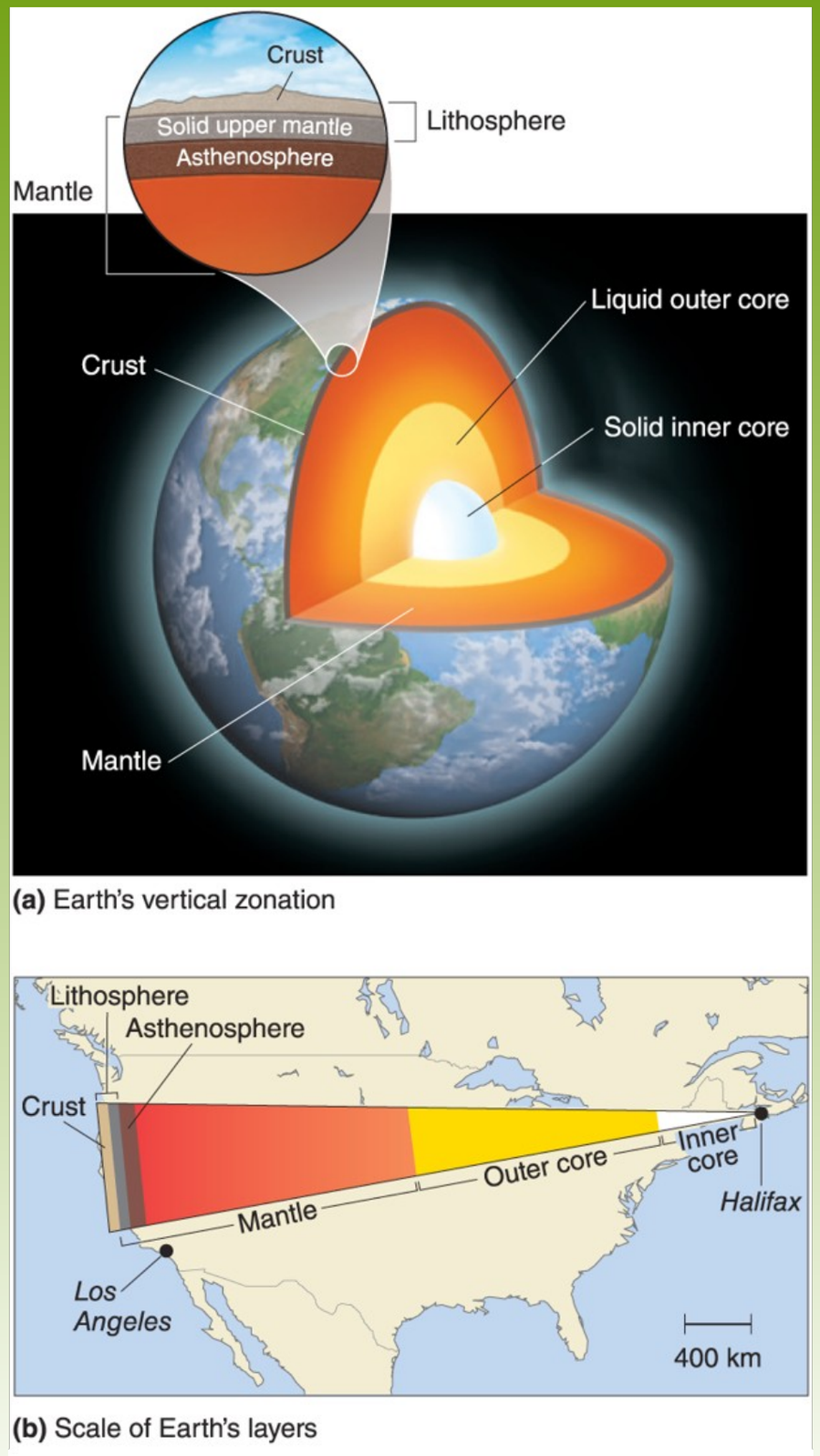

Figure 24.3

Earth's layers. (a) Earth is composed of concentric layers. (b) If we were to slice a wedge from Earth, it would cover the width of the United States.

Hot Spots

- The high temperature of Earth's outer core and mantle is thought to be the result of radioactive decay of various isotopes.
- The heat causes plumes of hot magma to well upward from the mantle and produce hot spots.
- **Hot spot** In geology, a place where molten material from Earth’s mantle reaches the lithosphere.

The theory of plate tectonics describes the movement of the lithosphere

- **Plate tectonics** The theory that the lithosphere of Earth is divided into plates, most of which are in constant motion.

- **Tectonic cycle** The sum of the processes that build up and break down the lithosphere.

- The theory of plate tectonics is a unifying theory in geology and earth sciences because it relates to so many aspects of the earth sciences.

Plate Movement

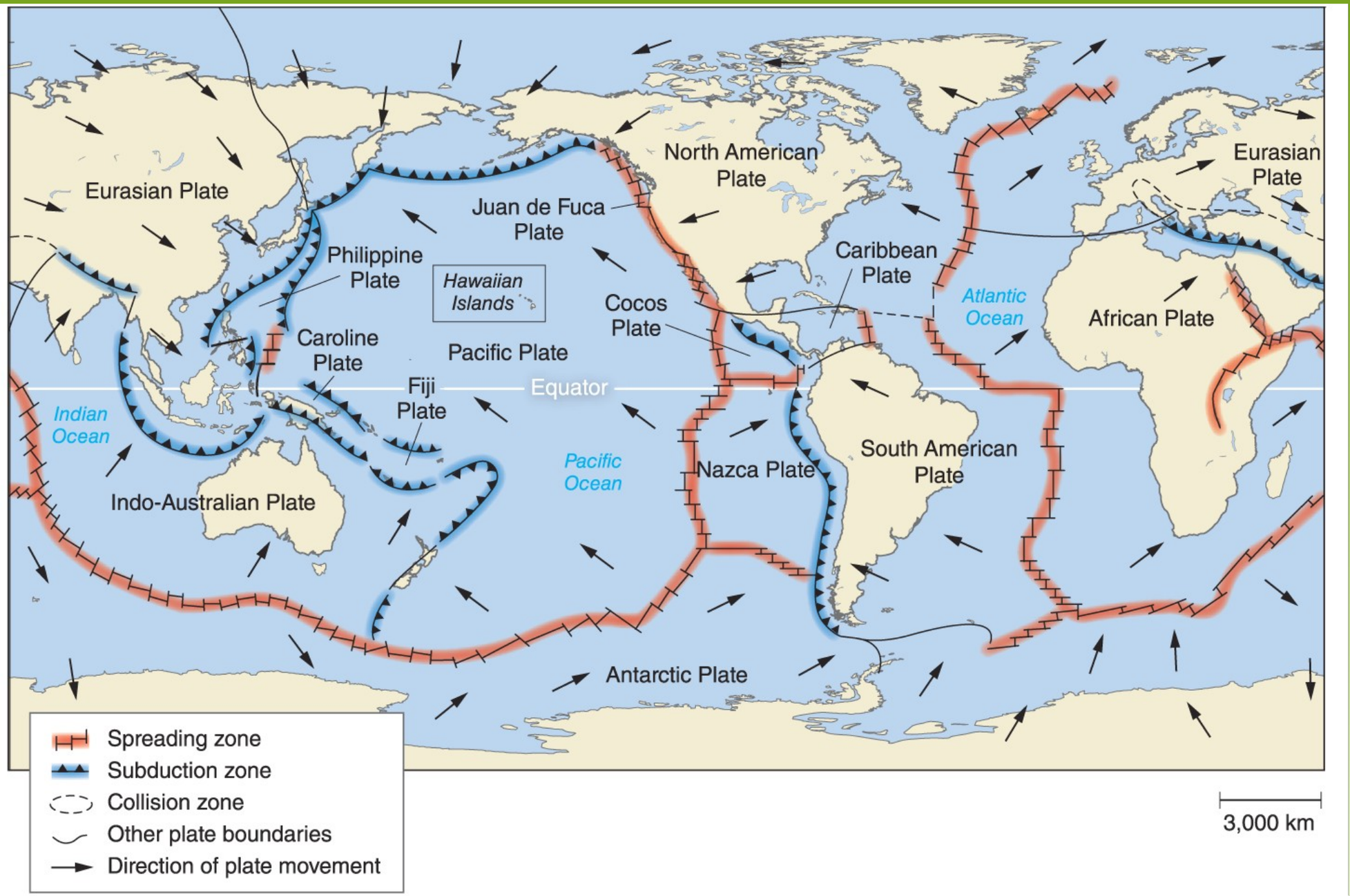

Figure 24.5

Tectonic plates. Earth is covered with tectonic plates, most of which are in constant motion. The arrows indicate the direction of plate movement. New lithosphere is added at spreading zones and older lithosphere is recycled into the mantle at subduction zones.

Plate Movement

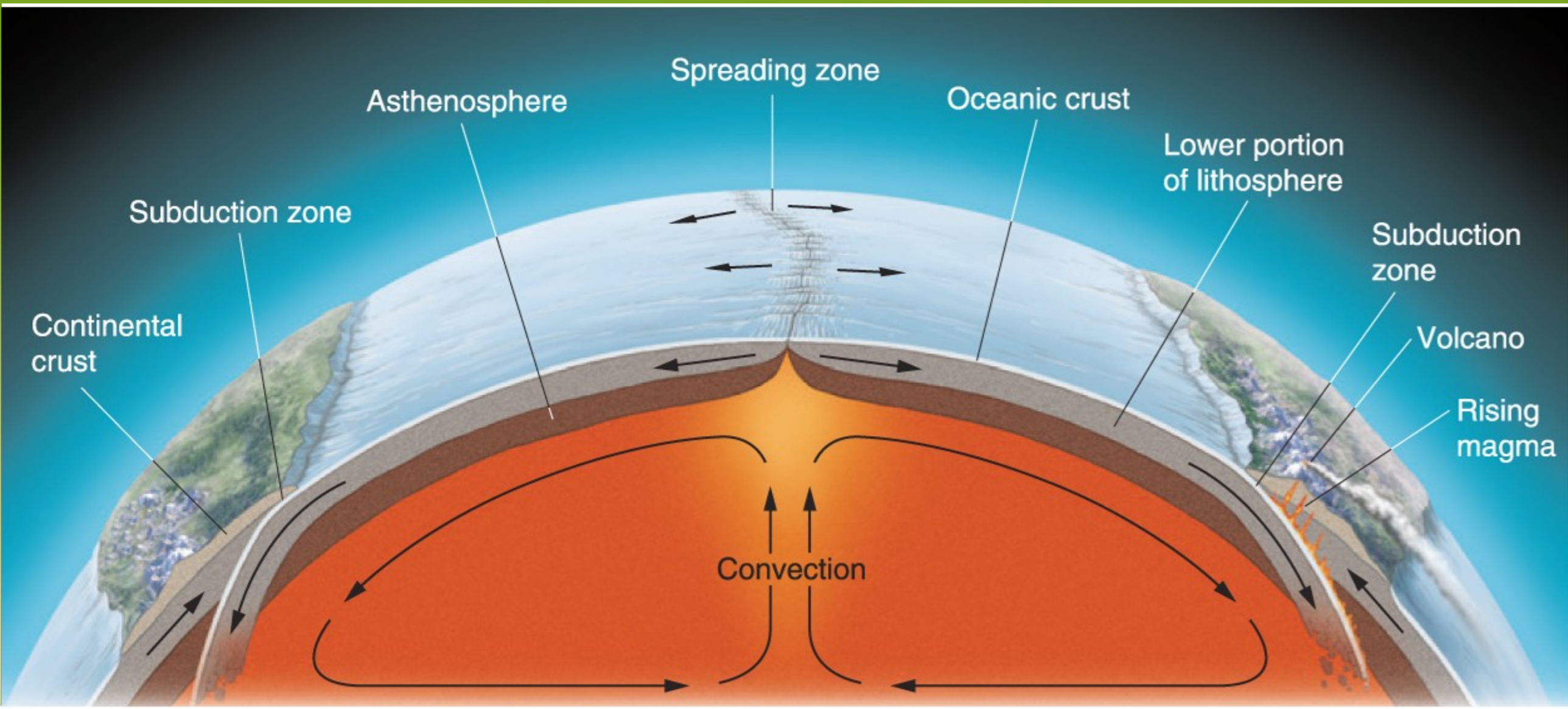

Figure 24.6

Convection and plate movement. Convection in the mantle causes oceanic plates to spread apart as new rock rises to the surface at spreading zones. Where oceanic and continental plate margins come together, older oceanic crust is subducted.

Consequences of Plate Movement

- **Subduction** The process of one crustal plate passing under another.

- **Volcano** A vent in the surface of Earth that emits ash, gases, or molten lava.

Consequences of Plate Movement

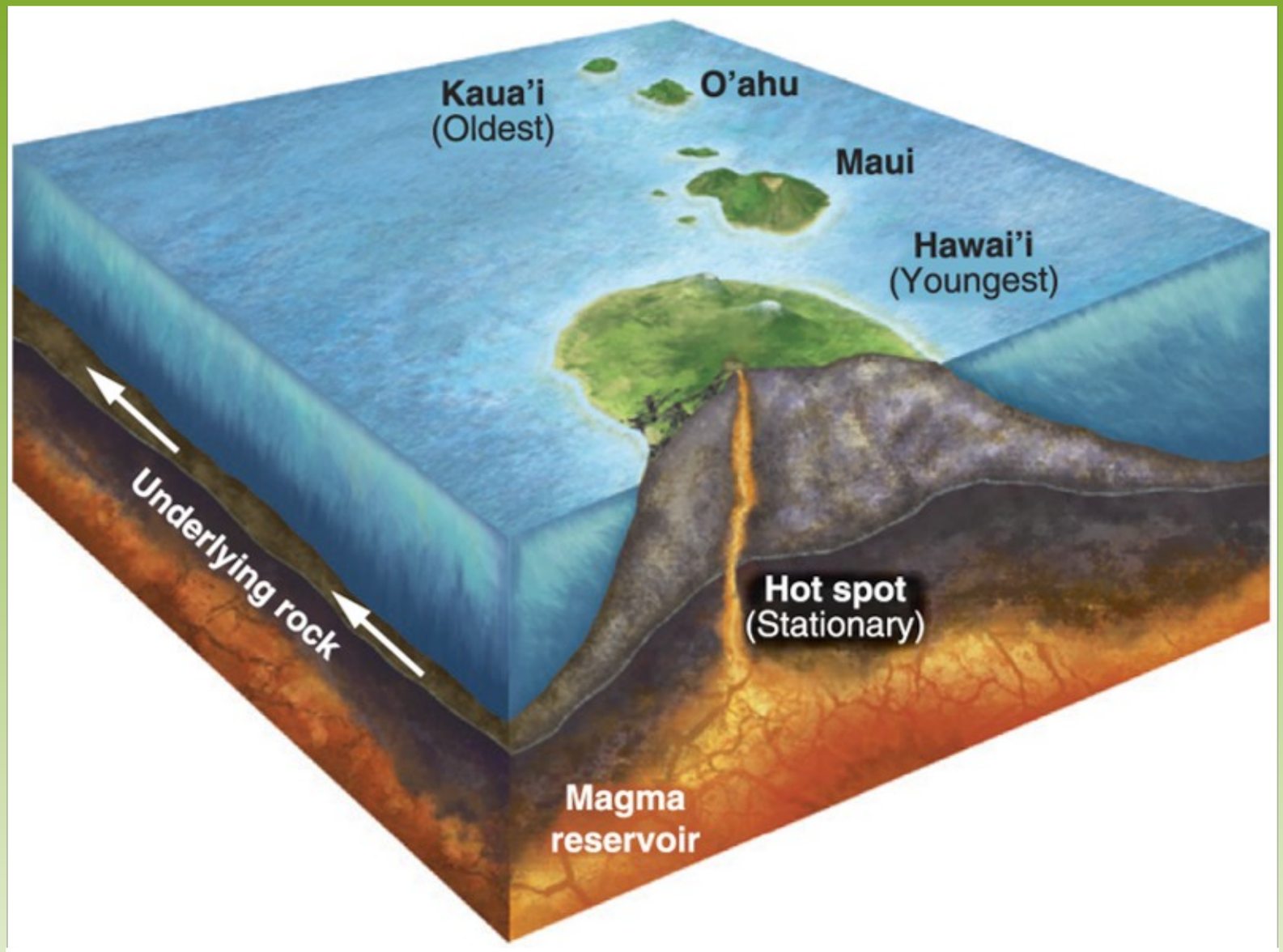

Figure 24.7a
Data from Jaques Descloitres

Plate movement over a hot spot. As the Pacific Plate moves over a hot spot, a series of volcanic eruptions, that occurred over several million years led to the formation of the Hawaiian Islands.

Types of Plate Contact

- **Divergent plate boundary** An area beneath the ocean where tectonic plates move away from each other.

- **Seafloor spreading** The formation of new ocean crust as a result of magma pushing upward and outward from Earth's mantle to the surface.

- **Convergent plate boundary** An area where plates move toward one another and collide.

- **Transform fault boundary** An area where tectonic plates move sideways past each other.

Types of Plate Contact

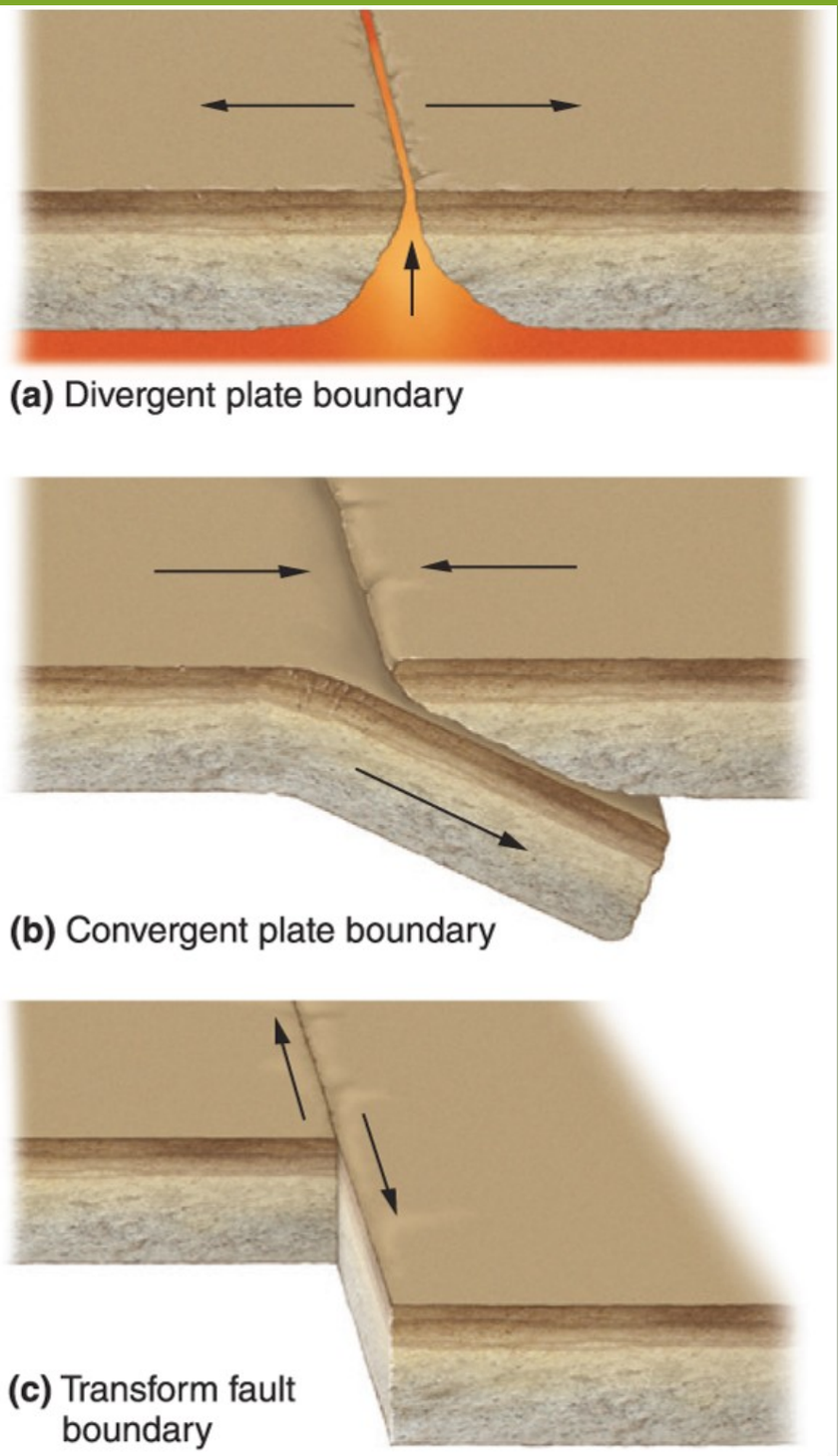

Figure 24.8

Types of plate boundaries.
(a) At divergent plate boundaries, plates move apart. (b) At convergent plate boundaries, plates collide.
(c) At transform fault boundaries, plates slide past each other.

Types of Plate Contact

- **Fault** A fracture in rock caused by a movement of Earth's crust.

- **Seismic activity** The frequency and intensity of earthquakes experienced over time.

- **Fault zone** A large expanse of rock where a fault has occurred.

Faults, Earthquakes, and Volcanoes

- **Earthquake** The sudden movement of Earth's crust caused by a release of potential energy along a geologic fault and usually causing a vibration or trembling at Earth's surface.

- **Epicenter** The exact point on the surface of Earth directly above the location where rock ruptures during an earthquake.

- **Richter scale** A scale that measures the largest ground movement that occurs during an earthquake.

- The Richter scale increases by a factor of 10, so an earthquake of 7 is 10 times greater than an earthquake of 6.

Faults, Earthquakes, and Volcanoes

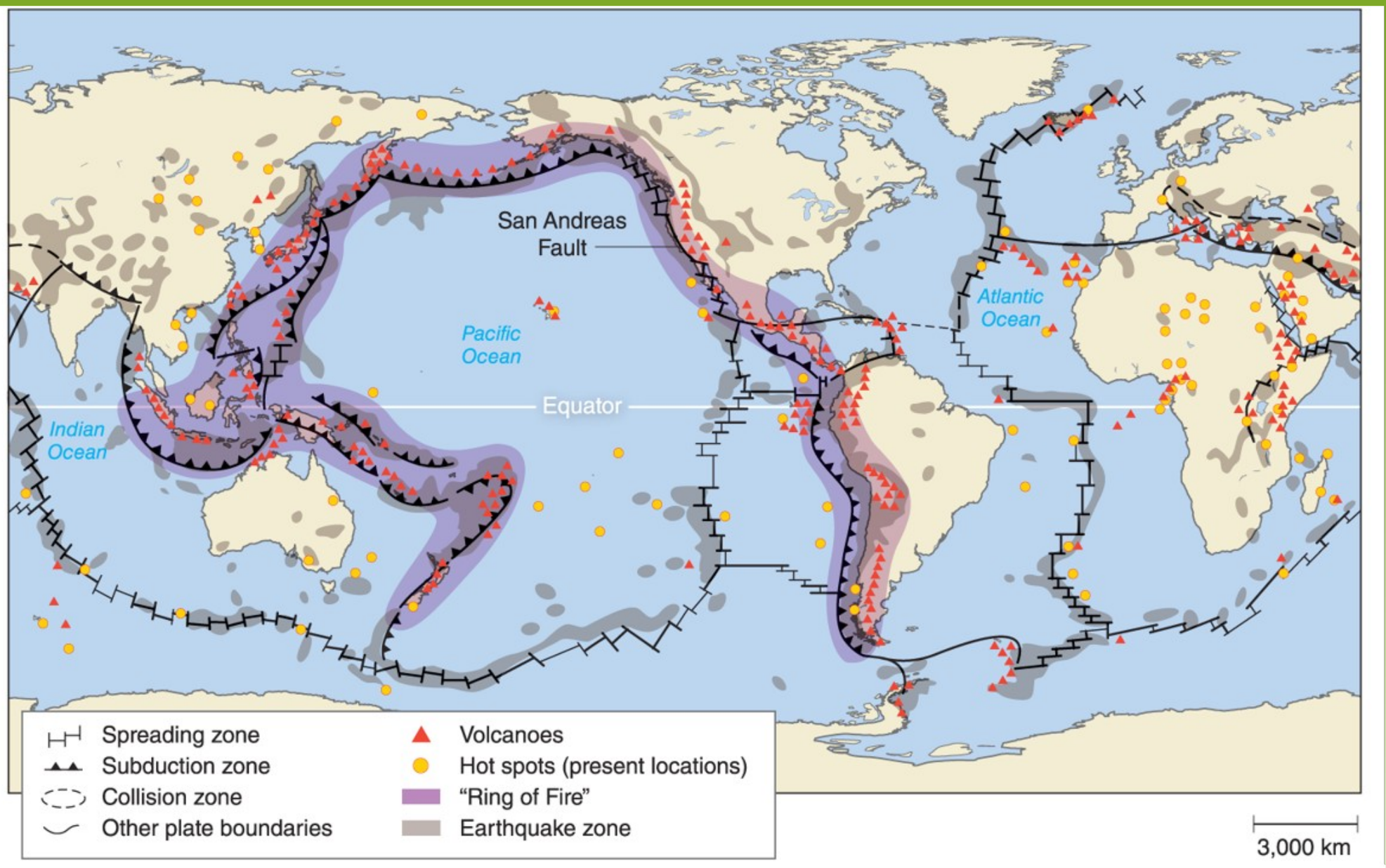

Figure 24.11

Locations of earthquakes and volcanoes. A "Ring of Fire" circles the Pacific Ocean along plate boundaries. Other zones of seismic and volcanic activity, including hot spots, are also shown on this map.

The rock cycle recycles scarce minerals and elements

- **Rock cycle** The geologic cycle governing the constant formation, alteration, and destruction of rock material that results from tectonics, weathering, and erosion, among other processes.

- The rock cycle is the slowest of all Earth's cycles.

The Rock Cycle

There are three major ways in which rocks at Earth's surface can form. This leads to three types of rock:

- Directly from molten magma (igneous)
- Compression of sediments (sedimentary)
- Exposure to high temperatures and pressures (metamorphic)

The Rock Cycle

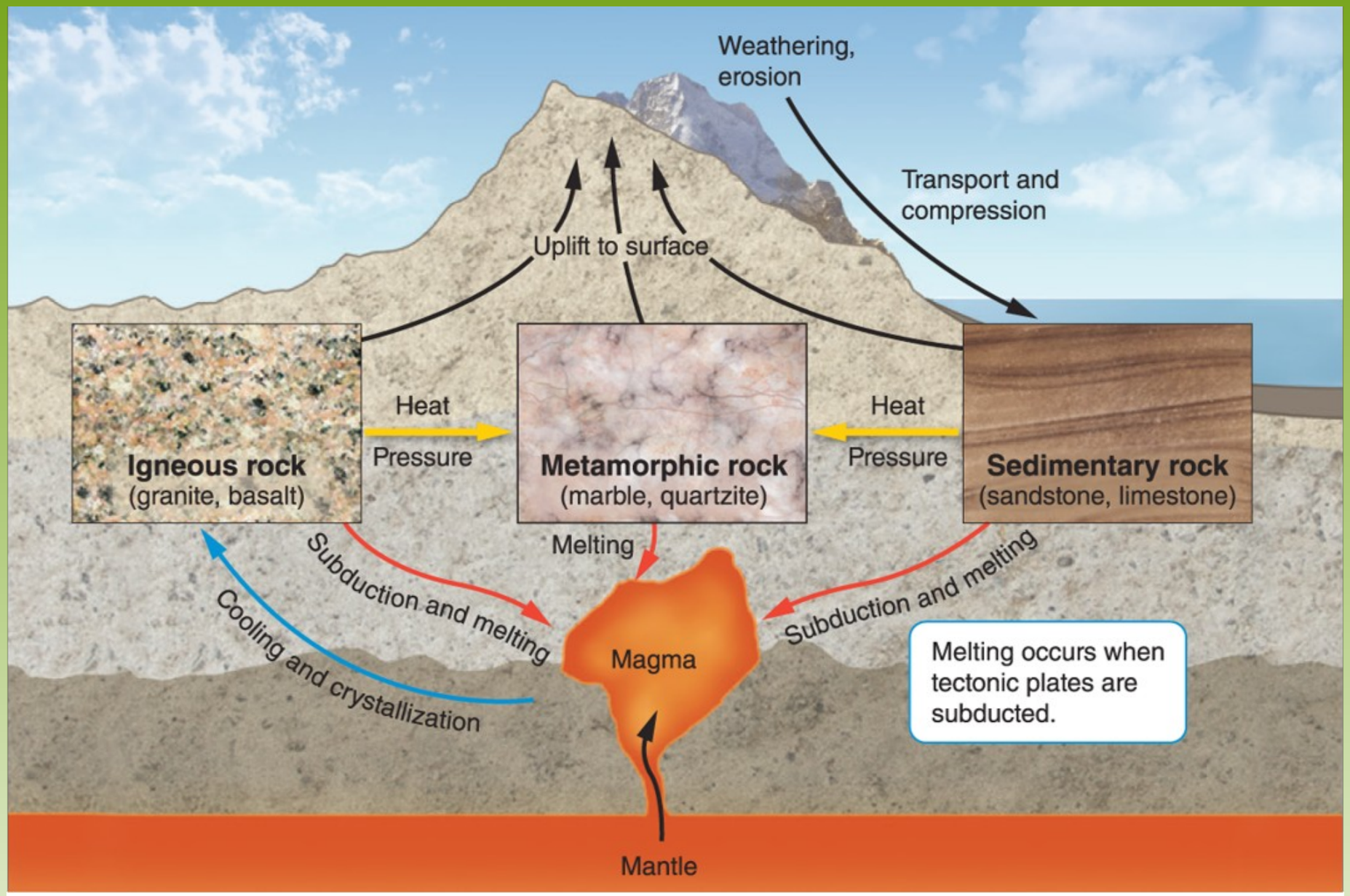

Figure 24.15

The rock cycle. The rock cycle slowly but continuously forms new rock and breaks down old rock. Three types of rock are created in the rock cycle: Igneous rock is formed from magma; sedimentary rock is formed by the compression of sedimentary materials; and metamorphic rock is created when rocks are subjected to high temperatures and pressures.

Igneous Rocks

- **Igneous rock** Rock formed directly from magma.

- **Intrusive igneous rock** Igneous rock that forms when magma rises up and cools in a place underground.

- **Extrusive igneous rock** Rock that forms when magma cools above the surface of Earth.

- **Fracture** In geology, a crack that occurs in rock as it cools.

Sedimentary Rock

- **Sedimentary rock** Rock that forms when sediments such as muds, sands, or gravels are compressed by overlying sediments.

- Sedimentary rocks hold the fossil record that provides a window into our past.

Metamorphic Rocks

- **Metamorphic rock** Rock that forms when sedimentary rock, igneous rock, or other metamorphic rock is subjected to high temperature and pressure.

- Metamorphic rock has been important as a building material throughout human history because it is structurally strong and visually attractive.

Module 25
Weathering and Soil Science

After reading this module, you should be able to

- understand how weathering and erosion occur and how they contribute to element cycling and soil formation.

- explain how soil forms and describe its characteristics.

- describe how humans extract elements and minerals and the social and environmental consequences of these activities.

The processes of weathering and erosion contribute to the recycling of elements

When rock is exposed at Earth's surface, it begins to break down through the processes of weathering and erosion.

Weathering

- **Physical weathering** The mechanical breakdown of rocks and minerals.

- **Chemical weathering** The breakdown of rocks and minerals by chemical reactions, the dissolving of chemical elements from rocks, or both.

- **Acid precipitation** Precipitation high in sulfuric acid and nitric acid from reactions between water vapor and sulfur and nitrogen oxides in the atmosphere. Also known as **Acid rain**.

Erosion

- **Erosion** The physical removal of rock fragments from a landscape or ecosystem.

Erosion is usually the result of two processes:

- Wind, water and ice move materials downslope.
- Living organisms burrow under the soil.

Soil links the rock cycle and the biosphere

Soil serves many functions:

- A medium for plant growth
- A filter for water
- A habitat for living organisms
- A filter for pollutants

Soil links the rock cycle and the biosphere

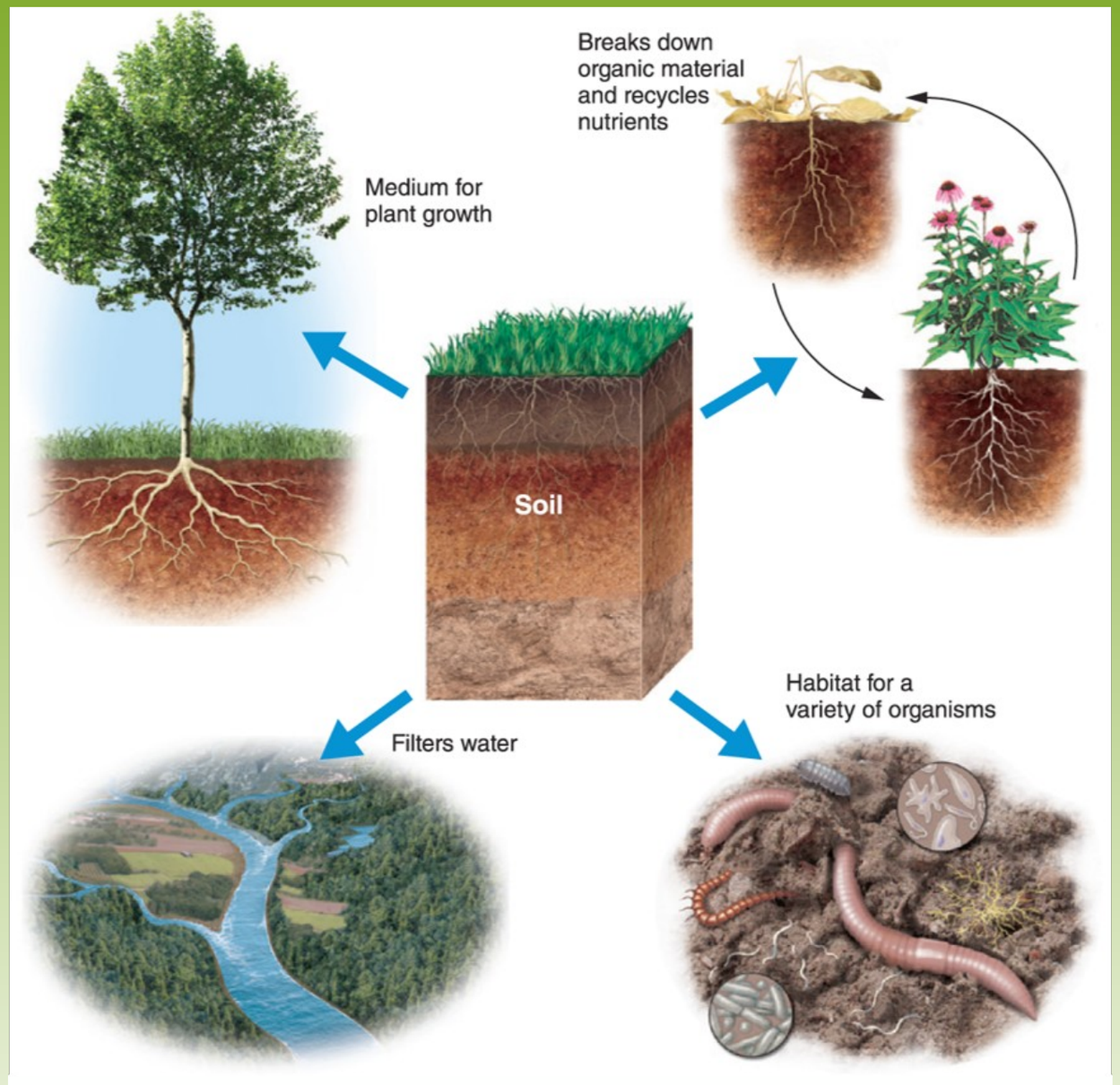

Figure 25.4

Ecosystem services provided by soil.
Soil serves as a medium for plant growth, as a habitat for other organisms, and as a recycling system for organic wastes. Soil also helps to filter and purify water.

The Formation of Soil

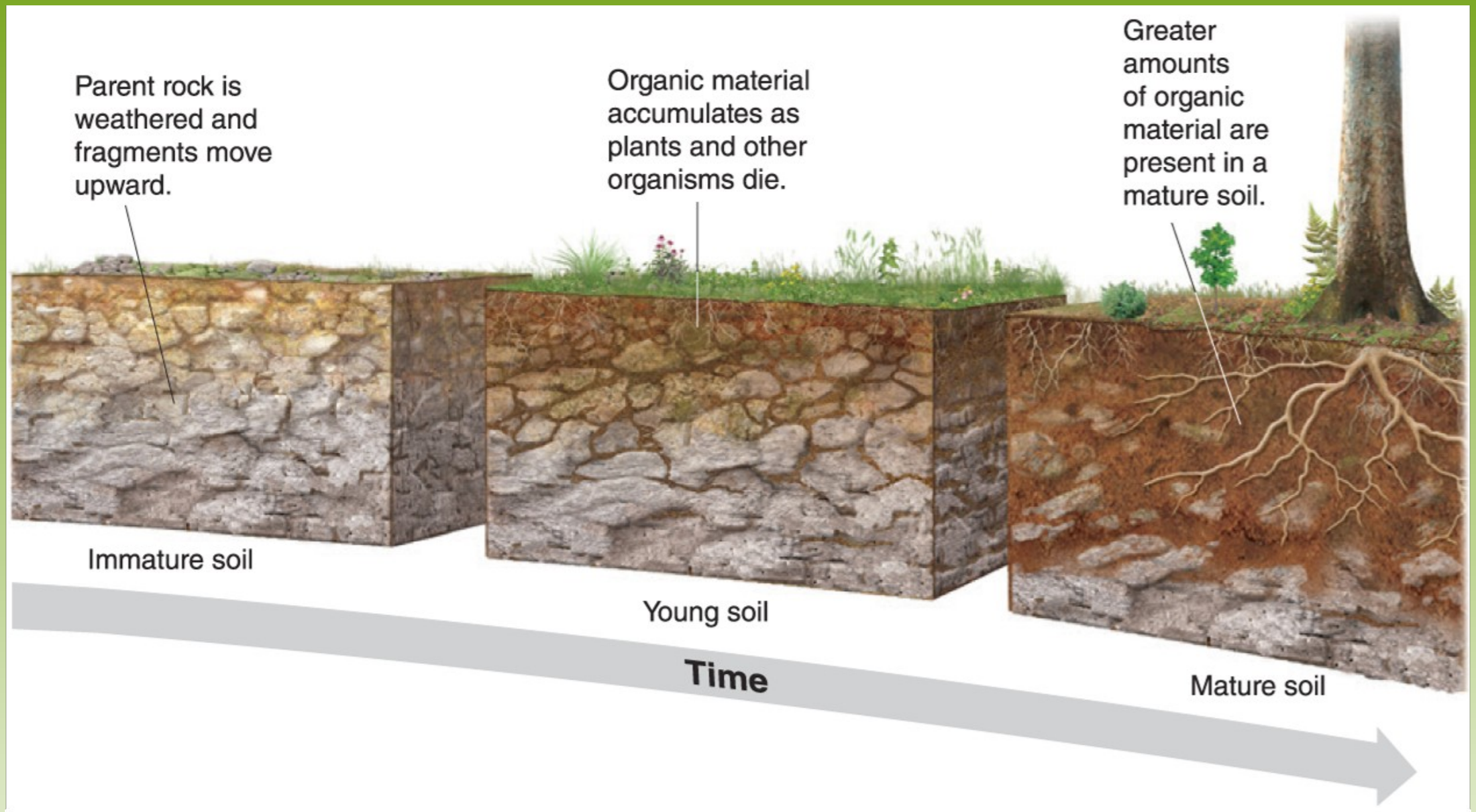

Figure 25.5

Soil formation. Soil is a mixture of organic and inorganic matter. The breakdown of rock and primary minerals from the parent material provides the inorganic matter. The organic matter comes from organisms and their wastes.

The Formation of Soil

Five factors determine the properties of soil:

- **Parent material** The underlying rock material from which the inorganic components of a soil are derived.
- Climate
- Topography
- Organisms
- Time

- **Soil degradation** The loss of some or all of a soil's ability to support plant growth.

Soil Horizons

- **Horizon** A horizontal layer in a soil defined by distinctive physical features such as texture and color.

Soil Horizons

There are five soil horizons:

- **O horizon** The organic horizon at the surface of many soils, composed of organic detritus in various stages of decomposition. **Humus** is the most fully decomposed organic matter in the lowest section of this horizon.

- **A horizon** Frequently the top layer of soil, a zone of organic material and minerals that have been mixed together. Also known as **Topsoil**.

- **E horizon** A zone of leaching, or eluviation, found in some acidic soils under the O horizon or, less often, the A horizon.

- **B horizon** A soil horizon composed primarily of mineral material with very little organic matter.

- **C horizon** The least-weathered soil horizon, which always occurs beneath the B horizon and is similar to the parent material.

Soil Horizons

O horizon: Organic matter in various stages of decomposition

A horizon (topsoil): Zone of overlying organic material mixed with underlying mineral material

E horizon: Zone of leaching of metals and nutrients; occurs in some soils beneath either the O horizon or the A horizon.

B horizon (subsoil): Zone of accumulation of metals and nutrients

C horizon (subsoil): Least-weathered portion of the soil profile, similar to the parent material

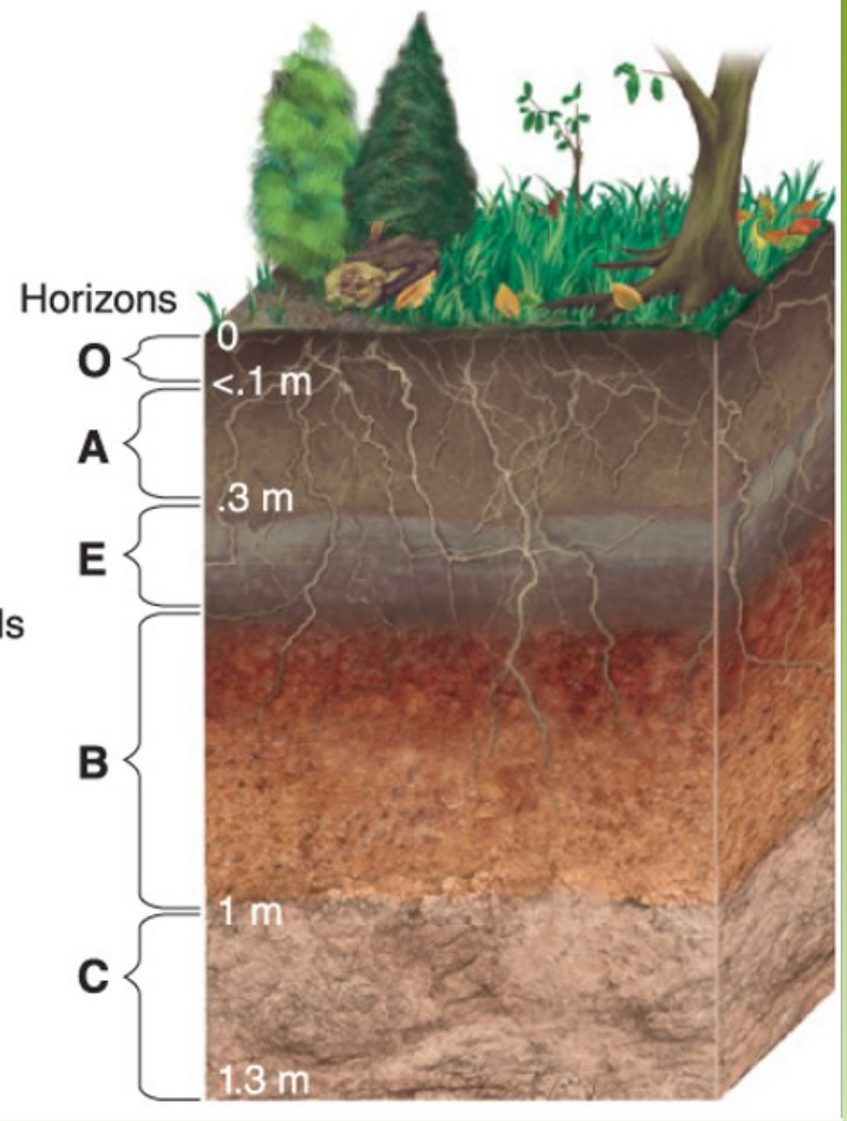

Figure 25.7

Soil horizons. All soils have horizons, or layers, which vary depending on soil-forming factors such as climate, organisms, and parent material. Most soils have either an O or A horizon and usually not both. Some soils that have an O horizon also have an E horizon.

Properties of Soil

There are three properties of soil:

- Physical
- Chemical
- Biological

Properties of Soil

- The physical properties of soil refer to physical characteristics such as size and weight.

- The texture of a soil is determined by its percentage of sand, silt, and clay.

- Soil permeability depends on its texture.

Properties of Soil

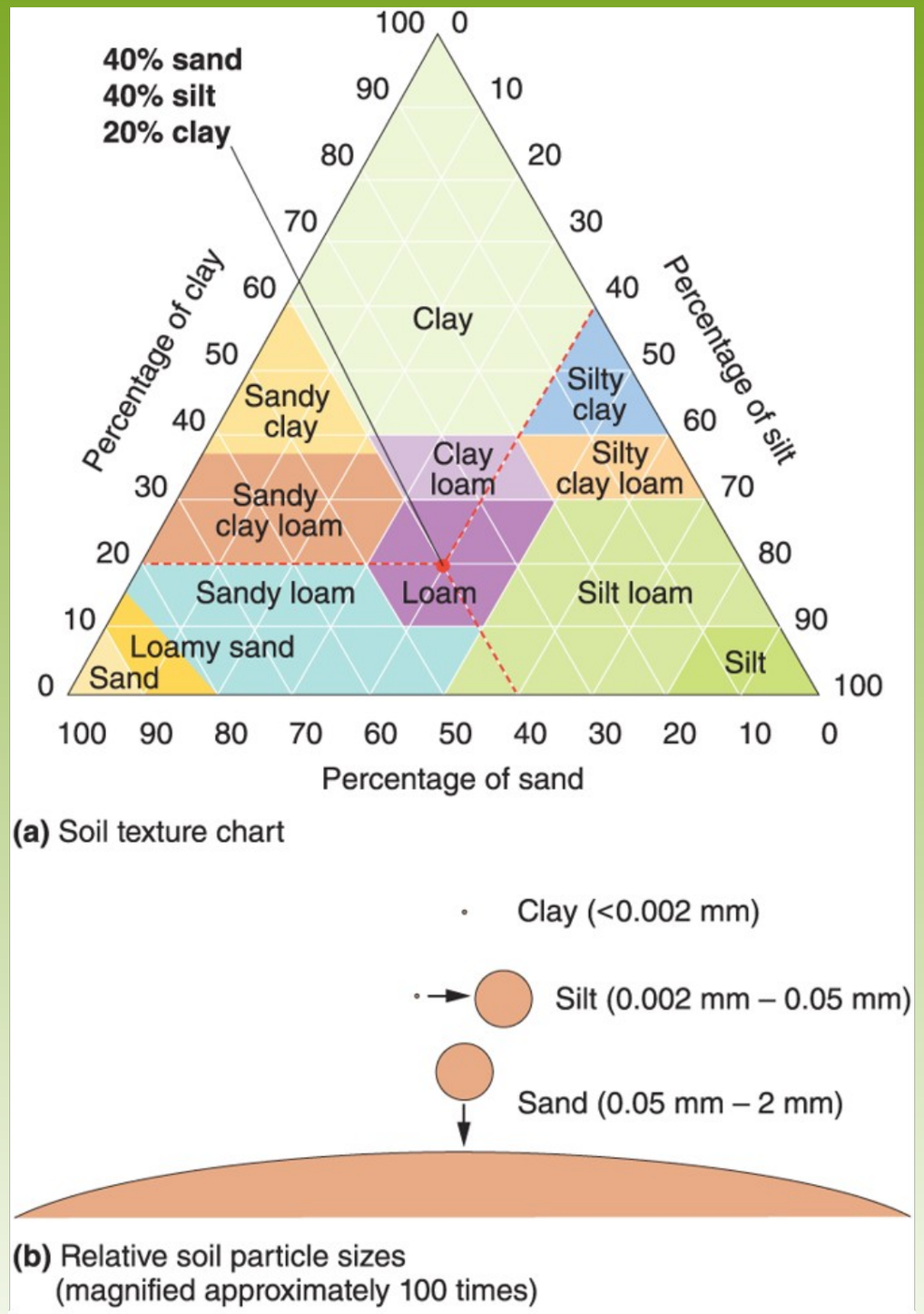

Figure 25.8

Soil properties. (a) Soils consist of a mixture of clay, silt, and sand. The relative proportions of these particles determine the texture of the soil.
(b) The relative sizes of sand, silt, and clay.

Properties of Soil

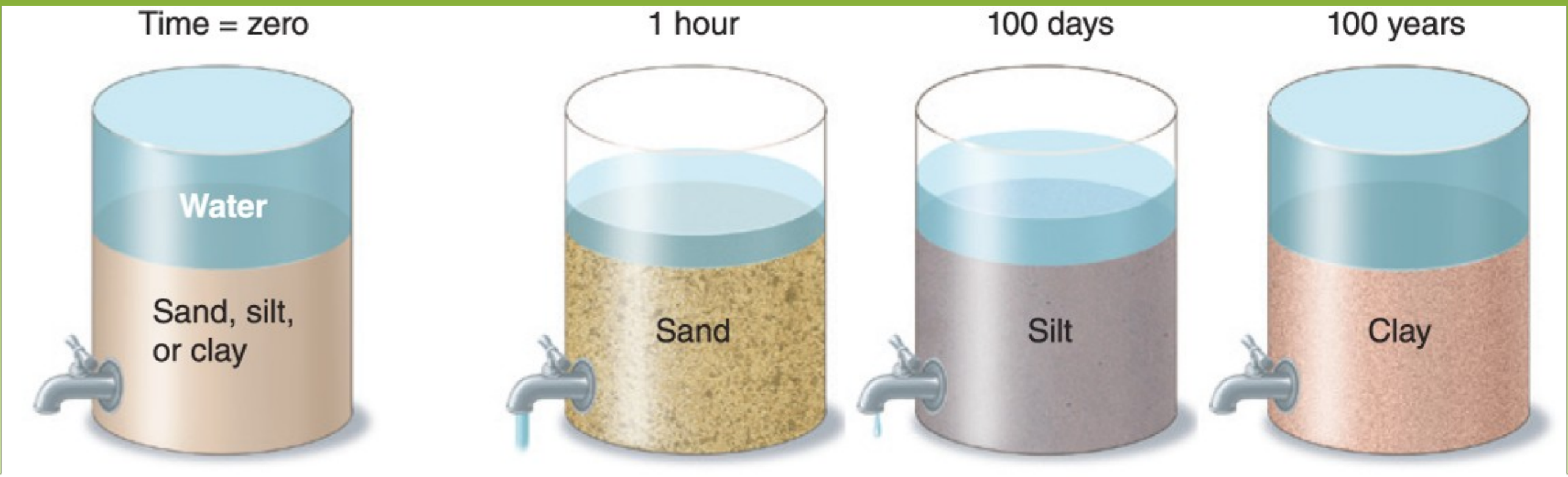

Figure 25.9

Soil permeability. The permeability of soil depends on its texture. Sand, with its large, loosely packed particles, drains quickly. Clay drains much more slowly.

Properties of Soil

- The chemical properties of soil help determine how a soil functions.

- **Cation exchange capacity (CEC)** The ability of a particular soil to adsorb and release cations.

- **Base saturation** The proportion of soil bases to soil acids, expressed as a percentage.

Properties of Soil

- The biological properties of soil refer to the activities of the many organisms living in soil.

Three groups of organisms account for most of the biological activity in soil:

- Fungi
- Bacteria
- Protozoans

Properties of Soil

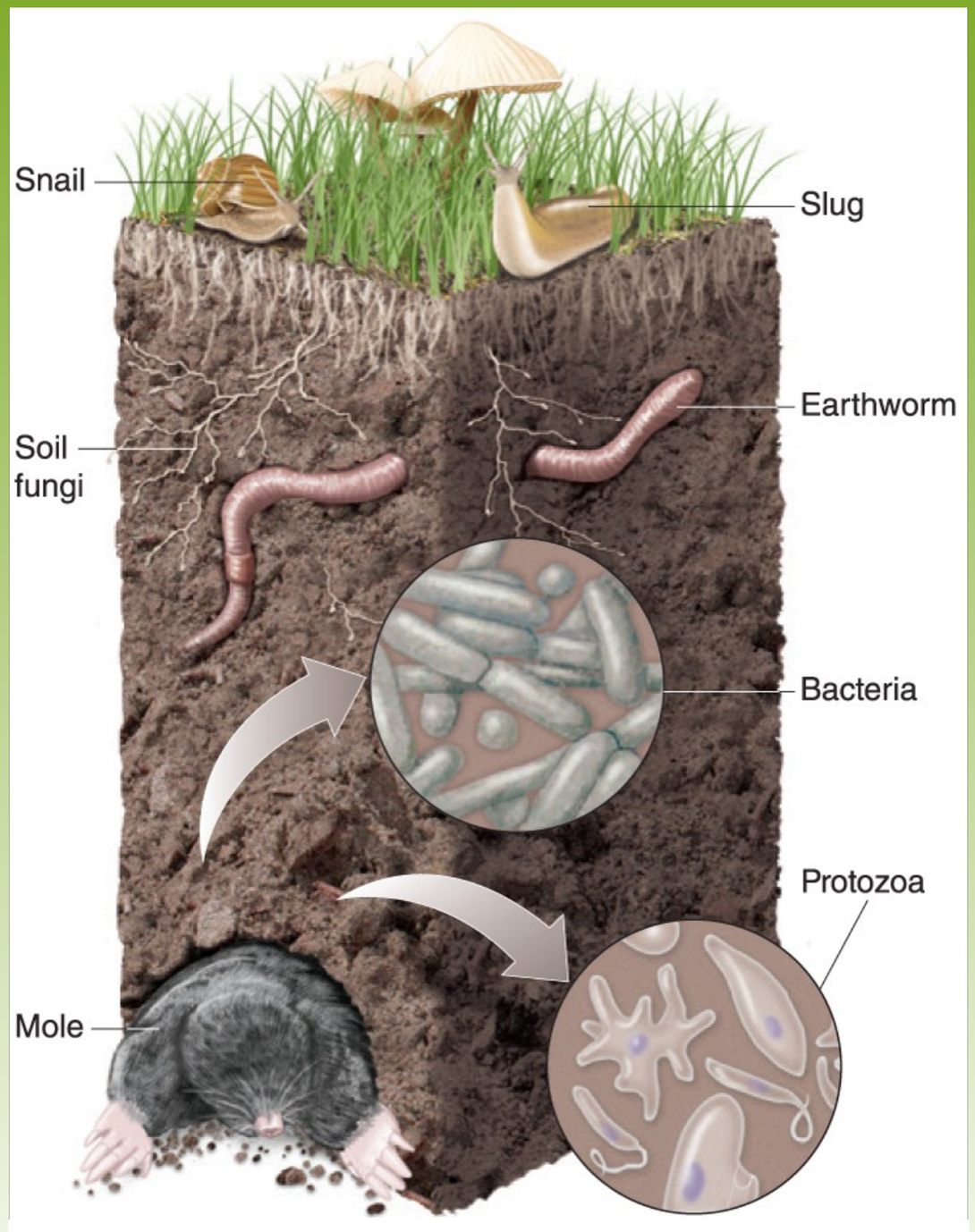

Figure 25.10

Soil organisms. Bacteria, fungi, and protozoans account for 80 to 90 percent of soil organisms. Also present are snails, slugs, insects, earthworms, and rodents.

The distribution of minerals on Earth has social and environmental consequences

- Rock and minerals are finite resources.
- Some resources are abundant but others are rare.

Abundance of Ores and Metals

- **Crustal abundance** The average concentration of an element in Earth's crust.

- **Ore** A concentrated accumulation of minerals from which economically valuable materials can be extracted.

- **Metal** An element with properties that allow it to conduct electricity and heat energy, and to perform other important functions.

- **Reserve** In resource management, the known quantity of a resource that can be economically recovered.

Abundance of Ores and Metals

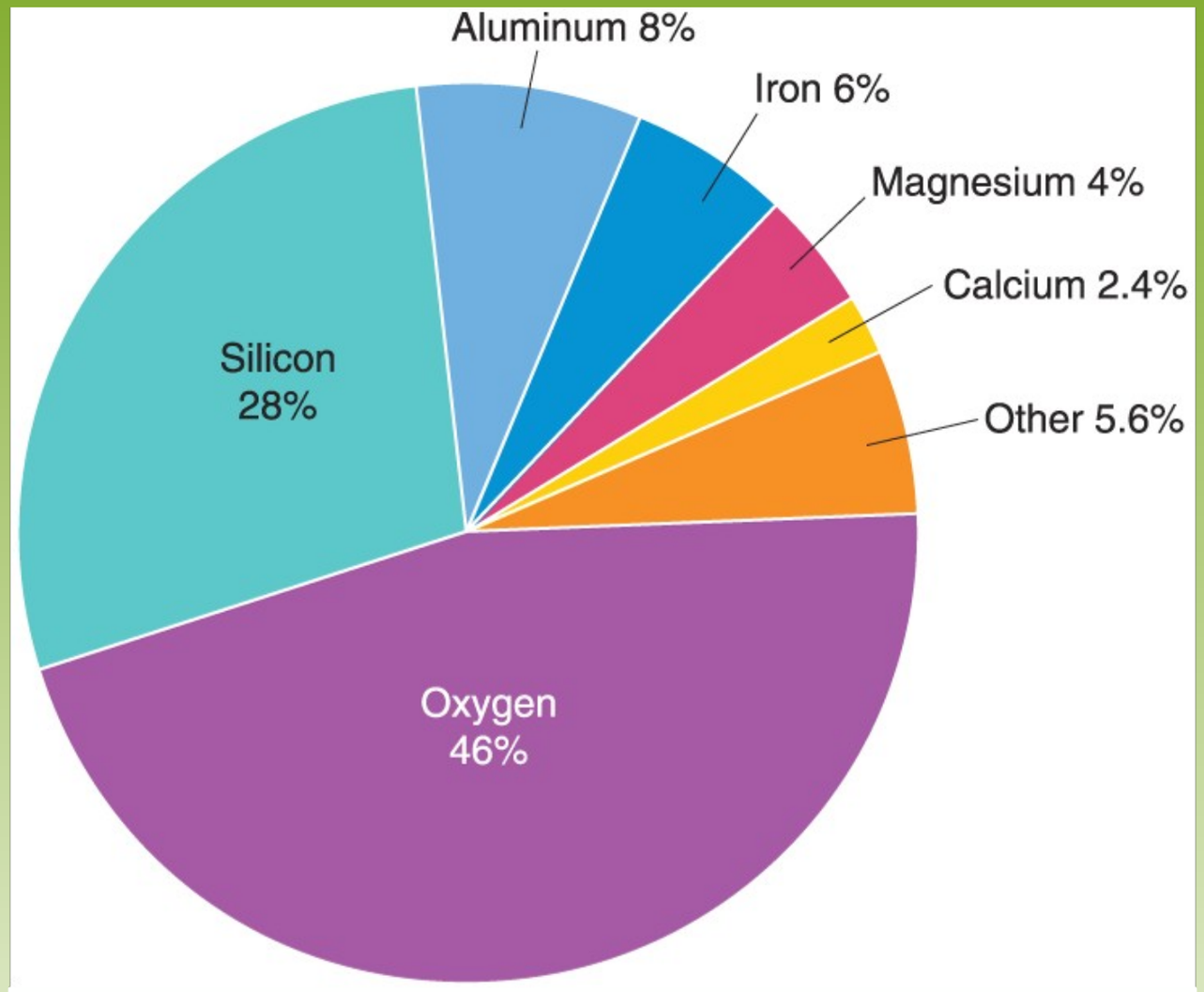

Figure 25.11

Elemental composition of Earth's crust. Oxygen is the most abundant element in the crust. Silicon, aluminum, and iron are the next three most abundant elements.

Abundance of Ores and Metals

TABLE 25.1 Approximate supplies of metal reserves remaining

Metal	Global reserves remaining (years)	U.S. reserves remaining (years)
Aluminum (Al)	330	2
Copper (Cu)	40	25
Lead (Pb)	20	15
Zinc (Zn)	20	15
Gold (Au)	20	15
Nickel (Ni)	35	5
Cobalt (Co)	50	30
Manganese (Mn)	40	0
Chromium (Cr)	20	0

Data from S. Marshak, Earth: Portrait of a Planet, 3rd ed. (W. W. Norton, 2007); U.S. Geological Survey Mineral Commodity Summaries 2017, https://minerals.usgs.gov/minerals/pubs/mcs/2017/mcs2017.pdf

Mining Techniques

- Mining can be on the surface or below the surface.

Surface mining includes:

- Strip mining
- Open-pit mining
- Mountaintop removal
- Placer mining

Surface Mining Techniques

- **Strip mining** The removal of strips of soil and rock to expose ore.

- **Mine tailings** Unwanted waste material created during mining including mineral and other residues that are left behind after the desired metal or ore is removed.

- **Open-pit mining** A mining technique that creates a large visible pit or hole in the ground.

- **Mountaintop removal** A mining technique in which the entire top of a mountain is removed with explosives.

- **Placer mining** The process of looking for minerals, metals, and precious stones in river sediments.

Subsurface Mining Techniques

- **Subsurface mining** Mining techniques used when the desired resource is more than 100 m (328 feet) below the surface of Earth.

- Coal, diamonds, and gold are some of the materials extracted by subsurface mining.

The Environment and Safety

TABLE 25.2 Types of mining operations and their effects

Type of operation	Effects on air	Effects on water	Effects on soil	Effects on biodiversity	Effects on humans
Surface mining	Significant dust from earth-moving equipment	Contamination of water that percolates through tailings	Most soil removed from site; may be replaced if reclamation occurs	Habitat alteration and destruction over the surface areas that are mined	Minimal in the mining process, but air quality and water quality can be adversely affected near the mining operation
Subsurface mining	Minimal dust at the mining site, but emissions from fossil fuels used to power mining equipment can be significant	Acid mine drainage as well as contamination of water that percolates through tailings		Road construction to mines fragments habitat	Occupational hazards in mine; possibility of death or chronic respiratory diseases such as black lung disease