14 Geology and Nonrenewable Minerals

CORE CASE STUDY Environmental Effects of Gold Mining

Mineral resources extracted from the earth's crust are processed into an incredible variety of products that can make life easier and provide economic benefits and jobs. But extracting minerals from the ground and converting them to such products have a number of harmful environmental effects.

For example, gold miners typically remove enough rock to equal the weight of 50 automobiles to extract an amount of gold that would fit inside your clenched fist. Most newlyweds would be surprised to know that about 5.5 metric tons (6 tons) of mining waste was created to make their two gold wedding rings. This waste is left piled near the mine sites and can pollute the air and nearby surface water.

Between 1980 and 2007, global gold production more than doubled. In 2007, South Africa, Australia, the United States, and Canada were, in order, the world's top producers of gold.

In Australia and North America, a mining technology called *cyanide heap leaching* is used by mining companies to level entire mountains of rock containing only small concentrations of gold. To extract the gold, miners spray a solution of highly toxic cyanide salts (which react with gold) onto huge open-air piles of crushed rock. The solution then drains into storage ponds (Figure 14-1). After the solution is circulated a number of times, the gold is removed from the ponds.

This cyanide is extremely toxic to birds and mammals drawn to these ponds in search of water. The ponds can also leak or overflow, posing threats to underground drinking water supplies and fish and other forms of life in nearby lakes and streams. Special liners in the collection ponds can prevent leaks, but some have failed. According to the U.S. Environmental Protection Agency, all such liners will eventually leak.

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Figure 14-1 Gold mine with cyanide leach piles and ponds in the Black Hills of the U.S. state of South Dakota.

In 2000, snow and heavy rains washed out an earthen dam on one end of a cyanide leach pond at a gold mine in Romania. The dam's collapse released large amounts of water laced with cyanide and toxic metals into the Tisza and Danube Rivers flowing through parts of Romania, Hungary, and Yugoslavia.

Several hundred thousand people living along these rivers were told not to fish or to drink or withdraw water from affected rivers or from wells along the rivers. Food industries and paper mills were shut down. Thousands of fish and other aquatic plants and animals were killed. This accident and another one that occurred in January 2001 could have been prevented if the mining company had installed a stronger containment dam and a backup collection pond to prevent leakage into nearby surface water.

In this chapter, we will look at the earth's dynamic geologic processes, the minerals such as gold that some of these processes produce, environmental effects of using such resources, their potential supplies, and how we might use them more sustainably.

Key Questions and Concepts

14-1 What are the earth's major geological processes and hazards?

CONCEPT 14-1A Gigantic plates in the earth's crust move very slowly atop the planet's mantle, and wind and water move matter from place to place across the earth's surface.

CONCEPT 14-1B Natural geological hazards such as earthquakes, tsunamis, volcanoes, and landslides can cause considerable damage.

14-2 How are the earth's rocks recycled?

CONCEPT 14-2 The three major types of rocks found in the earth's crust—sedimentary, igneous, and metamorphic—are recycled very slowly by the processes of erosion, melting, and metamorphism.

14-3 What are mineral resources and what are the environmental effects of using them?

CONCEPT 14-3A Some naturally occurring materials in the earth's crust can be extracted and made into useful products in processes that provide economic benefits and jobs.

CONCEPT 14-3B Extracting and using mineral resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.

14-4 How long will supplies of nonrenewable mineral resources last?

CONCEPT 14-4A All nonrenewable mineral resources exist in finite amounts, and as we get closer to depleting any mineral resource, the environmental impacts of extracting it generally become more harmful.

CONCEPT 14-4B An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are limits to this effect.

14-5 How can we use mineral resources more sustainably?

CONCEPT 14-5 We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.

Note: Supplements 2 (p. S4), 6 (p. S39), and 13 (p. S78) can be used with this chapter.

Civilization exists by geological consent,
subject to change without notice.

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14-1 What Are the Earth's Major Geological Processes and Hazards?

▶ **CONCEPT 14-1A Gigantic plates in the earth's crust move very slowly atop the planet's mantle, and wind and water move matter from place to place across the earth's surface.**

▶ **CONCEPT 14-1B Natural geological hazards such as earthquakes, tsunamis, volcanoes, and landslides can cause considerable damage.**

The Earth Is a Dynamic Planet

Geology, one of the subjects of this chapter, is the science devoted to the study of dynamic processes occurring on the earth's surface and in its interior. As the primitive earth cooled over eons, its interior separated into three major concentric zones: the *core,* the *mantle,* and the *crust* (Figure 3-6, p. 55).

The **core** is the earth's innermost zone. It is extremely hot and has a solid inner part, surrounded by a liquid core of molten or semisolid material. Surrounding the core is a thick zone called the **mantle.** Most of the mantle is solid rock, but under its rigid outermost part is the *asthenosphere*—a zone of hot, partly melted rock that flows and can be deformed like soft plastic.

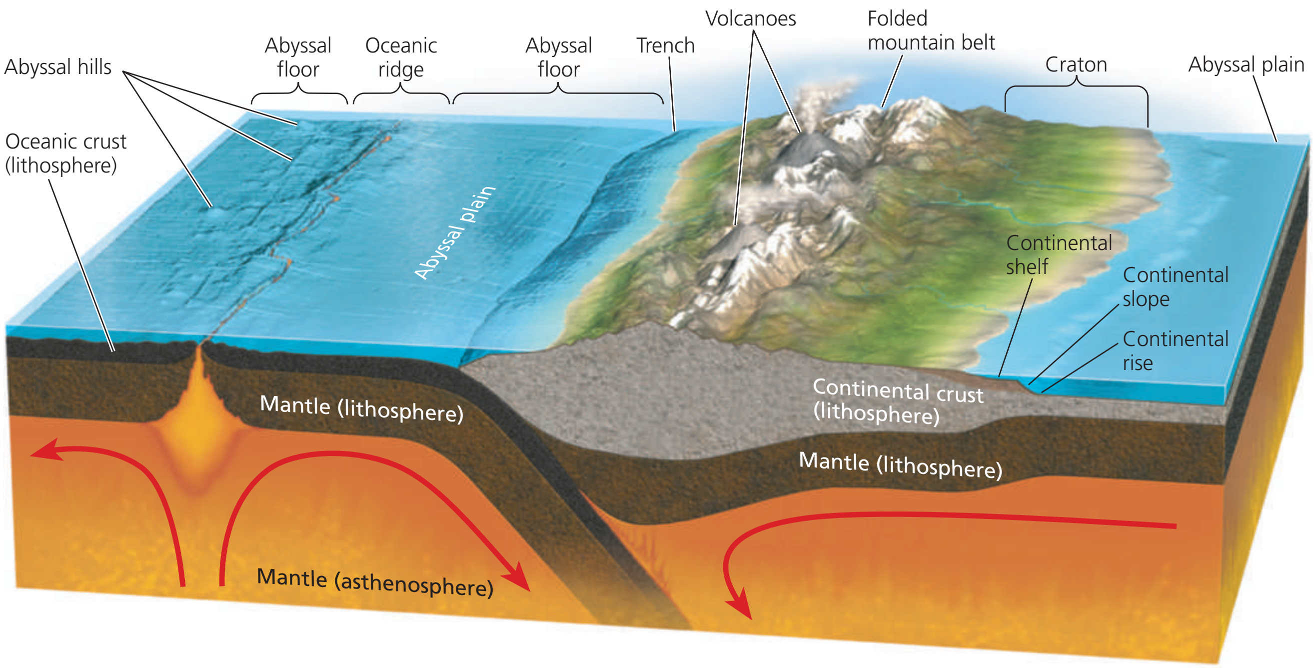
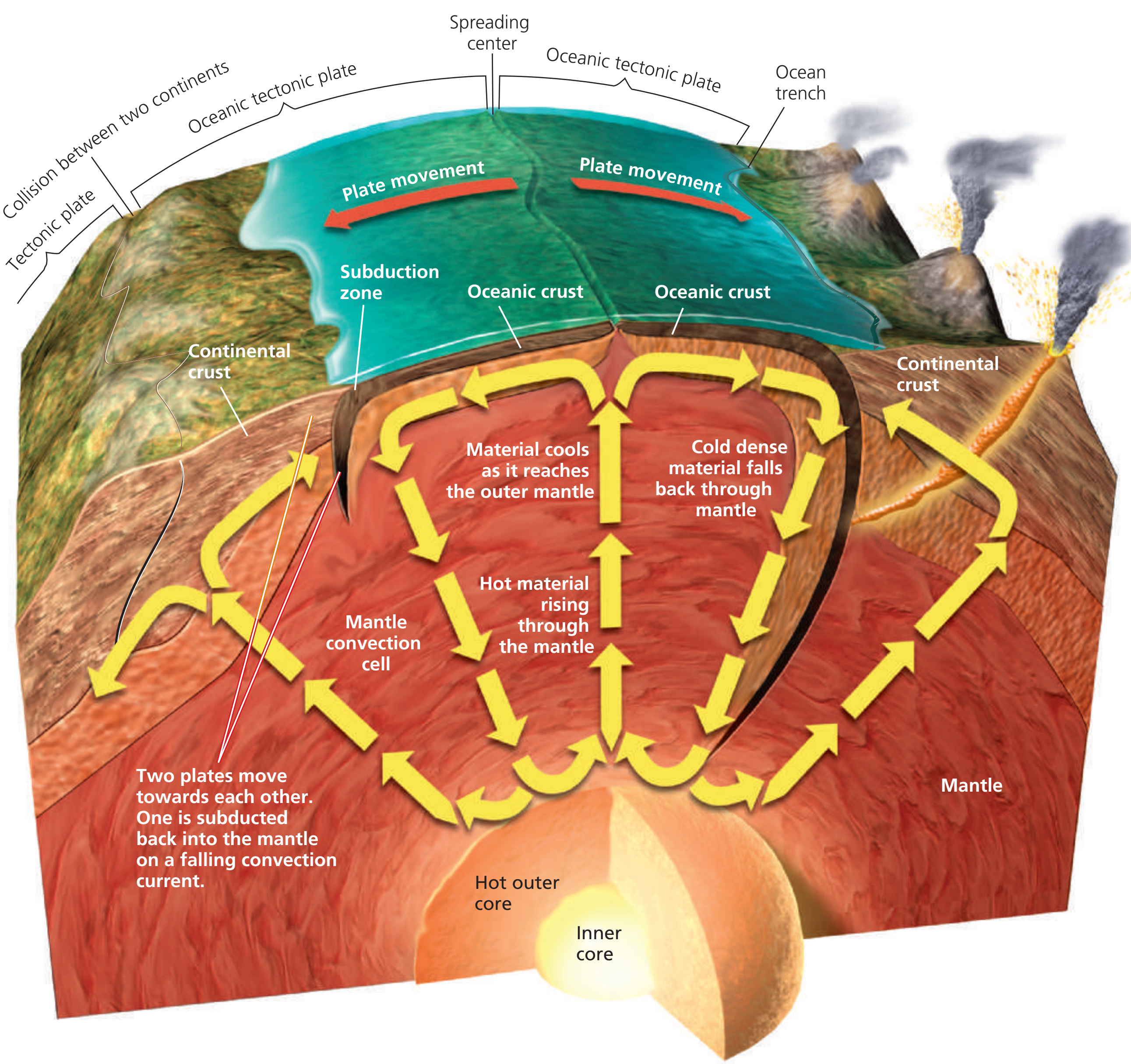


Figure 14-2 Major features of the earth's crust and upper mantle. The *lithosphere,* composed of the crust and outermost mantle, is rigid and brittle. The *asthenosphere,* a zone in the mantle, can be deformed by heat and pressure.



CENGAGENOW™
Active Figure 14-3 The earth's crust is made up of a mosaic of huge rigid plates, called *tectonic plates,* which move very slowly across the asthenosphere in response to forces in the mantle. *See an animation based on this figure at* CengageNOW™.

The outermost and thinnest zone of the earth is the **crust.** It consists of the *continental crust,* which underlies the continents (including the continental shelves extending into the oceans), and the *oceanic crust,* which underlies the ocean basins and makes up 71% of the earth's crust (Figure 14-2).

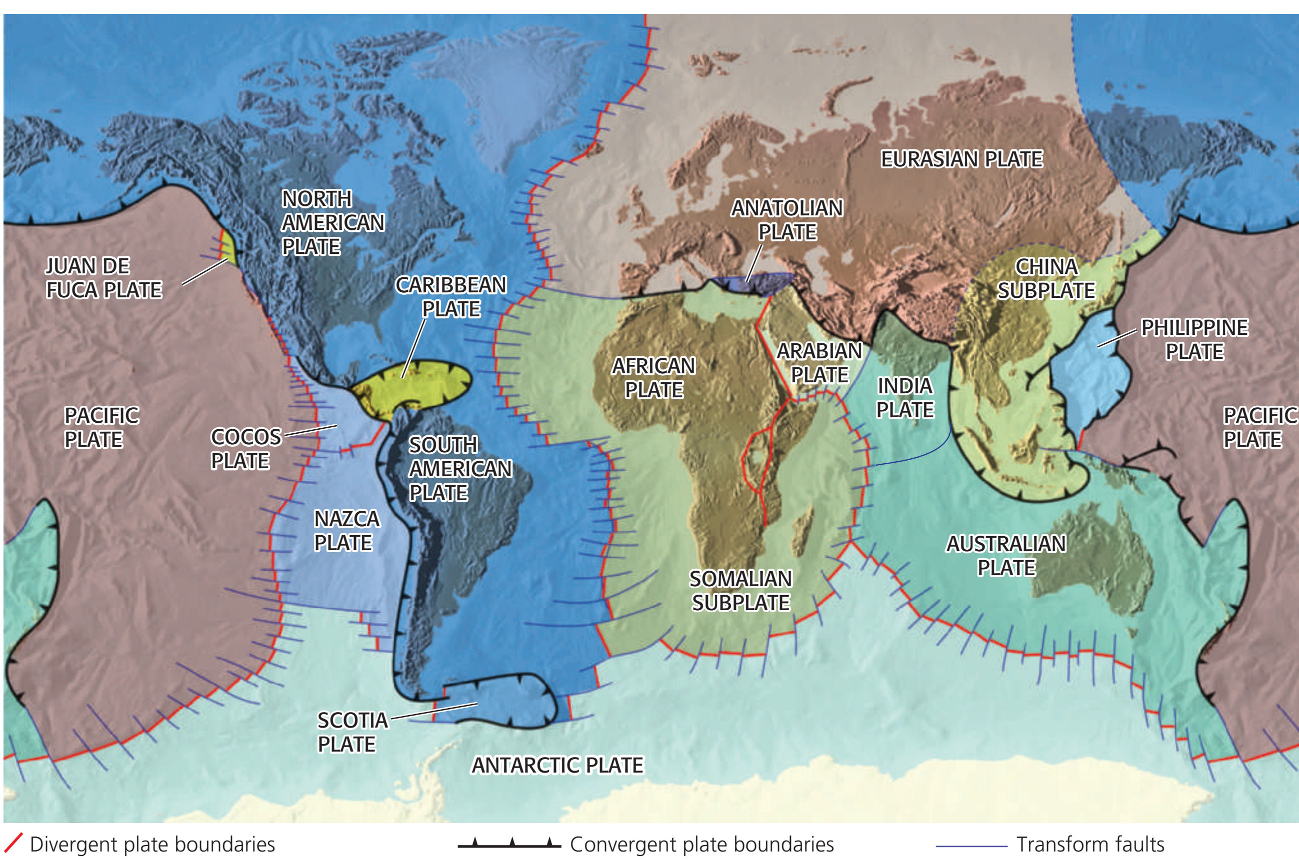
The Earth Beneath Your Feet Is Moving

We tend to think of the earth's crust, mantle, and core as fairly static. In reality, *convection cells* or *currents* move large volumes of rock and heat in loops within the mantle like gigantic conveyer belts (Figure 14-3). The flows of energy and heated material in the mantle's convection cells cause a dozen or so huge rigid plates, called **tectonic plates,** to move extremely slowly atop the denser mantle on hot soft rock in the underlying asthenosphere (Figures 14-3 and 14-4) (**Concept 14-1A**). These thick plates are composed of the continental and oceanic crust and the rigid, outermost part of the mantle (above the asthenosphere), a combination called the **lithosphere.**

These gigantic plates are somewhat like the world's largest and slowest-moving surfboards. Their typical speed is about the rate at which fingernails grow. You ride on one of these plates throughout your entire life without noticing. And throughout the earth's history, continents have split apart and joined as tectonic plates drifted thousands of kilometers back and forth atop the earth's mantle (Figure 4-6, p. 85).

Much of the geologic activity at the earth's surface takes place at the boundaries between tectonic plates as they separate, collide, or slide past one another. The tremendous forces produced at these plate boundaries can cause mountains to form, earthquakes to shake parts of the crust, and volcanoes to erupt.

When oceanic plates move apart from one another (*divergent plates*) molten rock, or *magma,* flows up through the resulting cracks. This creates *oceanic ridges* (Figure 14-2), some of which have higher peaks and deeper canyons than earth's continents have. When an oceanic plate collides with a continental plate (*convergent plates*), the continental plate usually rides up over the denser oceanic plate and pushes it down into the mantle (Figure 14-3) in a process called *subduction.* The area where this collision and subduction takes place is



CENGAGENOW™ **Active Figure 14-4** The earth's major tectonic plates. *See an animation based on this figure at* CengageNOW. **Question:** What plate are you riding on?

Figure 14-5 The San Andreas Fault as it crosses part of the Carrizo plain between San Francisco and Los Angeles, California (USA). This fault, which runs along almost the full length of California, is responsible for earthquakes of various magnitudes. **Question:** Is there a transform fault near where you live or go to school? (See Figure 14-4.)

called a *subduction zone.* Over time, the subducted plate melts and then rises again to the earth's surface as magma. A *trench* (Figure 14-2) ordinarily forms at the boundary between the two converging plates. When two continental plates collide, they push up mountain ranges, such as the Himalayas, along the collision boundary.

The third type of boundary is a *transform fault,* where plates slide and grind past one another along a fracture (fault) in the lithosphere. Most transform faults are located on the ocean floor but a few are found on land. For example, the North American Plate and the Pacific Plate slide past each other along California's San Andreas fault (Figure 14-5).

Some Parts of the Earth's Surface Build Up and Some Wear Down

Internal geologic processes, generated by heat from the earth's interior, typically build up the earth's surface in the form of continental and oceanic crust, including mountains and volcanoes (Figures 14-2 and 14-3).

By contrast, *external geologic processes,* driven directly or indirectly by energy from the sun (mostly in the form of flowing water and wind) and influenced by gravity, tend to wear down the earth's surface and move matter from one place to another (**Concept 14-1A**).

One major external geologic process is **weathering,** the physical, chemical, and biological processes that break down rocks into smaller particles that help build soil (Figure 14-6). These weathering processes play a key role in soil formation (Science, Focus, Figure 12-A, p. 281), a vital part of the earth's natural capital (**Concept 1-1A**, p. 6).

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Another major external process is *erosion,* discussed in Chapter 12 (pp. 287–288). In this process, material is dissolved, loosened, or worn away from one part of the earth's surface (Figure 12-10, p. 287) and deposited elsewhere. Flowing streams and rain cause most erosion. Wind also blows particles of soil from one area to another. Human activities—particularly those that destroy vegetation that holds soil in place—accelerate the process (Figure 7-13, p. 152, and Figure 10-11, p. 222).

Slowly flowing bodies of ice called *glaciers* also cause erosion. Under the influence of gravity, glaciers move slowly down a mountainside or over a wide area. During this movement, rock frozen to the glacial ice is pulled along or plucked out of the land surface. During the last ice age, which ended about 10,000 years ago, ice sheets called *continental glaciers* covered vast areas of North America, Europe, and Asia. The Great Lakes, the world's largest mass of freshwater, formed during this period as retreating glaciers gouged out huge basins. As the climate warmed and the glaciers melted, water filled these basins.

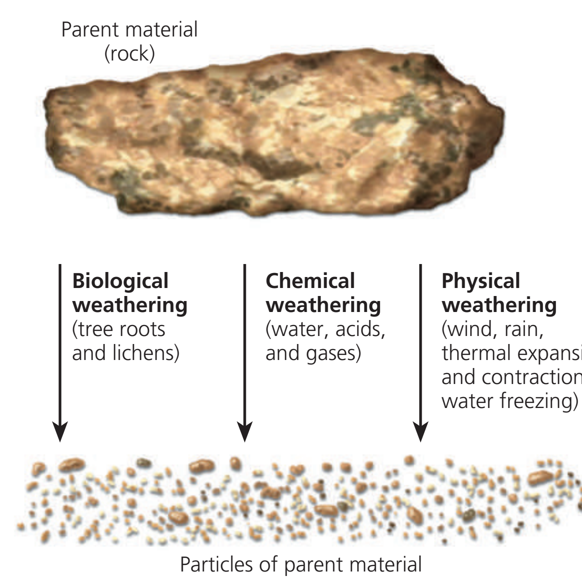


Figure 14-6 *Weathering:* Biological, chemical, and physical processes weather or convert rock into smaller fragments and particles. It is the first step in soil formation.

Volcanoes Release Molten Rock from the Earth's Interior

An active **volcano** occurs where magma reaches the earth's surface through a central vent or a long crack, called a *fissure* (Figure 14-7). Many volcanoes form when one tectonic plate slides under or moves away from another plate. Magma that reaches the earth's surface is called *lava.* Volcanic activity can release debris ranging from large chunks of lava rock to glowing hot ash, liquid lava, and gases (such as water vapor, carbon dioxide, and sulfur dioxide) into the environment (**Concept 14-1B**). Much of the world's volcanic activity is concentrated along the boundaries of the earth's tectonic plates (Figure 14-4).

The largest volcanic eruption during the 20th century occurred in 1991 when Mount Pinatubo exploded. It killed several hundred people, despite the evacuation of more than 200,000 people. Buildings covered with wet ash collapsed and the volcano ejected enough material into the atmosphere to reduce incoming solar energy and cool the earth's average temperature for 15 months.

The worst volcanic disaster in U.S. history occurred when Mount St. Helens in the state of Washington erupted on May 18, 1980. Fifty-seven people and large numbers of wild animals were killed, and large areas of forests were obliterated. However, through ecological succession, some of the vegetation has returned.

We tend to think of volcanic activity as an undesirable event, but it does provide some benefits. For example, it creates outstanding scenery in the form of majestic mountains, some lakes (such as Crater Lake in Oregon; Figure 8-16, left, p. 175), and other landforms. Perhaps the most important benefit of volcanism is the highly fertile soils produced by the weathering of lava.

We can reduce the loss of human life and some of the property damage caused by volcanic eruptions in several ways. For example, we use historical records and geologic measurements to identify high-risk areas, so that people can avoid living in those areas. We also use monitoring devices that warn us when volcanoes are likely to erupt, and we have developed evacuation plans for areas prone to volcanic activity.

Earthquakes Are Geological Rock-and-Roll Events

Forces inside the earth's mantle and along its surface push, deform, and stress rocks. At some point, the stress can cause the rocks to suddenly shift or break and produce a transform fault or fracture in earth's crust (Figure 14-5). When a fault forms, or when there is abrupt movement on an existing fault, energy that has accumulated over time is released in the form of vibrations, called *seismic waves,* which move in all directions

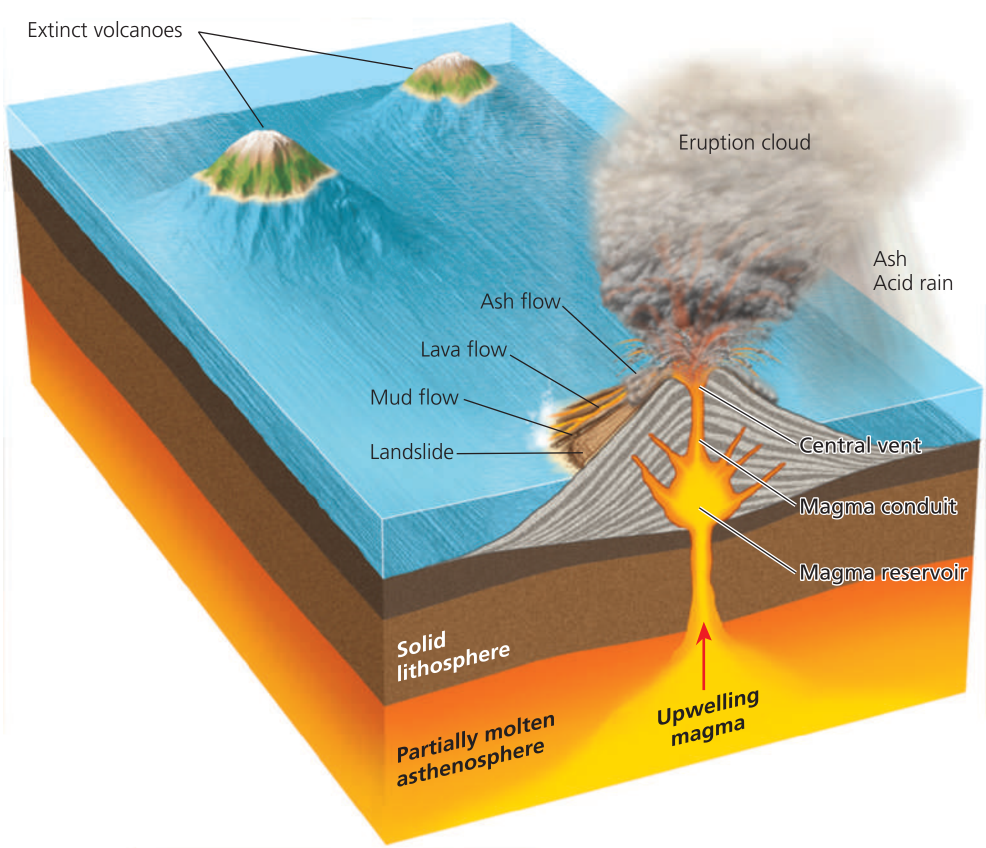


Figure 14-7 A *volcano* is created when magma in the partially molten asthenosphere rises in a plume through the lithosphere to erupt on the surface as lava, which builds a cone. Sometimes, internal pressure is high enough to cause lava, ash, and gases to be ejected into the atmosphere or to flow over land, causing considerable damage (**Concept 14-1B**). Chains of islands have been created by volcanoes that erupted and then became inactive.

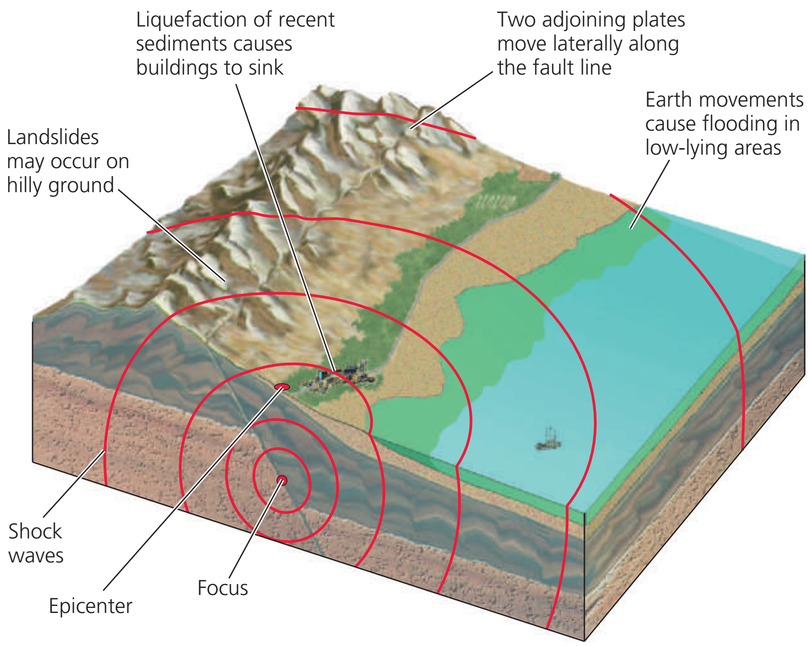


Figure 14-8 Major features and effects of an *earthquake,* one of nature's most powerful events.

through the surrounding rock. This internal geological process is called an **earthquake** (Figure 14-8 and **Concept 14-1B**). Most earthquakes occur at the boundaries of tectonic plates (Figure 14-4) when colliding plates create tremendous pressures in the earth's crust or when plates slide past one another at transform faults (Figure 14-5).

The place where an earthquake begins, often far below the earth's surface is called the *focus* (Figure 14-8). The earthquake's *epicenter* is found on the earth's surface directly above the focus. Relief of the earth's internal stress releases energy as shock (seismic) waves, which move outward from the earthquake's focus like ripples in a pool of water.

Scientists measure the severity of an earthquake by the *magnitude* of its seismic waves. The magnitude is a measure of ground motion (shaking) caused by the earthquake, as indicated by the *amplitude,* or size of the seismic waves when they reach a recording instrument, called a *seismograph.*

Each year, scientists record the magnitudes of more than 1 million earthquakes, most of which are too small to feel. Scientists use the *Richter scale,* on which each unit has amplitude 10 times greater than the next smaller unit. Thus, a magnitude 5.0 earthquake would result in ten times more ground shaking than a magnitude 4.0 earthquake. And the amount of ground movement from a magnitude 7.0 quake is 100 times greater than that of a magnitude 5.0 quake. Seismologists rate earthquakes as *insignificant* (less than 4.0 on the Richter scale), *minor* (4.0–4.9), *damaging* (5.0–5.9), *destructive* (6.0–6.9), *major* (7.0–7.9), and *great* (over 8.0). The largest recorded earthquake occurred in Chile on May 22, 1960 and measured 9.5 on the Richter scale.

Earthquakes often release *aftershocks* that gradually decrease in frequency over periods of as long as several months. Some are preceded by *foreshocks,* which occur from seconds to weeks before the main shock.

The *primary effects of earthquakes* include shaking and sometimes a permanent vertical or horizontal displacement of the ground. These effects may have serious consequences for people and for buildings, bridges, freeway overpasses, dams, and pipelines. A major earthquake is a very large rock-and-roll geological event.

One way to reduce the loss of life and property damage from earthquakes is to examine historical records and make geologic measurements to locate active fault zones. We can then map high-risk areas and establish building codes that regulate the placement and design of buildings in such areas. Then people can evaluate the risk and factor it into their decisions about where to live. Figure 14-9 shows the areas of greatest earthquake risk in the United States and Figure 14-10 shows areas of such risk throughout the world.

We can also increase research geared toward predicting when and where earthquakes will occur. And engineers know how to make homes, large buildings, bridges, and freeways more earthquake resistant. But this can be expensive, especially the reinforcement of existing structures.

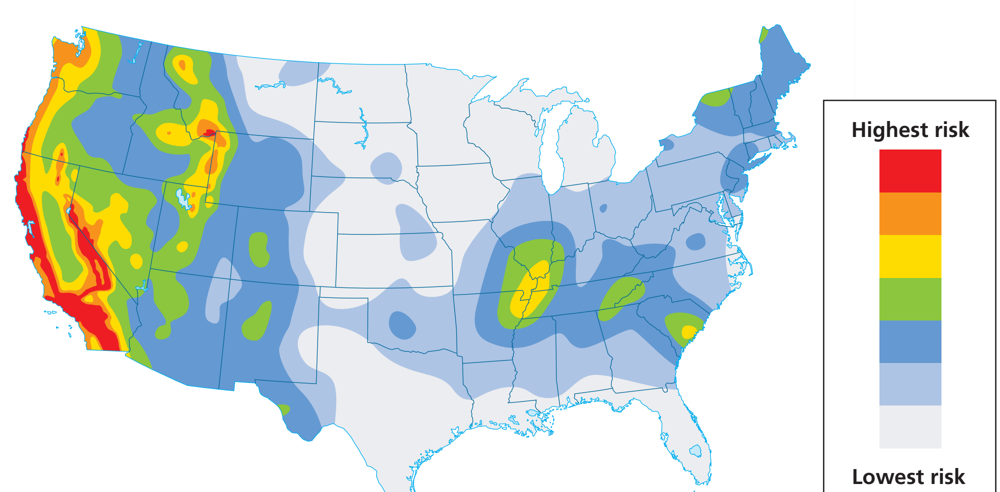


Figure 14-9 Areas of greatest earthquake (seismic) risk in the United States. **Question:** What is the degree of risk where you live or go to school? (Data from U.S. Geological Survey)

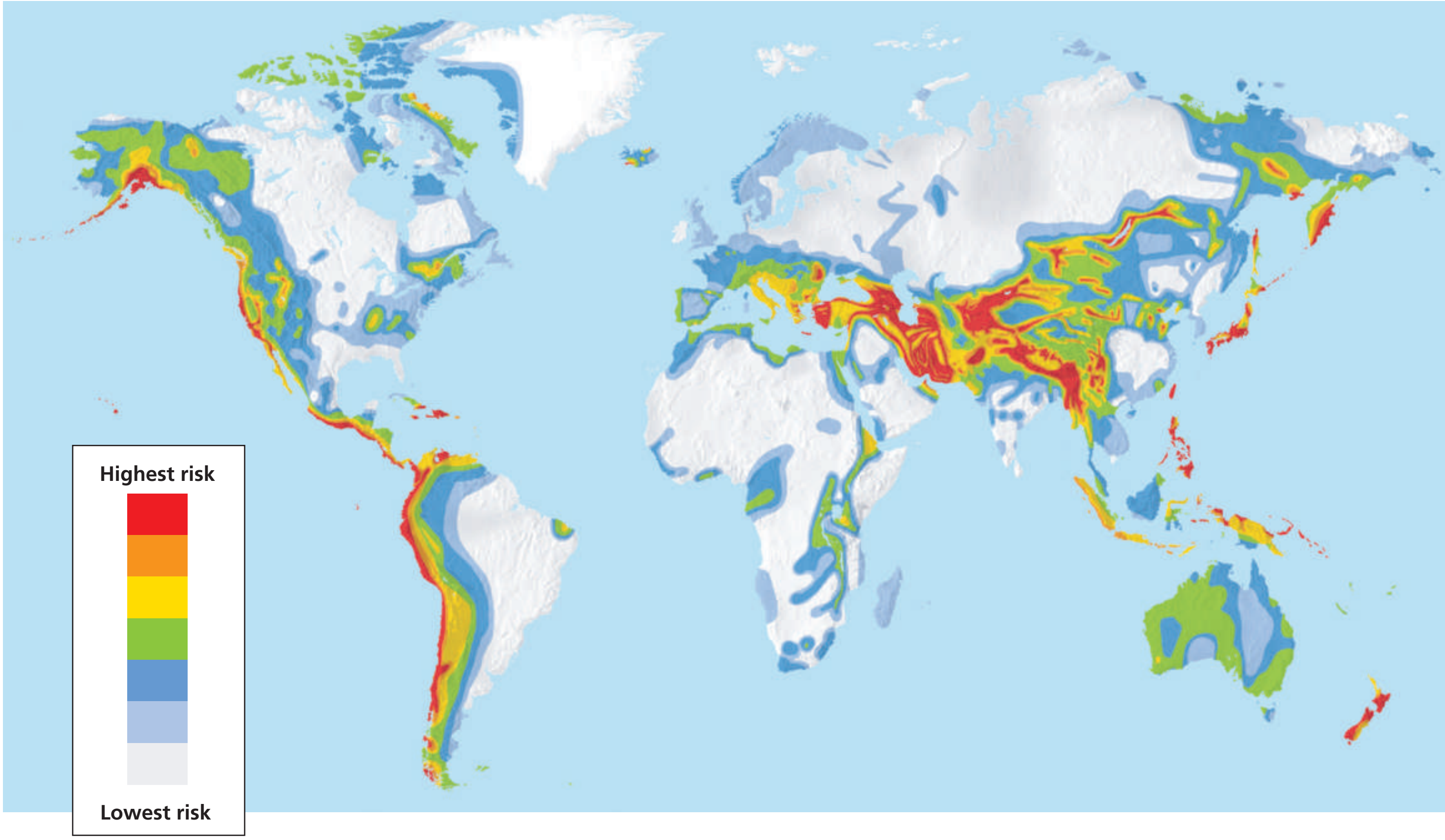


Figure 14-10 Areas of greatest earthquake (seismic) risk in the world. **Question:** How are these areas related to the boundaries of the earth's major tectonic plates as shown in Figure 14-4? (Data from U.S. Geological Survey)

Earthquakes on the Ocean Floor Can Cause Huge Waves Called Tsunamis

A **tsunami** is a series of large waves generated when part of the ocean floor suddenly rises or drops (Figure 14-11, p. 352). Most large tsunamis are caused when thrust faults in the ocean floor move up or down as a result of a large underwater earthquake, a landslide caused by such an earthquake, or in some cases by a volcanic eruption. Such earthquakes often occur offshore in subduction zones where a tectonic plate slips under a continental plate (Figure 14-3).

Tsunamis are often called tidal waves, although they have nothing to do with tides. They can travel far across the ocean at speeds as high as those of jet planes. In deep water the waves are very far apart—sometimes hundreds of kilometers—and their crests are not very high. As a tsunami approaches a coast, it slows down, its wave crests squeeze closer together, and their heights grow rapidly. It can hit a coast as a series of towering walls of water that can level buildings (**Concept 14-1B**).

Tsunamis can be detected through a network of ocean buoys to provide some degree of early warning. Another method makes use of a pressure recorder on the ocean floor, which measures changes in water pressure as the waves of a tsunami pass over it. These data are relayed to a weather buoy, which then transmits the data via satellite to tsunami emergency warning centers.

Between 1900 and late 2007, tsunamis killed an estimated 278,000 people in some Pacific Ocean regions. The largest loss of life occurred in December 2004 when a great underwater earthquake in the Indian Ocean with a magnitude of 9.15 caused a huge tsunami that generated waves that eventually were as high as 31 meters (100 feet). It killed 228,000 people and devastated many coastal areas of Indonesia (Figure 14-12, p. 352), Thailand, Sri Lanka, South India, and eastern Africa. Tragically, no buoys or gauges were in place in the Indian Ocean to provide an early warning of this tsunami.

Satellite observations and ground studies in February 2005 by the U.N. Environment Programme pointed to the role that healthy coral reefs (Figure 8-1, p. 162) and mangrove forests (Figure 8-8, p. 168) played in reducing the death toll and destruction from the 2004 tsunami. For example, intact mangrove forests in parts of Thailand helped to protect buildings and people from the force of the huge waves. In contrast, the extensive damage and high death toll in India's Tamus state has been attributed in part to the clearing of a third of its coastal mangrove forests in recent decades. In

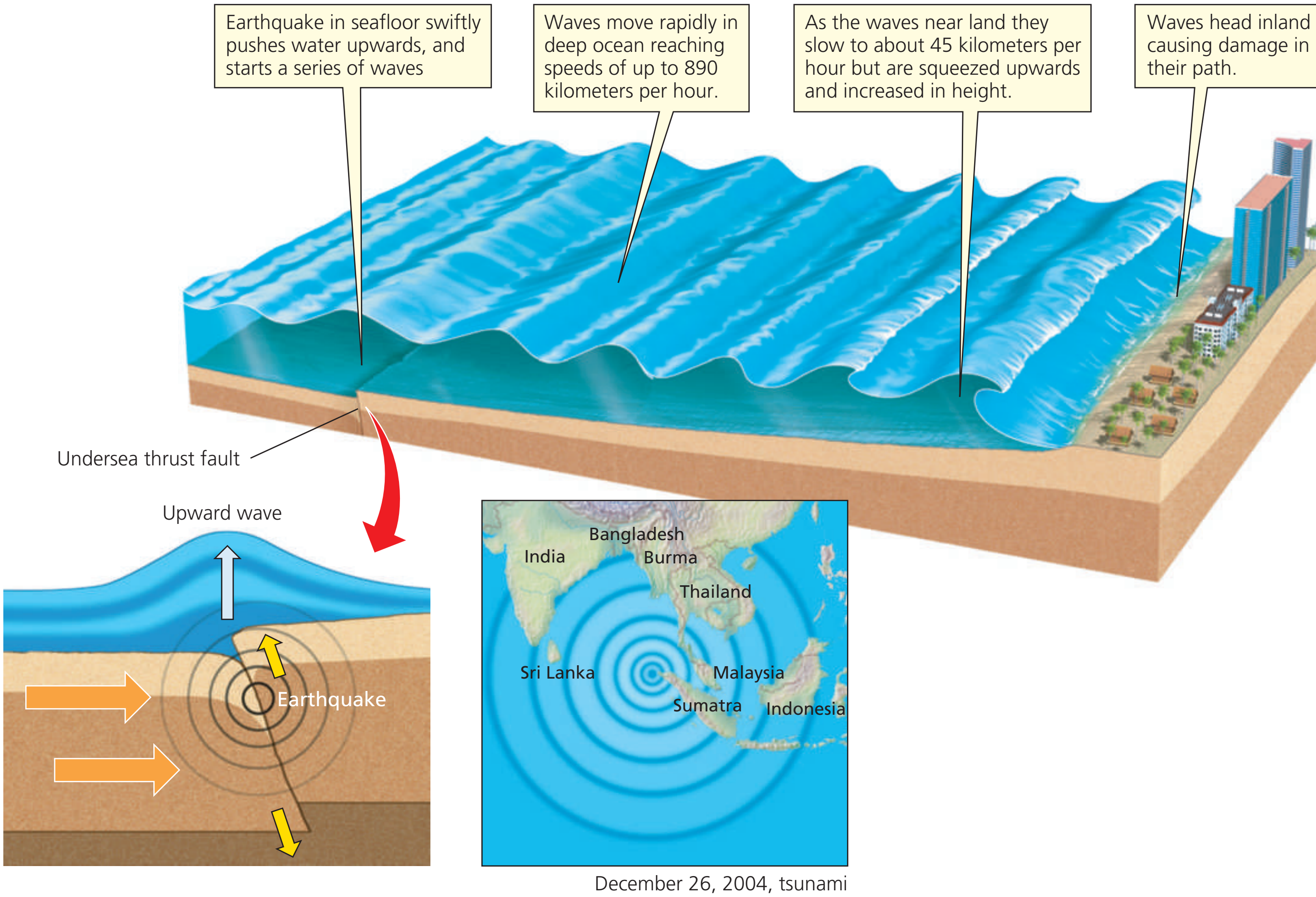


Figure 14-11 Formation of a tsunami and map of area affected by a large tsunami in December 2004.

Figure 14-12 In December 2004, a great earthquake with a magnitude of 9.15 on the seafloor of the Pacific Ocean created a large tsunami that killed 168,000 people in Indonesia. These photos show the Banda Aceh Shore near Gleebruk in Indonesia on June 23, 2004 before the tsunami (left) and on December 28, 2004 after it was stuck by the tsunami (right) (**Concept 14-1B**).

Sri Lanka, some of the greatest damage occurred where illegal coral mining and reef damage had caused severe beach erosion.

Gravity and Earthquakes Can Cause Landslides

The downward pull of gravity or the forces released by an earthquake can cause detached or loose rock, soil, and mud to slide down steep slopes.

Such movement, called *mass wasting,* is most common on the steep sides of mountains above valleys and on cliffs or steep slopes near the shores of oceans or lakes. Sometimes the movement is slow but some rockslides, avalanches, and mudslides occur quickly. In 1970, an earthquake in Peru caused a massive landslide that buried the town of Yungay and killed 17,000 people.

Mass wasting can cause considerable property damage when houses and other structures slide down hillsides or when avalanches, rockslides, or mudflows hit homes and properties (**Concept 14-1B**). Human activities such as forest clearing, road building, crop growing, and building of houses on steep and unstable slopes increase the frequency of, and the damage caused by, such geological events.

14-2 How Are the Earth's Rocks Recycled?

CONCEPT 14-2 The three major types of rocks found in the earth's crust—sedimentary, igneous, and metamorphic—are recycled very slowly by the processes of erosion, melting, and metamorphism.

There Are Three Major Types of Rocks

The earth's crust consists mostly of minerals and rocks. A **mineral** is an element or inorganic compound that occurs naturally in the earth's crust as a solid with a regular internal crystalline structure. A few minerals consist of a single element, such as gold, silver, and diamonds (carbon). But most of the more than 2,000 identified minerals occur as inorganic compounds formed by various combinations of elements. Examples include salt (sodium chloride or NaCl, Figure 2 in Supplement 6, p. S40) and quartzite (silicon dioxide or SiO_2).

Rock is a solid combination of one or more minerals found in the earth's crust. Some kinds of rock, such as limestone (calcium carbonate, or $CaCO_3$) and quartzite, contain only one mineral. Most rocks consist of two or more minerals. For example, granite is a mixture of mica, feldspar, and quartz crystals.

Based on the way it forms, rock is placed in three broad classes: sedimentary, igneous, or metamorphic (**Concept 14-2**). **Sedimentary rock** is made of *sediments*—dead plant and animal remains and existing rocks that are weathered (Figure 14-6) and eroded into tiny particles. These sediments are transported by water, wind, or gravity to downstream, downwind, downhill, or underwater sites. There they are deposited in layers that accumulate over time and increase the weight and pressure on underlying layers. Examples include *sandstone* and *shale* (formed from pressure created by deposited layers of mostly sand), *dolomite* and *limestone* (formed from the compacted shells, skeletons, and other remains of dead organisms), and *lignite* and *bituminous coal* (derived from compacted plant remains).

Igneous rock forms below or on the earth's surface when magma wells up from the earth's upper mantle or deep crust and then cools and hardens. Examples include *granite* (formed underground) and *lava rock* (formed aboveground). Although often covered by sedimentary rocks or soil, igneous rocks form the bulk of the earth's crust.

Metamorphic rock forms when a preexisting rock is subjected to high temperatures (which may cause it to melt partially), high pressures, chemically active fluids, or a combination of these agents. These forces transform a rock by reshaping its internal crystalline structure and its physical properties and appearance. Examples include *anthracite* (a form of coal), *slate* (formed when shale and mudstone are heated), and *marble* (produced when limestone is exposed to heat and pressure).

The Earth's Rocks Are Recycled Very Slowly

The interaction of physical and chemical processes that change rocks from one type to another is called the **rock cycle** (Figure 14-13, p. 354). This important form of natural capital recycles the earth's three types of rocks over millions of years and is the slowest of the earth's cyclic processes (**Concept 14-2**). In

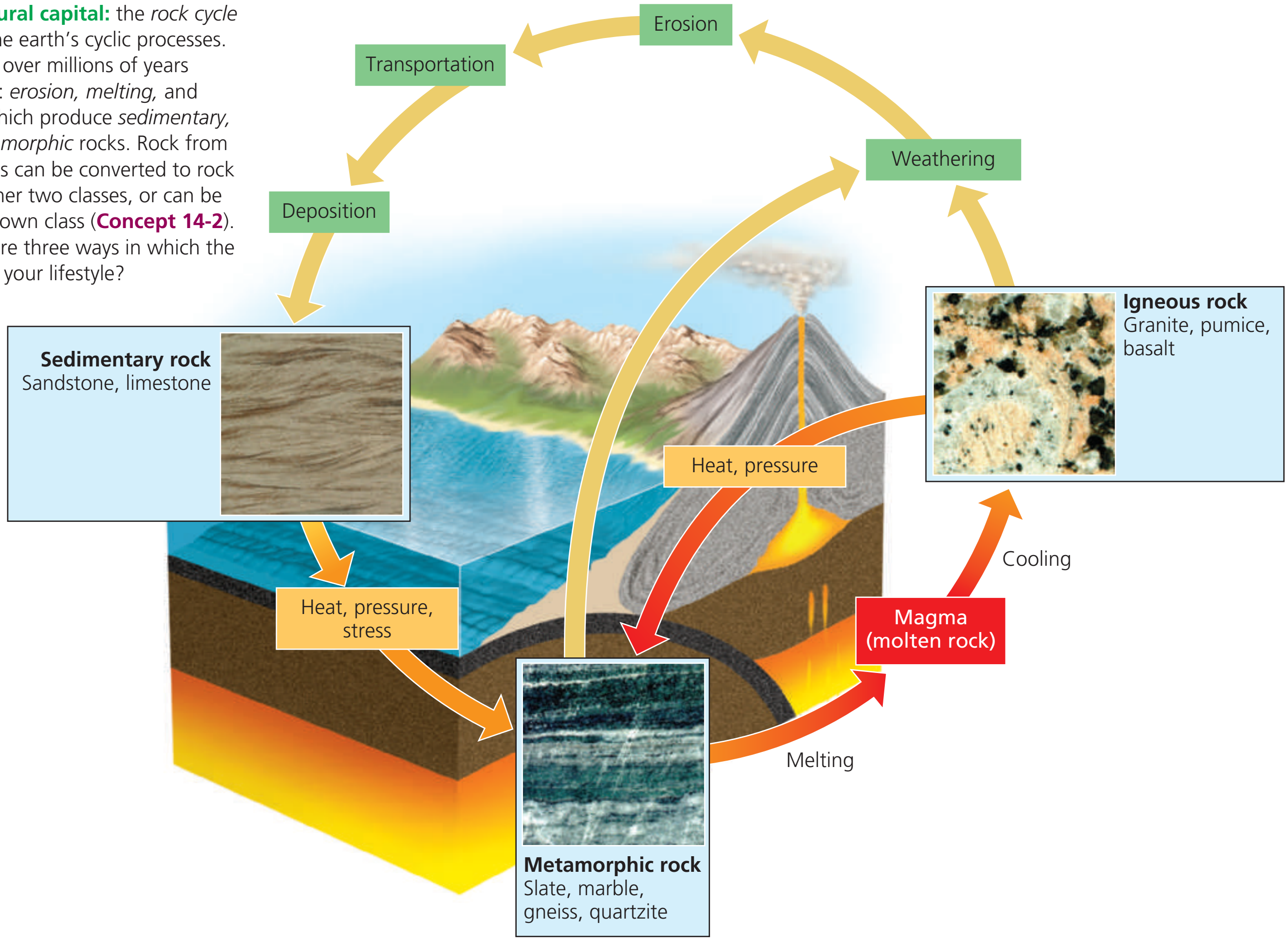


Figure 14-13 Natural capital: the *rock cycle* is the slowest of the earth's cyclic processes. Rocks are recycled over millions of years by three processes: *erosion, melting,* and *metamorphism,* which produce *sedimentary, igneous,* and *metamorphic* rocks. Rock from any of these classes can be converted to rock of either of the other two classes, or can be recycled within its own class (**Concept 14-2**). **Question:** What are three ways in which the rock cycle benefits your lifestyle?

this process, rocks are broken down, eroded, crushed, heated, melted, fused together into new forms by heat and pressure, cooled, and/or recrystallized within the earth's mantle and in the earth's crust.

The rock cycle also concentrates the planet's nonrenewable mineral resources on which our life processes depend. Without the earth's incredibly slow rock cycle, you would not exist.

14-3 What Are Mineral Resources and What Are the Environmental Effects of Using Them?

▶ **CONCEPT 14-3A Some naturally occurring materials in the earth's crust can be extracted and made into useful products in processes that provide economic benefits and jobs.**

▶ **CONCEPT 14-3B Extracting and using mineral resources can disturb the land, erode soils, produce large amounts of solid waste, and pollute the air, water, and soil.**

We Use a Variety of Nonrenewable Mineral Resources

A **mineral resource** is a concentration of naturally occurring material from the earth's crust that can be extracted and processed into useful products and raw materials at an affordable cost (**Concept 14-3A**). We know how to find and extract more than 100 minerals from the earth's crust. Examples are *fossil fuels* (such as coal), *metallic minerals* (such as aluminum, iron, and copper), and *nonmetallic minerals* (such as sand, gravel, and limestone). Because they take so long to form, these components of the earth's natural capital are classified as *nonrenewable mineral resources.*

An **ore** is rock that contains a large enough concentration of a particular mineral—often a metal—to make it profitable for mining and processing. A **high-grade ore** contains a fairly large amount of the desired nonrenewable mineral resource, whereas a **low-grade ore** contains a smaller amount.

Nonrenewable metal and nonmetal mineral resources are important parts of our lives. *Aluminum* (Al) is used for packaging and beverage cans and as a structural material in motor vehicles, aircraft, and buildings. *Steel,* an essential material used in buildings and motor vehicles, is a mixture (alloy) of iron (Fe) and other elements that are added to give it certain properties. *Manganese* (Mn), *cobalt* (Co), *molybdenum* (Mo) and *chromium* (Cr) are widely used in important steel alloys used in products such as lightbulbs, computers, automobiles, airplanes, oil drilling bits, pipelines, and turbines in power plants. *Copper* (Cu), a good conductor of electricity, is used for electrical and communications wiring. *Platinum* (Pt) is used in electrical equipment, as a catalyst in industry, and in automobile pollution control converters. *Gold* (Au) (**Core Case Study**) is used in electrical equipment, jewelry, coins, medical implants, and as a catalyst to speed up certain chemical reactions.

The most widely used nonmetallic minerals are sand and gravel. *Sand,* which is mostly silicon dioxide (SiO_2), is used to make glass, bricks, and concrete for construction of roads and buildings. *Gravel* is used for roadbeds and to make concrete. Another common nonmetallic mineral is *limestone* (mostly calcium carbonate, or $CaCO_3$), which is crushed to make road rock, concrete, and cement. *Phosphate salts* are mined and used in inorganic fertilizers and in some detergents.

Most published estimates of the supply of a given mineral resource refer to its **reserves**—identified resources from which the mineral can be extracted profitably at current prices. Reserves increase when new profitable deposits are found and when higher prices or improved mining technology make it profitable to extract deposits that previously were considered too expensive to extract.

Mineral Use Has Advantages and Disadvantages

Figure 14-14 depicts the typical life cycle of a metal resource. The processes of mining and converting minerals into useful products has a number of important benefits (**Concept 14-3A**). It generates significant income and provides local, state, and national revenues from taxes, fees, and royalties. It also provides employment in a variety of jobs directly and indirectly related to mineral extraction, processing, and use.

On the other hand, mining, processing, and using mineral resources take enormous amounts of energy and can disturb the land, erode soil, produce solid waste, and pollute the air, water, and soil (Figure 14-15, p. 356, and **Concept 14-3B**). Some environmental scientists and resource experts warn that the greatest danger from continually increasing our consumption of nonrenewable mineral resources may be the environmental damage caused by their extraction, processing, and conversion to products.

The environmental impacts from mining an ore are affected by its percentage of metal content, or *grade.* The more accessible and higher-grade ores are usually exploited first. As they are depleted, mining lower-grade ores takes more money, energy, water, and other materials and increases land disruption, mining waste, and pollution.

THINKING ABOUT
Low-Grade Ores

Use the second law of thermodynamics (**Concept 2-4B**, p. 40) to explain why mining lower-grade ores requires more energy and materials and increases land disruption, mining waste, and pollution.

There Are Several Ways to Remove Mineral Deposits

After suitable mineral deposits are located, several different mining techniques are used to remove them, depending on their location and type. Shallow deposits are removed by **surface mining,** and deep deposits are removed by **subsurface mining.**

In surface mining, gigantic mechanized equipment strips away the **overburden,** the soil and rock overlying a useful mineral deposit. It is usually discarded as waste material called **spoils.** When ore deposits that contain metals such as gold (**Core Case Study**) are dredged from streams, the unused materials or *tailings* are usually left on the land. If forests are present, they are also removed. Surface mining

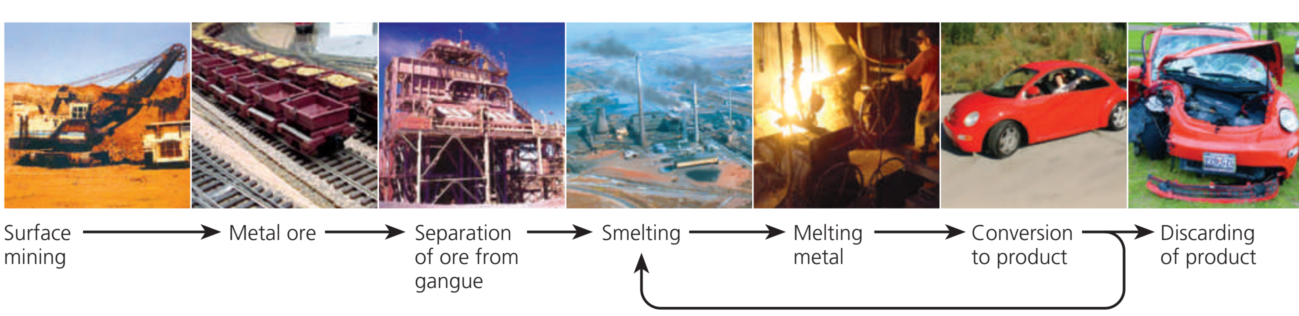


Figure 14-14 *Life cycle of a metal resource.* Each step in this process uses large amounts of energy and produces some pollution and waste.

NATURAL CAPITAL DEGRADATION

Extracting, Processing, and Using Nonrenewable Mineral and Energy Resources

Steps	Environmental Effects
Mining Exploration, extraction	Disturbed land; mining accidents; health hazards; mine waste dumping; oil spills and blowouts; noise; ugliness; heat
Processing Transportation, purification, manufacturing	Solid wastes; radioactive material; air, water, and soil pollution; noise; safety and health hazards; ugliness; heat
Use Transportation or transmission to individual user, eventual use, and discarding	Noise; ugliness; thermal water pollution; pollution of air, water, and soil; solid and radioactive wastes; safety and health hazards; heat

Figure 14-15 Some harmful environmental effects of extracting, processing, and using nonrenewable mineral and energy resources (**Concept 14-3B**). Providing the energy required to carry out each step causes additional pollution and environmental degradation. **Question:** What are three mineral resources that you used today? Which of these harmful environmental effects might have resulted from obtaining and using these resources?

Andre Maslennikov/Peter Arnold, Inc.

Figure 14-16 Natural capital degradation: This *open-pit* mine, located near the city of Kalgoolie in the outback of western Australia, is the world's largest gold mine. **Question:** Should governments require mining companies to fill in and restore such sites once their ore is depleted? Explain.

is used to extract about 90% of the nonfuel mineral and rock resources and 60% of the coal used in the United States.

The type of surface mining used depends on two factors: the resource being sought and the local topography. In **open-pit mining** (Figure 14-16), machines dig holes and remove ores (of metals such as iron, copper, and gold), sand, gravel, and stone (such as limestone and marble).

Strip mining is useful and economical for extracting mineral deposits that lie close to the earth's surface in large horizontal beds. In **area strip mining,** used where the terrain is fairly flat, gigantic earthmovers strip away the overburden, and power shovels—some as tall as a 20-story building—remove the mineral deposit. The resulting trench is filled with overburden, and a new cut is made parallel to the previous one. This process is repeated over the entire site.

Contour strip mining (Figure 14-17) is used mostly to mine coal on hilly or mountainous terrain. A huge power shovel cuts a series of terraces into the side of a hill. An earthmover removes the overburden, a power shovel extracts the coal, and the overburden from each new terrace is dumped onto the one below. Unless the land is restored, a wall of dirt is left in front of a highly erodible bank of soil and rock called a *highwall.*

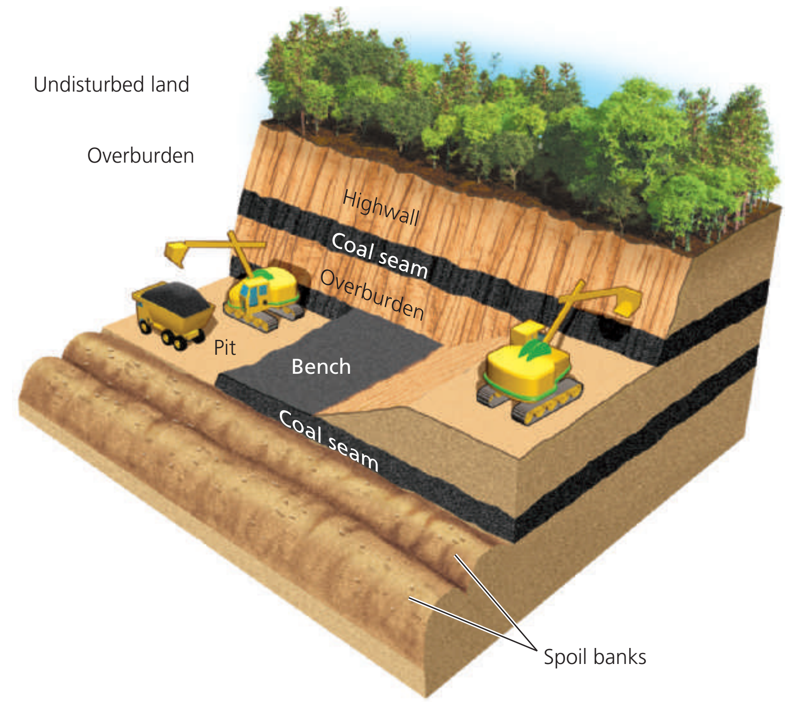


Figure 14-17 Natural capital degradation: *contour strip mining* of coal used in hilly or mountainous terrain.

Another surface mining method is **mountaintop removal.** In the Appalachian Mountain area of the United States, where this form of mining is prominent, explosives, large power shovels, and huge machines called draglines are used to remove the top of a mountain and expose seams of coal, which are then removed (Figure 14-19, p. 358).

Subsurface mining is used to remove coal and metal ores that are too deep to be extracted by surface mining. Miners dig a deep vertical shaft, blast open subsurface tunnels and chambers to reach the deposit, and use machinery to remove the ore or coal and transport it to the surface.

Mining Has Harmful Environmental Effects

Mining can do long-term harm to the environment in a number of ways. One type of damage is *scarring and disruption of the land surface* (**Core Case Study**, Figure 14-1, and Figures 14-16 through 14-20). CORE CASE STUDY

For example, area strip mining often leaves a series of hills, like waves of rubble, called *spoils banks* (Figure 14-18). Spoils and tailings are very susceptible to chemical weathering and erosion by water and wind. Regrowth of vegetation on these banks is quite slow because they have no topsoil and thus have to follow the long path of primary ecological succession (Figure 5-16, p. 116, and **Concept 5-4**, p. 115). CONCEPT LINK

In mountaintop removal (Figure 14-19, p. 358), colossal machines are used to plow great volumes of waste rock and dirt into valleys below the mountaintops, destroying forests, burying mountain streams, and increasing flood hazards. Toxic wastewater, produced when the coal is processed, is often stored in these

National Archives/EPA Documerica

Figure 14-18 Natural capital degradation: banks of waste or spoils created by *area strip mining* of coal on an unrestored, mostly flat area near Mulla, Colorado (USA). Government laws require at least partial restoration of newly strip-mined areas in the United States. Nevertheless, many previously mined sites have not been restored and restoration is not possible in some arid areas. **Question:** Should the government require mining companies to restore such sites as fully as possible? Explain.

Figure 14-19 Natural capital degradation: mountaintop coal mining operation in the U.S. state of West Virginia. The large amount of resulting debris is deposited in the valleys and streams below. Mountaintop removal for coal is also occurring in the U.S. states of Virginia, Tennessee, Kentucky, and Pennsylvania. See other mining sites at **www.appvoices.org/**. **Question:** Are you for or against mountaintop coal mining? Explain.

Jim Wark/Peter Arnold, Inc.

Claus Meyer/Peter Arnold, Inc.

Figure 14-20 Illegal gold mine in the Brazilian Amazon. Such mines degrade terrestrial biodiversity when numerous areas of tropical rain forest are cleared for mining sites.

valleys behind coal waste sludge dams, which can overflow or collapse, releasing toxic substances such as selenium, arsenic, and mercury. Nearby communities can be damaged economically, as well as environmentally.

According to the EPA, some 1,900 kilometers (1,200 miles) of Appalachia's rivers and streams have been buried, and 470 of its largest mountains have disappeared, leaving behind barren land and gigantic pits, some as large as Manhattan Island. You can tour some of the obliterated landscapes of Appalachia by visiting the website Appalachian Voices at **www.appvoices.org/**. In 2007, the U.S. Department of the Interior issued a rule that allows this type of mining to continue, with expanded dumping of mine waste into streams and valleys. Within a few years, this could result in the devastation of an area the size of the U.S. state of Delaware.

Since 1980, millions of miners have streamed into tropical forests and other tropical areas in search of gold (**Core Case Study**). These small-scale miners use destructive techniques to dig large pits by hand and dredge sediments from rivers. They also use hydraulic mining—a technique, outlawed in the United States—in which water cannons wash entire hillsides into collection boxes for removal of gold (Figure 14-20). Surface mining in tropical areas destroys or degrades biodiversity when forests are cleared and mining wastes pollute nearby streams or rivers.

CORE CASE STUDY

Surface mining sites can be cleaned up and restored (Figure 14-21), but it is costly. The U.S. Department of the Interior estimates that at least 500,000 surface-mined sites dot the U.S. landscape, mostly in the West. Cleaning up these sites would cost taxpayers as much as an estimated \$70 billion. And worldwide, cleaning up abandoned mining sites would cost trillions of dollars. Most of these sites probably will never be cleaned up.

Subsurface mining disturbs less than one-tenth as much land as surface mining disturbs, and it usually produces less waste material. However, it leaves much of the resource in the ground and is more dangerous and expensive than surface mining is. Hazards include cave-ins, explosions, fires, and diseases such as black lung, caused by prolonged inhalation of mining dust.

Another problem is *subsidence*—the collapse of land above some underground mines. It can tilt and damage houses, crack sewer lines, break gas mains, and disrupt groundwater systems.

Mining operations also produce large amounts of solid waste—three-fourths of all U.S. solid waste. One example is the huge amounts of solid waste produced from mining gold (**Core Case Study**).

Finally, mining causes major pollution of water and air. This is because wind and water erosion cause toxin-laced mining wastes to be deposited in areas other than the mining site. For example, *acid mine drainage* occurs when rainwater seeping through a mine or mine waste pile carries sulfuric acid (H_2SO_4, produced when aerobic bacteria act on iron sulfide minerals in spoils) to nearby streams and groundwater (see *The Habitable Planet,* Video 6, at **www.learner.org/resources/series209.html**).

In addition, huge amounts of water used to process ore often contain pollutants such as sulfuric acid, mercury, and arsenic. This contaminates water supplies and fish used for food, and it can destroy some forms of aquatic life. According to the EPA, mining has polluted about 40% of western watersheds in the United States.

Mining operations also emit toxic chemicals into the atmosphere. In the United States, the mining industry produces more toxic emissions than any other industry—typically accounting for almost half of such emissions.

Removing Metals from Ores Has Harmful Environmental Effects

Ore extracted by mining typically has two components: the *ore mineral,* containing the desired metal, and waste material called *gangue* (pronounced "gang"). Removing the gangue from ores produces tailings. Particles of toxic metals blown by the wind or leached from tailings by rainfall can contaminate surface water and groundwater.

After removal of the gangue, heat or chemical solvents are used to extract metals from the ores. Heating ores to release metals is called **smelting** (Figure 14-14). Without effective pollution control equipment, smelters emit enormous quantities of air pollutants, including sulfur dioxide and suspended particles, which damage vegetation and acidify soils in the surrounding area. They also cause water pollution and produce liquid and solid hazardous wastes that require safe disposal.

Princeton Hydro/Society for Ecological Restoration International

Before

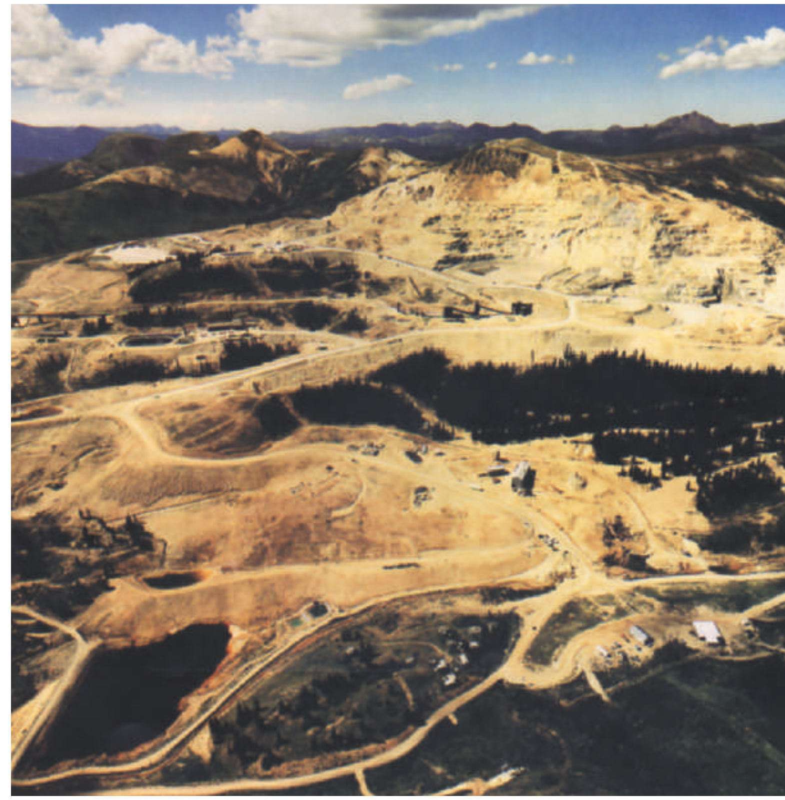
Princeton Hydro/Society for Ecological Restoration International

After

Figure 14-21 Ecological restoration of a mining site in New Jersey (USA) by Princeton Hydro.

An example of using chemicals to remove metals from their ores is the use of solutions of highly toxic cyanide salts to extract gold from its ore (**Core Case Study**). After extracting the gold, some mining companies have declared bankruptcy and walked away from their mining operations, leaving behind

Figure 14-22 **Natural capital degradation:** the Summitville gold mining site near Alamosa, Colorado (USA), became a toxic waste site after the Canadian company that owned it declared bankruptcy and abandoned it rather than cleaning up the acids and toxic metals that leaked from this site into the nearby Alamosa River. Cleanup by the EPA will cost U.S. taxpayers about $120 million.



U.S. Geological Survey

large amounts of cyanide-laden water in leaking holding ponds. A glaring example is the Summitville gold mine site near Alamosa, Colorado (USA) (Figure 14-22). A Canadian company used an 1872 U.S. mining law to buy the land from the federal government for a pittance, spent $1 million developing the site, and removed $98 million worth of gold. The company then declared bankruptcy and abandoned the site without doing any clean-up or restoration.

14-4 How Long Will Supplies of Nonrenewable Mineral Resources Last?

▶ **CONCEPT 14-4A All nonrenewable mineral resources exist in finite amounts, and as we get closer to depleting any mineral resource, the environmental impacts of extracting it generally become more harmful.**

▶ **CONCEPT 14-4B An increase in the price of a scarce mineral resource can lead to increased supplies and more efficient use of the mineral, but there are limits to this effect.**

Mineral Resources Are Distributed Unevenly

The earth's crust contains fairly abundant deposits of nonrenewable mineral resources such as iron and aluminum. But deposits of important mineral resources such as manganese, chromium, cobalt, and platinum are relatively scarce. The earth's geologic processes have not distributed deposits of nonrenewable mineral resources evenly. Some countries have rich mineral deposits and others have few or none.

Massive exports can deplete the supply of a country's nonrenewable minerals. During the 1950s, for example, South Korea exported large amounts of its iron and copper. Since the 1960s, the country has not had enough domestic iron and copper to support its rapid economic growth and now must import these metals to meet its domestic needs.

Five nations—the United States, Canada, Russia, South Africa, and Australia—supply most of the nonrenewable mineral resources used by modern societies. South Africa, for example, is nearly self-sufficient in the world's key mineral resources and is the world's largest producer of gold, chromium, and platinum. Three countries—the United States, Germany, and Russia—with only 8% of the world's population consume about 75% of the most widely used metals, but China is rapidly increasing its use of key metals.

Since 1900, and especially since 1950, there has been a sharp rise in the total and per capita use of nonrenewable mineral resources in the United States. As a result, the United States has depleted some of its once-rich deposits of metal mineral resources such as lead, aluminum, and iron. Currently, it depends on imports of 50% or more of 24 of its most important nonrenewable mineral resources. Some of these minerals are imported because they are used faster than they can be produced from domestic supplies; others are imported because foreign mineral deposits are of a higher grade and cheaper to extract than remaining U.S. reserves.

Most U.S. imports of nonrenewable metal resources come from reliable and politically stable countries. But experts are concerned about the availability of four *strategic metal resources*—manganese, cobalt, chromium, and platinum—that are essential for the country's economy and military strength. The United States has little or no reserves of these metals. Some analysts believe that nanomaterials (Science Focus, p. 362) may eventually be substituted for some of these metals.

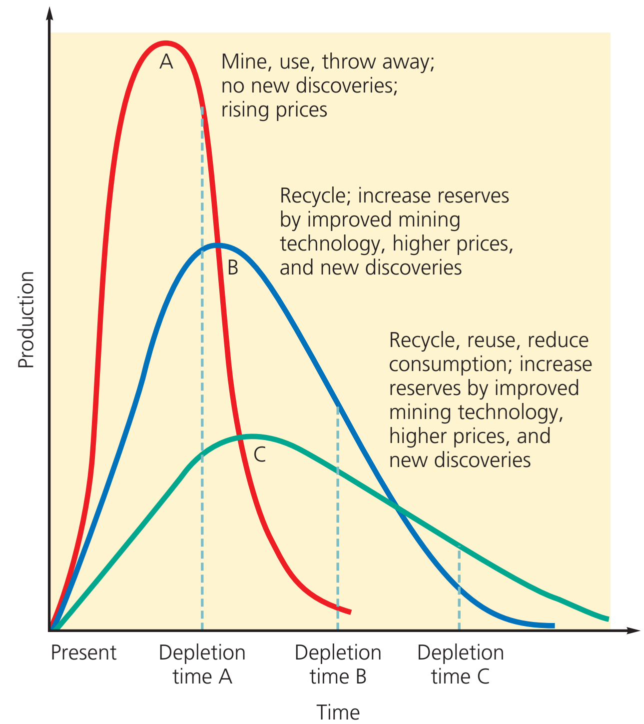


Figure 14-23 **Natural capital depletion:** *depletion curves* for a nonrenewable resource (such as aluminum or copper) using three sets of assumptions. Dashed vertical lines represent times when 80% depletion occurs.

Supplies of Nonrenewable Mineral Resources Can Be Economically Depleted

The future supply of nonrenewable minerals depends on two factors: the actual or potential supply of the mineral and the rate at which we use it. We never completely run out of any mineral, but a mineral becomes *economically depleted* when it costs more than it is worth to find, extract, transport, and process the remaining deposits (**Concept 14-4A**). At that point, there are five choices: *recycle or reuse existing supplies, waste less, use less, find a substitute,* or *do without.*

Depletion time is the time it takes to use up a certain proportion—usually 80%—of the reserves of a mineral at a given rate of use. When experts disagree about depletion times, it is often because they are using different assumptions about supplies and rates of use (Figure 14-23).

The shortest depletion time estimate assumes no recycling or reuse and no increase in reserves (curve A, Figure 14-23). A longer depletion time estimate assumes that recycling will stretch existing reserves and that better mining technology, higher prices, or new discoveries will increase reserves (curve B). An even longer depletion time assumes that new discoveries will further expand reserves and that recycling, reuse, and reduced consumption will extend supplies (curve C). Finding a substitute for a resource leads to a new set of depletion curves for the new resource.

According to a 2006 study by Thomas Graedel of Yale University, if all nations extract metal resources from the earth's crust at the same rate as developed nations do today, there may not be enough metal resources to meet the demand, even with extensive recycling. However, the successful development of nanotechnology, assuming we can minimize its potentially harmful environmental and health effects (Science Focus, p. 362), may help to reduce such shortages.

Market Prices Affect Supplies of Nonrenewable Minerals

Geologic processes determine the quantity and location of a mineral resource in the earth's crust. Economics determines what part of the known supply is extracted and used. An increase in the price of a scarce mineral resource can lead to increased supplies and can encourage more efficient use, but there are limits to this process (**Concept 14-4B**).

According to standard economic theory, in a competitive market system, a plentiful mineral resource is cheap when its supply exceeds demand. When a resource becomes scarce, its price rises. This can encourage exploration for new deposits, stimulate development of better mining technology, and make it profitable to mine lower-grade ores. It can also encourage a search for substitutes and promote resource conservation.

According to some economists, this price effect may no longer apply very well in most developed countries. Industry and government in such countries often use subsidies, taxes, regulations, and import tariffs to

SCIENCE FOCUS

The Nanotechnology Revolution

Nanotechnology, or *tiny tech,* uses science and engineering to manipulate and create materials out of atoms and molecules at the ultra-small scale of less than 100 nanometers. A nanometer equals one billionth of a meter. It is one hundred-thousandth the width of a human hair. At the nanoscale level, conventional materials have unconventional and unexpected properties (discussed in more detail on page S45 in Supplement 6).

Scientists envision arranging atoms of abundant substances such as carbon, oxygen, and silicon to create everything from medicines and solar cells to automobile bodies. Nanomaterials are currently used in more than 400 consumer products and the number is growing rapidly. Such products include stain-resistant and wrinkle-free coatings on clothes, odor-eating socks, self-cleaning coatings on windows and windshields, cosmetics, sunscreens with nanomolecules that block ultraviolet light, and food containers that release nanosilver ions to kill bacteria, molds, and fungi. **GREEN CAREER:** Environmental nanotechnology

Nanotechnologists envision a supercomputer the size of a sugar cube that could store all the information now found in the U.S. Library of Congress; biocomposite materials smaller than a human cell that would make our bones and tendons super strong; nanovessels that could be filled with medicines and delivered to cells anywhere in the body; and designer nanomolecules that could seek out and kill cancer cells.

Nanoparticles could also be used to remove industrial pollutants in contaminated air, soil, and groundwater, and nanofilters might be used to purify water and to desalinate water at an affordable cost. The technology could also be used to turn garbage into breakfast by mimicking how nature turns wastes into plant nutrients, thus following one of the four **principles of sustainability** (see back cover). The list could go on.

So what is the catch? Ideally, this bottom-up manufacturing process would occur with little environmental harm, without depleting nonrenewable resources, and with many potential environmental benefits. But there are concerns over some potential unintended harmful consequences.

So far, we know little about possible harmful effects of nanoparticles for workers and consumers, but a few studies have raised red flags (see Supplement 6, p. S45). As particles get smaller, they become more reactive and potentially more toxic to humans and other animals. Animal studies show that nanoparticles can move across the placenta from mother to fetus and from the nasal passage to the brain. They could also penetrate deeply into the lungs, be absorbed into the bloodstream, and penetrate cell membranes.

Many analysts say we need to take two steps before unleashing nanotechnology more broadly. *First,* carefully investigate its potential ecological, economic, health, and societal risks. *Second,* develop guidelines and regulations for controlling its growing applications until we know more about the potentially harmful effects of this new technology.

So far, governments have done little to evaluate and regulate the potentially harmful effects of this rapidly emerging technology. A 2008 study by Friends of the Earth found that untested and unapproved nanotechnology materials are being used in more than 100 food products and in food packaging. However, in 2007, DuPont and the environmental group Environmental Defense, jointly developed suggested guidelines for evaluating the safety and environmental risks of nanotechnology products.

If nanotechnology lives up to its potential, the mining and processing of most mineral resources may become obsolete businesses. This would eliminate the harmful environmental effects of mining and processing of mineral resources, and it would increase profits for nanomaterial companies. However, it would also eliminate businesses, including those that export mineral resources from many developing countries. And nanotech development could cause severe economic and social stress as jobs and entire industries disappear.

Critical Thinking

How might the development of nanotechnology affect the mining of gold (**Core Case Study**)?

CORE CASE STUDY

control the supplies, demands, and prices of minerals to such an extent that a truly competitive market does not exist.

Most mineral prices are kept artificially low because governments subsidize development of their domestic mineral resources to help promote economic growth and national security. In the United States, for instance, mining companies get subsidies in the form of depletion allowances amounting to 5–22% of their gross income from mineral extraction and processing (depending on the mineral). They can also reduce their taxes by deducting much of their costs for finding and developing mineral deposits.

Most consumers are unaware that the real costs of consumer products made from mineral resources are higher than their market prices, because consumers are also paying taxes to provide government subsidies and tax breaks for mining companies and to help control the harmful environmental effects of mineral extraction, processing, and use. If these hidden extra costs were included in the market prices of such goods, the harmful environmental effects of mineral extraction and processing (Figure 14-15) would be sharply reduced. Recycling and reuse would increase dramatically, and many of these minerals would be replaced with less environmentally harmful substitutes.

Between 1982 and 2007, U.S. mining companies received more than $6 billion in government subsidies (Case Study, at right). Critics argue that eliminating or sharply reducing such environmentally harmful subsidies would promote more efficient resource use, promote waste reduction and pollution prevention, and encourage recycling and reuse of mineral resources.

Mining company representatives insist that they need taxpayer subsidies and low taxes to keep the prices of minerals low for consumers (Case Study, below). They also claim that the subsidies encourage the companies not to move their mining operations to other countries where they will not face such taxes or mining and pollution control regulations.

THINKING ABOUT
Minerals and Nanotechnology

How might arguments for and against subsidies and low taxes for mineral resource extraction be affected by a nanotechnology revolution (Science Focus, at left) during the next 20 years?

Increasingly scarce investment capital and high financial risk can also hinder the development of new supplies of mineral resources. Typically, if geologists identify 10,000 possible deposits of a given resource, only 1,000 sites are worth exploring; only 100 justify drilling, trenching, or tunneling; and only 1 becomes a producing mine or well.

■ CASE STUDY
The U.S. General Mining Law of 1872

Some people have gotten rich by using the little-known U.S. General Mining Law of 1872. It was designed to encourage mineral exploration and the mining of *hard-rock minerals* (such as gold, silver, copper, zinc, nickel, and uranium) on U.S. public lands and to help develop the then-sparsely populated West.

Under this law, a person or corporation can file a mining claim or assume legal ownership of parcels of land on essentially all U.S. public lands except national parks and wilderness. To file a claim, you say you believe the land contains valuable hard-rock minerals and you promise to spend $500 to improve it for mineral development. You must then pay $120 per year for each 8-hectare (20-acre) parcel of land used to maintain the claim, whether or not a mine is in operation.

Until 1995 when a freeze on such land transfers was declared by Congress, one could pay the federal government $6–12 per hectare ($2.50–5.00 an acre) for land owned jointly by all U.S. citizens. One could then lease the land, build on it, sell it, or use it for essentially any purpose. People have constructed golf courses, hunting lodges, hotels, and housing subdivisions on public land that they bought from taxpayers at 1872 prices. According to a 2004 study by the Environmental Working Group, public lands containing an estimated $285 billion worth of publicly owned mineral resources have been transferred to private companies—one-fifth of them foreign companies—at 1872 giveaway prices.

In 2004, the mining company Phelps Dodge bought 63 hectares (155 acres) of U.S. Forest Service land atop Colorado's Mt. Emmons near the ski resort town of Crested Butte for $875. The land could be worth as much as $155 million. The company was able to buy the land because it had claimed the option to buy before the 1995 freeze.

According to the Bureau of Land Management, mining companies remove at least $4 billion worth of hard-rock minerals per year from U.S. public land. These companies pay taxpayers royalties amounting to only 2.3% of the value of the minerals, compared to royalties of 13.2% paid for oil, natural gas, and coal, and 14% for grazing rights on public lands. After removing valuable minerals such as gold, some mining companies have abandoned severely degraded and polluted mining sites and left the expensive cleanup to taxpayers (Figure 14-22).

In 1992, the 1872 law was modified to require mining companies to post bonds to cover 100% of the estimated cleanup costs in case they go bankrupt—a requirement that mining companies are lobbying Congress to overturn or greatly weaken. Because such bonds were not required in the past, the U.S. Department of the Interior estimates that cleaning up degraded land and streams on more than 500,000 abandoned hard-rock mining sites will cost U.S. taxpayers $32–72 billion. According to former Arkansas Senator Dale Bumpers, the 1872 mining law is a "license to steal" from U.S. citizens who jointly own all public lands.

Mining companies point out that they must invest large sums (often $100 million or more) to locate and develop an ore site before they make any profits from mining hard-rock minerals. They argue that government subsidized land costs allow them to provide high-paying jobs to miners, supply vital resources for industry, stimulate the national and local economies, reduce trade deficits, and keep mineral products affordable. But critics argue that the money taxpayers give up as subsidies to mining companies offsets the lower prices they pay for these products.

Critics of this ancient law call for permanently banning such sales of public lands, but some support 20-year leases of designated public land for hard-rock mining. Critics also call for much stricter environmental controls and cleanup restrictions on hard-rock mining. They want the government to set up a fund paid for by royalties from hard-rock mining companies to clean up abandoned mining sites. They would require mining companies to pay a royalty of 8–12% on the *gross income* based on the wholesale value of all minerals removed from public land—similar to the rates paid by oil, natural gas, and coal companies. They opposed basing the royalties on the net income (income after taxes and other expenses have been subtracted), which is favored by hard-rock mining interests. Mining companies have been pressuring the U.S. Congress to lift the ban on sales of public lands and have successfully opposed efforts to impose 8–12% royalties.

Canada, Australia, South Africa, and several other countries require higher royalty payments and have laws that make mining companies fully responsible for environmental damage.

Is Mining Lower-Grade Ores the Answer?

Some analysts contend that all we need do to increase supplies of a mineral is to extract lower grades of ore. They point to the development of new earth-moving equipment, improved techniques for removing impurities from ores, and other technological advances in mineral extraction and processing.

In 1900, the average copper ore mined in the United States was about 5% copper by weight. Today that ratio is 0.5%, and copper costs less (adjusted for inflation). New methods of mineral extraction may allow even lower-grade ores of some metals to be used.

However, several factors can limit the mining of lower-grade ores (**Concept 14-4B**). One is the increased cost of mining and processing larger volumes of ore. Another is the limited availability of freshwater needed to mine and process some minerals—especially in arid and semiarid areas. A third limiting factor is the environmental impacts of the increased land disruption, waste material, and pollution produced during mining and processing (Figure 14-15) (**Concept 14-4A**).

One way to improve mining technology is to use microorganisms that can extract minerals in a process called *in-place,* or *in situ,* (pronounced "in SY-too") *mining.* If naturally occurring bacteria cannot be found to extract a particular metal, genetic engineering techniques could be used to produce such bacteria. This biological approach, called *biomining,* removes desired metals from ores while leaving the surrounding environment undisturbed. It also reduces the air pollution associated with the smelting of metal ores and the water pollution associated with using hazardous chemicals such as cyanides and mercury to extract gold.

On the down side, microbiological ore processing is slow. It can take decades to remove the same amount of material that conventional methods can remove within months or years. However, genetic engineers are looking for ways to modify bacteria that could speed up the process. So far, biological mining methods are economically feasible only with low-grade ores for which conventional techniques are too expensive.

RESEARCH FRONTIER

Developing biomining and other new methods for extracting more minerals from ores. See **academic.cengage.com/biology/miller**.

Can We Extend Supplies by Getting More Minerals from the Ocean?

Some ocean mineral resources are dissolved in seawater. However, most of the chemical elements found in seawater occur in such low concentrations that recovering them takes more energy and money than they are worth. At current prices and with existing technology, only magnesium, bromine, and sodium chloride are abundant enough to be extracted profitably. On the other hand, deposits of minerals, mostly in sediments along the shallow continental shelf and near shorelines, are significant sources of sand, gravel, phosphates, sulfur, tin, copper, iron, tungsten, silver, titanium, platinum, and diamonds.

THINKING ABOUT

Extracting Minerals from Seawater

CONCEPT LINK

Use the second law of thermodynamics (**Concept 2-4B**, p. 40) to explain why it costs too much to extract most dissolved minerals from seawater.

Another potential source is hydrothermal ore deposits that form when mineral-rich superheated water shoots out of vents in solidified magma on the ocean floor. After mixing with cold seawater, particles of metal compounds (such as sulfides, silver, zinc, and copper) precipitate out and build up as mineral deposits around the vents. Currently, it costs too much to extract these minerals, even though some deposits contain large concentrations of important metals. There are also disputes over ownership of such resources located in international waters.

Another potential source of metals from the ocean floor is potato-size *manganese nodules* that cover about 25–50% of the Pacific Ocean floor. They could be sucked up from the ocean floor by giant vacuum pipes or scooped up by buckets on a continuous cable operated by a mining ship. However, marine scientists are concerned about the effects of such mining on aquatic life.

So far these nodules and resource-rich mineral beds in international waters have not been developed. As with hydrothermal ore deposits, this is because of high costs and squabbles over who owns them and how any profits made from extracting them should be distributed among the world's nations.

Some environmental scientists believe seabed mining probably would cause less environmental harm than mining on land. However, they are concerned that removing seabed mineral deposits and dumping back unwanted material will stir up ocean sediments, destroy seafloor organisms, and have potentially harmful effects on poorly understood ocean food webs and marine biodiversity. They call for more research to help evaluate such possible effects.

14-5 How Can We Use Mineral Resources More Sustainably?

▶ **CONCEPT 14-5 We can try to find substitutes for scarce resources, reduce resource waste, and recycle and reuse minerals.**

We Can Find Substitutes for Some Scarce Mineral Resources

Some analysts believe that even if supplies of key minerals become too expensive or scarce due to unsustainable use, human ingenuity will find substitutes (**Concept 14-5**). They point to the current *materials revolution* in which silicon and new materials, particularly ceramics and plastics, are being used as replacements for metals. And nanotechnology (Science Focus, p. 362) may also lead to the development of materials that can serve as substitutes for various minerals.

In 2005, for example, builders began constructing houses made of Styrofoam sprayed with a ceramic spray called Grancrete. This ceramic is affordable, is twice as strong as structural concrete, and will not leak or crack. It reduces the cost of house frame construction to about one-fifteenth of current costs. It also reduces the need for timber (thereby sparing many trees) and nonrenewable mineral resources used to construct houses. Lightweight Styrofoam blocks are also being used to pave bridges.

Plastic has replaced copper, steel, and lead in much piping. Fiber-optic glass cables that transmit pulses of light are replacing copper and aluminum wires in telephone cables. And in the future, nanowires may replace the optic glass cables.

High-strength plastics and composite materials strengthened by lightweight carbon and glass fibers are beginning to transform the automobile and aerospace industries. They cost less to produce than metals because manufacturing them requires less energy, they do not need painting (which reduces pollution and costs), and they can be molded into any shape. New plastics and gels are also being developed to provide superinsulation that will not take up much space.

RESEARCH FRONTIER

Materials science and engineering. See **academic.cengage .com/biology/miller**.

Use of plastics has drawbacks, chief of which is that making them by current methods requires the use of oil and other fossil fuels. These energy resources are nonrenewable and they have their own environmental impacts, discussed in the next chapter. However, chemists are learning how to make some plastics from plant materials.

Substitution is not a cure-all. For example, currently, platinum is unrivaled as an industrial catalyst, and chromium is an essential ingredient of stainless steel. We can try to find substitutes for scare resources but this may not always be possible.

We Can Recycle and Reuse Valuable Metals

After a pure metal is produced by smelting or chemical extraction, it is usually melted and molded into desired shapes to make products that are then used and discarded or recycled (Figure 14-14). A more sustainable way to use nonrenewable mineral resources (especially valuable or scarce metals such as gold, silver, iron, copper, steel, aluminum, and platinum) is to recycle or reuse them.

Recycling also has a much lower environmental impact than that of mining and processing metals from ores. For example, recycling aluminum beverage cans and scrap aluminum produces 95% less air pollution and 97% less water pollution and uses 95% less energy than mining and processing aluminum ore.

THINKING ABOUT
Metal Recycling and Nanotechnology

How might the development of a nanotechnology revolution (Science Focus, p. 362) over the next 20 years affect the recycling of metal mineral resources?

There Are Many Ways to Use Mineral Resources More Sustainably

Some analysts say we have been asking the wrong question. Instead of asking how we can increase supplies of nonrenewable minerals, we should be asking how we can decrease our use and waste of such resources. Answering that second question could provide important ways to use mineral resources more sustainably (**Concept 14-5**). Figure 14-24 (p. 366) and the Case Study below (p. 366) describe some of these strategies.

In 1975, the U.S. based Minnesota Mining and Manufacturing Company (3M), which makes 60,000

SOLUTIONS

Sustainable Use of Nonrenewable Minerals

- Do not waste mineral resources.
- Recycle and reuse 60–80% of mineral resources.
- Include the harmful environmental costs of mining and processing minerals in the prices of items (full-cost pricing).
- Reduce mining subsidies.
- Increase subsidies for recycling, reuse, and finding substitutes.
- Redesign manufacturing processes to use less mineral resources and to produce less pollution and waste (cleaner production).
- Use mineral resource wastes of one manufacturing process as raw materials for other processes.
- Slow population growth.

Figure 14-24 Ways to achieve more sustainable use of nonrenewable mineral resources (**Concept 14-5**). **Question:** Which two of these solutions do you think are the most important? Why?

different products in 100 manufacturing plants, began a Pollution Prevention Pays (3P) program. It redesigned its equipment and processes, used fewer hazardous raw materials, identified toxic chemical outputs (and recycled or sold them as raw materials to other companies), and began making more nonpolluting products. By 1998, 3M's overall waste production was down by one-third, its air pollutant emissions per unit of production were 70% lower, and the company had saved more than $750 million in waste disposal and material costs. This is an excellent example of why pollution prevention pays (**Concept 1-4**, p. 16). CONCEPT LINK

Since 1990, a growing number of companies have adopted similar pollution and waste prevention programs that lead to *cleaner production.* See the Guest Essay by Peter Montague on cleaner production on the website for this chapter.

■ **CASE STUDY**

Industrial Ecosystems: Copying Nature

An important goal for a sustainable society is to make its industrial manufacturing processes cleaner and more sustainable by redesigning them to mimic how nature deals with wastes. According to one **scientific principle of sustainability**, in nature, the waste outputs of one organism become the nutrient inputs of another organism, so that all of the earth's nutrients are endlessly recycled. SUSTAINABILITY

One way for industries to mimic nature is to recycle and reuse most minerals and chemicals instead of dumping them into the environment. Another is for industries to interact through *resource exchange webs* in which the wastes of one manufacturer become raw materials for another—similar to food webs in natural ecosystems (Figure 3-14, p. 63).

This is happening in Kalundborg, Denmark, where an electric power plant and nearby industries, farms, and homes are collaborating to save money and reduce their outputs of waste and pollution. They exchange waste outputs and convert them into resources, as shown in Figure 14-25. This cuts pollution and waste and reduces the flow of nonrenewable mineral and energy resources through their economy.

Today, about 20 ecoindustrial parks similar to the one in Kalundborg operate in various places in the world, including the U.S. city of Chattanooga, Tennessee (Case Study, p. 21). And more are being built or planned—some of them on abandoned industrial sites, called *brownfields.* Widespread use of the rapidly growing field of industrial ecology to develop a global network of industrial ecosystems over the next few decades could lead to an important *ecoindustrial revolution.* **GREEN CAREER:** Industrial ecology

These and other industrial forms of *biomimicry* provide many economic benefits for businesses. By encouraging recycling and pollution prevention, they reduce the costs of managing solid wastes, controlling pollution, and complying with pollution regulations. They also reduce a company's chances of being sued because of harms caused by their actions. In addition, companies improve the health and safety of workers by reducing workers' exposure to toxic and hazardous materials, thereby reducing company health-care insurance costs.

Biomimicry also stimulates companies to come up with new, environmentally beneficial and less resource-intensive chemicals, processes, and products that can be sold worldwide. Another benefit: such companies have a better image among consumers based on results rather than public relations campaigns.

THINKING ABOUT
Gold Mining

CORE CASE STUDY

How would you apply the solutions in Figure 14-24 to decreasing the need to mine gold (**Core Case Study**) and to reducing the harmful environmental effects of gold mining?

RESEARCH FRONTIER

Developing biomimicry and other ecoindustrial tools. See **academic.cengage.com/biology/miller**.

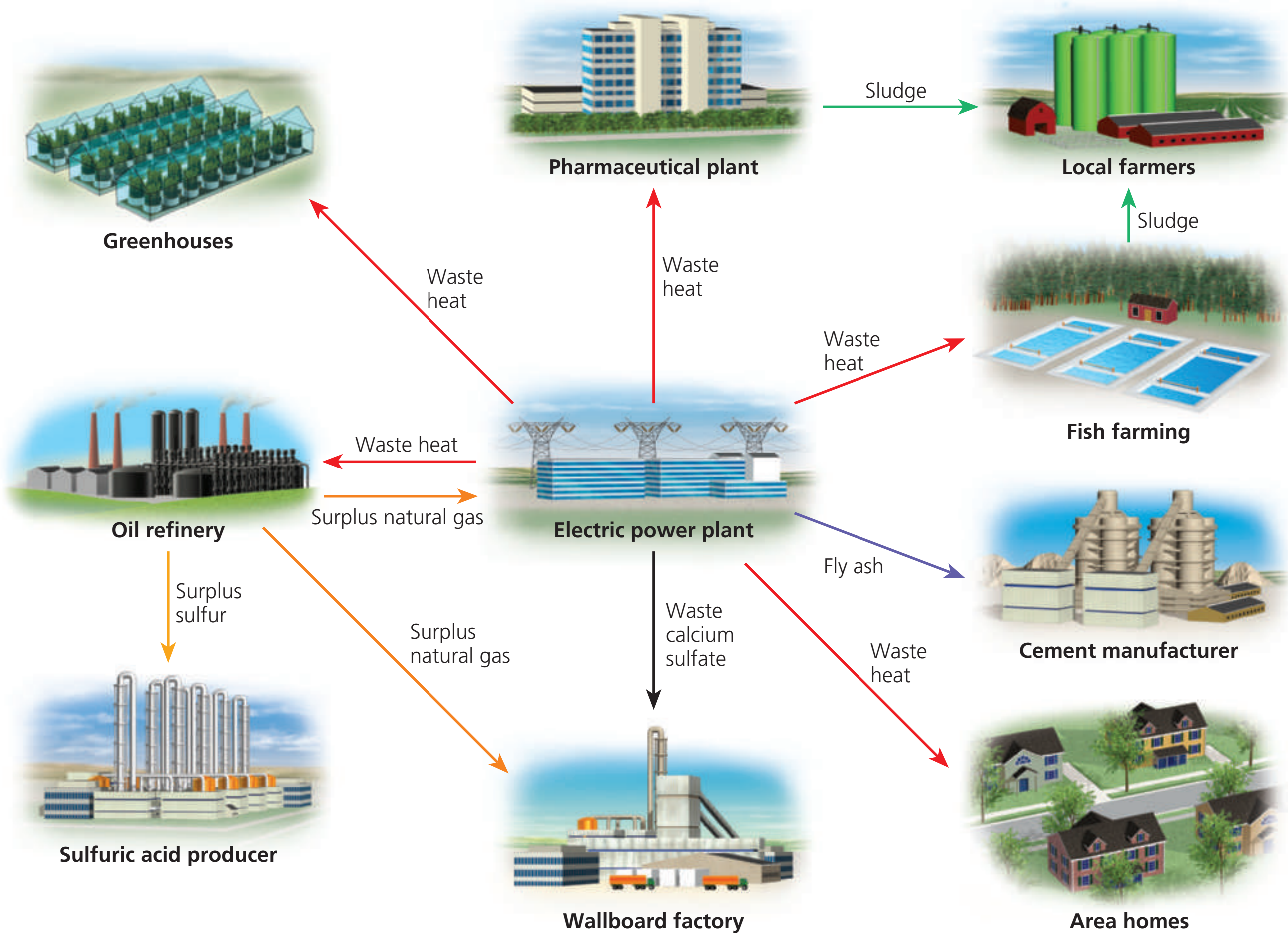


Figure 14-25 **Solutions:** an *industrial ecosystem* in Kalundborg, Denmark, reduces waste production by mimicking a food web in natural ecosystems. The wastes of one business become the raw materials for another. **Question:** Is there an industrial ecosystem near where you live or go to school? If not, think about where and how such a system could be set up.

REVISITING Gold Mining and Sustainability

In this chapter, we began with a discussion of the harmful effects of gold mining (**Core Case Study**). We also have discussed a number of exciting possibilities for extracting and using gold and other nonrenewable mineral resources in less harmful, more sustainable ways.

If developed safely, nanotechnology (Science Focus, p. 362) could provide more sustainable ways to make use of mineral resources. For example, it could be used to make cheap solar cells. This application of the first **principle of sustainability** could enable the use of solar energy to produce electricity for extracting and processing mineral resources and for a host of other environmentally beneficial processes that require electricity. Another promising technology is biomining—the use of microbes to extract mineral resources.

We can also use mineral resources more sustainably by recycling and reusing them and by reducing unnecessary resource use and waste. Industries can mimic nature by converting wastes to resources and exchanging them through a network resembling a food web (Figure 14-25). These solutions apply the recycling **principle of sustainability**.

Implementing these strategies will reduce both the need for mining and its resulting harmful environmental effects (Figure 14-15). This, in turn, will decrease the destruction and degradation of biodiversity and vital species interactions that help to keep species populations in check, in keeping with the two other **principles of sustainability**.

Mineral resources are the building blocks
on which modern society depends.
Knowledge of their physical nature and origins,
the web they weave
between all aspects of human society and the physical earth,
can lay the foundations for a sustainable society.

ANN DORR

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 345. Describe the environmental effects of gold mining.

2. Define **geology, core, mantle, crust, tectonic plate,** and **lithosphere.** What is a transform fault? What is **weathering** and why is it important? Define **volcano** and describe the nature and effects of a volcanic eruption. Define and describe the nature and effects of an **earthquake.** What is a **tsunami** and what are its effects?

3. Define **mineral, rock, sedimentary rock, igneous rock,** and **metamorphic rock** and give an example of each. Describe the nature and importance of the **rock cycle.**

4. Define **mineral resource** and list three types of such resources. Define **ore** and distinguish between a **high-grade ore** and a **low-grade ore.** What are **reserves?** Describe the life cycle of a metal resource. Describe the major harmful environmental effects of extracting, processing, and using nonrenewable mineral resources.

5. Distinguish between **surface mining** and **subsurface mining.** Define **overburden, spoils,** and **open-pit mining.** Define **strip mining** and distinguish among **area strip mining, contour strip mining,** and **mountaintop removal.** Describe the harmful environmental effects of mining. What is **smelting** and what are its major harmful environmental effects? What five nations supply most of the world's nonrenewable mineral resources? How dependent is the United States on other countries for important nonrenewable mineral resources?

6. Describe the advantages and disadvantages of the nanotechnology revolution. What are five possible options when a mineral becomes economically depleted? Define **depletion time** and describe three types of depletion curves for a mineral resource. Describe the conventional view of the relationship between the supply of a mineral resource and its market price. What factors can influence this market interaction? Describe the benefits and possible drawbacks of nanotechnology. Discuss the pros and cons of the U.S. General Mining Law of 1872.

7. Describe the opportunities and limitations of increasing mineral supplies by mining lower-grade ores. What are the advantages and disadvantages of biomining?

8. Describe the opportunities and limitations of getting more minerals from the ocean.

9. Describe the opportunities and limitations of finding substitutes for scarce mineral resources and recycling and reusing valuable metals. Describe ways of using nonrenewable mineral resources more sustainably. Describe the Pollution Prevention Pays program of the Minnesota Mining and Manufacturing Company. What is an industrial ecosystem? Describe the industrial ecosystem operating in Kalundborg, Denmark.

10. Describe the relationships between gold mining (**Core Case Study**) and the four **scientific principles of sustainability**. CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 14-5** to making your lifestyle more environmentally sustainable.

2. List three ways in which decreasing the need to mine gold and reducing its harmful environmental effects (**Core Case Study**) could benefit you. CORE CASE STUDY

3. What do you think would happen if **(a)** plate tectonics stopped and **(b)** erosion and weathering stopped? Explain.

4. You are an igneous rock. Write a report on what you experience as you move through the rock cycle (Figure 14-13). Repeat this exercise, assuming you are a sedimentary rock and then a metamorphic rock.

5. Use the second law of thermodynamics (**Concept 2-4B**, p. 40) to analyze the scientific and economic feasibility of each of the following processes: CONCEPT LINK
   a. Extracting most minerals dissolved in seawater
   b. Mining increasingly lower-grade deposits of minerals
   c. Using inexhaustible solar energy to mine minerals
   d. Continuing to mine, use, and recycle minerals at increasing rates

6. List three ways in which a nanotechnology revolution (Science Focus, p. 362) could benefit you and three ways in which it could harm you.

7. Describe the strategy you would use to promote **(a)** the nanotechnology revolution (Science Focus, p. 362) and **(b)** the spread of ecoindustrial ecosystems (Case Study, p. 366)? As part of your promotion strategy for each of these projects, describe three benefits to your community.

8. Explain why you support or oppose each of the following proposals concerning extraction of hard-rock minerals on public land in the United States: **(a)** halting the practice of granting title to public land for actual or claimed hard-rock mineral deposits, **(b)** requiring mining companies to pay a royalty of 8–12% on the *gross* income they earn

from hard-rock minerals that they extract from public lands, and **(c)** making hard-rock mining companies legally responsible for restoring the land and cleaning up environmental damage caused by their activities.

9. Congratulations! You are in charge of the world. What are the three most important features of your policy for developing and sustaining the world's nonrenewable mineral resources?

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

Uranium (U), which is used as a fuel in the reactors of nuclear power plants, is found in various rocks at different concentrations. A high-grade ore has 2% U, and a low-grade ore has 0.1% U. The estimated recoverable resources of uranium for the world add up to 4,743,000 metric tons. The United States has about 7% of the world's uranium resources, which amounts to about 332,000 metric tons.

1. Given that current worldwide usage of uranium is about 66,500 metric tons U per year, how long will the world's present recoverable resources last? (*Note:* 1 metric ton = 1,000 kg = 1.1 tons)
2. Assume U.S. usage is about 25% of world usage. If the United States were to rely only on its domestic uranium resources, how long would they last, assuming a 100% recovery rate (the amount of the resource that can be used)?
3. Assume that most U.S. ore bodies contain high-grade ore (2% U) and that recovery rates of minerals from the ore (accounting for losses in mining, extraction, and refining), average 65%, how many metric tons of ore will have to be mined to meet U.S. needs?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 14 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

AP* Review Questions for Chapter 14

1. Which of the terms below describes two ocean plates that move apart from one another?
(A) Convergent
(B) Divergent
(C) Transform
(D) Subduction
(E) Convection

2. Tectonic plates move slowly across the asthenosphere on
(A) ocean currents.
(B) ocean ridges.
(C) plate boundaries.
(D) convection currents.
(E) volcanoes.

Questions 3–5 refer to the three major types of rocks.

(A) Sedimentary
(B) Igneous
(C) Metamorphic

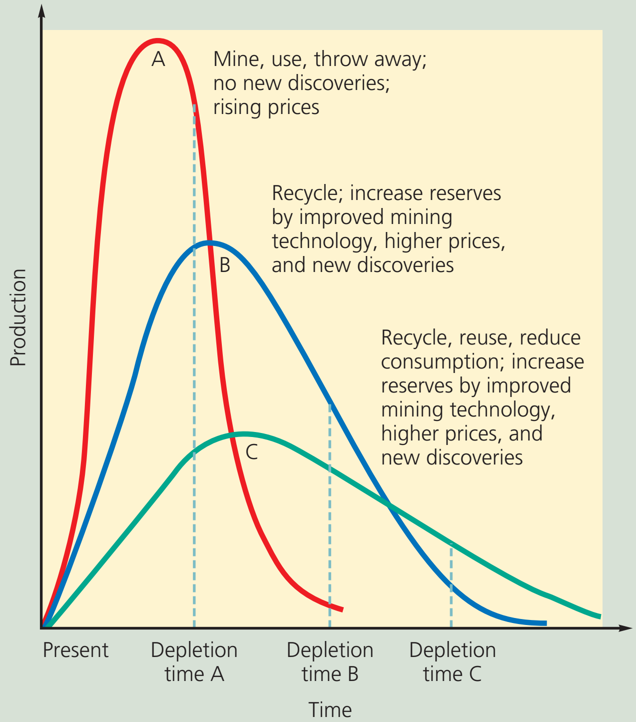
3. Rocks form when pre-existing rock is subjected to high temperatures, pressure, or chemicals.

4. Rock forms when dead plant and animal remains and existing rocks are weathered.

5. Rock forms when magma cools and hardens.

6. Strip mining is a useful and economic way to extract mineral resources. However, strip mining has all of the following harmful environmental effects EXCEPT
(A) swift regrowth of vegetation where strip mining has occurred.
(B) toxic substances are left behind.
(C) biodiversity is destroyed in the area.
(D) streams around the area are polluted
(E) air pollution around the area occurs.

Use the graph below to answer question 7.



7. According to the graph,
(A) recycling a resource does not significantly lower depletion time.
(B) mining, using and throwing away a resource, is the best way to lower depletion time.
(C) recycling a resource causes it to be depleted quickest.
(D) 80% depletion occurs slower as recycling, reuse, and reduction is implemented.
(E) as we recycle, reuse, and reduce our consumption rates, we slow down depletion time of nonrenewable resources.

8. Finding substitutes for mineral resources will
(A) shift mining to lower grade ores.
(B) have no environmental impacts.
(C) help to keep supplies of resources sustainable.
(D) cause thermal water pollution.
(E) cause eutrophication.

9. An abandoned industrial site that has soil, water, or air pollution is known as a
(A) resource.
(B) subsidy.
(C) mineral resource.
(D) brownfield.
(E) material.

10. When a mineral resource becomes scarce its
(A) price rises.
(B) demand goes down.
(C) price stays the same.
(D) virgin material increases.
(E) environmental impact goes down.

11. One big environmental problem with smelting is
(A) cost.
(B) subsidence.
(C) air pollution.
(D) hydraulic mining.
(E) substitution.

12. When a mineral resource is too deep to be surface mined, a technique known as this is used:
(A) Spoil banking
(B) Subsurface mining
(C) Processing
(D) Subsidence
(E) Smelting