Environmental Geology and Earth Resources

11

Learn geology or die!
–Louis Agassiz

These glacier-carved peaks in Chile's Paine del Torres National Park show the effects of geologic forces.

OBJECTIVES

After studying this chapter, you should be able to

- understand some basic geologic principles, including how plate-tectonic movements affect conditions for life on the earth.
- explain how the three major rock types form and how the rock cycle works.
- summarize economic mineralogy and strategic minerals.
- discuss the environmental effects of mining and mineral processing.
- recognize the geologic hazards of earthquakes, volcanoes, floods, and erosion.

LEARNING ONLINE

Visit our webpage at www.mhhe.com/environmentalscience for additional case studies, current environmental news, regional examples, and further readings within the online learning center to help you understand the material in this chapter. You'll also find active links to information pertaining to this chapter including:

Geology, U.S. Geological Survey
Worldwide volcanic activity map
Earthquake information from around the world
Cascades Volcano Observatory
Plate tectonics, U.S. Geological Survey
Geology of Hawaiian volcanoes
Savage Earth, Public Broadcasting System site on geological forces
Mining claims on public lands
Office of Surface Mining, U.S. Department of the Interior
Information for mining activists

Death in a Mine Pit

In 1995 several hundred migrating snow geese settled on the clear water of an idle mine pit in Butte, Montana. One of the few open bodies of water in the area, the lake was a tempting spot to rest. By morning, 342 dying birds and dead carcasses were found floating on the water. Autopsies revealed chemical burns in their esophaguses, stomachs, and intestines. The birds didn't know the water in the Berkeley mine pit, once the "richest hill on earth," is now one of the most confounding toxic waste sites in the West.

From the 1860s to the 1980s this mine was one of the United States' richest sources of metals, including copper, silver, lead, zinc, manganese, and gold. After mining stopped in 1981, groundwater, previously controlled with pumps, began to seep into the deep pit (fig. 11.1). Now the mine contains a 28-billion-gal reservoir of acidic, toxic, dissolved metals. The water is acidic because naturally occurring bacteria oxidize sulfur and other elements in the rocks. The acidic conditions then further mobilize copper, arsenic, cadmium, and a complex soup of other elements. Groundwater continues to seep into the pit, but there is nowhere to pump it without contaminating other ground and water systems.

The Berkeley pit is a notorious site, but it has plenty of company. Water contamination in and around mines, especially abandoned mines, is one of the greatest environmental challenges facing the mining industry and its regulators. Uranium mines in Utah produce radioactive dust and runoff; gold mines in South Dakota spill acids, arsenic, and cyanide into river systems; gold mines in Nevada are depleting precious groundwater to produce toxic lakes of used mineral solvents. Catastrophic fish kills have resulted from spilled mine wastes in eastern Europe. A single mine can cost hundreds of millions of dollars to clean up—if a cleanup method is known and if the mining company responsible is still in existence. Often, the public is left to pay for managing abandoned mines. (Adding insult to injury, mining companies in the United States still pay almost no royalties to the federal government for the resources they extract. Following an 1872 mining law, companies frequently extract billions of dollars worth of minerals for a few thousand dollars in payments to the taxpayers.)

FIGURE 11.1 *The Berkeley mine pit is one of many toxic reservoirs—and environmental challenges—left by mines that produce resources we use every day.*

In Butte and elsewhere, geologists, chemists, hydrologists, and other scientists are struggling to find new cleanup and water management methods. Some are searching for ways to extract usable elements from the water, but so far, extraction costs vastly exceed the potential value of recovered materials.

We all depend on mineral resources in almost every aspect of our lives. Environmental costs of extracting those minerals are one of the most important challenges in environmental geology today. In this chapter we will explore the nature and use of our major earth resources, as well as the earth processes that produce them and some of the hazards associated with natural geologic processes.

To learn more, see the Montana State University report at www.mtech.edu/research/J1998/ResRep98/BerkeleyPit.html.

A DYNAMIC PLANET

Although we think of the ground under our feet as solid and stable, the earth is a dynamic and constantly changing structure. Titanic forces stir inside the earth, causing continents to split, move apart, and then crash into each other in slow but inexorable collisions. In this section, we will look at the structure of our planet and some of the forces that shape it.

A Layered Sphere

The **core,** or interior of the earth, is composed of a dense, intensely hot mass of metal—mostly iron—thousands of kilometers in diameter (fig. 11.2). Solid in the center but more fluid in the outer core, this immense mass generates the magnetic field that envelops the earth.

Surrounding the molten outer core is a hot, pliable layer of rock called the **mantle.** The mantle is much less dense than the core because it contains a high concentration of lighter elements, such as oxygen, silicon, and magnesium.

The outermost layer of the earth is the cool, lightweight, brittle rock **crust.** The crust below oceans is relatively thin (8–15 km), dense, and young (less than 200 million years old) because of constant recycling. Crust under continents is relatively thick (25–75 km), light, and as old as 3.8 billion years because additional material is continually being added. It also is predominantly granitic while oceanic crust is mainly dense basaltic rock. Table 11.1 compares the composition of the whole earth (dominated by the dense core) and the crust.

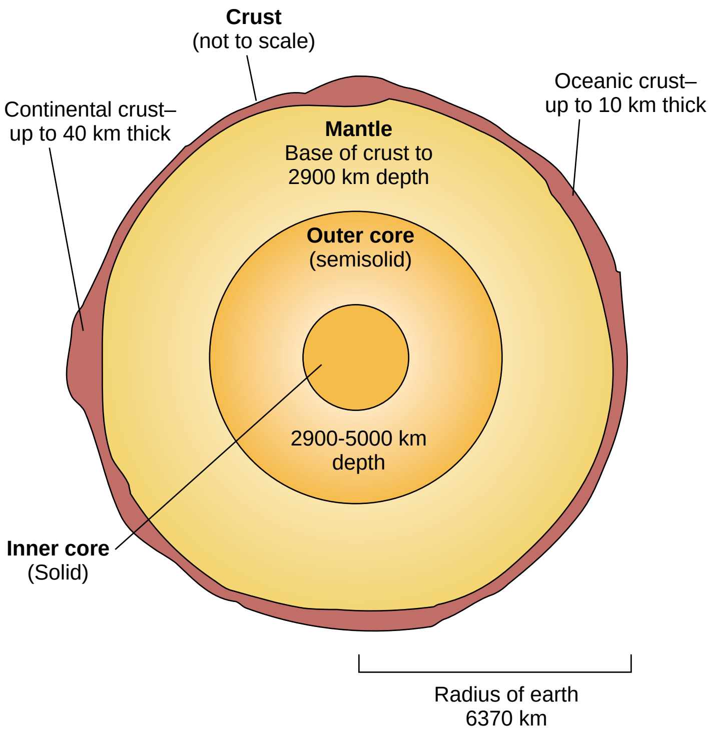

FIGURE 11.2 *The layered earth. The intensely hot, liquid or semisolid outer core consists primarily of molten metal. Around it is a solid but pliable mantle, hot enough to bend and flow like warm taffy. Floating on top of the mantle is a thin crust of rock that breaks into large, slowly moving tectonic plates. The crust appears ten times thicker in this drawing than it is in reality.*

TABLE 11.1 Eight Most Common Chemical Elements (Percent) in Whole Earth and Crust

WHOLE EARTH		CRUST	
Iron	33.3	Oxygen	45.2
Oxygen	29.8	Silicon	27.2
Silicon	15.6	Aluminum	8.2
Magnesium	13.9	Iron	5.8
Nickel	2.0	Calcium	5.1
Calcium	1.8	Magnesium	2.8
Aluminum	1.5	Sodium	2.3
Sodium	0.2	Potassium	1.7

Tectonic Processes and Shifting Continents

Hot enough to flow, the upper layer of the mantle has huge convection currents that break the overlying crust into a mosaic of huge blocks called **tectonic plates** (fig. 11.3). These plates slide slowly across the earth's surface like immense icebergs, in some places breaking up into smaller pieces, in other places crashing ponderously into each other to create new, larger landmasses. Ocean basins form where continents crack and pull apart. The Atlantic Ocean, for example, is growing slowly as Europe and Africa move away from the Americas. **Magma** (molten rock) forced up through the cracks forms new oceanic crust that piles up underwater in **midocean ridges.** Creating the largest mountain range in the world, these ridges wind around the earth for 74,000 km (46,000 mi) (see fig. 11.3 and physiographic map, p. 252). Although concealed from our view, this jagged range boasts higher peaks, deeper canyons, and sheerer cliffs than any continental mountains. Slowly spreading from these fracture zones, ocean plates push against continental plates.

Earthquakes are caused by the grinding and jerking as plates slide past each other. Mountain ranges like those on the west coast of North America and in Japan are pushed up at the margins of colliding continental plates. The Himalayas are still rising as the Indian subcontinent grinds slowly into Asia. Southern California is slowly sailing north toward Alaska. In about 30 million years, Los Angeles will pass San Francisco, if either still exists by then.

When an oceanic plate collides with a continental landmass, the continental plate usually rides up over the seafloor, while the oceanic plate is subducted, or pushed down into the mantle, where it melts and rises back to the surface as magma (fig. 11.4). Deep ocean trenches mark these subduction zones, and volcanoes form where the magma erupts through vents and fissures in the overlying crust. Trenches and volcanic mountains ring the Pacific Ocean rim from Indonesia to Japan to Alaska and down the west coast of the Americas, forming a so-called "ring of fire" where oceanic plates are being subducted under the continental plates. This ring is the source of more earthquakes and volcanic activity than any other place on the earth.

Over millions of years, continents can drift long distances. Antarctica and Australia once were connected to Africa, for instance, somewhere near the equator and supported luxuriant forests. Geologists suggest that several times in the earth's history most or all of the continents have gathered to form a single supercontinent, Pangaea, surrounded by a single global ocean (fig. 11.5). The rupture of this supercontinent and redistribution of its pieces has profound effects on the earth's climate and may help explain the periodic mass extinctions of organisms marking the divisions between many major geologic periods.

MINERALS AND ROCKS

A **mineral** is a naturally occurring, inorganic solid with a definite chemical composition and a specific internal crystal structure. A mineral is solid; therefore ice is a mineral (with a distinct composition and crystal structure), but liquid water is not. Similarly molten lava is not crystalline, although it generally hardens to create distinct minerals. Metals (such as iron, copper, aluminum, or gold) come from mineral ores, but once purified, metals are noncrystalline and thus are not minerals.

A **rock** is a solid, cohesive aggregate of one or more minerals. Within the rock, individual mineral crystals (or grains) are mixed together and held firmly in a solid mass. The grains may be large or small, depending on how the rock was formed, but each

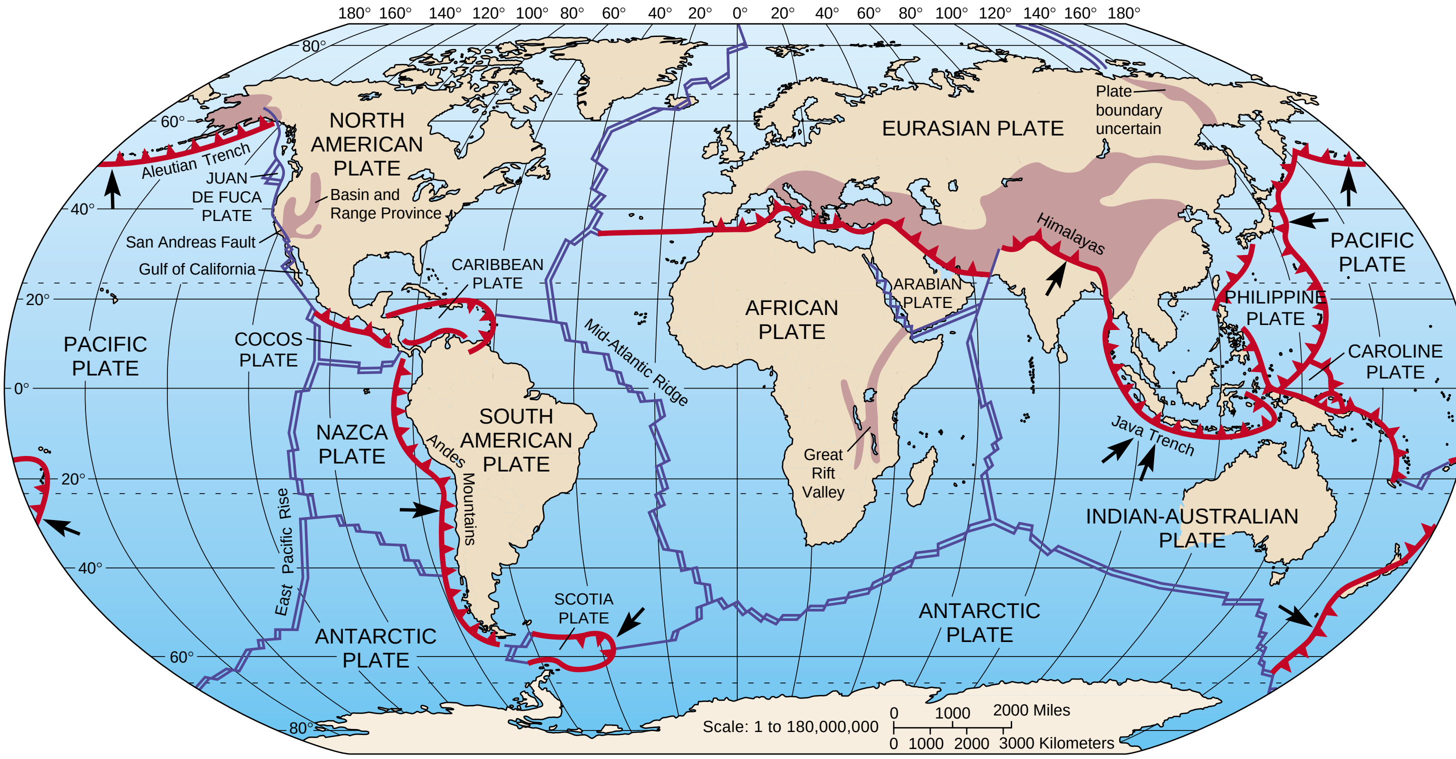

FIGURE 11.3 *Map of tectonic plates. Plate boundaries are dynamic zones, characterized by earthquakes and volcanism and the formation of great rifts and mountain ranges. Arrows indicate direction of subduction where one plate is diving beneath another. These zones are sites of deep trenches in the ocean floor and high levels of seismic and volcanic activity.*
Sources: U.S. Department of the Interior, U.S. Geological Survey.

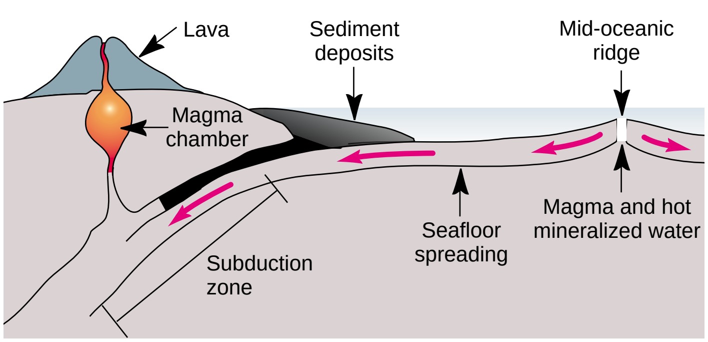

FIGURE 11.4 *Plate-tectonic movements drive the rock cycle. Old seafloor and sediment deposits melt in subduction zones. Magma rises to erupt through volcanoes or to recrystallize at depth into igneous rocks. Weathering breaks down surface rocks, and erosion deposits residue in sedimentary formations. Tectonic movements create pressure and heat, which cause metamorphism of both sedimentary and igneous rocks.*

FIGURE 11.5 *Pangaea, the ancient supercontinent of 200 million years ago, combined all the world's continents in a single landmass.*

grain retains its own unique mineral qualities. Each rock type has a characteristic mixture of minerals, grain sizes, and ways in which the grains are mixed and held together. Granite, for example, is a mixture of quartz, feldspar, and mica crystals. Rocks with a granite-like mineral content but much finer crystals are called rhyolite; chemically similar rocks with large crystals are called pegmatite.

Rock Types and How They Are Formed

Although rocks appear hard and permanent, they are part of a relentless cycle of formation and destruction. They are crushed, folded, melted, and recrystallized by dynamic processes related to those that shape the large-scale features of the earth's crust. We call this cycle of creation, destruction, and metamorphosis the **rock cycle** (fig. 11.6). Understanding something of how this cycle works helps explain the origin and characteristics of different types of rocks.

There are three major rock classifications: igneous, metamorphic, and sedimentary. **Igneous rocks** (from *igni*, the Latin word for fire) are solidified from hot, molten magma or lava. Most rock in the earth's crust is igneous. Magma extruded to the surface from volcanic vents cools quickly to make finely crystalline rocks such as basalt, rhyolite, or andesite. Magma that cools slowly in subsurface chambers or is intruded between overlying layers makes coarsely crystalline rocks, such as gabbro (rich in iron and silica) or granite (rich in aluminum and silica), depending on the chemical composition of the magma.

Metamorphic rocks form from the melting, contorting, and recrystallizing of other rocks. Deep in the ground, tectonic forces squeeze, fold, heat, and recrystallize solid rock. Under these conditions, chemical reactions can alter both the composition and structure of the component minerals. Metamorphic rocks are classified by their chemical composition and by the degree of recrystallization: some minerals form only under extreme pressure and heat (diamonds or jade, for example); others form under more moderate conditions (graphite or talc). Some common metamorphic rocks are marble (from limestone), quartzite (from sandstone), and slate (from mudstone and shale). Metamorphic rocks often have swirling patterns left by the twisting and folding that created them.

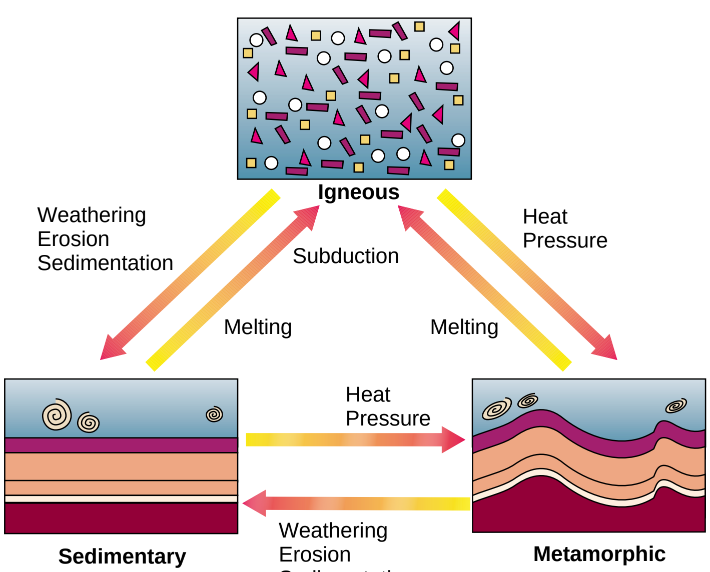

FIGURE 11.6 *The rock cycle consists of processes of creation, destruction, and metamorphosis. Each of the three rock types can be converted to either of the other types.*

FIGURE 11.7 *Soft sedimentary rock layers can be sculpted by erosion into remarkable shapes such as Rainbow Bridge in Utah.*

Sedimentary rocks are formed when loose grains of other rocks are consolidated by time and pressure. Sandstone, for example, is solidified from layers of sand, and mudstone consists of extremely hardened mud and clay. Tuff is formed from volcanic ash, and conglomerates are aggregates of sand and gravel. Some sedimentary rocks develop from crystals that precipitate out of extremely salty water. Rock salt, made of the mineral halite, is ground up to produce ordinary table salt (sodium chloride). Salt deposits often form when a body of saltwater dries up, leaving salt crystals behind. Limestone is a rock composed of cemented remains of marine organisms. You can often see the shapes of these organisms in a piece of limestone. Sedimentary formations often have distinctive layers that show different conditions when they were laid down. Relatively soft sedimentary rocks such as sandstone can be shaped by erosion into striking features (fig. 11.7).

Weathering and Sedimentation

Most crystalline rocks are extremely hard and durable, but exposure to air, water, changing temperatures, and reactive chemical agents slowly breaks them down in a process called **weathering.** Mechanical weathering is the physical breakup of rocks into smaller particles without a change in chemical composition of the constituent minerals. You have probably seen mountain valleys scraped by glaciers, or river and shoreline pebbles that are rounded from being rubbed against one another as they are tumbled by waves and currents. Chemical weathering is the selective removal or alteration of specific components that leads to weakening and disintegration of rock. Among the more important chemical weathering processes are oxidation (combination of oxygen with an element to form an oxide or hydroxide mineral) and hydrolysis (hydrogen atoms from water molecules combine with other chemicals to form acids). The products of these reactions are more susceptible to both mechanical weathering and to dissolving in water. For instance, when carbonic acid (formed when rainwater absorbs CO_2) percolates through porous limestone layers in the ground, it dissolves the rock and creates caves.

Particles of rock loosened by wind, water, ice, and other weathering forces are carried downhill, downwind, or downstream until they come to rest again in a new location. The deposition of these materials is called **sedimentation.** Water, wind, and glaciers deposit particles of sand, clay, or silt far from their source. Much of the American Midwest, for instance, is covered with hundreds of meters of sedimentary material left by glaciers (till, or rock debris deposited by glacial ice), wind (loess, or fine dust deposits), river deposits of sand and gravel, and ocean deposits of sand, silt, clay, and limestone.

ECONOMIC GEOLOGY AND MINERALOGY

Economic mineralogy is the study of minerals that are valuable for manufacturing and trade. Most economic minerals are metal ores. Nonmetallic geological resources include graphite, feldspar, quartz crystals, diamonds, and other crystals that are valued for their usefulness or beauty. Metals have been so important in human affairs that major epochs of human history are commonly known by the dominant materials and the technology to use them (Stone Age, Bronze Age, Iron Age, etc.). The mining, processing, and distribution of these materials have broad implications for both our culture and our environment. Most economically valuable crustal resources exist everywhere in small amounts; the important thing is to find them concentrated in economically recoverable levels.

Public policy in the United States has encouraged mining on public lands as a way of boosting the economy and utilizing natural resources. Today these policies are controversial, and there are efforts to recover public revenue from these publicly owned resources. (See the related essay "Should We Revise the 1872 Mining Law?" at www.mhhe.com/apps.)

Metals

Metals are malleable substances that have always received a great deal of attention because they are strong, relatively light, and can be reshaped for many purposes. The availability of metals and the methods to extract and use them have determined technological developments, as well as economic and political power for individuals and nations.

The metals consumed in greatest quantity by world industry include iron (740 million metric tons annually), aluminum (40 million metric tons), manganese (22.4 million metric tons), copper and chromium (8 million metric tons each), and nickel (0.7 million metric tons). Most of these metals are consumed in the United States, Japan, and Europe, in that order. They are produced primarily in South America, South Africa, and the former Soviet Union. It is easy to see how these facts contribute to a worldwide mineral trade network that has become crucially important to the economic and social stability of all nations involved (fig. 11.8). Table 11.2 shows the primary uses of these metals.

TABLE 11.2 Primary Uses of Some Major Metals Consumed in the United States

METAL	USE
Aluminum	Packaging foods and beverages (38%), transportation, electronics
Chromium	High-strength steel alloys
Copper	Building construction, electric and electronic industries
Iron	Heavy machinery, steel production
Lead	Leaded gasoline, car batteries, paints, ammunition
Manganese	High-strength, heat-resistant steel alloys
Nickel	Chemical industry, steel alloys
Platinum group	Automobile catalytic converters, electronics, medical uses
Gold	Medical, aerospace, electronic uses; accumulation as monetary standard
Silver	Photography, electronics, jewelry

Nonmetal Mineral Resources

Nonmetal minerals are a broad class that covers resources from silicate minerals (gemstones, mica, talc, and asbestos) to sand, gravel, salts, limestone, and soils. Sand and gravel production for road and building construction comprise by far the greatest volume and dollar value of all nonmetal mineral resources and a far greater volume than all metal ores. Sand and gravel are used mainly in brick and concrete construction, paving, as loose road filler, and for sandblasting. High-purity silica sand is our source of glass. These materials usually are retrieved from surface pit mines and quarries, where they have been deposited by glaciers, winds, or ancient oceans.

Limestone, like sand and gravel, is mined and quarried for concrete and crushed for road rock. It also is cut for building stone, pulverized for use as an agricultural soil additive that neutralizes acidic soil, and roasted in lime kilns and cement plants to make plaster (hydrated lime) and cement.

Evaporites (materials deposited by evaporation of chemical solutions) are mined for halite, gypsum, and potash. These are often found at or above 97-percent purity. Halite, or rock salt, is used for water softening and melting ice on winter roads in some northern areas. Refined, it is a source of table salt. Gypsum (calcium sulfate) now makes our plaster wallboard, but it has been used to cover walls ever since the Egyptians plastered their frescoed tombs along the Nile River some 5,000 years ago. Potash is an evaporite composed of a variety of potassium chlorides and potassium sulfates. These highly soluble potassium salts have long been used as a soil fertilizer.

Sulfur deposits are mined mainly for sulfuric acid production. In the United States, sulfuric acid use amounts to more than 200 lbs per person per year, mostly because of its use in industry, car batteries, and some medicinal products.

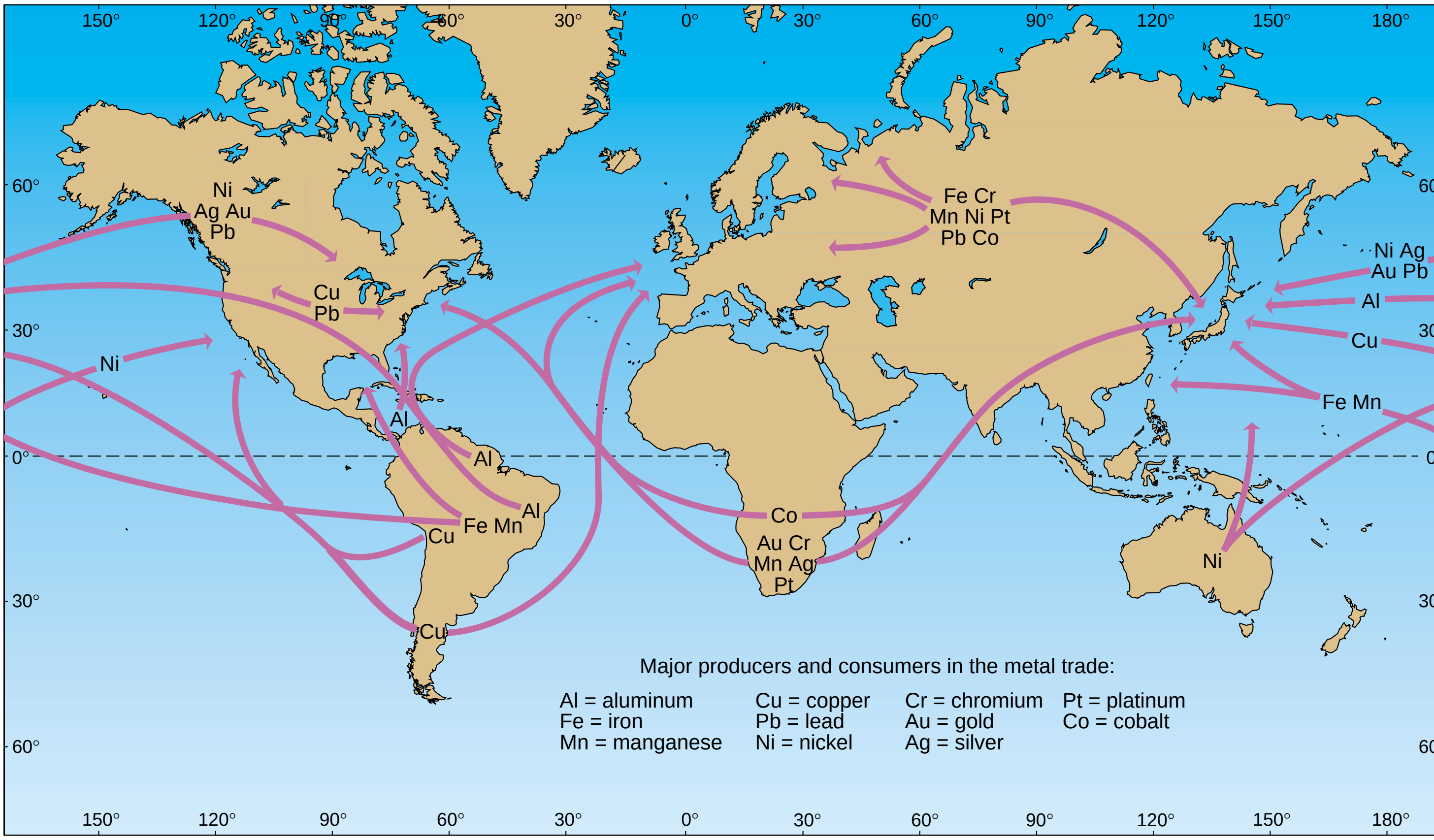

FIGURE 11.8 *Global metal trade. Metals produced in South Africa, South America, and the former Soviet Union are shipped to markets in the United States, Europe, and Japan, creating a global economic network on which both consumers and producers depend.*

Oil, Coal, and Uranium

Modern society functions largely on energy produced from geologic deposits of oil, coal, and natural gas. Nuclear energy, which runs on uranium, makes up a large portion of our electricity resources. Energy production from these sources is discussed in chapter 12. Oil, coal, and gas are organic, created by extreme time, heat, and pressure acting on the remains of ancient organisms. They are not minerals because they have no crystalline structure, but they can be considered part of economic mineralogy because they are such important resources. In addition to providing energy, oil is the source material for plastics, and natural gas is used to make agricultural fertilizers. The search for deposits of these organic deposits is one of the most important parts of economic mineralogy. Debates over exploitation and ownership of these resources play important roles in national and international politics. The Persian Gulf War of 1990 was fought over control of vast underground oil deposits, as has been the ongoing war in Chechnya. Debates over exploiting potential oil reserves in the Alaskan National Wildlife Refuge (ANWR) have raged in the U.S. for decades. (See the related essays “Exploiting Oil in ANWR” and “Oil and the War in Chechnya?” at www.mhhe.com/apps.)

APPLICATION: What geologic resources are you using right now?

Make a list of the geologic materials used in some of the objects you are using right now. For example, the computer used to write this chapter is made largely of plastic (from oil), silicon chips (sand), and copper wire, and it runs on energy from coal- and uranium-powered electric plants.

List the geologic materials in any of the following objects you are using right now: glasses, chair, table, pencil, light bulb, window, building, wristwatch, coffee cup, tooth fillings, other?

Strategic Metals and Minerals

World industry depends on about 80 minerals and metals, some of which exist in plentiful supplies. Three-fourths of these resources are abundant enough to meet all of our anticipated needs or have readily available substitutes. At least 18 metals, however, including tin, platinum, gold, silver, and lead, are in short supply.

Of these 80 metals and minerals, between one-half and one-third are considered "strategic" resources. **Strategic metals and minerals** are those that a country uses but cannot produce itself. As the term *strategic* suggests, these are materials that a government considers capable of crippling the country's economy or military strength if unstable global economics or politics were to cut off supplies. For this reason, wealthy industrial nations stockpile strategic resources, especially metals, in times when prices are low and a supply is available. Figure 11.9 shows some of the major stockpiles of strategic metals and ores in the United States.

For less wealthy mineral- and metal-producing nations, there is another side to strategic minerals. Many less-developed countries depend on steady mineral exports for most of their foreign exchange. Zambia, for instance, relies on cobalt production for 50 percent of its national income. If a steady international market is not maintained, such producer nations could be devastated. From the small-nation producer's point of view, metal or mineral exports, like concentration on any single product or industry, are an unstable economic foundation. Often no option exists, however, if a producer is to participate in the world economy. The environmental consequences of mining may not be a high priority under these circumstances.

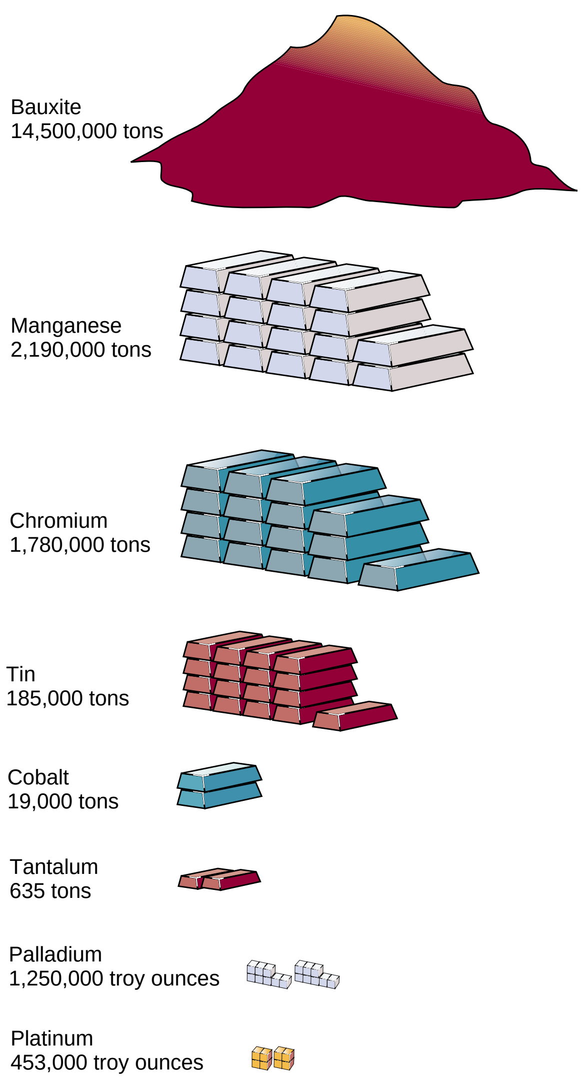

FIGURE 11.9 *U.S. stockpiles of strategic metals and metal ores.*

ENVIRONMENTAL EFFECTS OF RESOURCE EXTRACTION

Geologic resource extraction involves the physical processes of mining and the physical or chemical processes of separating minerals, metals, and other geologic resources from ores or other materials. An ore is a rock in which a valuable or useful metal occurs at a concentration high enough to make mining it economically attractive. For metals like copper, a concentration close to one percent is necessary to make an ore worth mining. For precious metals, like gold or platinum, 0.0001 percent may be enough to make mining and smelting worthwhile.

Mining

Geologic materials are extracted by several different techniques, depending on the accessibility of the resource and the content or concentration of the material sought. All of these methods have environmental hazards. Native metals deposited in the gravel of streambeds can be washed out hydraulically in a process called placer mining. This not only destroys streambeds but fills the water with suspended solids that smother aquatic life. Larger or deeper ore beds are extracted by strip-mining or open-pit mining, where overlying material is removed by large earth-moving equipment. The resulting pits can be many kilometers across and hundreds of meters deep (fig. 11.10). In some cases whole mountaintops or the surface of entire islands have been removed by surface mining. Even deeper deposits are reached by underground tunneling, an extremely dangerous process for mine workers. Old tunnels occasionally collapse or subside. In coal mines, natural gas poses dangers of explosion.

Mine wastes cause considerable environmental damage. Coal-bearing scrap heaps in or near coal mines can burn uncontrollably for years, producing noxious smoke and gases. Surface waste deposits called tailings can cause acidic or otherwise toxic runoff when rainwater percolates through piles of stored material. Tailings from uranium mines produce windborne radioactive dust.

Water leaking into mine shafts also dissolves metals and other toxic material. When this water is pumped out or allowed to seep into groundwater aquifers, it pollutes groundwater or streams. The Mineral Policy Center in Washington, D.C., estimates that 550,000 abandoned mines pockmark the U.S. landscape. Some 19,000 km (12,000 mi) of rivers and streams in the United States are contaminated by mine drainage. The Environmental Protection Agency estimates that cleaning up mines and mine drainage will cost $32 billion to $72 billion.

Huge strip-mines, in which vegetation, soil, and rock layers are stripped from the surface to expose minerals, produce half the coal we use in the United States. The surface material is replaced into the mine, but usually in long ridges, called spoil banks,

FIGURE 11.10 *The world's largest open-pit mine is Bingham Canyon, near Salt Lake City, UT. More than 5 billion tons of copper ore and waste material have been removed since 1906 to create a hole 800 m (2,640 ft) deep and nearly 4 km (2.5 mi) wide at the top.*

FIGURE 11.11 *Thousands of abandoned mines on public lands poison streams and groundwater with acid, metal-laced drainage. This old mine in Montana drains into the Blackfoot River, the setting of Norman Maclean's book* A River Runs Through It.

because this is the easiest way to dump it cheaply and quickly. Spoil banks are very susceptible to erosion and chemical weathering. Rainfall leaches numerous chemicals in toxic concentrations from the freshly exposed earth, and the water quickly picks up a heavy sediment load. Chemical- and sediment-runoff pollution is a major problem in many local watersheds (fig. 11.11). Acid runoff had contaminated 10,000 km (6,250 mi) of streams in the United States by 1980. Problems are made worse by the fact that the steep spoil banks are very slow to revegetate. Since the spoil banks do not have natural topsoil, succession, soil development, and establishment of a natural biological community occur very slowly.

The 1977 federal Surface Mining Control and Reclamation Act (SMCRA) requires better restoration of strip-mined lands, especially of land classed as prime farmlands, but restoration is difficult and expensive. Topsoil is often dispersed and buried by the heavy machinery working to resculpture the land. Compaction restricts root growth and causes poor drainage, resulting in wet, stagnant soil conditions. The difficulties of reestablishing vegetation in dry climates means that reclamation is essentially impossible where rainfall is less than 25 cm (10 in) per year.

The monetary expense of reclamation is also high. Minimum reclamation costs about $1,000 per acre (0.4 ha), while "complete" restoration (where it is possible) costs five times that much.

Nevertheless, 50 percent of U.S. coal (225 to 270 million metric tons per year) is strip-mined. Nearly a million acres (400,000 ha) of land in the United States have been degraded by strip-mining, often on public lands for which mining companies pay little or nothing.

Processing

Metals are extracted from ores by heating or with chemical solvents. Both processes release large quantities of toxic materials that can be even more environmentally hazardous than mining. **Smelting**—roasting ore to release metals—is a major source of air pollution. One of the most notorious examples of ecological devastation from smelting is a wasteland near Ducktown, Tennessee (fig. 11.12). In the mid-1800s, mining companies began excavating the rich copper deposits in the area. To extract copper from the ore, they built huge, open-air, wood fires, using timber from the surrounding forest. Dense clouds of sulfur dioxide released from sulfide ores poisoned the vegetation and acidified the soil over a 50-mi^2 (13,000-ha) area. Rains washed the soil off the denuded land, creating a barren moonscape where nothing could grow. Siltation of reservoirs on the Ocoee River impaired electric generation by the Tennessee Valley Authority (TVA).

Sulfur emissions from Ducktown smelters were reduced in 1907 after Georgia sued Tennessee over air pollution. In the 1930s the TVA began treating the soil and replanting trees to cut down on erosion. Recently, upwards of $250,000 per year has been spent on this effort. While the trees and other plants are still spindly and feeble, more than two-thirds of the area is considered “adequately” covered with vegetation. Similarly, smelting of copper-nickel ore in Sudbury, Ontario, a century ago caused widespread ecological destruction that is slowly being repaired following pollution-control measures (see fig. 9.24).

FIGURE 11.12 *A luxuriant forest once grew on this now barren hillside near Ducktown, TN. Smelter fumes killed all the vegetation nearly a century ago, and erosion has washed away all the topsoil. Restoration projects are slowly bringing back ground cover and rebuilding soil.*

Chemical extraction is used to dissolve or mobilize pulverized ore, but it uses and pollutes a great deal of water. A widely used method is **heap-leach extraction,** which involves piling crushed ore in huge heaps and spraying it with a dilute alkaline-cyanide solution (fig. 11.13). The solution percolates through the pile and dissolves gold. The gold-containing solution is then pumped to a processing plant that removes the gold by electrolysis. A thick clay pad and plastic liner beneath the ore heap is supposed to keep the poisonous cyanide solution from contaminating surface or groundwater, but leaks are common.

Once all the gold is recovered, mine operators may simply walk away from the operation, leaving vast amounts of toxic effluent in open ponds behind earthen dams. A case in point is the Summitville Mine near Alamosa, Colorado. After extracting $98 million in gold, the absentee owners declared bankruptcy in 1992, abandoning millions of tons of mine waste and huge leaking ponds of cyanide. The Environmental Protection Agency may spend more than $100 million trying to clean up the mess and keep the cyanide pool from spilling into the Alamosa River.

In 2000, an enormous cyanide spill from a gold-mining operation near Baia-Mare in Romania poisoned millions of fish and threatened drinking-water supplies along about 640 km (400 mi) of the Szamos, Tisza, and Danube Rivers in Hungary and Yugoslavia.

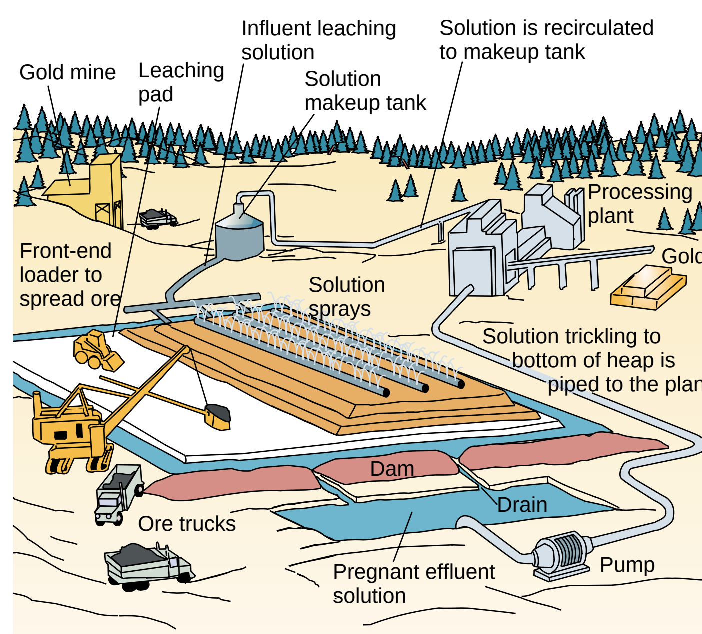

FIGURE 11.13 *In a heap-leach operation, huge piles of low-grade ore are heaped on an impervious pad and sprayed continuously with a cyanide solution. As the leaching solution trickles through the crushed ore, it extracts gold and other precious metals. The “pregnant” effluent solution is then pumped to a processing plant where metals are extracted and purified. This technique is highly profitable but carries large environmental risks.*

Source: George Laycock, *Audubon Magazine*, vol. 91(7), July 1989.

APPLICATION: Knowing your local geology

1. What type(s) of bedrock occurs in your area? Is your local bedrock igneous, metamorphic, or sedimentary? If you don't know, who might be able to tell you?
2. What kind of mineral (and nonmineral) resources are found in your area? How are they extracted? What environmental consequences are there from this extraction?

CONSERVING GEOLOGIC RESOURCES

Recycling offers great potential for extending our supplies of economic minerals and reducing the effects of mining and processing. The advantages of recycling are significant: less waste to dispose of, less land lost to mining, and less consumption of money, energy, and water resources.

Recycling

Some waste products already are being exploited, especially for scarce or valuable metals. Aluminum, for instance, must be extracted from bauxite by electrolysis, an expensive, energy-intensive process. Recycling waste aluminum, such as beverage cans, on the other hand, consumes one-twentieth of the energy of extracting new aluminum. Today, nearly two-thirds of all aluminum beverage cans in the United States are recycled, up from only 15 percent 20 years ago. The high value of aluminum scrap ($650 a ton versus $60 for steel, $200 for plastic, $50 for glass, and $30 for paperboard) gives consumers plenty of incentive to deliver their cans for collection. Recycling is so rapid and effective that half of all the aluminum cans now on a grocer's shelf will be made into another can within two months. Table 11.3 shows the energy cost of extracting other materials.

Platinum, the catalyst in automobile catalytic exhaust converters, is valuable enough to be regularly retrieved and recycled from used cars (fig. 11.14). Other commonly recycled metals are gold, silver, copper, lead, iron, and steel. The latter four are readily available in a pure and massive form, including copper pipes, lead batteries, and steel and iron auto parts. Gold and silver are valuable enough to warrant recovery, even through more difficult means.

Steel and Iron Recycling: Minimills

While total U.S. steel production has fallen in recent decades—largely because of inexpensive supplies from new and efficient Japanese steel mills—a new type of mill subsisting entirely on a readily available supply of scrap/waste steel and iron is a growing industry. Minimills, which remelt and reshape scrap iron and steel, are smaller and cheaper to operate than traditional integrated mills that perform every process from preparing raw ore to finishing iron and steel products. Minimills produce steel at between $225 and

TABLE 11.3 Energy Requirements in Producing Various Materials from Ore and Raw Source Materials

	ENERGY REQUIREMENT (MJ/kg)*	
PRODUCT	NEW	FROM SCRAP
Glass	25	25
Steel	50	26
Plastics	162	n.a.†
Aluminum	250	8
Titanium	400	n.a.†
Copper	60	7
Paper	24	15

Source: Data from E. T. Hayes, *Implications of Materials Processing,* 1997.

*megajoules per kilogram

†not available

FIGURE 11.14 *The richest metal source we have—our mountains of scrapped cars—offer a rich, inexpensive, and ecologically beneficial resource that can be "mined" for a number of metals.*

$480 per metric ton, while steel from integrated mills costs $1,425 to $2,250 per metric ton on average. The energy cost is likewise lower in minimills: 5.3 million BTU/ton of steel compared to 16.08 million BTU/ton in integrated mill furnaces. Minimills now produce about half of all of U.S. steel. Recycling is slowly increasing as raw materials become more scarce and wastes become more plentiful.

Substituting New Materials for Old

Mineral and metal consumption can be reduced by new materials or new technologies developed to replace traditional uses. This is a long-standing tradition; for example, bronze replaced stone technology, and iron replaced bronze. More recently, the introduction of plastic pipe has decreased our consumption of copper, lead, and steel pipes. In the same way, the development of fiber-optic technology and satellite communication reduces the need for copper telephone wires.

Iron and steel have been the backbone of heavy industry, but we are now moving toward other materials. One of our primary uses for iron and steel has been machinery and vehicle parts. In automobile production, steel is being replaced by polymers (long-chain organic molecules similar to plastics), aluminum, ceramics, and new high-technology alloys. All of these reduce vehicle weight and cost, while increasing fuel efficiency. Some of the newer alloys that combine steel with titanium, vanadium, or other metals wear much better than traditional steel. Ceramic engine parts provide heat insulation around pistons, bearings, and cylinders, keeping the rest of the engine cool and operating efficiently. Plastics and glass fiber–reinforced polymers are used in body parts and some engine components.

Electronics and communications (telephone) technology, once major consumers of copper and aluminum, now use ultrahigh-purity glass cables to transmit pulses of light, instead of metal wires carrying electron pulses. Once again, this technology has been developed for its greater efficiency and lower cost, but it also affects consumption of our most basic metals.

GEOLOGIC HAZARDS

Earthquakes, volcanoes, floods, and landslides are normal earth processes, events that have made our earth what it is today. However, when they affect human populations, their consequences can be among the worst and most feared disasters that befall us.

Earthquakes

Earthquakes are sudden movements in the earth's crust that occur along faults (planes of weakness), where one rock mass slides past another one. When movement along faults occurs gradually and relatively smoothly, it is called creep or seismic slip and may be undetectable to the casual observer. When friction prevents rocks from slipping easily, stress builds up until it is finally released with a sudden jerk. The point on a fault at which the first movement occurs during an earthquake is called the epicenter.

Earthquakes have always seemed mysterious, sudden, and violent, coming without warning and leaving ruined cities and dislocated landscapes in their wake. Cities such as Kobe, Japan, or Mexico City, parts of which are built on soft landfill or poorly consolidated soil, usually suffer the greatest damage from earthquakes (fig. 11.15). Water-saturated soil can liquify when shaken. Buildings sometimes sink out of sight or fall down like a row of dominoes under these conditions.

Earthquakes frequently occur along the edges of tectonic plates, especially where one plate is being subducted, or pushed down, beneath another. Earthquakes also occur in the centers of continents, however. In fact, one of the largest earthquakes ever recorded in North America was one of an estimated magnitude 8.8 that struck the area around New Madrid, Missouri, in 1812. Fortunately, few people lived there at the time, and the damage was minimal.

Modern contractors in earthquake zones attempt to prevent damage and casualties by constructing buildings that can withstand tremors. The primary methods used are heavily reinforced structures,

FIGURE 11.15 *An elevated freeway buckled and collapsed as a result of the 1995 earthquake in Kobe, Japan.*

strategically placed weak spots in the building that can absorb vibration from the rest of the building, and pads or floats beneath the building on which it can shift harmlessly with ground motion.

One of the most notorious effects of earthquakes is the tsunami. These giant sea swells (sometimes improperly called tidal waves) can move at 1,000 km/h (600 mph), or faster, away from the center of an earthquake. When these swells approach the shore, they can easily reach 15 m or more, and some have been as high as 65 m (nearly 200 ft). A 1960 tsunami coming from a Chilean earthquake still caused 7-m breakers when it reached Hawaii 15 hours later. Tsunamis also can be caused by underwater volcanic explosions or massive seafloor slumping. The eruption of the Indonesian volcano Krakatoa in 1883 created a tsunami 40 m (130 ft) high that killed 30,000 people on nearby islands.

Volcanoes

Volcanoes and undersea magma vents are the sources of most of the earth's crust. Over hundreds of millions of years, gaseous emissions from these sources formed the earth's earliest oceans and atmosphere. Many of the world's fertile soils are weathered volcanic materials. Volcanoes have also been an ever-present threat to human populations. One of the most famous historic volcanic eruptions was that of Mount Vesuvius in southern Italy, which buried the cities of Herculaneum and Pompeii in A.D. 79. The mountain had been showing signs of activity before it erupted, but many citizens chose to stay and take a chance on survival. On August 24, the mountain buried the two towns in ash. Thousands were killed by the dense, hot, toxic gases that accompanied the ash flowing down from the volcano's mouth. It continues to erupt from time to time.

Nuees ardentes (French for "glowing clouds") are deadly, denser-than-air mixtures of hot gases and ash like those that inundated Pompeii and Herculaneum. Temperatures in these clouds may exceed 1,000ºC, and they move at more than 100 km/h (60 mph). *Nuees ardentes* destroyed the town of St. Pierre on the Caribbean island of Martinique on May 8, 1902. Mount Pelee released a cloud of *nuees ardentes* that rolled down through the town, killing somewhere between 25,000 and 40,000 people within a few minutes. All of the town's residents died except for a single prisoner being held in the town dungeon.

Mudslides are also disasters sometimes associated with volcanoes. The 1985 eruption of Nevado del Ruíz, 130 km (85 mi) northwest of Bogotá, Colombia, caused mudslides that buried most of the town of Armero and devastated the town of Chinchina. An estimated 25,000 people were killed. Heavy mudslides also accompanied the eruption of Mount St. Helens in Washington in 1980. Sediments mixed with melted snow and the waters of Spirit Lake at the mountain's base and flowed many kilometers from their source. Extensive damage was done to roads, bridges, and property, but because of sufficient advance warning, there were few casualties.

Volcanic eruptions often release large volumes of ash and dust into the air. Mount St. Helens expelled 3 km^3 of dust and ash, causing ash fall across much of North America (fig. 11.16). This

FIGURE 11.16 *Volcanoes like Mount St. Helens are major geologic forces that redistribute rock material and release earth elements into the atmosphere.*

was only a minor eruption. An eruption in a bigger class of volcanoes was that of Tambora in Indonesia in 1815, which expelled 175 km^3 of dust and ash, more than 58 times that of Mount St. Helens. These dust clouds circled the globe and reduced sunlight and air temperatures enough so that 1815 was known as the year without a summer.

It is not just a volcano's dust that blocks sunlight. Sulfur emissions from volcanic eruptions combine with rain and atmospheric moisture to produce sulfuric acid (H_2SO_4). Droplets of H_2SO_4 interfere with solar radiation and can significantly cool the world climate. In 1991, Mt. Pinatubo in the Philippines emitted 20 million tons of sulfur dioxide aerosols that remained in the stratosphere for two years. This thin haze cooled the entire earth by 1º C and postponed global warming for several years. It also caused a 10 to 15 percent reduction in stratospheric ozone, allowing increased ultraviolet light to reach the earth's surface.

Floods

In most moderately humid climates, stream channels adjust to accommodate average maximum stream flows. Much of the year, the water level may be well below the stream bank height, but heavy rains or sudden snow melt can deliver more water than the stream can carry. Excess water that overflows stream banks and covers adjacent land is considered a **flood.** The severity of floods can be described by the depth of water above the normal stream banks or by how frequently a similar event normally occurs—on average—for a given area. Note that these are statistical averages over long time periods. A "10-year flood" would be expected to occur once in every ten years; a "100-year flood" would be expected to occur once every century. But two 100-year floods can occur in successive years or even in the same year.

The biggest economic loss from floods is usually not the buildings and property they carry away, but rather the contamination they cause. Virtually everything flood waters touch in a house—carpets, furniture, drapes, electronics, even drywall and insulation—must be removed and discarded. Although floods usually don't take as many lives as some other natural disasters, they are among the most costly because they occur relatively frequently and in populated river corridors.

Many human activities increase both the severity and frequency of floods. Paving roads and parking lots reduces water infiltration into the soil and speeds the rate of runoff into streams and lakes. Clearing forests for agriculture and filling cities with buildings similarly increase both the volume and rate of water discharge after a storm.

Under normal conditions, floods are mitigated by **floodplains**—low land that is periodically inundated during normal floods. However, floodplains are usually fertile, flat, and easily farmed. They are convenient for building and close to the river. In much of the developed world, floodplains are widely farmed, developed with cities and houses, and cleared of vegetation. Floodplains have lost much of their ability to absorb flood waters.

Even more than development, though, flood control structures have separated floodplains from rivers. Levees and flood walls are built to contain water within riverbanks, and river channels are dredged and deepened to allow water to recede faster. Every flood control structure simply transfers the problem downstream, however. The water has to go somewhere. If it doesn't soak into the ground upstream, it will simply exacerbate floods somewhere downstream—leading to more levee development, and then to more flooding further downstream, and so on (fig. 11.17).

FIGURE 11.17 *The Mississippi River inundated downtown Davenport, IA, during the summer floods of 1993. Although sympathetic with the heartbreak and economic losses caused by this flooding, many people argue that floodplains such as this never should have been settled in the first place.*

FIGURE 11.18 *Locks, dams, levees, and other flood control and navigational structures such as this complex on the Mississippi River at Dubuque, IA, have been a godsend for commercial shippers but have also been disastrous for riparian ecosystems, backwater sloughs, marshes, and the wildlife that depends on them.*

Flood Control

More than $25 billion of river-control systems have been built on the Mississippi and its tributaries. These systems have protected many communities over the past century (fig. 11.18). In the major floods of 1993, however, this elaborate system helped turn a large flood into a major disaster. Deprived of the ability to spill out over floodplains, the river is pushed downstream to create faster currents and deeper floods until eventually a levee gives way somewhere. Hydrologists calculate that the floods of 1993 were about 3 m (10 ft) higher than they would have been, given the same rainfall in 1900 before the flood-control structures were in place.

Under current rules, the government is obligated to finance most levees and flood control structures. Many people think that it would be much better to spend this money to restore wetlands, replace ground cover on water courses, build check dams on small streams, move buildings off the floodplain, and undertake other nonstructural ways of reducing flood danger. According to this view, floodplains should be used for wildlife habitat, parks, recreation areas, and other uses not susceptible to flood damage.

The National Flood Insurance Program administered by the Federal Emergency Management Agency (FEMA) was intended to aid people who cannot buy insurance at reasonable rates, but its effects have been to encourage building on the floodplains by making people feel that whatever happens, the government will take care of them. Many people would like to relocate homes and businesses out of harm's way after the recent floods or to improve them so they will be less susceptible to flooding, but owners of damaged property can collect only if they rebuild in the same place and in the same way as before. This serves to perpetuate problems rather than solve them.

Erosion

Gravity constantly pulls downward on every material everywhere on earth. Hillsides, beaches, even relatively flat farm fields can lose material to erosion. Often, water helps to mobilize loose material, and catastrophic landslides, beach erosion, and gully development can occur in a storm. Where houses are built on erodible surfaces, enormous loss of property can result.

Landslides, also called mass wasting or mass movement, occur when masses of material move downslope. Slow and subtle landslips are common, but rockslides, mudslides, and slumping can be swift and dangerous. In the United States alone, landslides and related mass wasting cause over $1 billion in property damage every year. When unconsolidated sediments on a hillside are saturated by a storm or exposed by logging, road building, or house construction, slopes are especially susceptible to sudden landslides.

Often people are unaware of the risks they face by locating on or under unstable hillsides. Sometimes they simply ignore clear and obvious danger. In Southern California, where land prices are high, people often build expensive houses on steep hills and in narrow canyons. Most of the time, this dry environment appears quite stable, but the chaparral vegetation burns frequently and fiercely. When fires expose the soil in late summer, heavy winter rains cause mudslides and debris flows that destroy whole neighborhoods (fig. 11.19).

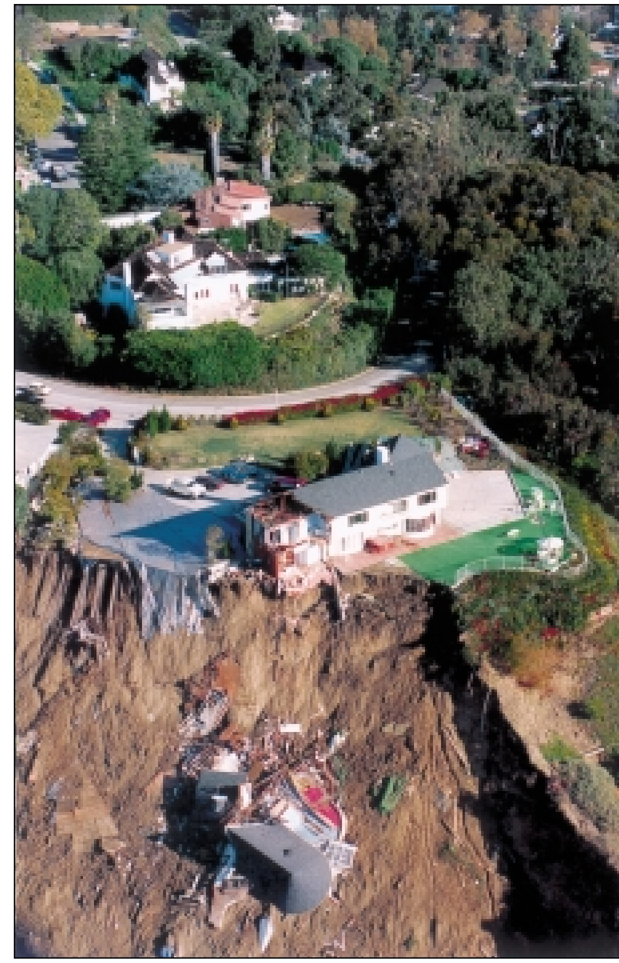

FIGURE 11.19 *Parts of an expensive house slide down the hillside in Pacific Palisades, CA. Building at the edge of steep slopes made of unconsolidated sediment in an earthquake-prone region is a risky venture.*

Gullying is the development of deep trenches on relatively flat ground. Especially on farm fields, which have a great deal of loose soil unprotected by plant roots, rainwater running across the surface can dig deep gullies. Sometimes land becomes useless for farming because gullying is so severe and because erosion has removed the fertile topsoil. Agricultural soil erosion has been described as an invisible crisis. Erosion has reduced the fertility of millions of acres of prime farmland in the United States alone.

Beach erosion occurs on all sandy shorelines because the motion of the waves is constantly redistributing sand and other sediments. One of the world's longest and most spectacular sand beaches runs down the Atlantic coast of North America from New England to Florida and around the Gulf of Mexico. Much of this beach lies on some 350 long, thin **barrier islands** that stand between the mainland and the open sea. Behind these barrier islands lie shallow bays or brackish lagoons fringed by marshes or swamps.

Early inhabitants recognized that the shore was a hazardous place to live and settled on the bay side of barrier islands or as far upstream on coastal rivers as was practical. Modern residents, however, place a high value on living where they have an ocean view and ready access to the beach. And they assume that modern technology makes them immune to natural forces. The most valuable and prestigious property is closest to the shore. Over the past 50 years, more than one million acres of estuaries and coastal marshes have been filled to make way for housing or recreational developments.

Construction directly on beaches and barrier islands can cause irreparable damage to the whole ecosystem. Normally fragile vegetative cover holds the shifting sand in place. Damaging this vegetation with construction, road-building, and breaching dunes with roads, can destabilize barrier islands. Storms then wash away beaches or even whole islands. A single severe storm in 1962 caused $300 million in property damage along the East Coast and left hundreds of beach homes tottering into the sea (fig. 11.20). FEMA estimates that 25 percent of all coastal homes in the U.S. will have the ground washed out from under them by 2060.

Cities and individual property owners often spend millions of dollars to protect beaches from erosion. Sand is dredged from the ocean floor or hauled in by the truckload, only to wash away again in the next storm. Building artificial barriers, such as groins or jetties, can trap migrating sand and build beaches in one area, but they often starve downstream beaches and make erosion there even worse (fig. 11.21).

As is the case for inland floodplains, government policies often encourage people to build where they probably shouldn't. Subsidies for road building and bridges, support for water and sewer projects, tax exemptions for second homes, flood insurance, and disaster relief are all good for the real estate and construction businesses but invite people to build in risky places. Flood insurance typically costs $300 per year for $80,000 of coverage. In 1998, FEMA paid out $40 billion in claims, 80 percent of which were flood related. Settlement usually requires that structures be rebuilt exactly where and as they were before. There is no restriction on how many claims can be made, and policies are rarely canceled, no matter what the risk. Some beach houses have been rebuilt—at public expense—three times in a decade. The General Accounting Office found that 2 percent of federal flood policies were responsible for 30 percent of the claims.

The Coastal Barrier Resources Act of 1982 prohibited federal support, including flood insurance, for development on sensitive islands and beaches. In 1992, however, the U.S. Supreme Court ruled that ordinances forbidding floodplain development amount to an unconstitutional "taking" or confiscation of private property.

FIGURE 11.20 *Winter storms have eroded the beach and undermined the foundations of homes on this barrier island. Breaking through protective dunes to build such houses damages sensitive plant communities and exposes the whole island to storm sand erosion. Coastal zone management attempts to limit development on fragile sites.*

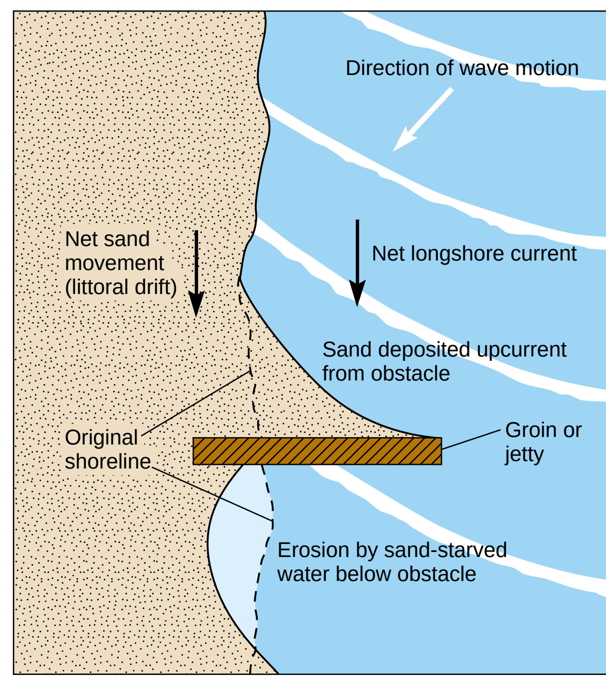

FIGURE 11.21 *Groins are structures built perpendicular to a beach to slow erosion and trap sand. They build up beaches toward prevailing wind and wave direction but starve beaches and increase erosion downstream. Dashed line indicates original shoreline.*

SUMMARY

The earth is a complex, dynamic system. Although it seems stable and permanent to us, the crust is in constant motion. Huge blocks called tectonic plates slide over the surface of the ductile mantle. They crash into each other in ponderous slow motion, crumpling their margins into mountain ranges and causing earthquakes. Often, one plate slides under another, carrying rock layers down into the mantle, where they melt and flow back toward the surface to form new rocks.

Rocks are classified according to composition, structure, and origin. The three basic types of rock are igneous, metamorphic, and sedimentary. These rock types can be transformed from one to another by way of the rock cycle, a continuous process of weathering, transport, burial in sediments, metamorphism, melting, and recrystallization.

During the cooling and crystallization process that forms rock from magma, minerals and metals can become concentrated enough to become economically important reserves if they are close enough to the surface to be reached by mining. Having a reliable supply of strategically important minerals and metals is vital in industrialized societies.

A few places in the world are especially rich in mineral deposits. South Africa and the former Soviet Union contain most of the world's supply of several strategic minerals. Less-developed countries, most of which are in the tropics or the Southern Hemisphere, are often the largest producers of ores and raw mineral resources for the strategic materials on which the industrialized world depends. The major consumers of these resources are the industrialized countries.

Both mining and processing of metals and mineral resources can have negative environmental effects. Mine drainage has polluted thousands of kilometers of streams and rivers. Fumes from smelters kill forests and spread pollution over large areas. Surface mining results in removal of natural ecosystems, soil disruption, creation of trenches or open pits, and tailings accumulations. It is now required that strip-mined areas be recontoured, but revegetation is often difficult and limited in species composition. Smelting and chemical extraction processes also create pollution problems.

Worldwide, only a small percentage of metals are recycled, although it is not a difficult process technically. Recycling saves energy and reduces environmental damage caused by mining and smelting. It reduces waste production and makes our metal supplies last much longer. Substitution of materials usually occurs when mineral supplies become so scarce that prices are driven up. Many of the strategic metals that we now stockpile may become obsolete when newer, more useful substitutes are found.

Earthquakes, volcanoes, floods, and erosion are natural geological processes. When they affect human lives and property, however, they become some of the worst "natural disasters" known. Some of these natural disasters, especially floods and erosion, are made more serious by human activities and land-use decisions.

QUESTIONS FOR REVIEW

1. Describe the layered structure of the earth.
2. What are tectonic plates, and why are they important to us?
3. Why are there so many volcanoes and earthquakes along the "ring of fire" that rims the Pacific Ocean?
4. Define mineral and rock.
5. Describe the rock cycle, and name the three main rock types that it produces.
6. Give some examples of nonmetal mineral resources, and describe how they are used.
7. Give some examples of strategic metals. Where are the largest supplies of these resources located?
8. What are some environmental hazards associated with mineral extraction?
9. Describe some ways we recycle metals and other mineral resources.
10. Describe some of the leading geologic hazards and their effects.

THINKING SCIENTIFICALLY

1. Understanding and solving the environmental problems of mining are basically geologic problems, but geologists need information from a variety of environmental and scientific fields. What are some of the other sciences (or disciplines) that could contribute to solving mine contamination problems?
2. Geologists are responsible for identifying and mapping mineral resources. But mineral resources are buried below the soil and covered with vegetation. How do you suppose geologists in the field find clues about the distribution of rock types?
3. If you had an igneous rock with very fine crystals and one with very large crystals, which would you expect to have formed deep in the ground, and why?
4. If you look at a map of the world, what are some of the shapes that suggest the continents were once joined together?
5. The idea of tectonic plates shifting across the earth's surface is central to explanations of geologic processes. Why is this idea still called the "theory" of plate-tectonic movement?

6. Geologic evidence from fossils and sediments provided important evidence for past climate change. What sorts of evidence in the rocks and landscape around you suggest that the place where you lived once looked much different than it does today?

KEY TERMS

barrier islands 263
core 250
crust 250
earthquakes 260
flood 262
floodplains 262
heap-leach extraction 258
igneous rocks 253
landslides 263
magma 251
mantle 250
metamorphic rocks 253
midocean ridges 251
mineral 251
rock 251
rock cycle 253
sedimentary rocks 253
sedimentation 254
smelting 258
strategic metals and minerals 256
tectonic plates 251
volcanoes 261
weathering 253

WEB EXERCISES

Earth Resources: World Petroleum Supplies

Understanding the distribution of world petroleum supplies is one of the most current and urgent topics in environmental geology. The U.S. Geological Survey (USGS) monitors and assesses world oil and gas supplies because they are such important commodities. Look at the USGS World Petroleum Assessment 2000 at energy.cr.usgs.gov/energy/WorldEnergy/WEnergy.html.

This site is also accessible from the main USGS energy page energy.usgs.gov/

1. Find the selection box labeled "Maps Showing Geology, Oil, and Gas," and select a continent or region. Where is the greatest concentration of oil and gas sites?
2. Click on "Geologic Units" below the map to see a key. What type of geologic features or ages are associated with most of the oil or gas fields in the area at which you are looking?

Understanding Volcanoes

USGS Hawaii Volcano Observatory is one of the most important places for studying and understanding volcanoes. Visit the observatory's web site at hvo.wr.usgs.gov/

1. Which of the volcanoes discussed at this website is the largest in the world? Which is the most active?
2. Why are earthquakes discussed on this volcano website?
3. What are the major hazards to people from these volcanoes?

For a good collection of volcano images, go to the USGS Cascades Volcano Observatory at vulcan.wr.usgs.gov/Photo/framework.html

Evaluating Erosion on Farmland

The Natural Resources Conservation Service (NRCS), part of the U.S. Department of Agriculture, is the agency that monitors agricultural resources and conditions. Among its data-gathering efforts, the NRCS produces a Natural Resources Inventory (NRI), with maps of farmland conditions across the mainland United States. Visit the NRCS/NRI website at www.nhq.nrcs.usda.gov/land/index/nri97maps.html#maps

Find the list of erosion maps. Look at several of the maps. First identify the meaning of the colors. Then identify the major concentration of high and low erosion rates.

1. Where is wind erosion worst? Where is water erosion worst?
2. Where are the most acres of highly erodible cropland? What kind of physical features might occur there?