Chapter 14 - Geology and Earth Resources

Key Terms

bauxite
chemical weathering
converging plate boundary
core
crust
diverging plate boundary
earthquake
heap leach extraction
igneous rock
lava
lithification
magma
mantle
mass wasting
mechanical weathering
metal
metamorphic rock
mineral
mineral resources
rock
rock cycle
sedimentary rock
sedimentation
smelting
subsurface mining
surface mining
tectonic plates
transform boundary
tsunami
volcano
weathering

Skills

1. Examine plate tectonics, distinguishing between transform, converging, and diverging plate boundaries and the geologic hazards associated with each.
2. Diagram the rock cycle, including the relationships between the three types of rocks.
3. Assess the importance of mineral mining and processing.
4. Compare and contrast the economic and environmental costs and benefits of mining and processing.
5. Classify the types of geological hazards.
6. Contrast the different types of weathering.

Take Note: It is imperative that you are familiar with the earth's structure. You must be familiar with the plate tectonic theory and know what geologic hazards are associated with the different types of plate interactions.

Earth's Structure

The center of the earth, the core, is comprised primarily of iron with a small amount of nickel. The core is thought to generate the magnetic field associated with the earth. Surrounding the core is the mantle, the largest part of the earth's structure. The mantle contains large amounts of oxygen, silicon, and magnesium. The asthenosphere is the portion of the slightly molten upper mantle, which allows it to flow. The asthenosphere is the origin of magma. The solid upper mantle and lower portion of the crust form the lithosphere, broken into a series of plates, known as tectonic plates. The crust is comprised of continental and oceanic crust. Continental crust has large amounts of calcium, potassium, sodium, silicon, and aluminum. Oceanic crust composition is primarily igneous rock called basalt.

Plate tectonics

The tectonic plates are formed by the convection currents in the asthenosphere, which fracture the lithosphere into separate plates. There are three types of interactions at plate boundaries: divergent plate, convergent plate, and transform plate. At divergent plate boundaries, the plates slowly pull apart. Magma rises up to fill the void created when the plates separate. Therefore, the rock formed at these junctions is igneous rock. Divergent plate boundaries form mid-oceanic ridges in the oceanic crust. The mid-Atlantic ridge is an example of a divergent plate boundary. These oceanic mountains are far greater in size than any continental mountains. Convergent plate boundaries form when two plates collide. Typically a continental plate will rise above an oceanic plate in these areas, forming an area called a subduction zone, where the oceanic plate descends into the asthenosphere, forming more magma. Convergent plate boundaries therefore are usually indicated by volcanic activity. An example of mountains formed by a convergent plate boundary is the Andes Mountains in South America. Deep ocean trenches such as the Marianas Trench are also characteristic of subduction zones. The Ring of Fire and area of intense earthquakes and volcanoes in the Pacific Ocean are also associated with subduction zones. Transform plate boundaries occur when two plates slide sideways against each other. An example of a transform plate boundary is the San Andreas fault in California. Transform boundaries frequently experience earthquakes.

Rocks and Minerals

A mineral is a naturally occurring inorganic solid element or compound with a definite chemical composition and a regular crystalline structure. Examples of minerals include silicate minerals such as quartz or feldspar; carbonate minerals such as calcite or dolomite; sulfide minerals like galena or pyrite; sulfate minerals such as gypsum; and native element minerals that form gold, silver, diamonds, and graphite. Rocks are solid aggregates of one or more minerals. Rocks have characteristic composition. For example, granite is a mixture of feldspar, quartz, and mica crystals.

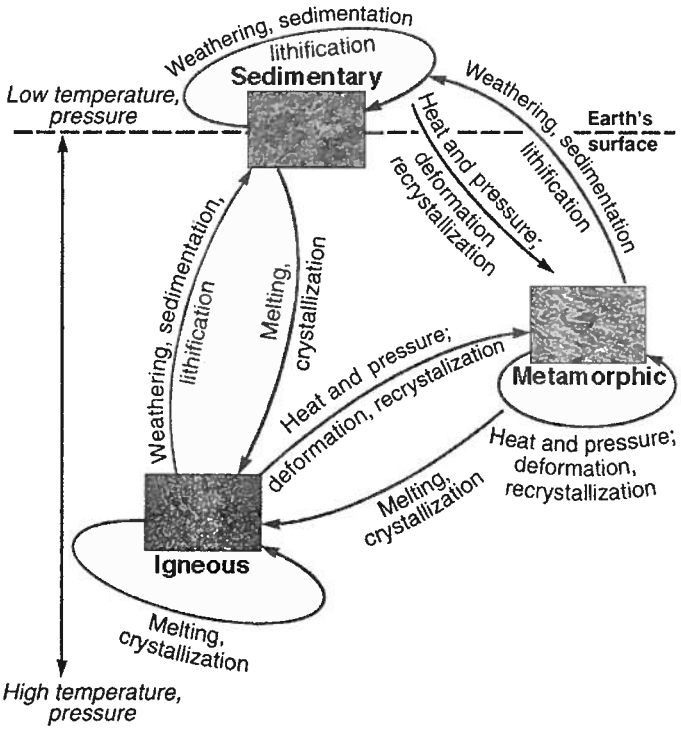
Rock Cycle

Weathering is a process by which rock is worn away to form individual particles. There are two major types of weathering. Mechanical weathering is the physical breakdown of rock without altering the chemical nature of the rock. Frost wedging is an example of mechanical weathering. Water expands when it freezes, so if rocks are penetrated by water that then freezes, the rock fractures into smaller pieces. Rocks abrading against other rocks in streams or in a glacier also cause mechanical weathering. Thermal expansion and contraction of rocks will also cause small pieces of the rock to break off. Organisms, including trees, worms, and rodents, can cause mechanical weathering by burrowing through the rock. Chemical weathering is the breakdown of a rock by altering its chemical nature. A good natural example of chemical weathering is the formation of soil by the growth of lichens on bare rock. Lichens secrete carbonic acid, which chemically degrades rock, forming soil. Other examples of chemical weathering include oxidation of rock (such as olivine weathering to form hematite) and hydrolysis (such as feldspar forming clay). Different rocks are susceptible to different types of weathering. For example, sandstone is susceptible to mechanical weathering, whereas limestone is susceptible to chemical weathering by acids.

Rocks are continually weathered to form particles that collect in a process known as sedimentation. These sediments may be compressed or compacted in a process called lithification to reform new rock. Rocks in subduction zones melt upon reaching the asthenosphere, only to re-emerge as igneous rock arising from magma. The process of rock formation, weathering, and lithification is known as the rock cycle.

Three major types of rocks arise from the rock cycle: igneous, sedimentary, and evaporite. Igneous rocks are the most common type of rocks on earth. They arise from cooled magma. Examples of igneous rock include basalt, granite, obsidian, and pumice. Sedimentary rock arises from the compression or compaction of sediments formed by weathering. Evaporite rocks form when a body of salt water dries up and the salt remains. Examples of sedimentary rock include sandstone, limestone, conglomerate, and the evaporate rock halite. Although technically formed by compression of ancient land plants, lignite and bituminous coal are considered to be biochemical sedimentary rocks. Metamorphic rocks are rocks formed from sedimentary or igneous rocks subjected to high heat and pressure. Examples of metamorphic rock include marble, slate, schist, and quartzite. Anthracite is a type of metamorphic rock, because it forms from lower grades of coal exposed to heat and pressure.

Figure 14.1 The rock cycle



Economic Geology and Mineralogy

Economic mineralogy is the study of minerals that have economic value to humans. Many valuable minerals are metal bearing ores, such as bauxite for aluminum or hematite for iron. The metals most used throughout the world are iron, aluminum, manganese, copper, chromium, and nickel. The greatest users of the metals are the United States, Japan, and Europe. Nonmetallic mineral

resources include mica, asbestos, limestone, gravel, sand, graphite, quartz, diamonds, and other gemstones. Sand and gravel production combine to form the greatest proportion in volume and economic value of all of the nonmetallic mineral resources. Sand and gravel are used in bricks and concrete. Silica sand is the basis of glass. Limestone is quarried for concrete, road rock, and building stone and is used as the source of lime in agriculture, aquatics, and in power plants. Evaporite deposits are mined for gypsum (used in drywall), halite (road and table salt), and potash (potassium salts used in fertilizer).

General Mining Law of 1872

The General Mining Law was passed to encourage prospectors to use federal land and to promote commerce. The law allows miners to stake claims on federal land and take any minerals they find. They can purchase land for $5 an acre or less, and then they own the land as private property. For little money, companies have purchased land that contains billions of dollars worth of minerals. Land also may be resold for development. Mining companies can take any ore that they wish without extra payments to the government. Worse still, they can deduct a depletion allowance from their taxes, which lowers their taxes as the resource declines. Many people suggest that mining companies pay royalties on the ore extracted from these mines to reflect the profit being made by the companies. They also want legislation requiring remediation of mined lands.

> Take Note: You must be able to delineate the damage to an ecosystem incurred when mineral extraction takes place. Also, be able to describe environmental damage associated not only with mining of minerals, but of smelting the ores to remove the desired metals. Free response questions often ask the origin of a specific pollutant, and students frequently forget that smelting is the origin of heavy metal and sulfur dioxide emissions.

Environmental Impacts of Resource Extraction

Mining results in the removal of land surface to get to the mineral desired. This destruction of land causes habitat loss for wildlife and deforestation and induces erosion. Additionally, due to the machinery involved in extraction, air pollution may be high in these areas, including sulfur dioxide and particulate pollution. Water pollution is common. Water may be contaminated by the sediments from erosion. Many minerals are frequently found in conjunction with sulfide ores, which may form sulfuric acid when exposed to water. The release of sulfuric acid from mines is called acid mine drainage. The drainage can acidify streams, resulting in death of pH sensitive species, which decreases stream biodiversity. There is also an increased toxicity due to aluminum solubility when streams are acidified. Frequently cyanide, mercury, or other toxins are used to extract minerals from mines.

The main types of mines are placer mines, open pit mines, strip mines, and subsurface mines. Placer mines remove valuable minerals such as gold, diamonds, and coal from streams. They contaminate surface water ecosystems because they use water cannons to remove minerals from hillsides. Open pit mines, or quarries, are used for sand, gravel, copper, and a variety of other materials. These mines frequently fill with water after they have been abandoned, resulting in acidification or concentrated heavy metals depending upon the original type of mine. Strip mines, or surface mines, are frequently used to remove coal from the western United States. These mines remove the

topsoil from a strip of land, then remove the surface rock, or overburden. The mineral is then extracted, and the overburden is replaced in the mines in long ridges called spoil banks. These banks are susceptible to erosion and weathering. There is no topsoil, so vegetation is slow to recover in these areas. In 1977, Congress passed the Surface Mining Control and Reclamation Act (SMCRA), which requires that mined areas be returned to their approximate original topography and replanted. Subsurface mines have been used to harvest tin, lead, copper, and coal. Underground mines frequently collapse or have explosions from dust or natural gas leaks. Some coal mines catch on fire and remain smoldering for years. One fire in China has been burning for 400 years, and one in Pennsylvania has been burning for over 40 years. Subsurface mines may strike groundwater and contaminate it with heavy metals.

A new type of mining known as mountaintop removal has developed in the Appalachians. This mining involves removing the overburden from the top of a seam of coal and placing it in a nearby valley. The coal is then extracted from the mine. The entire topography of an area is altered when mountaintop removal is used. Miners apply for a variance to the SMCRA to be able to carry out mountaintop removal.

Smelting is the heating of an ore to extract the desired metal. Tremendous amounts of air pollution are released during the smelting process. The fossil fuel used to melt the ore will produce its own air pollutants, and the heating of the ore typically releases large amounts of sulfur dioxide. The city of Ducktown, Tennessee, is notorious for the copper smelting that occurred in the area, which resulted in ruination of the entire ecosystem due to acid deposition when the sulfur dioxide emitted from the process acidified the soil. The area has been replanted and treated to improve the pH of the soil to a more neutral level. Arsenic and lead may be present in ores and may be released during the smelting process.

Heap leach extraction is the process of spraying ore with a cyanide solution to dissolve gold or silver, then removed in an electrolysis process. In 2000, this method resulted in the contamination of the Danube River with cyanide and heavy metals from a leaking wastewater lagoon at a smelter in Romania. The cyanide killed hundreds of fish as it progressed down the Danube through Hungary and Yugoslavia. The spill also impacted species such as birds, which feed upon fish.

Conserving Geological Resources

One of the easiest ways to preserve geological resources is by recycling metals. To create a market for recycled material, it must be economically profitable to recycle. One of the most successful recycling programs is the recycling of steel. Nearly all steel in the United States contains at least 25 percent recycled steel, and some contain 100 percent recycled steel. Much of this steel comes from steel cans, automobiles, buildings and bridges, and appliances. Mining and smelting iron to obtain steel consumes far more energy than melting old steel and forming new steel cans or girders. Aluminum, derived from an ore called bauxite, must be mined and extracted from the ore in a complicated process. By recycling aluminum in cans, the costs associated with the extraction of virgin ore are dramatically lowered. Aluminum is also easy to recycle and can easily be melted and remade into a can almost immediately. Other metals that may be recycled include lead (auto batteries), platinum (catalytic converters), gold, silver, copper (pipes and electrical wiring), and iron.

Natural resources may also be saved by developing new materials to replace those formed from metals. For example, polyvinyl chloride (PVC) pipes are now used in plumbing to replace copper, lead, and steel pipes. Ceramics, alloys (titanium mixed with steel), and aluminum are used to replace metals in the engine and frames of automobiles. The copper and aluminum wire used in years past for wiring electronics is replaced by glass cables.

Geologic Hazards

Volcanoes typically occur at convergent or divergent plate boundaries. An exception to this volcano forming geology is the Hawaiian Islands, formed by a mantle plume from a hot spot in the middle of an oceanic plate. There are currently 550 active volcanoes in the world and countless dormant volcanoes. Volcanic eruptions cannot be predicted, but a volcano may give several warning signs that it is about to erupt, including increased seismic activity; gas emissions; and pyroclastic debris, including ash. Humans are killed not only by lava but also by the large amounts of ash and toxic gases emitted during an eruption. Gases emitted during an eruption include water vapor; carbon dioxide; nitrogen; carbon monoxide; and sulfur gases, including sulfur dioxide and hydrogen sulfide. Water vapor comprises up to 80 percent of the gases released during an eruption. Mudslides are often caused by volcanic eruptions and contribute to human deaths. Volcanic dust tends to block sunlight, resulting in cooler regional temperatures. Additionally, the sulfur dioxide emitted combines with atmospheric water to create a sulfur haze, which reflects sunlight and contributes to global cooling. When Mount Pinatubo in the Philippines erupted in 1991, the sulfur haze that formed cooled the earth by 1°C.

Earthquakes are movements that occur along fault lines where plate boundaries meet. The area under the earth that is the origin of the earthquake is called the focus, and the site on the surface of the land that is the origin is known as the epicenter. Earthquakes tend to have a series of aftershocks, or the smaller quakes that occur after a quake. Earthquakes are particularly dangerous because they cannot be predicted. People that die during an earthquake are usually killed by substandard construction. Buildings constructed in earthquake prone areas should adhere to stringent standards for construction, so that not only are the buildings maintained, but the loss of life is minimized. Earthquakes under water, landslides into the ocean, or volcanic eruptions can cause a tsunami. The tsunami of 2004 that occurred in the Indian Ocean killed more than 300,000 people. The Ring of Fire in the Pacific Ocean is particularly vulnerable to tsunami formation because it is such a geologically active area. The United States has deployed tsunami detection buoys to allow for early notification that a tsunami is on its way. A worldwide detection system is to be established by 2015 after countries pledged to prevent deaths similar to those that occurred in Southeast Asia in 2004.

Floods are the leading cause of death by natural disaster, but storms such as hurricanes or tropical cyclones cause the most property damage.

Mass wasting is the movement downhill of large amounts of earth, rocks, or ice at one time. The material can move quickly, as in an avalanche or landslide, or slowly, as in a mud flow. Mass wasting can cause enormous amounts of property damage when homes or businesses are built upon unstable ground.

Chapter 14 Questions

1. The most prevalent element in the earth's crust is
a. nitrogen. b. potassium. c. sulfur. d. hydrogen. e. oxygen.

2. The most prevalent element in the earth's core is
a. lead. b. nickel. c. mercury. d. iron. e. uranium

3. The most common rock on earth is
a. sedimentary. b. igneous. c. metamorphic. d. limestone. e. marble.

4. Which of the following is not a metamorphic rock?
a. schist b. marble c. limestone d. anthracite e. slate

5. Which of the following is an example of chemical weathering?
a. a rock fractured by the freezing of water in the cracks of the rock
b. a rock in the desert expands when heated during the day then contracts at night, which breaks off pieces of rock
c. rushing water smooths rocks in a streambed
d. rocks in a glacier scrape the underlying bedrock, causing fractures
e. a rock loses particles upon exposure to rain, which dissolves portions of the rock

6. Which of the following statements is true regarding volcanic eruptions?
a. Lava is always emitted during a volcanic eruption.
b. Water vapor makes up the greatest proportion of gases during a volcanic eruption.
c. Most people killed during an eruption are killed by the lava flow.
d. No volcanoes have erupted in the continental United States since 1920.
e. Volcanic eruptions contribute to global warming.

7. All of the following are environmental impacts of mining except
a. depletion of ore resources. b. increased erosion.
c. deforestation. d. loss of biodiversity.
e. acid mine drainage.

8. The geologic hazard that results in the most human deaths is
a. volcanoes. b. earthquakes. c. floods. d. mass wasting. e. landslides.

9. The San Andreas Fault is found at a
a. transform boundary. b. diverging plate boundary. c. converging plate boundary.
d. subduction zone. e. oceanic ridge system.

10. Which of the following volcanoes does not occur at a plate boundary?
a. Mt. Pinatubo, Philippines b. Mt. St. Helens, Washington
c. Kilauea, Hawaii d. Cotopaxi, Ecuador
e. Mt. Etna, Italy

Chapter 14 Answers

1. e. Oxygen is the most prevalent element in the earth's crust. It is found in many types of rocks.
2. d. Iron is the most prevalent element in the earth's core.
3. b. Igneous is the most common rock on earth. Sedimentary rock is common on land, but most of the ocean floor is igneous. Limestone is a sedimentary rock, and marble is metamorphic.
4. c. Limestone is a sedimentary rock.
5. e. If rain dissolves portions of a rock, then the rock is undergoing chemical weathering. The other examples are mechanical weathering.
6. b. Water vapor makes up the greatest proportion of gases during a volcanic eruption. Lava is not always emitted during a volcanic eruption, and humans are frequently killed by the gases and ash. Mount St. Helens in Washington erupted in 1980. Volcanic eruptions usually result in global cooling, due to the ash and sulfur aeroso! decreasing sunlight to the planet.
7. a. Depletion of ore resources is an economic impact of mining.
8. c. Floods are the geologic hazard that results in the most human deaths.
9. a. The San Andreas Fault is found at a transform boundary.
10. c. Kilauea does not occur at a plate boundary. It occurs at a mantle plume in an ocean plate.