Nuclear Energy

When scientists discovered that atoms had smaller fundamental parts, scientists wondered if atoms could be split. In 1919, Ernest Rutherford first studied and explained the results of bombarding atomic nuclei with high-energy particles. In the 30 years that followed his research, nuclear (NOO klee uhr) technologies were developed that allowed atomic weapons to be made and allowed nuclear reactions to be used to generate electricity. Energy that is produced by using these technologies is called *nuclear energy*.

nuclear fission the process by which the nucleus of a heavy atom splits into two or more fragments; the process releases neutrons and energy

Nuclear Fission

One form of nuclear energy is produced by splitting the nuclei of heavy atoms. This splitting of the nucleus of a large atom into two or more smaller nuclei is called **nuclear fission**. The process of nuclear fission is shown in **Figure 4.**

The forces that hold the nucleus of an atom together are more than 1 million times stronger than the strongest chemical bonds between atoms. If a nucleus is struck by a free neutron, however, the nucleus of the atom may split. When the nucleus splits, it releases additional neutrons as well as energy. The newly released neutrons strike other nearby nuclei, which causes those nuclei to split and to release more neutrons and more energy. A chain reaction occurs as more neutrons strike neighboring atoms. If a fission reaction is allowed to continue uncontrolled, the reaction will escalate quickly and may result in an explosion. However, controlled fission produces heat that can be used to generate electricity.

Reading Check **What causes a chain reaction during nuclear fission? (See the Appendix for answers to Reading Checks.)**

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Nuclear Energy
SciLinksCode: HQ61047

Figure 4 ▶ An Example of a Nuclear Fission Reaction

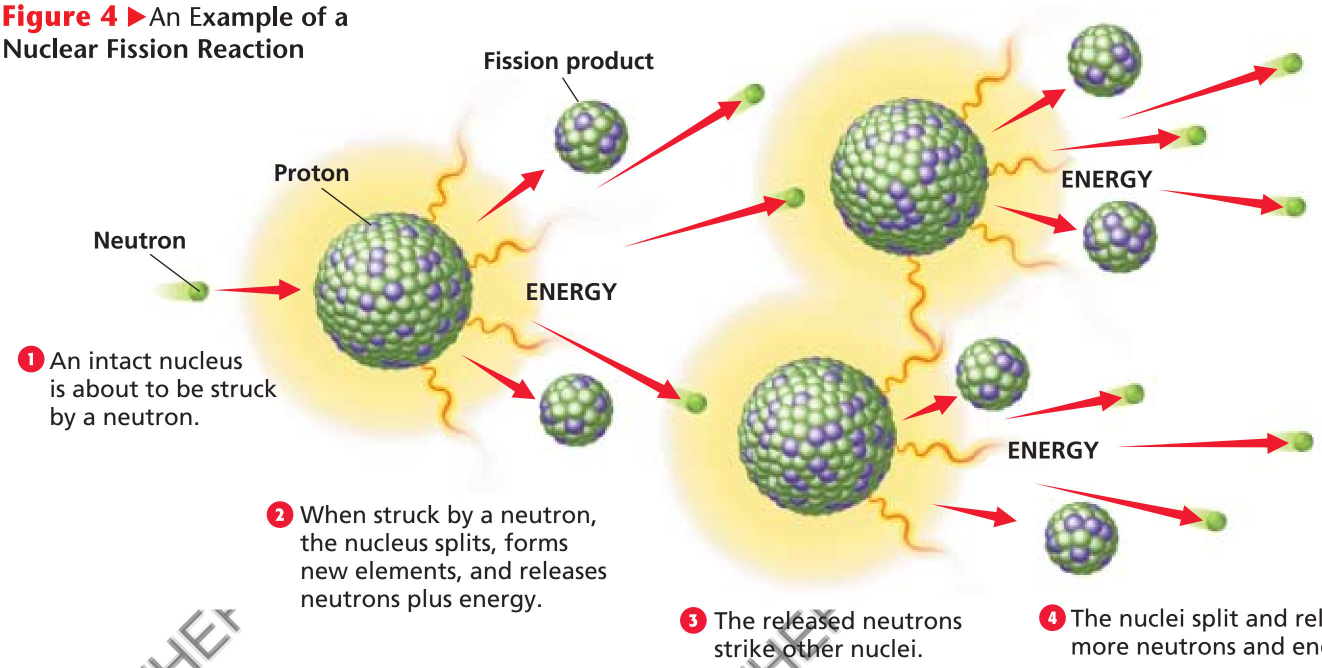
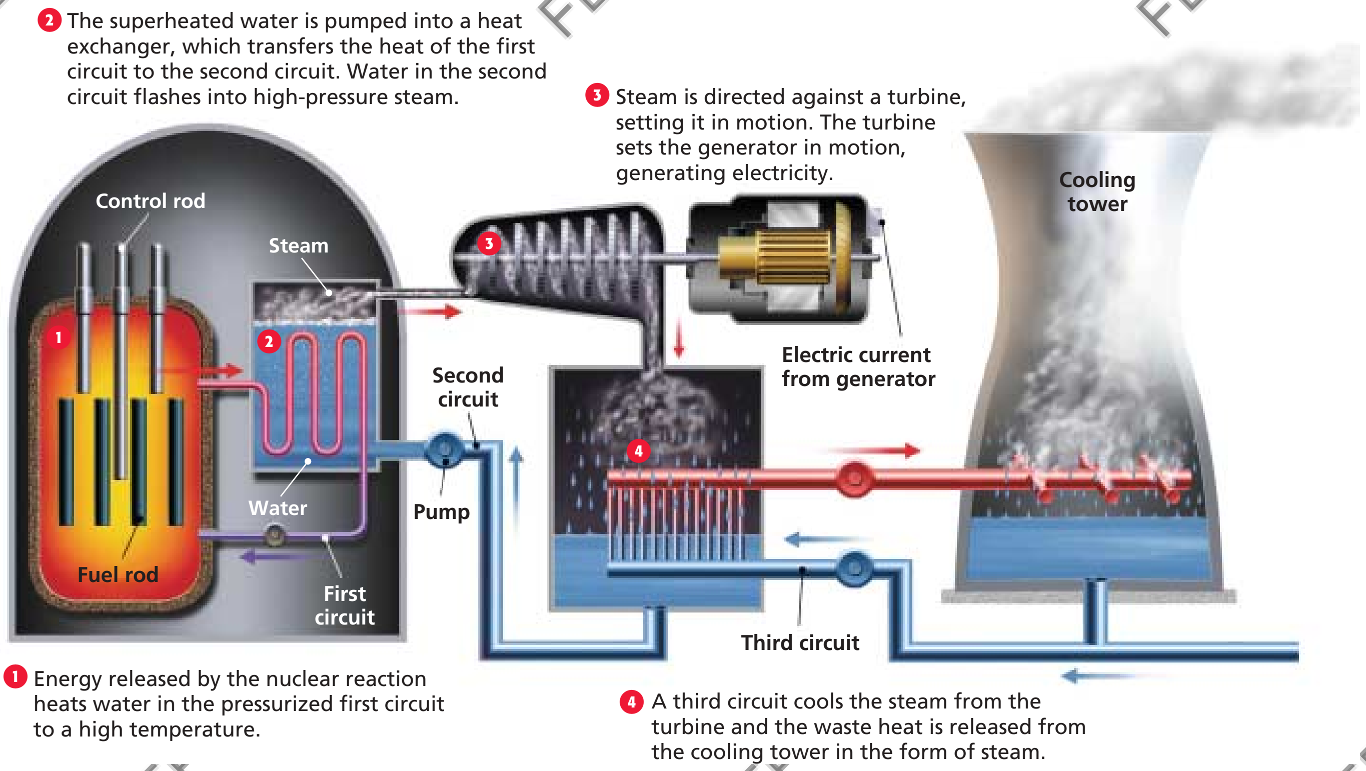


Figure 5 ▶ How a Nuclear Power Plant Generates Electricity



How Fission Generates Electricity

When a nuclear power plant is working correctly, the chain reaction that occurs during nuclear fission is controlled. The flow of neutrons into the fission reaction is regulated so that the reaction can be slowed down, speeded up, or stopped as needed. The specialized equipment in which controlled nuclear fission is carried out is called a *nuclear reactor*.

During fission, a tremendous amount of heat energy is released. This heat energy can in turn be used to generate electricity. **Figure 5** shows how nuclear fission inside a nuclear reactor can be used to generate electricity. Currently, only one kind of naturally occurring element is used for nuclear fission. It is a rare isotope of the element uranium called *uranium-235*, or ^{235}U. Because ^{235}U is rare, the ore that is mined is processed into fuel pellets that have a high ^{235}U content. After this process is complete, the fuel pellets are said to be uranium-enriched pellets.

These enriched fuel pellets are placed into rods to make *fuel rods*. Bundles of these fuel rods are then bombarded by neutrons. When struck by a neutron, the ^{235}U nuclei in the fuel rods split and release neutrons and energy. The resulting chain reaction causes the fuel rods to become very hot.

Water is pumped around the fuel rods to absorb and remove the heat energy. The water is then pumped into a second circuit, where the water becomes steam. The steam turns the turbines that provide power for electric generators. A third water circuit carries away excess heat and releases it into the environment.

Graphic Organizer — Chain-of-Events Chart

Create the Graphic Organizer entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each step of how electricity is generated by fission.

Figure 6 ▶ These water pools store radioactive wastes. The blue glow indicates that the waste products are highly radioactive.

Advantages and Disadvantages of Nuclear Fission

Nuclear power plants burn no fossil fuels and produce no air pollution. But because nuclear fission uses and produces radioactive materials that have very long half-lives, wastes must be safely stored for thousands of years. These waste products give off high doses of radiation that can destroy plant and animal cells and can cause harmful changes in the genetic material of living cells.

Currently, nuclear power plants store their nuclear wastes in dry casks or in onsite water pools, as shown in **Figure 6.** Other wastes are either stored onsite or transported to one of three disposal facilities in the United States. The U.S. Department of Energy has plans for a permanent disposal site for highly radioactive nuclear wastes.

Nuclear Fusion

All of the energy that reaches Earth from the sun is produced by a kind of nuclear reaction, called nuclear fusion. During **nuclear fusion,** the nuclei of hydrogen atoms combine to form larger nuclei of helium. This process releases energy. Fusion reactions occur only at temperatures of more than 15,000,000°C.

For more than 40 years, scientists have been trying to harness the energy released by nuclear fusion to produce electricity. More research is needed before a commercial fusion reactor can be built. If such a reactor could be built in the future, hydrogen atoms from ocean water might be used as the fuel. With ocean water as fuel, the amount of energy available from nuclear fusion would be almost limitless. Scientists also think that wastes from fusion would be much less dangerous than wastes from fission. The only byproducts of fusion are helium nuclei, which are harmless to living cells.

nuclear fusion the process by which nuclei of small atoms combine to form new, more massive nuclei; the process releases energy

Section 2 Review

1. **Explain** why coal, petroleum, and natural gas are called *fossil fuels.*
2. **Compare** how coal, petroleum, and natural gas form.
3. **Describe** the kind of rock structures in which petroleum reservoirs form.
4. **Identify** the naturally occurring element that is used for nuclear fission.
5. **Explain** how nuclear fission generates electricity.
6. **Summarize** the process of nuclear fusion.

CRITICAL THINKING

7. **Analyzing Relationships** Why have we been able to build nuclear power plants for only the last 50 years?
8. **Recognizing Relationships** Can the waste products of nuclear fission be safely disposed of in rivers or lakes? Explain your answer.
9. **Making Comparisons** How do the processes of nuclear fusion and nuclear fission differ?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *nonrenewable resource, fossil fuel, coal, carbonization, peat, lignite, bituminous coal, anthracite coal, petroleum,* and *natural gas.*

Section 3 Renewable Energy

If current trends continue and worldwide energy needs increase, the world's supply of fossil fuels may be used up in the next 200 years. Nuclear energy does not use fossil fuels, but numerous safety concerns are associated with it. Therefore, many nations are researching alternative energy sources to ensure that safe energy resources will be available far into the future. Resources that can be replaced within a human life span or as they are used are called **renewable resources**.

Geothermal Energy

In many locations, water flows far beneath Earth's surface. This water may flow through rock that is heated by nearby magma or by hot gases that are released by magma. This water becomes heated as it flows through the rock. The hot water, or the resulting steam, is the source of a large amount of heat energy. This heat energy is called **geothermal energy,** which means "energy from the heat of Earth's interior."

Engineers and scientists have harnessed geothermal energy by drilling wells to reach the hot water. Sometimes, water is first pumped down into the hot rocks if water does not already flow through them. The resulting steam and hot water can be used as a source of heat. The steam and hot water also serve as sources of power to drive turbines, which generate electricity.

The city of San Francisco, for example, obtains some of its electricity from a geothermal power plant located in the nearby mountains. In Iceland, 85% of the homes are heated by geothermal energy. Italy and Japan have also developed power plants that use geothermal energy. A geothermal power plant is shown in **Figure 1.**

OBJECTIVES

- **Explain** how geothermal energy may be used as a substitute for fossil fuels.
- **Compare** passive and active methods of harnessing energy from the sun.
- **Explain** how water and wind can be harnessed to generate electricity.

KEY TERMS

renewable resource
geothermal energy
solar energy
hydroelectric energy
biomass

renewable resource a natural resource that can be replaced at the same rate at which the resource is consumed

geothermal energy the energy produced by heat within Earth

Figure 1 ▶ These swimmers are enjoying the hot water near a geothermal power plant in Svartsbening, Iceland.

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Solar Energy

solar energy the energy received by Earth from the sun in the form of radiation

Another source of renewable energy is the sun. Every 15 minutes, Earth receives enough energy from the sun to meet the energy needs of the world for one year. Energy from the sun is called **solar energy.** The challenge scientists face is how to capture even a small part of the energy that travels to Earth from the sun.

Converting sunshine into heat energy can be done in two ways. A house that has windows facing the sun collects solar energy through a *passive system*. The system is passive because it does not use moving parts. Sunlight enters the house and warms the building material, which stores some heat for the evening. An *active system* includes the use of solar collectors. One type of *solar collector* is a box that has a glass top. The box is commonly placed on the roof of a building. Water circulates through tubes within the box. The sun heats the water as it moves through the tubes, which provides heat and hot water. On cloudy days, however, there may not be enough sunlight to heat the water. So, the system must use heat that was stored from previous days.

Photovoltaic cells are another active system that converts solar energy directly into electricity. Photovoltaic cells work well for small objects, such as calculators. Producing enough electricity from these cells to power cities is under investigation.

Quick LAB 30 min

Solar Collector

Procedure

1. Line the inside of a **small, shallow pan** with **black plastic.** Use **tape** to attach a **thermometer** to the inside of the pan. Fill the pan with enough **room temperature water** to cover the end of the thermometer. Fasten **plastic wrap** over the pan with a **rubber band.** Be sure you can read the thermometer.
2. Place the pan in a sunny area. Use a **stopwatch** to record the temperature every 5 min until the temperature stops rising. Discard the water.
3. Repeat steps 1 and 2, but do not cover the pan with plastic wrap.
4. Repeat steps 1 and 2, but do not line the pan with black plastic.
5. Repeat steps 1 and 2. But do not line the pan with plastic, and do not cover the pan with plastic wrap.
6. Calculate the rate of temperature change for each trial by subtracting the beginning temperature from the ending temperature. Divide this number by the number of minutes the temperature increased to find the rate of temperature range.

Analysis

1. What are the variables in this investigation? Which trial had the greatest rate of temperature change? the smallest rate of temperature change?
2. Which variable that you tested has the most significant effect on temperature change?
3. What materials would you use to design and build an efficient solar collector? Explain your answer.

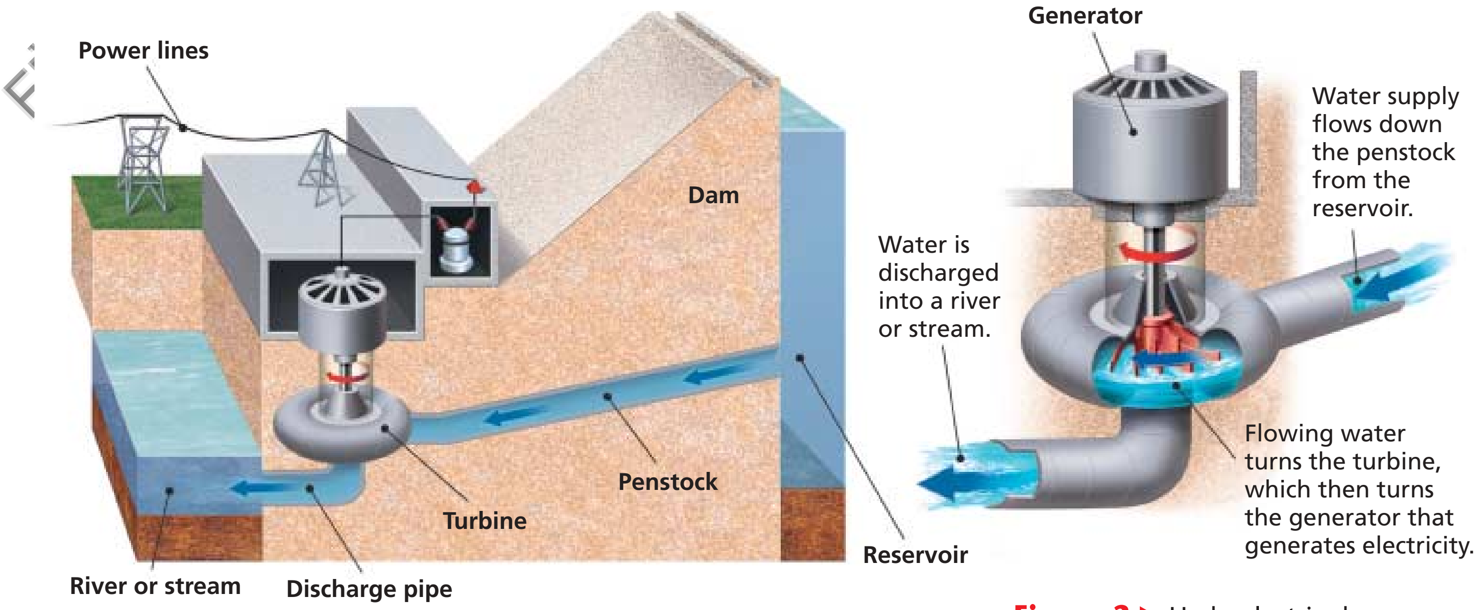

Figure 2 ▶ Hydroelectric dams use moving water to turn turbines. The movement of the turbine powers a generator that generates electricity.

Energy from Moving Water

One of the oldest sources of energy comes from moving water. Energy can be harnessed from the running water of rivers and streams or from ocean tides. In some areas of the world, energy needs can be met by **hydroelectric energy,** or the energy produced by running water. Today, 11% of the electricity in the United States comes from hydroelectric power plants. At a hydroelectric plant, massive dams hold back running water and channel the water through the plant. Inside the plant, the water spins turbines, which turn generators that produce electricity. An example of a hydroelectric plant is shown in **Figure 2.**

Another renewable source of energy for moving water is the tides. Tides are the rising and falling of sea level at certain times of the day. To make use of this tidal flow, people have built dams to trap the water at high tide and to then release it at low tide. As the water is released, it turns the turbines within the dams.

hydroelectric energy electrical energy produced by the flow of water

biomass plant material, manure, or any other organic matter that is used as an energy source

Energy from Biomass

Other renewable resources are being exploited to help supply our energy needs. Renewable energy sources that come from plant material, manure, and other organic matter, such as sawdust or paper waste, are called **biomass.** Biomass is a major source of energy in many developing countries. More than half of all trees that are cut down are used as fuel for heating or cooking. Bacteria that decompose the organic matter produce gases, such as methane, that can also be burned. Liquid fuels, such as ethanol, also form from the action of bacteria on biomass. All of these resources can be burned to generate electricity.

Reading Check **Name three sources of renewable energy. (See the Appendix for answers to Reading Checks.)**

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Renewable Resources
SciLinksCode: HQ61291

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Figure 3 ▶ The spinning blades of a windmill are connected to a generator. When winds cause the blades to spin faster, the generator produces more energy.

Energy from Wind

Wind is the movement of air over Earth's surface. Wind results from air pressure differences caused by the sun's uneven heating of Earth's surface. Wind turbines use the movement of air to convert wind energy into mechanical energy, which is used to generate electricity.

Wind energy is now being used to produce electricity in locations that have constant winds. Small, wind-driven generators are used to meet the energy needs of individual homes. *Wind farms,* such as the one shown in **Figure 3,** may have hundreds of giant wind turbines that can produce enough energy to meet the electricity needs of entire communities. However, wind generators are not practical everywhere. Even in the most favorable locations, such as in windy mountain passes, the wind does not always blow. Because the wind does not always blow, wind energy cannot be depended on as an energy source for every location.

Section 3 Review

1. **Explain** why many nations are researching alternative energy resources.
2. **Explain** how geothermal energy may be used as a substitute for fossil fuels.
3. **Describe** both passive and active methods of harnessing energy from the sun.
4. **Summarize** how electrical energy is generated from running water.
5. **Describe** how biomass can be used as fuels to generate electricity.
6. **Explain** how water and wind can be harnessed to generate electricity.

CRITICAL THINKING

7. **Making Comparisons** Both fossil fuels and biomass fuels come from plant and animal matter. Why are fossil fuels considered to be nonrenewable, and why is biomass considered to be renewable?
8. **Demonstrating Reasoned Judgement** If you were asked to construct a power plant that uses only renewable energy sources in your area, what type of energy would you use? Explain.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *renewable resource, solar collector, geothermal energy, solar energy, passive system, active system, hydroelectric energy, biomass,* and *wind energy.*

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ENVIRONMENTAL CONNECTION

Section 4 Resources and Conservation

At the present rate of use, scientists estimate that the worldwide coal reserves will last about 200 years. Many scientists also think that within the next 20 years, humans will have used half of Earth's oil supply. This limited supply of fossil fuels and other traditional energy resources has inspired research into possible new energy sources.

Scientists are also studying how the use of traditional energy sources affects Earth's ecosystems. We have learned that mining can damage or destroy fragile ecosystems. Fossil fuels and nuclear power generation may add pollution to Earth's air, water, and soil. However, people can reduce the environmental impact of their resource use. Many governments and public groups have worked to create and enforce policies that govern the use of these natural resources.

OBJECTIVES

- **Describe** two environmental impacts of mining and the use of fossil fuels.
- **Explain** two ways the environmental impacts of mining can be reduced.
- **Identify** three ways that you can conserve natural resources.

KEY TERM

conservation
recycling

Environmental Impacts of Mining

Mining for minerals can cause a variety of environmental problems. Mining may cause both air and noise pollution. Nearby water resources may also be affected by water that carries toxic substances from mining processes. Surface mining is particularly destructive to wildlife habitats. For example, surface mining often uses controlled explosions to remove layers of rock and soil, as shown in **Figure 1.** Some mining practices cause increased erosion and soil degradation. Regions above subsurface mines may sink, or subside, because of the removal of the materials below. This sinking results in the formation of sinkholes. Fires in coal mines are also very difficult to put out and are commonly left to burn out, which may take several decades or centuries.

Figure 1 ▶ The surface of this gold mine in Nevada is being blasted to remove layers of rock.

Quick LAB 30 min

Reclamation

Procedure

1. Use a **plastic spoon** to remove the first layer of gelatin from a **multi-layered gelatin dessert cup** into a **small bowl.**
2. Remove the next layer of gelatin, and discard it.
3. Restore the dessert cup by replacing the first layer of gelatin.

Analysis

1. What does the first layer of gelatin on the restored dessert cup represent?
2. Does the "reclaimed" dessert cup resemble the original, untouched dessert cup?
3. What factors would you address to make reclamation more successful?

Mining Regulations

In the United States, federal and state laws regulate the operation of mines. These laws were designed to prevent mining operations from contaminating local air, water, and soil resources. Some of these federal laws include the Clean Water Act, the Safe Drinking Water Act, and the Comprehensive Response Compensation and Liability Act. All mining operations must also comply with the federal Endangered Species Act, which protects threatened or endangered species and their habitats from being destroyed by mining practices.

Mine Reclamation

To reduce the amount of damage done to ecosystems, mining companies are required to return mined land to its original condition after mining is completed. This process, called *reclamation,* helps reduce the long-lasting environmental impact of mining. In addition to reclamation, some mining operations work hard to reduce environmental damage through frequent inspections and by using processes that reduce environmental impacts.

Fossil Fuels and the Environment

Fossil-fuel procurement affects the environment. Strip mining of coal can leave deep holes where coal was removed. Without plants and topsoil to protect it, exposed land often erodes quickly. When rocks that are exposed during mining get wet, they can weather to form acids. If runoff carries the acids into nearby rivers and streams, aquatic life may be harmed.

Fossil-fuel use also contributes to air pollution. The burning of coal that has a high sulfur content releases large amounts of sulfur dioxide, SO_2, into the atmosphere. When SO_2 combines with water in the air, acid precipitation forms. When petroleum and natural gas are burned, they also release pollutants that can damage the environment. The burning of gasoline in cars is a major contributor to air pollution. But emissions testing, which is shown in **Figure 2,** and careful maintenance help reduce the amount of pollutants released into the air. Emissions testing and maintenance includes the testing of a car's catalytic converter, a device that removes numerous pollutants from the exhaust before the exhaust leaves the car.

Reading Check **Name two ways the use of fossil fuel affects the environment. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Emissions testing and maintenance of pollution-reducing devices in today's vehicles can help reduce air pollution.

Conservation

Many people and businesses around the world have adopted practices that help reduce the negative effects of the burning of fossil fuels and the use of other natural resources. This preservation and wise use of natural resources is called **conservation.** By conserving natural resources, people can ensure that limited natural resources last longer. Conservation can also help reduce the environmental damage and amount of pollution that can result from the mining and use of natural resources.

Mineral Conservation

Earth's mineral resources are being used at a faster rate each year. Every new person added to the world's population represents a need for additional mineral resources. In developing countries, people are using more mineral resources as their countries become more industrialized. This increased demand for minerals has led many scientists to look for ways to conserve Earth's minerals.

One way to conserve minerals is to use other abundant or renewable materials in place of scarce or nonrenewable minerals. Another way to conserve minerals is by recycling them. **Recycling** is the process of using materials more than once. Some metals, such as iron, copper, and aluminum, are often recycled, as shown in **Figure 3.** Glass and many building materials can also be efficiently recycled. Recycling does require energy, but recycling uses less energy than the mining and manufacturing of new resources does.

Figure 3 ▶ These cubes are made up of metals that have been compacted and are being sent to a recycling plant. ***Can you identify the source of these metals?***

conservation the preservation and wise use of natural resources

recycling the process of recovering valuable or useful materials from waste or scrap; the process of reusing some items

Connection to ENVIRONMENTAL SCIENCE

Methane Hydrates

One potential alternative energy source that scientists are hopeful about is methane hydrates. Methane hydrates are solid, icelike crystals that have gas molecules trapped within the crystal structure of water ice. The ice crystals form a lattice that holds the methane and other gas molecules in place.

This potential new energy source is located in the frozen soil in Arctic regions and on the sea floor. Most deposits of methane hydrate are located near continental margins, where ocean life is abundant. Methane hydrates are stable in sea-floor sediments at temperatures and pressures that are common at depths of 300 m in Arctic regions and at depths of 500 m in tropical regions.

While these energy compounds may look like ice, they burn with intense flame. When methane hydrates burn, they release much less carbon dioxide than the burning of traditional fossil fuels. Scientists are researching the possibility of using methane hydrates in transportation and for generating electricity.

However, scientists are concerned about the environmental impacts of mining this resource. Also, because methane is a powerful greenhouse gas, even a modest quantity of methane released into the atmosphere could affect global temperatures.

A researcher holds a chunk of burning methane hydrate.

Figure 4 ▶ Fiberglass insulation is used in homes to reduce the energy required for heating and cooling.

Fossil-Fuel Conservation

Fossil fuels can be conserved by reducing the amount of energy used every day. If less energy is used, fewer fossil fuels must be burned every day to supply the smaller demand for energy. Energy can be conserved in many ways. **Figure 4** shows insulation being installed into a new house to reduce the amount of energy that will be needed for cooling and heating. Using energy-efficient appliances also reduces the amount of electricity used every day. In addition, simple actions, such as turning off lights when you leave a room and washing only full loads of laundry and dishes will reduce energy use.

Reducing the amount of driving you do also conserves fossil fuels. There is evidence that an average car produces more than 8 kg of carbon dioxide for every 3.8 L (1 gal) of gasoline burned. Even fuel-efficient and hybrid cars release some pollutants into the air. When making short trips, consider walking or riding your bicycle. You can also combine errands so that you can make fewer trips in your car.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Conservation
SciLinks code: HQ60344

Conservation of Other Natural Resources

Conservation is important for other natural resources, such as water. Some scientists estimate that by the year 2050, the world will have a critical shortage of freshwater resources because of the increased need by a larger human population. Water can be conserved by using water-saving shower heads, faucets, and toilets. By turning off the faucet as you brush your teeth, you can conserve up to 1 gallon of water every day. You can also help conserve water by watering plants in the morning or at night and by planting native plants in your yard.

Section 4 Review

1. **Name** two environmental problems associated with the mining and use of coal.
2. **Explain** two ways the environmental impacts of mining can be reduced.
3. **Describe** two reasons why scientists are looking for alternatives to fossil fuels.
4. **Define** the term *reclamation* in your own words.
5. **Identify** three ways that you can conserve natural resources every day.
6. **State** one way that recycling can help conserve energy.

CRITICAL THINKING

7. **Analyzing Concepts** How do you think fossil-fuel use affects soil resources?
8. **Applying Ideas** Why does recycling require less energy than developing a new resource does?
9. **Drawing Conclusions** List 10 ways a small community can conserve energy and resources.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *recycling, conservation, alternate energy source, renewable energy source, environmental impact, acid precipitation,* and *reclamation.*

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Chapter 7 Highlights

Sections

1 Mineral Resources

Key Terms

ore, 155
lode, 156
placer deposit, 156
gemstone, 157

Key Concepts

- Ores are mineral deposits from which metallic and nonmetallic minerals can be profitably removed.
- Minerals are important sources of many useful and valuable materials.
- Humans obtain mineral resources through mining.

2 Nonrenewable Energy

nonrenewable resource, 159
fossil fuel, 159
nuclear fission, 162
nuclear fusion, 164

- Chemical and physical changes over time change the remains of plants into coal.
- Petroleum and natural gas formed from the remains of ancient microorganisms.
- Today, fossil fuels provide much of the world's energy.
- Nuclear fission can produce energy to generate electricity.

3 Renewable Energy

renewable resource, 165
geothermal energy, 165
solar energy, 166
hydroelectric energy, 167
biomass, 167

- Geothermal energy is energy from the heat of Earth's interior.
- Solar energy from the sun can be harnessed by both passive and active methods.
- Alternative sources of renewable energy include hydroelectric, tidal, solar, and wind energy.

4 Resources and Conservation

conservation, 171
recycling, 171

- Fossil fuels are nonrenewable resources. Once a nonrenewable resource is depleted, the resource may take millions of years to be replenished.
- Responsible mining operations work hard to return mined land to good condition through reclamation.
- Conservation is the preservation and wise use of natural resources.

Chapter 7 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *placer deposit*
2. *solar energy*
3. *conservation*

For each pair of terms, explain how the meanings of the terms differ.

4. *renewable resource* and *nonrenewable resource*
5. *ore* and *lode*
6. *nuclear fission* and *nuclear fusion*
7. *fossil fuel* and *biomass*
8. *geothermal energy* and *hydroelectric energy*

Understanding Key Concepts

9. Metals are known to
   - **a.** have a dull surface.
   - **b.** provide fuel.
   - **c.** conduct heat and electricity well.
   - **d.** occur only in placer deposits.

10. Energy resources that formed from the remains of once-living things are called
   - **a.** minerals.
   - **b.** gemstones.
   - **c.** metals.
   - **d.** fossil fuels.

11. Impermeable rock that occurs at the top of an oil reservoir is called
   - **a.** coal.
   - **b.** peat.
   - **c.** cap rock.
   - **d.** water.

12. Plastics, synthetic fabrics, and synthetic rubber are composed of chemicals that are derived from
   - **a.** anthracite.
   - **b.** petroleum.
   - **c.** peat.
   - **d.** minerals.

13. The splitting of the nucleus of an atom to produce energy is called
   - **a.** geothermal energy.
   - **b.** nuclear fission.
   - **c.** nuclear fusion.
   - **d.** hydroelectric power.

14. Energy experts have harnessed geothermal energy by
   - **a.** building dams.
   - **b.** building wind generators.
   - **c.** drilling wells.
   - **d.** burning coal.

15. In a hydroelectric power plant, running water produces energy by spinning a
   - **a.** turbine.
   - **b.** windmill.
   - **c.** fan.
   - **d.** reactor.

Short Answer

16. Compare the three ways that ores commonly form.

17. Name two regulations that mining operations must follow to reduce the impact they have on the environment.

18. Identify and describe the uses for three mineral resources.

19. Describe one advantage and one disadvantage of obtaining energy from nuclear fission.

20. Describe one advantage and one disadvantage to the use of solar energy.

21. Identify two ways recycling can reduce energy use.

22. Explain two ways that moving water can be used to generate electricity.

23. Compare two types of mining, and describe the possible environmental impact of each type.

Critical Thinking

24. Applying Ideas You learn that the price of iron is higher than it has been in 20 years. Do you think it might be profitable for a company to mine hematite? Explain your answer.

25. Understanding Relationships A certain area has extensive deposits of shale. Why might a petroleum geologist be interested in examining the area?

26. Identifying Trends Hybrid cars have efficient gasoline and electric motor combinations. They have other design elements that make them extremely fuel efficient. Do you expect that there will be more or fewer hybrid cars on the road in the future? Explain.

27. Making Inferences A certain company in your area produces ^{235}U pellets and fuel rods. With which energy source is the company involved? Explain.

Concept Mapping

28. Use the following terms to create a concept map: *resource, renewable, nonrenewable, fossil fuel, nuclear energy, geothermal energy, solar energy, hydroelectric energy,* and *conservation.*

Math Skills

29. Making Calculations In one year, the United States produced 95,000 megawatts of power from renewable energy sources. If 3% of that amount of power came from wind energy, how much energy did wind power produce that year?

30. Making Calculations A water-efficient washing machine uses 16 gallons of water per load of laundry. Older washing machines use more than 40 gallons of water per load of laundry. If you wash an average of 10 loads of laundry a month, how many gallons of water would you save in a year if you switched to the water-efficient washer?

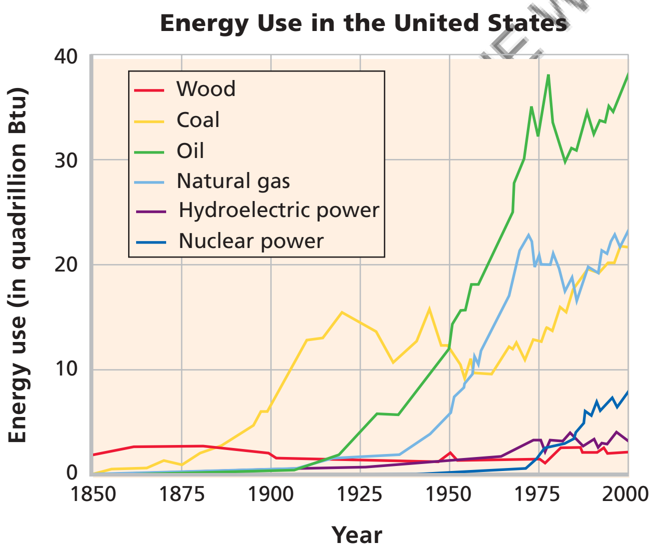
Writing Skills

31. Researching Information A debate surrounds municipal recycling programs. Do some research, and write a paragraph explaining each side of the debate. Write another paragraph explaining your view on whether recycling programs should be continued.

32. Writing Persuasively Research the pros and cons of building dams to harness energy. Write a letter to the editor of a local newspaper to express your opinion about whether dams should be used for generating electricity.

Interpreting Graphics

The graph below shows the different contributions of various fuels to the U.S. energy supply since 1850. Use this graph to answer the questions that follow.



33. What were the two main energy sources used in 1875?

34. When did oil first become a more widely used energy source than coal?

35. The use of oil and natural gas rise and fall together. How do you explain this pattern?

Chapter 7 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the number of the correct answer.**

1 Which of the following is an example of a nonmetal mineral resource?
A. gold
B. quartz
C. aluminum
D. graphite

2 Nonmetals are identified by their
F. ability to conduct heat
G. shiny surfaces
H. ability to conduct electricity
I. dull surfaces

3 A mineral deposit called a *lode* is formed by
A. metal fragments deposited in stream beds
B. layers accumulating in cooling magma
C. hot mineral solutions in cracks in rock
D. precipitation of minerals from seawater

4 Which of the following is an example of a nonrenewable resource?
F. natural gas
G. sunlight
H. falling water
I. wind

5 A material from which mineral resources can be mined profitably is a(n)
A. gemstone
B. ore
C. nodule
D. renewable resource

Directions (6-8): **For *each* question, write a short response.**

6 Federal and state laws require mining companies to return land to its original condition or better than its original condition when mining operations are completed. What is this process called?

7 What are the three forms of fossil fuels, and what form does each one take?

8 Name three common items that may be recycled to save energy and natural resources?

Reading Skills

Directions (9–11): **Read the passage below. Then, answer the questions.**

Fossil Fuels

All fossil fuels form from the buried remains of ancient organisms. But different types of fossil fuels form in different ways and from different types of organisms. Petroleum and natural gas form mainly from the remains of microscopic sea life. When these organisms die, their remains collect on the ocean floor, where they are buried by sediment. Over time, the sediment slowly becomes rock and traps the organic remains. Through physical and chemical changes over millions of years, the remains become petroleum and natural gas. Gradually, more rocks form above the rocks that contain the fossil fuels. Under the pressure of overlying rocks and sediments, the fossil fuels are able to move through permeable rocks. Permeable rocks are rocks that allow fluids, such as petroleum and natural gas, to move through them. These permeable rocks become reservoirs that hold petroleum and natural gas.

9 What process causes organic remains to turn into fossil fuels?
A. pressure caused by overlying rocks and sediments
B. the constant layering of remains from microscopic sea life
C. millions of years of physical and chemical changes
D. the movement of fluids through layers of permeable rock

10 Which of the following statements can be inferred from the information in the passage?
F. Fossil fuel formation is ongoing, and current remains may become petroleum in the future.
G. Fossil fuel formation happened millions of years ago and no longer takes place today.
H. Current petroleum and natural gas reservoirs are found only beneath the ocean floor.
I. Permeable rocks are also a good place to find other fossil fuels, such as coal.

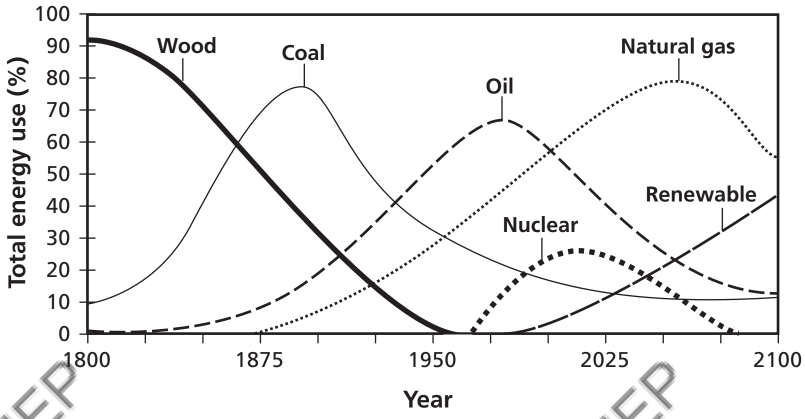
11 Why do we consider petroleum and natural gas to be nonrenewable resources?

Interpreting Graphics

Directions (12–14): **For *each* question below, record the correct answer on a separate sheet of paper.**

The graph below illustrates the sources of energy used in the United States since 1850. Future statistics are predicted based on current trends and technology development. Use this graph to answer questions 12 and 13.

U.S. Energy Use from 1850 to 2100



12 Which of the following is the main reason that coal became a more widely used energy source than wood in the mid-1800s?

A. Coal burns easier than wood does.
B. Coal is renewable resource, unlike wood.
C. Coal is a more efficient energy-producer than wood.
D. Coal produces fewer byproducts and waste than wood does.

13 Evaluate reasons why nuclear power is predicted to peak in usage around the year 2025, and then steadily decline in usage?

The table below shows common minerals and their uses. Use this table to answer question 14.

Minerals and Their Uses

Minerals	Uses
Gold	electronics, coins, dental work, and jewelry
Galena	solder and batteries
Quartz	glass
Sulfur	medicines, gunpowder, and rubber
Graphite	pencils, paint, and ubricants
Hematite	making steel
Chalcopyrite	coins, jewelry, and cables

14 Use your everyday knowledge of automobiles to describe the part of an automobile for which each mineral listed in the table may be used.

Test TIP

When a question refers to a graph, study the data plotted on the graph to determine any trends or anomalies before you try to answer the question.

Using Scientific Methods

Objectives

- **Prepare** a detailed sketch of your solution to the design problem.
- **Design and build** a functional windmill that lifts a specific weight as quickly as possible.

Materials

- blow-dryer, 1,500 W
- dowel or smooth rod
- foam board
- glue, white
- paper clips, large (30)
- paper cup, small (1)
- spools of thread, empty (2)
- string, 50 cm
- *optional materials for windmill blades:* foam board, paper plates, paper cups, or any other lightweight materials

Safety

Blowing in the Wind

MEMO
To: Division of Research and Development

Quixote Alternative Energy Systems is accepting design proposals to develop a windmill that can be used to lift window washers to the tops of buildings. As part of the design engineering team, your division has been asked to develop a working model of such a windmill. Your task is to design and build a model that can lift 30 large paper clips a vertical distance of 50 cm. The job will be given to the team whose model can lift the paper clips the fastest.

ASK A QUESTION

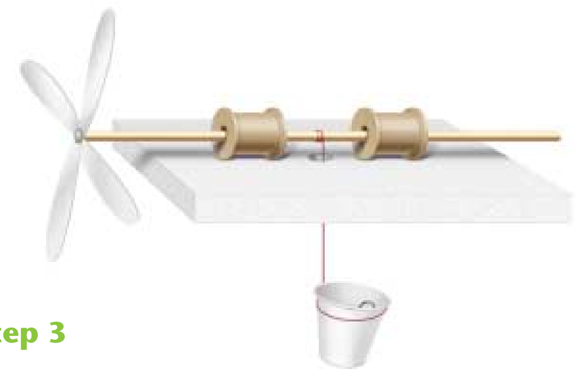
1. What is the best windmill design?

FORM A HYPOTHESIS

2. Brainstorm with a partner or small group of classmates to design a windmill using only the objects listed in the materials list. Sketch your design, and write a few sentences about how you think your windmill design will perform.

TEST THE HYPOTHESIS

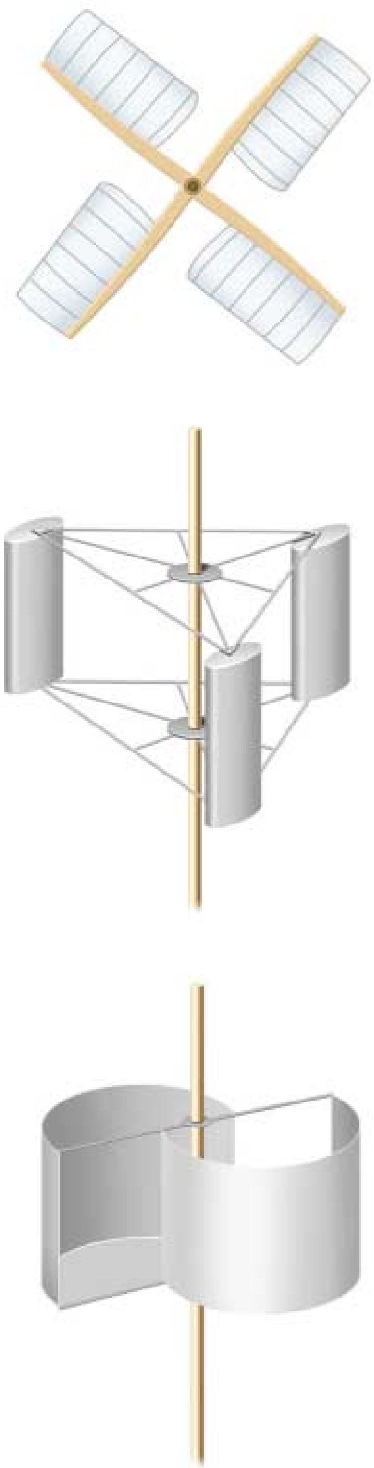
3. Have your teacher approve your design before you begin construction. Build the base for your windmill by using glue to attach the two spools to the foam board. Make sure the spools are parallel before you glue them. Pass a dowel rod through the center of the spools. The dowel should rotate freely. Attach one end of the string securely to the dowel between the two spools.



Step 3

4. Poke a hole through the middle of the foam board to allow the string to pass through. Place your windmill base between two lab tables or in any area that will allow the string to hang freely.
5. After you have decided on your final design, attach the windmill blades to the base.
6. If you have time, you may want to try using different material to construct your windmill blades. Test the various blades to determine whether they improve the original design. You may also want to vary the number and size of the blades on your windmill.
7. Attach the cup to the end of the string. Fill the cup with 30 paper clips. Turn on the blow-dryer, and measure the time it takes for your windmill to lift the cup.

Step 2
Sample windmill blade designs



ANALYSIS AND CONCLUSION

1. **Evaluating Methods** After you test all of the designs, determine which design took the shortest amount of time to complete the test. What elements of the design do you think made it the strongest?
2. **Evaluating Models** Describe how you would change your design to make your windmill work better or faster.

Extension

1. **Research** Windmills have been used for more than 2,000 years. Research the three basic types of vertical axis machines and the applications in which they are used. Prepare a report of your findings.
2. **Making Models** Adapt your design to make a water wheel. You will find that water wheels can lift much more weight than a windmill can. Find designs on the Internet for micro-hydropower water wheels, such as the Pelton wheel, and use the designs as inspiration for your models. You can even design your own dam and reservoir.

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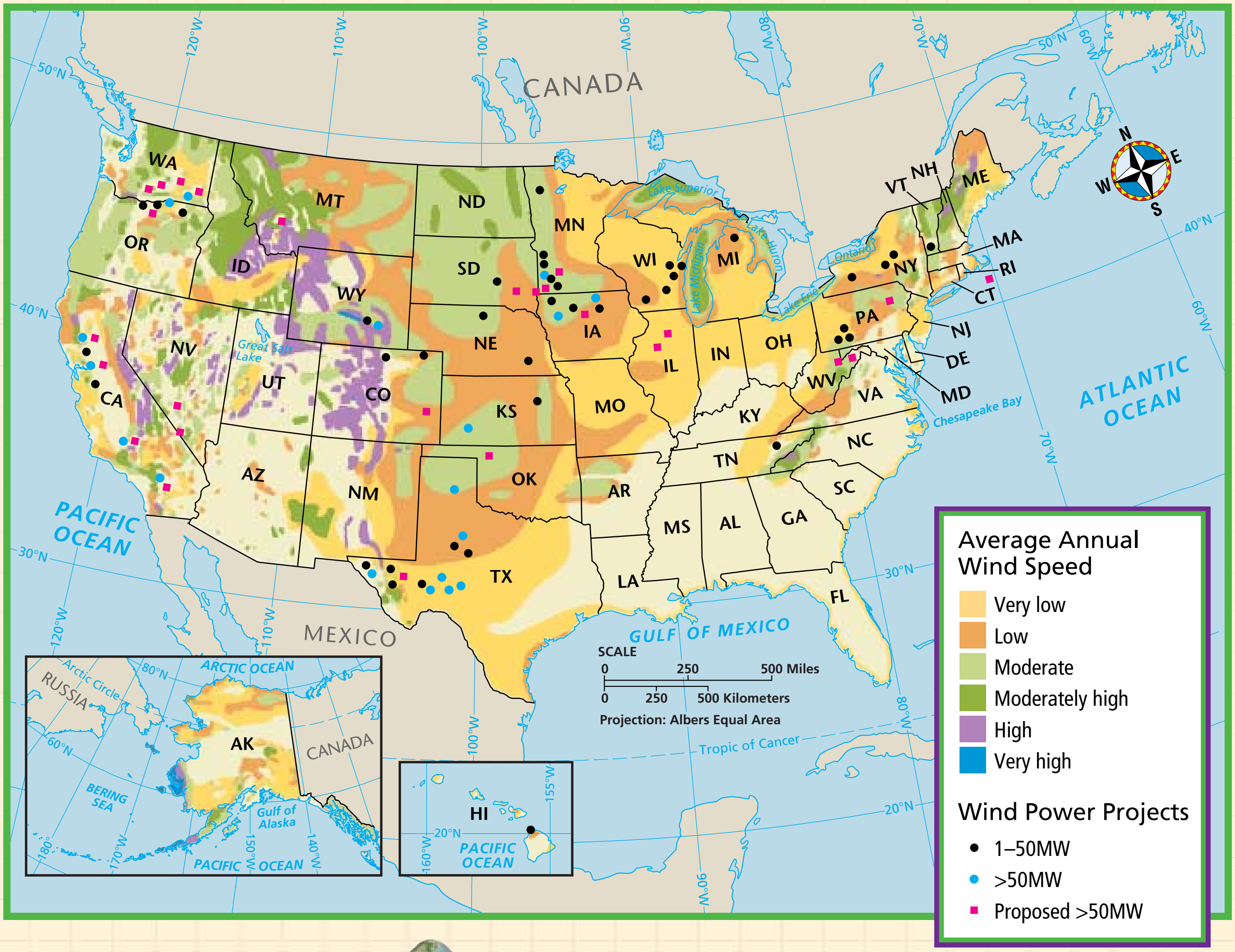
MAPS in Action

Wind Power in the United States



Map Skills Activity

This map shows average wind speeds and the locations of wind power projects throughout the United States. Use the map to answer the questions below:

1. **Using a Key** Name two states that have areas of very high wind speed.
2. **Using a Key** Which two states have the most proposed wind power projects?
3. **Making Comparisons** Which state has the most wind power projects currently in operation?
4. **Inferring Relationships** Examine Idaho, Wyoming, Montana, and Colorado. What landscape feature might account for the strong winds in those states?
5. **Identifying Trends** What states have more than four existing wind power projects that are larger than 50 MegaWatts (MW)?
6. **Making Comparisons** Because of their potential for wind power projects, the Great Plains states (MT, WY, CO, ND, SD, NE, KS, OK, TX, MN, and IA) have been called the "Saudi Arabia of wind energy." Why do you think this comparison has been made?

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EYE on the Environment

What's Mined Is Yours

In every state of the United States, centuries of mining have left marks on the states' ecosystems. National parks alone contain more than 3,200 abandoned mining sites.

Environmental Scars

In a typical mining operation, bulldozers clear away layers of soil, which destroys vegetation and drastically changes the landscape. Streams may be diverted and cause floods in some areas.

Long-term effects can be even more serious. When discarded rock is exposed to air and rainfall, chemical reactions can occur. As a result of the chemical reactions, acids may seep into the ground and pollute nearby waterways. Even years later, plants and animals may still be unable to live in the area because of the affects of mining.

Taking Responsibility

Most mining companies take environmental issues very seriously. New techniques and a better understanding of natural processes have made reclaiming land more effective than ever. Unfortunately, reclamation is very expensive. Returning land to its original state may cost as much as $20,000 per acre. As environmental laws become tougher, mining companies must be more creative to make a profit. Because of low-grade resources and world markets, thousands of people have lost their jobs and local economies have suffered greatly when mining operations go out of business.

No Easy Answers

As the population of the United States grows, we will need more of the metal ores, fossil fuels, and other products that the mining industry provides. Fortunately, reclamation efforts are constantly improving. In addition, efforts to recycle and reuse the resources that we already have are increasing. Nonetheless, finding a compromise between our need for mineral resources and our concern for environmental damage will continue to be expensive and difficult.


▲ At the Flambeau Mine, a copper mine in Wisconsin, waster rock was stored in protected areas to minimize the impact in the enviroment.

◀ After the Flambeau Mine was closed, the waste rock and soil were replaced. A few years later, as seen in this photo, the reclaimed land was restored to its original state.

Extension

1. **Research** Find out the top three mineral resources that your state produces. In what part of the state are they located? How are the minerals extracted, and how are they used?

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Unit 3 HISTORY OF THE EARTH

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Unit 3 Outline

CHAPTER 8
The Rock Record

CHAPTER 7
A View of Earth's Past

▶ Scientists learn about Earth's past by studying rocks and fossils. This fossil from the Green River formation in Wyoming is a fossilized predatory fish called *Mioplosus*. This extraordinary fossil captures a *Mioplosus* in the act of devouring a small fish.

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Chapter 8 The Rock Record

Sections

1 Determining Relative Age

2 Determining Absolute Age

3 The Fossil Record

What You'll Learn

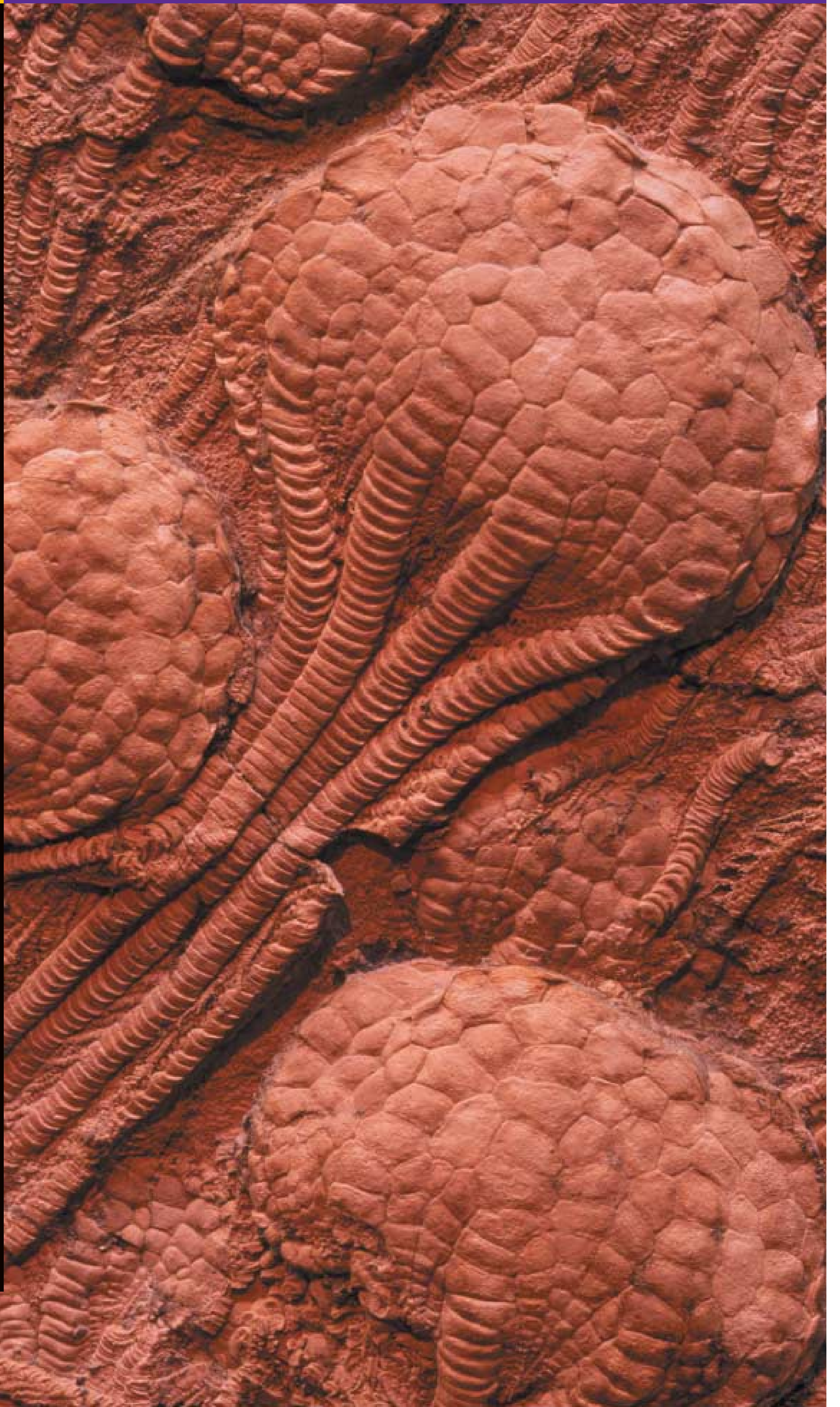
- How scientists determine relative age
- How scientists determine absolute age
- How fossils form

Why It's Relevant

To study Earth's 4.6 billion year history, scientists look to the information stored in rocks. Scientists must determine the age of rocks to put the events of Earth's history in order.

PRE-READING ACTIVITY

Table Fold Before you read this chapter, create the **FoldNote** entitled "Table Fold" described in the Skills Handbook section of the Appendix. Label the columns of the table fold with "Absolute age" and "Relative age." As you read the chapter, write examples of each topic under the appropriate column.



▶ This slab of beautifully preserved crinoids shows each organism's 10 radial arms. Crinoids have been inhabiting aquatic environments on Earth for almost 490 million years.

Section 1 Determining Relative Age

Geologists estimate that Earth is about 4.6 billion years old. The idea that Earth is billions of years old originated with the work of James Hutton, an 18th-century Scottish physician and farmer. Hutton, who is shown in **Figure 1,** wrote about agriculture, weather, climate, physics, and even philosophy. Hutton was also a keen observer of the geologic changes taking place on his farm. Using scientific methods, Hutton drew conclusions based on his observations. Today, he is most famous for his ideas and writings about geology.

OBJECTIVES

- **State** the principle of uniformitarianism.
- **Explain** how the law of superposition can be used to determine the relative age of rocks.
- **Compare** three types of unconformities.
- **Apply** the law of crosscutting relationships to determine the relative age of rocks.

KEY TERMS

uniformitarianism
relative age
law of superposition
unconformity
law of crosscutting relationships

Uniformitarianism

Hutton theorized that the same forces that changed the landscape of his farm had changed Earth's surface in the past. He thought that by studying the present, people could learn about Earth's past. Hutton's principle of **uniformitarianism** is that current geologic processes, such as volcanism and erosion, are the same processes that were at work in the past. This principle is one of the basic foundations of the science of geology. Geologists later refined Hutton's ideas by pointing out that although the processes of the past and present are the same, the rates of the processes may vary over time.

uniformitarianism a principle that geologic processes that occurred in the past can be explained by current geologic processes

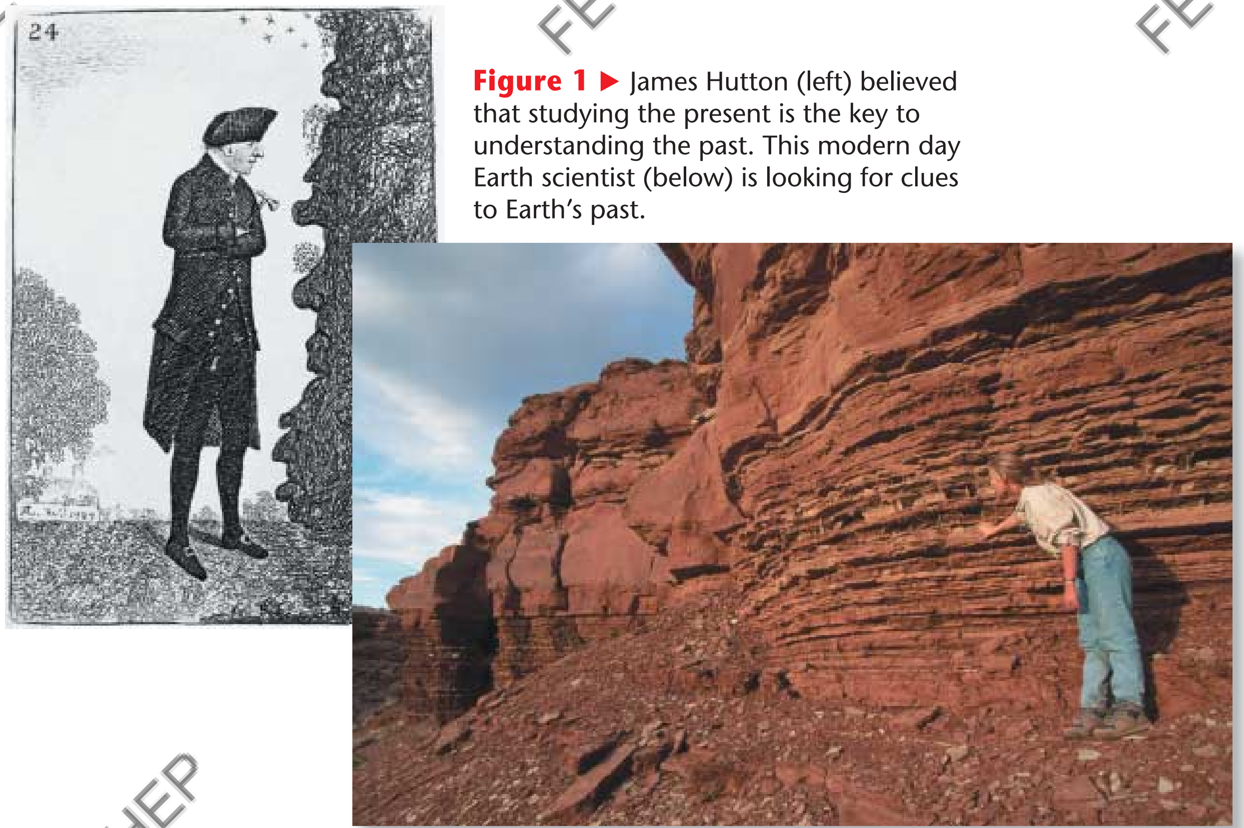


Figure 1 ▶ James Hutton (left) believed that studying the present is the key to understanding the past. This modern day Earth scientist (below) is looking for clues to Earth's past.

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QuickLAB — 20 min

What's Your Relative Age?

Procedure

1. Form a group with 5 to 10 of your classmates.
2. Work together to arrange group members in order from oldest to youngest.

Analysis

1. How did you determine your classmates' relative ages?
2. How did the relative ages compare to the absolute ages of your classmates?
3. How is this process of determining relative and absolute age different from the way scientists date rocks?

Earth's Age

Before Hutton's research was completed, many people thought that Earth was only about 6,000 years old. They also thought that all geologic features had formed at the same time. Hutton's principle of uniformitarianism raised some serious questions about Earth's age. Hutton observed that the forces that changed the land on his farm operated very slowly. He reasoned that millions of years must be needed for those same forces to create the complicated rock structures observed in Earth's crust. He concluded that Earth must be much older than previously thought. Hutton's observations and conclusions about the age of Earth encouraged other scientists to learn more about Earth's history. One way to learn about Earth's past is to determine the order in which rock layers and other rock structures formed.

Reading Check **What evidence did Hutton propose to show that Earth is very old? (See the Appendix for answers to Reading Checks.)**

Relative Age

In the same way that a history book shows an order of events, layers of rock, called *strata,* show the sequence of events that took place in the past. Using a few basic principles, scientists can determine the order in which rock layers formed. Once they know the order, a relative age can be determined for each rock layer. **Relative age** indicates that one layer is older or younger than another layer but does not indicate the rock's age in years.

relative age the age of an object in relation to the ages of other objects

Various types of rock form layers. Igneous rocks form layers when successive lava flows stack on top of each other. Some types of metamorphic rock, such as marble, also have layers. To determine the relative age of rocks, however, scientists commonly study the layers in sedimentary rocks, such as those shown in **Figure 2.**

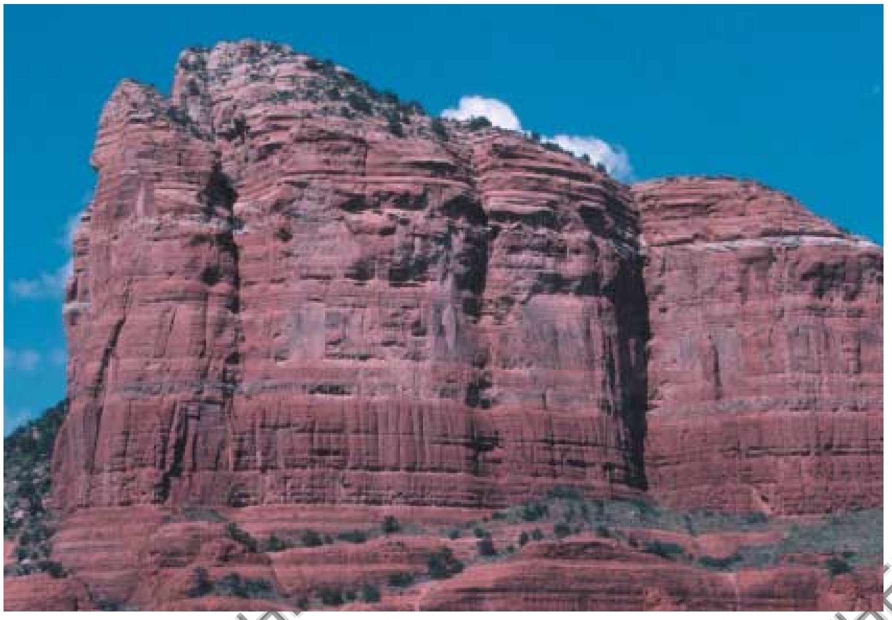

Figure 2 ▶ The layers of sedimentary rock that make up Canyon de Chelly in Arizona were deposited over millions of years.

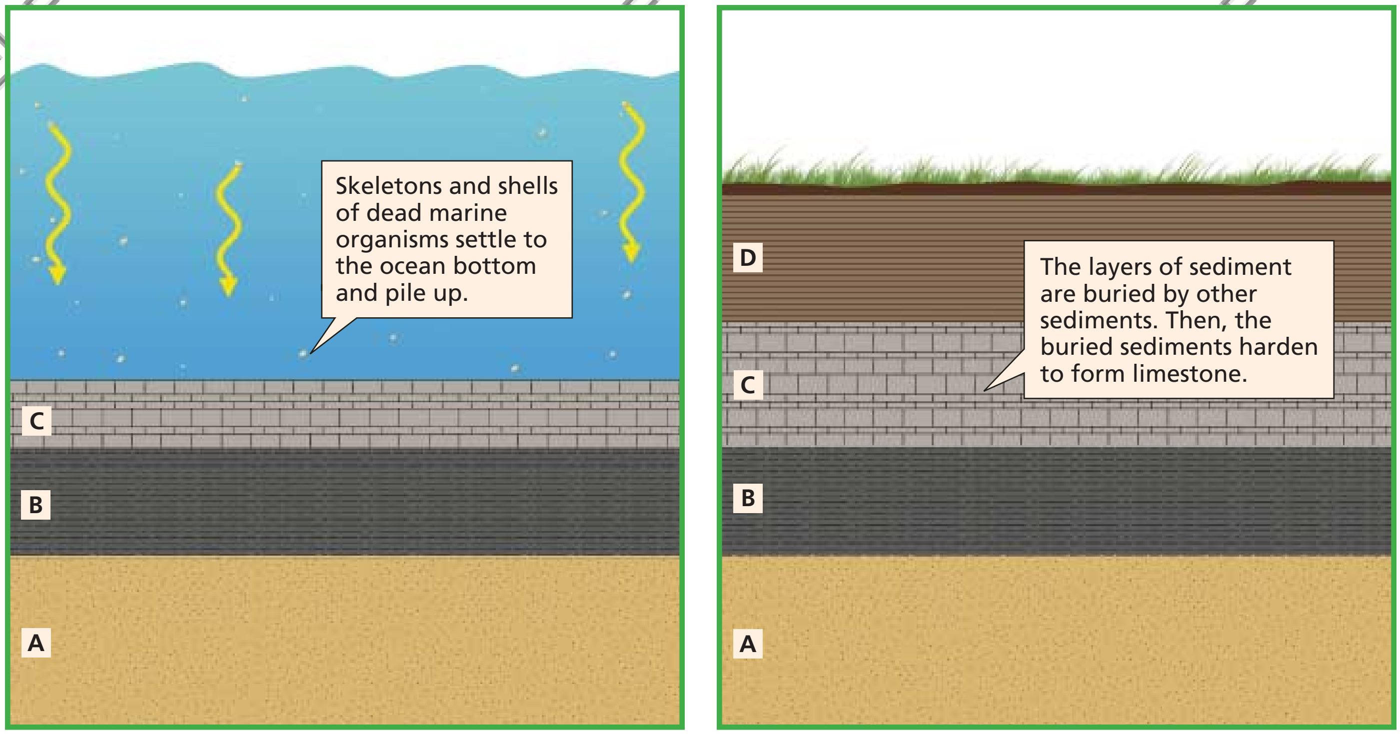

Figure 3 ▶ By applying the law of superposition, geologists are able to determine that layer D is the youngest bed in this rock section. ***According to the law of superposition, is layer B older or younger than layer C?***

Law of Superposition

Sedimentary rocks form when new sediments are deposited on top of old layers of sediment. As the sediments accumulate, they are compressed and harden into sedimentary rock layers which are called *beds*. The boundary between two beds is called a *bedding plane*.

Scientists use a basic principle called the law of superposition to determine the relative age of a layer of sedimentary rock. The **law of superposition** is that an undeformed sedimentary rock layer is older than the layers above it and younger than the layers below it. According to the law of superposition, layer A, shown in **Figure 3**, was the first layer deposited, and thus it is the oldest layer. The last layer deposited was layer D, and thus it is the youngest layer.

law of superposition the law that a sedimentary rock layer is older than the layers above it and younger than the layers below it if the layers are not disturbed

Principle of Original Horizontality

Scientists also know that sedimentary rock generally forms in horizontal layers. The *principle of original horizontality* is that sedimentary rocks left undisturbed will remain in horizontal layers. Therefore, scientists can assume that sedimentary rock layers that are not horizontal have been tilted or deformed by crustal movements that happened after the layers formed.

In some cases, tectonic forces push older layers on top of younger ones or overturn a group of rock layers. In such cases, the law of superposition cannot be easily applied. So, scientists must look for clues to the original position of layers and then apply the law of superposition.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Law of Superposition
SciLinks code: HQ60858

Figure 4 ▶ **Sedimentary Rock Structures**

Graded Bedding Heavy particles settle to the bottom of a lake or river faster than smaller particles do and create graded beds like this one.

Cross-beds As sand slides down the slope of a large sand dune, the sand forms slanting layers like the ones shown here.

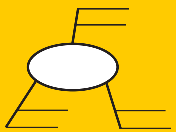
Ripple Marks When waves move back and forth on a beach, ripple marks like these commonly form.

Graded Bedding

One possible clue to the original position of rock layers is the size of the particles in the layers. In some depositional environments, the largest particles of sediment are deposited in the bottom layers, as shown in **Figure 4.** The arrangement of layers in which coarse and heavy particles are located in the bottom layers is called *graded bedding*. If larger particles are located in the top layers, the layers may have been overturned by tectonic forces.

Graphic Organizer **Spider Map**

Create the **Graphic Organizer** entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Unconformities." Create a leg for each type of unconformity. Then, fill in the map with details about each type of unconformity.



Cross-Beds

Another clue to the original position of rock layers is in the shape of the bedding planes. When sand is deposited, sandy sediment forms curved beds at an angle to the bedding plane. These beds are called *cross-beds* and are shown in **Figure 4.** The tops of these layers commonly erode before new layers are deposited. So, the sediment appears to be curved at the bottom of the layer and to be cut off at the top. By studying the shape of the cross-beds, scientists can determine the original position of these layers.

Ripple Marks

Ripple marks are small waves that form on the surface of sand because of the action of water or wind. When the sand becomes sandstone, the ripple marks may be preserved, as shown in **Figure 4.** In undisturbed sedimentary rock layers, the crests of the ripple marks point upward. By examining the orientation of ripple marks, scientists can establish the original arrangement of the rock layers. The relative ages of the rocks can then be determined by using the law of superposition.

Reading Check **How can ripple marks indicate the original position of rock layers? (See the Appendix for answers to Reading Checks.)**

Unconformities

Movements of Earth's crust can lift up rock layers that were buried and expose them to erosion. Then, if sediments are deposited, new rock layers form in place of the eroded layers. The missing rock layers create a break in the geologic record in the same way that pages missing from a book create a break in a story. A break in the geologic record is called an **unconformity.** An unconformity shows that deposition stopped for a period of time, and rock may have been removed by erosion before deposition resumed.

unconformity a break in the geologic record created when rock layers are eroded or when sediment is not deposited for a long period of time

As shown in **Table 1,** there are three types of unconformities. An unconformity in which stratified rock rests upon unstratified rock is called a *nonconformity*. The boundary between a set of tilted layers and a set of horizontal layers is called an *angular unconformity*. The boundary between horizontal layers of old sedimentary rock and younger, overlying layers that are deposited on an eroded surface is called a *disconformity*. According to the law of superposition, all rocks beneath an unconformity are older than the rocks above the unconformity.

Table 1 ▼

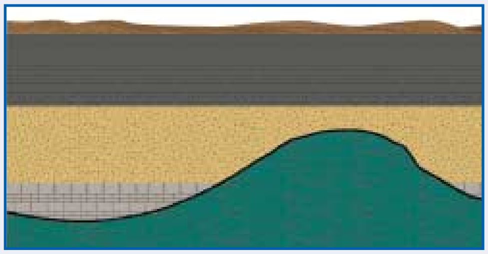
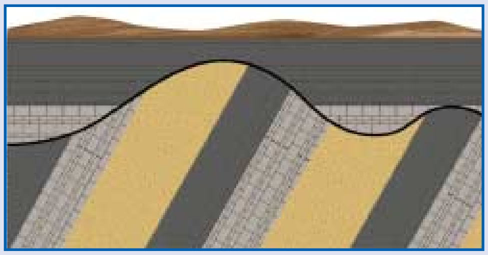
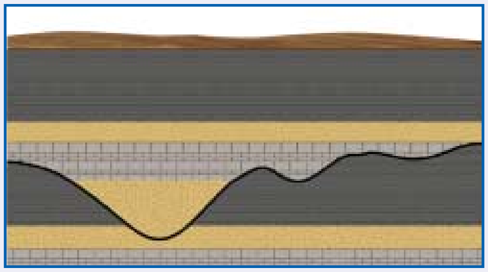
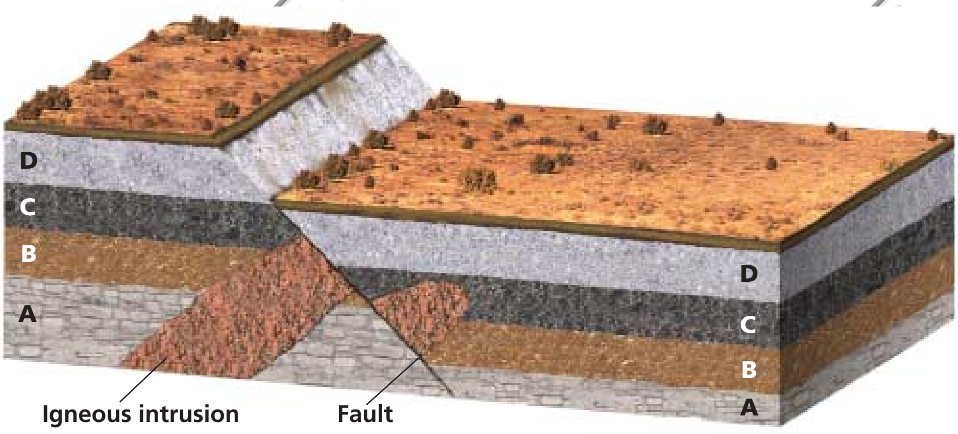
Types of Unconformities		
Type	**Example**	**Description**
Nonconformity		Unstratified igneous or metamorphic rock may be uplifted to Earth's surface by crustal movements. Once the rock is exposed, it erodes. Sediments may then be deposited on the eroded surface. The boundary between the new sedimentary rock and the igneous or metamorphic rock is a *nonconformity*. The boundary represents an unknown period of time during which the older rock was eroded.
Angular unconformity		An *angular unconformity* forms when rock deposited in horizontal layers is folded or tilted and then eroded. When erosion stops, a new horizontal layer is deposited on top of a tilted layer. When the bedding planes of the older rock layers are not parallel to those of the younger rock layers deposited above them, an angular unconformity results.
Disconformity		Sometimes, layers of sediments are uplifted without folding or tilting and are eroded. Eventually, the area subsides and deposition resumes. The layers on either side of the boundary are nearly horizontal. Although the rock layers look as if they were deposited continuously, a large time gap exists where the upper and lower layers meet. This gap is known as a *disconformity*.

Figure 5 ▶ The law of crosscutting relationships can be used to determine the relative ages of rock layers and the faults and intrusions within them.



Crosscutting Relationships

When rock layers have been disturbed by faults or intrusions, determining relative age may be difficult. A *fault* is a break or crack in Earth's crust along which rocks shift their position. An *intrusion* is a mass of igneous rock that forms when magma is injected into rock and then cools and solidifies. In such cases, scientists may apply the law of crosscutting relationships. The **law of crosscutting relationships** is that a fault or igneous intrusion is always younger than the rock layers it cuts through. If a fault or intrusion cuts through an unconformity, the fault or intrusion is younger than all the rocks it cuts through above and below the unconformity.

law of crosscutting relationships the principle that a fault or body of rock is younger than any other body of rock that it cuts through

Figure 5 shows a series of rock layers that contains both a fault and an igneous intrusion. As you can see, an intrusion cuts across layers A, B, and C. According to the law of crosscutting relationships, the intrusion is younger than layers A, B, and C. The fault is younger than the intrusion and all four layers.

Section 1 Review

1. **Explain** why it is important for scientists to be able to determine the relative age of rocks.
2. **State** the principle of uniformitarianism in your own words.
3. **Explain** how the law of superposition can be used to determine the relative age of sedimentary rock.
4. **Explain** the difference between an unconformity and a nonconformity.
5. **Compare** an angular unconformity with a disconformity.
6. **Describe** how the law of crosscutting relationships helps scientists determine the relative ages of rocks.

CRITICAL THINKING

7. **Making Comparisons** Which would be more difficult to recognize: a nonconformity or a disconformity? Explain your answer.
8. **Analyzing Relationships** Suppose that you find a series of rock layers in which a fault ends at an unconformity. Explain how you could apply the law of crosscutting relationships to determine the relative age of the fault and of the rock layers that were deposited above the unconformity.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *principle of original horizontality, relative age, graded bedding, law of superposition, cross-bed,* and *ripple mark*.

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Section 2 Determining Absolute Age

Relative age indicates only that one rock formation is younger or older than another rock formation. To learn more about Earth's history, scientists often need to determine the numeric age, or **absolute age,** of a rock formation.

Absolute Dating Methods

Scientists use a variety of methods to measure absolute age. Some methods use geologic processes that can be observed and measured over time. Other methods measure the chemical composition of certain materials in rock.

Rates of Erosion

One way to estimate absolute age is to study rates of erosion. For example, if scientists measure the rate at which a stream erodes its bed, they can estimate the age of the stream. But determining absolute age by using the rate of erosion is practical only for geologic features that formed within the past 10,000 to 20,000 years. One example of such a feature is Niagara Falls, which is shown in **Figure 1.** For older surface features, such as the Grand Canyon, which formed over millions of years, the method is less dependable because rates of erosion may vary greatly over millions of years.

OBJECTIVES

- **Summarize** the limitations of using the rates of erosion and deposition to determine the absolute age of rock formations.
- **Describe** the formation of varves.
- **Explain** how the process of radioactive decay can be used to determine the absolute age of rocks.

KEY TERMS

absolute age
varve
radiometric dating
half-life

absolute age the numeric age of an object or event, often stated in years before the present, as established by an absolute-dating process, such as radiometric dating

Figure 1 ▶ The rocky ledge above Niagara Falls has been eroding at a rate of about 1.3 m per year for nearly 9,900 years. ***How many kilometers has the ledge been eroded in the last 9,900 years?***

MATHPRACTICE

Deposition If 30 cm of sediments are deposited every 1,000 years, how long would 10 m of sediments take to accumulate?

Rates of Deposition

Another way to estimate absolute age is to calculate the rate of sediment deposition. By using data collected over a long period of time, geologists can estimate the average rates of deposition for common sedimentary rocks such as limestone, shale, and sandstone. In general, about 30 cm of sedimentary rock are deposited over a period of 1,000 years. However, any given sedimentary layer that is being studied may not have been deposited at an average rate. For example, a flood can deposit many meters of sediment in just one day. In addition, the rate of deposition may change over time. Therefore, this method of determining absolute age is not always accurate; it merely provides an estimate.

Varve Count

varve a banded layer of sand and silt that is deposited annually in a lake, especially near ice sheets or glaciers, and that can be used to determine absolute age

You may know that a tree's age can be estimated by counting the growth rings in its trunk. Scientists have devised a similar method for estimating the age of certain sedimentary deposits. Some sedimentary deposits show definite annual layers, called **varves,** that consist of a light-colored band of coarse particles and a dark band of fine particles.

Varves generally form in glacial lakes. During the summer, when snow and ice melt rapidly, a rush of water can carry large amounts of sediment into a lake. Most of the coarse particles settle quickly to form a layer on the bottom of the lake. With the coming of winter, the surface of the lake begins to freeze. Fine clay particles still suspended in the water settle slowly to form a thin layer on top of the coarse sediments. A coarse summer layer and the overlying, fine winter layer make up one varve. Thus, each varve represents one year of deposition. Some varves are shown in **Figure 2.** By counting the varves, scientists can estimate the age of the sediments.

Reading Check **How are varves like tree rings? (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Varves (below), which form in glacial lakes (right), can be counted to determine the absolute age of sediments.

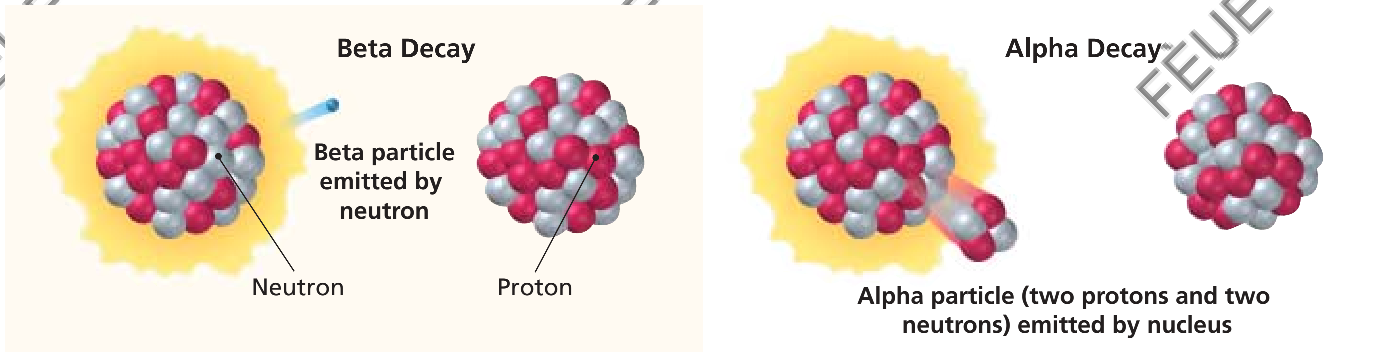


Figure 3 ▶ Beta decay and alpha decay are two forms of radioactive decay. In all forms of radioactive decay, an atom emits particles and energy.

Radiometric Dating

Rocks generally contain small amounts of radioactive material that can act as natural clocks. Atoms of the same element that have different numbers of neutrons are called *isotopes*. *Radioactive isotopes* have nuclei that emit particles and energy at a constant rate regardless of surrounding conditions. **Figure 3** shows two of the ways that radioactive isotopes decay. During the emission of the particles, large amounts of energy are released. Scientists use this natural breakdown of isotopes to accurately measure the absolute age of rocks. The method of using radioactive decay to measure absolute age is called **radiometric dating**.

As an atom emits particles and energy, the atom changes into a different isotope of the same element or an isotope of a different element. Scientists measure the concentrations of the original radioactive isotope, or *parent isotope*, and of the newly formed isotopes, or *daughter isotopes*. Using the known decay rate, the scientists compare the proportions of the parent and daughter isotopes to determine the absolute age of the rock.

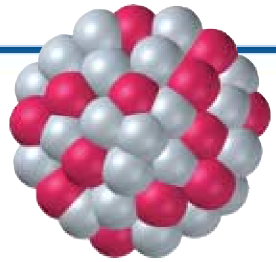
radiometric dating a method of determining the absolute age of an object by comparing the relative percentages of a radioactive (parent) isotope and a stable (daughter) isotope

Connection to CHEMISTRY

Radioactive Decay of Uranium

Uranium is a radioactive element that occurs in some rocks. One form of uranium, which is represented by the symbol ^{238}U, has a mass number of 238 and an atomic number of 92. The atomic number is the number of protons in the nucleus. The mass number is the sum of the number of protons and neutrons in the nucleus. Uranium-238 is particularly useful in establishing the absolute ages of rocks.

The highly radioactive nucleus of ^{238}U spontaneously emits two protons and two neutrons in a process called *alpha decay* or alpha particle emission. The loss of protons and neutrons from the nucleus decreases both the atomic number and the mass number. After the first decay of ^{238}U, the new nucleus has a mass number of 234 and an atomic number of 90. The atom has changed into an isotope of thorium, ^{234}Th.



The ^{234}Th nucleus is also radioactive, and one of its neutrons changes into a proton and an electron in a process called *beta decay*. The change of the neutron to a proton increases the atomic number by one, and the thorium isotope then becomes an isotope of protactinium, ^{234}Pa, which is also radioactive.

The cycle of radioactive decay continues until a stable, or nonradioactive, form of lead is produced. A form of lead that has a mass number of 206, ^{206}Pb, is the final product of this radioactive-decay chain. In this chain of decay, ^{238}U is the parent isotope and ^{206}Pb is a daughter isotope. The time required for half of any given amount of ^{238}U to decay into ^{206}Pb is 4.5 billion years. Thus, 4.5 billion years is the half-life of ^{238}U.

Figure 4 ▶ After each half-life, one-half of the parent isotope is converted into a daughter isotope. After four half-lives, only 1/16 of the parent isotope remains.

Half-Life

Radioactive decay happens at a relatively constant rate that is not changed by temperature, pressure, or other environmental conditions. Scientists have determined that the time required for half of any amount of a particular radioactive isotope to decay is always the same and can be determined for any isotope. Therefore, a **half-life** is the time it takes half the mass of a given amount of a radioactive isotope to decay into its daughter isotopes. If you began with 10 g of a parent isotope, you would have 5 g of that isotope after one half-life of that isotope. At the end of a second half-life, one-fourth, or 2.5 g, of the original isotope would remain. Three-fourths of the sample would now be the daughter isotope. This process is shown in **Figure 4.**

half-life the time required for half of a sample of a radioactive isotope to break down by radioactive decay to form a daughter isotope

By comparing the amounts of parent and daughter isotopes in a rock sample, scientists can determine the age of the sample. The greater the percentage of daughter isotopes present in the sample, the older the rock is. But comparing parent to daughter isotopes works only when the sample has not gained or lost either parent or daughter isotopes through leaking or contamination.

QuickLAB 10 min

Radioactive Decay

Procedure

1. Use a **clock or watch that has a second hand** to record the time.
2. Wait 20 s, and then use **scissors** to carefully cut a **sheet of paper** in half. Select one piece, and set the other piece aside.
3. Repeat step 2 until nine 20 s intervals have elapsed.

Analysis

1. What does the whole piece of paper used in this investigation represent?
2. What do the pieces of paper that you set aside in each step represent?
3. What is the half-life of your paper isotope?
4. How much of your paper isotope was left after the first three intervals? after six intervals? after nine intervals? Express your answers as percentages.
5. What two factors in your model must remain constant so that your model is accurate? Explain your answer.

Table 1 ▼

Radiometric Dating Methods				
Radiometric dating method	**Parent Isotope**	**Daughter isotope**	**Half-life**	**Effective dating range**
Radiocarbon dating	carbon-14, ^{14}C	nitrogen-14, 14N	5,730 years	less than 70,000 years
Argon-argon dating, $^{39}Ar/^{40}Ar$	potassium-40, ^{40}K irradiated to form argon-39, ^{39}Ar	argon-40, ^{40}Ar	1.25 billion years	50,000 to 4.6 billion years
Potassium-argon dating, $^{40}K/^{40}Ar$	potassium-40, ^{40}K	Argon-40, ^{40}Ar	1.25 billion years	50,000 to 4.6 billion years
Rubidium-strontium dating, $^{87}Rb/^{87}Sr$	rubidium-87, ^{87}Rb	strontium-87, ^{87}Sr	48.8 billion years	10 million to 4.6 billion years
Uranium-lead dating, $^{235}U/^{207}Pb$	uranium-235, ^{235}U	lead-207, ^{207}Pb	704 million years	10 million to 4.6 billion years
Uranium-lead dating, $^{238}U/^{206}Pb$	uranium-238, ^{238}U	lead-206, ^{206}Pb	4.5 billion years	10 million to 4.6 billion years
Thorium-lead dating	thorium-232, ^{232}Th	lead-208, ^{208}Pb	14.0 billion years	less than 200 million years

Radioactive Isotopes

The amount of time that has passed since a rock formed determines which radioactive element will give a more accurate age measurement. If too little time has passed since radioactive decay began, there may not be enough of the daughter isotope for accurate dating. If too much time has passed, there may not be enough of the parent isotope left for accurate dating.

Uranium-238, ^{238}U (which is read as "U two thirty-eight"), has an extremely long half-life of 4.5 billion years. ^{238}U is most useful for dating geologic samples that are more than 10 million years old, as long as they contain uranium. In addition to ^{238}U, several other radioactive isotopes are used to date rock samples. One such isotope is potassium-40, ^{40}K, which has a half-life of 1.25 billion years. ^{40}K occurs in mica, clay, and feldspar and is used to date rocks that are between 50,000 and 4.6 billion years old. Rubidium-87, ^{87}Rb, has a half-life of about 49 billion years. ^{87}Rb, which commonly occurs in minerals that contain ^{40}K, can be used to verify the age of rocks previously dated by using ^{40}K. **Table 1** provides a list of other radiometric dating methods.

Reading Check **How does the half-life of an isotope affect the accuracy of the radiometric dating method? (See the Appendix for answers to Reading Checks.)**

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Radiometric Dating
SciLinks code: HQ61261

Figure 5 ▶ This scientist is preparing a mammoth's tooth for carbon-14 dating, which will determine the tooth's absolute age.

Carbon Dating

Younger rock layers may be dated indirectly by dating organic material found within the rock. The ages of wood, bones, shells, and other organic remains that are included in the layers and that are less than 70,000 years old can be determined by using a method known as *carbon-14 dating,* or *radiocarbon dating*, as shown in **Figure 5.** The isotope carbon-14, ^{14}C, combines with oxygen to form radioactive carbon dioxide, CO_2. Most CO_2 in the atmosphere contains nonradioactive carbon-12, ^{12}C. Only a small amount of CO_2 in the atmosphere contains ^{14}C.

Plants absorb CO_2, which contains either ^{12}C or ^{14}C during photosynthesis. Then, when animals eat the plants or the plant-eating animals, the ^{12}C and ^{14}C become part of the animals' body tissues. Thus, all living organisms contain both ^{12}C and ^{14}C.

To find the age of a small amount of organic material, scientists first determine the ratio of ^{14}C to ^{12}C in the sample. Then, they compare that ratio with the ratio of ^{14}C to ^{12}C known to exist in a living organism. While organisms are alive, the ratio of ^{12}C to ^{14}C remains relatively constant. When a plant or an animal dies, however, the ratio begins to change. The half-life of ^{14}C is only about 5,730 years. Because the organism is dead, it no longer absorbs ^{12}C and ^{14}C, and the amount of ^{14}C in the organism's tissues decreases steadily as the radioactive ^{14}C decays to nonradioactive nitrogen-14, ^{14}N.

Section 2 Review

1. **Differentiate** between relative and absolute age.
2. **Summarize** why calculations of absolute age based on rates of erosion and deposition can be inaccurate.
3. **Describe** varves, and describe how and where they form.
4. **Explain** how radiometric dating is used to estimate absolute age.
5. **Define** half-life, and explain how it helps determine an object's absolute age.
6. **List** three methods of radiometric dating, and explain the age range for which they are most effective.

CRITICAL THINKING

7. **Demonstrating Reasoned Judgment** Suppose you have a shark's tooth that you suspect is about 15,000 years old. Would you use ^{238}U or ^{14}C to date the tooth? Explain your answer.
8. **Making Inferences** You see an advertisement for an atomic clock. You also know that radioactive decay emits harmful radiation. Do you think the atomic clock contains decaying isotopes? Explain.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *absolute age, varve, radiometric dating, parent isotope, daughter isotope,* and *carbon dating.*

Section 3 The Fossil Record

The remains of animals or plants that lived in a previous geologic time are called **fossils.** Fossils, such as the one shown in **Figure 1,** are an important source of information for finding the relative and absolute ages of rocks. Fossils also provide clues to past geologic events, climates, and the evolution of living things over time. The study of fossils is called **paleontology.**

Almost all fossils are discovered in sedimentary rock. The sediments that cover the fossils slow or stop the process of decay and protect the body of the dead organism from damage. Fossils are rarely discovered in igneous rock or metamorphic rock because intense heat, pressure, and chemical reactions that occur during the formation of these rock types destroy all organic structures.

OBJECTIVES

- **Describe** four ways in which entire organisms can be preserved as fossils.
- **List** five examples of fossilized traces of organisms.
- **Describe** how index fossils can be used to determine the age of rocks.

KEY TERMS

fossil
paleontology
trace fossil
index fossil

Interpreting the Fossil Record

The fossil record provides information about the geologic history of Earth. By revealing the ways that organisms have changed throughout the geologic past, fossils provide important clues to the environmental changes that occurred in Earth's past. For example, fossils of marine animals and plants have been discovered in areas far from any ocean. These fossils tell us that such areas were covered by an ocean in the past. Scientists can use this information to learn about how environmental changes have affected living organisms.

fossil the trace or remains of an organism that lived long ago, most commonly preserved in sedimentary rock

paleontology the scientific study of fossils

Figure 1 ▶ Paleontologists are unearthing the remains of rhinoceroses that are 10 million years old at this site in Orchard, Nebraska.

Fossilization

Normally, dead plants and animals are eaten by other animals or decomposed by bacteria. If left unprotected, even hard parts such as bones decay and leave no trace of the organism. Only dead organisms that are buried quickly or protected from decay can become fossils. Generally, only the hard parts of organisms, such as wood, bones, shells, and teeth, become fossils. In rare cases, an entire organism may be preserved. In some types of fossils, only a replica of the original organism remains. Other fossils merely provide evidence that life once existed. **Table 1** describes different ways that fossils can form.

How Fossils Form

Mummification Mummified remains are often found in very dry places, because most bacteria, which cause decay, cannot survive in these places. Some ancient civilizations mummified their dead by carefully extracting the body's internal organs and then wrapping the body in carefully prepared strips of cloth.

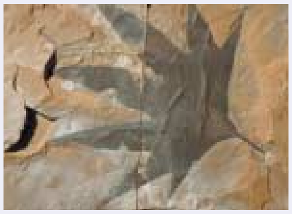
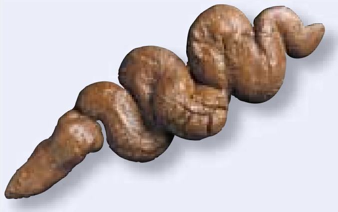
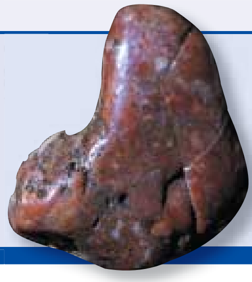
Amber Hardened tree sap is called *amber*. Insects become trapped in the sticky sap and are preserved when the sap hardens. In many cases, delicate features such as legs and antennae have been preserved. In rare cases, DNA has been recovered from amber.

Tar Seeps When thick petroleum oozes to Earth's surface, the petroleum forms a tar seep. Tar seeps are commonly covered by water. Animals that come to drink the water can become trapped in the sticky tar. Other animals prey on the trapped animals and can also become trapped. The remains of the trapped animals are covered by the tar and preserved.

Freezing The low temperatures of frozen soil and ice can protect and preserve organisms. Because most bacteria cannot survive freezing temperatures, organisms that are buried in frozen soil or ice do not decay.

Petrification Mineral solutions such as groundwater replace the original organic materials that were covered by layers of sediment with new materials. Some common petrifying minerals are silica, calcite, and pyrite. The substitution of minerals for organic material often results in the formation of a nearly perfect mineral replica of the original organism.

Table 2 ▼

Types of Fossils	
	**Imprints** Carbonized imprints of leaves, stems, flowers, and fish made in soft mud or clay have been found preserved in sedimentary rock. When original organic material partially decays, it leaves behind a carbon-rich film. An imprint displays the surface features of the organism.
Molds and Casts Shells often leave empty cavities called *molds* within hardened sediment. When a shell is buried, its remains eventually decay and leave an empty space. When sand or mud fills a mold and hardens, a natural cast forms. A cast is a replica of the original organism.	
	**Coprolites** Fossilized dung or waste materials from ancient animals are called *coprolites.* They can be cut into thin sections and observed through a microscope. The materials identified in these sections reveal the feeding habits of ancient animals, such as dinosaurs.
Gastroliths Some dinosaurs had stones in their digestive systems to help grind their food. In many cases, these stones, which are called *gastroliths,* survive as fossils. Gastroliths can often be recognized by their smooth, polished surfaces and by their close proximity to dinosaur remains.	

Types of Fossils

Fossils can show a remarkable amount of detail about ancient organisms. **Table 2** describes some of these fossils. In some cases, no part of the original organism survives in fossil form. But **trace fossils,** or fossilized evidence of past animal movement such as tracks, footprints, borings, and burrows, can still provide information about prehistoric life.

trace fossil a fossilized mark that formed in sedimentary rock by the movement of an animal on or within soft sediment

A trace fossil, such as the footprint of an animal, is an important clue to the animal's appearance and activities. Suppose a giant dinosaur left deep footprints in soft mud. Sand or silt may have blown or washed into the footprint so gently that the footprints remained intact. Then, more sediment may have been deposited over the prints. As time passed, the mud containing the footprints hardened into sedimentary rock and preserved the footprints. Scientists have discovered ancient footprints of reptiles, amphibians, birds, and mammals.

Reading Check **What is a trace fossil? (See the Appendix for answers to Reading Checks.)**

Index Fossils

Paleontologists can use fossils to determine the relative ages of the rock layers in which the fossils are located. Fossils that occur only in rock layers of a particular geologic age are called **index fossils.** To be an index fossil, a fossil must meet certain requirements. First, it must be present in rocks scattered over a large region. Second, it must have features that clearly distinguish it from other fossils. Third, the organisms from which the fossil formed must have lived during a short span of geologic time. Fourth, the fossil must occur in fairly large numbers within the rock layers.

Figure 2 ▶ If you discovered fossils such as these ammonites, you would know that the surrounding rock formed between 180 million and 206 million years ago.

Index Fossils and Absolute Age

Scientists can use index fossils to estimate absolute ages of specific rock layers. Because organisms that formed index fossils lived during short spans of geologic time, the rock layer in which an index fossil was discovered can be dated accurately.

The ammonite fossils in **Figure 2** show that the rock in which the fossils were observed formed between 180 million and 206 million years ago. Scientists can also use index fossils to date rock layers in separate areas. So, an index fossil discovered in rock layers in different areas of the world indicates that the rock layers in these areas formed during the same time period.

Geologists also use index fossils to help locate rock layers that are likely to contain oil and natural gas deposits. These deposits form from plant and animal remains that change by chemical processes over millions of years.

index fossil a fossil that is used to establish the age of rock layers because it is distinct, abundant, and widespread and existed for only a short span of geologic time

Section 3 Review

1. **Describe** four ways in which an entire organism can be preserved as a fossil.
2. **List** four types of fossils that can be used to provide indirect evidence of organisms.
3. **Explain** how geologists use fossils to date sedimentary rock layers.
4. **Compare** the process of mummification with the process of petrification.
5. **Describe** how index fossils can be used to determine the age of rocks.

CRITICAL THINKING

6. **Applying Ideas** What two characteristics do all good sources of animal fossils have in common?
7. **Identifying Relationships** If a rock layer in Mexico and a rock layer in Australia contain the same index fossil, what do you know about the absolute ages of the layers in both places? Explain your answer.

CONCEPT MAPPING

8. Use the following terms to create a concept map: *fossil, mummification, amber, tar seep, freezing,* and *petrification.*

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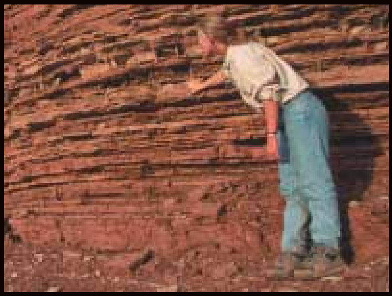
Chapter 8 Highlights

Sections

1 Determining Relative Age



Key Terms

uniformitarianism, 185
relative age, 186
law of superposition, 187
unconformity, 189
law of crosscutting relationships, 190

Key Concepts

- According to the principle of uniformitarianism, the forces that are changing Earth's surface today are the same forces that changed Earth's surface in the past.
- Scientists use the law of superposition to determine the relative ages of rock layers.
- Nonconformities, angular unconformities, and disconformities are interruptions in the sequence of rock layers and are collectively known as unconformities.
- Scientists use the law of crosscutting relationships to determine the relative ages of rock layers.

2 Determining Absolute Age

absolute age, 191
varve, 192
radiometric dating, 193
half-life, 194

- Absolute age is the numeric age of an object given in years.
- Because they can change over time, the rates of erosion and deposition are imprecise methods for determining absolute age of rocks.
- Varves are layers of sediment that form in glacial lakes as a result of the annual cycle of freezing and thawing of the glacier.
- Radioactive elements decay at constant and measurable rates and can be used to determine absolute age.

3 The Fossil Record

fossil, 197
paleontology, 197
trace fossil, 199
index fossil, 200

- Entire organisms may be preserved in amber, in tar seeps, or through freezing or mummification.
- Fossilized evidence of organisms includes trace fossils, imprints, molds, casts, coprolites, and gastroliths.
- Index fossils occur only in rock layers of a particular geologic age.

Chapter 8 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *uniformitarianism*
2. *varve*
3. *radiometric dating*
4. *half-life*

For each pair of terms, explain how the meanings of the terms differ.

5. *relative age* and *absolute age*
6. *law of superposition* and *law of crosscutting relationships*
7. *trace fossil* and *index fossil*

Understanding Key Concepts

8. Varves are layers of
   - **a.** limestone mixed with coarse sediments.
   - **b.** alternating coarse and fine sediments.
   - **c.** fossils.
   - **d.** sediments that have gaps that represent missing time in the rock sequence.

9. An unconformity that results when new sediments are deposited on eroded horizontal layers is a(n)
   - **a.** angular unconformity.
   - **b.** disconformity.
   - **c.** crosscut unconformity.
   - **d.** nonconformity.

10. A fault or intrusion is younger than the rock it cuts through, according to the
    - **a.** type of unconformity.
    - **b.** law of superposition.
    - **c.** law of crosscutting relationships.
    - **d.** principle of uniformitarianism.

11. The age of a rock in years is the rock's numerical age, or
    - **a.** index age.
    - **b.** relative age.
    - **c.** half-life age.
    - **d.** absolute age.

12. A gap in the sequence of rock layers is a(n)
    - **a.** bedding plane.
    - **b.** varve.
    - **c.** unconformity.
    - **d.** uniformity.

13. The process by which the remains of an organism are preserved by drying is called
    - **a.** petrification.
    - **b.** mummification.
    - **c.** erosion.
    - **d.** superposition.

14. Molds that fill with sediment sometimes produce
    - **a.** casts.
    - **b.** gastroliths.
    - **c.** coprolites.
    - **d.** imprints.

Short Answer

15. What prompted James Hutton to formulate the principle of uniformitarianism?
16. Describe how the law of superposition helps scientists determine relative age.
17. Compare and contrast the three types of unconformities.
18. How do scientists use radioactive decay to determine absolute age?
19. Besides radiometric dating, what are three other methods of estimating absolute age?
20. List and describe five ways that organisms can be preserved.
21. List the four characteristics that define an index fossil.

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Thinking

g **Inferences** James Hutton developed
rinciple of uniformitarianism by ob-
ng geologic changes on his farm. What
ges might he have observed?

ing Ideas How might a scientist de-
ne the original positions of the
nentary layers beneath an angular un-
rmity?

zing Relationships One intrusion cuts
gh all the rock layers. Another intru-
s eroded and lies beneath several
s of sedimentary rock. Which intrusion
unger? Explain your answer.

zing Concepts A fossil that has unusual
res is found in many areas on Earth.
resents a brief period of geologic time
ccurs in small numbers. Would this
make a good index fossil? Explain.

g **Comparisons** Compare the processes
ummification and freezing.

t Mapping

ne following terms to create a concept
*relative age, law of superposition, un-
rmity, law of crosscutting relationships,
ute age, radiometric dating, carbon dat-*
nd *index fossil*.

kills

g **Calculations** Scientists know that
a million grams of ^{238}U, 1/7,600 g of
per year will be produced by
active decay. How many grams of
vould be left after 1 million years?

ing Quantities A sample contains
g of an isotope that has a half-life of
ears. How many half-lives will have to
before the sample contains less than
of the parent isotope?

30. Making Calculations The half-life of ^{238}U is 4.5 billion years. How many years would 16 g of ^{238}U take to decay into 0.5 g of ^{238}U and 15.5 g of daughter products?

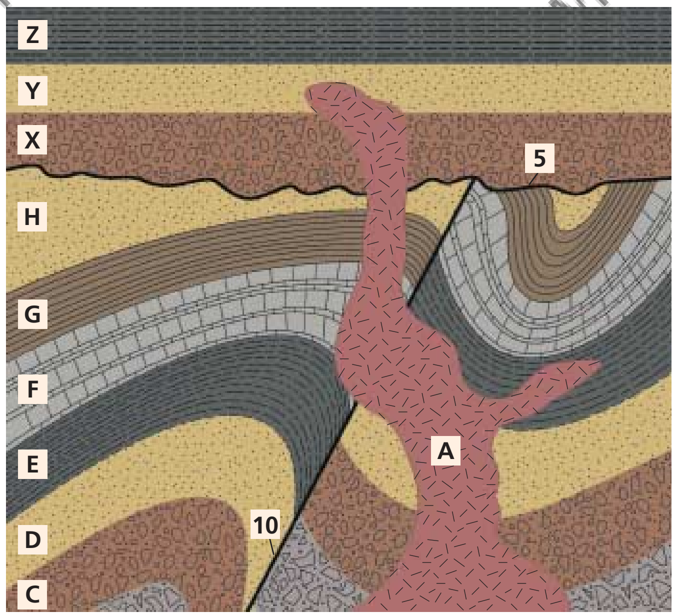
Writing Skills

31. Writing Persuasively Imagine that you are James Hutton. Write a letter to a fellow scientist to convince him or her of the validity of the principle of uniformitarianism.

32. Outlining Topics Describe what happens to the amount of an isotope as it undergoes radioactive decay through three half-lives.

Interpreting Graphics

The illustration below shows crosscutting relationships in an outcrop of rock. Use this illustration to answer the questions that follow.



33. Is intrusion A older or younger than fault 10? Explain your answer.

34. What type of unconformity does feature 5 represent? Explain your answer.

35. Which rock formation is older: layer X or layer Y? Explain your answer.

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Chapter 8 Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 A scientist used radiometric dating during an investigation. The scientist used this method because he or she wanted to determine the

A. relative age of rocks
B. absolute age of rocks
C. climate of a past era
D. fossil types in a rock

2 Fossils that provide direct evidence of the feeding habits of ancient animals are known as

F. coprolites
G. molds and casts
H. imprints
I. trace fossils

3 One way to estimate the absolute age of rock is

A. nonconformity
B. varve count
C. the law of superposition
D. the law of crosscutting relationships

4 To be an index fossil, a fossil must

F. be present in rocks that are scattered over a small geographic area
G. contain remains of organisms that lived for a long period of geologic time
H. occur in small numbers within the rock layers
I. have features that clearly distinguish it from other fossils

5 Which of the following statements best describes the relationship between the law of superposition and the principle of original horizontality?

A. Both describe the deposition of sediments in horizontal layers.
B. Both conclude that Earth is more than 100,000 years old.
C. Both indicate the absolute age of layers of rock.
D. Both recognize that the geologic processes in the past are the same as those at work now.

Directions (6): **For *each* question, write a short response.**

6 What is the name for a type of fossil that can be used to establish the age of rock?

Reading Skills

Directions (7–10): **Read the passage below. Then, answer the questions on a separate sheet of paper.**

Illinois Nodules

Around three hundred million years ago, the region that is now Illinois had a very different climate. Swamps and marshes covered much of the area. Scientists estimate that no fewer than 500 species lived in this ancient environment. Today, the remains of these organisms are found preserved within structures known as nodules. Nodules are round or oblong structures that are usually composed of cemented sediments. Sometimes, these nodules contain the fossilized hard parts of plants and animals. The Illinois nodules are extremely rare because many contain finely detailed impressions of the soft parts of the organisms together with the hard parts. Because they are rare, these nodules are desired for their incredible scientific value and may be found in fossil collections around the world.

7 According to the passage above, which of the following statements about nodules is correct?

A. Nodules are rarely round or oblong.
B. Nodules are usually composed of cemented sediments.
C. Nodules are rarely found outside of Illinois.
D. Nodules will always contain fossils.

8 What is the most unusual feature of the nodules found in modern-day Illinois?

F. their bright coloration
G. the fact that they come in many more unusual shapes that other nodules
H. the fact that they contain both the soft and hard parts of animals
I. their extremely heavy weight

9 Which of the following statements can be inferred from the information in the passage?

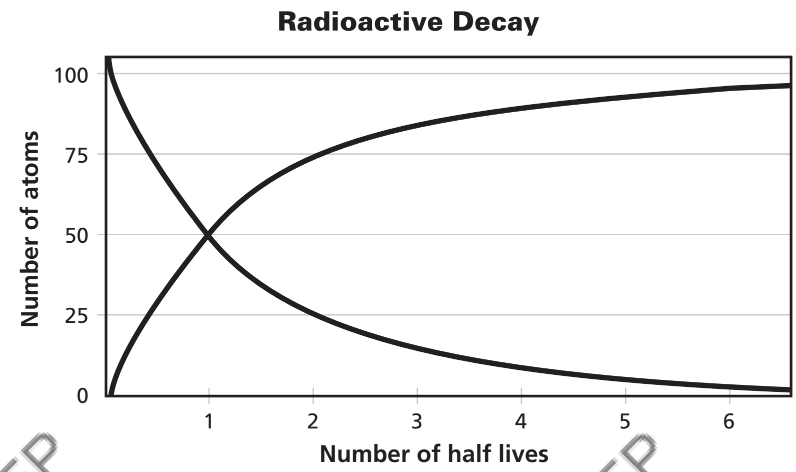
A. Illinois nodules are sought by scientists.
B. Nodules can be purchased from the state.
C. Similar nodules can be found in nearby Iowa.
D. Nodules contain dinosaur fossils.

10 What might scientists learn from nodules that contains the soft and hard parts of an animal?

Interpreting Graphics

Directions (11–13): **For *each* question below, record the correct answer on a separate sheet of paper.**

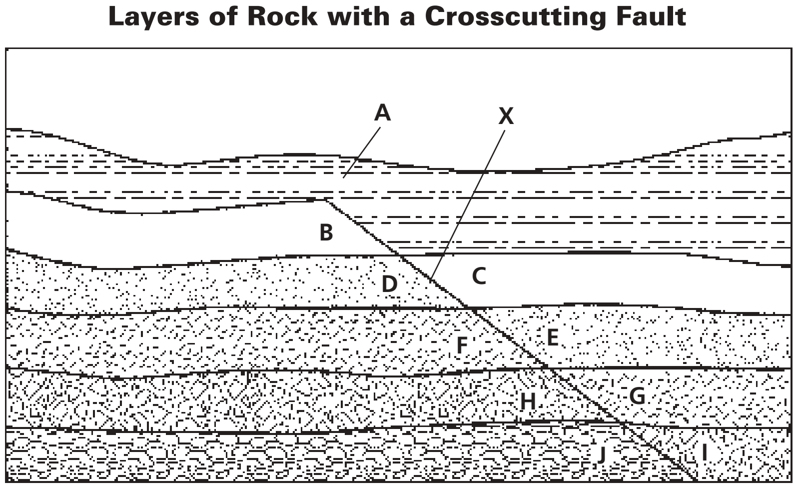
The graph below shows the rate of radioactive decay. Use this graph to answer question 11.



11 How many half-lives have passed when the number of daughter atoms is approximately three times the number of parent atoms?

A. one
B. two
C. three
D. four

The diagram below shows crosscutting taking place in layers of rock. Use this diagram to answer questions 12 and 13.



12 Which of the letter combinations below belonged to the same layer of rock before the fault disrupted the layer?

A. C and D
B. C and F
C. G and I
D. G and F

13 Which is older, structure B or structure X? Explain your answer. What structure shown on the diagram is the youngest?

Test TIP

If time permits, take short mental breaks to improve your concentration during a test.

Making Models Lab

Objectives

- USING SCIENTIFIC METHODS **Model** the way different types of fossils form.
- **Demonstrate** how certain types of fossils form.

Materials

- clay, modeling
- container, plastic
- hard objects such as a shell, key, paper clip, or coin
- leaf
- newspaper
- paper, carbon, soft
- paper, white (1 sheet)
- pencil (or wood dowel)
- plaster of Paris
- spoon, plastic
- tweezers
- water
- wax paper

Safety

Types of Fossils

Paleontologists study fossils to find evidence of the kinds of life and conditions that existed on Earth in the past. Fossils are the remains of ancient plants and animals or evidence of their presence. In this lab, you will use various methods to make models of fossils.

PROCEDURE

1. Place a ball of modeling clay on a flat surface that is covered with wax paper.
2. Press the clay down to form a flat disk about 8 cm in diameter. Turn the clay over so that the smooth, flat surface is facing up.
3. Choose a small, hard object. Press the object onto the clay carefully so that you do not disturb the indentation. Is the indentation left by the object a mold or a cast? What features of the object are best shown in the indentation? Sketch the indentation.
4. On a second piece of smooth, flat clay, make a shallow imprint to represent the burrow or footprint of an animal. Sketch your fossil imprint.

Step 3

5. Fill a plastic container with water to a depth of 1 to 2 cm. Stir in enough plaster of Paris to make a paste that has the consistency of whipped cream.

6. Using the plastic spoon, fill both indentations with plaster. Allow excess plaster to run over the edges of the imprints. Let the plaster set for about 15 minutes until it hardens.

7. After the plaster has hardened, remove both pieces of plaster from the clay. Do the pieces of hardened plaster represent molds or casts?

8. Place the carbon paper on a flat surface with the carbon facing up. Gently place the leaf on the carbon paper, and cover it with several sheets of newspaper. Roll the pencil or wooden dowel back and forth across the surface of the newspaper several times, and press firmly to bring the leaf into full contact with the carbon paper.

9. Remove the newspaper. Lift the leaf by using the tweezers, and place it on a clean sheet of paper with the carbon-coated side facing down. Cover the leaf with clean wax paper, and roll your pencil across the surface of the wax paper.

10. Remove the wax paper and leaf. Observe and describe the carbon print left by the leaf.

Step 6

Step 9

ANALYSIS AND CONCLUSION

1. **Analyzing Results** Look at the molds and casts made by others in your class. Identify as many of the objects used to make the molds and casts as you can.

2. **Making Comparisons** How does the carbon print you made differ from an actual carbonized imprint fossil?

3. **Applying Ideas** Trace fossils are evidence of the movement of an animal on or within soft sediment. Why are imprints, molds, and casts not considered trace fossils?

Extension

1. **Making Predictions** Which organism—a rabbit, a housefly, an earthworm, or a snail—would be most likely to form fossils? Which of the organisms would leave trace fossils? Explain.

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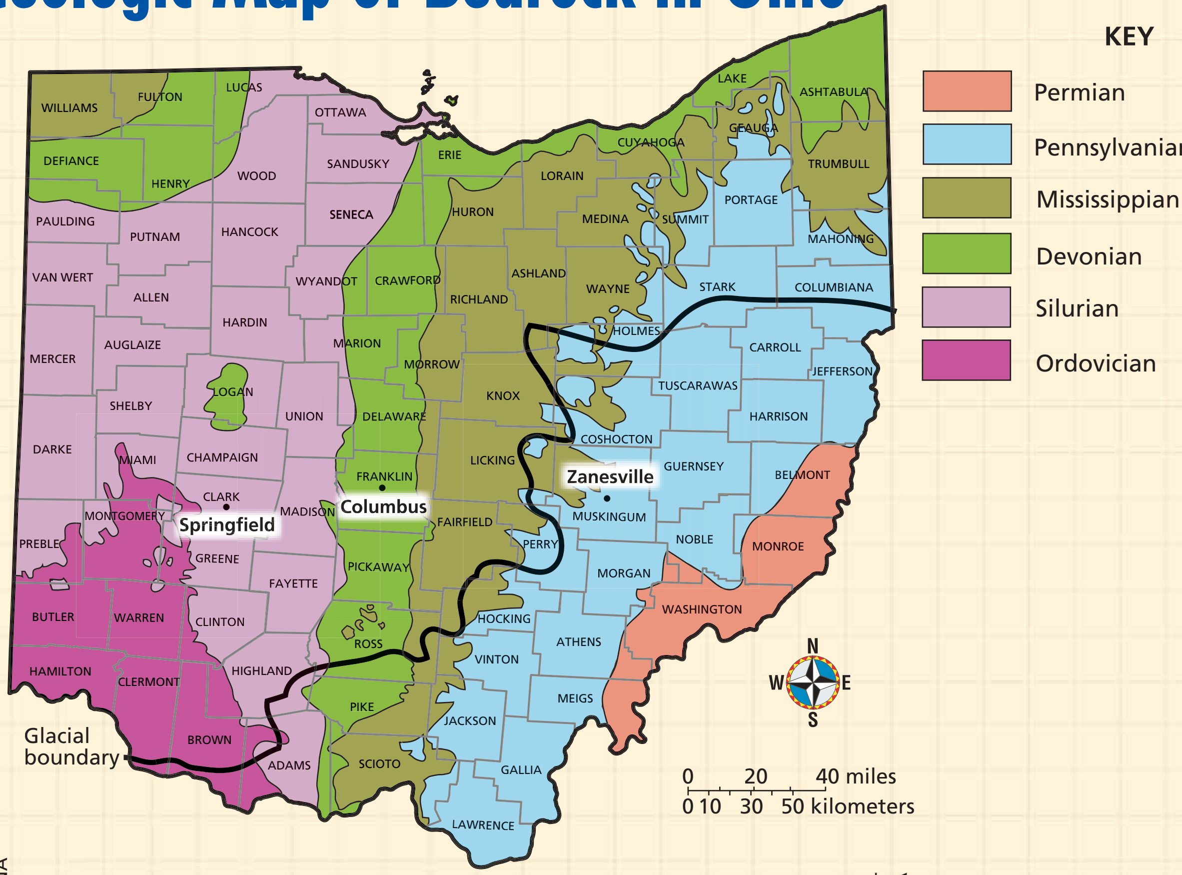
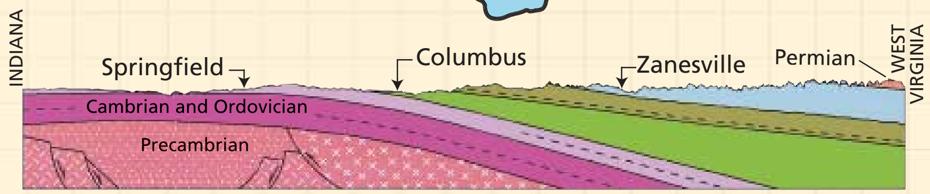
MAPS in Action

Geologic Map of Bedrock in Ohio





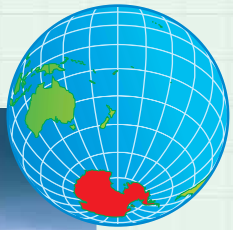
Map Skills Activity

This map shows the ages of the bedrock in Ohio. Bedrock is the solid rock that lies underneath all surface soil and other loose material. Use the map to answer the questions below.

1. **Using the Key** What geologic periods are represented in the bedrock of Ohio?
2. **Analyzing Data** Where is the youngest bedrock in Ohio? Where is the oldest bedrock in Ohio?
3. **Identifying Trends** If you traveled from east to west across Ohio, how would the ages of the rock beneath you change?
4. **Analyzing Relationships** Based on the geologic cross section, how does the shape of the rock beds cause rocks of different ages to be exposed at different places in Ohio?
5. **Identifying Relationships** Why is Mississippian rock likely to be located next to Devonian rock?
6. **Using the Key** The first reptiles appeared in the fossil record during the Pennsylvanian Period. If you wanted to look for fossils of these reptiles in Ohio, in what part of the state would you look? Explain your answer.

EYE on the Environment

Clues to Climate Change



◀ Today, Antarctica is populated only by organisms that can survive extreme cold, such as these penguins.

It is hard to imagine that the bitter cold climate of Antarctica was once much warmer than it is now and that the icy landscape supported thick forests. But studies of fossils found in ocean-floor sediments off the coast of Antarctica indicate climate change.

Finding Fossil Clues

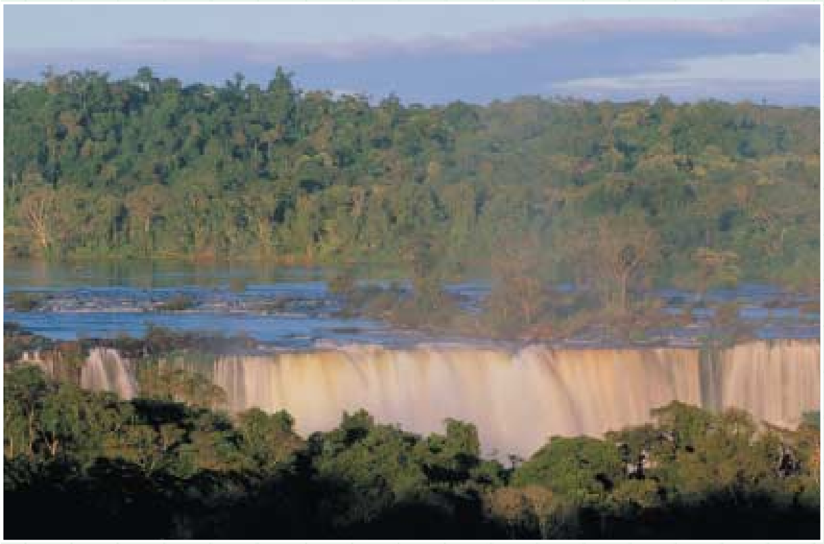
Scientists working on the Ocean Drilling Project have found samples of sediments from 60 million years ago to the present day. These samples reveal much about the complex history of climatic changes in Antarctica.

Fossil spores and pollen that are more than 39 million years old indicate that beech-tree forests once grew in Antarctica. Samples of sediment that are 37 million to 60 million years old contained soil that normally occurs in warm, humid climates. Thus, scientists learned that prior to 37 million years ago the climate in Antarctica was temperate.

Polar Beaches?

Fossils of freshwater organisms indicate that organisms were carried from Antarctic lakes to the ocean floor by rivers as recently as 20 million years ago. The fossils are evidence that the climate was once warm enough for unfrozen lakes to exist.

Scientists also discovered fossils of marine organisms that can live only in sunny coastal waters. Those found off the east coast were more than 15 million years old, and those found off the west coast were more than 4.8 million years old.



◀ About 60 million years ago, Antarctica may have looked like this Brazilian rain forest.

Extension

1. **Research** When did the ice shelves that now cover the ocean off the east and west coasts of Antarctica form? Research this topic, and write a report about your findings.

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Chapter 9 A View of Earth's Past

Sections

1 Geologic Time
2 Precambrian Time and the Paleozoic Era
3 The Mesozoic and Cenozoic Eras

What You'll Learn

- How geologic time is divided
- What organisms lived during each geologic period

Why It's Relevant

The geologic time scale provides a framework for understanding the geologic processes that shape Earth. The fossil record shows that Earth is a constantly changing planet.

PRE-READING ACTIVITY

FOLDNOTES

Two-Panel Flip Chart Before you read this chapter, create the FoldNote entitled "Two-Panel Flip Chart" described in the Skills Handbook section of the Appendix. Label the flaps of the two-panel flip chart with "Geologic Time Scale" and "Geologic History." As you read the chapter, write information you learn about each category under the appropriate flap.

▶ This illustration shows an artist's idea of how a mother *Hypacrosaurus* may have looked as she fed her hatchlings. Because most dinosaur fossils are only fossilized bone, many other characteristics, such as skin color, are left to our imagination.

Section 1 Geologic Time

Earth's surface is constantly changing. Mountains form and erode; oceans rise and recede. As conditions on Earth's surface change, some organisms flourish and then later become extinct. Evidence of change is recorded in the rock layers of Earth's crust. To describe the sequence and length of this change, scientists have developed a *geologic time scale*. This scale outlines the development of Earth and of life on Earth.

OBJECTIVES

- **Summarize** how scientists worked together to develop the geologic column.
- **List** the major divisions of geologic time.

KEY TERMS

geologic column
era
period
epoch

The Geologic Column

By studying fossils and applying the principle that old layers of rock are below young layers, 19th-century scientists determined the relative ages of sedimentary rock in different areas around the world. No single area on Earth contained a record of all geologic time. So, scientists combined their observations to create a standard arrangement of rock layers. As shown in the example in **Figure 1,** this ordered arrangement of rock layers is called a **geologic column.** A geologic column represents a timeline of Earth's history. The oldest rocks are at the bottom of the column.

geologic column an ordered arrangement of rock layers that is based on the relative ages of the rocks and in which the oldest rocks are at the bottom

Rock layers in a geologic column are distinguished by the types of rock the layers are made of and by the kinds of fossils the layers contain. Fossils in the upper, more-recent layers resemble modern plants and animals. Most of the fossils in the lower, older layers are of plants and animals that are different from those living today. In fact, many of the fossils discovered in old layers are from species that have been extinct for millions of years.

Reading Check **Where would you find fossils of extinct animals on a geologic column? (See the Appendix for answers to Reading Checks.)**

Figure 1 ▶ By combining observations of rock layers in areas A, B, and C, scientists can construct a geologic column. ***Why is relative position important in determining the ages of rock layers?***

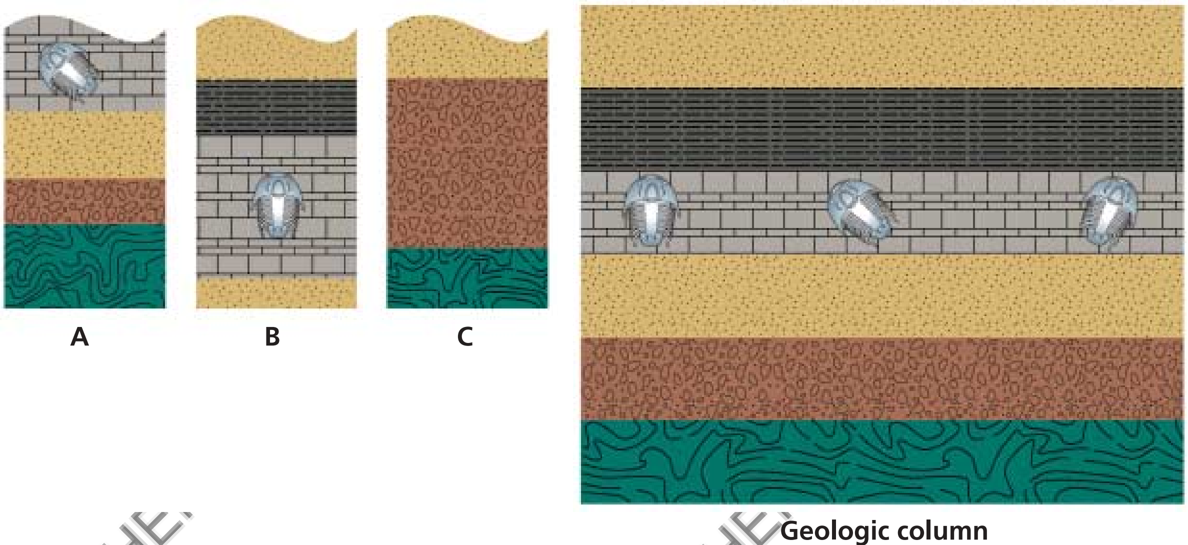

Figure 2 ▶ This scientist is collecting rock samples that contain fossilized fungal spores that date the rock to the Triassic Period.

Using a Geologic Column

When the first geologic columns were being developed, scientists estimated the ages of rock layers by using factors such as the average rates of sediment deposition. The development of radiometric dating methods, however, allowed scientists to determine the absolute ages of rock layers with more accuracy.

Scientists can now use geologic columns to estimate the age of rock layers that cannot be dated radiometrically. To determine the layer's age, scientists compare a given rock layer with a similar layer in a geologic column that contains the same fossils or that has the same relative position. If the two layers match, they likely formed at about the same time. The scientist in **Figure 2** is investigating the ages of sedimentary rocks.

Divisions of Geologic Time

The geologic history of Earth is marked by major changes in Earth's surface, climate, and types of organisms. Geologists use these indicators to divide the geologic time scale into smaller units. Rocks grouped within each unit contain similar fossils. In fact, a unit of geologic time is generally characterized by fossils of a dominant life-form. A simplified geologic time scale is shown in **Table 1**.

Because Earth's history is so long, Earth scientists commonly use abbreviations when they discuss geologic time. For example, Ma stands for *mega-annum,* which means "one million years."

Quick LAB 30 min

Geologic Time Scale

Procedure

1. Copy the table shown at right onto a piece of **paper.**
2. Complete the table by using the scale 1 cm is equal to 10 million years.
3. Lay a **5 m strip of adding-machine paper** flat on a hard surface. Use a **meterstick,** a **metric ruler,** and a **pencil** to mark off the beginning and end of Precambrian time according to the time scale you calculated. Do the same for the three eras. Label each time division, and color each a different color with **colored pencils.**
4. Pick two periods from the geologic time scale. Using the same scale that was used in step 2, calculate the scale length for each period listed. Mark the boundaries of each period on the paper strip, and label the periods on your scale.

Era	Length of time (years)	Scale length
Precambrian	4,058,000,000	
Paleozoic	291,000,000	
Mesozoic	185,500,000	
Cenozoic	65,500,000 (to present)	

5. Decorate your strip by adding names or drawings of the organisms that lived in each division of time.

Analysis

1. When did humans appear? What is the scale length from that period to the present?
2. Add the lengths of the Paleozoic, Mesozoic, and Cenozoic Eras. What percentage of the geologic time scale do these eras combined represent? What percentage of the geologic time scale does Precambrian time represent?

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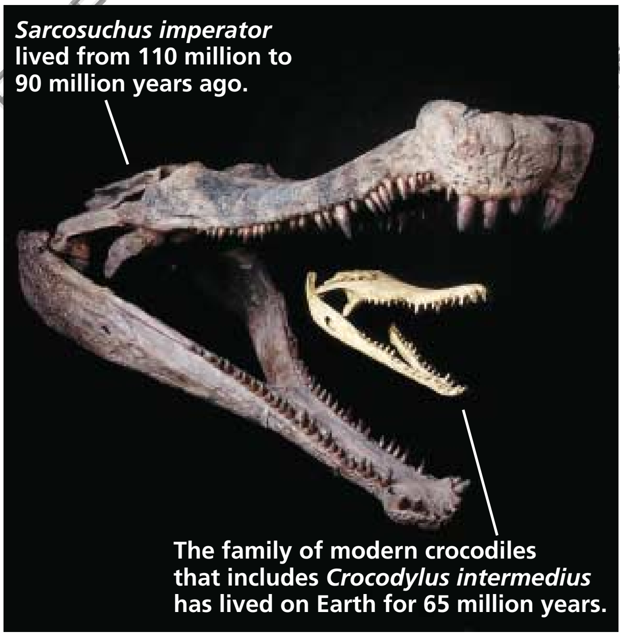

Figure 3 ▶ Crocodilians have lived on Earth for more than two geologic eras without major anatomical changes.

Eons and Eras

The largest unit of geologic time is an *eon*. Geologic time is divided into four eons—the Hadean eon, the Archean eon, the Proterozoic eon, and the Phanerozoic eon. The first three eons of Earth's history are part of a time interval commonly known as *Precambrian time*. This 4 billion year interval contains most of Earth's history. Very few fossils exist in early Precambrian rocks, so dividing Precambrian time into smaller time units is difficult.

After Precambrian time the Phanerozoic eon began. This eon, as well as most eons, is divided into smaller units of geologic time called **eras.** The first era of the Phanerozoic eon was the *Paleozoic Era* which lasted about 292 million years. Paleozoic rocks contain fossils of a wide variety of marine and terrestrial life forms. After the Paleozoic Era, the *Mesozoic Era* began and lasted about 183 million years. Mesozoic fossils include early forms of birds and of reptiles, such as the giant crocodilian shown in **Figure 3.** The present geologic era is the *Cenozoic Era,* which began about 65 million years ago. Fossils of mammals are common in Cenozoic rocks.

era a unit of geologic time that includes two or more periods

period a unit of geologic time that is longer than an epoch but shorter than an era

epoch a subdivision of geologic time that is longer than an age but shorter than a period

Periods and Epochs

Eras are divided into shorter time units called **periods.** Each period is characterized by specific fossils and is usually named for the location in which the fossils were first discovered. Where the rock record is most complete and least deformed, a detailed fossil record may allow scientists to divide periods into shorter time units called **epochs.** Epochs may be divided into smaller units of time called *ages*. Ages are defined by the occurrence of distinct fossils in the fossil record.

Section 1 Review

1. **Summarize** the reasons that many scientists had to work together to develop the geologic column.
2. **Describe** the major events in any one period of geologic time.
3. **Explain** why constructing geologic columns is useful to Earth scientists.
4. **List** the following units of time in order of length from shortest to longest: *year, period, era, eon, age,* and *epoch*.
5. **Name** the three eras of the Phanerozoic Eon, and identify how long each one lasted.
6. **Compare** geologic time with the geologic column.

CRITICAL THINKING

7. **Analyzing Relationships** When a scientist discovers a new type of fossil, what characteristic of the rock around the fossil would he or she want to learn first?
8. **Predicting Consequences** How would our understanding of Earth's past change if a scientist discovered a mammal fossil from the Paleozoic Era?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *geologic time, Precambrian time, Paleozoic Era, Mesozoic Era, Cenozoic Era, period,* and *epoch.*

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Section 2 Precambrian Time and the Paleozoic Era

History is a record of past events. Just as the history of civilizations is written in books, the geologic history of Earth is recorded in rock layers. The types of rock and the fossils that occur in each layer reveal information about the environment when the layer formed. For example, the presence of a limestone layer in a region indicates that the area was once covered by water.

OBJECTIVES

- **Summarize** how evolution is related to geologic change.
- **Identify** two characteristics of Precambrian rock.
- **Identify one** major geologic and two major biological developments during the Paleozoic Era.

KEY TERMS

evolution
Precambrian time
Paleozoic Era

Evolution

Fossils indicate the kinds of organisms that lived when rock formed. By examining rock layers and fossils, scientists have discovered evidence that species of living things have changed over time. Scientists call this process evolution. **Evolution** is the gradual development of new organisms from preexisting organisms. Scientists think that evolution occurs by means of natural selection. Evidence for evolution includes the similarity in skeletal structures of animals, as shown in **Figure 1.** The theory of evolution by natural selection was proposed in 1859 by Charles Darwin, an English naturalist.

evolution a heritable change in the characteristics within a population from one generation to the next; the development of new types of organisms from preexisting types of organisms over time.

Evolution and Geologic Change

Major geologic and climatic changes can affect the ability of some organisms to survive. For example, dramatic changes in sea level greatly affect organisms that live in coastal areas. By using geologic evidence, scientists try to determine how environmental changes affected organisms in the past. The fossil record shows that some organisms survived environmental changes while other organisms disappeared. Scientists use fossils to learn why some organisms survived long periods of time without changing while other organisms changed or became extinct.

Figure 1 ▶ Bones in the front limbs of these animals are similar even though the limbs are used in different ways. Similar structures indicate a common ancestor.

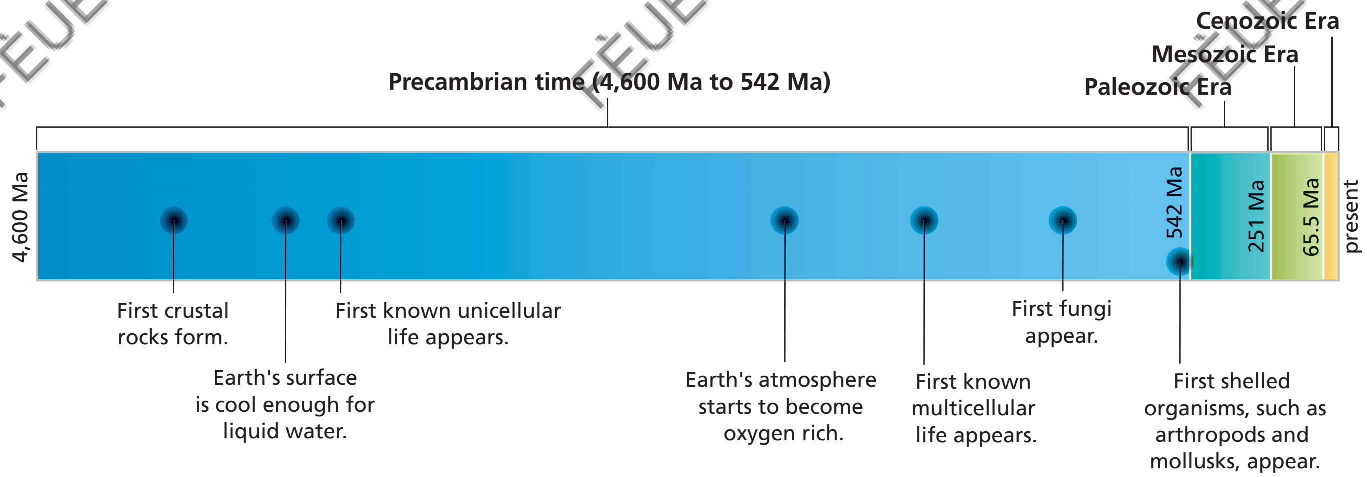


Figure 2 ▶ Precambrian Timeline
How many million years ago did the first unicellular life appear?

Precambrian time the interval of time in the geologic time scale from Earth's formation to the beginning of the Paleozoic era, from 4.6 billion to 542 million years ago

Precambrian Time

Most scientists agree that Earth formed about 4.6 billion years ago as a large cloud, or *nebula,* spun around the newly formed sun. As material spun around the sun, particles of matter began to clump together and eventually formed Earth and the other planets of the solar system. The time interval that began with the formation of Earth and ended about 542 million years ago is known as **Precambrian time.** This division of geologic time makes up about 88% of Earth's history, as shown in **Figure 2.**

Even though Precambrian time makes up such a large part of Earth's history, we know relatively little about what happened during that time. We lack information partly because the Precambrian rock record is difficult to interpret. Most Precambrian rocks have been so severely deformed and altered by tectonic activity that the original order of rock layers is rarely identifiable.

Reading Check **How old is Earth? (See the Appendix for answers to Reading Checks.)**

Connection to BIOLOGY

Natural Selection

In part, evolution occurs through a process called *natural selection*. Natural selection has four basic principles. First, every species produces more offspring than will survive to maturity. Second, individuals in a population are slightly different, and each individual has a unique combination of traits. Third, the environment does not have enough resources to support all of the individuals that are born. Fourth, only individuals that are well suited to the environment are likely to survive and reproduce.

Natural selection ensures that individuals who have better traits for surviving in their environment are more likely to pass those traits to their offspring. One of the assumptions of evolution is that only organisms that can adapt to the environmental changes will survive. Organisms that cannot survive—in other words, those that are unfit to live and reproduce in the changing environment—become extinct.

Because their fur hides them from predators, rabbits that are adapted to survive in the arctic are white. Brown rabbits are adapted to survive in other environments.

Precambrian Rocks

Large areas of exposed Precambrian rocks, called *shields,* exist on every continent. Precambrian shields are the result of several hundred million years of volcanic activity, mountain building, sedimentation, and metamorphism. After they were metamorphosed and deformed, the rocks of North America's Precambrian shield were uplifted and exposed at Earth's surface. Nearly half of the valuable mineral deposits in the world occur in the rocks of Precambrian shields. These valuable minerals include nickel, iron, gold, and copper.

Precambrian Life

Fossils are rare in Precambrian rocks, probably because Precambrian life-forms lacked bones, shells, or other hard parts that commonly form fossils. Also, Precambrian rocks are extremely old. Some date back nearly 3.9 billion years. Over this long period of time, volcanic activity, erosion, and extensive crustal movements, such as folding and faulting, probably destroyed most of the fossils that may have formed during Precambrian time.

Of the few Precambrian fossils that have been discovered, the most common are *stromatolites,* or reeflike deposits formed by blue-green algae. Stromatolites form today in warm, shallow waters, as shown in **Figure 3.** The presence of stromatolite fossils in Precambrian rocks indicates that shallow seas covered much of Earth during periods of Precambrian time. Imprints of marine worms, jellyfish, and single-celled organisms have also been discovered in rocks from late Precambrian Time.

Quick LAB 10 min

Chocolate Candy Survival

Procedure

1. Lay a **piece of colorful cloth** on a table.
2. Randomly sprinkle a handful of **candy-coated chocolate bits** on the cloth.
3. Look away for 1 min.
4. For 10 s, pick up chocolate bits one at a time. Record the colors of candy you picked up.
5. Repeat steps 1–4 with a piece of **colorful cloth that has a different pattern.**

Analysis

1. What colors were you more likely to pick up in the first trial? What about those candies made you pick them up?
2. When you changed the color of the cloth, did you change the color of candies you picked up?
3. How could camouflage help an organism survive?

Figure 3 ▶ Stromatolites, which are mats of blue-green algae, are the most common Precambrian fossils.

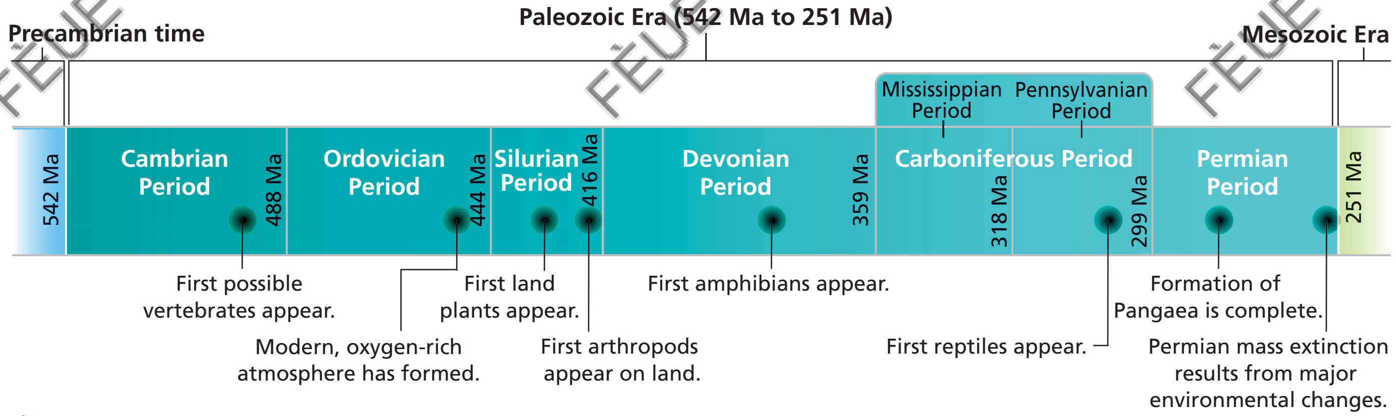


Figure 4 ▶ Paleozoic Timeline

The Paleozoic Era

Paleozoic Era the geologic era that followed Precambrian time and that lasted from 542 million to 251 million years ago

As shown in **Figure 4,** the geologic era that began about 542 million years ago and ended about 251 million years ago is called the **Paleozoic Era.** At the beginning of the Paleozoic Era, Earth's landmasses were scattered around the world. By the end of the Paleozoic Era, these landmasses had collided to form the supercontinent Pangaea. This tectonic activity created new mountain ranges and lifted large areas of land above sea level.

Unlike Precambrian rocks, Paleozoic rocks hold an abundant fossil record. The number of plant and animal species on Earth increased dramatically at the beginning of the Paleozoic Era. Because of this rich fossil record, North American geologists have divided the Paleozoic Era into seven periods.

The Cambrian Period

The Cambrian Period is the first period of the Paleozoic Era. A variety of marine life-forms appeared during this period. These Cambrian life-forms were more advanced than previous life-forms and quickly displaced the primitive organisms as the dominant life-forms. The explosion of Cambrian life may have been partly due to the warm, shallow seas that covered much of the continents during the time period. Marine *invertebrates*, or animals that do not have backbones, thrived in the warm waters. The most common of the Cambrian invertebrates were *trilobites*, such as the one shown in **Figure 5.** Scientists use many trilobites as *index fossils* to date rocks to the Cambrian Period.

The second most common animals of the Cambrian Period were the *brachiopods*, a group of shelled animals. Fossils indicate that at least 15 different families of brachiopods existed during this period. A few kinds of brachiopods exist today, but modern brachiopods are rare. Other common Cambrian invertebrates include worms, jellyfish, snails, and sponges. However, no evidence of land-dwelling plants or animals has been discovered in Cambrian rocks.

Reading Check **Name three common invertebrates from the Cambrian Period. (See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ During the early Paleozoic Era, various types of trilobites, such as this fossilized trilobite from the genus *Moducia,* flourished in the warm, shallow seas.

7606

Figure 6 ▶ During the Silurian Period, eurypterids lived in shallow lagoons. Eurypterids had one pair of legs for swimming and had four or five pairs for walking.

The Ordovician Period

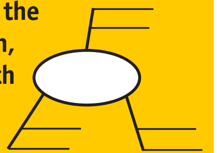
During the Ordovician (AWR duh VISH uhn) Period populations of trilobites began to shrink. Clamlike brachiopods and cephalopod mollusks became the dominant invertebrate life-forms. Large numbers of corals appeared. Colonies of tiny invertebrates called *graptolites* also flourished in the oceans, and primitive fish appeared. By this period, *vertebrates,* or animals that have backbones, had appeared. The most primitive vertebrates were fish. Unlike modern fish, Ordovician fish did not have jaws or teeth and their bodies were covered with thick, bony plates. During the Ordovician Period, as during the Cambrian Period and Precambrian times, there was no plant life on land.

The Silurian Period

Vertebrate and invertebrate marine life continued to thrive during the Silurian Period. Echinoderms, relatives of modern sea stars, and corals became more common. Scorpion-like sea creatures called *eurypterids* (yoo RIP tuhr IDZ), such as the one shown in **Figure 6,** also existed during the Silurian Period. Fossils of giant eurypterids nearly 3 m long have been discovered in western New York. Near the end of this period, the earliest land plants as well as animals, such as scorpions, evolved on land.

Graphic Organizer **Spider Map**

Create the Graphic Organizer entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Periods of the Paleozoic Era." Create a leg for each period in the Paleozoic Era. Then, fill in the map with details about each time period.



The Devonian Period

The Devonian Period is called the *Age of Fishes* because fossils of many bony fishes were discovered in rocks of this period. One type of fish, called a *lungfish,* had the ability to breathe air. Other air-breathing fish, called *rhipidistians,* (RIE puh DIS tee uhnz) had strong fins that may have allowed them to crawl onto the land for short periods of time. The first amphibians, from the genus *Ichthyostega* (IK thee oh STEG uh), probably evolved from rhipidistians. *Ichthyostega,* which resembled huge salamanders, are thought to be the ancestors of modern amphibians such as frogs and toads. During the Devonian Period, land plants, such as giant horsetails, ferns, and cone-bearing plants, also began to develop. In the sea, brachiopods and mollusks continued to thrive.

Figure 7 ▶ During the Carboniferous Period, crinoids, such as the one shown here, were common in the oceans. Crinoids are thought to be ancestors of modern sea stars.

The Carboniferous Period

During the Carboniferous Period, the climate was generally warm, and the humidity was extremely high over most of the world. Forests and swamps covered much of the land. Coal deposits in Pennsylvania, Ohio, and West Virginia are the fossilized remains of these forests and swamps. During this period, the rock in which some major oil deposits occur also formed. *Carboniferous* means "carbon bearing." In North America, the Carboniferous Period is divided into the Mississippian and Pennsylvanian Periods.

Amphibians and fish continued to flourish during the Carboniferous Period. *Crinoids,* like the one shown in **Figure 7,** were common in the oceans. Insects, such as giant cockroaches and dragonflies, were common on land. Toward the end of the Pennsylvanian Period, vertebrates that were adapted to life on land appeared. These early reptiles resembled large lizards.

The Permian Period

The Permian Period marks the end of the Paleozoic Era. A *mass extinction* of a large number of Paleozoic life-forms occurred at the end of the Permian Period. The continents had joined to form the supercontinent Pangaea. The collision of tectonic plates created the Appalachian Mountains. On the northwest side of the mountains, areas of desert and dry savanna climates developed. The shallow inland seas that had covered much of Earth disappeared. As the seas retreated, many species of marine invertebrates, including trilobites and eurypterids, became extinct. However, fossils indicate that reptiles and amphibians survived the environmental changes and dominated Earth in the millions of years that followed the Paleozoic Era.

Section 2 Review

1. **Summarize** how evolution is related to geologic change.
2. **Identify** two characteristics of most Precambrian rocks.
3. **Explain** why fossils are rare in Precambrian rocks.
4. **Identify** one life-form from each of the six periods of the Paleozoic Era.
5. **Explain** why the Devonian Period is commonly called the *Age of Fishes*.
6. **Describe** the kinds of life-forms that became extinct during the mass extinction at the end of the Permian Period.

CRITICAL THINKING

7. **Drawing Conclusions** Identify one way in which the formation of Pangaea affected Paleozoic life.
8. **Identifying Relationships** Why is Precambrian time—about 88% of geologic time—not divided into smaller units based on the fossil record?
9. **Analyzing Processes** Explain two ways in which the geologic record of the Paleozoic Era supports the theory of evolution.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *Paleozoic Era, invertebrate, Cambrian Period, Ordovician Period, vertebrate,* and *Silurian Period.*

Section 3 The Mesozoic and Cenozoic Eras

At the end of the Permian Period, 90% of marine organisms and 78% of land organisms died. This episode during which an enormous number of species died, or **mass extinction,** left many resources available for the surviving life-forms. Because resources and space were readily available, an abundance of new life-forms appeared. These new life-forms evolved, and some flourished while others eventually became extinct.

OBJECTIVES

- **List** the periods of the Mesozoic and Cenozoic Eras.
- **Identify** two major geologic and biological developments during the Mesozoic Era.
- **Identify** two major geologic and biological developments during the Cenozoic Era.

KEY TERMS

mass extinction
Mesozoic Era
Cenozoic Era

The Mesozoic Era

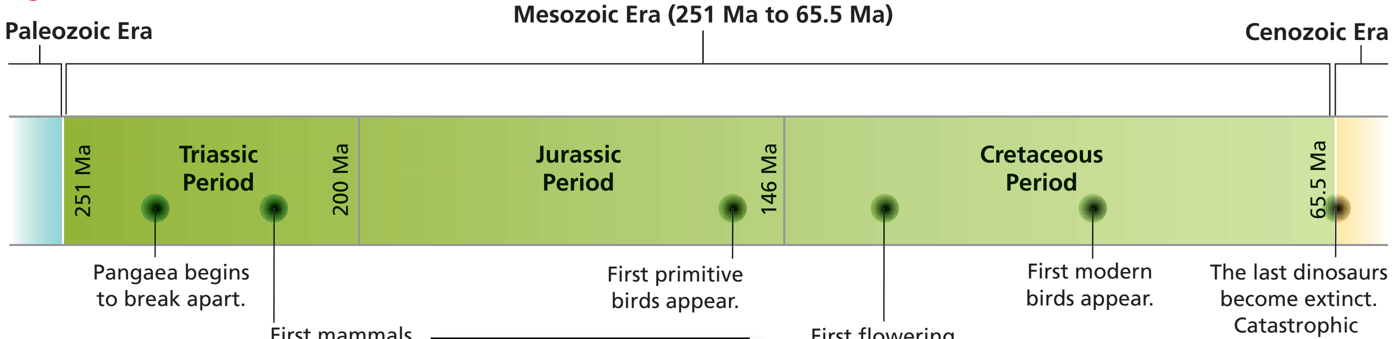
As shown in **Figure 1,** the geologic era that began about 251 million years ago and ended about 65 million years ago is called the **Mesozoic Era.** Earth's surface changed dramatically during the Mesozoic Era. As Pangaea broke into smaller continents, the tectonic plates drifted and collided. These collisions uplifted mountain ranges such as the Sierra Nevada in California and the Andes in South America. Shallow seas and marshes covered much of the land. In general, the climate was warm and humid.

Conditions during the Mesozoic Era favored the survival of reptiles. Lizards, turtles, crocodiles, snakes, and a variety of dinosaurs flourished during the Mesozoic Era. Thus, this era is also known as the *Age of Reptiles*. The Mesozoic Era has a rich fossil record and is divided into three periods.

mass extinction an episode during which large numbers of species become extinct

Mesozoic Era the geologic era that lasted from 251 million to 65.5 million years ago; also called the *Age of Reptiles*

Figure 1 ▶ Mesozoic Timeline



Icthyosaurus lived during the Triassic and Jurassic Periods.

The aerial *Quetzalcoatlus* lived during the Cretaceous Period.

Figure 2 ▶ A group of dinosaurs from the genus *Coelophysis* raced through a Triassic conifer forest in what is now New Mexico.

The Triassic Period

Dinosaurs appeared during the Triassic Period of the Mesozoic Era. Some dinosaurs were the size of squirrels. Others weighed as much as 15 tons and were nearly 30 m long. However, most of the dinosaurs of the Triassic Period were about 4 m to 5 m long and moved very quickly. As shown in **Figure 2,** these dinosaurs roamed through lush forests of cone-bearing trees and *cycads*, which are plants that resemble the palm trees of today.

Reptiles called *ichthyosaurs* lived in the Triassic oceans. New forms of marine invertebrates also evolved. The most distinctive was the ammonite, a type of shellfish that is similar to the modern nautilus. Ammonites serve as Mesozoic index fossils. The first mammals, small rodent-like forest dwellers, also appeared.

The Jurassic Period

Dinosaurs became the dominant life-form during the Jurassic Period. Fossil records indicate that two major groups of dinosaurs evolved. These groups are distinguished by their hip-bone structures. One group, called *saurischians,* or "lizard-hipped" dinosaurs, included herbivores, which are plant eaters, and carnivores, which are meat eaters. Among the largest saurischians were herbivores of the genus *Apatosaurus,* first known as *Brontosaurus*, which weighed up to 50 tons and grew to 25 m long.

The other major group of Jurassic dinosaurs, called *ornithischians,* or "bird-hipped" dinosaurs, were herbivores. Among the best known of the ornithischians were herbivores of the genus *Stegosaurus,* which were about 9 m long and about 3 m tall at the hips. In addition, flying reptiles called *pterosaurs* were common during the Jurassic Period. Like modern bats, pterosaurs flew on skin-covered wings. Fossils of the earliest birds, such as the one shown in **Figure 3,** also occur in Jurassic rocks.

Reading Check **Name two fossils that were discovered in the fossil record of the Jurassic Period. (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ The *Archaeopteryx* (AWR kee AUP tuhr IKS) was one of the first birds that appeared during the Jurassic Period.

Figure 4 ▶ This 41-foot long *Tyrannosaurus rex* was discovered near Faith, South Dakota. This specimen, named Sue, was displayed in the Field Museum in Chicago in 2000.

The Cretaceous Period

Dinosaurs continued to dominate Earth during the Cretaceous Period. Among the most spectacular dinosaurs was the carnivore *Tyrannosaurus rex*, such as the one shown in **Figure 4.** The *Tyrannosaurus rex* stood nearly 6 m tall and had huge jaws with sharp teeth that were up to 15 cm long. Also, among the common Cretaceous dinosaurs were the armored *ankylosaurs,* horned dinosaurs called *ceratopsians,* and duck-billed dinosaurs called *hadrosaurs*.

Plant life had become very sophisticated by the Cretaceous Period. The earliest flowering plants, or *angiosperms,* appeared during this period. The most common of these plants were trees such as magnolias and willows. Later, trees such as maples, oaks, and walnuts became abundant. Angiosperms became so successful that they are the dominant type of land plant today.

The Cretaceous-Tertiary Mass Extinction

The Cretaceous Period ended in another mass extinction. No dinosaur fossils have been found in rocks that formed after the Cretaceous Period. Some scientists believe that this extinction was caused by environmental changes that were the result of the movement of continents and increased volcanic activity.

However, many scientists accept the *impact hypothesis* as the explanation for the extinction of the last dinosaurs. This hypothesis is that about 65 million years ago, a giant meteorite crashed into Earth. The impact of the collision raised enough dust to block the sun's rays for many years. As Earth's climate became cooler, plant life began to die, and many animal species became extinct. As the dust settled over Earth, the dust formed a layer of iridium-laden rock. Iridium is a substance that is uncommon in rocks on Earth but that is common in meteorites.

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Topic: Mass Extinctions
SciLinks code: HQ60916
Topic: Geologic Time Scale
SciLinks code: HQ60669

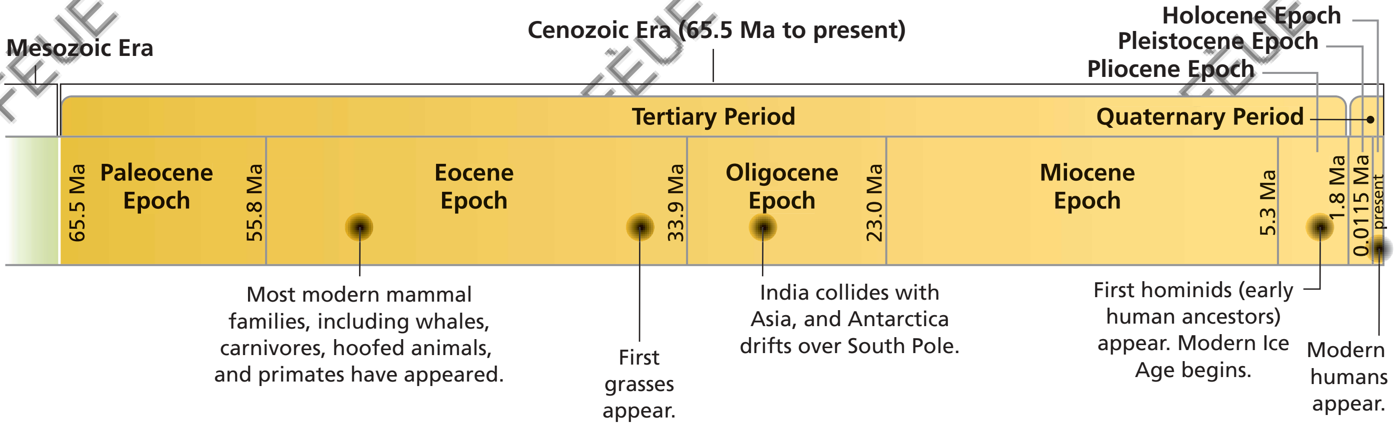

Figure 5 ▶ Cenozoic Timeline

The Cenozoic Era

Cenozoic Era the current geologic era, which began 65.5 million years ago; also called the *Age of Mammals*

As shown in **Figure 5,** the **Cenozoic Era** is the division of geologic time that began about 65 million years ago and that includes the present period. During this era, the continents moved to their present-day positions. As tectonic plates collided, huge mountain ranges, such as the Alps and the Himalayas in Eurasia, formed.

During the Cenozoic Era, dramatic changes in climate have occurred. At times, continental ice sheets covered nearly one-third of Earth's land. As temperatures decreased during the ice ages, new species that were adapted to life in cooler climates appeared. Mammals became the dominant life-form and underwent many changes. The Cenozoic Era is thus commonly called the *Age of Mammals*.

The Quaternary and Tertiary Periods

The Cenozoic Era is divided into two periods. The Tertiary Period includes the time before the last ice age. The Quaternary Period began with the last ice age and includes the present. These periods have been divided into seven epochs. The Paleocene, Eocene, Oligocene, Miocene, and Pliocene Epochs make up the *Tertiary Period*. The Pleistocene and Holocene Epochs make up the *Quaternary Period*.

Figure 6 ▶ The *tarsier* is the sole modern survivor of a group of primates common during the earlier Cenozoic Era. ***Why are mammals better suited to cool climates than reptiles are?***

The Paleocene and Eocene Epochs

The fossil record indicates that during the Paleocene Epoch many new mammals, such as small rodents, evolved. The first primates also evolved during the Paleocene Epoch. A modern survivor of an early primate group is shown in **Figure 6.**

Other mammals, including the earliest known ancestor of the horse, evolved during the Eocene Epoch. Fossil records indicate that the first whales, flying squirrels, and bats appeared during this epoch. Small reptiles continued to flourish. Worldwide, temperatures dropped by about 4°C at the end of the Eocene Epoch.

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The Oligocene and Miocene Epochs

During the Oligocene Epoch, the Indian subcontinent began to collide with the Eurasian continent, which caused the uplifting of the Himalayas. The worldwide climate became significantly cooler and drier. This change in climate favored grasses as well as cone-bearing and hardwood trees. Many early mammals became extinct. However, large species of deer, pigs, horses, camels, cats, and dogs flourished. Marine invertebrates, especially clams and snails, also continued to flourish.

During the Miocene Epoch, circumpolar currents formed around Antarctica, and the modern Antarctic icecap began to form. By the late Miocene Epoch, tectonic forces and dropping sea levels caused the Mediterranean Sea to dry up and refill several times. The largest known land mammals existed during this epoch. Miocene rocks also contain fossils of horses, camels, deer, rhinoceroses, pigs, raccoons, wolves, foxes, and the earliest saber-toothed cats, which are now extinct.

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Topic: Geologic Periods and Epochs
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The Pliocene Epoch

During the Pliocene Epoch, predators—including members of the bear, dog, and cat families—evolved into modern forms. Herbivores, such as the giant ground sloth shown in **Figure 7,** flourished. The first modern horses also appeared in this epoch.

Toward the end of the Pliocene Epoch, dramatic climatic changes occurred, and the continental ice sheets began to spread. With more and more water locked in ice, sea level fell. The Bering land bridge appeared between Eurasia and North America. Changes in Earth's crust between North America and South America formed the Central American land bridge. Various species migrated between the continents across these two major land bridges.

Reading Check **Why did sea level fall in the Pliocene Epoch? (See the Appendix for answers to Reading Checks.)**

Figure 7 ▶ Giant ground sloths lived during the late Pliocene in parts of North America and South America. These slow-moving leaf-eaters could grow as large as an African bull elephant and weigh as much as 5 tons.

Figure 8 ▶ This painting from the Stone Age was made by early humans between 15,000 and 13,000 years ago in a cave in Lascaux, France.

The Pleistocene Epoch

The Pleistocene Epoch began 1.8 million years ago. In Eurasia and North America, ice sheets advanced and retreated several times. Some animals had characteristics that allowed them to endure the cold climate, such as the thick fur that covered woolly mammoths and woolly rhinoceroses. Many other species survived by moving to warmer regions. Some species, such as giant ground sloths and dire wolves, became extinct.

Fossils of the earliest ancestors of modern humans were discovered in Pleistocene sediments. Evidence of more-modern human ancestors, such as the cave painting shown in **Figure 8,** indicates that early humans may have been hunters.

The Holocene Epoch

The Holocene Epoch, which includes the present, began about 11,500 years ago, as the last glacial period ended. As the ice sheets melted, sea level rose about 140 m, and the coastlines took on their present shapes. The North American Great Lakes also formed as the last ice sheets retreated. During the early Holocene Epoch, modern humans (*Homo sapiens*) developed agriculture and began to make and use tools made of bronze and iron.

Human history is extremely brief. If you think of the entire history of Earth as one year, the first multicellular organisms would have appeared in September. The dinosaurs would have disappeared at 8 P.M. on December 26. Modern humans would have would not have appeared until 11:48 P.M. on December 31.

Section 3 Review

1. **List** the periods of the Mesozoic Era, and describe one major life-form in each division.
2. **Identify** two major geologic and two major biological developments of the Mesozoic Era.
3. **List** the periods and epochs of the Cenozoic Era, and describe one major life-form in each division.
4. **Identify** two major geologic and two major biological developments of the Cenozoic Era.
5. **Explain** how the ice ages affected animal life during the Cenozoic Era.
6. **Identify** the era, period, and epoch we are in today.
7. **Describe** the worldwide environmental changes that set the stage for the Age of Mammals.

CRITICAL THINKING

8. **Drawing Conclusions** Explain the criteria scientists may have used for dividing the Cenozoic Era into the Tertiary and Quaternary Periods.
9. **Identifying Relationships** Suppose that you are a geologist who is looking for the boundary between the Cretaceous and Tertiary Periods in an outcrop. What characteristics would you look for to determine the location of the boundary? Explain your answer.

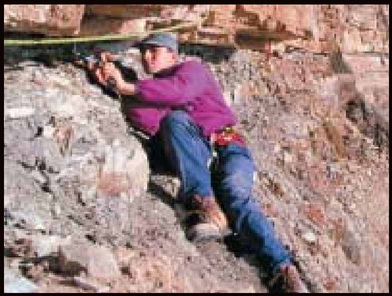
CONCEPT MAPPING

10. Use the following terms to create a concept map: *Mesozoic Era, Age of Reptiles, Jurassic Period, Triassic Period, Cretaceous Period, Cenozoic Era, Age of Mammals, Tertiary Period,* and *Quaternary Period.*

Chapter 9 Highlights

Sections

1 Geologic Time



Key Terms

geologic column, 211
era, 214
period, 214
epoch, 214

Key Concepts

- The geologic column is based on observations of the relative ages of rock layers throughout the world.
- Geologists used major changes in Earth's climate and extinctions recorded in the fossil record to divide the geologic time scale into smaller units.
- Geologic time is subdivided into eons, eras, periods, epochs, and ages.

2 Precambrian Time and the Paleozoic Era

evolution, 215
Precambrian time, 216
Paleozoic Era, 218

- Precambrian rocks may contain valuable minerals but few fossils.
- Evolution is the gradual development of organisms from other organisms. Evidence for the theory of evolution occurs throughout the fossil record.
- The rock record reveals the evolution of marine invertebrates and vertebrates during the Paleozoic Era.

3 The Mesozoic and Cenozoic Eras

mass extinction, 221
Mesozoic Era, 221
Cenozoic Era, 224

- The rock record of the Mesozoic Era reveals an environment that favored the development of reptiles.
- The Mesozoic Era ended with a mass extinction that included the extinction of the dinosaurs.
- The rock record of the Cenozoic Era includes the present period and reveals the rise of mammals as a predominant life-form.

Chapter 9 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *evolution*
2. *geologic column*
3. *period*

For each pair of terms, explain how the meanings of the terms differ.

4. *era* and *epoch*
5. *period* and *era*
6. *Mesozoic Era* and *Cenozoic Era*
7. *Precambrian time* and *Paleozoic Era*

Understanding Key Concepts

8. The geologic time scale is a
   - **a.** scale for weighing rocks.
   - **b.** scale that divides Earth's history into time intervals.
   - **c.** rock record of Earth's past.
   - **d.** collection of the same kind of rocks.

9. Scientists are able to determine the absolute ages of most rock layers in a geologic column by using
   - **a.** the law of superposition.
   - **b.** radiometric dating.
   - **c.** rates of deposition.
   - **d.** rates of erosion.

10. To determine the age of a specific rock, scientists might correlate it with a layer in a geologic column that has the same relative position and
    - **a.** fossil content.
    - **b.** weight.
    - **c.** temperature.
    - **d.** density.

11. Geologic periods can be divided into
    - **a.** eras.
    - **b.** epochs.
    - **c.** days.
    - **d.** months.

12. Precambrian time ended about
    - **a.** 4.6 billion years ago.
    - **b.** 542 million years ago.
    - **c.** 65 million years ago.
    - **d.** 25 thousand years ago.

13. The most common fossils that occur in Precambrian rocks are
    - **a.** graptolites.
    - **b.** trilobites.
    - **c.** eurypterids.
    - **d.** stromatolites.

14. The first vertebrates appeared during
    - **a.** Precambrian time.
    - **b.** the Paleozoic Era.
    - **c.** the Mesozoic Era.
    - **d.** the Cenozoic Era.

15. The *Age of Reptiles* is the name commonly given to
    - **a.** Precambrian time.
    - **b.** the Paleozoic Era.
    - **c.** the Mesozoic Era.
    - **d.** the Cenozoic Era.

16. The first flowering plants appeared during the
    - **a.** Cretaceous Period.
    - **b.** Triassic Period.
    - **c.** Carboniferous Period.
    - **d.** Ordovician Period.

17. The *Age of Mammals* is the name commonly given to
    - **a.** Precambrian time.
    - **b.** the Paleozoic Era.
    - **c.** the Mesozoic Era.
    - **d.** the Cenozoic Era.

Short Answer

18. Write a short paragraph that describes the evolution of plants that is indicated by the fossil record.

19. Describe the events that may have led to the Cretaceous-Tertiary mass extinction. What evidence have scientists discovered that supports their hypothesis?

20. Describe the criteria that scientists use to divide a geologic column into different layers.

21. Identify two organisms that are found in the fossil record of a different geologic era but that are still living on Earth today. Identify what characteristic(s) have given them their long-term success.

Critical Thinking

22. **Analyzing Ideas** Why can Precambrian time not be divided into periods by using fossils?

23. **Applying Ideas** Many coal and oil deposits formed during the Carboniferous Period. What element would you expect to find in both oil and coal?

24. **Identifying Relationships** What information in the geologic record might lead scientists to infer that shallow seas covered much of Earth during the Paleozoic Era?

25. **Making Comparisons** Compare the causes of the Permian mass extinction with those of the Cretaceous mass extinction.

Concept Mapping

26. Use the following terms to create a concept map: *geologic time, Paleozoic Era, Mesozoic Era, stromatolite, Precambrian time, eurypterid, crinoid, Cenozoic Era, trilobite, saurischian, ornithischian, dinosaur, mammal,* and *human*.

Math Skills

27. **Scientific Notation** Write the beginning and end dates of each geologic era in scientific notation.

28. **Making Calculations** The Methuselah tree in California is 4.6×10^3 years old. How many times older than this tree is Earth ?

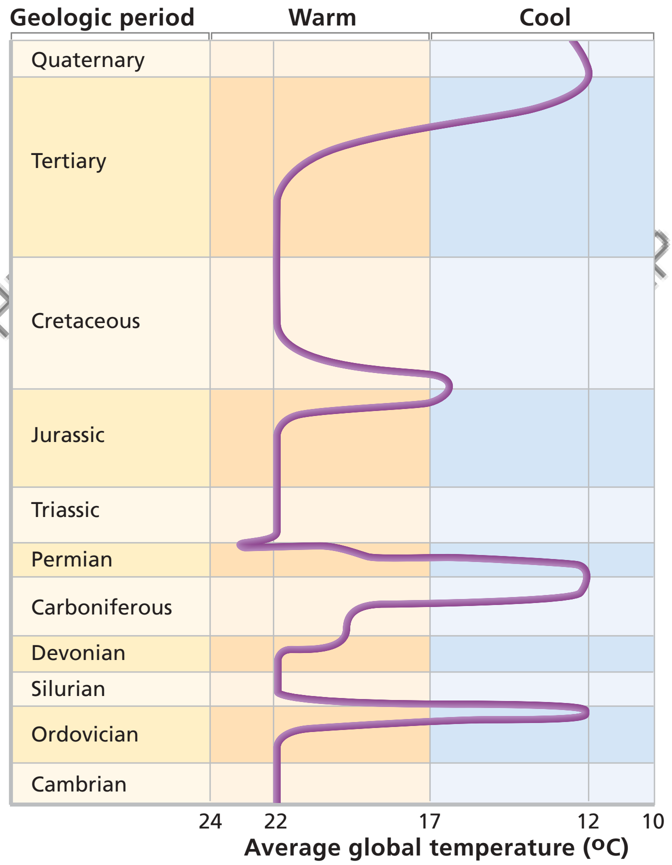
Writing Skills

29. **Creative Writing** Write an essay about a trip back in time that includes descriptions of the organisms that lived during one of the geologic periods described in this chapter.

30. **Writing from Research** Research the discoveries made by British anthropologists Louis S. B. Leakey and Mary Leakey in Olduvai Gorge in Tanzania, Africa. Write a report about your findings.

Interpreting Graphics

The graph below shows average global temperatures since Precambrian time. Use this graph to answer the questions that follow.



31. During which two periods were Earth's average global temperature the highest?

32. During which periods did Earth's average global temperature decrease?

33. Based on the graph, could climate change have caused the Permian mass extinction? Is climate change a likely cause of the mass extinction at the Cretaceous-Tertiary boundary? Explain your answer.

Chapter 9 Standardized Test Prep

Understanding Concepts

Directions (1–4): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Dinosaurs first became the dominant life-forms during which geologic period?
- **A.** Quaternary Period
- **B.** Jurassic Period
- **C.** Triassic Period
- **D.** Cretaceous Period

2 Pangaea broke into separate continents during
- **F.** the Paleozoic Era
- **G.** the Mesozoic Era
- **H.** the Cenozoic Era
- **I.** Precambrian time

3 Why are fossils rarely found in Precambrian rock?
- **A.** Most Precambrian organisms did not have hard body parts that commonly form fossils.
- **B.** Precambrian rock is buried too deeply for geologists to study it.
- **C.** Most Precambrian organisms were too small to leave fossil remains.
- **D.** Precambrian rock is made of a material that prevented the formation of fossils.

4 Which of the following statements describes a principle of natural selection?
- **F.** The environment has more than enough resources to support all of the individuals that are born in a given ecosystem.
- **G.** Only individuals well-suited to the environment are likely to survive and reproduce.
- **H.** Individuals in a healthy population are identical and have the same traits.
- **I.** Most species produce plentiful offspring that will all live until maturity and reproduce.

Directions (5–7): **For *each* question, write a short response.**

5 What is the term for the largest unit of geologic time?

6 What is the term for the gradual development of organisms from other organisms by means of natural selection?

7 Why is the Cenozoic Era also known as the Age of the Mammals?

Reading Skills

Directions (8–11): **Read the passage below. Then, answer the questions below on a separate sheet of paper.**

The Discovery of a Dinosaur

In 1995, paleontologist Paul Sereno was working in a previously unexplored region of Morocco when his team made an astounding discovery—an enormous dinosaur skull. The skull was nearly 1.6 m long. Given the size of the skull, Sereno concluded that the skeleton of the animal that it came from must have been about 14 m long—about as long as a full-sized school bus. The dinosaur was even larger than the *Tyrannosaurus rex.* The newly discovered dinosaur was thought to be 90 million years old. It most likely chased other dinosaurs by running on large, powerful hind legs, and its bladelike teeth must have meant certain death for its prey.

8 Which of the following is evidence that the dinosaur described in the passage above was most likely a predator?
- **A.** It had sharp, bladelike teeth.
- **B.** It had a large skeleton and powerful hind legs used for running.
- **C.** It was found next to the bones of a smaller animal.
- **D.** It was more than 90 million years old.

9 What types of information do you think that fossilized teeth provide about an organism?
- **F.** the color of its skin
- **G.** the types of food it ate
- **H.** the speed at which it ran
- **I.** the mating habits it had

10 According to the passage, which of the following statements is true?
- **A.** This dinosaur was most likely a predator.
- **B.** This skull belonged to a large Tyrannosaurus rex.
- **C.** This dinosaur had powerful arms.
- **D.** This dinosaur ate mainly plants and berries.

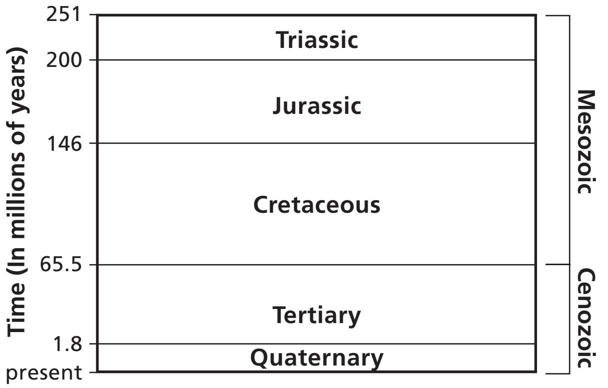
11 What are some methods that scientists might have used to determine that the age of the dinosaur skull was 90 million years old?

Interpreting Graphics

***Directions (12–15):* For *each* question below, record the correct answer on a separate sheet of paper.**

The timeline below shows the time divisions of the Mesozoic and Cenozoic eras. Use this timeline to answer questions 12 through 14.

The Mesozoic and Cenozoic Eras



12 Human civilization developed during which of the following periods of time?

A. Triassic Period
B. Jurassic Period
C. Tertiary Period
D. Quaternary Period

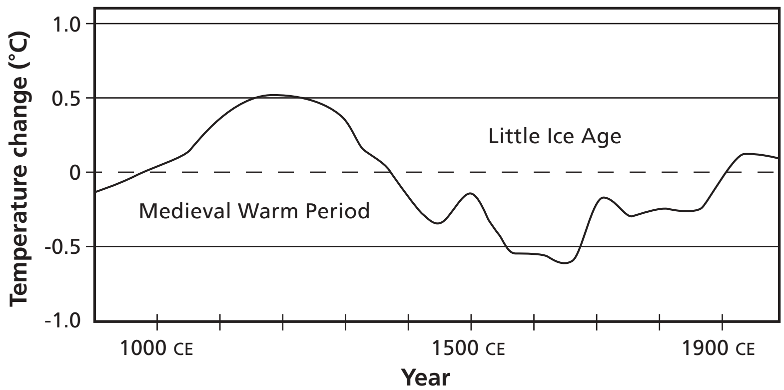
13 If Earth formed aboutd 4.6 billion years ago, what percentage of Earth's total history did the Cenozoic period fill?

F. about 1.5%
G. about 10.5%
H. about 15%
I. about 50%

14 Which event coincides with the start of the Cenozoic Era?

The graph below shows data on global temperature changes during the last millennium. Use this graph to answer question 15.

The Medieval Warm Period and the Little Ice Age



15 How do you think the temperature changes during the Little Ice Age of the Middle Ages affected the freezing and thawing of global waters? Explain your answer.

Test TIP

Simply keeping a positive attitude during any test will help you focus on the test and likely improve your score.

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Chapter 9 Skills Practice Lab

Objectives

- **Apply** the law of superposition to sample rock columns.
- **Demonstrate** the use of index fossils in determining relative and absolute ages.
- **Evaluate** the usefulness of different methods used for determining relative and absolute age.

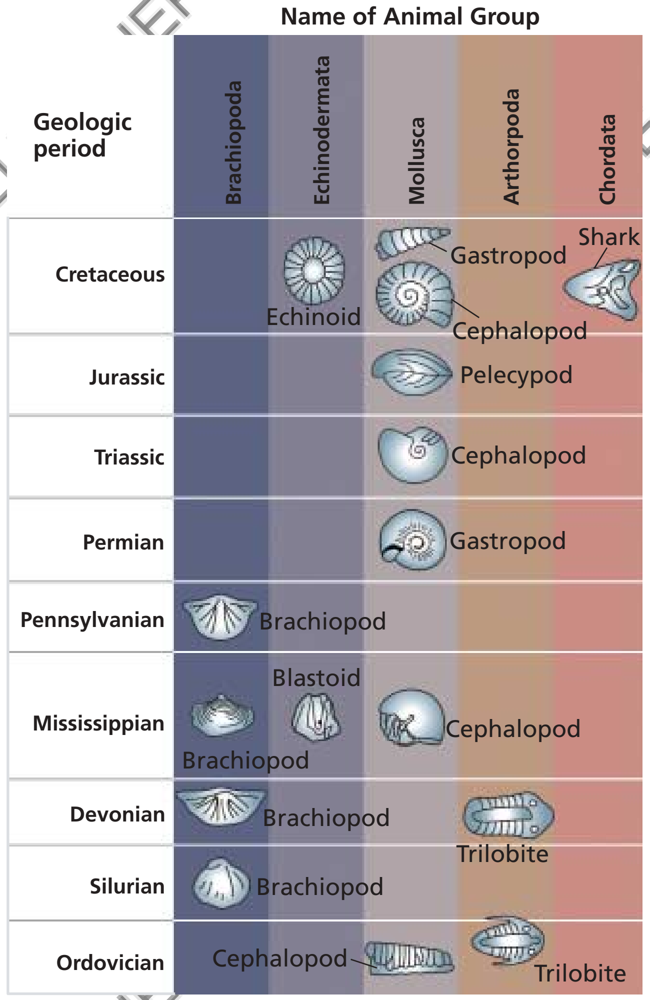
Materials

paper
pencil

History in the Rocks

Geologists have discovered much about the geologic history of Earth by studying the arrangement of fossils in rock layers, as well as by studying the arrangement of the rock layers themselves. Fossils provide clues about the environment in which the organism that formed the fossil existed. Scientists can determine the age of the rocks in which fossils occur because the ages of many fossils have been determined by radiometric dating of associated igneous rocks. Radiometric dating, fossil age, and rock arrangement are all used to determine changes that have occurred in the arrangement of the rock layers through geologic time. In this lab, you will discover how the geologic history of an area can be determined by examining the arrangement of fossils and rock layers.

Figure A



PROCEDURE

1. Study the index fossils shown in **Figure A.** Note their placement in related groups and the geologic periods in which they lived.
2. Select one of the four fossil arrangements shown in **Figure B.** This figure shows how some of these fossils may occur in a series of rock layers. Record the number of the arrangement that you are using.
3. Using **Figure A,** identify all the fossils in your arrangement and the geologic time in which the organisms that formed the fossils lived.
4. List the fossil names in order from bottom to top.
5. Do the fossils in your arrangement appear in the order of geologic time?
6. Do the fossils in your arrangement show a complete sequence of geologic periods? If not, which periods are missing?
7. Repeat steps 2–6 with each of the other three fossil arrangements.

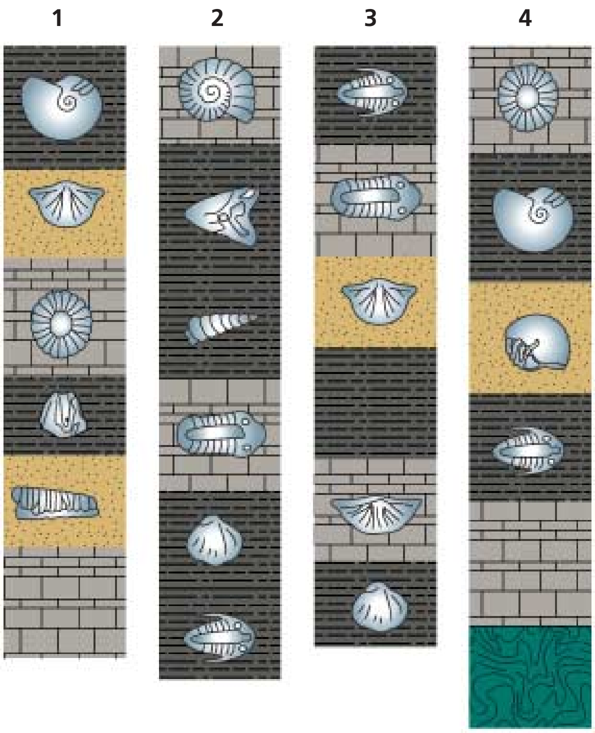


Figure B

ANALYSIS AND CONCLUSION

1. **Analyzing Processes** What processes or events might explain the order in which each of the fossil arrangements was found?

2. **Evaluating Assumptions** Based on your observations in the procedure, why is it necessary that a fossil be found in a wide variety of geographic areas to be considered an index fossil?

3. **Explaining Events** Study arrangement 3 in **Figure B.** Note that there is a rock layer that contains no fossils between two rock layers that contain fossils. How might this have occurred?

Extension

1. **Examining Data** Collect fossils in your area. Identify the fossils you have collected, and describe what your area was like when the organisms existed.

2. **Research** Find out how index fossils are used to help petroleum geologists locate oil reservoirs. Then, use that information to give an oral report to your class.

MAPS in Action

Fossil Evidence for Gondwanaland

Map Skills Activity

This map shows areas where selected fossils have been found. Use the map to answer the questions below.

1. **Using the Key** On which continents have fossils from ferns of the genus *Glossopteris* been found?
2. **Using the Key** On which continents have fossils of organisms from the genus *Lystrosaurus* been found?
3. **Making Comparisons** Which fossil shown on the map was spread over the smallest area?
4. **Inferring Relationships** Based on the map, what continents were connected to Africa when the continents formed a supercontinent?
5. **Inferring Relationships** Based on the map, what continents were connected to Antarctica when the continents formed a supercontinent?
6. **Analyzing Relationships** How would you argue against a claim that ferns from the genus *Glossopteris* evolved independently on separate continents or were transported between continents that were not connected? Explain your answer.
7. **Identifying Trends** If the continents were to continue the motion they have had since the time the continents formed Gondwanaland, would you expect the east coast of South America and the west coast of Africa to be moving closer together or farther apart? Explain your answer.

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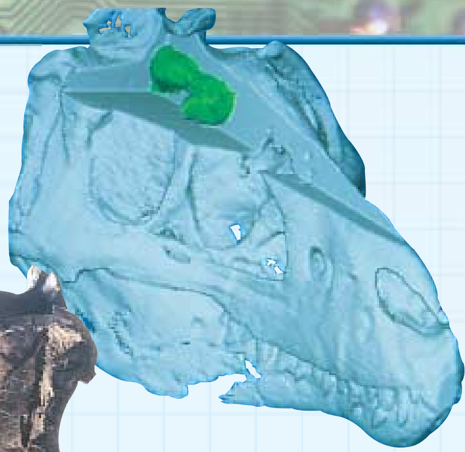
SCIENCE AND TECHNOLOGY

CT Scanning Fossils

Paleontologists studying dinosaur bones want to learn as much as possible from the fossils they find. However, scientists often have to destroy a fossil to look inside it.

▼ This fossil is the skull of a *Nanotyrannus lancensis.*



▲ This CT image shows the size and location of the dinosaur's brain.

The Price of Discovery

Usually, paleontologists examine the inside of a fossil by grinding away the specimen layer by layer. Unfortunately, by the time all of the fossil's internal structures are revealed, the specimen is completely destroyed.

Sectioning a fossil by layers also takes a lot of time. Scientists must carefully document each fresh surface because it will be destroyed later to uncover the next surface. Scientists record their observations by measuring, drawing, photographing, and making an imprint of each new surface.

New Uses for Technology

But now, some paleontologists can use *computerized axial tomography,* or CT scanning, to examine certain fossils without destroying them. CT scanning was originally developed for diagnosing illnesses in people. A CT scanner bombards an object with X rays from all angles within a single plane. The scanner measures the absorption of this radiation to create a map of the different densities within the object. Denser areas absorb more of the X rays' energy and appear white or light gray. Less dense areas appear dark gray or black. Once the object has been scanned in one plane, it is moved less than a millimeter and another scan is performed. This process is repeated until the entire object has been scanned. A computer imaging program then assembles the cross sections into a picture that can be viewed from any angle.

CT scanning allows scientists to study some extremely fragile fossils that cannot be studied by using traditional methods. It also allows scientists to study rare or unique fossils that must be preserved. Using CT scans, paleontologists can study the interior of fossils in a much less destructive way and in much less time.

◀ High-resolution CT scanners provide unparalleled views of the internal structures of fossils.

Extension

1. **Making Comparisons** Research another use of CT scans. Write a brief report about your findings.

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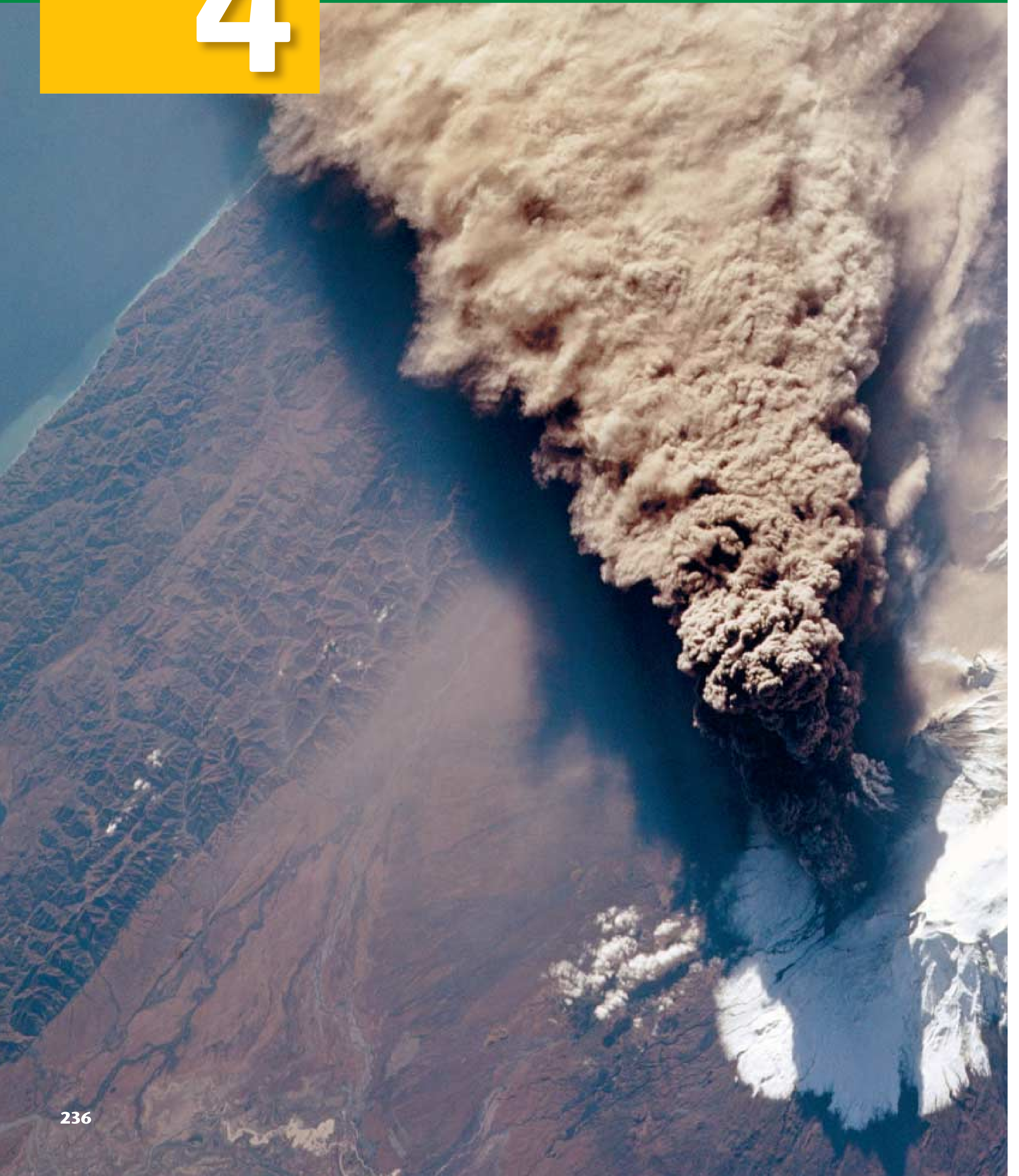
Unit 4 THE DYNAMIC EARTH



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Unit 4 Outline

CHAPTER 10
Plate Tectonics

CHAPTER 11
Deformation of the Crust

CHAPTER 12
Earthquakes

CHAPTER 13
Volcanoes

▶ This photo was taken from the space shuttle *Endeavor* as Russia's Kliuchevskoi volcano erupted on September 30, 1994. The volcanic cloud reached 60,000 ft into the atmosphere, and wind carried the ash as far as 640 mi from the volcano.

Chapter 10 Plate Tectonics

Sections

1. Continental Drift
2. The Theory of Plate Tectonics
3. The Changing Continents

What You'll Learn

- How scientists developed the theory of plate tectonics
- Why tectonic plates move
- How Earth's geography has changed

Why It's Relevant

Understanding why and how tectonic plates move provides a basis for understanding other concepts of Earth science.

PRE-READING ACTIVITY

FOLDNOTES

Tri-Fold Before you read this chapter, create the FoldNote entitled "TriFold" described in the Skills Handbook section of the Appendix. Write what you know about plate tectonics in the column labeled "Know." Then, write what you want to know in the column labeled "Want." As you read the chapter, write what you learn in the column labeled "Learn."

▶ The island of Iceland is being torn into two pieces as two tectonic plates pull apart. Iceland is one of only a few places on Earth where this process can be seen on land.

Section 1 Continental Drift

One of the most exciting recent theories in Earth science began with observations made more than 400 years ago. As early explorers sailed the oceans of the world, they brought back information about new continents and their coastlines. Mapmakers used the information to chart the new discoveries and to make the first reliable world maps.

As people studied the maps, they were impressed by the similarity of the continental shorelines on either side of the Atlantic Ocean. The continents looked as though they would fit together like parts of a giant jigsaw puzzle. The east coast of South America, for example, seemed to fit perfectly into the west coast of Africa, as shown in **Figure 1.**

OBJECTIVES

- **Summarize** Wegener's hypothesis of continental drift.
- **Describe** the process of sea-floor spreading.
- **Identify** how paleomagnetism provides support for the idea of sea-floor spreading.
- **Explain** how sea-floor spreading provides a mechanism for continental drift.

KEY TERMS

continental drift
mid-ocean ridge
sea-floor spreading
paleomagnetism

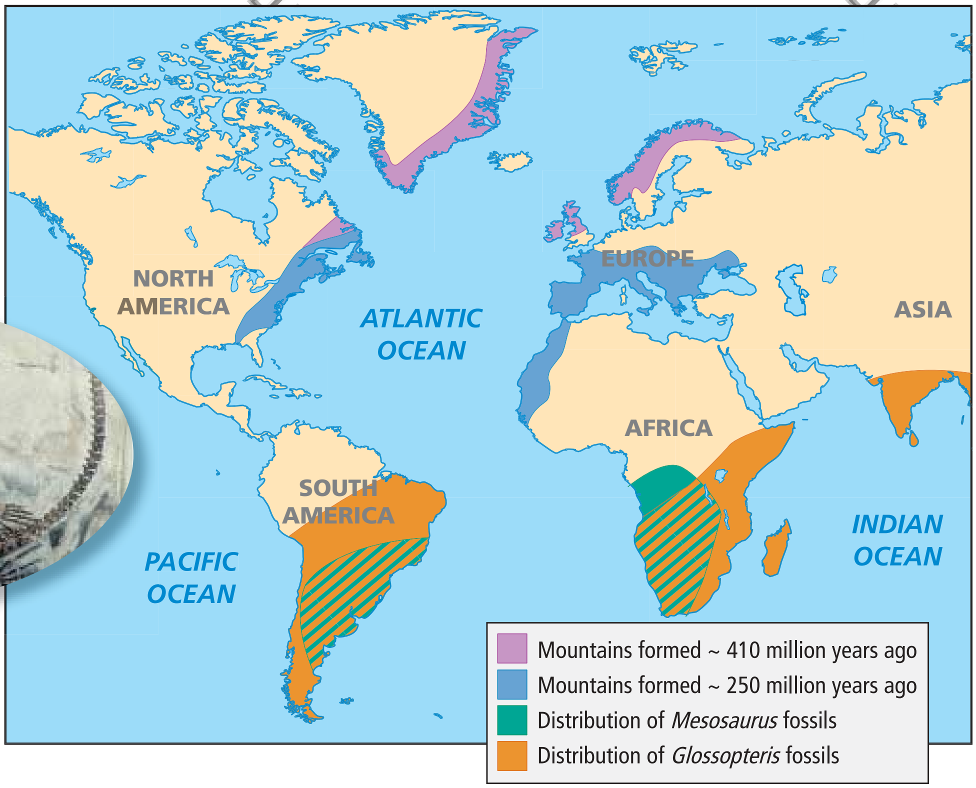
Wegener's Hypothesis

In 1912, a German scientist named Alfred Wegener (VAY guh nuhr) proposed a hypothesis that is now called **continental drift.** Wegener hypothesized that the continents once formed part of a single landmass called a *supercontinent*. According to Wegener, this supercontinent began breaking up into smaller continents about 250 million years ago (during the Mesozoic Era). Over millions of years, these continents drifted to their present locations. Wegener speculated that the crumpling of the crust in places may have produced mountain ranges such as the Andes on the western coast of South America.

continental drift the hypothesis that states that the continents once formed a single landmass, broke up, and drifted to their present locations

Figure 1 ▶ Early explorers noticed that the coastlines of Africa and South America could fit together like puzzle pieces. ***Can you identify any other continents that could fit together like puzzle pieces?***

Figure 2 ▶ Fossils of *Mesosaurus*, such as the one shown below, were found in both South America and western Africa. Mountain chains of similar ages also exist on different continents, as shown in the map at right.



Fossil Evidence

In addition to seeing the similarities in the coastlines of the continents, Wegener found other evidence to support his hypothesis. He reasoned that if the continents had once been joined, fossils of the same plants and animals should be found in areas that had once been connected. Wegener knew that identical fossils of *Mesosaurus,* a small, extinct land reptile, had been found in both South America and western Africa. *Mesosaurus,* a fossil of which is shown in **Figure 2,** lived 270 million years ago (during the Paleozoic Era). Wegener knew that it was unlikely that these reptiles had swum across the Atlantic Ocean. He also saw no evidence that land bridges had once connected the continents. So, he concluded that South America and Africa had been joined at one time in the past.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Continental Drift
SciLinks code: HQ60351

Evidence from Rock Formations

Geologic evidence also supported Wegener's hypothesis of continental drift. The ages and types of rocks in the coastal regions of widely separated areas, such as western Africa and eastern South America, matched closely. Mountain chains that ended at the coastline of one continent seemed to continue on other continents across the ocean, as shown in **Figure 2.** The Appalachian Mountains, for example, extend northward along the eastern coast of North America, and mountains of similar age and structure are found in Greenland, Scotland, and northern Europe. If the continents are assembled into a model supercontinent, the mountains of similar age fit together in continuous chains.

ic Evidence

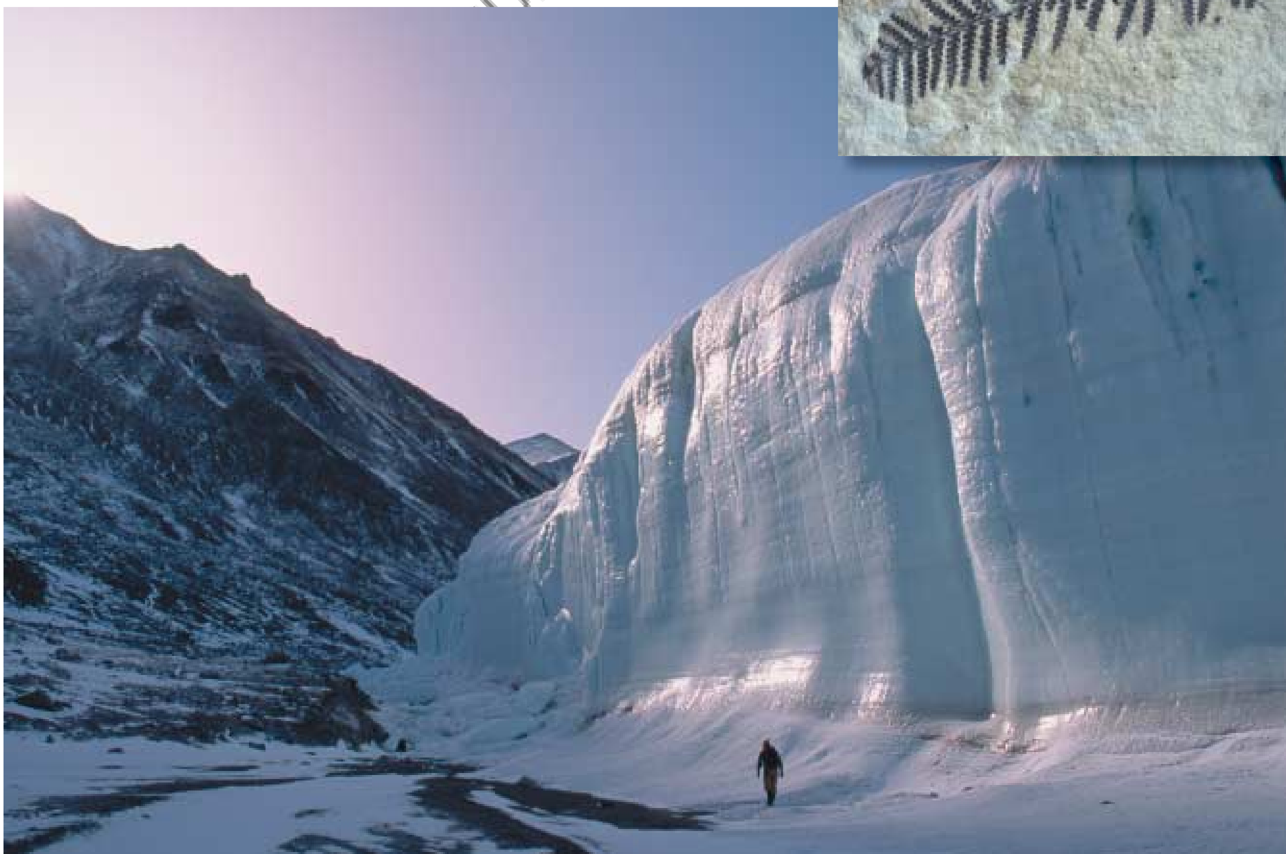
; in climatic patterns also suggest that the continents ›t always been located where they are now. Geologists ·ed layers of debris from ancient glaciers in southern nd South America. Today, those areas have climates that warm for glaciers to form. Other fossil evidence—such lant fossil shown in **Figure 3**—indicated that tropical or ical swamps covered areas that now have much colder ;. Wegener suggested that if the continents were once nd positioned differently, evidence of climatic differences e easy to explain.

ɟ Mechanisms

the evidence that supports the hypothesis of continental egener's ideas were strongly opposed. Other scientists of ɛ rejected the mechanism by which Wegener proposed : continents moved. Wegener suggested that the conti- owed through the rock of the ocean floor. However, this s easily disproved by geologic evidence. Wegener spent of his life searching for a mechanism that would gain c consensus. Unfortunately, Wegener died in 1930 before ified a plausible explanation.

ɟ Check Why did many scientists reject Wegener's sis of continental drift? (See the Appendix for answers ng Checks.)

Figure 3 ▶ The climate of Antarctica was not always as harsh and cold as it is today. When the plant that became this fossil lived, the climate of Antarctica was warm and tropical.



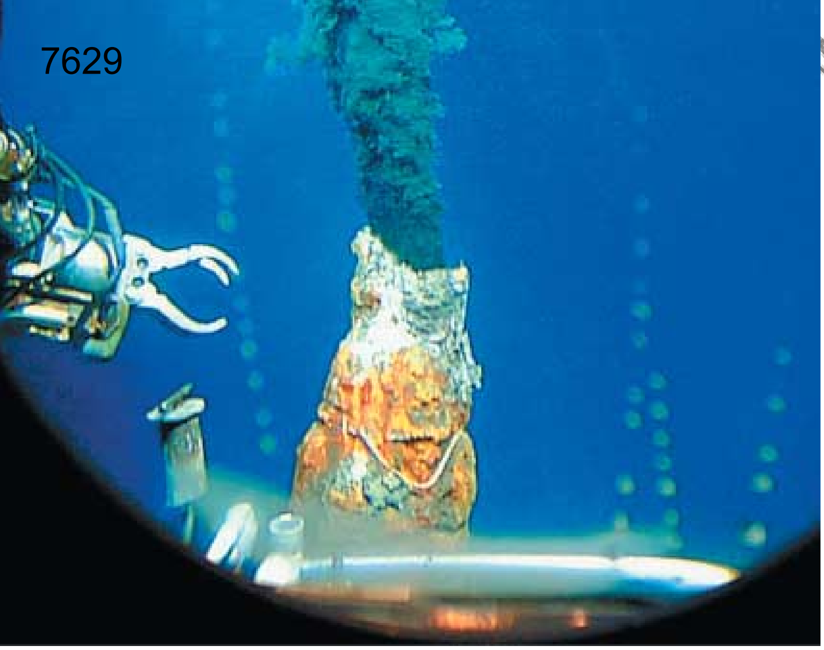


Figure 4 ▶ Black smokers are vents on the sea floor that form as hot, mineral-rich water rushes from the hot rock at mid-ocean ridges and mixes with the surrounding cold ocean water. This photo was taken from a submersible.

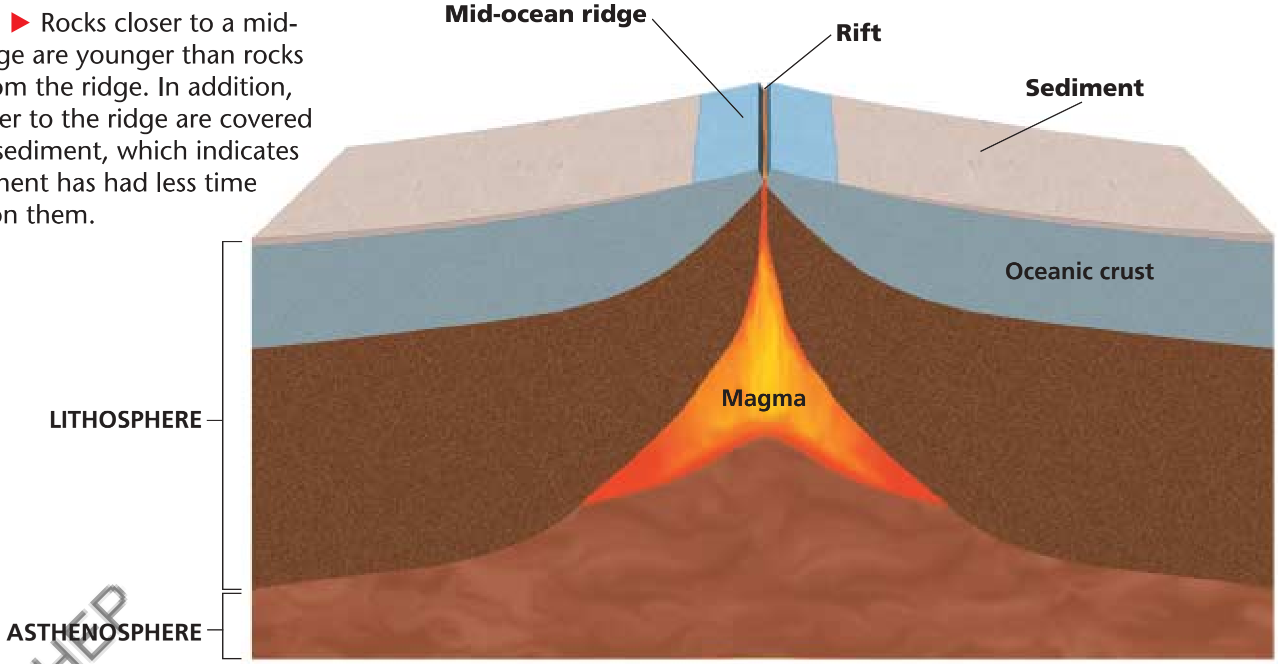
Mid-Ocean Ridges

The evidence that Wegener needed to support his hypothesis was discovered nearly two decades after his death. The evidence lay on the ocean floor. In 1947, a group of scientists set out to map the Mid-Atlantic Ridge. The Mid-Atlantic Ridge is part of a system of **mid-ocean ridges,** which are undersea mountain ranges through the center of which run steep, narrow valleys. A special feature of mid-ocean ridges is shown in **Figure 4.** While studying the Mid-Atlantic Ridge, scientists noticed two surprising trends. First, they noticed that the sediment that covers the sea floor is thinner closer to a ridge than it is farther from the ridge, as shown in **Figure 5.** This evidence suggests that sediment has been settling on the sea floor farther from the ridge for a longer time than it has been settling near the ridge. Scientists then examined the remains of tiny ocean organisms found in the sediment to date the sediment. The distribution of these organisms showed that the closer the sediment is to a ridge, the younger the sediment is. This evidence indicates that rocks closer to the ridge are younger than rocks farther from the ridge.

Second, scientists learned that the ocean floor is very young. While rocks on land are as old as 3.8 billion years, none of the oceanic rocks are more than 175 million years old. Radiometric dating also showed evidence that sea-floor rocks closer to a mid-ocean ridge are younger than sea-floor rocks farther from a ridge.

mid-ocean ridge a long, undersea mountain chain that has a steep, narrow valley at its center, that forms as magma rises from the asthenosphere, and that creates new oceanic lithosphere (sea floor) as tectonic plates move apart

Figure 5 ▶ Rocks closer to a mid-ocean ridge are younger than rocks farther from the ridge. In addition, rocks closer to the ridge are covered with less sediment, which indicates that sediment has had less time to settle on them.



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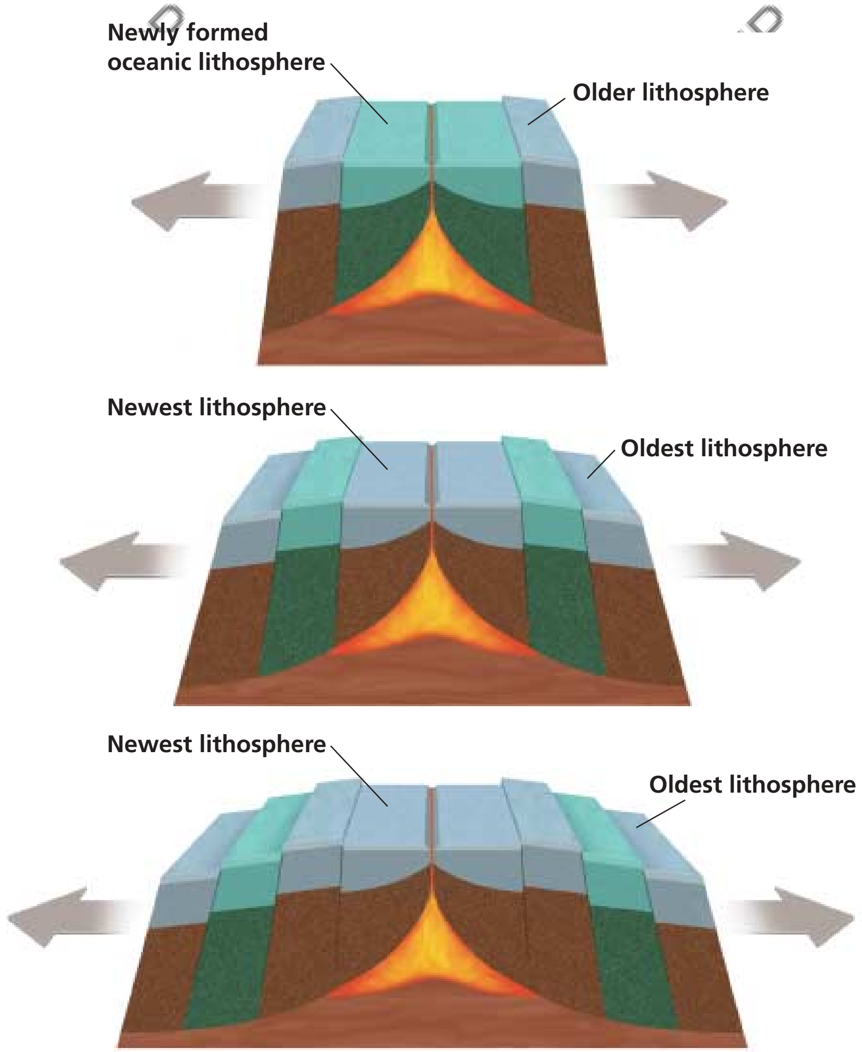
Sea-Floor Spreading

In the late 1950s, a geologist named Harry Hess suggested a new hypothesis. He proposed that the valley at the center of the ridge was a crack, or *rift,* in Earth's crust. At this rift, molten rock, or *magma*, from deep inside Earth rises to fill the crack. As the ocean floor moves away from the ridge, rising magma cools and solidifies to form new rock that replaces the ocean floor. This process is shown in **Figure 6.** Robert Dietz, another geologist, named this process by which new ocean lithosphere (sea floor) forms as magma rises to Earth's surface and solidifies at a mid-ocean ridge as **sea-floor spreading.** Hess suggested that if the ocean floor is moving, the continents might be moving, too. Hess thought that sea-floor spreading was the mechanism that Wegener had failed to find.

Still, Hess's ideas were only hypotheses. More evidence for sea-floor spreading would come years later, in the mid-1960s. This evidence would be discovered through **paleomagnetism,** the study of the magnetic properties of rocks.

Reading Check **How does new sea floor form? (See the Appendix for answers to Reading Checks.)**



sea-floor spreading the process by which new oceanic lithosphere (sea floor) forms as magma rises to Earth's surface and solidifies at a mid-ocean ridge

paleomagnetism the study of the alignment of magnetic minerals in rock, specifically as it relates to the reversal of Earth's magnetic poles; also the magnetic properties that rock acquires during formation

Graphic Organizer **Chain-of-Events Chart**

Create the Graphic Organizer entitled "Chain-of-Events Chart" described in the Skills Handbook section of the Appendix. Then, fill in the chart with details about each step of sea-floor spreading.

Figure 6 ▶ As the ocean floor spreads apart at a mid-ocean ridge, magma rises to fill the rift and then cools to form new rock. As this process is repeated over millions of years, new sea floor forms.

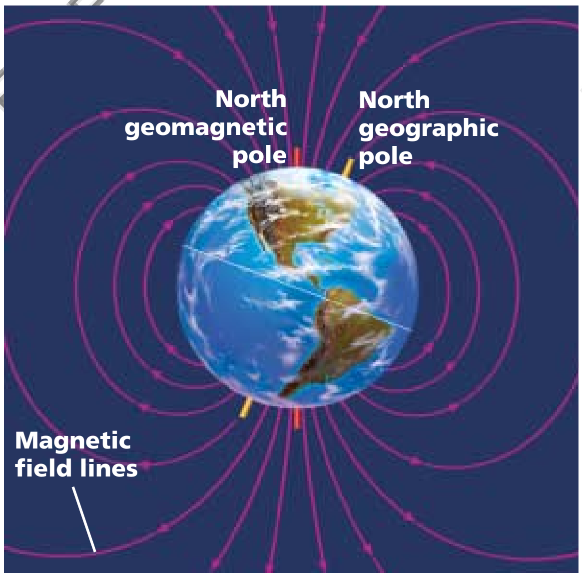


Figure 7 ▶ Earth acts as a giant magnet because of currents in Earth's core.

Paleomagnetism

If you have ever used a compass to determine direction, you know that Earth acts as a giant magnet. Earth has north and south geomagnetic poles, as shown in **Figure 7.** The compass needle aligns with the field of magnetic force that extends from one pole to the other.

As magma solidifies to form rock, iron-rich minerals in the magma align with Earth's magnetic field in the same way that a compass needle does. When the rock hardens, the magnetic orientation of the minerals becomes permanent. This residual magnetism of rock is called *paleomagnetism*.

Magnetic Reversals

Geologic evidence suggests that Earth's magnetic field has not always pointed north, as it does now. Scientists have discovered rocks whose magnetic orientations point opposite of Earth's current magnetic field. Scientists have dated rocks of different magnetic polarities. All rocks with magnetic fields that point north, or *normal polarity,* are classified in the same time periods. All rocks with magnetic fields that point south, or *reversed polarity,* also fell into specific time periods. When scientists placed these periods of normal and reverse polarity in chronological order, they discovered a pattern of alternating normal and reversed polarity in the rocks. Scientists used this pattern to create the *geomagnetic reversal time scale*.

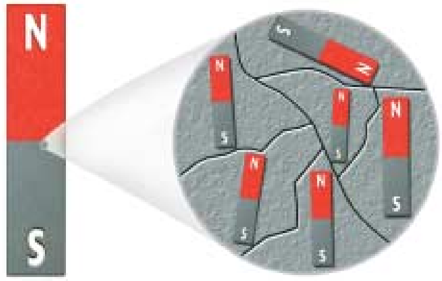
Connection to PHYSICS

What Makes Materials Magnetic?

Some materials are magnetic, while others are not. So, what makes a material magnetic? All matter is composed of atoms. In atoms, electrons are the negatively charged particles that move around the nucleus. The motion of electrons in an atom produces magnetic fields that can give the atom a north pole and a south pole.

In most materials, the magnetic fields of individual atoms are not aligned, so the materials are not magnetic. However, in some materials, such as the iron in some rocks, the atoms group together in tiny regions called *domains*. The atoms in a domain are arranged so that the north and south poles of the atoms are aligned to create a stronger magnetic field than that of a single atom. If most of the domains in an object are also aligned, their magnetic fields combine to make the whole object magnetic.

If the domains in an object are randomly arranged, the magnetic fields of individual domains cancel each other out and the object does not have magnetic properties.



If most of the domains in an object are aligned, the magnetic fields of individual domains combine to make the object magnetic.

Magnetic Symmetry

As scientists were learning about the age of the sea floor, they also were finding puzzling magnetic patterns on the ocean floor. The scientists used the geomagnetic reversal time scale to help them unravel the mystery of these magnetic patterns.

Scientists noticed that the striped magnetic pattern on one side of a mid-ocean ridge is a mirror image of the striped pattern on the other side of the ridge. These patterns are shown in **Figure 8.** When drawn on maps of the ocean floor, these patterns showed alternating bands of normal and reversed polarity that match the geomagnetic reversal time scale. Scientists suggested that as new sea floor forms at a mid-ocean ridge, the new sea floor records reversals in Earth's magnetic field.

By matching the magnetic patterns on each side of a mid-ocean ridge to the geomagnetic reversal time scale, scientists could assign ages to the sea-floor rocks. The scientists found that the ages of sea-floor rocks were also symmetrical. The youngest rocks were at the center, and older rocks were farther away on either side of the ridge. The only place on the sea floor that new rock forms is at the rift in a mid-ocean ridge. Thus, the patterns indicate that new rock forms at the center of a ridge and then moves away from the center in opposite directions. Thus, the symmetry of magnetic patterns—and the symmetry of ages of sea-floor rocks—supports Hess's idea of sea-floor spreading.

Reading Check **How are magnetic patterns in sea-floor rock evidence of sea-floor spreading? (See the Appendix for answers to Reading Checks.)**

QuickLAB 10 min

Making Magnets

Procedure

1. Slide one end of a **bar magnet** down the side of a **5 inch iron nail** 10 times. Always slide the magnet in the same direction.
2. Hold the nail over a small pile of **steel paperclips.** Record what happens.
3. Slide the bar magnet back and forth 10 times down the side of the nail. Repeat step 2.

Analysis

1. What was the effect of sliding the magnet down the nail in one direction? in different directions?
2. How does this lab demonstrate the idea of domains?

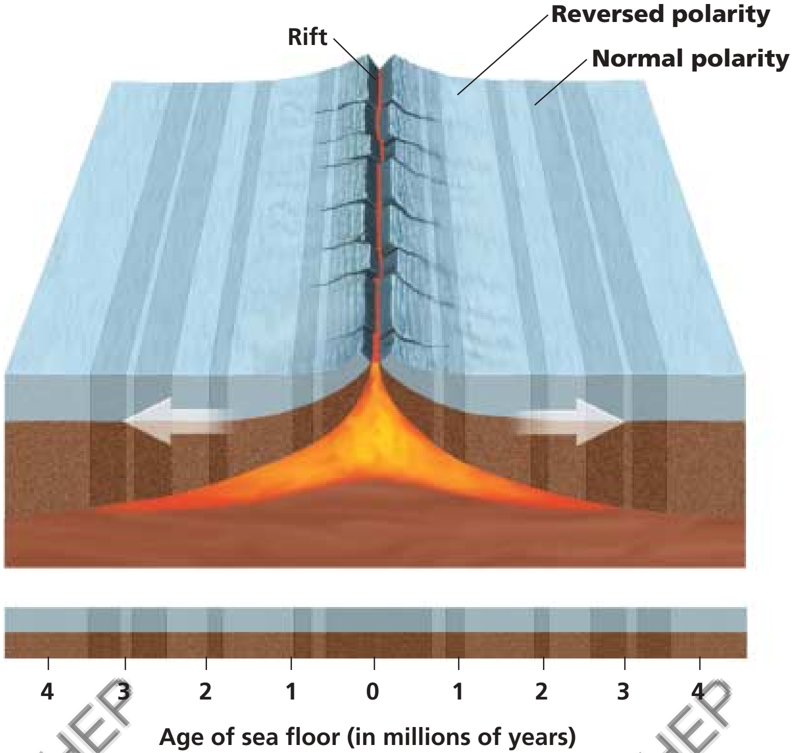


Figure 8 ▶ The stripes in the sea floor shown here illustrate Earth's alternating magnetic field. Dark stripes represent normal polarity, while the lighter stripes represent reversed polarity. ***What is the polarity of the rocks closest to the rift?***

Figure 9 ▶ Scientists collected samples of these sedimentary rocks in California and used the magnetic properties of the samples to date the rocks by using the geomagnetic reversal time scale.

Wegener Redeemed

Another group of scientists discovered that the reversal patterns seen in rocks on the sea floor also appeared in rocks on land, such as those shown in **Figure 9.** The reversals in the land rocks matched the geomagnetic reversal time scale. Because the same pattern occurs in rocks of the same ages on both land and the sea floor, scientists became confident that magnetic patterns show changes over time. Thus, the idea of sea-floor spreading gained further favor in the scientific community.

Scientists reasoned that sea-floor spreading provides a way for the continents to move over Earth's surface. Continents are carried by the widening sea floor in much the same way that objects are moved by a conveyer belt. The molten rock from a rift cools, hardens, and then moves away in the opposite direction on both sides of the ridge. Here, at last, was the mechanism that verified Wegener's hypothesis of continental drift.

Section 1 Review

1. **Describe** the observation that first led to Wegener's hypothesis of continental drift.
2. **Summarize** the evidence that supports Wegener's hypothesis.
3. **Compare** sea-floor spreading and the formation of mid-ocean ridges.
4. **Explain** how scientists know that Earth's magnetic poles have reversed many times during Earth's history.
5. **Identify** how magnetic symmetry can be used as evidence of sea-floor spreading.
6. **Explain** how scientists date sea-floor rocks.

CRITICAL THINKING

7. **Making Inferences** How does evidence that sea-floor rocks farther from a ridge are older than rocks closer to the ridge support the idea of sea-floor spreading?
8. **Analyzing Ideas** Explain how sea-floor spreading provides an explanation for how continents may move over Earth's surface.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *continental drift, paleomagnetism, fossils, climate, sea-floor spreading, geologic evidence, supercontinent,* and *mid-ocean ridge.*

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Section 2 The Theory of Plate Tectonics

By the 1960s, evidence supporting continental drift and sea-floor spreading led to the development of a theory called *plate tectonics*. **Plate tectonics** is the theory that explains why and how continents move and is the study of the formation of features in Earth's crust.

How Continents Move

Earth's crust and the rigid, upper part of the mantle form a layer of Earth called the **lithosphere.** The lithosphere forms the thin outer shell of Earth. It is broken into several blocks, called *tectonic plates,* that ride on a deformable layer of the mantle called the *asthenosphere* in much the same way that blocks of wood float on water. The **asthenosphere** (as THEN uh sfir) is a layer of "plastic" rock just below the lithosphere. Plastic rock is solid rock that is under great pressure and that flows very slowly, like putty does. **Figure 1** shows what tectonic plates may look like.

Earth's crust is classified into two types—*oceanic crust* and *continental crust*. Oceanic crust is dense and is made of rock that is rich in iron and magnesium. Continental crust has a low density and is made of rock that is rich in silica. Tectonic plates can include continental crust, oceanic crust, or both. The continents and oceans are carried along on the moving tectonic plates in the same way that passengers are carried by a bus.

OBJECTIVES

- **Summarize** the theory of plate tectonics.
- **Identify** and describe the three types of plate boundaries.
- **List** and describe three causes of plate movement.

KEY TERMS

plate tectonics
lithosphere
asthenosphere
divergent boundary
convergent boundary
transform boundary

plate tectonics the theory that explains how large pieces of the lithosphere, called *plates,* move and change shape

lithosphere the solid, outer layer of Earth that consists of the crust and the rigid upper part of the mantle

asthenosphere the solid, plastic layer of the mantle beneath the lithosphere; made of mantle rock that flows very slowly, which allows tectonic plates to move on top of it

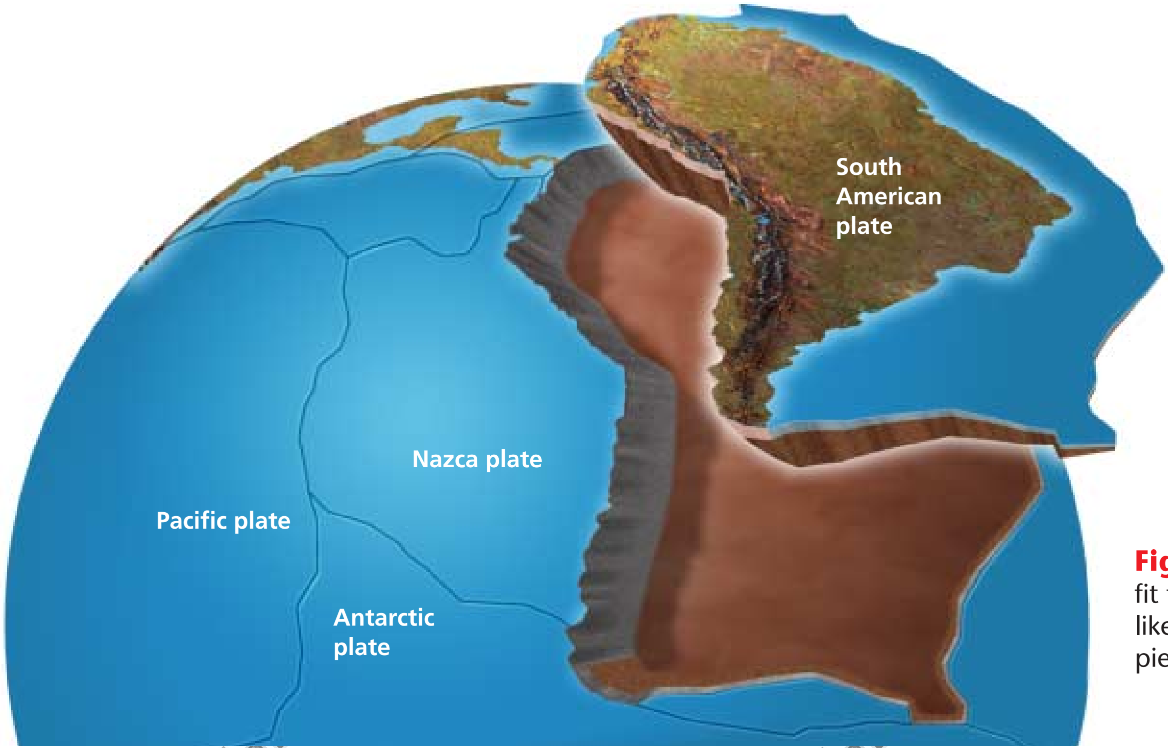


Figure 1 ▶ Tectonic plates fit together on Earth's surface like three-dimensional puzzle pieces.

MATHPRACTICE

The Rate of Plate Movement Tectonic plates move slowly on Earth's surface. The rate of plate movement can be calculated by using the following equation:

$$rate = \frac{distance}{time}$$

In kilometers, how far would a plate that moves 4 cm per year move in 2 million years?

Tectonic Plates

Scientists have identified about 15 major tectonic plates. While many plates are bordered by major surface features, such as mountain ranges or deep trenches in the oceans, the boundaries of the plates are not always easy to identify. As shown in **Figure 2**, the familiar outlines of the continents and oceans do not always match the outlines of plate boundaries. Some plate boundaries are located within continents far from mountain ranges.

Earthquakes

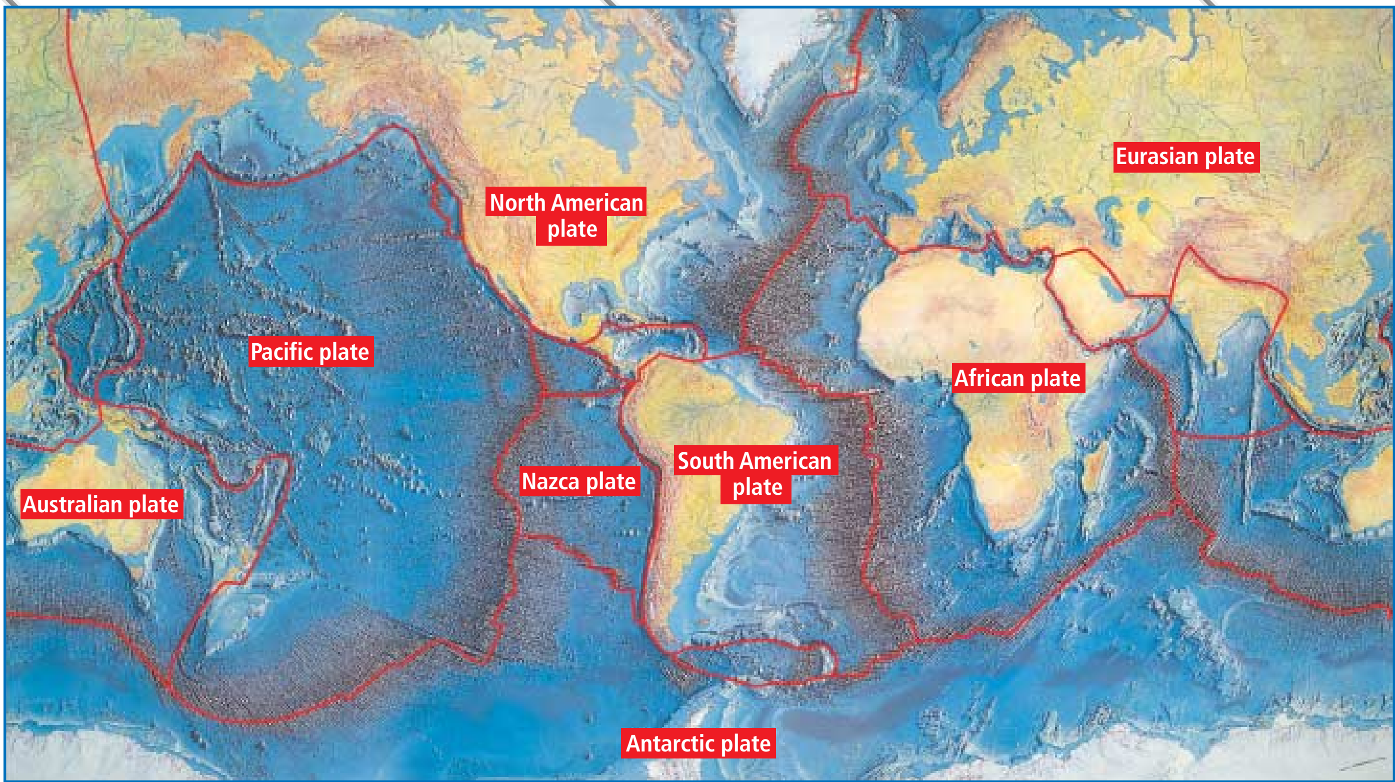
Scientists identify plate boundaries primarily by studying data from earthquakes. When tectonic plates move, sudden shifts can occur along their boundaries. These sudden movements are called *earthquakes*. Frequent earthquakes in a given zone are evidence that two or more plates may meet in that area.

Volcanoes

The locations of volcanoes can also help identify the locations of plate boundaries. Some volcanoes form when plate motions generate magma that erupts on Earth's surface. For example, the Pacific Ring of Fire is a zone of active volcanoes that encircles the Pacific Ocean. This zone is also one of Earth's major earthquake zones. The characteristics of this zone indicate that the Pacific Ocean is surrounded by plate boundaries.

Reading Check **How do scientists identify locations of plate boundaries? (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Tectonic plates may contain both oceanic and continental crust. Notice that the boundaries of plates do not always match the outlines of continents.



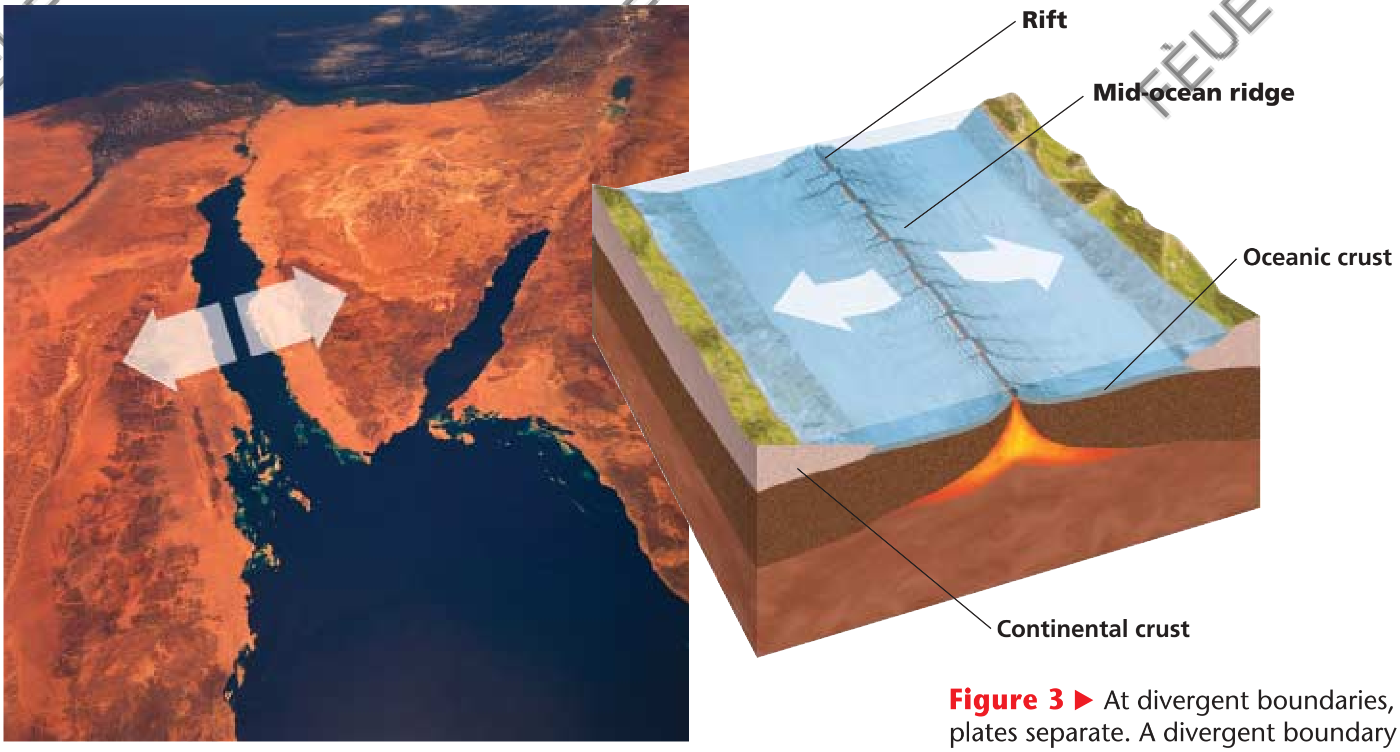


Figure 3 ▶ At divergent boundaries, plates separate. A divergent boundary exists in the Red Sea between the Arabian Peninsula and Africa.

Types of Plate Boundaries

Some of the most dramatic changes in Earth's crust, such as earthquakes and volcanic eruptions, happen along plate boundaries. Plate boundaries may be in the middle of the ocean floor, around the edges of continents, or even within continents. There are three types of plate boundaries. These plate boundaries are divergent boundaries, convergent boundaries, and transform boundaries. Each plate boundary is associated with a characteristic type of geologic activity.

Divergent Boundaries

The way that plates move relative to each other determines how the plate boundary affects Earth's surface. At a **divergent boundary,** two plates move away from each other. A divergent boundary is illustrated in **Figure 3.**

divergent boundary the boundary between tectonic plates that are moving away from each other

At divergent boundaries, magma from the asthenosphere rises to the surface as the plates move apart. The magma then cools to form new oceanic lithosphere. The newly formed rock at the ridge is warm and light. This warm, light rock is elevated above the surrounding sea floor and forms an undersea mountain range known as a *mid-ocean ridge*. Along the center of a mid-ocean ridge is a *rift valley,* a narrow valley that forms where the plates separate.

Most divergent boundaries are located on the ocean floor. However, rift valleys may also form where continents are separated by plate movement. For example, the Red Sea occupies a huge rift valley formed by the separation of the African plate and the Arabian plate, as shown in **Figure 3.**

Convergent Boundaries

convergent boundary the boundary between tectonic plates that are colliding

As plates pull apart at one boundary, they push into neighboring plates at other boundaries. **Convergent boundaries** are boundaries that form where two plates collide.

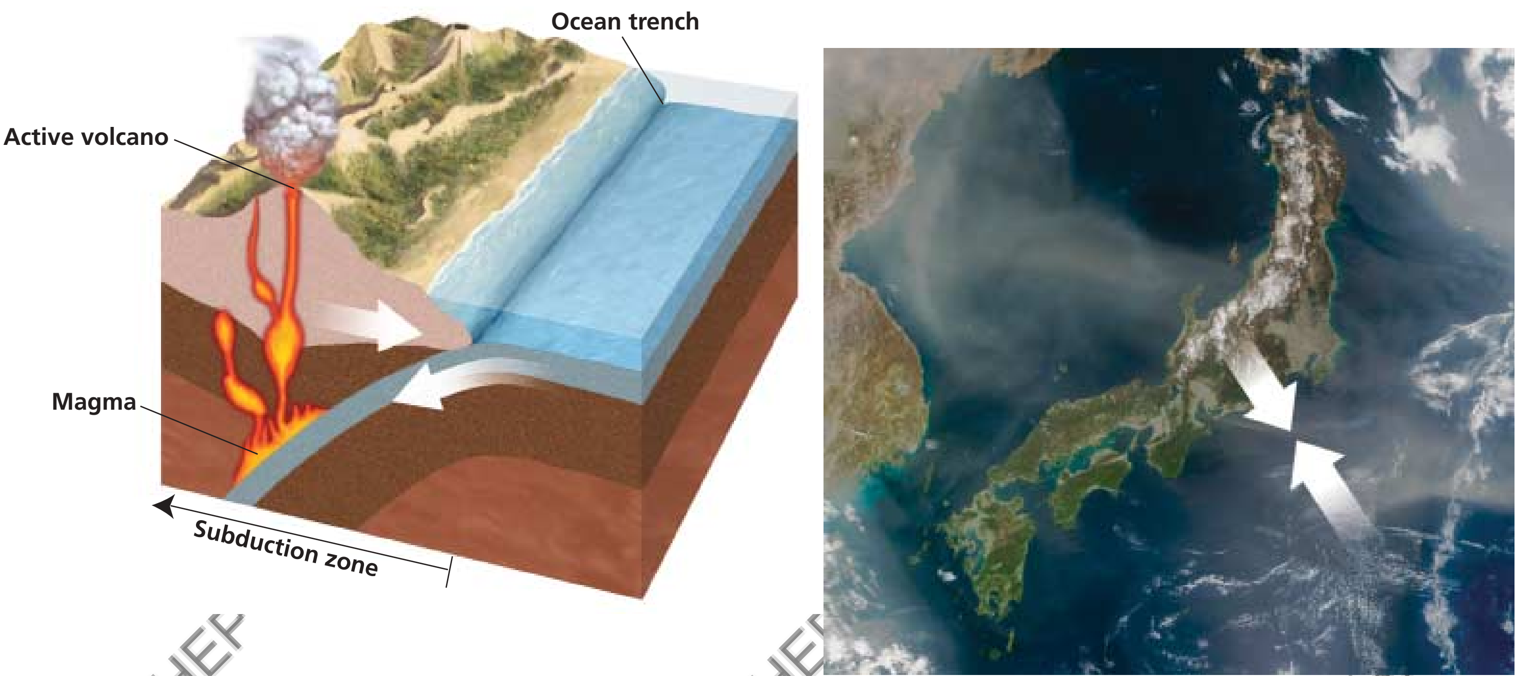
Three types of collisions can happen at convergent boundaries. One type happens when oceanic lithosphere collides with continental lithosphere, as shown in **Figure 4.** Because oceanic lithosphere is denser, it *subducts,* or sinks, under the less dense continental lithosphere. The region along a plate boundary where one plate moves under another plate is called a *subduction zone.* Deep-ocean trenches form at subduction zones. As the oceanic plate subducts, it heats up and releases fluids into the mantle above it. The addition of these fluids causes material in the overlying mantle to melt to form magma. The magma rises to the surface and forms volcanic mountains.

A second type of collision happens when two plates made of continental lithosphere collide. In this type of collision, neither plate subducts because neither plate is dense enough to subduct under the other plate. Instead, the colliding edges crumple and thicken, which causes uplift that forms large mountain ranges. The Himalaya Mountains formed in this type of collision.

The third type of collision happens between two plates that are made of oceanic lithosphere. One plate subducts under the other plate, and a deep-ocean trench forms. Fluids released from the subducted plate cause mantle rock to melt and form magma. The magma rises to the surface to form an *island arc,* which is a chain of volcanic islands. Japan is an example of an island arc.

Reading Check **Describe the three types of collisions that happen at convergent boundaries. (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ Plates collide at convergent boundaries. The islands of Japan are formed by the subduction of the Pacific plate and the Philippine plate under the Eurasian plate.



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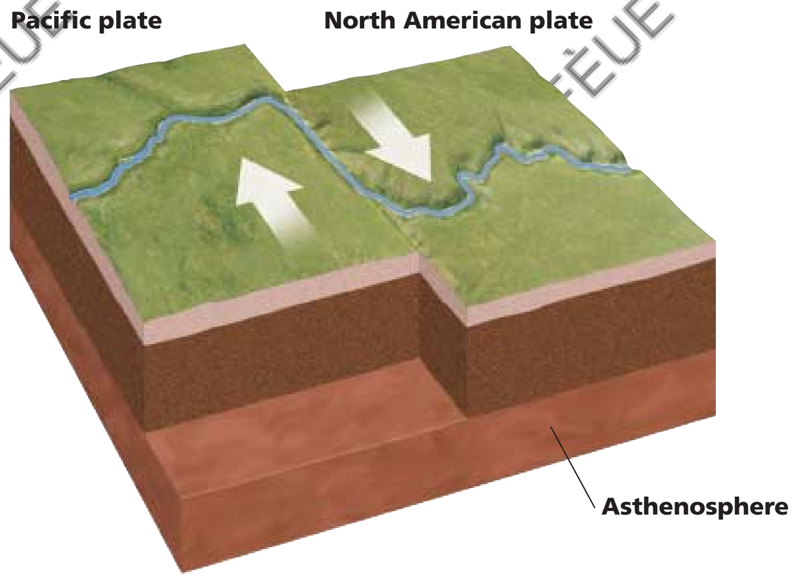


Figure 5 ▶ Plates slide past each other at transform boundaries. The course of the stream in the photo changed because the plates moved past each other at the San Andreas Fault in California.

Transform Boundaries

The boundary at which two plates slide past each other horizontally, as shown in **Figure 5**, is called a **transform boundary.** However, the plate edges usually do not slide along smoothly. Instead, they scrape against each other in a series of sudden spurts of motion that are felt as earthquakes. Unlike other types of boundaries, transform boundaries do not produce magma. The San Andreas Fault in California is a major transform boundary between the North American plate and the Pacific plate.

Transform motion also occurs along mid-ocean ridges. Short segments of a mid-ocean ridge are connected by transform boundaries called *fracture zones*.

Table 1 summarizes the three types of plate boundaries. The table also describes how each type of plate boundary changes Earth's surface and includes examples of each type of plate boundary.

transform boundary the boundary between tectonic plates that are sliding past each other horizontally

Table 1 ▼

Plate Boundary Summary		
Type of boundary	**Description**	**Example**
Divergent	plates moving away from each other to form rifts and mid-ocean ridges	North American and Eurasian plates at the Mid-Atlantic Ridge
Convergent	plates moving toward each other and colliding to form ocean trenches, mountain ranges, volcanoes, and island arcs	South American and Nazca plates at the Chilean trench along the west coast of South America
Transform	plates sliding past each other while moving in opposite directions	North American and Pacific plates at the San Andreas Fault in California

Causes of Plate Motion

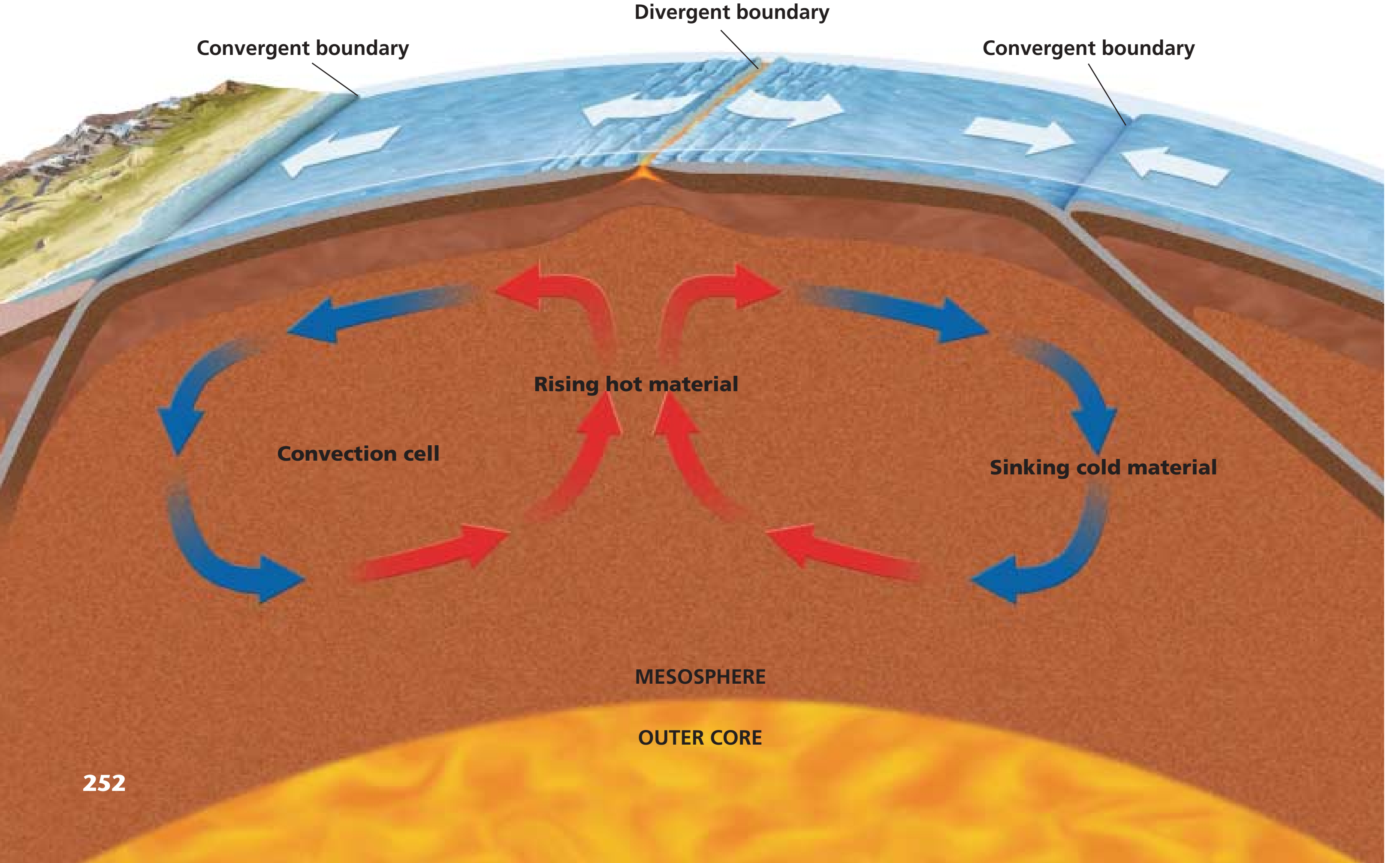
Scientists don't fully understand what force drives plate tectonics. Many scientists think that the movement of tectonic plates is partly due to convection. *Convection* is the movement of heated material due to differences in density that are caused by differences in temperatures. This process can be modeled by boiling water in a pot on the stove. As the water at the bottom of the pot is heated, the water at the bottom expands and becomes less dense than the cooler water above it. The cooler, denser water sinks, and the warmer water rises to the surface to create a cycle called a *convection cell*.

Mantle Convection

Scientists think that Earth is also a convecting system. Energy generated by Earth's core and radioactivity within the mantle heat mantle material. This heated material rises through the cooler, denser material around it. As the hot material rises, the cooler, denser material flows away from the hot material and sinks into the mantle to replace the rising material. As the mantle material moves, it drags the overlying tectonic plates along with it, as shown in **Figure 6.**

Convection currents and the resulting drag on the bottoms of tectonic plates can explain many aspects of plate movement. But scientists have identified two specific mechanisms of convection that help drive the process of plate movement.

Figure 6 ▶ Scientists think that tectonic plates are part of a convection system. ***How is the rising of hot material related to the location of divergent boundaries?***



Ridge Push

Newly formed rock at a mid-ocean ridge is warm and less dense than older rock nearby. The warm, less dense rock is elevated above nearby rock, and older, denser rock slopes downward away from the ridge. As the newer, warmer rock cools and becomes denser, it begins to sink into the mantle and pull away from the ridge.

As the cooling rock sinks, the asthenosphere below it exerts force on the rest of the plate. This force is called *ridge push*. This force pushes the rest of the plate away from the mid-ocean ridge. Ridge push is illustrated in **Figure 7.**

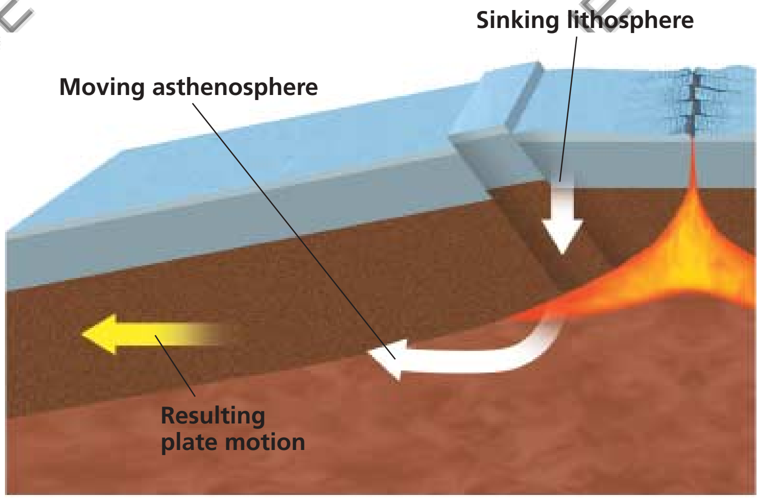


Figure 7 ▶ As the cooling lithosphere sinks, the asthenosphere moves away from the sinking lithosphere and pushes on the bottom of the plate. The plate moves in the direction that it is pushed by the asthenosphere.

Scientists think that ridge push may help drive plate motions. However, most scientists agree that ridge push is not the main driving force of plate motion. So, scientists looked to convergent boundaries for other clues to the forces that drive plate motion.

Reading Check **How may density differences in the rock at a mid-ocean ridge help drive plate motion? (See the Appendix for answers to Reading Checks.)**

QuickLAB 30 min

Tectonic Plate Boundaries

Procedure

1. Using a **ruler,** draw two 7 cm × 12 cm rectangles on a **piece of paper.** Cut them out with **scissors.**
2. Use a rolling pin to flatten **two different colored pieces of clay** to about 1/2 cm thick.
3. Use a **plastic knife** to cut each piece of clay into a 7 cm × 12 cm rectangle. Place a paper rectangle on each piece of clay.
4. Place the two clay models side by side on a flat surface and paper side down.
5. Place one hand on each piece of clay, and slowly push the blocks together until the edges begin to buckle and rise off the surface of the table.
6. Turn the clay models around so that the unbuckled edges are touching each other.
7. Place one hand on each clay model. Apply slight pressure toward the plane where the two blocks meet. Slide one clay model forward 7 cm and the other model backward about 7 cm.

Analysis

1. What type of plate boundary are you modeling in step 5?
2. What type of plate boundary are you modeling in step 7?
3. How do you think the processes modeled in this activity might affect the appearance of Earth's surface?

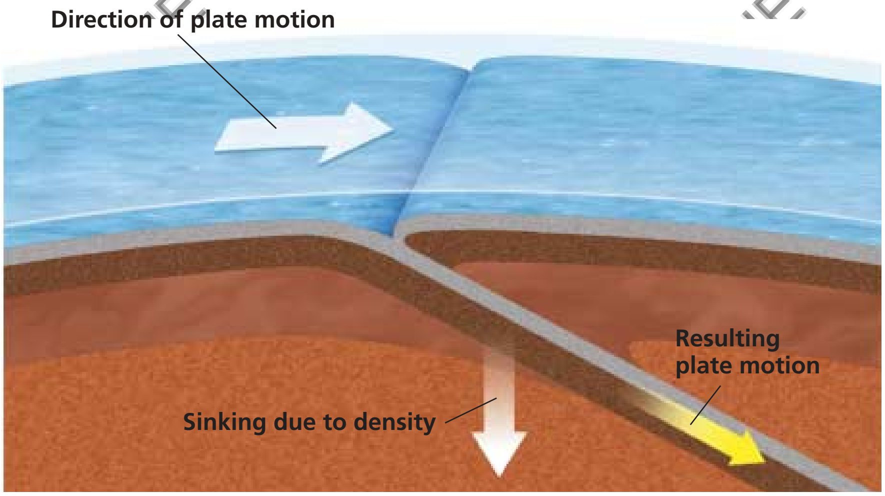


Figure 8 ▶ The leading edge of the subducting plate pulls the rest of the subducting plate into the asthenosphere in a process called *slab pull*.

Slab Pull

Where plates pull away from each other at mid-ocean ridges, magma from the asthenosphere rises to the surface. The magma then cools to form new lithosphere. As the lithosphere moves away from the mid-ocean ridge, the lithosphere cools and becomes denser. Where the lithosphere is dense enough, it begins to subduct into the asthenosphere. As the leading edge of the plate sinks, it pulls the rest of the plate along behind it. The force exerted by the sinking plate is called *slab pull*. This process is shown in **Figure 8.** In general, plates that are subducting move faster than plates that are not subducting. This evidence indicates that the downward pull of the subducting lithosphere is a strong driving force for tectonic plate motion.

All three mechanisms of Earth's convecting system—drag on the bottoms of tectonic plates, ridge push, and slab pull—work together to drive plate motions. These mechanisms form a system that makes Earth's tectonic plates move constantly.

Section 2 Review

1. **Summarize** the theory of plate tectonics.
2. **Explain** why most earthquakes and volcanoes happen along plate boundaries.
3. **Identify and describe** the three major types of plate boundaries.
4. **Compare** the changes in Earth's surface that happen at a convergent boundary with those that happen at a divergent boundary.
5. **Describe** the role of convection currents in plate movement.
6. **Describe** how ridge push and slab pull contribute to the movement of tectonic plates.

CRITICAL THINKING

7. **Making Inferences** How do convergent boundaries add material to Earth's surface?
8. **Determining Cause and Effect** Explain how the outward transfer of heat energy from inside Earth drives the movement of tectonic plates.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *tectonic plate, divergent, convergent, convection, transform, ridge push, slab pull, subduction zone,* and *mid-ocean ridge.*

Section 3 The Changing Continents

The continents did not always have the same shapes that they do today. And geologic evidence indicates that they will not stay the same shape forever. In fact, the continents are always changing. Slow movements of tectonic plates change the size and shape of the continents over millions of years.

OBJECTIVES

- **Identify** how movements of tectonic plates change Earth's surface.
- **Summarize** how movements of tectonic plates have influenced climates and life on Earth.
- **Describe** the supercontinent cycle.

KEY TERMS

rifting
terrane
supercontinent cycle
Pangaea
Panthalassa

Reshaping Earth's Crust

All of the continents that exist today contain large areas of stable rock, called *cratons,* that are older than 540 million years. Rocks within the cratons that have been exposed at Earth's surface are called *shields*. Cratons represent ancient cores around which the modern continents formed.

Rifting and Continental Reduction

One way that continents change shape is by breaking apart. **Rifting** is the process by which a continent breaks apart. New, smaller continents may form as a result of this process. The reason that continents rift is not entirely known. Because continental crust is thick and has a high silica content, continental crust acts as an insulator. This insulating property prevents heat in Earth's interior from escaping. Scientists think that as heat from the mantle builds up beneath the continent, continental lithosphere becomes thinner and begins to weaken. Eventually, a rift forms in this zone of weakness, and the continent begins to break apart, as shown in **Figure 1.**

rifting the process by which Earth's crust breaks apart; can occur within continental crust or oceanic crust

Figure 1 ▶ The East African Rift Valley formed as Africa began rifting about 30 million years ago.

terrane a piece of lithosphere that has a unique geologic history and that may be part of a larger piece of lithosphere, such as a continent

Terranes and Continental Growth

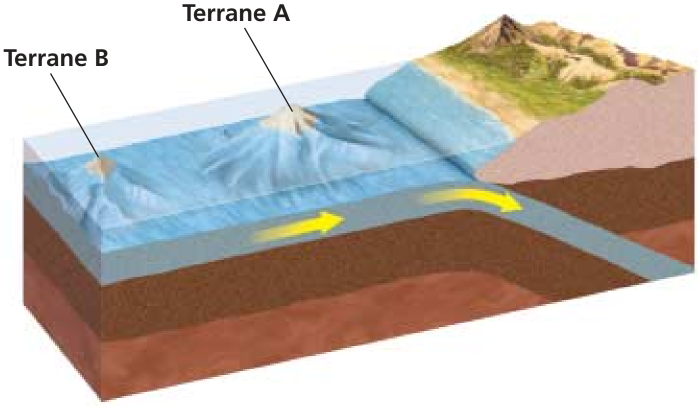
Continents change not only by breaking apart but also by gaining material. Most continents consist of cratons surrounded by a patchwork of terranes. A **terrane** is a piece of lithosphere that has a unique geologic history that differs from the histories of surrounding lithosphere. A terrane can be identified by three characteristics. First, a terrane contains rock and fossils that differ from the rock and fossils of neighboring terranes. Second, there are major faults at the boundaries of a terrane. Third, the magnetic properties of a terrane generally do not match those of neighboring terranes.

Terranes become part of a continent at convergent boundaries. When a tectonic plate carrying a terrane subducts under a plate made of continental crust, the terrane is scraped off the subducting plate, as shown in **Figure 2.** The terrane then becomes part of the continent. Some terranes may form mountains, while other terranes simply add to the surface area of a continent. The process in which a terrane becomes part of a continent is called *accretion* (uh KREE shuhn).

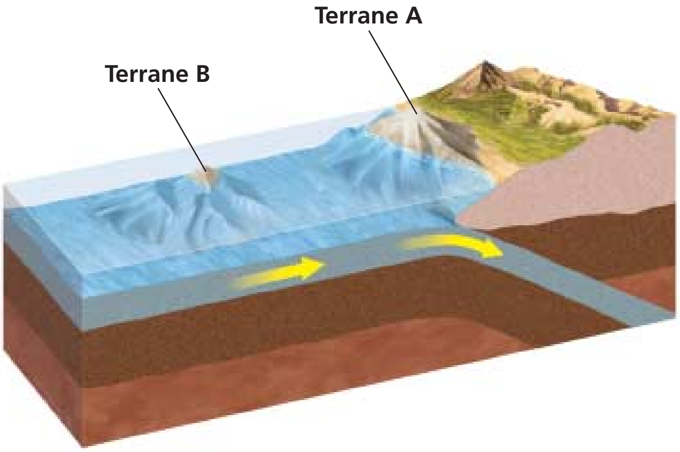
A variety of materials can form terranes. Terranes may be small volcanic islands or underwater mountains called *seamounts*. Small coral islands, or *atolls*, can also form terranes. And large chunks of continental crust can be terranes. When large terranes and continents collide, major mountain chains often form. For example, the Himalaya Mountains formed when India began colliding with Asia about 45 million years ago (during the Cenozoic Era).

Reading Check **Describe the process of accretion. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ As oceanic crust subducts, a terrane is scraped off the ocean floor and becomes part of the continental crust. ***What would you expect to happen to sediments on the sea floor when the plate they are on subducts?***



As the oceanic plate subducts, terranes are carried closer to the continent.



When the terrane reaches the subduction zone, the terrane is scraped off the subducting plate and is added to the continent's edge.

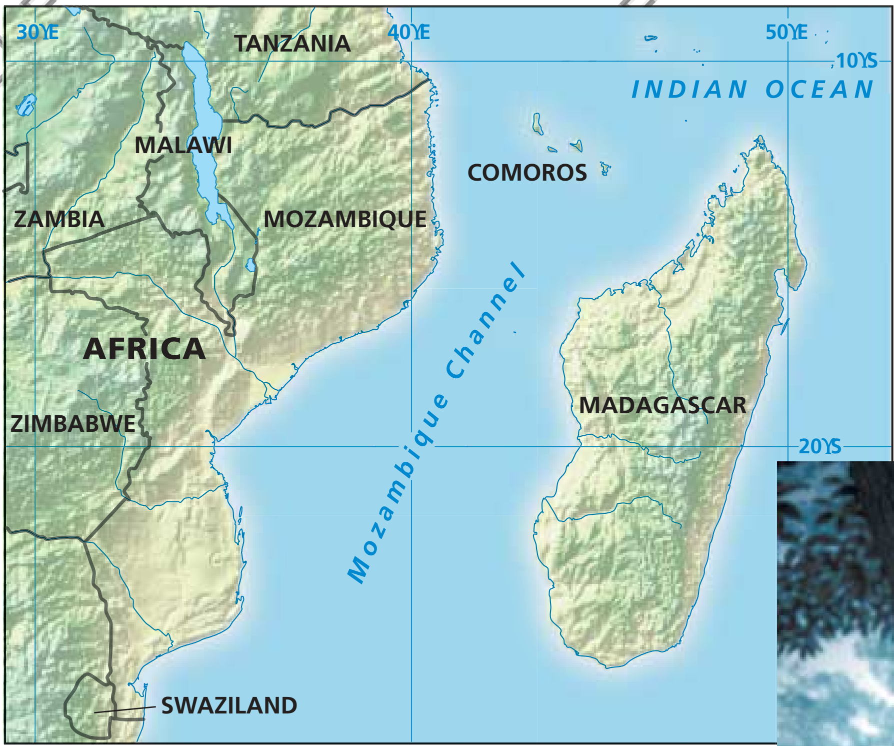


Figure 3 ▶ Madagascar separated from Africa about 165 million years ago and separated from India about 88 million years ago. This separation isolated the plants and animals on the island of Madagascar. As a result, unique species of plants and animals evolved on Madagascar. These species, such as the fossa (below), are found nowhere else on Earth.

Effects of Continental Change

Modern climates are a result of past movements of tectonic plates. A continent's location in relation to the equator and the poles affects the continent's overall climate. A continent's climate is also affected by the continent's location in relation to oceans and other continents. Mountain ranges affect air flow and wind patterns around the globe. Mountains also affect the amount of moisture that reaches certain parts of a continent. When continents move, the flow of air and moisture around the globe changes and causes climates to change.

Changes in Climate

Geologic evidence shows that ice once covered most of Earth's continental surfaces. Even the Sahara in Africa, one of the hottest places on Earth today, was once covered by a thick ice sheet. This ice sheet formed when all of the continents were close together and were located near the South Pole. As continents began to drift around the globe, however, global temperatures changed and much of the ice sheet melted.

Changes in Life

As continents rift or as mountains form, populations of organisms are separated. When populations are separated, new species may evolve from existing species. Sometimes, isolation protects organisms from competitors and predators and may allow the organismsm to evolve into unique organisms, as shown in **Figure 3**.

The Supercontinent Cycle

Using evidence from many scientific fields, scientists can construct a general picture of continental change throughout time. They think that at several times in the past, the continents were arranged into large landmasses called *supercontinents*. These supercontinents broke apart to form smaller continents that moved around the globe. Eventually, the smaller continents joined again to form another supercontinent. When the last supercontinent broke apart, the modern continents formed. A new supercontinent is likely to form in the future. The process by which supercontinents form and break apart over time is called the **supercontinent cycle** and is shown in **Figure 4.**

supercontinent cycle the process by which supercontinents form and break apart over millions of years

Pangaea the supercontinent that formed 300 million years ago and that began to break up beginning 250 million years ago

Panthalassa the single, large ocean that covered Earth's surface during the time the supercontinent Pangaea existed

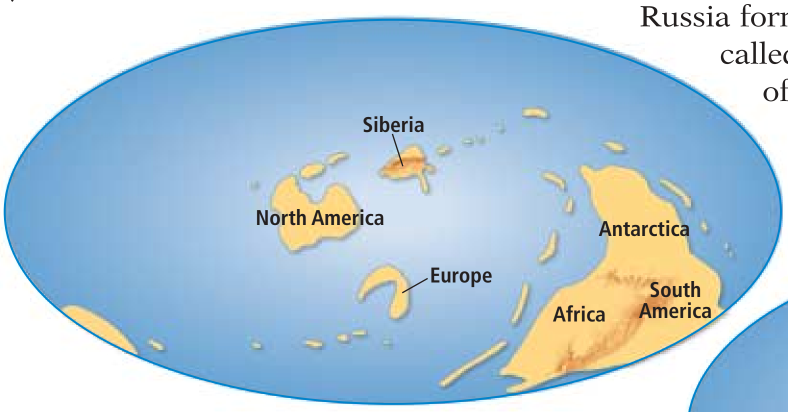
Why Supercontinents Form

The movement of plates toward convergent boundaries eventually causes continents to collide. Because continental lithosphere does not subduct, the convergent boundary between two continents becomes inactive, and a new convergent boundary forms. Over time, all of the continents collide to form a supercontinent. Then, heat from Earth's interior builds up under the supercontinent, and rifts form in the supercontinent. The supercontinent breaks apart, and plates carrying separate continents move around the globe.

Formation of Pangaea

The supercontinent **Pangaea** (pan JEE uh) formed about 300 million years ago (during the Paleozoic Era). As the continents collided to form Pangaea, mountains formed. The Appalachian Mountains of eastern North America and the Ural Mountains of Russia formed during these collisions. A body of water called the Tethys Sea cut into the eastern edge of Pangaea. The single, large ocean that surrounded Pangaea was called **Panthalassa.**

Figure 4 ▶ Over millions of years, supercontinents form and break apart in a cycle known as the *supercontinent cycle*.



About 450 million years ago Earth's continents were separated, as they are today.

260 million to 240 million years ago Pangaea had formed and was beginning to break apart.

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Breakup of Pangaea

About 250 million years ago (during the Paleozoic Era), Pangaea began to break into two continents—*Laurasia* and *Gondwanaland*. A large rift split the supercontinent from east to west. Then, Laurasia began to drift northward and rotate slowly, and a new rift formed. This rift separated Laurasia into the continents of North America and Eurasia. The rift eventually formed the North Atlantic Ocean. The rotation of Laurasia also caused the Tethys Sea to close. The Tethys Sea eventually became the Mediterranean Sea.

As Laurasia began to break apart, Gondwanaland also broke into two continents. One continent broke apart to become the continents of South America and Africa. About 150 million years ago (during the Mesozoic Era), a rift between Africa and South America opened to form the South Atlantic Ocean. The other continent separated to form India, Australia, and Antarctica. As India broke away from Australia and Antarctica, it started moving northward, toward Eurasia. About 60 million years ago (during the Cenozoic Era), India collided with Eurasia, and the Himalaya Mountains began to form.

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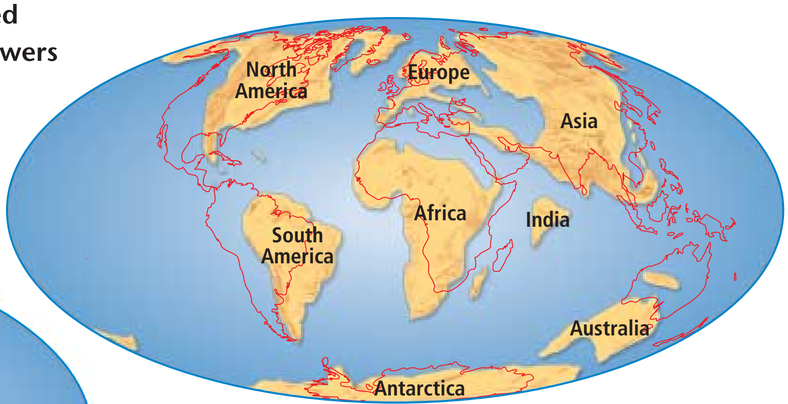
The Modern Continents

Slowly, the continents moved into their present positions. As the continents drifted, they collided with terranes and other continents. These collisions welded new crust onto the continents and uplifted the land. Mountain ranges, such as the Rocky Mountains, the Andes, and the Alps, formed. Tectonic plate motion also caused new oceans to open up and caused others to close.

Reading Check **What modern continents formed from Gondwanaland? (See the Appendix for answers to Reading Checks.)**



70 million to 50 million years ago
The continents were moving toward their current positions. The current positions of the continents are shown here in red.

160 million to 140 million years ago
Pangaea split into two continents—Laurasia to the north and Gondwanaland to the south.

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Geography of the Future

As tectonic plates continue to move, Earth's geography will change dramatically. If plate movements continue at current rates, in about 150 million years, Africa will collide with Eurasia, and the Mediterranean Sea will close. A new ocean will form as east Africa separates from the rest of Africa and moves eastward. As the North American and South American plates move westward and as Eurasia and Africa move eastward, the Atlantic Ocean will become wider. Australia will continue to move north and eventually will collide with Eurasia.

In North America, Mexico's Baja Peninsula and the part of California that is west of the San Andreas Fault will move to where Alaska is today. If this plate movement occurs as predicted, Los Angeles will be located north of San Francisco's current location. Scientists predict that in 250 million years, the continents will come together again to form a new supercontinent, as shown in **Figure 5.**

Figure 5 ▶ Scientists predict that movements of tectonic plates will cause a supercontinent to form in the future.

Section 3 Review

1. **Identify** how rifting and accretion change the shapes of continents.
2. **Describe** why a terrane has a different geologic history from that of the surrounding area.
3. **Summarize** how continental rifting may lead to changes in plants and animals.
4. **Describe** the supercontinent cycle.
5. **Explain** how the theory of plate tectonics relates to the formation and breakup of Pangaea.
6. **Compare** Pangaea and Gondwanaland.
7. **List** three changes in geography that are likely to happen in the future.

CRITICAL THINKING

8. **Identifying Relationships** The interior parts of continents generally have colder climates than coastal areas do. How does this fact explain the evidence that the climate on Pangaea was cooler than many modern climates?
9. **Determining Cause and Effect** Explain how mountains on land can be composed of rocks that contain fossils of marine animals.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *supercontinent, rifting, atoll, continent, terrane, seamount, accretion,* and *Pangaea.*

Chapter 10 Highlights

Sections

1 Continental Drift

Key Terms

continental drift, 239
mid-ocean ridge, 242
seafloor spreading, 243
paleomagnetism, 243

Key Concepts

- Fossil, rock, and climatic evidence supports Wegener's hypothesis of continental drift. However, Wegener could not explain the mechanism by which the continents move.
- New ocean floor is constantly being produced through sea-floor spreading, which creates mid-ocean ridges and changes the topography of the sea floor.
- Sea-floor spreading provides a mechanism for continental drift.

2 The Theory of Plate Tectonics

plate tectonics, 247
lithosphere, 247
asthenosphere, 247
divergent boundary, 249
convergent boundary, 250
transform boundary, 251

- The theory of plate tectonics proposes that changes in Earth's crust are caused by the very slow movement of large tectonic plates.
- Earthquakes, volcanoes, and young mountain ranges tend to be located in belts along the boundaries between tectonic plates.
- Tectonic plates meet at three types of boundaries—divergent, convergent, and transform. The geologic activity that occurs along the three types of plate boundaries differs according to the way plates move relative to each other.
- Tectonic plates may be part of a convecting system that is driven by differences in density and heat.

3 The Changing Continents

rifting, 255
terrane, 256
supercontinent cycle, 258
Pangaea, 258
Panthalassa, 258

- Continents grow through the accretion of terranes. Continents break apart through rifting.
- Movements of tectonic plates have altered climates on continents and have created conditions that lead to changes in plants and animals.
- Continents collide to form supercontinents and then break apart in a cycle called the *supercontinent cycle*.
- Earth's tectonic plates continue to move, and in the future, the continents will likely be in a different configuration.

Chapter 10 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *sea-floor spreading*
2. *convection*
3. *divergent boundary*
4. *terrane*

For each pair of terms, explain how the meanings of the terms differ.

5. *convergent boundary* and *subduction zone*
6. *continental drift* and *plate tectonics*
7. *ridge push* and *slab pull*
8. *Pangaea* and *Panthalasa*

Understanding Key Concepts

9. Support for Wegener's hypothesis of continental drift includes evidence of changes in
   a. climatic patterns. **c.** terranes.
   b. Panthalassa. **d.** subduction.

10. New ocean floor is constantly being produced through the process known as
    a. subduction.
    b. continental drift.
    c. sea-floor spreading.
    d. terranes.

11. An underwater mountain chain that formed by sea-floor spreading is called a
    a. divergent boundary.
    b. subduction zone.
    c. mid-ocean ridge.
    d. convergent boundary.

12. Scientists think that the upwelling of mantle material at mid-ocean ridges is caused by the motion of tectonic plates and comes from
    a. the lithosphere. **c.** the asthenosphere.
    b. terranes. **d.** rift valleys.

13. The layer of plastic rock that underlies the tectonic plates is the
    a. lithosphere. **c.** oceanic crust.
    b. asthenosphere. **d.** terrane.

14. The region along tectonic plate boundaries where one plate moves beneath another is called a
    a. rift valley.
    b. transform boundary.
    c. subduction zone.
    d. convergent boundary.

15. Two plates grind past each other at a
    a. transform boundary.
    b. convergent boundary.
    c. subduction zone.
    d. divergent boundary.

16. Convection occurs because heated material becomes
    a. less dense and rises.
    b. denser and rises.
    c. denser and sinks.
    d. less dense and sinks.

Short Answer

17. Explain the role of technology in the progression from the hypothesis of continental drift to the theory of plate tectonics.

18. Summarize how the continents moved from being part of Pangaea to their current locations.

19. Why do most earthquakes and volcanoes happen at or near plate boundaries?

20. Explain the following statement: "Because of sea-floor spreading, the ocean floor is constantly renewing itself."

21. Describe how rocks that form at a mid-ocean ridge become magnetized.

22. How may continental rifting influence the evolution of plants and animals?

Critical Thinking

23. Making Comparisons How are tectonic plates like the pieces of a jigsaw puzzle?

24. Making Inferences If Alfred Wegener had found identical fossil remains of plants and animals that had lived no more than 10 million years ago in both eastern Brazil and western Africa, what might he have concluded about the breakup of Pangaea?

25. Identifying Relationships Assume that the total surface area of Earth is not changing. If new material is being added to Earth's crust at one boundary, what would you expect to be happening at another boundary?

26. Making Predictions One hundred fifty million years from now, the continents will have drifted to new locations. How might these changes affect life on Earth?

Concept Mapping

27. Use the following terms to create a concept map: *asthenosphere, lithosphere, divergent boundary, convergent boundary, transform boundary, subduction zone, mid-ocean ridge, plates, convection, continental drift, theory of plate tectonics,* and *sea-floor spreading*.

Math Skills

28. Making Calculations The coasts of Africa and South America began rifting about 150 million years ago. Today, the coast of South America is about 6,660 km from the coast of Africa. Using the equation *velocity* = *distance* ÷ *time,* determine how fast the continents moved apart in millimeters per year.

29. Using Equations Assume that scientists know the rate at which the North American and Eurasian plates are moving away from each other. If t = time, d = distance, and v = velocity, what equation can they use to determine when North America separated from Eurasia during the breakup of Pangaea?

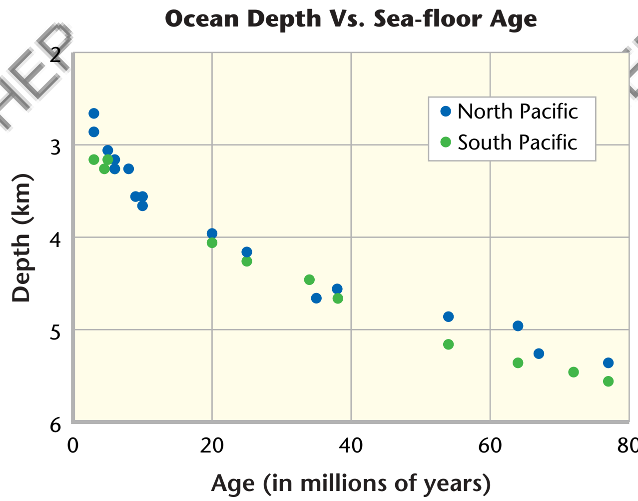
Writing Skills

30. Writing Persuasively Imagine that you are Alfred Wegener. Write a persuasive essay to explain your idea of continental drift. Use only evidence originally used by Wegener to support his hypothesis.

31. Communicating Main Ideas Explain how the research of Wegener, Hess, and others led to the theory of plate tectonics.

Interpreting Graphics

The graph below shows the relationship between the age of sea floor rocks and the depth of the sea floor beneath the ocean surface. Use the graph to answer the questions that follow.



32. How old is the sea floor at a depth of 4 km?

33. Approximately how deep is the sea floor when it is 55 million years old?

34. What can you infer about the age of very deep sea floor from the data in the graph?

35. The ridge in the South Pacific Ocean is spreading faster than the ridge in the North Pacific Ocean. If this graph showed the depth of the sea floor in relation to the distance from the ridge, how would the graphs of the North Pacific and South Pacific ridges differ?

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Chapter 10 Standardized Test Prep

Understanding Concepts

Directions (1–4): **For *each* question, write on a separate sheet of paper the number of the correct answer.**

1 Which of the following factors is most important when determining the type of collision that forms when two lithospheric plates collide?
- **A.** the density of each plate
- **B.** the size of each plate
- **C.** the paleomagnetism of the rock
- **D.** the length of the boundary

2 At locations where sea-floor spreading occurs, rock is moved away from a mid-ocean ridge. What replaces the rock as it moves away?
- **F.** molten rock
- **G.** older rock
- **H.** continental crust
- **I.** compacted sediment

3 Which of the following was a weakness of Wegener's proposal of continental drift when he first proposed the hypothesis?
- **A.** an absence of fossil evidence
- **B.** unsupported climatic evidence
- **C.** unrelated continent features
- **D.** a lack of proven mechanisms

4 Which of the following statements describes a specific type of continental growth?
- **F.** Continents change not only by gaining material but also by losing material.
- **G.** Terranes become part of a continent at convergent boundaries.
- **H.** Ocean sediments move onto land because of sea-floor spreading.
- **I.** Rifting adds new rock to a continent and causes the continent to become wider.

Directions (5–6): **For *each* question, write a short response.**

5 What is the name for the process by which the Earth's crust breaks apart?

6 What is the name for the layer of plastic rock directly below the lithosphere?

Reading Skills

Directions (7–9): **Read the passage below. Then, answer the questions.**

The Himalaya Mountains

The Himalaya Mountains are a range of mountains that is 2,400 km long and that arcs across Pakistan, India, Tibet, Nepal, Sikkim, and Bhutan. The Himalaya mountains are the highest Mountains on Earth. Nine mounains in the chain, including Mount Everest, the tallest above-water mountain on Earth, rise to heights of more than 8,000 m above sea-level. Mount Everest stands 8,850 m tall.

The formation of the Himalaya Mountains began about 80 million years ago. A tectonic plate carrying the Indian subcontinent collided with the Eurasian plate. The Indian plate was denser than the Eurasian plate. This difference in density caused the uplifting of the Eurasian plate and the subsequent formation of the Himalaya Mountains. This process continues today. The Indian plate continues to push under the Eurasian plate. New measurements show that Mount Everest is moving to the northeast by as much as 10 cm per year.

7 According to the passage, what geologic process formed the Himalaya Mountains?
- **A.** divergence
- **B.** continental rifting
- **C.** strike-slip faulting
- **D.** convergence

8 Which of the following statements is a fact according to the passage?
- **F.** The nine tallest mountains on Earth are located in the Himalaya Mountains.
- **G.** The Himalaya Mountains are the longest mountain chain on Earth.
- **H.** The Himalaya Mountains are located within six countries.
- **I.** The Himalaya Mountains had completely formed by 80 million years ago.

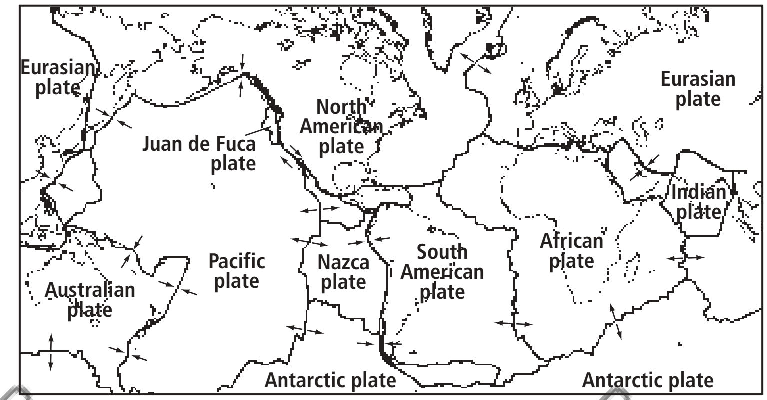
9 Which plate is being subducted along the fault that formed the Himalaya Mountains?
- **A.** The Indian plate is being subducted.
- **B.** The Eurasian plate is being subducted.
- **C.** Both plates are being equally subducted.
- **D.** Neither plate is being subducted.

Interpreting Graphics

***Directions (10–13):* For *each* question below, record the correct answer on a separate sheet of paper.**

The map below shows the locations of the Earth's major tectonic plate boundaries. Use this map to answer questions 10 and 11.

Earth's Tectonic Plates



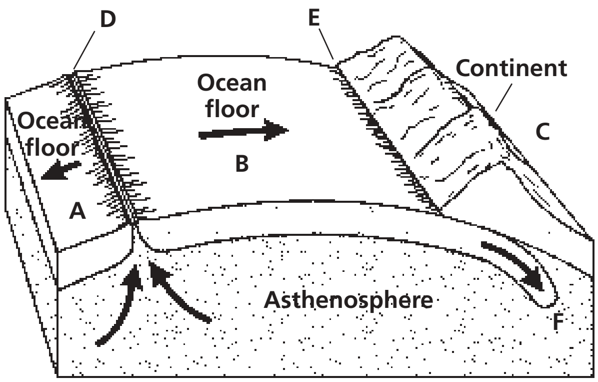
10 What type of boundary is found between the South American plate and the African plate?

A. convergent
B. divergent
C. transform
D. subduction

11 What type of boundary is found between the South American plate and the African plate? What surface features are most often found at boundaries of this type?

The graphic below shows a strike-slip fault along a transform boundary. Use the graphic to answer questions 12 and 13.

Plate Boundaries



12 What type of crustal interaction is indicated by the letter E?

F. continental rifting
G. sea-floor spreading
H. divergence
I. subduction

13 Describe how a transform boundary differs from the boundaries shown by letters D and E in terms of plate movement and magmatic activity.

Test TIP

If you become short on time, quickly scan the unanswered questions to see which questions are easiest to answer.

Chapter 10

Making Models Lab

Objectives

- **Model** the formation of sea floor.
- **Identify** how magnetic patterns are caused by sea-floor spreading.

Materials

marker
paper, unlined
ruler, metric
scissors or utility knife
shoebox

Safety

Sea-Floor Spreading

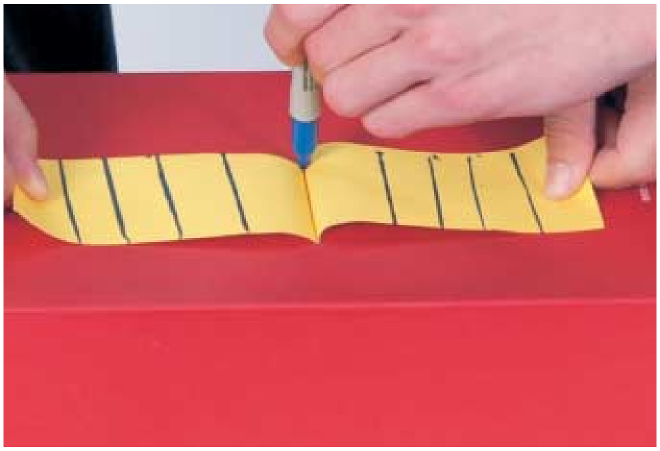
The places on Earth's surface where plates pull apart have many names. They are called divergent boundaries, mid-ocean ridges, and spreading centers. The term *spreading center* refers to the fact that sea-floor spreading happens at these locations. In this lab, you will model the formation of new sea floor at a divergent boundary. You will also model the formation of magnetic patterns on the sea floor.

PROCEDURE

1. Cut two identical strips of unlined paper, each 7 cm wide and 30 cm long.
2. Cut a slit 8 cm long in the center of the bottom of a shoebox.
3. Lay the strips of paper together on top of each other end to end so that the ends line up. Push one end of the strips through the slit in the shoe box, so that a few centimeters of both strips stick out of the slit.

Step 3

4. Place the shoe box flat on a table open side down, and make sure the ends of the paper strips are sticking up.
5. Separate the strips, and hold one strip in each hand. Pull the strips apart. Then, push the strips down against the shoe box.
6. Use a marker to mark across the paper strips where they exit the box. One swipe with the marker should mark both strips.
7. Pull the strips evenly until about 2 cm have been pulled through the slit.
8. Mark the strips with the marker again.
9. Repeat steps 7 and 8, but vary the length of paper that you pull from the slit. Continue this process until both strips are pulled out of the box.



Step 6

ANALYSIS AND CONCLUSION

1. **Evaluating Models** How does this activity model sea-floor spreading?
2. **Analyzing Models** What do the marker stripes in this model represent?
3. **Analyzing Methods** If each 2 cm marked on the paper is equal to 3 million years, how could you use your model to determine the age of certain points on the sea floor?
4. **Applying Conclusions** You are given only the paper strips with marks already drawn on them. How would you use the paper strips to reconstruct the way in which the sea-floor was formed?

Extension

1. **Making Models** Design a model that shows what happens at a convergent boundary and what happens at a transform boundary. Present these models to the class.

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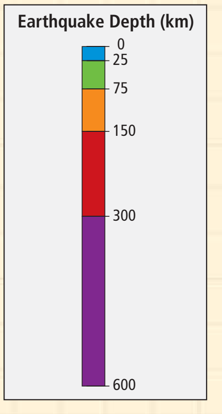
MAPS in Action

Locations of Earthquakes in South America, 2002–2003



Map Skills Activity

This map shows the locations and depths of earthquakes that registered magnitudes greater than 5 and that happened in South America in 2002 and 2003. Use the map to answer the questions below.

1. **Using the Key** How many earthquakes happened at a depth greater than 300 km?
2. **Analyzing Data** Deep earthquakes are earthquakes that happen at a depth greater than 300 km. Which earthquakes happen more frequently: deep earthquakes or shallow earthquakes?
3. **Making Comparisons** How does the earthquake activity on the eastern edge of South America differ from the earthquake activity on the western edge?
4. **Inferring Relationships** The locations of earthquakes and plate boundaries are related. Where would you expect to find a major plate boundary?
5. **Identifying Trends** In what part of South America do most deep earthquakes happen? What relationships do you see between the locations of shallow and deep earthquakes in South America?
6. **Analyzing Relationships** Most deep earthquakes happen where subducting plates move deep into the mantle. What type of plate boundary is indicated by the earthquake activity in South America? Explain your answer.

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The Mid-Atlantic Ridge

Deep in the Atlantic Ocean lies a mountain range so vast that it dwarfs the Himalaya Mountains. This mountain range, called the *Mid-Atlantic Ridge,* is the mid-ocean ridge at the diverging boundary between the North American and Eurasian plates and also between the South American and African plates.

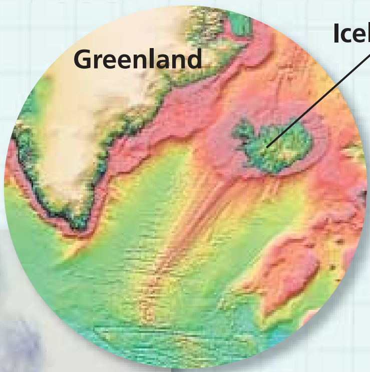
Sea-Floor Spreading on Land

Most of Earth's mid-ocean ridges are underwater, but part of the Mid-Atlantic Ridge rises above sea level just south of the Arctic Circle. The exposed section of the Mid-Atlantic Ridge forms the country of Iceland. Since Iceland was founded by Vikings more than 1,000 years ago, its inhabitants have contended with constant geologic activity associated with sea-floor spreading.

Lots and Lots of Lava

Separation of Earth's crust along the Mid-Atlantic Ridge affects Iceland's landscape in several ways. The movement of magma causes frequent earthquakes. Iceland is also one of the most volcanically active areas in the world. It contains about 200 volcanoes and averages one eruption every five years. Magma flowing up from the mantle creates numerous hot springs, geysers, and sulfurous gas vents. Scientists estimate that one-third of the total lava flow from Earth in the last 500 years has occurred on Iceland.

Despite Iceland's numerous volcanoes, much of its lava comes not from isolated eruptions but from cracks, or *fissures,* in the crust. In a recent rifting episode that lasted nearly 10 years, a series of fissures spit out enough molten basalt to cover 35 km^2 of land and individual fissures grew as much as 8 m in width. At present, sea-floor spreading adds an average of 2.5 cm of new material to Iceland each year. At this rate, Iceland will grow 25 km in width during the next million years.



◀ The Helgafjell volcano erupted in a curtain of fire that rained black ash on the town of Reykjavik Iceland, in 1973.

Extension

1. **Making Inferences** If geologists want to locate the youngest rocks on Iceland, where should they look? Where should they look to find the oldest rocks? Explain your answers.

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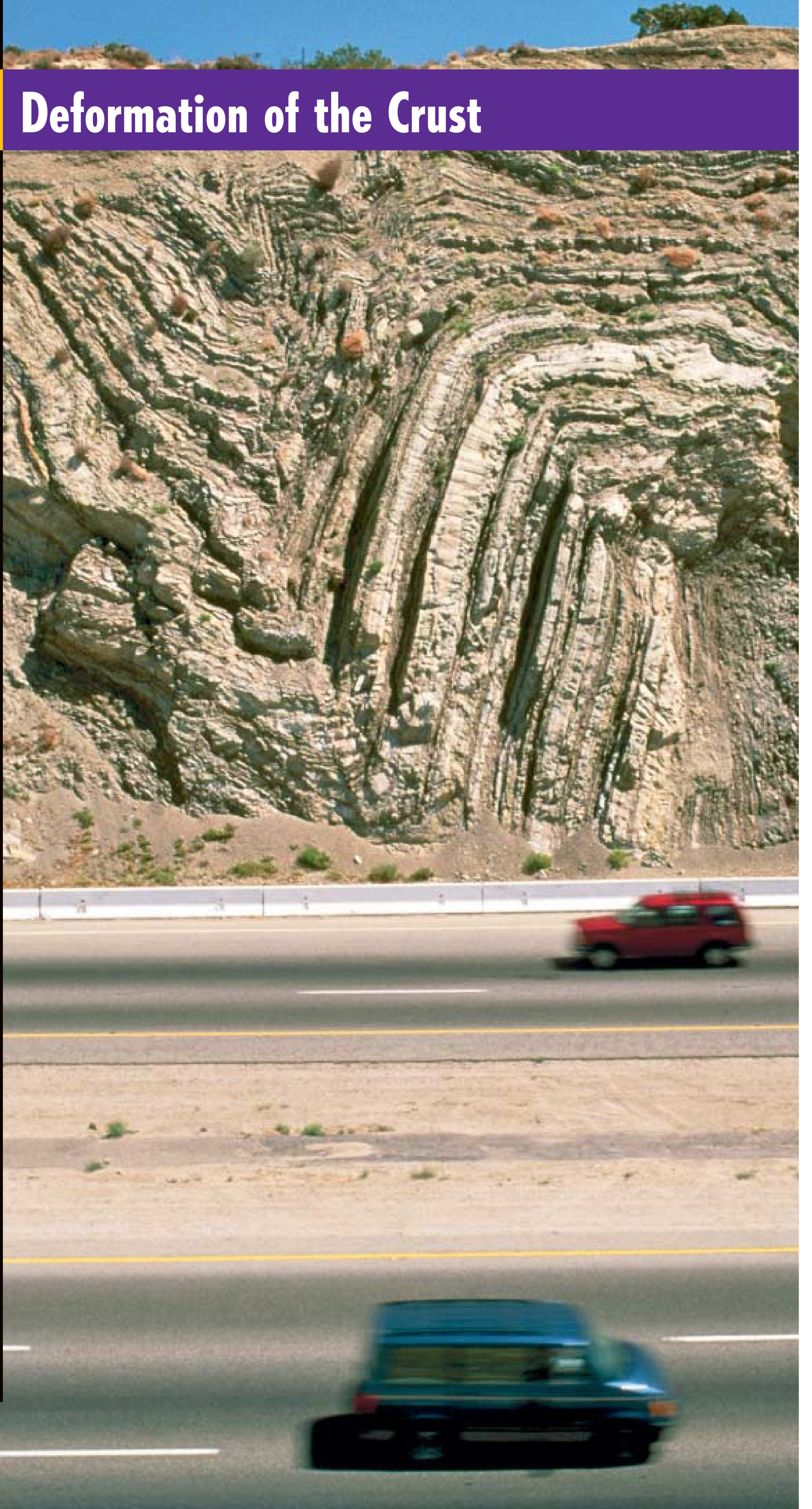
Chapter 11

Deformation of the Crust



Sections

1 How Rock Deforms

2 How Mountains Form

What You'll Learn

- How Earth's crust responds to stress
- What forms deformed rock takes
- How forces in the crust cause mountains to form

Why It's Relevant

Many of the most dramatic features of Earth's surface are the result of deformation of the crust. Knowing how rock responds to stress provides a strong basis for understanding why and how Earth's surface changes.

PRE-READING ACTIVITY

FOLDNOTES

Key-Term Fold Before you read this chapter, create the **FoldNote** entitled "Key-Term Fold" described in the Skills Handbook section of the Appendix. Write a key term from the chapter on each tab of the key-term fold. Under each tab, write the definition of the key term.

▶ To build this portion of Highway 14 in California, construction crews had to cut through a hill. The exposed rock in the roadcut shows layers of sedimentary rock that have been folded by the stress caused by the nearby San Andreas fault.

Section 1 How Rock Deforms

The Himalayas, the Rockies, and the Andes are some of Earth's most majestic mountain ranges. Mountain ranges are visible reminders that the shape of Earth's surface changes constantly. These changes result from **deformation,** or the bending, tilting, and breaking of Earth's crust.

OBJECTIVES

- **Summarize** the principle of isostasy.
- **Identify** the three main types of stress.
- **Compare** folds and faults.

KEY TERMS

deformation
isostasy
stress
strain
fold
fault

Isostasy

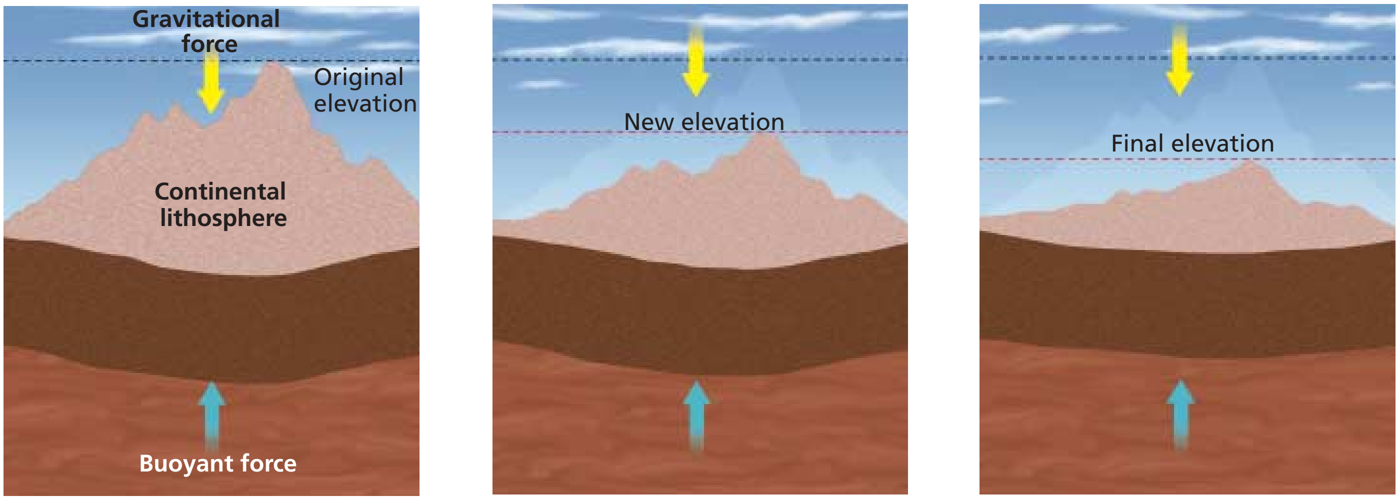
Deformation sometimes occurs because the weight of some part of Earth's crust changes. Earth's crust is part of the lithospheric plates that ride on top of the plastic part of the mantle called the *asthenosphere*. When parts of the lithosphere thicken and become heavier, they sink deeper into the asthenosphere. If parts of the lithosphere thin and become lighter, the lithosphere rises higher in the asthenosphere.

Vertical movement of the lithosphere depends on two opposing forces. One force is the force due to gravity, or weight, of the lithosphere pressing down on the asthenosphere. The other force is the buoyant force of the asthenosphere pressing up on the lithosphere. When these two forces are balanced, the lithosphere and asthenosphere are in a state called **isostasy.** However, when the weight of the lithosphere changes, the lithosphere sinks or rises until a balance of the forces is reached again. The movements of the lithosphere to reach isostasy are called *isostatic adjustments*. One type of isostatic adjustment is shown in **Figure 1.** As these isostatic adjustments occur, areas of the crust are bent up and down. This bending causes rock in that area to deform.

deformation the bending, tilting, and breaking of Earth's crust; the change in shape or volume of rock in response to stress

isostasy a condition of gravitational and buoyant equilibrium between Earth's lithosphere and asthenosphere

Figure 1 ▶ **Isostatic Adjustments as a Result of Erosion**



When the gravitational force equals the buoyant force, the lithosphere and asthenosphere are in isostasy.

As erosion wears away the crust, the lithosphere becomes lighter and is pushed up by the asthenosphere.

As erosion continues, the isostatic adjustment also continues.

Figure 2 ▶ Mt. Katahdin in Baxter State Park, Maine, has been worn down by weathering. As the mountain shrinks, the crust underneath it is uplifted.

Quick LAB — 5 min

Modeling Isostasy

Procedure

1. Fill a **1 L beaker** with **500 mL of water.**
2. Place a **wooden block** in the water. Use a **grease pencil** to mark on the side of the beaker the levels of the top and the bottom of the block.
3. Place a **small mass,** of about 1 g, on the wooden block. Use a **second grease pencil** to mark the levels of the top and the bottom of the block.

Analysis

1. What happens to the block of wood when the weight is added?
2. What type of isostatic adjustment does this activity model?

Mountains and Isostasy

In mountainous regions, isostatic adjustments constantly occur. Over millions of years, the rock that forms mountains is worn away by the erosive actions of wind, water, and ice. This erosion can significantly reduce the height and weight of a mountain range, such as the one shown in **Figure 2.** As a mountain becomes smaller, the surrounding crust becomes lighter and the area may rise by isostatic adjustment in a process called *uplift*.

Deposition and Isostasy

Another type of isostatic adjustment occurs in areas where rivers carrying large amounts of mud, sand, and gravel flow into larger bodies of water. When a river flows into the ocean, most of the material that the river carries is deposited on the nearby ocean floor. The added weight of the deposited material causes the ocean floor to sink by isostatic adjustment in a process known as *subsidence*. This process is occurring in the Gulf of Mexico at the mouth of the Mississippi River, where a thick accumulation of deposited materials has formed.

Glaciers and Isostasy

Isostatic adjustments also occur as a result of the growth and retreat of glaciers and ice sheets. When a large amount of water is held in glaciers and ice sheets, the weight of the ice causes the lithosphere beneath the ice to sink. Simultaneously, the ocean floor rises because the weight of the overlying ocean water is less. When glaciers and ice sheets melt, the land that was covered with ice slowly rises as the weight of the crust decreases. As the water returns to the ocean, the ocean floor sinks.

Stress

As Earth's lithosphere moves, the rock in the crust is squeezed, stretched, and twisted. These actions exert force on the rock. The amount of force that is exerted on each unit of area is called **stress.** For example, during isostatic adjustments, the lithosphere sinks and rises atop the asthenosphere. As the lithosphere sinks, the rock in the crust is squeezed and the direction of stress changes. As the lithosphere rises, the rock in the crust is stretched and the direction of stress changes again. Similarly, stress occurs in Earth's crust when tectonic plates collide, separate, or scrape past each other. **Figure 3** shows the three main types of stress.

stress the amount of force per unit area that acts on a rock

Compression

The type of stress that squeezes and shortens a body is called *compression*. Compression commonly reduces the amount of space that rock occupies. In addition to reducing the volume of rock, compression pushes rocks higher up or deeper down into the crust. Much of the stress that occurs at or near convergent boundaries, where tectonic plates collide, is compression.

Tension

Another type of stress is tension. *Tension* is stress that stretches and pulls a body apart. When rocks are pulled apart by tension, they tend to become thinner. Much of the stress that occurs at or near divergent boundaries, where tectonic plates pull apart, is tension.

Shear Stress

The third type of stress is shear stress. *Shear stress* distorts a body by pushing parts of the body in opposite directions. Sheared rocks bend, twist, or break apart as they slide past each other. Shear stress is common at transform boundaries, where tectonic plates slide horizontally past each other. However, each type of stress occurs at or near all types of plate boundaries and in various other regions of the crust, too.

Reading Check **Which two kinds of stress pull rock apart? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ **Types of Stress**

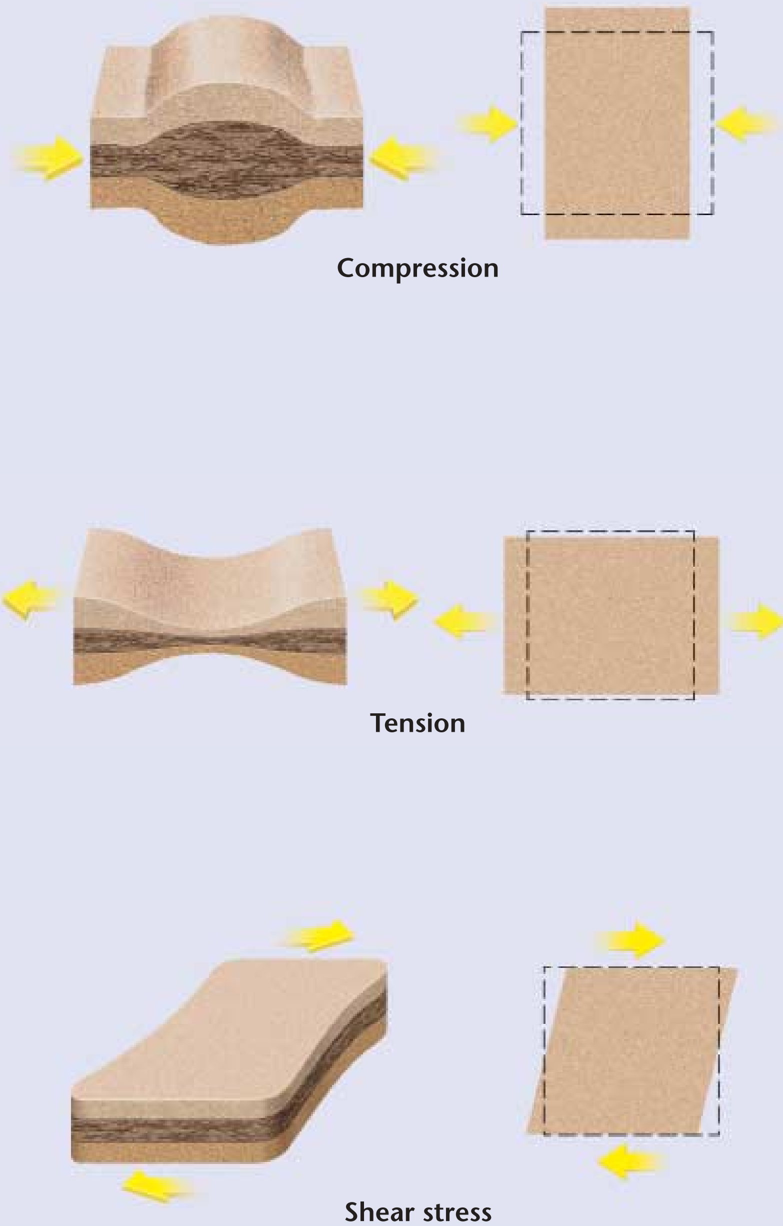


Figure 4 ▶ This rock deformation in Kingman, Arizona, is an example of brittle strain.

strain any change in a rock's shape or volume caused by stress

Strain

When stress is applied to rock, rock may deform. Any change in the shape or volume of rock that results from stress is called **strain.** When stress is applied slowly, the deformed rock may regain its original shape when the stress is removed. However, the amount of stress that rock can withstand without permanently changing shape is limited. This limit varies with the type of rock and the conditions under which the stress is applied. If a stress exceeds the rock's limit, the rock's shape permanently changes.

Types of Permanent Strain

Materials that respond to stress by breaking or fracturing are *brittle*. Brittle strain appears as cracks or fractures, as **Figure 4** shows. *Ductile* materials respond to stress by bending or deforming without breaking. Ductile strain is a change in the volume or shape of rock in which the rock does not crack or fracture. Brittle strain and ductile strain are types of permanent strain.

Factors That Affect Strain

The composition of rock determines whether rock is ductile or brittle. Temperature and pressure also affect how rock deforms. Near Earth's surface, where temperature and pressure are low, rock is likely to deform in a brittle way. At higher temperature and pressure, rock is more likely to deform in a ductile way.

The type of strain that stress causes is determined by the amount and type of stress and by the rate at which stress is applied to rock. The greater the stress on rock is, the more likely rock is to undergo brittle strain. The more quickly stress is applied to rock, the more likely rock is to respond in a brittle way.

QuickLAB **15 min**

Modeling Stress and Strain

Procedure

1. Put on a pair of **gloves,** and pick up a 5 cm × 5 cm square of **frozen plastic play putty.** Hold one edge of the frozen putty in each hand.
2. Try to pull the putty apart by pulling the edges away from each other.
3. Push the edges of the frozen putty toward each other. (You may have to reshape the putty between steps.)
4. Push one edge of the frozen putty away from you, and pull the other edge toward you.
5. Repeat steps 2–4, but use a 5 cm × 5 cm square of **warm plastic play putty.**

Analysis

1. What types of stress did you model in steps 2, 3, and 4?
2. Make a table that lists the characteristics of the two substances that you modeled, the stresses that you modeled, and the resulting strain on each model.
3. How does the frozen putty respond to the stress? How does the warm putty's response to the stress differ from the frozen putty's response?

Folds

When rock responds to stress by deforming in a ductile way, folds commonly form. A **fold** is a bend in rock layers that results from stress. A fold is most easily observed where flat layers of rock were compressed or squeezed inward. As stress was applied, the rock layers bent and folded. Cracks sometimes appear in or near a fold, but most commonly the rock layers remain intact. Although a fold commonly results from compression, it can also form as a result of shear stress.

fold a form of ductile strain in which rock layers bend, usually as a result of compression

Anatomy of a Fold

Folds have features by which they can be identified. Scientists use these features to describe folds. The main features of a fold are shown by the illustration in **Figure 5.** The sloping sides of a fold are called *limbs*. The limbs meet at the bend in the rock layers, which is called the *hinge*. Some folds also contain an additional feature. If a fold's structure is such that a plane could slice the fold into two symmetrical halves, the fold is symmetrical. The plane is called the fold's *axial plane*. However, the two halves of a fold are rarely symmetrical.

Many folds bend vertically, but folds can have many other shapes, as shown by the photograph in **Figure 5.** Folds can be asymmetrical. Sometimes, one limb of a fold dips more steeply than the other limb does. If a fold is *overturned,* the fold appears to be lying on its side. Folds can have open shapes or be as tight as a hairpin. A fold's hinge can be a smooth bend or may come to a sharp point. Each fold is unique because the combination of stresses and conditions that caused the fold was unique.

Reading Check **Name two features of a fold. (See the Appendix for answers to Reading Checks.)**

MATHPRACTICE

Units of Stress
Two units are commonly used to describe stress or pressure. One unit is the pascal (Pa). A pascal is a measure of force (in newtons) divided by area (in square meters). The other unit of stress is the pound per square inch (psi). If the pressure in a region of Earth's crust is measured as 25 MPa (megapascals) and as 3,626 psi, how many pounds per square inch does 1 MPa equal? (Note: 1 MPa = 1,000,000 Pa)

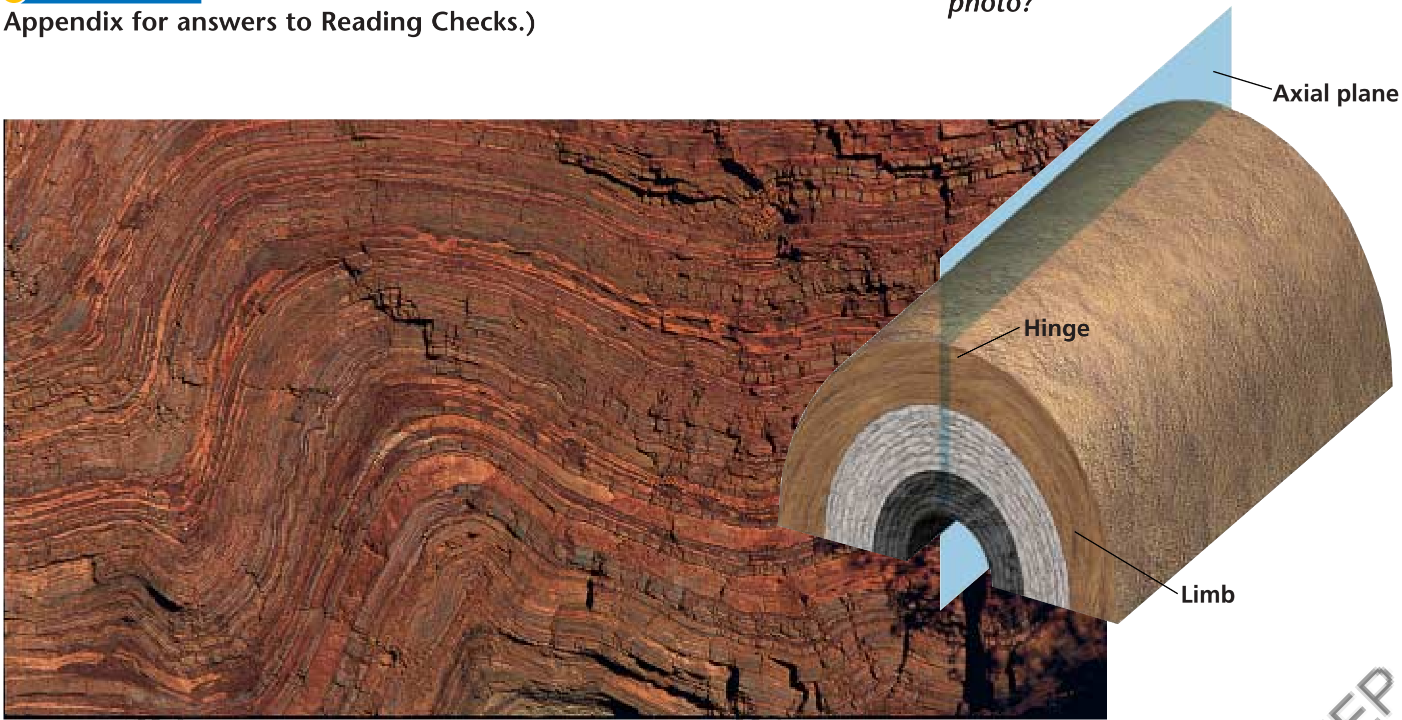


Figure 5 ▶ Although not every fold is symmetrical, every fold has a hinge and limbs. ***Can you identify the limbs and hinge of each fold in the photo?***

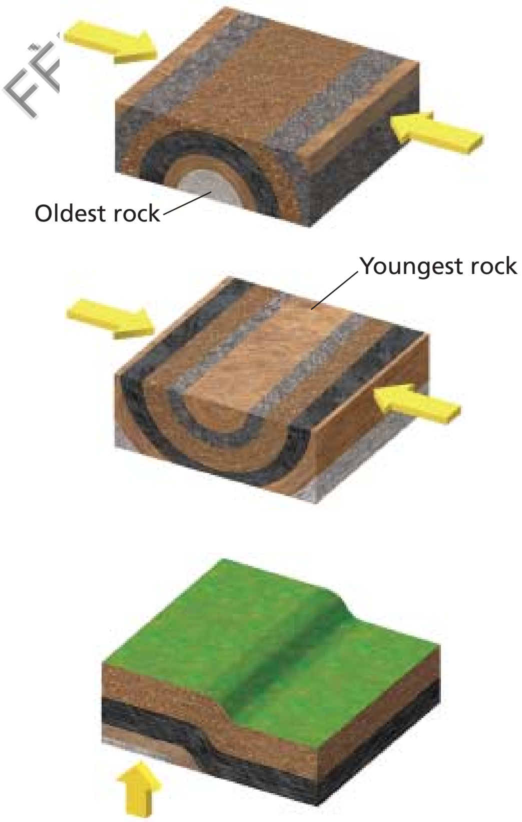


Figure 6 ▶ The three major types of folds are anticlines (top), synclines (middle), and monoclines (bottom).

Types of Folds

To categorize a fold, scientists study the relative ages of the rocks in the fold. The rock layers of the fold are identified by age from youngest to oldest. An *anticline* is a fold in which the oldest layer is in the center of the fold. Anticlines are commonly arch shaped. A *syncline* is a fold in which the youngest layer is in the center of the fold. Synclines are commonly bowl shaped. A *monocline* is a fold in which both limbs are horizontal or almost horizontal. Monoclines form when one part of Earth's crust moves up or down relative to another part. The three major types of folds are shown in **Figure 6.**

Sizes of Folds

Folds, which appear as wavelike structures in rock layers, vary greatly in size. Some folds are small enough to be contained in a hand-held rock specimen. Other folds cover thousands of square kilometers and can be seen only from the air.

Sometimes, a large anticline forms a ridge. A *ridge* is a large, narrow strip of elevated land that can occur near mountains. Nearby, a large syncline may form a valley. The ridges and valleys of the Appalachian Mountains are examples of landforms that were formed by anticlines and synclines.

Connection to ENGINEERING

Oil Traps

Oil and natural gas form where the remains of organisms, especially marine plants, are buried in an environment that prevents the remains from rapidly decomposing. Over millions of years, chemical reactions slowly change the organic remains into oil and natural gas.

When prospecting for oil and natural gas, oil companies look for porous and permeable rock layers. Porous rock has spaces between rock particles. Permeable rock is rock in which the pore spaces are connected, so fluids can flow through the rock. When a rock layer is both porous and permeable and contains oil or gas, the layer is called a *reservoir*.

Because oil and natural gas are fluids that have low densities, they move upward through rock toward Earth's surface. Oil and gas move through rock layers until they meet an impermeable rock layer or structure, which then traps the oil and gas below it.

In addition to looking for porous and permeable rock layers, petroleum engineers look for rock layers that have been folded. Many folds are anticlines in which layers of impermeable rock overlay layers of permeable rock. Because the limbs of the fold slope upward, the oil and natural gas rise through the permeable layer to the crest of the anticline and are trapped there by the impermeable layer. Engineers can then drill through the impermeable layer to reach the oil or gas reservoir.

This oil pump brings oil and natural gas up to the surface.

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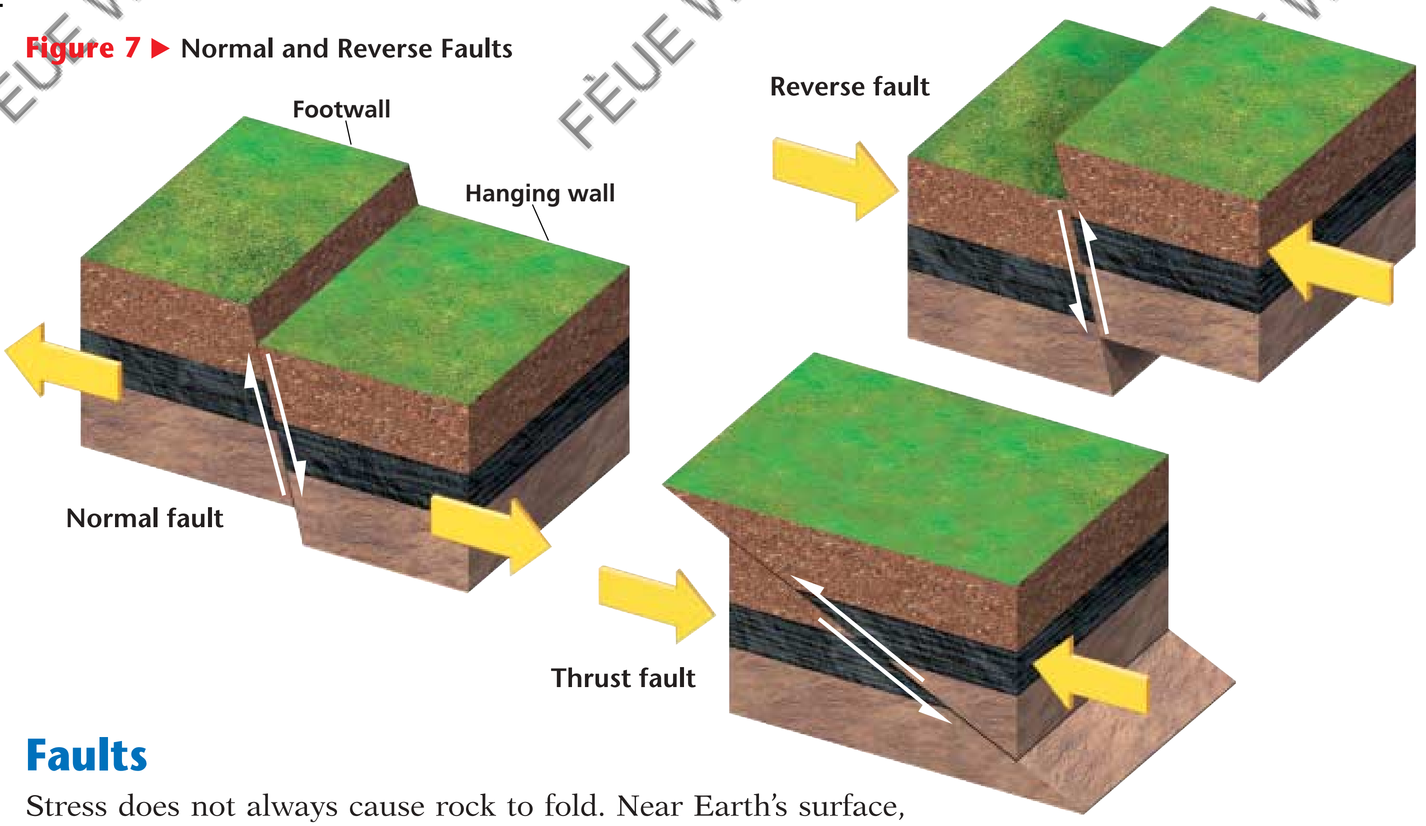
Figure 7 ▶ Normal and Reverse Faults



Faults

Stress does not always cause rock to fold. Near Earth's surface, where temperatures and pressure are low, stresses may simply cause rock to break. Breaks in rock are divided into two categories. A break along which there is no movement of the surrounding rock is called a *fracture*. A break along which the surrounding rock moves is called a **fault.** The surface or plane along which the motion occurs is called the *fault plane*. In a nonvertical fault, the *hanging wall* is the rock above the fault plane. The *footwall* is the rock below the fault plane.

fault a break in a body of rock along which one block slides relative to another; a form of brittle strain

Normal Faults

As shown in **Figure 7,** a *normal fault* is a fault in which the hanging wall moves downward relative to the footwall. Normal faults commonly form at divergent boundaries, where the crust is being pulled apart by tension. Normal faults may occur as a series of parallel fault lines, forming steep, steplike landforms. The Great Rift Valley of East Africa formed by large-scale normal faulting.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Folding and Faulting

SciLinks code: HQ60589

Reverse Faults

When compression causes the hanging wall to move upward relative to the footwall, also shown in **Figure 7,** a *reverse fault* forms. A *thrust fault* is a special type of reverse fault in which the fault plane is at a low angle or is nearly horizontal. Because of the low angle of the fault plane, the rock of the hanging wall is pushed up and over the rock of the footwall. Reverse faults and thrust faults are common in steep mountain ranges, such as the Rockies and the Alps.

Reading Check **How does a thrust fault differ from a reverse fault? (See the Appendix for answers to Reading Checks.)**

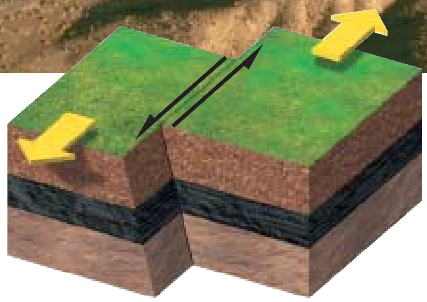

Figure 8 ▶ The San Andreas fault system stretches more than 1,200 km across California and is the result of two tectonic plates moving in different directions.

Strike-Slip Faults

In a *strike-slip fault,* the rock on either side of the fault plane slides horizontally in response to shear stress. Strike-slip faults got their name because they slide, or *slip,* parallel to the direction of the length, or *strike,* of the fault. Some strike-slip fault planes are vertical, but many are sloped.

Strike-slip faults commonly occur at transform boundaries, where tectonic plates grind past each other as they move in opposite directions. These motions cause shear stress on the rocks at the edges of the plates. Strike-slip faults also occur at fracture zones between offset segments of mid-ocean ridges. Commonly, strike-slip faults occur as groups of smaller faults in areas where large-scale deformation is happening.

Sizes of Faults

Like folds, faults vary greatly in size. Some faults are so small that they affect only a few layers of rock in a small region. Other faults are thousands of kilometers long and may extend several kilometers below Earth's surface. Generally, large faults that cover thousands of kilometers are composed of systems of many smaller, related faults, rather than of a single fault. The San Andreas fault in California, shown in **Figure 8,** is an example of a large fault system.

Section 1 Review

1. **Summarize** how isostatic adjustments affect isostasy.
2. **Identify and describe** three types of stress.
3. **Compare** stress and strain.
4. **Describe** one type of strain that results when rock responds to stress by permanently deforming without breaking.
5. **Identify** features that all types of folds share and features that only some types of folds have.
6. **Describe** four types of faults.
7. **Compare** folding and faulting as responses to stress.

CRITICAL THINKING

8. **Applying Ideas** Why is faulting most likely to occur near Earth's surface and not deep within Earth?
9. **Making Comparisons** How would the isostatic adjustment that results from the melting of glaciers differ from the isostatic adjustment that may occur when a large river empties into the ocean?
10. **Analyzing Relationships** You are examining a rock outcrop that shows a fold in which both limbs are horizontal but occur at different elevations. What type of fold does this outcrop show, and what can you say about the type of stress that the rock underwent?
11. **Predicting Consequences** You are watching a lab experiment in which a rock sample is being gently heated and slowly bent. Would you expect the rock to fold or to fracture? Explain your reasoning.

CONCEPT MAPPING

12. Use the following terms to create a concept map: *stress, compression, strain, tension, shear stress, folds,* and *faults.*

Section 2 How Mountains Form

A mountain is the most extreme type of deformation. Mount Everest, whose elevation is more than 8 km above sea level, is Earth's highest mountain. Forces inside Earth cause Mount Everest to grow taller every year. Mount St. Helens, a volcanic mountain, captured the world's attention in 1980 when its explosive eruption devastated the surrounding area.

OBJECTIVES

- **Identify** the types of plate collisions that form mountains.
- **Identify** four types of mountains.
- **Compare** how folded and fault-block mountains form.

KEY TERMS

mountain range
folded mountain
fault-block mountain
dome mountain

Mountain Ranges and Systems

A group of adjacent mountains that are related to each other in shape and structure is called a **mountain range.** Mount Everest is part of the Great Himalaya Range, and Mount St. Helens is part of the Cascade Range. A group of mountain ranges that are adjacent is called a *mountain system*. In the eastern United States, for example, the Great Smoky, Blue Ridge, Cumberland, and Green mountain ranges make up the Appalachian mountain system.

The largest mountain systems are part of two larger systems called *mountain belts*. Earth's two major mountain belts, the circum-Pacific belt and the Eurasian-Melanesian belt, are shown in **Figure 1.** The circum-Pacific belt forms a ring around the Pacific Ocean. The Eurasian-Melanesian belt runs from the Pacific islands through Asia and southern Europe and into northwestern Africa.

mountain range a series of mountains that are closely related in orientation, age, and mode of formation

Figure 1 ▶ Most mountain ranges lie along either the Eurasian-Melanesian mountain belt or the circum-Pacific mountain belt.

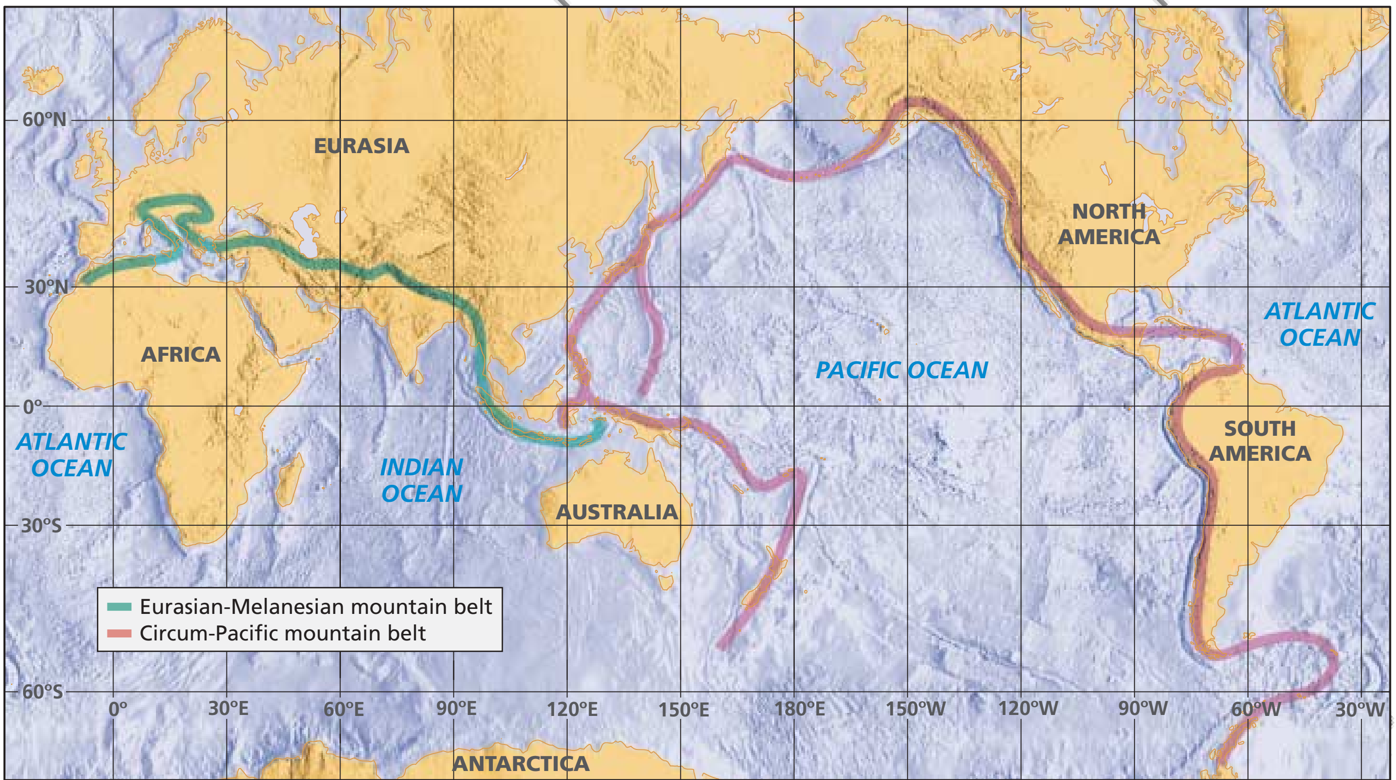

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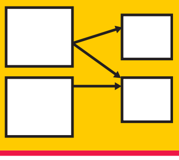
Plate Tectonics and Mountains

Both the circum-Pacific and the Eurasian-Melanesian mountain belts are located along convergent plate boundaries. Scientists think that the location of these two mountain belts provides evidence that most mountains form as a result of collisions between tectonic plates. Some mountains, such as the Appalachians, do not lie along active convergent plate boundaries. However, evidence indicates that the places at which these ranges formed were previously active plate boundaries.

Graphic Organizer **Cause-and-Effect Map**

Create the **Graphic Organizer** entitled "Cause-and-Effect Map" described in the Skills Handbook section of the Appendix. Label the effect with "Mountain formation." Then, fill in the map with causes of mountain formation and details about why mountains form.

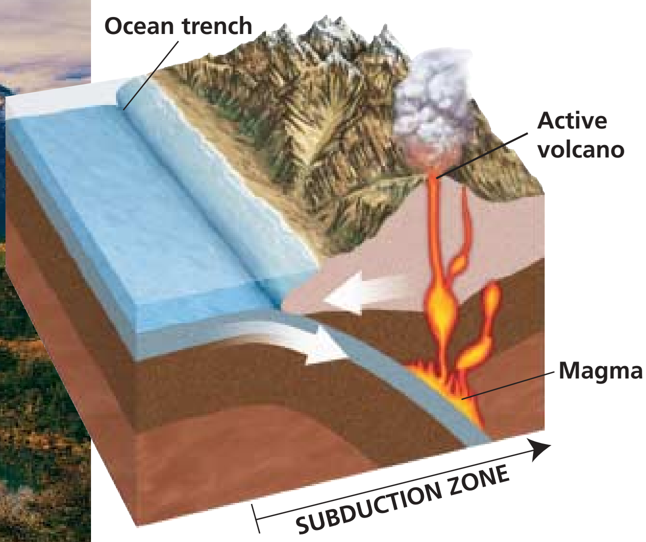


Collisions Between Continental and Oceanic Crust

Some mountains form when oceanic lithosphere and continental lithosphere collide at convergent plate boundaries. When the moving plates collide, the oceanic lithosphere subducts beneath the continental lithosphere, as shown in **Figure 2.** This type of collision produces such large-scale deformation of rock that high mountains are uplifted. In addition, the subduction of the oceanic lithosphere causes partial melting of the overlying mantle and crust. This melting produces magma that may eventually erupt to form volcanic mountains on Earth's surface. The mountains of the Cascade Range in the northwest region of the United States formed in this way. The Andes mountains on the western coast of South America are another example of mountains that formed by this type of collision.

Some mountains at the boundary between continental lithosphere and oceanic lithosphere may form by a different process. As the oceanic lithosphere subducts, pieces of crust called *terranes* are scraped off. These terranes then become part of the continent and may form mountains.

Figure 2 ▶ The Andes, shown below, are being uplifted as the Pacific plate subducts beneath the South American plate.



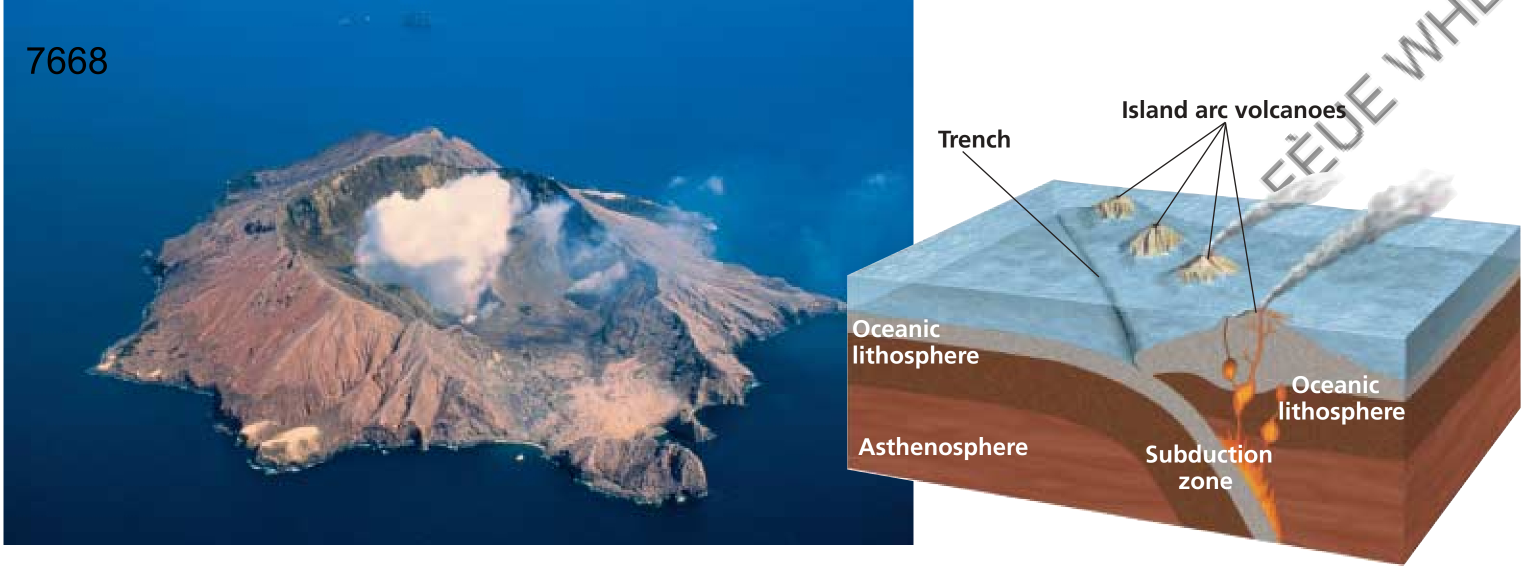


Figure 3 ▶ The Mariana Islands in the North Pacific Ocean are volcanic mountains that formed by the collision of two oceanic plates.

Collisions Between Oceanic Crust and Oceanic Crust

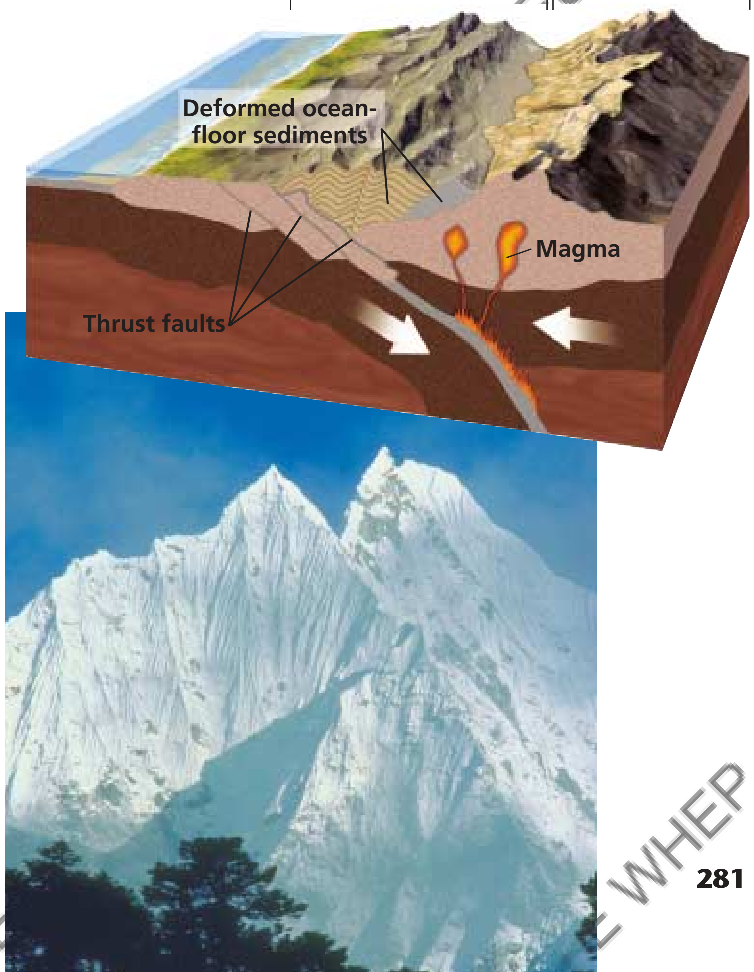
Volcanic mountains commonly form where two plates whose edges consist of oceanic lithosphere collide. In this collision, the denser oceanic plate subducts beneath the other oceanic plate, as shown in **Figure 3.** As the denser oceanic plate subducts, fluids from the subducting lithosphere cause partial melting of the overlying mantle and crust. The resulting magma rises and breaks through the oceanic lithosphere. These eruptions of magma form an arc of volcanic mountains on the ocean floor. The Mariana Islands are the peaks of volcanic mountains that rose above sea level.

Collisions Between Continents

Mountains can also form when two continents collide, as **Figure 4** shows. The Himalaya Mountains formed from such a collision. About 100 million years ago, India broke apart from Africa and Antarctica and became a separate continent. The Indian plate then began moving north toward Eurasia. The oceanic lithosphere of the Indian plate subducted beneath the Eurasian plate. This subduction continued until the continental lithosphere of India collided with the continental lithosphere of Eurasia. Because the two continents have equally dense lithosphere, subduction stopped, but the collision continued. The intense deformation that resulted from the collision uplifted the Himalayas. Because the plates are still colliding, the Himalayas are still growing taller.

Reading Check **Why are the Himalayas growing taller today? (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ The Himalayas formed when India collided with Eurasia.



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Topic: Types of Mountains

SciLinks code: HQ61568

Types of Mountains

Mountains are more than just elevated parts of Earth's crust. Mountains are complicated structures whose rock formations provide evidence of the stresses that created the mountains. Scientists classify mountains according to the way in which the crust was deformed and shaped by mountain-building stresses. Examples of several types of mountains are shown in **Figure 5.**

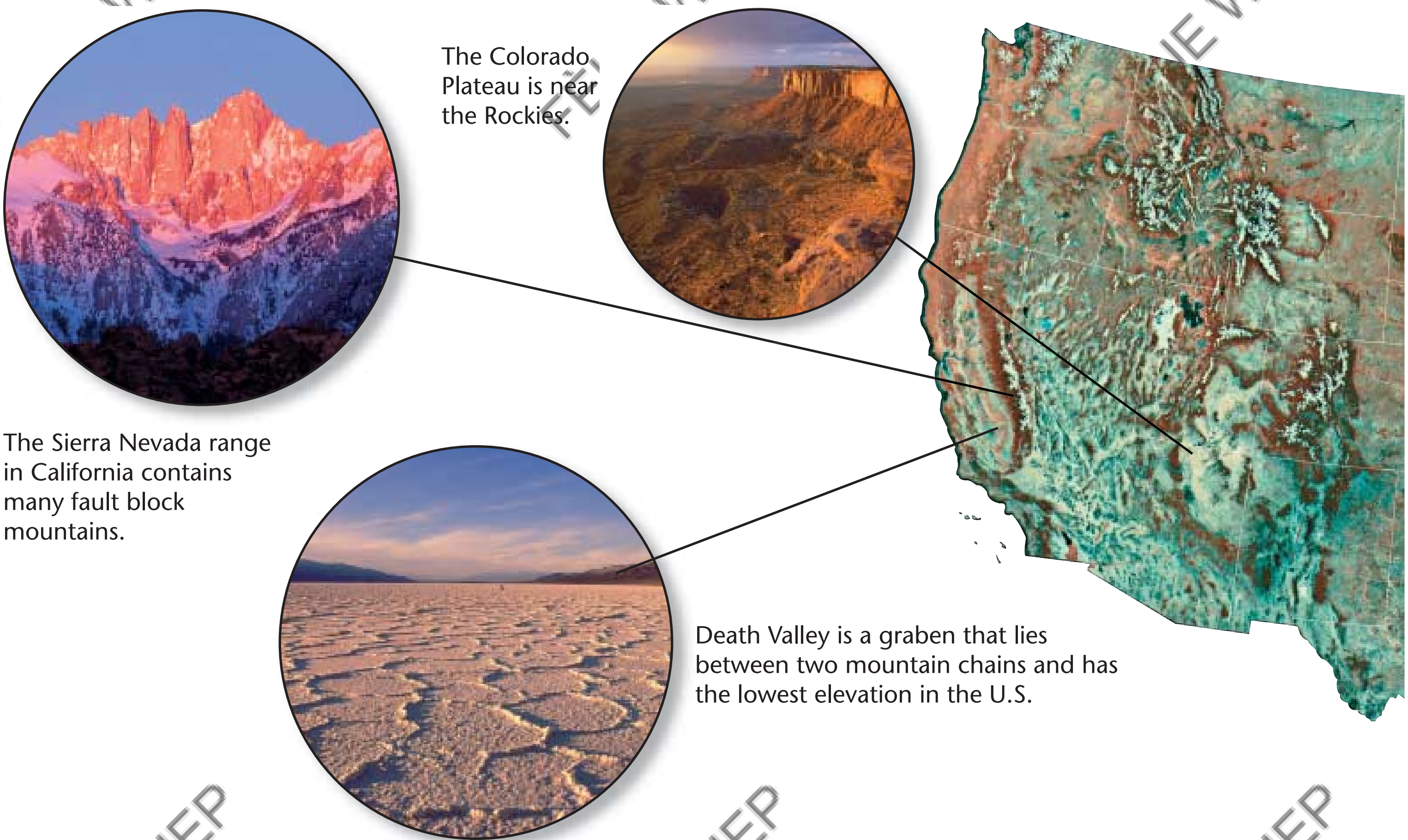
Folded Mountains and Plateaus

The highest mountain ranges in the world consist of folded mountains that form when continents collide. **Folded mountains** form when tectonic movements squeeze rock layers together into accordion-like folds. Parts of the Alps, the Himalayas, the Appalachians, and Russia's Ural Mountains consist of very large and complex folds.

The same stresses that form folded mountains also uplift plateaus. *Plateaus* are large, flat areas of rock high above sea level. Most plateaus form when thick, horizontal layers of rock are slowly uplifted so that the layers remain flat instead of faulting and folding. Most plateaus are located near mountain ranges. For example, the Tibetan Plateau is next to the Himalaya Mountains, and the Colorado Plateau is next to the Rockies. Plateaus can also form when layers of molten rock harden and pile up on Earth's surface or when large areas of rock are eroded.

folded mountain a mountain that forms when rock layers are squeezed together and uplifted

Figure 5 ▶ Mountains in the United States



The Colorado Plateau is near the Rockies.

The Sierra Nevada range in California contains many fault block mountains.

Death Valley is a graben that lies between two mountain chains and has the lowest elevation in the U.S.

Fault-Block Mountains and Grabens

Where parts of Earth's crust have been stretched and broken into large blocks, faulting may cause the blocks to tilt and drop relative to other blocks. The relatively higher blocks form **fault-block mountains.** The Sierra Nevada range of California consists of many fault-block mountains.

The same type of faulting that forms fault-block mountains also forms long, narrow valleys called *grabens*. Grabens develop when steep faults break the crust into blocks and one block slips downward relative to the surrounding blocks. Grabens and fault-block mountain ranges commonly occur together. For example, the Basin and Range Province of the western United States consists of grabens separated by fault-block mountain ranges.

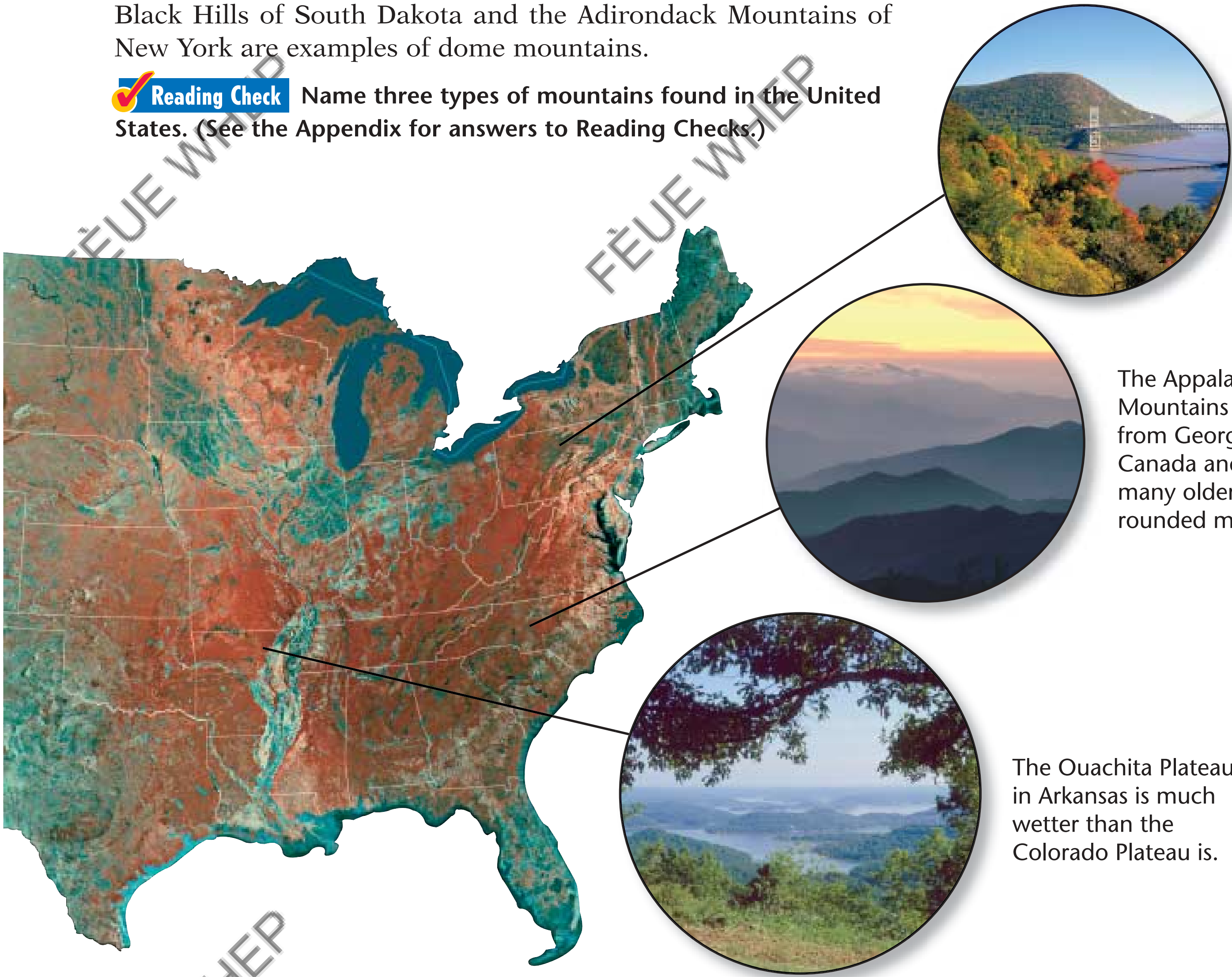
fault-block mountain a mountain that forms where faults break Earth's crust into large blocks and some blocks drop down relative to other blocks

dome mountain a circular or elliptical, almost symmetrical elevation or structure in which the stratified rock slopes downward gently from the central point of folding

Dome Mountains

A rare type of mountain forms when magma rises through the crust and pushes up the rock layers above the magma. The result is a **dome mountain,** a circular structure made of rock layers that slope gently away from a central point. Dome mountains may also form when tectonic forces gently uplift rock layers. The Black Hills of South Dakota and the Adirondack Mountains of New York are examples of dome mountains.

Reading Check **Name three types of mountains found in the United States. (See the Appendix for answers to Reading Checks.)**



This dome mountain is part of the Adirondacks in New York.

The Appalachian Mountains stretch from Georgia to Canada and contain many older, more rounded mountains.

The Ouachita Plateau in Arkansas is much wetter than the Colorado Plateau is.

Figure 6 ▶ Mount St. Helens (front) and Mount Rainier (back) in the Cascade Range of the western United States are volcanic mountains that formed along a convergent boundary.

Volcanic Mountains

Mountains that form when magma erupts onto Earth's surface are called *volcanic mountains*. Volcanic mountains commonly form along convergent plate boundaries. The Cascade Range of Washington, Oregon, and northern California is composed of this type of volcanic mountain, two of which are shown in **Figure 6.**

Some of the largest volcanic mountains are part of the mid-ocean ridges along divergent plate boundaries. Magma rising to Earth's surface at divergent boundaries makes mid-ocean ridges volcanically active areas. The peaks of these volcanic mountains sometimes rise above sea level to form volcanic islands, such as the Azores in the North Atlantic Ocean.

Other large volcanic mountains form on the ocean floor at hot spots. *Hot spots* are volcanically active areas that lie far from tectonic plate boundaries. These areas seem to correspond to places where hot material rises through Earth's interior and reaches the lithosphere. The Hawaiian Islands are an example of this type of volcanic mountain. The main island of Hawaii is a volcanic mountain that reaches almost 9 km above the ocean floor and has a base that is more than 160 km wide.

Section 2 Review

1. **Describe** three types of tectonic plate collisions that form mountains.
2. **Summarize** the process by which folded mountains form.
3. **Compare** how plateaus form with how folded mountains form.
4. **Describe** the formation of fault-block mountains.
5. **Explain** how dome mountains form.
6. **Explain** how volcanic mountains form.

CRITICAL THINKING

7. **Making Connections** Explain two ways in which volcanic mountains might get smaller.
8. **Making Connections** Explain why fault-block mountains and grabens are commonly found near each other.
9. **Analyzing Ideas** You are standing on a large, flat area of land and are examining the nearby mountains. You notice that many of the mountains have large folds. Are you standing on a plateau or a graben? Explain your answer.
10. **Making Predictions** Igneous rocks form from cooled magma. Near what types of mountains would you expect to find new igneous rocks?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *mountain range, fault-block mountains, mountain belt, folded mountains, mountain system, dome mountains,* and *volcanic mountains.*

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Chapter 11 Highlights

Sections

1 How Rock Deforms

Key Terms

- **deformation,** 271
- **isostasy,** 271
- **stress,** 273
- **strain,** 274
- **fold,** 275
- **fault,** 277

Key Concepts

- Tectonic plate movement and isostatic adjustments cause stress on the rock in Earth's crust.
- Stress can squeeze rock together, pull rock apart, and bend and twist rock.
- Stress on rock can cause strain, or the deformation of rock. Rock can deform by folding or by breaking to form fractures or faults.
- Three types of faults occur in rock: normal faults, reverse faults (including thrust faults), and strike-slip faults.

2 How Mountains Form

Key Terms

- **mountain range,** 279
- **folded mountain,** 282
- **fault-block mountain,** 283
- **dome mountain,** 283

Key Concepts

- Mountains make up mountain ranges, which, in turn, make up mountain systems. The largest mountain systems form two major mountain belts.
- Four types of mountains are folded mountains, fault-block mountains, dome mountains, and volcanic mountains.
- Mountains commonly form as the result of the collision of tectonic plates.
- A mountain is classified according to the way in which the crust deforms when the mountain forms.

Chapter 11 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *isostasy*
2. *compression*
3. *shear stress*

For each pair of terms, explain how the meanings of the terms differ.

4. *stress* and *strain*
5. *fold* and *fault*
6. *syncline* and *monocline*
7. *dome mountains* and *volcanic mountains*
8. *folded mountains* and *fault-block mountains*

Understanding Key Concepts

9. When the weight of an area of Earth's crust increases, the lithosphere
   - **a.** sinks.
   - **b.** melts.
   - **c.** rises.
   - **d.** collides.

10. The force per unit area that changes the shape and volume of rock is
    - **a.** footwall.
    - **b.** isostasy.
    - **c.** rising.
    - **d.** stress.

11. Shear stress
    - **a.** bends, twists, or breaks rock.
    - **b.** causes isostasy.
    - **c.** causes rock to melt.
    - **d.** causes rock to expand.

12. When stress is applied under conditions of high pressure and high temperature, rock is more likely to
    - **a.** fracture.
    - **b.** sink.
    - **c.** fault.
    - **d.** fold.

13. Folds in which both limbs remain horizontal are called
    - **a.** monoclines.
    - **b.** fractures.
    - **c.** synclines.
    - **d.** anticlines.

14. When a fault is not vertical, the rock above the fault plane makes up the
    - **a.** tension.
    - **b.** footwall.
    - **c.** hanging wall.
    - **d.** compression.

15. A fault in which the rock on either side of the fault plane moves horizontally in nearly opposite directions is called a
    - **a.** normal fault.
    - **b.** reverse fault.
    - **c.** strike-slip fault.
    - **d.** thrust fault.

16. The largest mountain systems are part of still larger systems called
    - **a.** continental margins.
    - **b.** ranges.
    - **c.** belts.
    - **d.** synclines.

17. Large areas of flat-topped rock high above the surrounding landscape are
    - **a.** grabens.
    - **b.** footwalls.
    - **c.** hanging walls.
    - **d.** plateaus.

Short Answer

18. Name two types of deformation in Earth's crust, and explain how each type occurs.

19. Explain how to identify an anticline.

20. Identify the two major mountain belts on Earth.

21. Describe how the various types of mountains are categorized.

22. Identify the two forces that are kept in balance by isostatic adjustments.

23. Compare the features of dome mountains with those of fault-block mountains.

Critical Thinking

24. **Evaluating Ideas** If thick ice sheets covered large parts of Earth's continents again, how would you expect the lithosphere to respond to the added weight of the continental ice sheets? Explain your answer.

25. **Analyzing Relationships** When the Indian plate collided with the Eurasian plate and produced the Himalaya Mountains, which type of stress most likely occurred? Which type of stress is most likely occurring along the Mid-Atlantic Ridge? Which type of stress would you expect to find along the San Andreas fault? Explain your answers.

26. **Making Predictions** If the force that causes a rock to deform slightly begins to ease, what may happen to the rock? What might happen if the force causing the deformation became greater?

27. **Analyzing Processes** Why do you think that dome mountains do not always become volcanic mountains?

Concept Mapping

28. Use the following terms to create a concept map: *stress, strain, brittle, ductile, folds, fault, normal fault, reverse fault, thrust fault,* and *strike-slip fault*.

Math Skills

29. **Making Calculations** Scientists calculate that parts of the Himalayas are growing at a rate of 6.1 mm per year. At this rate, in how many years will the Himalayas have grown 1 m taller?

30. **Analyzing Data** Rock stress is measured as 48 MPa at point A below Earth's surface. At point B nearby, stress is measured as 12 MPa. What percentage of the stress at point A is the stress at point B equal to?

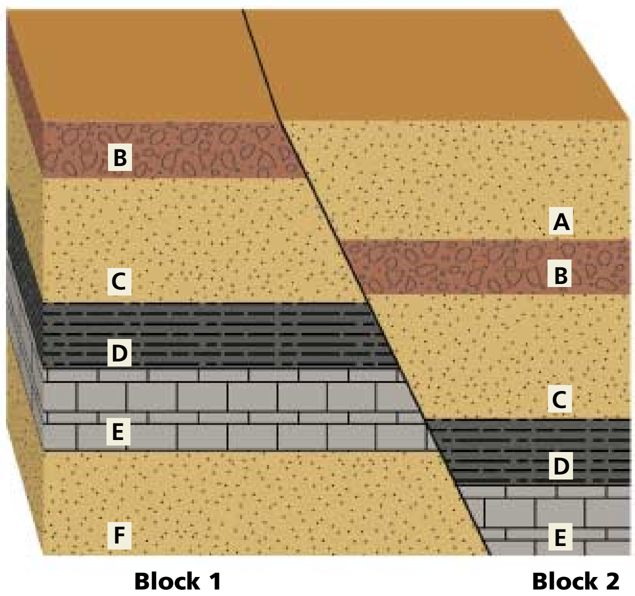
Writing Skills

31. **Creative Writing** Write a short story from the perspective of a rock that is being deformed. Describe the stresses that are affecting the rock and the final result of the stress.

32. **Writing from Research** Look for photos or illustrations of folding and faulting in a particular area. Then, research the geologic history of the area, and write a report based on your findings. Use any photos or drawings that you find to illustrate your report.

Interpreting Graphics

The diagram below shows a fault. Use the diagram below to answer the questions that follow.



33. Is Block 2 a footwall or a hanging wall? Explain your answer.

34. What type of fault is illustrated? Explain your answer.

35. What type of stress generally causes this type of fault?

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Chapter 11 Standardized Test Prep

Understanding Concepts

***Directions (1–4):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Where are most plateaus located?
A. near mountain ranges
B. bordering ocean basins
C. beneath grabens
D. alongside diverging boundaries

2 Which of the following features form where parts of the crust have been broken by faults?
F. monoclines
G. plateaus
H. synclines
I. grabens

3 Which of the following statements describes the formation of rock along strike-slip faults?
A. Rock on either side of the fault plane slides vertically.
B. Rock on either side of the fault plane slides horizontally.
C. Rock in the hanging wall is pushed up and over the rock of the footwall.
D. Rock in the hanging wall moves down relative to the footwall.

4 Which does not result in mountain formation?
F. collisions between continental and oceanic crust
G. subduction of one oceanic plate beneath another oceanic plate
H. deposition and isostasy
I. deformation caused by collisions between two or more continents

***Directions (5–7):* For *each* question, write a short response.**

5 What is the term for a condition of gravitational equilibrium in Earth's crust?

6 What is the term for a type of stress that squeezes and shortens a body?

7 As a volcanic mountain range is built, isostatic adjustment will cause the crust beneath the mountain range to do what?

Reading Skills

***Directions (8–10):* Read the passage below. Then, answer the questions.**

Stress and Strain

Stress is defined as the amount of force per unit area on a rock. When enough stress is placed on a rock, the rock becomes strained. This strain causes the rock to deform, usually by bending and breaking. For example, if you put a small amount of pressure on the ends of a drinking straw, the straw may not bend—even though you have put stress on it. However, when you put enough pressure on it, the straw bends, or becomes strained.

One example of stress is when tectonic plates collide. When plates collide, a large amount of stress is placed on the rocks that make up the plate, especially the rocks at the edge of the plates involved in the collision. Because of the stress, these rocks become extremely strained. In fact, even the shapes of the tectonic plates can change as a result of these powerful collisions.

8 Based on the passage, which of the following statements is not true?
A. Strain can cause a rock to deform by bending or breaking.
B. Rocks, like drinking straws, will not bend when pressure is applied to them.
C. Stress is defined as amount of force per unit area that is put on a rock.
D. A large amount of stress is placed on the rocks involved in tectonic plate collisions.

9 Which of the following statements can be inferred from the information in the passage?
F. The stress of tectonic plate collisions often creates large, smooth plains of rock.
G. The stress of tectonic plate collisions often creates large, mountain chains.
H. Bending a drinking straw requires the same amount of pressure that is needed to bend a rock.
I. The only time a rock has stress is when the rock is involved in a tectonic collision.

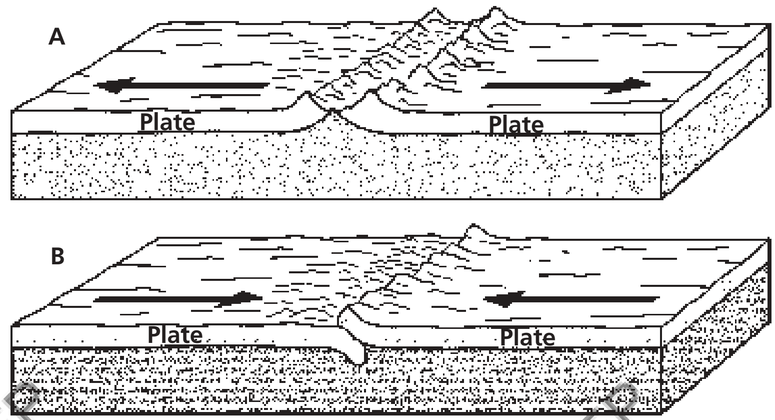
10 What happens to rocks when plates collide?

Interpreting Graphics

***Directions (11–14):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagrams below show a divergent and a convergent plate boundary. Use these diagrams to answer questions 11 and 12.

Divergent and Convergent Plate Boundaries



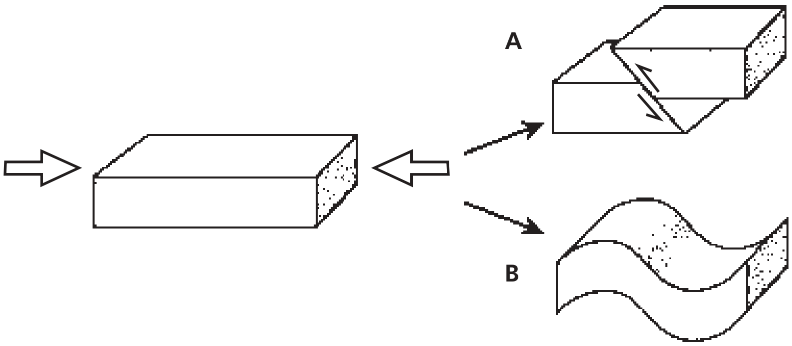
11 Which of the following is not likely to be found at or occur at the boundary found in diagram A?

A. volcanoes
B. lava flows
C. earthquakes
D. subduction

12 How does the subduction of the oceanic crust shown in diagram B produce volcanic mountains?

The diagram below shows two possible outcomes when pressure, which is represented by the large arrows, is applied to the rock on the left. Use this diagram to answer questions 13 and 14.

Rock Deformation



13 What type of deformation is seen in the rock labeled A?

F. brittle
G. ductile
H. folding
I. monocline

14 Describe the type of rock deformation shown in Figure B. Under what conditions is this type of deformation likely to occur?

Test TIP

Carefully study all of the details of a diagram before answering the question or questions that refer to it.

Making Models Lab

Continental Collisions

Objectives

- **Model** collisions between continents.
- **Explain** how mountains form at convergent boundaries.

Materials

- blocks, wooden, 2.5 cm × 2.5 cm × 6 cm
- bobby pins, long (5)
- cardboard, thick, 15 cm × 30 cm
- napkins, paper, light- and dark-colored
- paper, adding-machine, 6 cm × 35 cm
- ruler, metric
- scissors
- tape, masking

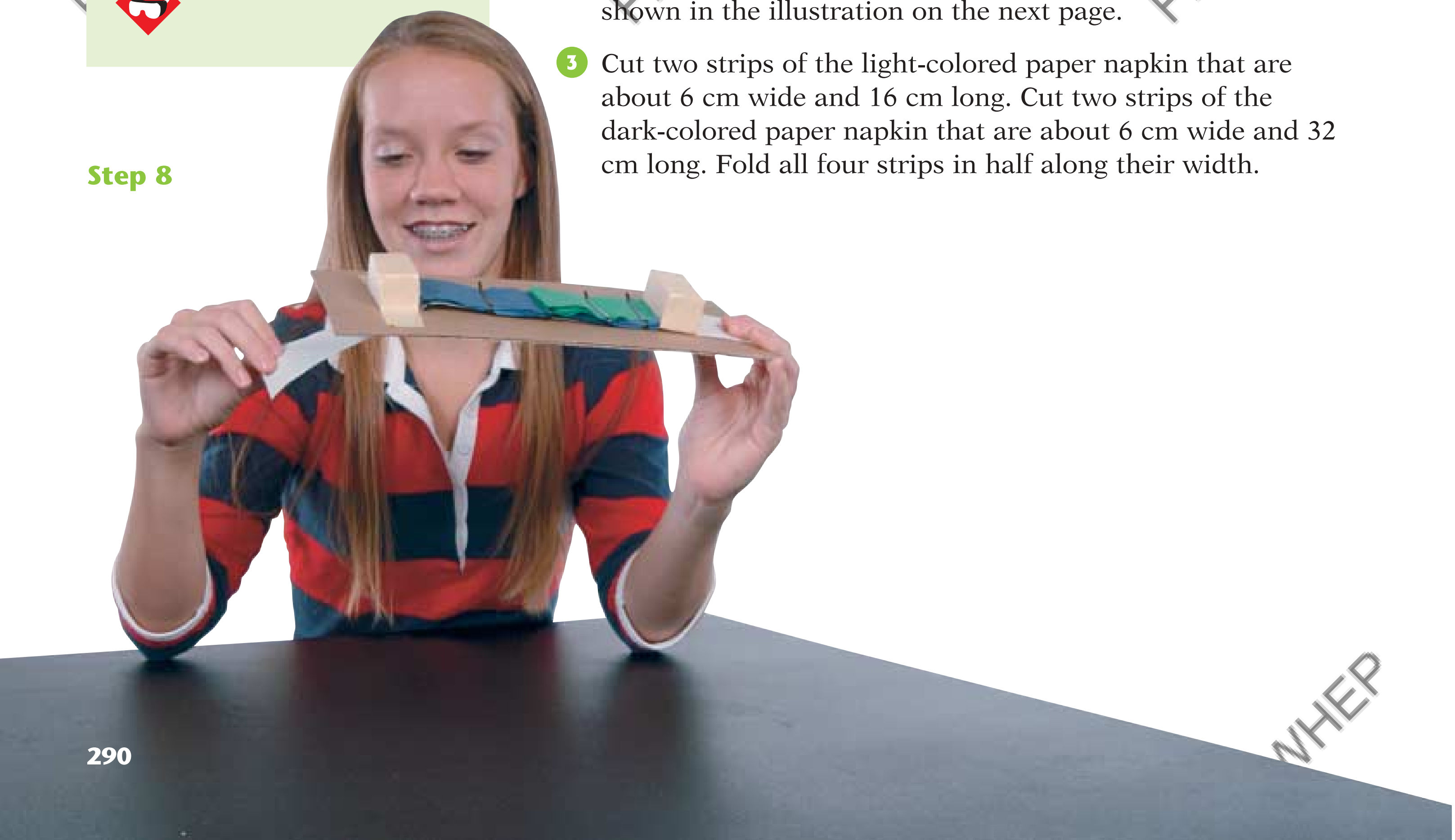
Safety

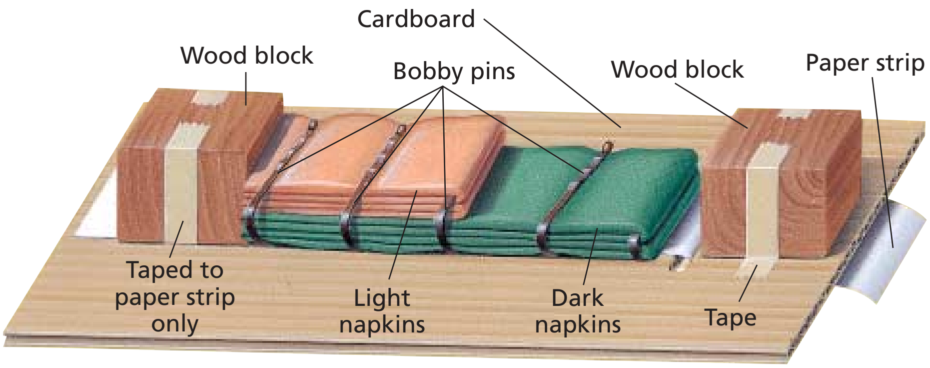
When the subcontinent of India broke away from Africa and Antarctica and began to move northward toward Eurasia, the oceanic crust on the northern side of India began to subduct beneath the Eurasian plate. The deformation of the crust resulted in the formation of the Himalaya Mountains. Earthquakes in the Himalayan region suggest that India is still pushing against Eurasia. In this lab, you will create a model to help explain how the Himalaya Mountains formed as a result of the collision of the Indian and Eurasian tectonic plates.

PROCEDURE

1. To assemble the continental-collision model, cut a 7 cm slit in the cardboard. The slit should be about 6 cm from (and parallel to) one of the short edges of the cardboard. Cut the slit wide enough such that the adding-machine paper will feed through the slit without being loose.
2. Securely tape one wood block along the slit between the slit and the near edge of the cardboard. Tape the other block across the paper strip about 6 cm from one end of the paper. The blocks should be parallel to one another, as shown in the illustration on the next page.
3. Cut two strips of the light-colored paper napkin that are about 6 cm wide and 16 cm long. Cut two strips of the dark-colored paper napkin that are about 6 cm wide and 32 cm long. Fold all four strips in half along their width.

Step 8





4. Stack the napkin strips on top of each other such that all of the folds are along the same side. Place the two dark-colored napkins on the bottom.
5. Place the napkin strips lengthwise on the paper strip. The nonfolded ends of the napkin strips should be butted up against the wood block that is taped to the paper strip.
6. Using the bobby pins, attach the napkins to the paper strip, as shown in the illustration above.
7. Push the long end of the paper strip through the slit in the cardboard until the first fold of the napkin rests against the fixed wood block.
8. Hold the cardboard at about eye level, and pull down gently on the paper strip. You may need a partner's help. Observe what happens as the dark-colored napkins contact the fixed wood block and as you continue to pull down on the paper strip. Stop pulling when you feel resistance from the strip.

ANALYSIS AND CONCLUSION

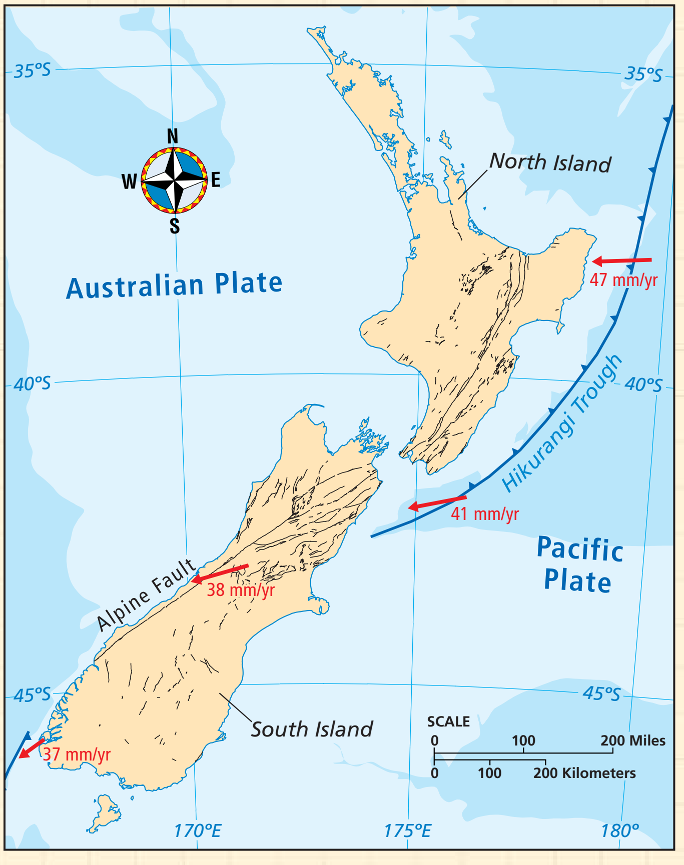
1. **Evaluating Methods** Explain what is represented by the dark napkins, the light napkins, and the wood blocks.
2. **Analyzing Processes** What plate-tectonics process is represented by the motion of the paper strip in the model? Explain your answer.
3. **Applying Ideas** What type of mountain would result from the kind of collision shown by the model?
4. **Evaluating Models** Explain how the process modeled here differs from the way the Himalaya Mountains formed.

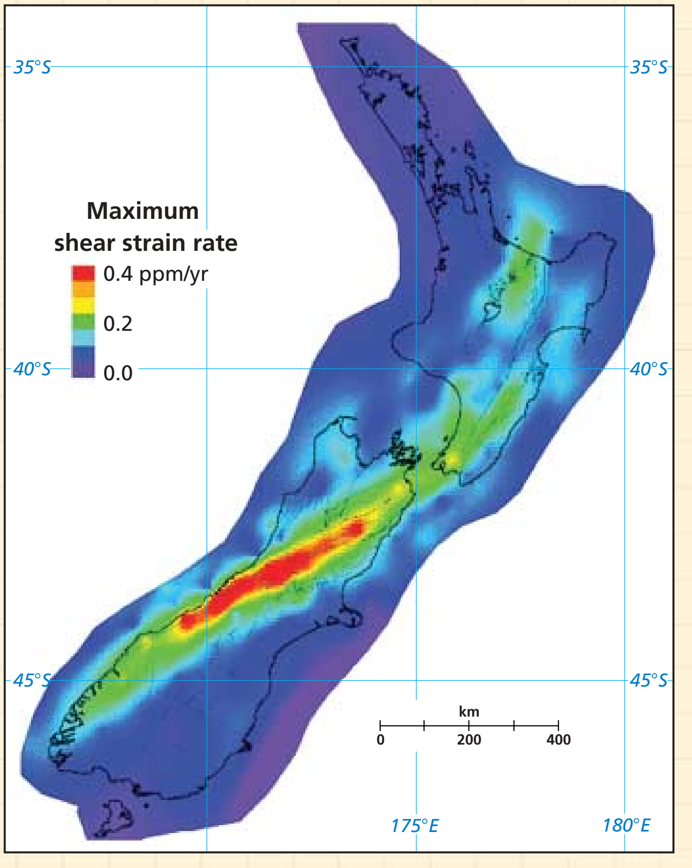
Extension

1. **Analyzing Data** Obtain a world map of earthquake epicenters. Study the map. Describe the pattern of epicenters in the Himalayan region. Does the pattern suggest that the Himalaya Mountains are still growing?
2. **Writing from Research** Read about the breakup of Gondwanaland and the movement of India toward the Northern hemisphere. Write about stages in India's movement. List the time frame in which each important event occurred.

MAPS in Action

Shear Strain in New Zealand





Map Skills Activity

The map above shows the plate boundary zone of New Zealand. In this region, the Australian plate is moving north, while the Pacific plate is moving west. These complex plate movements create areas of tension, compression, and shear stress, which result in strain. Strain is measured in parts per million (ppm) per year (yr). The map on the right shows strain in New Zealand. Use the two maps to answer the questions below.

1. **Using a Key** What is the highest amount of shear strain shown on the map?
2. **Identifying Locations** Using latitude and longitude, describe the location of the area that has the highest amount of shear strain.
3. **Using a Key** What is the approximate length of the area of maximum shear strain?
4. **Understanding Relationships** What type of plate boundary is located along the east coast of the North Island? Explain your answer.
5. **Comparing Areas** In what areas might you expect to find compression? Explain your answer.
6. **Making Inferences** What type of fault is the Alpine Fault? Explain your answer.
7. **Drawing Conclusions** A mountain range known as the *Southern Alps* runs through the center of the South Island. What type of mountains do you think the Southern Alps are? Explain your answer.

IMPACT on Society

The Disappearing Mediterranean

Two of the most breathtaking regions of the world are the Alps and the Mediterranean. The Alps, considered to be among Earth's most beautiful mountains, have become a vast natural playground for skiers, hikers, and climbers. The Mediterranean plays host to travelers from around the world who wish to sample the diverse cultures, balmy climate, and famous beach resorts that surround the Mediterranean Sea. Local residents depend on the sea for their economic well-being.

Push and Pull

The same natural forces that uplifted the Alps are slowly swallowing up the Mediterranean. The Alps were formed—and are still being shaped—by the collision of two tectonic plates. Italy, part of which rides on the African plate, collided with Eurasia sometime in the past. The collision formed the Alps, but it did not stop the movement of the African plate.

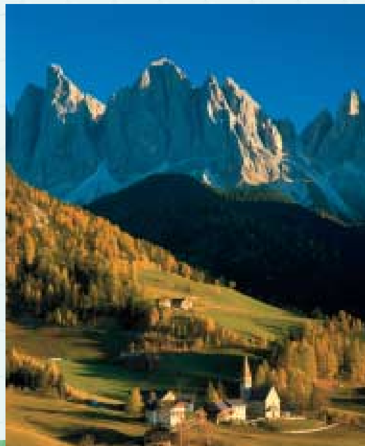
The History of Tomorrow

The northern oceanic crust of the African plate, which is the sea floor of the Mediterranean, is still subducting beneath the continental crust of Eurasia. As more oceanic crust subducts, the Mediterranean Sea will become smaller. Italy, which continues to be pushed into Eurasia, will eventually cease to exist as we know it. When the northern coast of the African continent finally collides with Eurasia, the Mediterranean Sea will disappear completely. Of course, this process will take millions of years, because tectonic plates move so slowly.

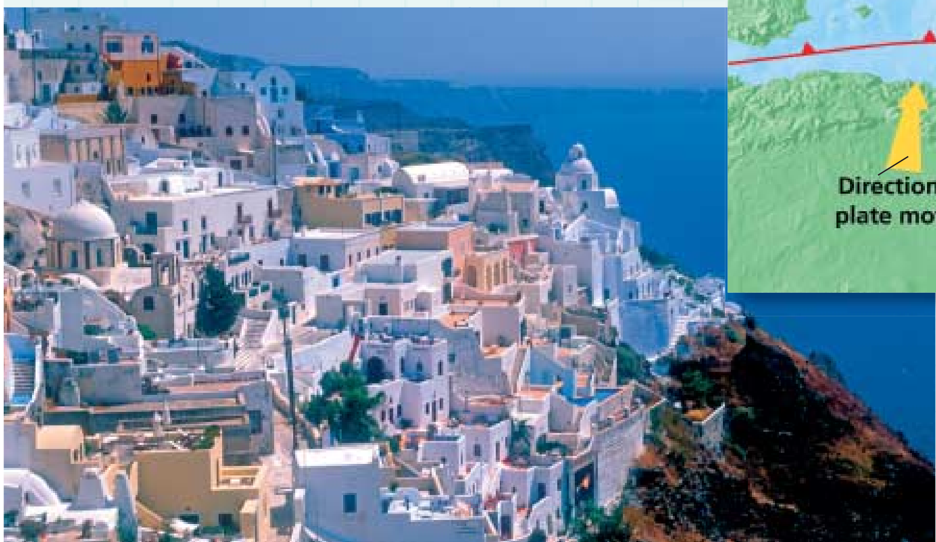
Extension

1. **Applying Ideas** What do you think will happen to the Alps as the African plate continues to push northward?

▼ The Alps formed when the African plate collided with Eurasia.



▼ The Aegean Sea is part of the larger Mediterranean Sea, which is slowly disappearing.



◀ Santorini, Greece, is an island in the Aegean Sea.

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Chapter 12 Earthquakes

Sections

1 How and Where Earthquakes Happen

2 Studying Earthquakes

3 Earthquakes and Society

What You'll Learn

- What causes earthquakes
- How scientists measure earthquakes
- How earthquakes cause damage

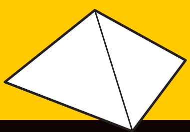
Why It's Relevant

Understanding how, where, and why earthquakes happen can help scientists and engineers reduce earthquake damage and save lives. Studying earthquakes also helps scientists understand Earth's interior.

PRE-READING ACTIVITY

FOLDNOTES

Pyramid Before you read this chapter, create the **FoldNote** entitled "Pyramid" described in the Skills Handbook section of the Appendix. Label the sides of the pyramid with "How earthquakes happen," "How earthquakes are studied," and "How earthquakes affect society." As you read the chapter, write characteristics of each topic on the appropriate pyramid side.



▶ This expressway in Kobe, Japan, was toppled by the ground shaking of an earthquake that lasted 20 seconds and had a moment magnitude of 6.9.

Section 1 How and Where Earthquakes Happen

Earthquakes are one of the most destructive natural disasters. A single earthquake can kill thousands of people and cause millions of dollars in damage. **Earthquakes** are defined as movements of the ground that are caused by a sudden release of energy when rocks along a fault move. Earthquakes usually occur when rocks under stress suddenly shift along a fault. A *fault* is a break in a body of rock along which one block slides relative to another.

OBJECTIVES

- **Describe** elastic rebound.
- **Compare** body waves and surface waves.
- **Explain** how the structure of Earth's interior affects seismic waves.
- **Explain** why earthquakes generally occur at plate boundaries.

KEY TERMS

earthquake
elastic rebound
focus
epicenter
body wave
surface wave
P wave
S wave
shadow zone
fault zone

Why Earthquakes Happen

The rocks along both sides of a fault are commonly pressed together tightly. Although the rocks may be under stress, friction prevents them from moving past each other. In this immobile state, a fault is said to be *locked*. Parts of a fault remain locked until the stress becomes so great that the rocks suddenly grind past each other. This slippage causes the trembling and vibrations of an earthquake.

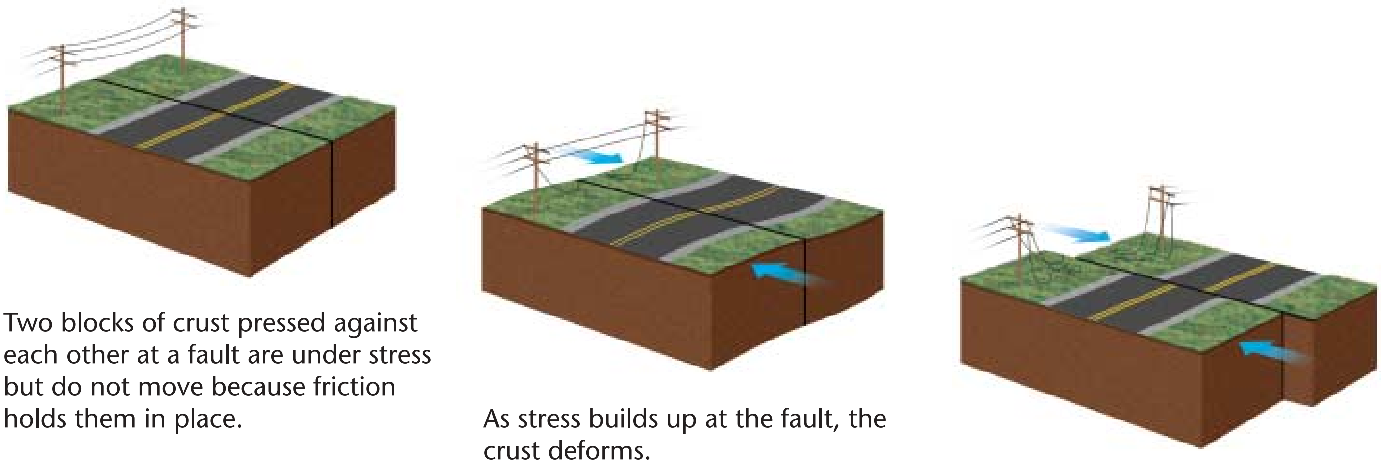
Elastic Rebound

Geologists think that earthquakes are a result of elastic rebound. **Elastic rebound** is the sudden return of elastically deformed rock to its undeformed shape. In this process, the rocks on each side of a fault are moving slowly. If the fault is locked, stress in the rocks increases. When the rocks are stressed past the point at which they can maintain their integrity, they fracture. The rocks then separate at their weakest point and *rebound*, or spring back to their original shape. This process is shown in **Figure 1.**

earthquake a movement or trembling of the ground that is caused by a sudden release of energy when rocks along a fault move

elastic rebound the sudden return of elastically deformed rock to its undeformed shape

Figure 1 ▶ **Elastic Rebound**



Two blocks of crust pressed against each other at a fault are under stress but do not move because friction holds them in place.

As stress builds up at the fault, the crust deforms.

The rock fractures and then snaps back into its original shape, which causes an earthquake.

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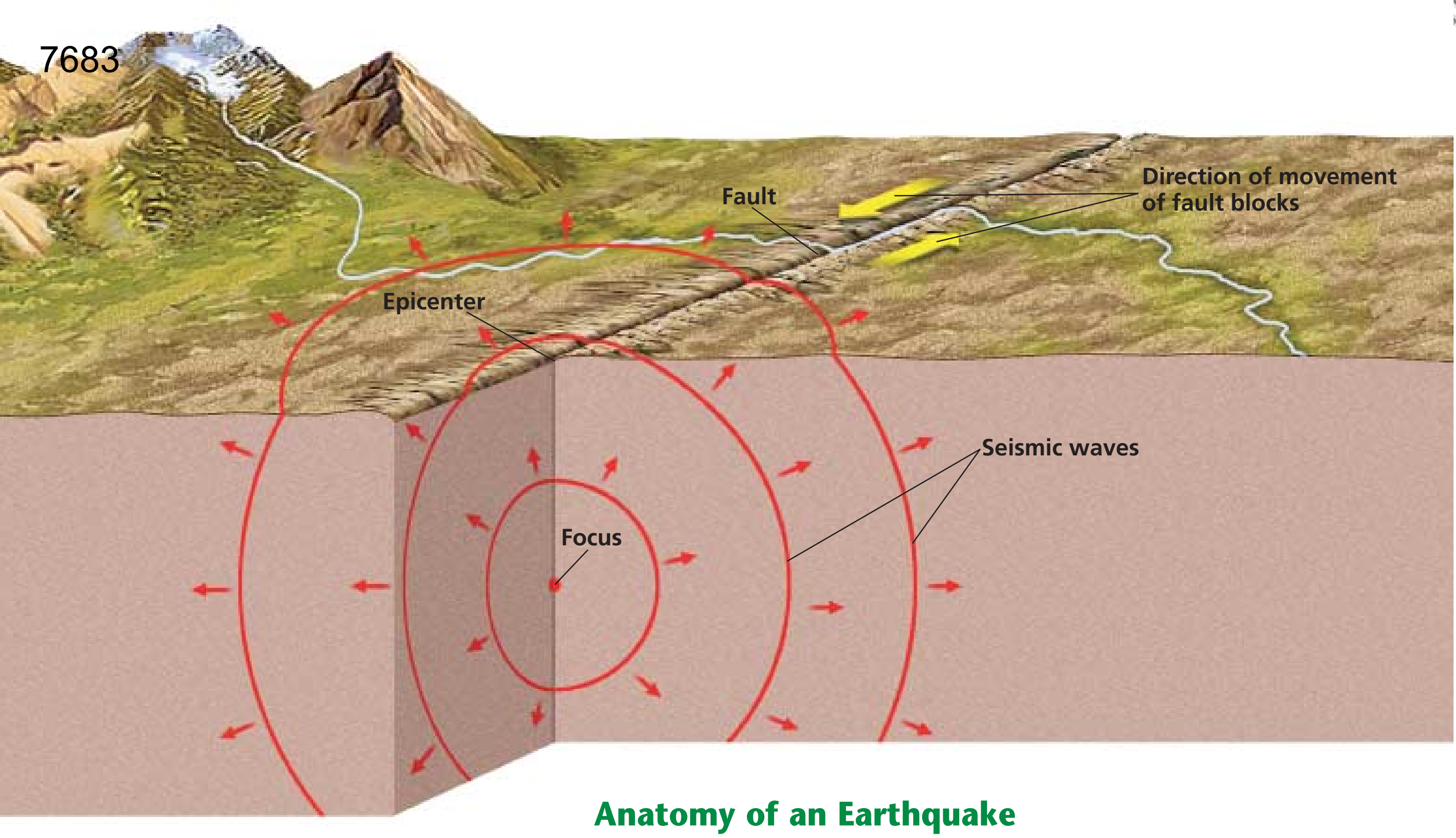

Figure 2 ▶ The epicenter of an earthquake is the point on the surface directly above the focus.

Anatomy of an Earthquake

The location within Earth along a fault at which the first motion of an earthquake occurs is called the **focus** (plural, *foci*). The point on Earth's surface directly above the focus is called the **epicenter** (EP i SENT uhr), as shown in **Figure 2.**

Although the focus depths of earthquakes vary, about 90% of continental earthquakes have a shallow focus. Earthquakes that have shallow foci take place within 70 km of Earth's surface. Earthquakes that have intermediate foci occur at depths between 70 km and 300 km. Earthquakes that have deep foci take place at depths between 300 km and 650 km. Earthquakes that have deep foci usually occur in subduction zones and occur farther from the plate boundary than shallower earthquakes do.

By the time the vibrations from an earthquake that has an intermediate or deep focus reach the surface, much of their energy has dissipated. For this reason, the earthquakes that usually cause the most damage usually have shallow foci.

focus the location within Earth along a fault at which the first motion of an earthquake occurs

epicenter the point on Earth's surface directly above an earthquake's starting point, or focus

body wave in geology, a seismic wave that travels through the body of a medium

surface wave in geology, a seismic wave that travels along the surface of a medium and that has a stronger effect near the surface of the medium than it has in the interior

Seismic Waves

As rocks along a fault slip into new positions, the rocks release energy in the form of vibrations called *seismic waves*. These waves travel outward in all directions from the focus through the surrounding rock. This wave action is similar to what happens when you drop a stone into a pool of still water and circular waves ripple outward from the center.

Earthquakes generally produce two main types of waves. **Body waves** are waves that travel through the body of a medium. **Surface waves** travel along the surface of a body rather than through the middle. Each type of wave travels at a different speed and causes different movements in Earth's crust.

Body Waves

Body waves can be placed into two main categories: P waves and S waves. **P waves,** also called *primary waves* or *compression waves*, are the fastest seismic waves and are always the first waves of an earthquake to be detected. P waves cause particles of rock to move in a back-and-forth direction that is parallel to the direction in which the waves are traveling, as shown in **Figure 3.** P waves can move through solids, liquids, and gases. The more rigid the material is, the faster the P waves travel through it.

S waves, also called *secondary waves* or *shear waves*, are the second-fastest seismic waves and arrive at detection sites after P waves. S waves cause particles of rock to move in a side-to-side direction that is perpendicular to the direction in which the waves are traveling. Unlike P waves, however, S waves can travel through only solid material.

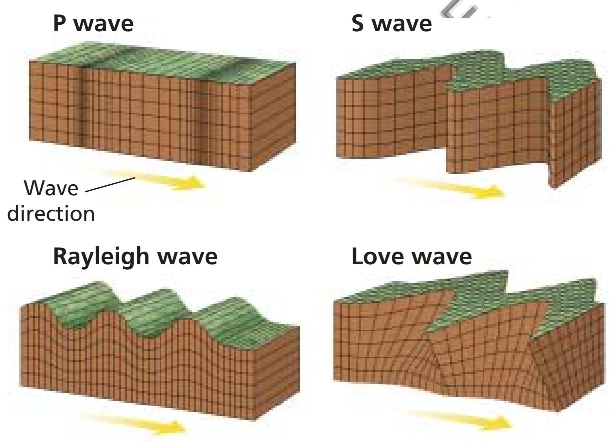

Figure 3 ▶ The different types of seismic waves cause different rock movements, which have different effects on Earth's crust.

Surface Waves

Surface waves form from motion along a shallow fault or from the conversion of energy when P waves and S waves reach Earth's surface. Although surface waves are the slowest-moving waves, they may cause the greatest damage during an earthquake. The two types of surface waves are Love waves and Rayleigh waves. *Love waves* cause rock to move side-to-side and perpendicular to the direction in which the waves are traveling. *Rayleigh waves* cause the ground to move with an elliptical, rolling motion.

Reading Check **Describe the two types of surface waves. (See the Appendix for answers to Reading Checks.)**

P wave a primary wave, or compression wave; a seismic wave that causes particles of rock to move in a back-and-forth direction parallel to the direction in which the wave is traveling; P waves are the fastest seismic waves and can travel through solids, liquids, and gases

S wave a secondary wave, or shear wave; a seismic wave that causes particles of rock to move in a side-to-side direction perpendicular to the direction in which the wave is traveling; S waves are the second-fastest seismic waves and can travel only through solids

Connection to ENGINEERING

Seismic Reflection Surveying

Many surveying companies have discovered the usefulness of seismic waves in mapping underground features. These features can be used to identify possible mineral deposits and oil or natural gas reservoirs.

In seismic surveying, a seismic shock is generated by using explosives, air guns, or a mechanical thumper. The seismic waves produced by the shock travel through the ground and reflect off bedding planes or other features below the surface. The reflected waves travel back to the surface, where they are recorded by an array of geophones. *Geophones* are instruments that convert the motion of a seismic wave into an electrical signal.

The geophones are set up in a straight line to collect data that are used to construct a two-dimensional profile of the underground layers. Scientists can also arrange the geophones in more-complex patterns to create three-dimensional images of the layers. Because each underground layer reflects waves at a different time, scientists can plot all of the data to construct an accurate picture of the underground layers.

Seismic reflection can be used to study phenomena at a variety of scales. It may be used to study just the top few tens of meters of soil and rock, or it may be used to study the structure of the deep crust. In particular, this technology has been adapted for use by oil and natural gas exploration companies to locate oil and gas reservoirs.

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Topic: Earthquakes
SciLinks code: HQ60453
Topic: Seismic Waves
SciLinks code: HQ61371

shadow zone an area on Earth's surface where no direct seismic waves from a particular earthquake can be detected

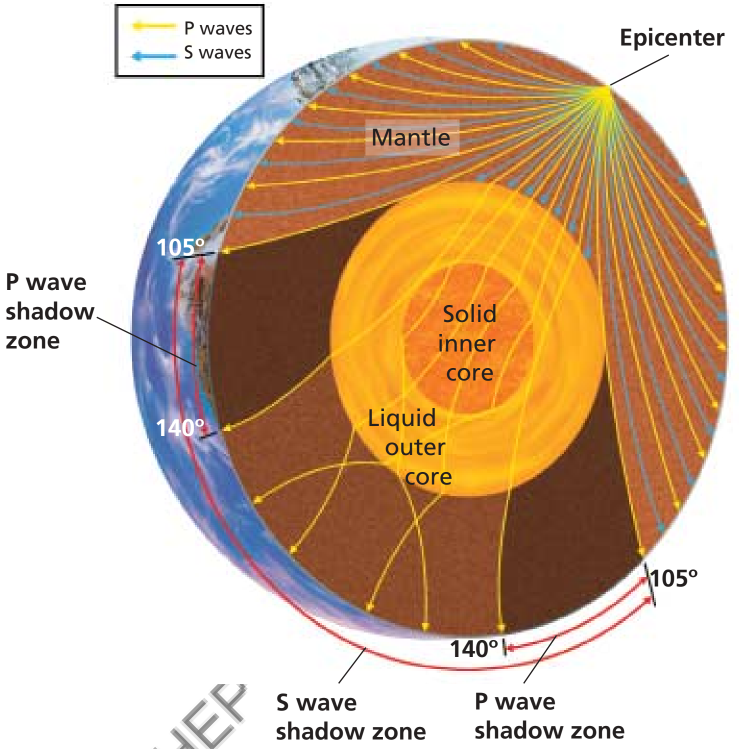
Seismic Waves and Earth's Interior

Seismic waves are useful to scientists in exploring Earth's interior. The composition of the material through which P waves and S waves travel affects the speed and direction of the waves. For example, P waves travel fastest through materials that are very rigid and are not easily compressed. By studying the speed and direction of seismic waves, scientists can learn more about the makeup and structure of Earth's interior.

Earth's Internal Layers

In 1909, Andrija Mohorovičić (MOH hoh ROH vuh CHICH), a Croatian scientist, discovered that the speed of seismic waves increases abruptly at about 30 km beneath the surface of continents. This increase in speed takes place because the mantle is denser than the crust. The location at which the speed of the waves increases marks the boundary between the crust and the mantle. The depth of this boundary varies from about 10 km below the oceans to about 30 km below continents. By studying the speed of seismic waves, scientists have been able to locate boundaries between other internal layers of Earth. The three main compositional layers of Earth are the *crust,* the *mantle,* and the *core*. Earth is also composed of five mechanical layers—the *lithosphere,* the *asthenosphere,* the *mesosphere,* the *outer core,* and the *inner core*.

Figure 4 ▶ P waves and S waves behave differently as they pass through different structural layers of Earth.



Shadow Zones

Recordings of seismic waves around the world reveal shadow zones. **Shadow zones** are locations on Earth's surface where no body waves from a particular earthquake can be detected. Shadow zones exist because the materials that make up Earth's interior are not uniform in rigidity. When seismic waves travel through materials of differing rigidities, the speed of the waves changes. The waves will also bend and change direction as they pass through different materials.

As shown in **Figure 4,** a large S-wave shadow zone covers the side of Earth that is opposite an earthquake. S waves do not reach the S-wave shadow zone because they cannot pass through the liquid outer core. Although P waves can travel through all of the layers, the speed and direction of the waves change as the waves pass through each layer. The waves bend in such a way that a P-wave shadow zone forms.

Reading Check **What causes the speed of a seismic wave to change? (See the Appendix for answers to Reading Checks.)**

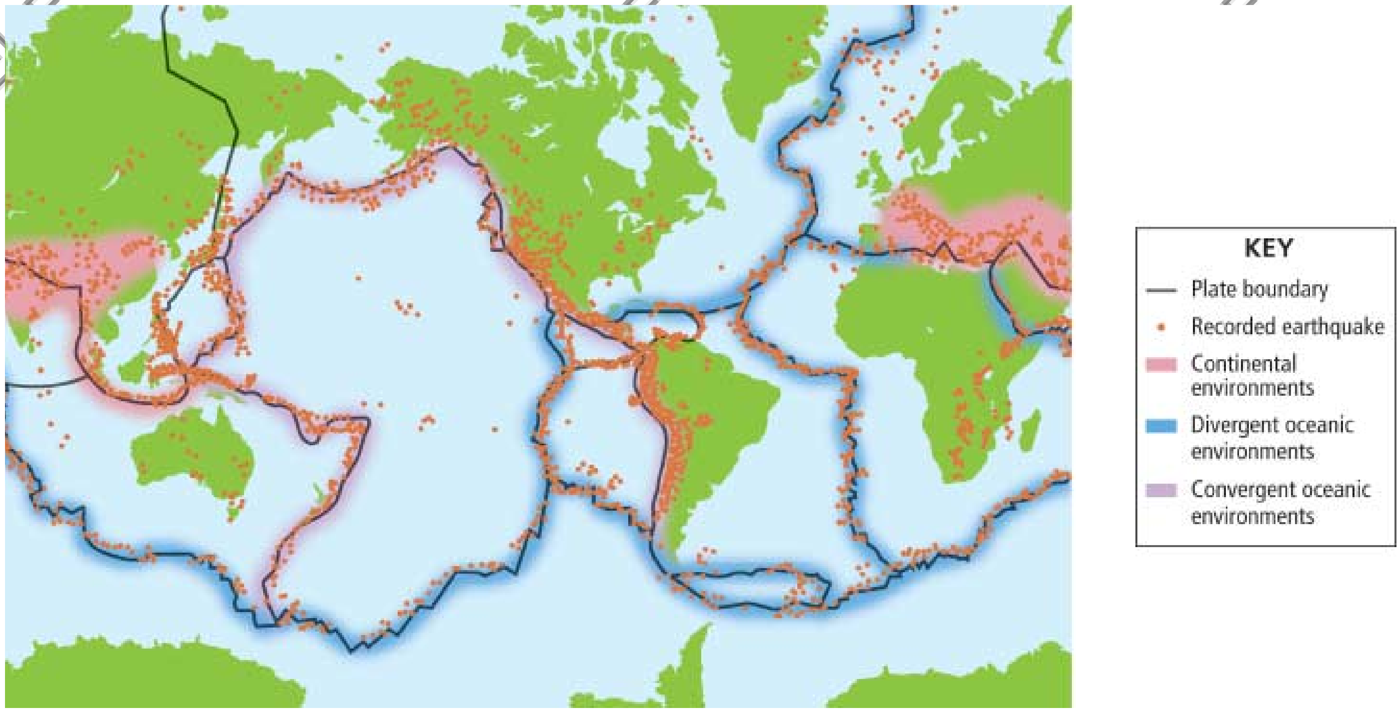


Figure 5 ▶ Earthquakes are the result of tectonic stresses in Earth's crust and occur in three main tectonic settings—mid-ocean ridges, subduction zones, and continental collisions.

Earthquakes and Plate Tectonics

Earthquakes are the result of stresses in Earth's lithosphere. Most earthquakes occur in three main tectonic environments, as shown in **Figure 5.** These settings are generally located at or near tectonic plate boundaries, where stress on the rock is greatest.

Convergent Oceanic Environments

At convergent plate boundaries, plates move toward each other and collide. The plate that is denser subducts, or sinks into the asthenosphere below the other plate. As the plates move, the overriding plate scrapes across the top of the subducting plate, and earthquakes occur. Convergent oceanic boundaries can occur between two oceanic plates or between one oceanic plate and one continental plate.

Divergent Oceanic Environments

At the divergent plate boundaries that make up the mid-ocean ridges, plates are moving away from each other. Earthquakes occur along mid-ocean ridges because oceanic lithosphere is pulling away from both sides of each ridge. This spreading motion causes earthquakes along the ocean ridges.

Continental Environments

Earthquakes also occur at locations where two continental plates converge, diverge, or move horizontally in opposite directions. As the continental plates interact, the rock surrounding the boundary experiences stress. The stress may cause mountains to form and also causes frequent earthquakes.

Graphic Organizer **Spider Map**

Create the Graphic Organizer entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Major earthquake zones." Create a leg for each type of earthquake zone. Then, fill in the map with details about each type of earthquake zone.

Figure 6 ▶ A series of parallel transform faults, seen in the center of this photo, make up part of the North Anatolian fault zone in Turkey.

Fault Zones

At some plate boundaries, there are regions of numerous, closely spaced faults called **fault zones.** Fault zones form at plate boundaries because of the intense stress that results when the plates separate, collide, subduct, or slide past each other. One such fault zone is the North Anatolian fault zone, shown in **Figure 6,** that extends almost the entire length of the country of Turkey. Where the edge of the Arabian plate pushes against the Eurasian plate, the small Turkish microplate is squeezed westward. When enough stress builds up, movement occurs along one or more of the individual faults in the fault zone and sometimes causes major earthquakes.

fault zone a region of numerous, closely spaced faults

Earthquakes Away from Plate Boundaries

Not all earthquakes result from movement along plate boundaries. The most widely felt series of earthquakes in the history of the United States did not occur near an active plate boundary. Instead, these earthquakes occurred in the middle of the continent, near New Madrid, Missouri, in 1811 and 1812. The vibrations from the earthquakes that rocked New Madrid were so strong that they caused damage as far away as South Carolina.

It was not until the late 1970s that studies of the Mississippi River region revealed an ancient fault zone deep within Earth's crust. This zone is thought to be part of a major fault zone in the North American plate. Scientists have determined that the fault formed at least 600 million years ago and that it was later buried under many layers of sediment and rock.

Section 1 Review

1. **Describe** elastic rebound.
2. **Explain** the difference between the epicenter and the focus of an earthquake.
3. **Compare** body waves and surface waves.
4. **Explain** how seismic waves help scientists learn about Earth's interior.
5. **Explain** how the structure of Earth's interior affects seismic wave speed and direction.
6. **Explain** why earthquakes generally take place at plate boundaries.
7. **Describe** a fault zone, and explain how earthquakes occur along fault zones.

CRITICAL THINKING

8. **Applying Ideas** In earthquakes that cause the most damage, at what depth would movement along a fault most likely occur?
9. **Identifying Patterns** If a seismologic station measures P waves but no S waves from an earthquake, what can you conclude about the earthquake's location?
10. **Making Inferences** If an earthquake occurs in the center of Brazil, what can you infer about the geology of that area?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *earthquake, seismic wave, body wave, surface wave, P wave, S wave, Rayleigh wave,* and *Love wave.*

Section 2 Studying Earthquakes

The study of earthquakes and seismic waves is called *seismology*. Many scientists study earthquakes because earthquakes are the best tool Earth scientists have for investigating Earth's internal structure and dynamics. These scientists have developed special sensing equipment to record, locate, and measure earthquakes.

OBJECTIVES

- **Describe** the instrument used to measure and record earthquakes.
- **Summarize** the method scientists use to locate an epicenter.
- **Describe** the scales used to measure the magnitude and intensity of earthquakes.

KEY TERMS

seismograph
seismogram
magnitude
intensity

Recording Earthquakes

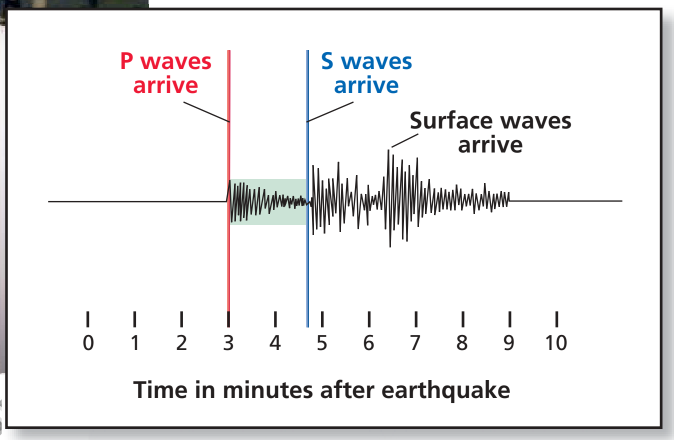
Vibrations in the ground can be detected and recorded by using an instrument called a **seismograph** (SIEZ MUH graf), such as the one shown in **Figure 1.** A modern three-component seismograph consists of three sensing devices. One device records the vertical motion of the ground. The other two devices record horizontal motion—one for east-west motion and the other for north-south motion. Seismographs record motion by tracing wave-shaped lines on paper or by translating the motion into electronic signals. The electronic signals can be recorded on magnetic tape or can be loaded directly into a computer that analyzes seismic waves. A tracing of earthquake motion that is recorded by a seismograph is called a **seismogram.**

Because they are the fastest-moving seismic waves, P waves are the first waves to be recorded by a seismograph. S waves travel much slower than P waves. Therefore, S waves are the second waves to be recorded by a seismograph. Surface waves, or Rayleigh and Love waves, are the slowest-moving waves. Thus, Rayleigh and Love waves are the last waves to be recorded by a seismograph.

seismograph an instrument that records vibrations in the ground

seismogram a tracing of earthquake motion that is recorded by a seismograph

Figure 1 ▶ A seismograph station has banks of seismographs to record earthquakes. Each type of seismic wave leaves a unique "signature" on a seismogram (inset).



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Topic: Earthquake Measurement
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Locating an Earthquake

To determine the distance to an epicenter, scientists analyze the arrival times of the P waves and the S waves. The longer the lag time between the arrival of the P waves and the arrival of the S waves is, the farther away the earthquake occurred. To determine how far an earthquake is from a given seismograph station, scientists consult a lag-time graph. This graph translates the difference in arrival times of the P waves and S waves into distance from the epicenter to each station. The start time of the earthquake can also be determined by using this graph.

To locate the epicenter of the earthquake, scientists use computers to perform complex triangulations based on information from several seismograph stations. Before computers were widely available, scientists performed this calculation in a simpler and more imprecise way. On a map, they drew circles around at least three seismograph stations that recorded vibrations from the earthquake. The radius of each circle was equal to the distance from that station to the earthquake's epicenter. The point at which all of the circles intersected indicated the location of the epicenter of the earthquake.

Quick LAB 20 min

Seismographic Record

Procedure

1. Line a **shoe box** with a **plastic bag.** Fill the box to the rim with **sand.** Put on the lid.
2. Mark an X near the center of the lid.
3. Fasten a **felt-tip pen** to the lid of the box with a tight **rubber band** so that the pen extends slightly beyond the edge of the box.
4. Have a partner hold a **pad a paper** so that the paper touches the pen.
5. Hold a **ball** over the X at a height of 30 cm. As your partner slowly moves the paper horizontally past the pen, drop the ball on the X.
6. Label the resulting line with the type of material in the box.
7. Replace about 2/3 of the sand with crumpled **newspaper.** Put on the lid, and fasten the pen to the lid with the rubber band.
8. Repeat steps 4–6.

Analysis

1. What do the lines on the paper represent?
2. What do the sand and newspaper represent?
3. Compare the lines made in steps 4–6 with those made in step 8. Which material vibrated more when the ball was dropped on it? Explain why one material might vibrate more than the other.
4. How might different types of crustal material affect seismic waves that pass through it?
5. How might the distance of the epicenter of an earthquake from a seismograph affect the reading of a seismograph?

Figure 2 ▶ The 1995 earthquake in Kobe, Japan, had a moment magnitude of 6.9, lasted 20 s, and killed 5,470 people.

Earthquake Measurement

Scientists who study earthquakes are interested in the amount of energy released by an earthquake. Scientists also study the amount of damage done by the earthquake. These properties are studied by measuring magnitude and intensity.

Magnitude

The measure of the strength of an earthquake is called **magnitude.** Magnitude is determined by measuring the amount of ground motion caused by an earthquake. Seismologists express magnitude by using a magnitude scale, such as the Richter scale or the moment magnitude scale.

magnitude a measure of the strength of an earthquake

The *Richter scale* measures the ground motion from an earthquake to find the earthquake's strength. While the Richter scale was widely used for most of the 20th century, scientists now prefer the moment magnitude scale. *Moment magnitude* is a measurement of earthquake strength based on the size of the area of the fault that moves, the average distance that the fault blocks move, and the rigidity of the rocks in the fault zone. Although the moment magnitude and the Richter scales provide similar values for small earthquakes, the moment magnitude scale is more accurate for large earthquakes.

The moment magnitude of an earthquake is expressed by a number. The larger the number, the stronger the earthquake. The largest earthquake that has been recorded registered a moment magnitude of 9.5 The earthquake in Kobe, Japan, in 1995 that caused the damage shown in **Figure 2** had a moment magnitude of 6.9. Earthquakes that have moment magnitudes of less than 2.5 usually are not felt by people.

Reading Check **What is the difference between the Richter scale and the moment magnitude scale? (See the Appendix for answers to Reading Checks.)**

MATHPRACTICE

Magnitudes On both the moment magnitude scale and the Richter scale, the energy of an earthquake increases by a factor of about 30 for each increment on the scale. Thus, a magnitude 4 earthquake releases 30 times as much energy as a magnitude 3 earthquake does. How much more energy does a magnitude 6 earthquake release than a magnitude 3 earthquake does?

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Table 1 ▼

Modified Mercalli Intensity Scale	
Intensity	**Description**
I	is not felt except by very few under especially favorable conditions
II	is felt by only few people at rest; delicately suspended items may swing
III	is felt by most people indoors; vibration is similar to the passing of a large truck
IV	is felt by many people; dishes and windows rattle; sensation is similar to a building being struck
V	is felt by nearly everyone; some objects are broken; and unstable objects are overturned
VI	is felt by all people; some heavy objects are moved; causes very slight damage to structures
VII	causes slight to moderate damage to ordinary buildings; some chimneys are broken
VIII	causes considerable damage (including partial collapse) to ordinary buildings
IX	causes considerable damage (including partial collapse) to earthquake-resistant buildings
X	destroys some to most structures, including foundations; rails are bent
XI	causes few structures, if any, to remain standing; bridges are destroyed and rails are bent
XII	causes total destruction; distorts lines of sight; objects are thrown into the air

Intensity

Before the development of magnitude scales, the size of an earthquake was determined based on the earthquake's effects. A measure of the effects of an earthquake on a particular area is the earthquake's **intensity.** The modified *Mercalli scale,* shown in **Table 1,** expresses intensity in Roman numerals from I to XII and provides a description of the effects of each earthquake intensity. The highest-intensity earthquake is designated by Roman numeral XII and is described as total destruction. The intensity of an earthquake depends on the earthquake's magnitude, the distance between the epicenter and the affected area, the local geology, and the earthquake's duration.

intensity in Earth science, the amount of damage caused by an earthquake

Section 2 Review

1. **Describe** the instrument that is used to record seismic waves.
2. **Compare** a seismograph and a seismogram.
3. **Summarize** the method that scientists used to identify the location of an earthquake before computers became widely used.
4. **Describe** the scales that scientists use to measure the magnitude of an earthquake.
5. **Explain** the difference between magnitude and intensity of an earthquake.

CRITICAL THINKING

6. **Analyzing Methods** Explain why it would be difficult for scientists to locate the epicenter of an earthquake if they have seismic wave information from only two locations.
7. **Evaluating Data** Explain why an earthquake with a moderate magnitude might have a high intensity?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *seismograph, seismogram, epicenter, P wave, S wave, magnitude,* and *intensity.*

Section 3 Earthquakes and Society

OBJECTIVES

- **Discuss** the relationship between tsunamis and earthquakes.
- **Describe** two possible effects of a major earthquake on buildings.
- **List** three safety techniques to prevent injury caused by earthquake activity.
- **Identify** four methods scientists use to forecast earthquake risks.

KEY TERMS

tsunami
seismic gap

Movement of the ground during an earthquake seldom directly causes many deaths or injuries. Instead, most injuries result from the collapse of buildings and other structures or from falling objects and flying glass. Other dangers include landslides, fires, explosions caused by broken electric and gas lines, and floodwaters released from collapsing dams.

Tsunamis

An earthquake whose epicenter is on the ocean floor may cause a giant ocean wave called a **tsunami** (tsoo NAH mee), which may cause serious destruction if it crashes into land. A tsunami may begin to form when a sudden drop or rise in the ocean floor occurs because of faulting associated with undersea earthquakes. The drop or rise of the ocean floor causes a large mass of sea water to also drop or rise. This mass of water moves up and down as it adjusts to the change in sea level. This movement sets into motion a series of long, low waves that increase in height as they near the shore. These waves are tsunamis. A tsunami may also be triggered by an underwater landslide caused by an earthquake.

tsunami a giant ocean wave that forms after a volcanic eruption, submarine earthquake, or landslide

Destruction to Buildings and Property

Most buildings are not designed to withstand the swaying motion caused by earthquakes. Buildings whose walls are weak may collapse completely. Very tall buildings may sway so violently that they tip over and fall onto lower neighboring structures, as shown in **Figure 1.**

The type of ground beneath a building can affect the way in which the building responds to seismic waves. A building constructed on loose soil and rock is much more likely to be damaged during an earthquake than a building constructed on solid ground is. During an earthquake, the loose soil and rock can vibrate like jelly. Buildings constructed on top of this kind of ground experience exaggerated motion and sway violently.

Figure 1 ▶ Rescue workers surround a building that collapsed in Taipei, Taiwan, during the earthquake of 1999.

Figure 2 ▶ In Tokyo, Japan—an area that has a high earthquake-hazard level—earthquake safety materials are available at disaster control centers.

Earthquake Safety

A destructive earthquake may take place in any region of the United States. However, destructive earthquakes are more likely to occur in certain geographic areas, such as California or Alaska. People who live near active faults should be ready to follow a few simple earthquake safety rules. These safety rules may help prevent death, injury, and property damage.

Before an Earthquake

Before an earthquake occurs, be prepared. Keep on hand a supply of canned food, bottled water, flashlights, batteries, and a portable radio. Some safety material is shown in **Figure 2.** Plan what you will do if an earthquake strikes while you are at home, in school, or in a car. Discuss these plans with your family. Learn how to turn off the gas, water, and electricity in your home.

During an Earthquake

When an earthquake occurs, stay calm. During the few seconds between tremors, you can move to a safer position. If you are indoors, protect yourself from falling debris by standing in a doorway or crouching under a desk or table. Stay away from windows, heavy furniture, and other objects that might topple over. If you are in school, follow the instructions given by your teacher or principal. If you are in a car, stop in a place that is away from tall buildings, tunnels, power lines, or bridges. Then, remain in the car until the tremors cease.

After an Earthquake

After an earthquake, be cautious. Check for fire and other hazards. Always wear shoes when walking near broken glass, and avoid downed power lines and objects touched by downed wires.

QuickLAB 10 min

Earthquake-Safe Buildings

Procedure

1. On a tabletop, build one structure by stacking **building blocks** on top of each other.
2. Pound gently on the side of the table. Record what happens to the structure.
3. Using **rubber bands,** wrap sets of three blocks together. Build a second structure by using these blocks.
4. Repeat step 2.

Analysis

1. Which of your structures was more resistant to damage caused by the "earthquake"?
2. How could this model relate to building real structures, such as elevated highways?

Earthquake Warnings and Forecasts

Humans have long dreamed of being able to predict earthquakes. Accurate earthquake predictions could help prevent injuries and deaths that result from earthquakes.

Today, scientists study past earthquakes to predict where future earthquakes are most likely to occur. Using records of past earthquakes, scientists can make approximate forecasts of future earthquake risks. However, there is currently no reliable way to predict exactly when or where an earthquake will occur. Even the best forecasts may be off by several years.

To make forecasts that are more accurate, scientists are trying to detect changes in Earth's crust that can signal an earthquake. Faults near many population centers have been located and mapped. Instruments placed along these faults measure small changes in rock movement around the faults and can detect an increase in stress. Currently, however, these methods cannot provide reliable or accurate predictions of earthquakes.

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Topic: Earthquakes and Society
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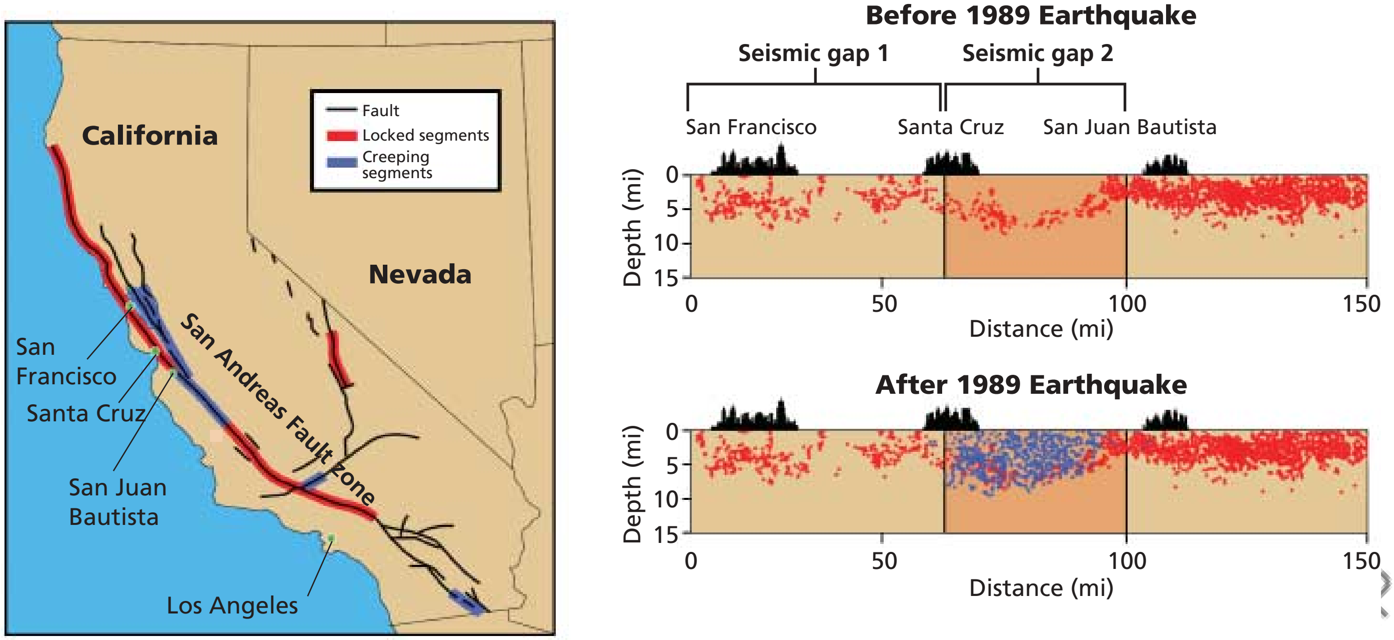
Seismic Gaps

Scientists have identified zones of low earthquake activity, or seismic gaps, along some faults. A **seismic gap** is an area along a fault where relatively few earthquakes have occurred recently but where strong earthquakes occurred in the past. Some scientists think that seismic gaps are likely locations of future earthquakes. Several gaps that exist along the San Andreas Fault zone may be sites of major earthquakes in the future. One of these locations, Loma Prieta, California, is shown in **Figure 3.**

Reading Check **Why do scientists think that seismic gaps are areas where future earthquakes are likely to occur? (See the Appendix for answers to Reading Checks.)**

seismic gap an area along a fault where relatively few earthquakes have occurred recently but where strong earthquakes are known to have occurred in the past

Figure 3 ▶ Each red dot in the cross section of the San Andreas Fault represents an earthquake or aftershock before the 1989 Loma Prieta earthquake. Note how seismic gap 2 was filled by the 1989 earthquake and its aftershocks, which are represented by the blue dots.



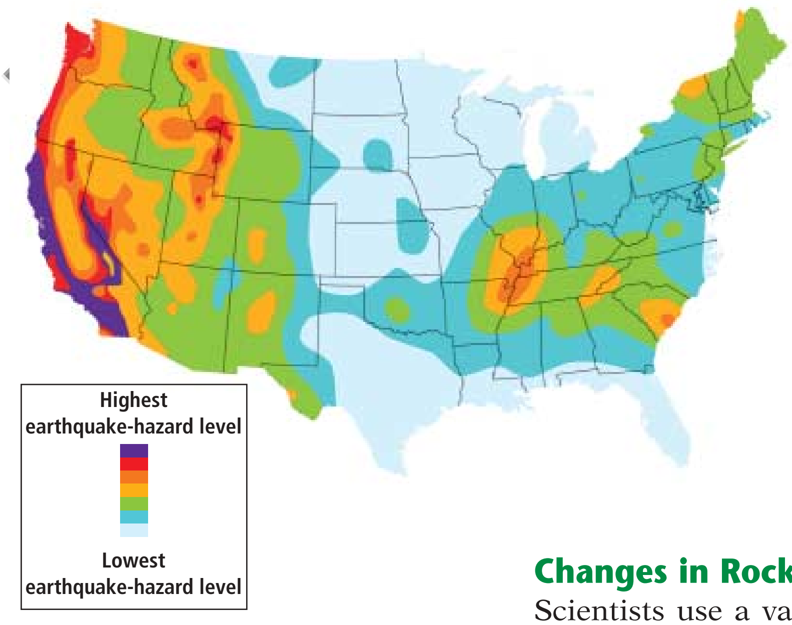


Figure 4 ▶ California, which has experienced severe earthquakes recently, has the highest earthquake-hazard level of the contiguous United States.

Foreshocks

Some earthquakes are preceded by little earthquakes called *foreshocks*. Foreshocks can precede an earthquake by a few seconds or a few weeks. In 1975, geophysicists in China recorded foreshocks near the city of Haicheng, which had a history of earthquakes. The city was evacuated the day before a major earthquake. The earthquake caused widespread destruction, but few lives were lost thanks to the warning. However, the Haicheng earthquake is the only example of a successful prediction made by using this method.

Changes in Rocks

Scientists use a variety of sensors to detect slight tilting of the ground and to identify the strain and cracks in rocks caused by the stress that builds up in fault zones. When these cracks in the rocks are filled with water, the magnetic and electrical properties of the rocks may change. Scientists also monitor natural gas seepage from rocks that are strained or fractured from seismic activity. Scientists hope that they will one day be able to use these signals to predict earthquakes.

Reliability of Earthquake Forecasts

Unfortunately, not all earthquakes have foreshocks or other precursors. Earthquake prediction is mostly unreliable. However, scientists have been able to determine areas that have a high earthquake-hazard level, as shown in **Figure 4.** Scientists continue to study seismic activity so that they may one day make accurate forecasts and save more lives.

Section 3 Review

1. **Discuss** the relationship between tsunamis and earthquakes.
2. **Describe** two possible effects of a major earthquake on buildings.
3. **List** three safety rules to follow when an earthquake strikes.
4. **Describe** how identifying seismic gaps may help scientists predict earthquakes.
5. **Identify** changes in rocks that may signal earthquakes.

CRITICAL THINKING

6. **Applying Concepts** What type of building construction and location regulations should be included in the building code of a city that is located near an active fault?
7. **Applying Concepts** You are a scientist assigned to study an area that has a high earthquake-hazard level. Describe a program that you could set up to predict potential earthquakes.

CONCEPT MAPPING

8. Use the following terms to create a concept map: *earthquake, earthquake-hazard level, damage, tsunami, safety,* and *prediction.*

Chapter 12 Highlights

Sections

1 How and Where Earthquakes Happen

Key Terms

earthquake, 295
elastic rebound, 295
focus, 296
epicenter, 296
body wave, 296
surface wave, 296
P wave, 297
S wave, 297
shadow zone, 298
fault zone, 300

Key Concepts

- In the process of elastic rebound, stress builds in rocks along a fault until they break and spring back to their original shape.
- There are two major types of seismic waves: body waves and surface waves.
- Different seismic waves act differently depending on the material of Earth's interior through which they pass.
- Most earthquakes occur near tectonic plate boundaries.

2 Studying Earthquakes

seismograph, 301
seismogram, 301
magnitude, 303
intensity, 304

- Scientists use seismographs to record earthquake vibrations.
- The difference in the times that P waves and S waves take to arrive at a seismograph station helps scientists locate the epicenter of an earthquake.
- Earthquake magnitude scales describe the strength of an earthquake. Intensity is a measure of the effects of an earthquake.

3 Earthquakes and Society

tsunami, 305
seismic gap, 307

- Most earthquake damage is caused by the collapse of buildings and other structures.
- Tsunamis often are caused by ocean-floor earthquakes.
- People who follow safety guidelines are less likely to be harmed by an earthquake.
- Seismic gaps, tilting ground, and variations in rock properties are some of the changes in Earth's crust that scientists use when trying to predict earthquakes.

Chapter 12 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *elastic rebound*
2. *fault zone*
3. *seismic gap*

For each pair of terms, explain how the meanings of the terms differ.

4. *focus* and *epicenter*
5. *body wave* and *surface wave*
6. *P wave* and *S wave*
7. *seismograph* and *seismogram*
8. *intensity* and *magnitude*

Understanding Key Concepts

9. Vibrations in Earth that are caused by the sudden movement of rock are called
   - **a.** epicenters.
   - **b.** earthquakes.
   - **c.** faults.
   - **d.** tsunamis.

10. In the process of elastic rebound, as a rock becomes stressed, it first
    - **a.** deforms.
    - **b.** melts.
    - **c.** breaks.
    - **d.** shifts position.

11. Earthquakes that cause severe damage are likely to have what characteristic?
    - **a.** a deep focus
    - **b.** an intermediate focus
    - **c.** a shallow focus
    - **d.** a deep epicenter

12. Most earthquakes occur
    - **a.** in mountains.
    - **b.** along major rivers.
    - **c.** at plate boundaries.
    - **d.** in the middle of tectonic plates.

13. P waves travel
    - **a.** only through solids.
    - **b.** only through liquids and gases.
    - **c.** through both solids and liquids.
    - **d.** only through liquids.

14. S waves cannot pass through
    - **a.** solids.
    - **b.** the mantle.
    - **c.** Earth's outer core.
    - **d.** the asthenosphere.

15. Most injuries during earthquakes are caused by
    - **a.** the collapse of buildings.
    - **b.** cracks in Earth's surface.
    - **c.** the vibration of S waves.
    - **d.** the vibration of P waves.

16. Which of the following is *not* a method used to forecast earthquake risks?
    - **a.** identifying seismic gaps
    - **b.** determining moment magnitude
    - **c.** recording foreshocks
    - **d.** detecting changes in the rock

Short Answer

17. How do seismic waves help scientists understand Earth's interior?

18. Why is the S-wave shadow zone larger than the P-wave shadow zones are?

19. How do scientists determine the location of an earthquake's epicenter?

20. Why do scientists prefer the moment magnitude scale to the Richter scale?

21. How might tall buildings respond during a major earthquake?

22. What should you do if you are in a car when an earthquake happens?

23. List three changes in rock that may one day be used to help forecast earthquakes.

Critical Thinking

24. Understanding Relationships Why might surface waves cause the greatest damage during an earthquake?

25. Determining Cause and Effect Two cities are struck by the same earthquake. The cities are the same size, are built on the same type of ground, and have the same types of buildings. The city in which the earthquake produced a maximum intensity of VI on the Mercalli scale suffered $1 million in damage. The city in which the earthquake produced a maximum intensity of VIII on the Mercalli scale suffered $50 million in damage. What might account for this great difference in the costs of the damage?

26. Recognizing Relationships Would an earthquake in the Rocky Mountains in Colorado be likely to form a tsunami? Explain your answer.

Concept Mapping

27. Use the following terms to create a concept map: *earthquake, elastic rebound, surface wave, body wave, seismic wave, tsunami, seismograph, magnitude, intensity, moment magnitude scale,* and *Richter scale.*

Math Skills

28. Making Calculations If a P wave traveled 6.1 km/s, how long would the P wave take to travel 800 km?

29. Using Equations An earthquake with a magnitude of 3 releases 30 times more energy than does an earthquake with a magnitude of 2. How much more energy does an earthquake with a magnitude of 8 release than an earthquake with a magnitude of 6 does?

30. Making Calculations Of the approximately 420,000 earthquakes recorded each year, about 140 have a magnitude greater than 6. What percentage of all earthquakes have a magnitude greater than 6?

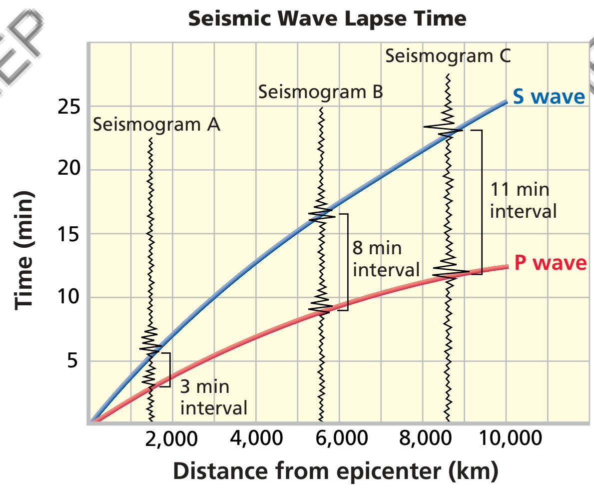
Writing Skills

31. Writing from Research Find out how and why the worldwide network of seismograph stations was formed. Also, find out how all the stations in the network work together. Prepare a report about your findings.

32. Communicating Main Ideas Find out which earthquake registered the highest intensity in history. Write a brief report that describes the effects of this earthquake.

Interpreting Graphics

The graph below shows three seismograms from a single earthquake. Use the graph to answer the questions that follow.



33. How far from the epicenter is seismograph B?

34. How far from the epicenter is seismograph C?

35. Which seismograph is farthest from the epicenter?

36. Why is there an 8 min interval between P waves and S waves in seismogram B but an 11 min interval between P waves and S waves in seismogram C?

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Chapter 12 Standardized Test Prep

Understanding Concepts

***Directions (1–5):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 Energy waves that produce an earthquake begin at what location on or within Earth?

A. the epicenter
B. the seismic gap
C. the focus
D. the shadow zone

2 The fastest-moving seismic waves produced by an earthquake are called

F. P waves
G. S waves
H. Raleigh waves
I. surface waves

3 The magnitude of an earthquake can be expressed numerically by using

A. only the Richter scale
B. only the Mercalli scale
C. both the Mercalli scale and the moment magnitude scale
D. both the Richter scale and the moment magnitude scale

4 Most earthquake-related injuries are caused by

F. tsunamis
G. collapsing buildings
H. rolling ground movements
I. sudden cracks in the ground

5 Which of the following is least likely to cause deaths during an earthquake?

A. floodwaters from collapsing dams
B. falling objects and flying glass
C. actual ground movement
D. fires from broken electric and gas lines

***Directions (6–8):* For *each* question, write a short response.**

6 What is the name of the instrument that is used to detect and record seismic waves?

7 What is the term for waves that move through a medium instead of along its surface?

8 Where is the Ring of Fire located?

Reading Skills

***Directions (9–11):* Read the passage below. Then, answer the questions.**

The Loma Prieta Earthquake

At 5:04 P.M. on October 17, 1989, life in California's San Francisco Bay Area seemed relatively normal. While more than 62,000 excited fans filled Candlestick Park to watch the third game of baseball's World Series, other people were still rushing home from a long day's work or picking their children up from extracurricular activites. By 5:05 P.M., the situation had changed drastically. The area was rocked by the 6.9 Loma Prieta earthquake. The earthquake lasted 20 seconds and caused 62 deaths, 3,757 injuries, and the destruction of more than 1,000 homes and businesses. By midnight, the city was fighting more than 20 large structural fires resulting from the earthquake. People suffered injuries from collapses in weakened structures for days following the initial earthquake. Considering that the earthquake was of such a high magnitude and that it happened during the busy rush hour, it is amazing that more people were not injured or killed.

9 What type of waves are the most likely to have caused the damage described during the Loma Prieta earthquake?

A. P waves
B. S waves
C. body waves
D. surface waves

10 Which of the following statements can be inferred from the information in the passage?

F. *Loma Prieta* is the Spanish term for "deadly earthquake."
G. The damage caused by the earthquake continued even after the waves had passed.
H. There were fewer people injured in this earthquake than in most earthquakes.
I. The Loma Prieta earthquake has the highest magnitude of any earthquake ever recorded.

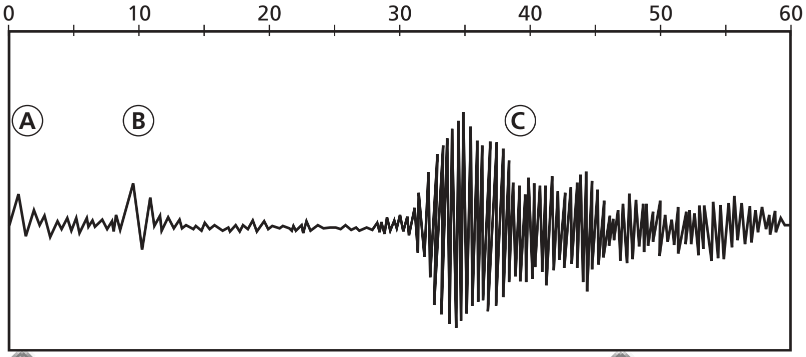
11 The 6.9 rating of the Loma Prieta earthquake is a rating on what measurement scale?

Interpreting Graphics

***Directions (13–15):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram shows a recording of data by a seismograph. Use this diagram to answer questions 13 and 14.

Reading a Seismogram



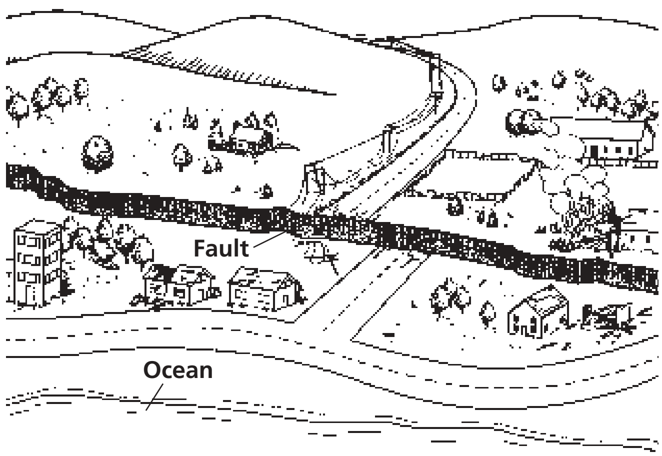
13 What type of seismic waves are indicated by the points on the seismogram marked by the letter A?

A. Love waves
B. Rayleigh waves
C. P waves
D. S waves

14 What type of seismic waves are indicated by the point on the seismogram marked by the letter C? How are these waves connected to the smaller waves that preceded them?

The illustration below shows the damage caused following an earthquake. Objects shown in this illustration are not drawn to scale. Use this illustration to answer question 15.

Earthquake Damage



15 What safety hazards can you identify in this scene? What safety advice would you give to someone approaching the scene above? How should people prepare for dealing with such post-earthquake safety hazards?

Test TIP

Always read the full question to make sure you understand what is being asked before you look at the answer choices.

Chapter 12

Skills Practice Lab

Objectives

- USING SCIENTIFIC METHODS **Analyze** P waves and S waves to determine the distance from a city to the epicenter of an earthquake.
- **Determine** the location of an earthquake epicenter by using the distance from three different cities to the epicenter of an earthquake.

Materials

calculator
drawing compass
ruler

Finding an Epicenter

An earthquake releases energy that travels through Earth in all directions. This energy is in the form of waves. Two kinds of seismic waves are P waves and S waves. P waves travel faster than S waves and are the first to be recorded at a seismograph station. The S waves arrive after the P waves. The time difference between the arrival of the P waves and the S waves increases as the waves travel farther from their origin. This difference in arrival time, called *lag time*, can be used to find the distance to the epicenter of the earthquake. Once the distance from three different locations is determined, scientists can find the approximate location of the epicenter.

PROCEDURE

1. The average speed of P waves is 6.1 km/s. The average speed of S waves is 4.1 km/s. Calculate the lag time between the arrival of P waves and S waves over a distance of 100 km.

2. The graph below shows seismic records made in three cities following an earthquake. These traces begin at the left. The arrows indicate the arrival of the P waves. The beginning of the next wave on each seismograph record indicates the arrival of the S wave. Use the time scale to find the lag time between the P wave and the S waves for each city. Draw a table similar to **Table 1.**

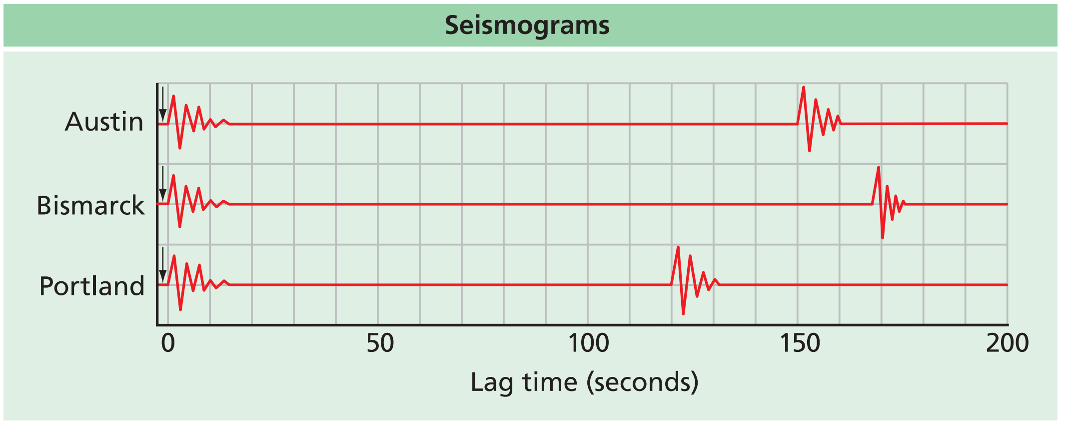


Table 1

City	Lag time (seconds)	Distance from city to epicenter
Austin		
Bismarck		
Portland		

3. Record lag time for each city in the table.

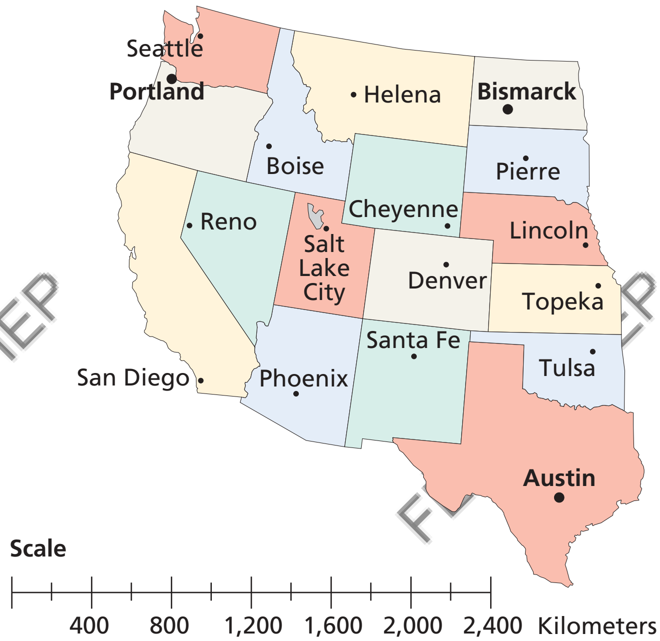
4. Use the lag times found in step 2 and the lag time per 100 km found in step 1 to calculate the distance from each city to the epicenter of the earthquake by using the equation below.

$$distance = \frac{measured\ lag\ time\ (s) \times 100\ \text{km}}{lag\ time\ for\ 100\ km}$$

5. Record distances in the table.

6. Copy the map at right, which shows the location of the three cities. Using the map scale on your copy of the map, adjust the compass so that the radius of the circle with Austin at the center is equal to the calculation for Austin in step 2. Put the point of the compass on Austin. Draw a circle on your copy of the map.

7. Repeat step 6 for Bismarck and for Portland. The epicenter of the earthquake is located near the point at which the three circles intersect.



ANALYSIS AND CONCLUSION

1. **Evaluating Data** Describe the location of the earthquake's epicenter. To which city is the location of the earthquake's epicenter closest?

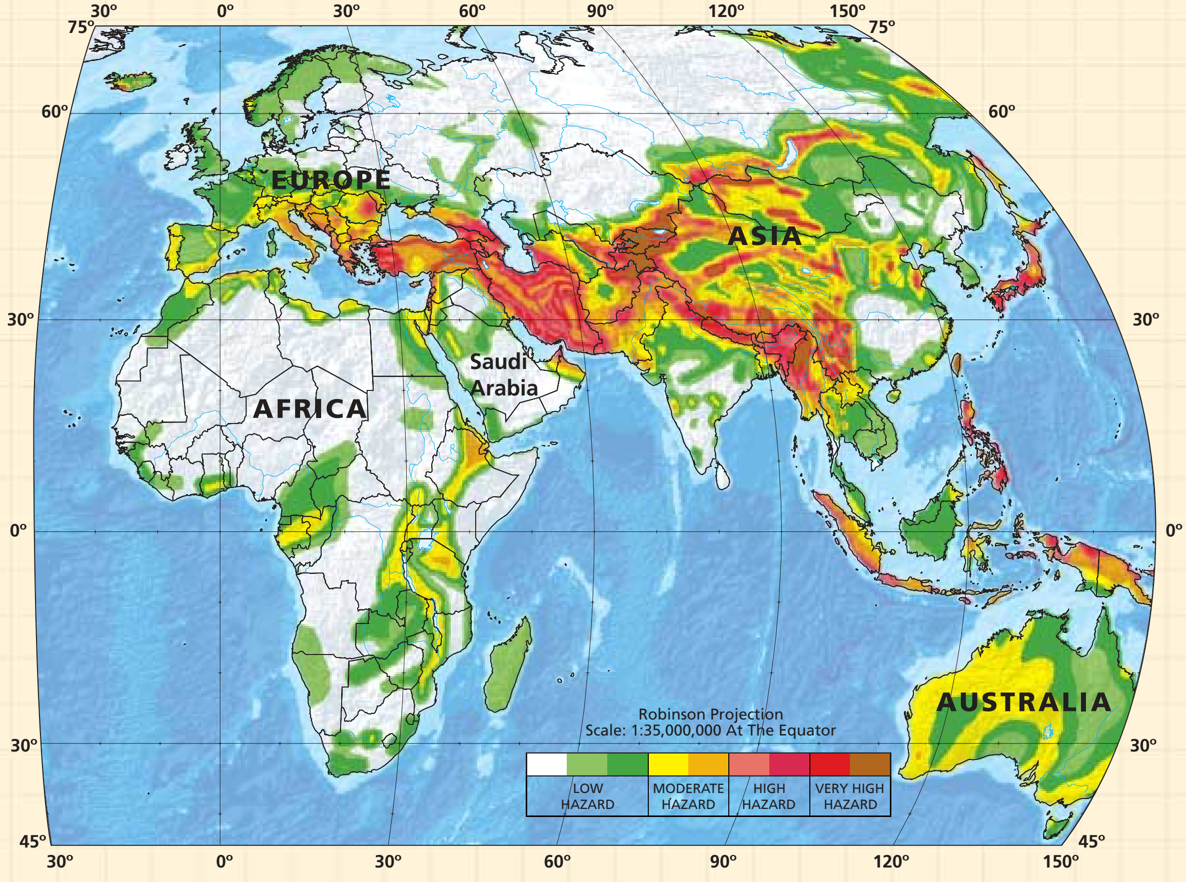
2. **Analyzing Processes** Why must measurements from three locations be used to find the epicenter of an earthquake?

Extension

1. **Evaluating Data** Research earthquakes in the United States. What is the probability of a major earthquake occurring in the area where you live? If an earthquake did occur in your area, what would most likely cause the earthquake?

MAPS in Action

Earthquake Hazard Map



Map Skills Activity

This map shows the earthquake-hazard levels for Europe, Asia, Africa, and Australia. Use the map to answer the questions below.

1. **Using a Key** Which areas of the map have a very high earthquake-hazard level?
2. **Using a Key** Determine which areas of the map have very low earthquake-hazard levels.
3. **Inferring Relationships** Most earthquakes take place near tectonic plate boundaries. Based on the hazard levels, describe the areas of the map where you think tectonic plate boundaries are located.
4. **Analyzing Relationships** In Asia, just below 60° north latitude, there are areas that have high earthquake-hazard levels but no plate boundaries. Explain why these areas might experience earthquakes.
5. **Forming a Hypothesis** There is a tectonic plate boundary between Africa and Saudi Arabia. However, the earthquake-hazard level in that region is low. Explain the low earthquake-hazard level.
6. **Analyzing Relationships** A divergent plate boundary began to tear apart the continent of Africa about 30 million years ago. Where on the continent of Africa would you expect to find landforms created by this boundary? Explain your answer.

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Career Focus

Geophysicist

Earth's surface may appear solid and unmoving. But Wayne Thatcher sees daily evidence that Earth's surface is always changing. As a research geophysicist for the U.S. Geological Survey, Thatcher studies the forces that shape Earth's crust, such as earthquakes.

Tools of the Trade

To measure ground deformation, Thatcher and his colleagues use global positioning system (GPS) and radar satellite images. GPS is a network of satellites that is commonly used for navigation of ships and aircraft. Thatcher uses GPS to measure changes in Earth's crust. By measuring ground elevation changes of a few millimeters, GPS enables discoveries that would not have been made many years ago.

Thatcher also uses Interferometric Synthetic Aperture Radar (InSAR), a remote-sensing technique that uses satellite radio waves to create three-dimensional images of Earth's surface. In this way, InSAR is able to map ground displacement from one satellite pass to the next, which helps scientists form mappings of deformation over months or years.

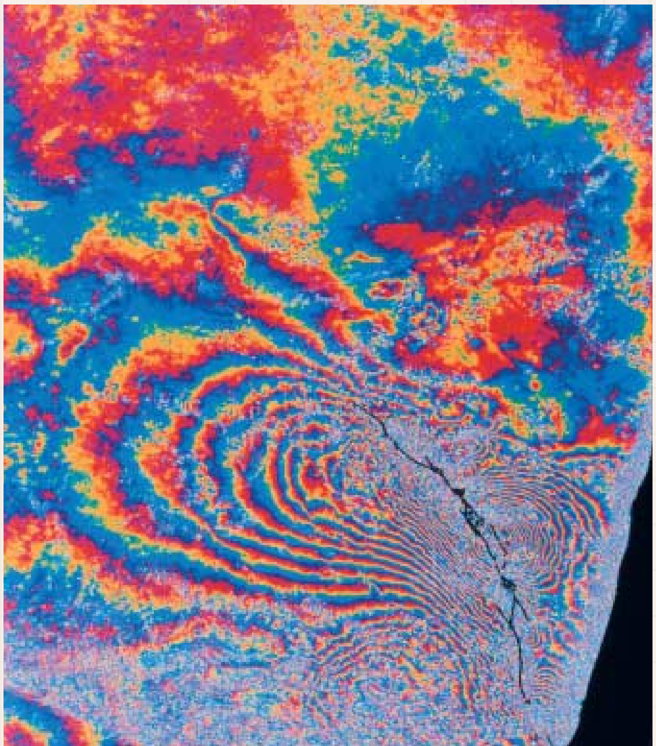
Predicting Future Earthquakes

For Thatcher and other geophysicists, the ability to forecast an earthquake remains an ongoing research aim. "Prediction is one of our ultimate goals," he notes. "We can estimate the level of risk based on GPS or InSAR readings. For example, we can track fault movements and note that 'something's got to give' and a quake is due."

"Geophysics is a very international field of study. It's good to compare similarities and differences with other researchers who study earthquakes and volcanoes around the world."

—Wayne Thatcher, Ph.D.

For his research, Thatcher travels to fault zones throughout the western United States, where he sets up GPS benchmark sites. Trips to the sites in later years enable scientists to measure the rate and extent of movement of Earth's crust. Thatcher also journeys to other geologically active parts of the world, such as Japan, New Zealand, and Greece.



◀ This colored satellite map shows the ground displacement after a 7.3 moment magnitude earthquake in Landers, California, on June 28, 1992.

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Chapter 13 Volcanoes

Sections

1 Volcanoes and Plate Tectonics

2 Volcanic Eruptions

What You'll Learn

- Where volcanoes are located
- What causes volcanic eruptions
- How lava affects the shape of volcanoes

Why It's Relevant

Volcanoes can form features such as mountains or islands. Volcanic eruptions can also endanger human life. Learning about volcanoes can help scientists better predict eruptions and can prepare people to evacuate dangerous areas.

PRE-READING ACTIVITY

FOLDNOTES

Table Fold Before you read this chapter, create the FoldNote entitled "Table Fold" described in the Skills Handbook section of the Appendix. Label the columns of the table fold with "Slope," "Lava," and "Eruption style." Label the rows with the three different types of volcanic cones. As you read the chapter, write examples of each topic under the appropriate column.

▶ Because volcanic eruptions add new material to Earth's surface, they have formed many islands, such as the Hawaiian Island chain. There, you can witness the volcanic processes that form islands, as shown in this photo.

Section 1 Volcanoes and Plate Tectonics

Volcanic eruptions can cause some of the most dramatic changes to Earth's surface. Some eruptions can be more powerful than the explosion of an atomic bomb. The cause of many of these eruptions is the movement of tectonic plates. The movement of tectonic plates is driven by Earth's internal heat.

By studying temperatures within Earth, scientists can learn more about volcanic eruptions. **Figure 1** shows estimates of Earth's inner temperatures and pressures. As the graph shows, the combined temperature and pressure in the lower part of the mantle keeps the rocks below their melting point.

OBJECTIVES

- **Describe** the three conditions under which magma can form.
- **Explain** what volcanism is.
- **Identify** three tectonic settings where volcanoes form.
- **Describe** how magma can form plutons.

KEY TERMS

magma
volcanism
lava
volcano
hot spot

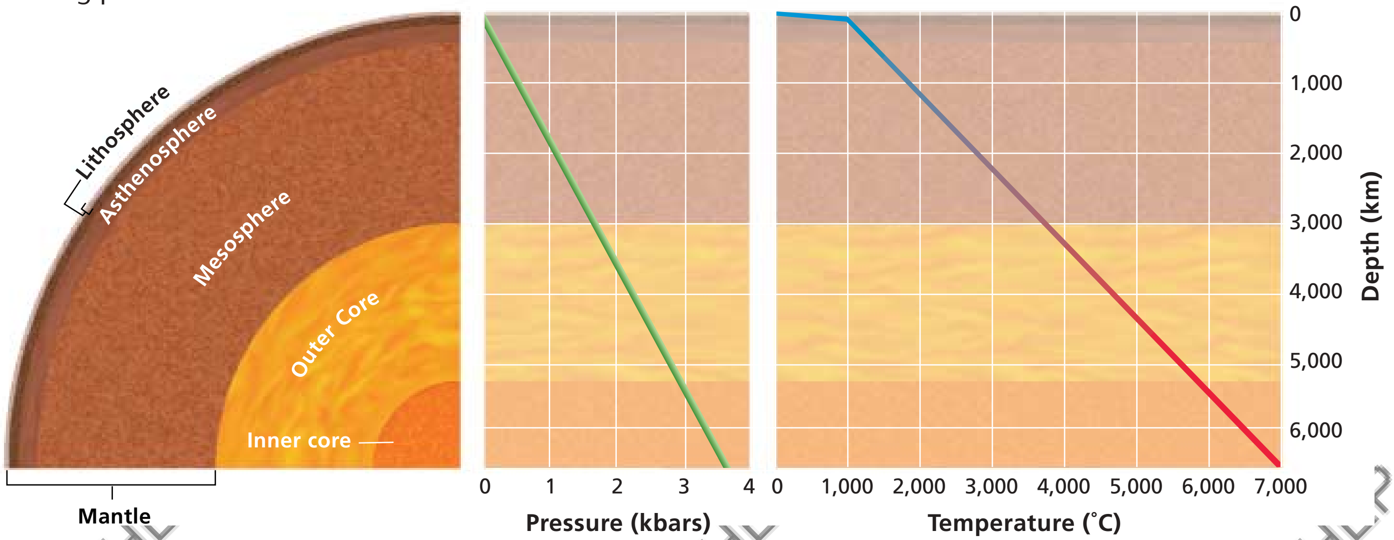
Formation of Magma

Despite the high temperature in the mantle, most of this zone remains solid because of the large amount of pressure from the surrounding rock. Sometimes, however, solid mantle and crust melt to form **magma,** or liquid rock that forms under Earth's surface.

Magma can form under three conditions. First, if the temperature of rock rises above the melting point of the minerals the rock is composed of, the rock will melt. Second, rock melts when excess pressure is removed from rock that is above its melting point. Third, the addition of fluids, such as water, may decrease the melting point of some minerals in the rock and cause the rock to melt.

magma liquid rock produced under Earth's surface

Figure 1 ▶ Temperature and pressure increase as depth beneath Earth's surface increases. So, rock in the lower mantle stays below its melting point.



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Volcanism

volcanism any activity that includes the movement of magma toward or onto Earth's surface

lava magma that flows onto Earth's surface; the rock that forms when lava cools and solidifies

volcano a vent or fissure in Earth's surface through which magma and gases are expelled

Any activity that includes the movement of magma onto Earth's surface is called **volcanism.** Magma rises upward through the crust because the magma is less dense than the surrounding rock. As bodies of magma rise toward the surface, they can become larger in two ways. First, because they are so hot, they can melt some of the surrounding rock. Second, as the magma rises, it is forced into cracks in the surrounding rock. This process causes large blocks of overlying rock to break off and melt. Both of these processes add material to the magma body.

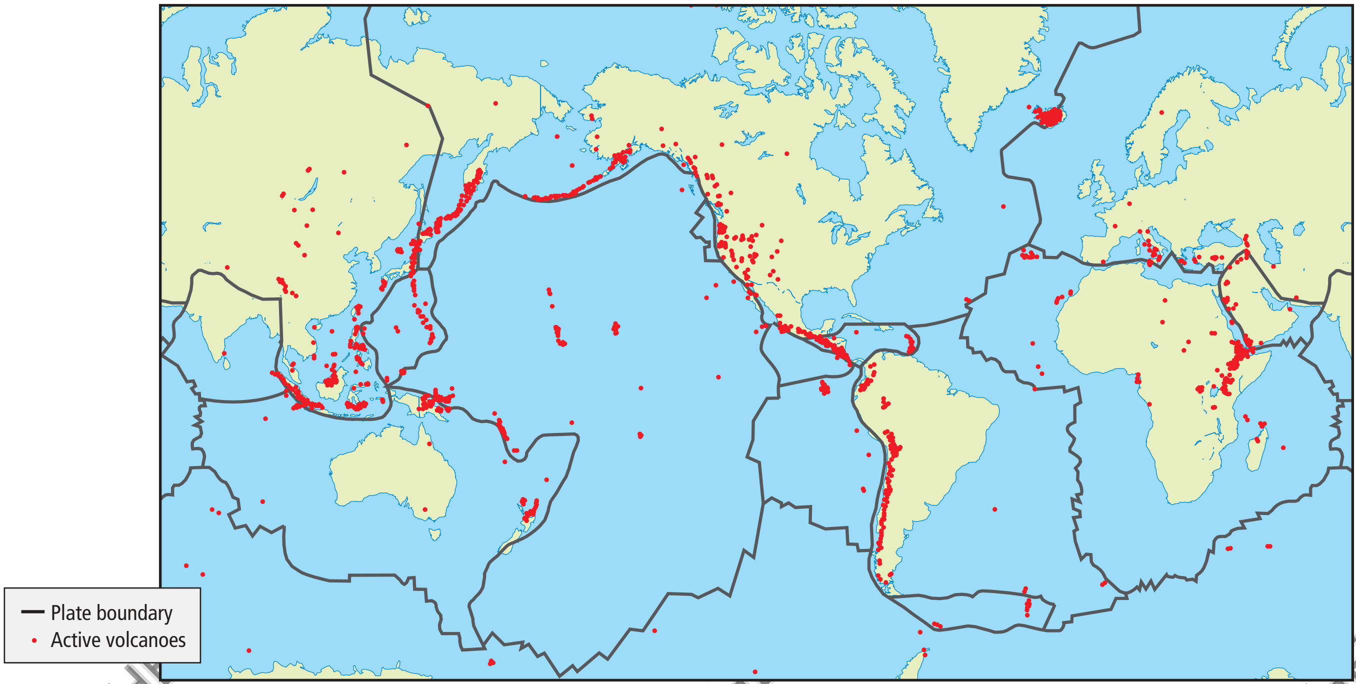
When magma erupts onto Earth's surface, the magma is called **lava.** As lava flows from an opening, or *vent,* the material may build up as a cone of material that may eventually form a mountain. The vent in Earth's surface through which magma and gases are expelled is called a **volcano.**

Major Volcanic Zones

If you were to plot the locations of the volcanoes that have erupted in the past 50 years, you would see that the locations form a pattern across Earth's surface. Like earthquakes, most active volcanoes occur in zones near both convergent and divergent boundaries of tectonic plates, as shown in **Figure 2.**

A major zone of active volcanoes encircles the Pacific Ocean. This zone, called the Pacific Ring of Fire, is formed by the subduction of plates along the Pacific coasts of North America, South America, Asia, and the islands of the western Pacific Ocean. The Pacific Ring of Fire is also one of Earth's major earthquake zones.

Figure 2 ▶ This map shows the locations of major tectonic plate boundaries and of active volcanoes. ***What is the relationship between the volcanoes and tectonic plate boundaries?***



Subduction Zones

Many volcanoes are located along *subduction zones,* where one tectonic plate moves under another. When a plate that consists of oceanic lithosphere meets one that consists of continental lithosphere, the denser oceanic lithosphere moves beneath the continental lithosphere. A deep *trench* forms on the ocean floor along the edge of the continent where the plate is subducted. The plate that consists of continental lithosphere buckles and folds to form a line of mountains along the edge of the continent.

As the oceanic plate sinks into the asthenosphere, fluids such as water from the subducting plate combine with crust and mantle material. These fluids decrease the melting point of the rock and cause the rock to melt and form magma. When the magma rises through the lithosphere and erupts on Earth's surface, lines of volcanic mountains form along the edge of the tectonic plate.

If two plates that have oceanic lithosphere at their boundaries collide, one plate subducts, and a deep trench forms. As in the case of continental lithosphere colliding with oceanic lithosphere, magma also forms as fluids are introduced into the mantle during oceanic plate collisions. Some of the magma breaks through the overriding plate to Earth's surface. Over time, a string of volcanic islands, called an *island arc,* forms on the overriding plate, as shown in **Figure 3.** The early stages of this type of subduction produce an arc of small volcanic islands, such as the Aleutian Islands, which are in the North Pacific Ocean and between Alaska and Siberia. As more magma reaches the surface, the islands become larger and join to form one landmass, such as the volcanic islands that joined to form present-day Japan.

Reading Check **When a plate that consists of oceanic crust and one that consists of continental crust meet, which plate subducts beneath the other plate? (See the Appendix for answers to Reading Checks.)**

Quick LAB 5 min

Changing Melting Point

Procedure

1. Place a **piece of ice** on a small **paper plate.**
2. Wait 1 min, and observe how much ice has melted. Remove the meltwater from the plate.
3. Pour **1/4 teaspoon of salt** onto a **second piece of ice.**
4. Wait 1 min, and observe how much ice has melted.

Analysis

1. What happened to the rate of melting when you added salt to the ice?
2. In this model, what is represented by the ice? by the salt?

Figure 3 ▶ The Aleutian Islands (below) formed when oceanic lithosphere subducted beneath oceanic lithosphere and caused magma to rise to the surface and erupt to form volcanic islands (left).

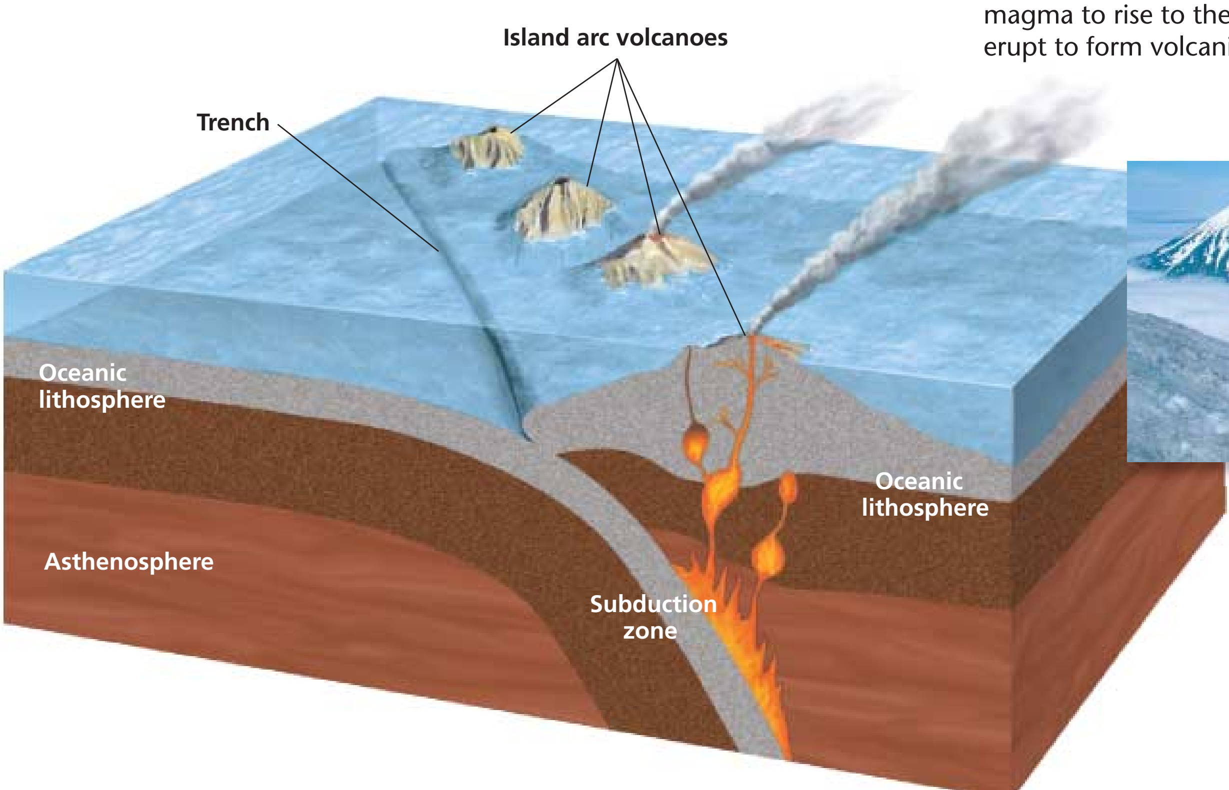


Figure 4 ▶ When water rapidly cools hot lava, a hard, pillow-shaped crust forms. As the crust cools, it contracts and cracks. Hot lava flows through the cracks in the crust and then cools quickly to form another pillow-shaped structure.

Mid-Ocean Ridges

The largest amount of magma comes to the surface where plates are moving apart at mid-ocean ridges. Thus, the interconnected mid-ocean ridges that circle Earth form a major zone of volcanic activity. As plates pull apart, magma flows upward along the rift zone. The upwelling magma adds material to the mid-ocean ridge and creates new lithosphere along the rift. This magma erupts to form underwater volcanoes. **Figure 4** shows pillow lava, an example of volcanic rock that forms underwater at a mid-ocean ridge. Pillow lava is named for its pillow shape, which is caused by the water that rapidly cools the outer surface of the lava.

Most volcanic eruptions that happen along mid-ocean ridges are unnoticed by humans because the eruptions take place deep in the ocean. An exception is found on Iceland. Iceland is one part of the Mid-Atlantic Ridge that is above sea level. One-half of Iceland is on the North American plate and is moving westward. The other half is on the Eurasian plate and is moving eastward. The middle of Iceland is cut by large *fissures,* which are cracks through which lava flows to Earth's surface.

Connection to GEOLOGY

Sea-floor Formation

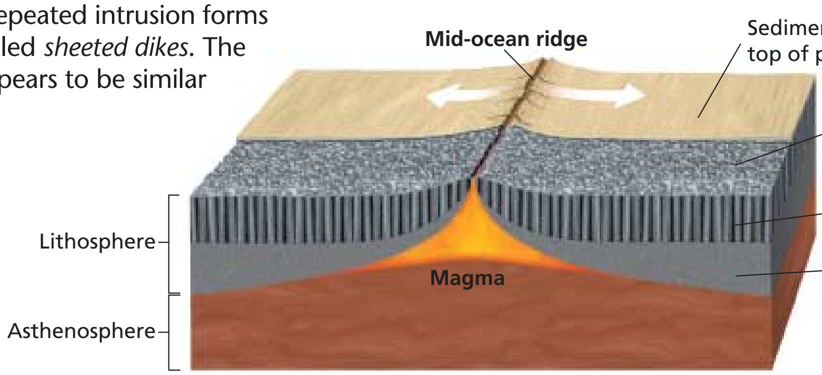
At mid-ocean ridges, magma moves upward from the asthenosphere. When the magma reaches the surface, the magma cools to form new sea-floor rock. When new sea floor forms at a mid-ocean ridge, a special sequence of rocks forms. This sequence forms because of the way the magma rises and cools. The thickness of the layers in this sequence varies greatly worldwide.

At the base of the new lithosphere, where the plates pull apart, a magma chamber forms. This chamber is cooled by circulating sea water. As the magma slowly cools, large crystals form. The crystals stick to the roof and sides of the magma chamber or sink to the bottom of the chamber and form a type of rock called *gabbro*. Gabbro forms the base layer in the rock sequence.

In the rift where the plates pull apart, the magma repeatedly intrudes. This repeated intrusion forms a series of vertical dikes called *sheeted dikes*. The structure of these dikes appears to be similar to a deck of cards standing on end. The sheeted-dike complex forms the middle layer in the rock sequence.

At the top of the new lithosphere, where the magma comes into contact with the cold ocean water, the magma freezes rapidly. This rapid freezing causes pillow lava to form. Pillow lava forms the uppermost layer in the rock sequence.

Sea-floor rock that formed millions of years ago can be seen on land today. When one plate subducts under another plate, some of the subducting crust is scraped off and becomes part of the overriding plate. The crust that was scraped off is later uplifted and exposed on land, where geologists can study the rock to learn more about the formation of sea floor.



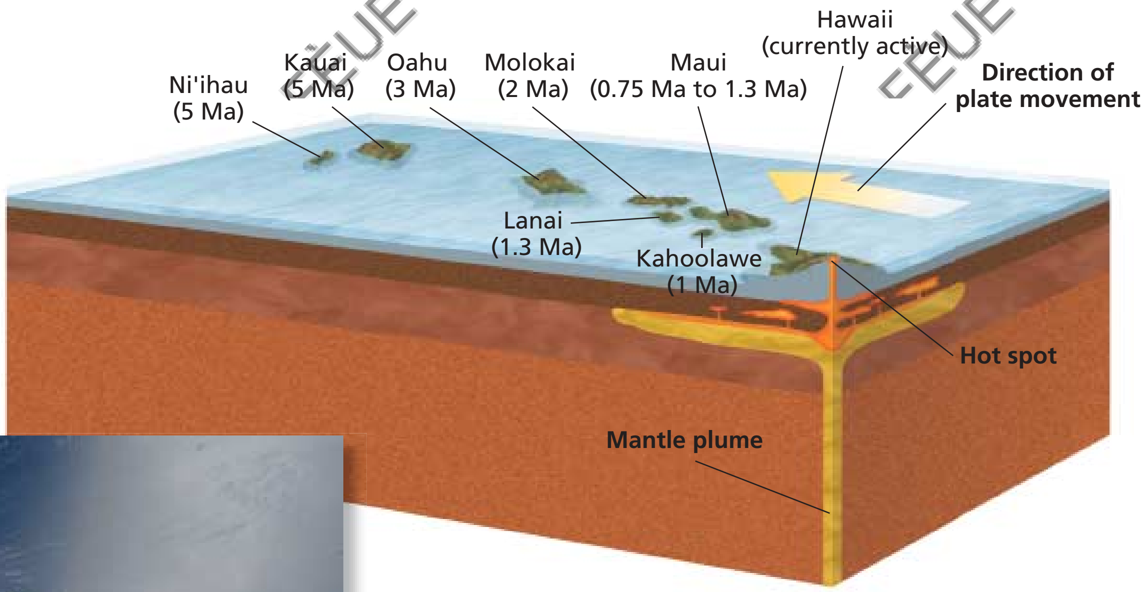


Figure 5 ▶ As a tectonic plate moves over a stationary mantle plume, volcanic mountains form (above). The Hawaiian Islands (left) formed in this way.

Hot Spots

Not all volcanoes develop along plate boundaries. Areas of volcanism within the interiors of lithospheric plates are called **hot spots.** Most hot spots form where columns of solid, hot material from the deep mantle, called *mantle plumes,* rise and reach the lithosphere. When a mantle plume reaches the lithosphere, the plume spreads out. As magma rises to the surface, it breaks through the overlying crust. Volcanoes can then form in the interior of a tectonic plate, as shown in **Figure 5.**

Mantle plumes appear to remain nearly stationary. However, the lithospheric plate above a mantle plume continues to drift slowly. So, the volcano on the surface is eventually carried away from the mantle plume. The activity of the volcano stops because a hot spot that contains magma no longer feeds the volcano. However, a new volcano forms where the lithosphere has moved over the mantle plume.

Other scientists think that hot spots are the result of cracks in Earth's crust. The theory argues that hot-spot volcanoes occur in long chains because they form along cracks in Earth's crust. Both theories may be correct.

hot spot a volcanically active area of Earth's surface, commonly far from a tectonic plate boundary

Reading Check **Explain how one mantle plume can form several volcanic islands. (See the Appendix for answers to Reading Checks.)**

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Figure 6 ▶ Devils Tower in Wyoming is an example of a pluton called a *volcanic neck,* a formation caused by cooling of magma within the vent of a volcano. The outer part of the volcano eroded, and only the volcanic neck remains.

Intrusive Activity

Because magma is less dense than solid rock, magma rises through the crust toward the surface. As the magma moves upward, it comes into contact with, or *intrudes,* the overlying rock. Because of magma's high temperature, magma affects surrounding rock in a variety of ways. Magma may melt surrounding rock or may change the rock. Magma may also fracture surrounding rock and cause fissures to form or cause the surrounding rock to break apart and fall into the magma. Rock that falls into the magma may eventually melt, or the rock may combine with the new *igneous rock,* which is rock that forms when the magma cools.

When magma does not reach Earth's surface, the magma may cool and solidify inside the crust. This process results in large formations of igneous rock called *plutons,* as shown in **Figure 6.** Plutons can vary greatly in size and shape. Small plutons called *dikes* are tabular in shape and may be only a few centimeters wide. *Batholiths* are large plutons that cover an area of at least 100 km^2 when they are exposed on Earth's surface.

Section 1 Review

1. **Describe** three conditions that affect whether magma forms.
2. **Explain** how magma reaches Earth's surface.
3. **Compare** magma with lava.
4. **Describe** how subduction produces magma.
5. **Identify** three tectonic settings where volcanoes commonly occur.
6. **Summarize** the formation of hot spots.
7. **Describe** two igneous structures that form under Earth's surface.

CRITICAL THINKING

8. **Identifying Relationships** Describe how the presence of ocean water in crustal rocks might affect the formation of magma.
9. **Applying Ideas** Yellowstone National Park in Wyoming is far from any plate boundary. How would you explain the volcanic activity in the park?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *magma, volcanism, vent, volcano, subduction zone, hot spot, dike,* and *pluton*.

Section 2 Volcanic Eruptions

Volcanoes can be thought of as windows into Earth's interior. Lava that erupts from them provides an opportunity for scientists to study the nature of Earth's crust and mantle. By analyzing the composition of volcanic rocks, geologists have concluded that there are two general types of magma. **Mafic** (MAF ik) describes magma or rock that is rich in magnesium and iron and is commonly dark in color. **Felsic** (FEL sik) describes magma or rock that is rich in light-colored silicate materials. Mafic rock commonly makes up the oceanic crust, whereas felsic and mafic rock commonly make up the continental crust.

OBJECTIVES

- **Explain** how the composition of magma affects volcanic eruptions and lava flow.
- **Describe** the five major types of pyroclastic material.
- **Identify** the three main types of volcanic cones.
- **Describe** how a caldera forms.
- **List** three events that may signal a volcanic eruption.

KEY TERMS

mafic
felsic
pyroclastic material
caldera

Types of Eruptions

The *viscosity,* or resistance to flow, of magma affects the force with which a particular volcano will erupt. The viscosity of magma is determined by the magma's composition. Because mafic magmas produce runny lava that has a low viscosity, they typically cause quiet eruptions. Because felsic magmas produce sticky lava that has a high viscosity, they typically cause explosive eruptions. Magma that contains large amounts of trapped, dissolved gases is more likely to produce explosive eruptions than is magma that contains small amounts of dissolved gases.

mafic describes magma or igneous rock that is rich in magnesium and iron and that is generally dark in color

felsic describes magma or igneous rock that is rich in feldspar and silica and that is generally light in color

Quiet Eruptions

Oceanic volcanoes commonly form from mafic magma. Because of mafic magma's low viscosity, gases can easily escape from mafic magma. Eruptions from oceanic volcanoes, such as those in Hawaii, shown in **Figure 1,** are usually quiet.

Figure 1 ▶ Lava flows from a quiet eruption like a red-hot river would flow. This lava flowed several miles from the Kilauea volcano to the sea.

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Figure 2 ▶ Types of Mafic Lava Flow

Pahoehoe is the least viscous type of mafic lava. It forms wrinkly volcanic rock when it cools.

Aa lava is more viscous than pahoehoe lava and forms sharp volcanic rock when it cools.

Blocky lava is the most viscous type of mafic lava and forms chunky volcanic rock when it cools.

MATHPRACTICE

A Lot of Lava Since late 1986, Kilauea volcano in Hawaii has been erupting mafic lava. In 2003, the total volume of lava that had been produced by this eruption was 0.6 mi^3, or 2.5 km^3. Calculate the average amount of lava, in cubic meters, that erupts from Kilauea each year.

Lava Flows

When mafic lava cools rapidly, a crust forms on the surface of the flow. If the lava continues to flow after the crust forms, the crust wrinkles to form a volcanic rock called *pahoehoe* (pah HOH ee HOH ee), which is shown in **Figure 2.** Pahoehoe forms from hot, fluid lava. As it cools, it forms a smooth, ropy texture. Pahoehoe actually means “ropy” in Hawaiian.

If the crust deforms rapidly or grows too thick to form wrinkles, the surface breaks into jagged chunks to form *aa* (AH AH). Aa forms from lava that has the same composition as pahoehoe lava. Aa lava’s texture results from differences in gas content and in the rate and slope of the lava flow.

Blocky lava has a higher silica content than aa lava does, which makes blocky lava more viscous than aa lava. The high viscosity causes the cooled lava at the surface to break into large chunks, while the hot lava underneath continues to flow. This process gives the lava flow a blocky appearance.

Reading Check **How do flow rate and gas content affect the appearance of lavas? (See the Appendix for answers to Reading Checks.)**

Explosive Eruptions

Unlike the fluid lavas produced by oceanic volcanoes, the felsic lavas of continental volcanoes, such as Mount St. Helens, tend to be cooler and stickier. Felsic lavas also contain large amounts of trapped gases, such as water vapor and carbon dioxide. When a volcano erupts, the dissolved gases within the lava escape and send molten and solid particles shooting into the air. So, felsic lava tends to explode and throw pyroclastic material into the air. **Pyroclastic material** consists of fragments of rock that form during a volcanic eruption.

pyroclastic material fragments of rock that form during a volcanic eruption

Types of Pyroclastic Material

Some pyroclastic materials form when magma breaks into fragments during an eruption because of the rapidly expanding gases in the magma. Other pyroclastic materials form when fragments of erupting lava cool and solidify as they fly through the air.

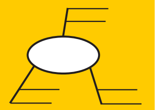
Scientists classify pyroclastic materials according to the sizes of the particles, as shown in **Figure 3.** Pyroclastic particles that are less than 2 mm in diameter are called *volcanic ash*. Volcanic ash that is less than 0.25 mm in diameter is called *volcanic dust*. Most volcanic dust and ash settles on the land that immediately surrounds the volcano. However, some of the smallest dust particles may travel around Earth in the upper atmosphere.

Large pyroclastic particles that are less than 64 mm in diameter, are called *lapilli* (luh PIL IE), which is from a Latin word that means "little stones." Lapilli generally fall near the vent.

Large clots of lava may be thrown out of an erupting volcano while they are red-hot. As they spin through the air, they cool and develop a round or spindle shape. These pyroclastic particles are called *volcanic bombs*. The largest pyroclastic materials, known as *volcanic blocks*, form from solid rock that is blasted from the vent. Some volcanic blocks are the size of a small house.

Graphic Organizer **Spider Map**

Create the Graphic Organizer entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Pyroclastic material." Create a leg for each type of pyroclastic material. Then, fill in the map with details about each type of pyroclastic material.



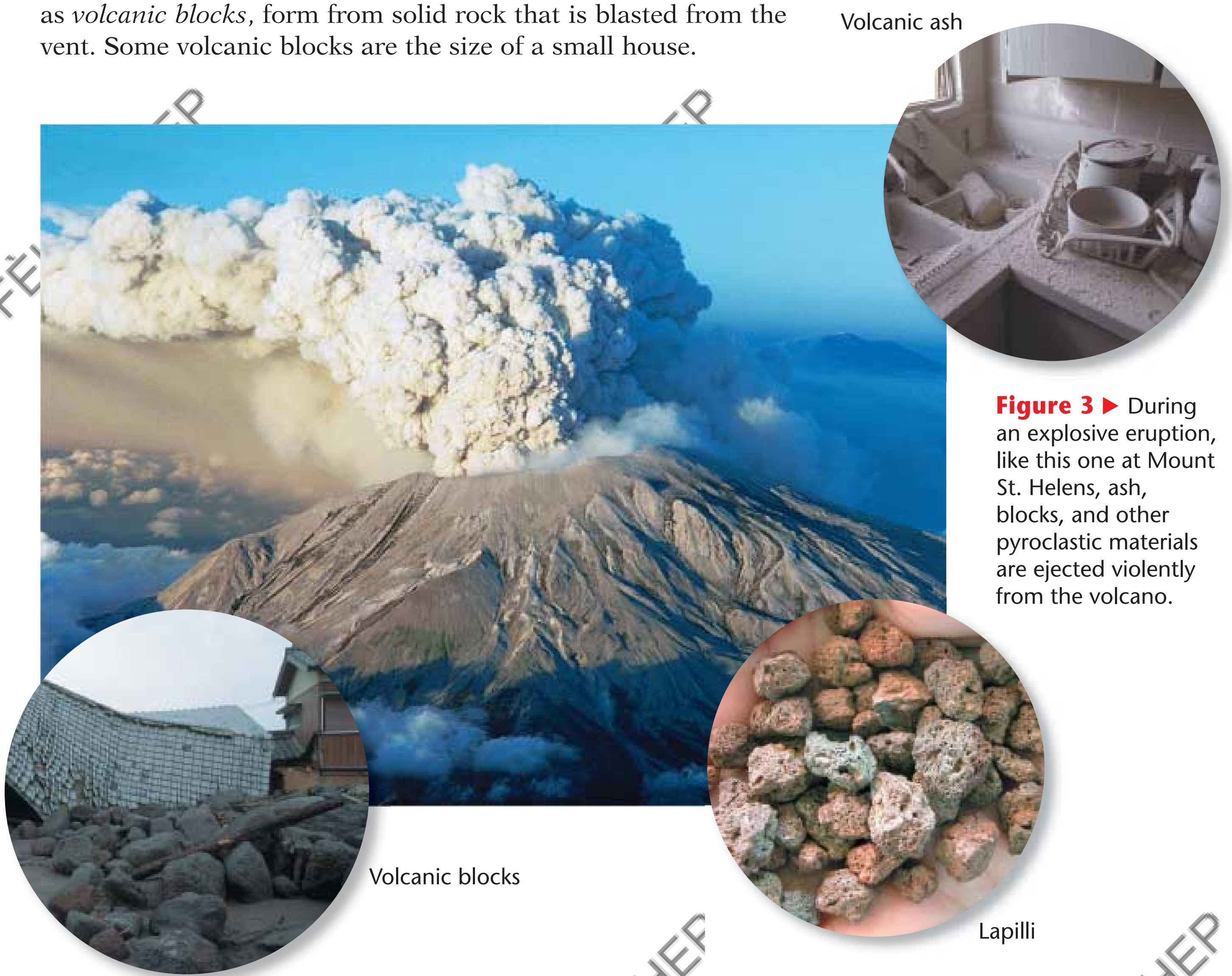


Figure 3 ▶ During an explosive eruption, like this one at Mount St. Helens, ash, blocks, and other pyroclastic materials are ejected violently from the volcano.

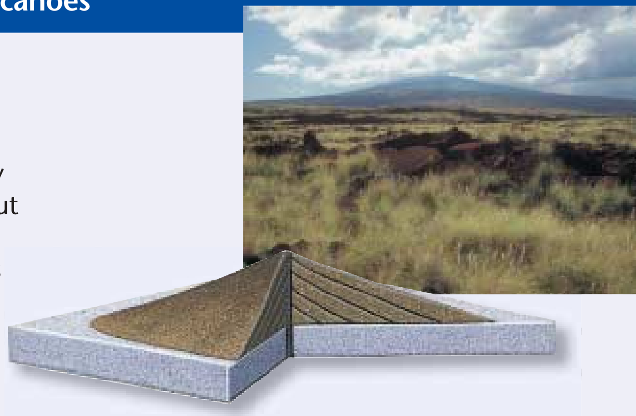
Types of Volcanoes

Volcanic activity produces a variety of characteristic features that form during both quiet and explosive eruptions. The lava and pyroclastic material that are ejected during volcanic eruptions build up around the vent and form volcanic cones. Volcanic cones are classified as three main types, as described in **Table 1.**

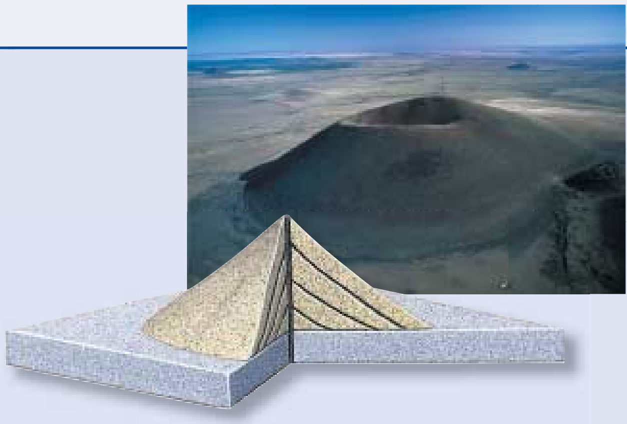
The funnel-shaped pit at the top of a volcanic vent is known as a *crater*. The crater forms when material is blown out of the volcano by explosions. A crater usually becomes wider as weathering and erosion break down the walls of the crater and allow loose materials to collapse into the vent. Sometimes, a small cone forms within a crater. This formation occurs when subsequent eruptions cause material to build up around the vent.

Table 1 ▶ Volcanic cones are classified into three main categories. ***Which type of volcano would form from lava that is highly viscous?***

Types of Volcanoes



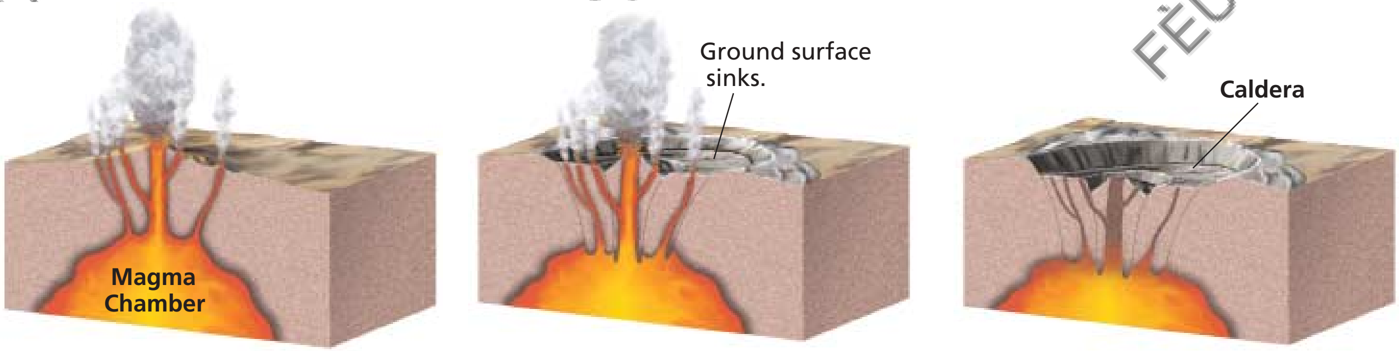
Shield Volcanoes Volcanic cones that are broad at the base and have gently sloping sides are called *shield volcanoes*. A shield volcano covers a wide area and generally forms from quiet eruptions. Layers of hot, mafic lava flow out around the vent, harden, and slowly build up to form the cone. The Hawaiian Islands form a chain of shield volcanoes that built up from the ocean floor at a hot spot.



Cinder Cones A type of volcano that has very steep slopes is a cinder cone. The slope angles of the cinder cones can be close to 40°, and the slopes are rarely more than a few hundred meters high. Cinder cones form from explosive eruptions and are made of pyroclastic material.

Composite Volcanoes Composite volcanoes are made of alternating layers of hardened lava flows and pyroclastic material. During a quiet eruption, lava flows cover the sides of the cone. Then, when an explosive eruption occurs, large amounts of pyroclastic material are deposited around the vent. The explosive eruption is followed again by quiet lava flows. Composite volcanoes, also known as *stratovolcanoes*, commonly develop to form large volcanic mountains.

Figure 4 ▶ **The Formation of a Caldera**



A cone forms from volcanic eruptions.

Volcanic eruptions partially empty the magma chamber.

The top of the cone collapses inward to form a caldera.

Calderas

When the magma chamber below a volcano empties, the volcanic cone may collapse and leave a large, basin-shaped depression called a **caldera** (kal DER uh). The process of caldera formation is shown in **Figure 4.**

Eruptions that discharge large amounts of magma can also cause a caldera to form. Krakatau, a volcanic island in Indonesia, is an example of this type of caldera. When the volcanic cone exploded in 1883, a caldera with a diameter of 6 km formed.

Calderas may later fill with water to form lakes. Thousands of years ago, the cone of Mount Mazama in Oregon collapsed and formed a caldera. The caldera eventually filled with water and is now called Crater Lake.

caldera a large, circular depression that forms when the magma chamber below a volcano partially empties and causes the ground above to sink

Reading Check **Describe two ways that calderas form. (See the Appendix for answers to Reading Checks.)**

QuickLAB 25 min

Volcanic Cones

Procedure

1. Pour **1/2 cup (about 4 oz) of dry plaster of Paris** into a **measuring cup.**
2. Use a **graduated cylinder** to measure **60 mL of water,** and add the water to the dry plaster in the measuring cup. Use a **mixing spoon** to blend the mixture until it is smooth.
3. Hold the measuring cup about 2 cm over a **paper plate.** Pour the contents slowly and steadily onto the center of the plate. Allow the plaster to dry.
4. On a clean paper plate, pour **dry oatmeal or potato flakes** slowly until the mound is approximately 5 cm high.
5. Without disturbing the mound, use a **protractor** to measure its slope.
6. When the plaster cone has hardened, remove it from the plate. Measure the average slope angle of the cone.

Analysis

1. Which cone represents a cinder cone? Which cone represents a shield volcano? Compare the slope angles formed by these cones.
2. How would the slope be affected if the oatmeal were rounder, and how would the slope be affected if the oatmeal were thicker?
3. How would you use the same supplies to model a composite volcano?

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Figure 5 ▶ These scientists are sampling gases emitted from the fumarole field on Vulcano Island in Italy.

Predicting Volcanic Eruptions

A volcanic eruption can be one of Earth's most destructive natural phenomena. Scientists, such as those in **Figure 5,** look for a variety of events that may signal the beginning of an eruption.

Earthquake Activity

One of the most important warning signals of volcanic eruptions is changes in earthquake activity around the volcano. Growing pressure on the surrounding rocks from magma that is moving upward causes small earthquakes. Temperature changes within the rock and fracturing of the rock around a volcano also cause small earthquakes. An increase in the strength and frequency of earthquakes may be a signal that an eruption is about to occur.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Predicting Volcanic Eruptions

SciLinks code: HQ61209

Patterns in Activity

Before an eruption, the upward movement of magma beneath the surface may cause the surface of the volcano to bulge outward. Special instruments can measure small changes in the tilt of the ground surface on the volcano's slopes.

Predicting the eruption of a particular volcano also requires some knowledge of its previous eruptions. Scientists compare the volcano's past behavior with current daily measurements of earthquakes, surface bulges, and changes in the amount and composition of the gases that the volcano emits. Unfortunately, only a few of the active volcanoes in the world have been studied by scientists long enough to establish any activity patterns. Also, volcanoes that have been dormant for long periods of time may, with little warning, suddenly become active.

Section 2 Review

1. **Summarize** the difference between mafic and felsic magma.
2. **Explain** how the composition of magma affects the force of volcanic eruptions.
3. **Compare** three major types of lava flows.
4. **Define** *pyroclastic material*, and list three examples.
5. **Identify** the three main types of volcanic cones.
6. **Describe** how calderas form.
7. **List** three events that may precede a volcanic eruption.

CRITICAL THINKING

8. **Applying Ideas** Would quiet eruptions or explosive eruptions be more likely to increase the steepness of a volcanic cone? Explain your answer.
9. **Drawing Conclusions** Why would a sudden increase of earthquake activity around a volcano indicate a possible eruption?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *mafic lava, felsic lava, pahoehoe, aa, shield volcano, pyroclastic material, lapilli, volcanic bomb, volcanic block, volcanic ash,* and *volcanic dust.*

Chapter 13 Highlights

Sections

1 Volcanoes and Plate Tectonics

Key Terms

magma, 319
volcanism, 320
lava, 320
volcano, 320
hot spot, 323

Key Concepts

- Magma can form when temperature or pressure changes in mantle rock. Magma also may form when water is added to hot rock.
- Volcanism is any activity that includes the movement of magma onto Earth's surface.
- Volcanism is common at convergent and divergent boundaries between tectonic plates.
- Hot spots are areas of volcanic activity that are located over rising mantle plumes that can exist far from tectonic plate boundaries.
- Magma that cools below Earth's surface forms intrusive igneous rock bodies called plutons.

2 Volcanic Eruptions

mafic, 325
felsic, 325
pyroclastic material, 326
caldera, 329

- Lava and magma can be described as mafic or felsic.
- Hot, less viscous, mafic lava commonly causes quiet eruptions. Cool, more viscous, felsic lava commonly causes explosive eruptions, especially if it contains trapped gases.
- Volcanic cones are classified into three categories based on composition and form.
- A caldera forms where a volcanic cone collapses and leaves a large, basin-shaped depression.
- Events that might signal a volcanic eruption include changes in earthquake activity, changes in the volcano's shape, changes in composition and amount of gases emitted, and changes in the patterns of the volcano's normal activity.

Chapter 13 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *volcanism*
2. *hot spot*
3. *pyroclastic material*

For each pair of terms, explain how the meanings of the terms differ.

4. *magma* and *lava*
5. *mafic* and *felsic*
6. *shield volcano* and *composite volcano*
7. *crater* and *caldera*

Understanding Key Concepts

8. A characteristic of lava that determines the force of a volcanic eruption is
   a. color. **c.** density.
   b. viscosity. **d.** age.

9. Island arcs form when oceanic lithosphere subducts under
   a. continental lithosphere.
   b. calderas.
   c. volcanic bombs.
   d. oceanic lithosphere.

10. Areas of volcanism within tectonic plates are called
    a. hot spots. **c.** calderas.
    b. cones. **d.** fissures.

11. Explosive volcanic eruptions commonly result from
    a. mafic magma. **c.** aa lava.
    b. felsic magma. **d.** pahoehoe lava.

12. Pyroclastic materials that form rounded or spindle shapes as they fly through the air are called
    a. ash. **c.** lapilli.
    b. volcanic bombs. **d.** volcanic blocks.

13. A cone formed by only solid fragments built up around a volcanic opening is a
    a. shield volcano.
    b. cinder cone.
    c. composite volcano.
    d. stratovolcano.

14. The depression that results when a volcanic cone collapses over an emptying magma chamber is a
    a. crater. **c.** vent.
    b. caldera. **d.** fissure.

15. Scientists have discovered that before an eruption, earthquakes commonly
    a. stop.
    b. increase in number.
    c. have no relationship with volcanism.
    d. decrease in number.

Short Answer

16. At what point does magma become lava?
17. Describe how tectonic movement can form volcanoes.
18. Name the process that includes the movement of magma onto Earth's surface.
19. What may happen to magma that does not reach Earth's surface?
20. How is the composition of magma related to the force of volcanic eruptions?
21. List and describe the major types of pyroclastic material.
22. Compare the three main types of volcanic cones.
23. What signs can scientists study to try to predict volcanic eruptions?

Critical Thinking

24. Analyzing Ideas Why is most lava that forms on Earth's surface unnoticed and unobserved?

25. Identifying Relationships The Pacific Ring of Fire is a zone of major volcanic activity because of tectonic plate boundaries. Identify another area of Earth where you might expect to find volcanic activity.

26. Analyzing Processes Why does felsic lava tend to form composite volcanoes and cinder cones rather than shield volcanoes?

27. Making Inferences How might geologists distinguish an impact crater on Earth, such as Meteor Crater in Arizona, from a volcanic crater?

28. Making Comparisons Sinkholes form when the roof of an underground cave is not supported by groundwater. Compare this process to the process by which calderas form.

Concept Mapping

29. Use the following terms to create a concept map: *magma, lava, volcano, pluton, mafic lava, felsic lava, pyroclastic material, volcanic ash, volcanic dust, lapilli, volcanic bomb, volcanic block, volcanic cone, shield volcano, cinder cone,* and *composite volcano*.

Math Skills

30. Making Calculations On day 1, a volcano expelled 5 metric tons of sulfur dioxide. On day 2, the same volcano expelled 12 metric tons of sulfur dioxide. What is the percentage increase of sulfur dioxide expelled from day 1 to day 2?

31. Interpreting Statistics A lava flow travels for 7.3 min before it flows into the ocean. The velocity of the lava is 3 m/s. How far did the lava flow travel?

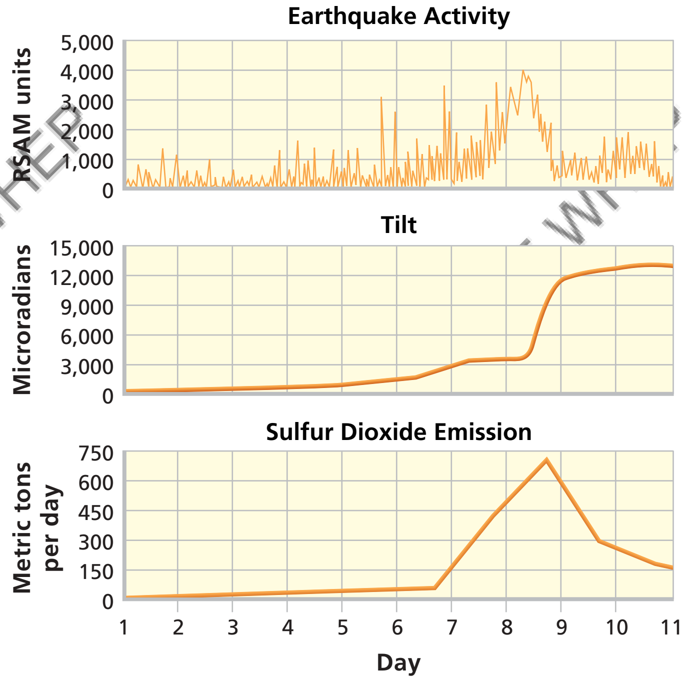
Writing Skills

32. Outlining Topics Outline the essential steps in the process of caldera formation.

33. Communicating Main Ideas Write an essay describing the formation of a volcano.

Interpreting Graphics

The graphs below show data about earthquake activity; the slope angle, or *tilt*, of the ground; and the amount of gas emitted for a particular volcano over a period of 10 days. Use the graphs to answer the questions that follow.



34. On what day did the volcano erupt? Explain your answer.

35. For how many days before the eruption did gas emission increase?

36. Why do you think the slope angle of the ground did not return to its original angle after the eruption?

Standardized Test Prep

Understanding Concepts

Directions (1–5): **For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 What type of volcanic rock commonly makes up much of the continental crust?
A. basalt rock that is rich in olivines
B. felsic rock that is rich in silicates
C. limestone that is rich in calcium carbonate
D. mafic rock that is rich in iron and magnesium

2 Which of the following formations results from magma that cools before it reaches Earth's surface?
F. batholiths
G. mantle plumes
H. volcanic blocks
I. aa lava

3 How does volcanic activity contribute to plate margins where new crust is being formed?
A. Where plates collide at subduction zones, rocks melt and form pockets of magma.
B. Between plate boundaries, hot spots may form a chain of volcanic islands.
C. When plates pull apart at oceanic ridges, magma creates new ocean floor.
D. At some boundaries, new crust is formed when one plate is forced on top of another.

4 An important warning sign of volcanic activity
F. would be a change in local wind patterns
G. is a bulge in the surface of the volcano
H. might be a decrease in earthquake activity
I. is a marked increase in local temperatures

5 Which aspect of mafic lava is important in the formation of smooth, ropy pahoehoe lava?
A. a fairly high viscosity
B. a fairly low viscosity
C. rapidly deforming crust
D. rapid underwater cooling

Directions (6–7): **For *each* question, write a short response.**

6 What is the name for rounded blobs of lava formed by the rapid, underwater cooling of lava?

7 Where is the Ring of Fire located?

Reading Skills

Directions (8–10): **Read the passage below. Then, answer the questions.**

Volcanoes That Changed the Weather

In 1815, Mt. Tambora in Indonesia erupted violently. Following this eruption, one of the largest recorded weather-related disruptions of the last 10,000 years occurred throughout North America and Western Europe. The year 1816 became known as "the year without a summer." Snowfalls and a killing frost occurred during the summer months of June, July, and August of that year. A similar, but less severe episode of cooling followed the 1991 eruption of Mt. Pinatubo. Eruptions such as these can send gases and volcanic dust high into the atmosphere. Once in the atmosphere the gas and dust travel great distances, block sunlight, and cause short-term cooling over large areas of the globe. Some scientists have even suggested a connection between volcanoes and the ice ages.

8 What can be inferred from the passage?
A. Earthquakes can create the same atmospheric effects as volcanoes do.
B. Volcanic eruptions can have effects far beyond their local lava flows.
C. Major volcanic eruptions are common events.
D. The year 1815 also had a number of earthquakes and other natural disasters.

9 According to the passage, which of the following statements is false?
F. The year 1816 became known as "the year without a summer."
G. The world experienced a period of unusually warm weather after Mt. Pinatubo erupted
H. Mt. Pinatubo erupted in 1991.
I. Eruptions send gas and dust into the atmosphere, where they travel around the globe.

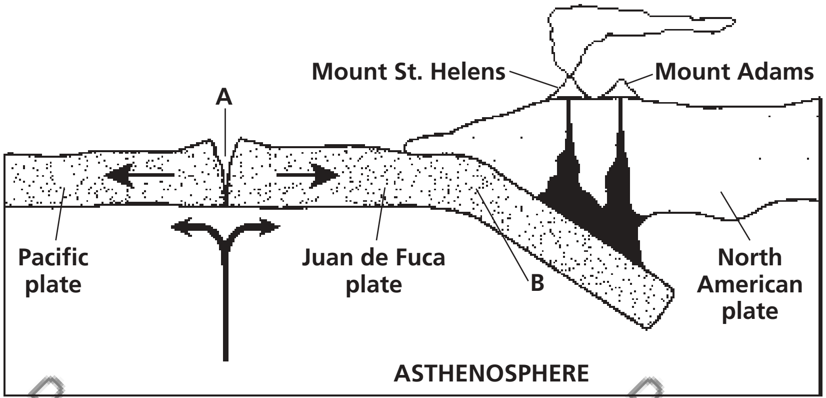
10 The eruptions described in the passage changed the weather briefly. Some scientists believe that periods of severe volcanic activity can produce long-term changes to the climate. Suggest one specific way in which the materials sent into the atmosphere by volcanoes might cause long-term changes to global climate and temperature?

Interpreting Graphics

***Directions (11–13):* For *each* question below, record the correct answer on a separate sheet of paper.**

Base your answers to question 11 on the cross-section below, which shows volcanic activity in the Cascade region of the Pacific West Coast.

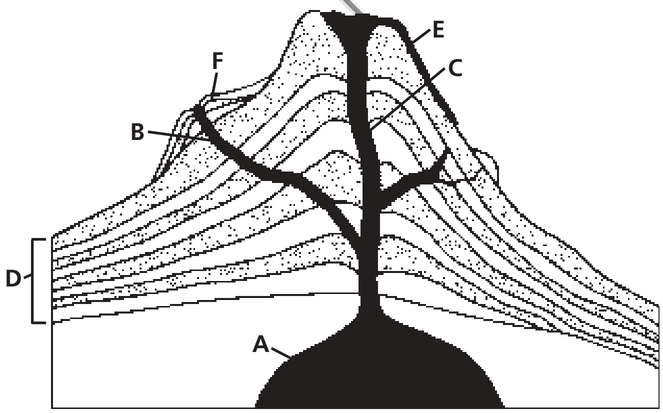
Cross-Section of the Juan de Fuca Ridge



11 Explain how the tectonic activity near point B causes the volcanic activity at Mount St. Helens and Mount Adams in the Cascade Range?

Base your answers to questions 12 and 13 on the diagram of the interior of a volcano shown below.

Interior of a Volcano



12 What is the term for the underground pool of molten rock, marked by the letter A, that feeds the volcano?

A. fissure
B. intrusion
C. lava pool
D. magma chamber

13 Letter D shows alternating layers in the volcanic cone. What are these layers made of, and what does this lead you to believe about the type of volcano that is represented in the diagram above?

Test TIP

When using a diagram to answer questions, carefully study each part of the figure as well as any lines or labels used to indicate parts of the diagram.

Chapter 13

Making Models Lab

Objectives

- **Create** a working apparatus to test carbon dioxide levels.
- **USING SCIENTIFIC METHODS** **Analyze** the levels of carbon dioxide emitted from a model volcano.
- **Predict** the possibility of an eruption from a model volcano.

Materials

- baking soda, 15 cm^3
- drinking bottle, 16 oz
- box or stand for plastic cup
- clay, modeling
- coin
- cup, clear plastic, 9 oz
- graduated cylinder
- limewater, 1 L
- straw, drinking, flexible
- tissue, bathroom (2 sheets)
- vinegar, white, 140 mL
- water, 100 mL

Safety

Volcano Verdict

You will need to have a partner for this exploration. You and your partner will act as geologists who work in a city located near a volcano. City officials are counting on you to predict when the volcano will erupt next. You and your partner have decided to use limewater as a gas-emissions tester. You will use this tester to measure the levels of carbon dioxide emitted from a simulated volcano. The more active the volcano is, the more carbon dioxide it releases.

PROCEDURE

1. Carefully pour limewater into the plastic cup until the cup is three-fourths full. Place the cup on a box or stand. This will be your gas-emissions tester.
2. Now, build a model volcano. Begin by pouring 50 mL of water and 70 mL of vinegar into the drink bottle.
3. Form a plug of clay around the short end of the straw. The clay plug must be large enough to cover the opening of the bottle. Be careful not to get the clay wet.

Step 5

4. Sprinkle 5 cm^3 of baking soda along the center of a single section of bathroom tissue. Then, roll the tissue, and twist the ends so that the baking soda can't fall out.
5. Drop the tissue into the drink bottle, and immediately put the short end of the straw inside the bottle to make a seal with the clay.
6. Put the other end of the straw into the limewater.
7. Record your observations. You have just taken your first measurement of gas levels from the volcano.
8. Imagine that it is several days later and that you need to test the volcano again to collect more data. Before you continue, toss a coin. If it lands heads up, go to step 9. If it lands tails up, go to step 10. Write down the step that you follow.
9. Repeat steps 1–7. But use 2 cm^3 of baking soda in the tissue in step 4 instead of 5 cm^3. (Note: You must use fresh water, vinegar, and limewater.) Record your observations.
10. Repeat steps 1–7. But use 8 cm^3 of baking soda in the tissue in step 4 instead of 5 cm^3. (Note: You must use fresh water, vinegar, and limewater.) Record your observations.

Mount Usu, 770 kilometers from Tokyo in Japan, erupted on March 31, 2000.

ANALYSIS AND CONCLUSION

1. **Explaining Events** How do you explain the difference in the appearance of the limewater from one trial to the next?
2. **Recognizing Patterns** What does the data that you collected tell you about the activity in the volcano?
3. **Evaluating Results** Based on your results in step 9 or 10, do you think it would be necessary to evacuate the city?
4. **Applying Conclusions** How would a geologist use a gas-emissions tester to predict volcanic eruptions?

Extension

1. **Evaluating Data** Scientists base their predictions of eruptions on a variety of evidence before recommending an evacuation. What other forms of evidence would a scientist need to know to predict an eruption?

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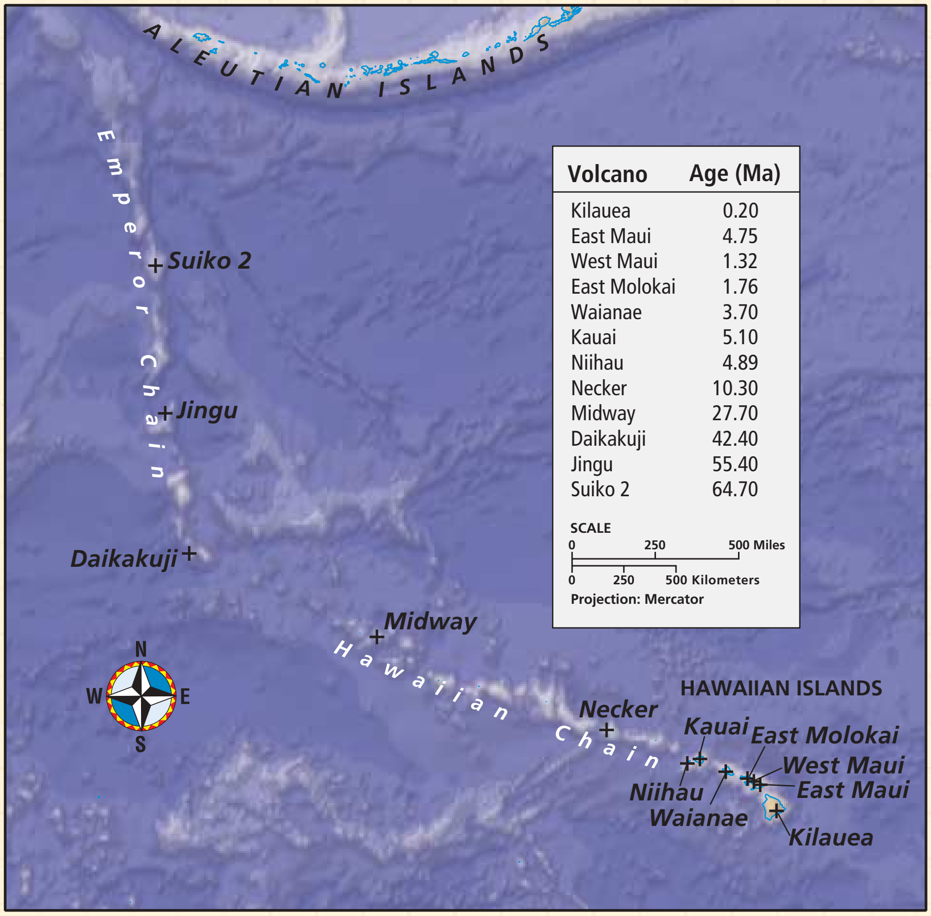
MAPS in Action

The Hawaiian-Emperor Seamount Chain



Volcano	Age (Ma)
Kilauea	0.20
East Maui	4.75
West Maui	1.32
East Molokai	1.76
Waianae	3.70
Kauai	5.10
Niihau	4.89
Necker	10.30
Midway	27.70
Daikakuji	42.40
Jingu	55.40
Suiko 2	64.70

Map Skills Activity

This map shows the locations and ages of islands and seamounts in the Hawaiian-Emperor seamount chain, which is located in the Pacific Ocean. Use the map to answer the questions below.

1. **Inferring Relationships** Under which volcano is the hot spot presently located?
2. **Using the Key** Which volcano is the oldest?
3. **Evaluating Data** A seamont is a submarine volcanic mountain. Would you expect older volcanoes to be seamounts or islands? Explain your answer.
4. **Analyzing Data** Which island signifies a change in direction of the movement of the Pacific plate? Explain your answer.
5. **Identifying Trends** In which direction has the Pacific plate been moving since the formation of the islands in the seamount chain changed direction?
6. **Analyzing Relationships** How many years ago did the Pacific plate change its direction?
7. **Analyzing Data** What is the average speed of the Pacific plate over the last 65 million years?
8. **Predicting Consequences** Where would you expect a new volcano to form 1 million years from now?

The Effects of Volcanoes on Climate

Some scientists think that average temperatures around the globe will rise by 2°C by the year 2050 because of the air pollution released by the use of fossil fuels by humans. To understand the possible effects of human activity on Earth's environment, scientists are studying another source of atmospheric pollution—volcanoes.

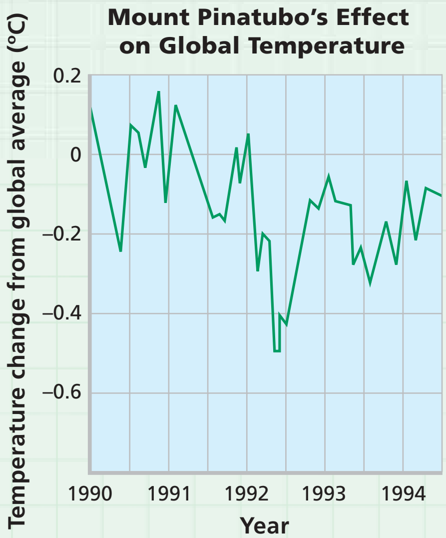
Volcanic Ash

The lava, gases, and ash that erupt into the atmosphere during a volcanic eruption can darken the skies for hundreds of kilometers. In the months after an eruption, some of this material settles to Earth, but much of it remains in the atmosphere, where wind currents disperse it around the world. While the dust and gases are not visible, they affect the climate of the entire planet.

Blocking the Sun's Energy

In June of 1991, Mount Pinatubo began a long series of eruptions. The resulting lava, ash, and mud flows devastated 20,000 km^2 of land. The eruption also released more than 18 million metric tons of sulfur dioxide into the atmosphere. Sulfur dioxide combines with water to become sulfuric acid, which reflects the sun's energy back into space. Scientists predicted that these large amounts of sulfur dioxide would have a cooling effect on Earth's surface. As predicted, average global surface temperatures dropped about 0.6°C by late 1992 and began to recover slowly after that.

By using data collected from several volcanic eruptions, scientists are developing computer models that may help them better understand and predict global climate changes.



▲ The low average global temperatures in 1992 are most likely caused by Mount Pinatubo's eruption in 1991.

Learning how the atmosphere is affected by such natural events will also help scientists understand how pollution from human sources affects the atmosphere.

Extension

1. **Applying Ideas** How would you determine if the 1991 eruption of Mount Pinatubo affected the average monthly temperatures in your community?
2. **Research** Find out how the 1980 eruption of Mount St. Helens changed nearby ecosystems, and identify which effects are still noticeable today.

▼ During the 1991 eruption of Mount Pinatubo in the Philippines, ash fell like snow falls for several days.

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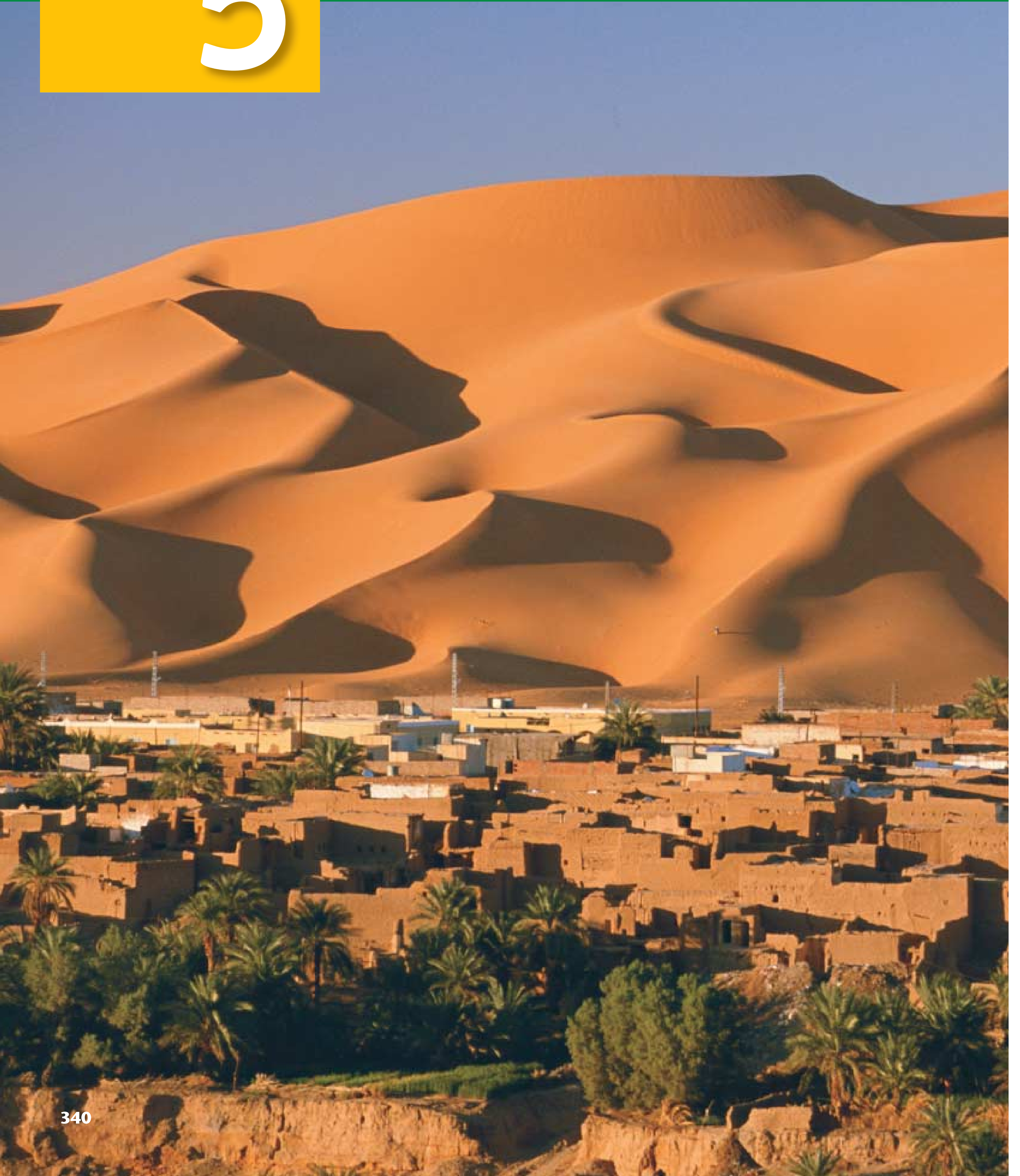
Unit 5 RESHAPING THE CRUST



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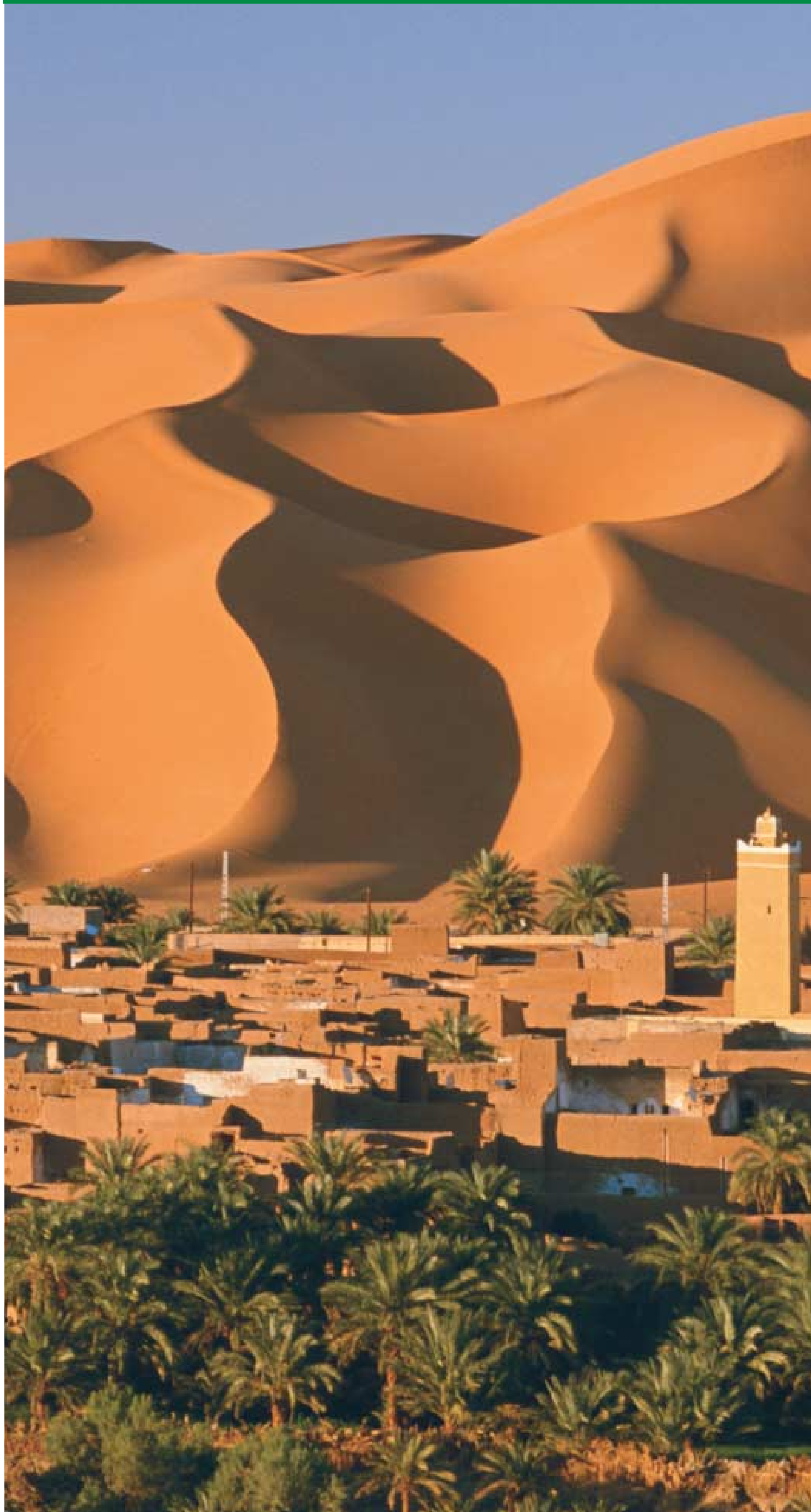
Unit 5 Outline



CHAPTER 14
Weathering and Erosion

CHAPTER 15
River Systems

CHAPTER 16
Groundwater

CHAPTER 17
Glaciers

CHAPTER 18
Erosion by Wind and Waves

▶ Earth's surface is constantly shaped by the action of wind and water. Winds in the Sahara move enormous amounts of sand and form huge sand dunes, such as these near the town of Kerzaz in Algeria, Africa.

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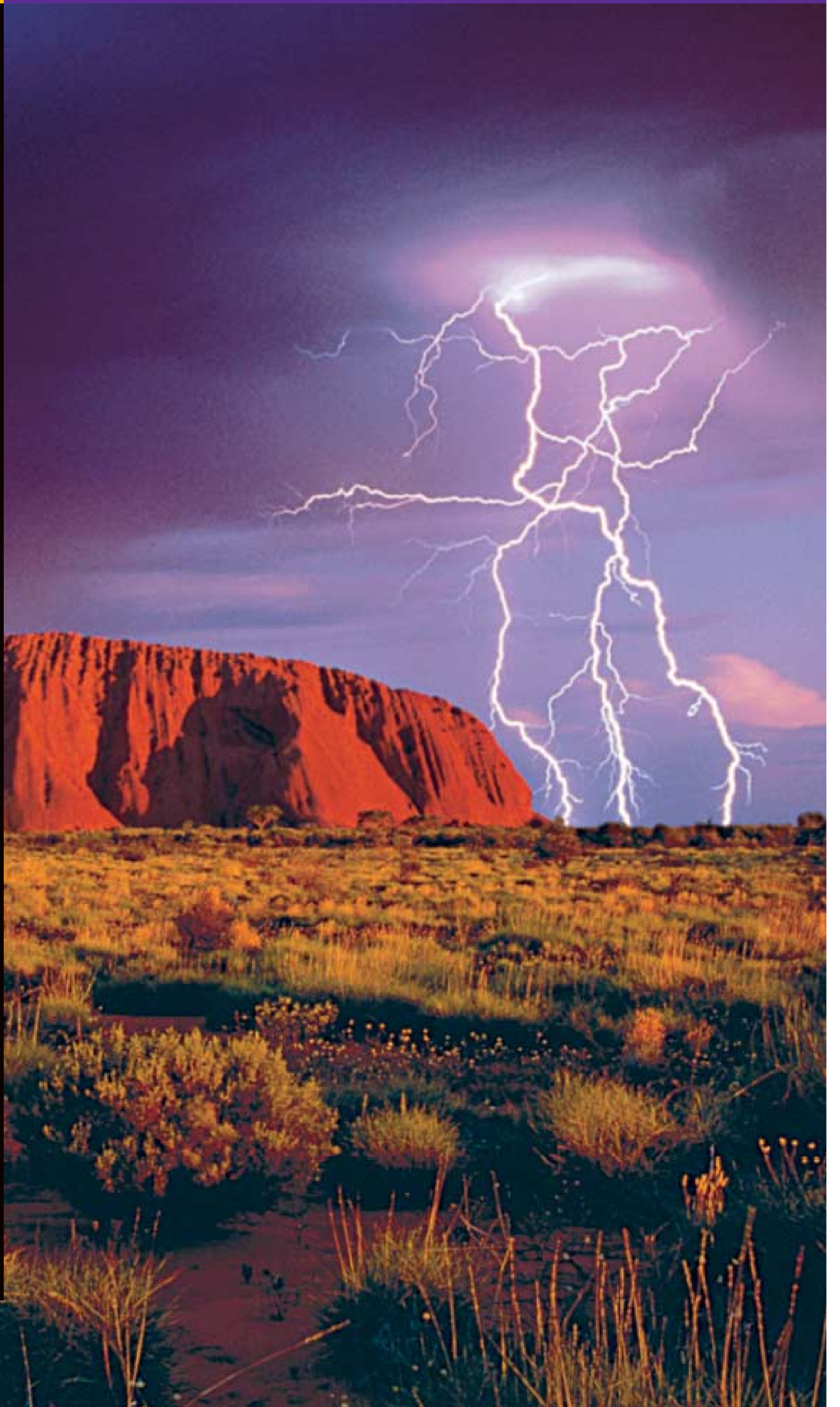
Chapter 14 Weathering and Erosion



Sections

What You'll Learn

- How rock breaks down
- How soil forms
- What agents erode rock and soil

Why It's Relevant

Weathering and erosion change the shape of Earth's surface and are essential to the formation of soil, one of our most important natural resources.

PRE-READING ACTIVITY

FOLDNOTES

TriFold Before you read this chapter, create the FoldNote entitled "TriFold" described in the Skills Handbook Section of the Appendix. Write what you know about weathering and erosion in the column labeled "Know." Then, write what you want to know in the column labeled "Want." As you read the chapter, write what you learn about weathering and erosion in the column labeled "Learn."

▶ Ayers Rock in Australia, also called *Uluru* by the aboriginal peoples of Australia, is gray under its red surface. The surface appears red because iron in the rock oxidizes when it is exposed to air and water.

Section 1 Weathering Processes

Most rocks deep within Earth's crust formed under conditions of high temperature and pressure. When these rocks are uplifted to the surface, they are no longer exposed to extreme temperatures and pressure. Uplifted rock is, however, exposed to the gases and water in Earth's atmosphere.

Because of these environmental factors, surface rocks undergo changes in their appearance and composition. The change in the physical form or chemical composition of rock materials is called **weathering**. There are two main types of weathering processes—mechanical weathering and chemical weathering. Each type of weathering has different effects on rock.

OBJECTIVES

- **Identify** three agents of mechanical weathering.
- **Compare** mechanical and chemical weathering processes.
- **Describe** four chemical reactions that decompose rock.

KEY TERMS

weathering
mechanical weathering
abrasion
chemical weathering
oxidation
hydrolysis
carbonation
acid precipitation

Mechanical Weathering

The process by which rock is broken down into smaller pieces by physical means is **mechanical weathering**. Mechanical weathering is strictly a physical process and does not change the composition of the rock. Common agents of mechanical weathering are ice, plants and animals, gravity, running water, and wind.

Physical changes within the rock itself affect mechanical weathering. For example, as overlying rocks are removed from above granite that formed deep beneath Earth's surface, the pressure on the granite decreases. As a result of the decreasing pressure, the granite expands. Long, curved cracks, called *joints*, that are parallel to the surface develop in the rock. When joints develop on the surface of the rock, the rock breaks into curved sheets that peel away from the underlying rock in a process called *exfoliation*. One example of granite exfoliation on a dome in Yosemite National Park is shown in **Figure 1.**

weathering the natural process by which atmospheric and environmental agents, such as wind, rain, and temperature changes, disintegrate and decompose rocks

mechanical weathering the process by which rocks break down into smaller pieces by physical means

Figure 1 ▶ This area of Yosemite National Park is part of a dome of granite that is shedding large sheets of rock through the process of exfoliation.

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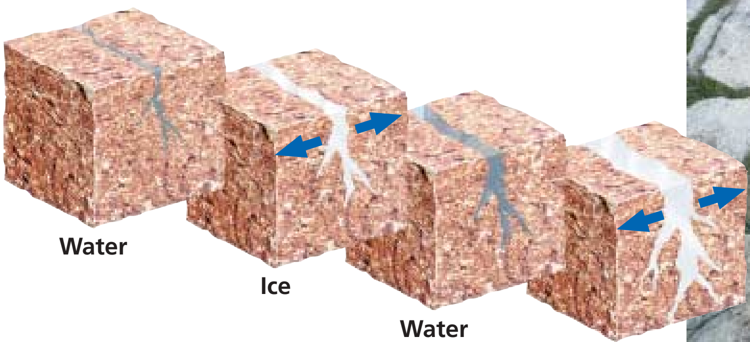
Figure 2 ▶ Water flows into a crack in a rock's surface. When the water freezes, it expands and causes the crack to widen. Ice wedging is responsible for most of the cracks shown in the photograph.



Ice Wedging

A type of mechanical weathering that occurs in cold climates is called *ice wedging*. Ice wedging occurs when water seeps into cracks in rock and then freezes. When the water freezes, its volume increases by about 10% and creates pressure on the surrounding rock. Every time the ice thaws and refreezes, cracks in the rock widen and deepen. This process eventually splits the rock apart, as shown in **Figure 2.** Ice wedging commonly occurs at high elevations and in cold climates. It also occurs in climates where the temperature regularly rises above and then falls below freezing, such as in the northern United States.

SCiLINKS. NSTA Developed and maintained by the National Science Teachers Association

For a variety of links related to this subject, go to www.scilinks.org

Topic: Weathering
SciLinksCode: HQ61648
Topic: Acid Precipitation
SciLinksCode: HQ61690

Abrasion

The collision of rocks that results in the breaking and wearing away of the rocks is a form of mechanical weathering called **abrasion.** Abrasion is caused by gravity, running water, and wind. Gravity causes loose soil and rocks to move down the slope of a hill or mountain. Rocks break into smaller pieces as they fall and collide. Running water can carry particles of sand or rock that scrape against each other and against stationary rocks. Thus, exposed surfaces are weathered by abrasion.

Wind is another agent of abrasion. When wind lifts and carries small particles, it can hurl them against surfaces, such as rocks. As the airborne particles strike the rock, they wear away the surface in the same way that a sandblaster would.

abrasion the grinding and wearing away of rock surfaces through the mechanical action of other rock or sand particles

Reading Check **Describe two types of mechanical weathering. (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ This gray wolf (left) is burrowing into soil to make a den. Prairie dogs (above) also dig into soil and rock to form extensive burrows, where an entire prairie dog community may live.

Organic Activity

Plants and animals are important agents of mechanical weathering. As plants grow, the roots grow and expand to create pressure that wedges rock apart. The roots of small plants cause small cracks to form in the rocks. Eventually, the roots of large plants and trees can fit in the cracks and make the cracks bigger.

The digging activities of burrowing animals, shown in **Figure 3,** also cause weathering. Common burrowing animals include ground squirrels, prairie dogs, ants, earthworms, coyotes, and rabbits. Earthworms and other animals that move soil expose new rock surfaces to both mechanical and chemical weathering. Animal activities and plants can weather rocks dramatically over a long period of time.

QuickLAB 15 min

Mechanical Weathering

Procedure

1. Examine some **silicate rock chips** by using a **hand lens.** Observe the shape and surface texture.
2. Fill a **plastic container** that has a **tight-fitting lid** about half full of rock chips. Add **water** to just cover the chips.
3. Tighten the lid, and shake the container 100 times.
4. Hold a **strainer** over another container. Pour the water and rock chips into the strainer.
5. Move your finger around the inside of the empty container. Describe what you feel.
6. Use the hand lens to observe the rock chips.
7. Pour the water into a **glass jar,** and examine the water with the hand lens.
8. Put the rock chips and water back into the container that has the lid. Repeat steps 3–7.
9. Repeat step 8 two more times.

Analysis

1. Did the amount and particle size of the sediment that was left in the container change during your investigation? Explain your answer.
2. How did the appearance of the rock chips change? How did the appearance of the water change?
3. How does the transport of rock particles by water, such as in a river, affect the size and shape of the rock particles?

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chemical weathering the process by which rocks break down as a result of chemical reactions

oxidation a reaction that removes one or more electrons from a substance such that the substance's valence or oxidation state increases; in geology, the process by which an element combines with oxygen

Chemical Weathering

The process by which rock is broken down because of chemical interactions with the environment is **chemical weathering.** Chemical weathering, or decomposition, occurs when chemical reactions act on the minerals in rock. Chemical reactions commonly occur between rock, water, carbon dioxide, oxygen, and acids. Acids are substances that form *hydronium ions,* or H_3O^+, in water. Hydronium ions are electrically charged and can pull apart the chemical bonds of the minerals in rock. Bases can also chemically weather rock. Bases are substances that form *hydroxide ions,* or OH^-, in water. Chemical reactions with either acids or bases can change the structure of minerals, which leads to the formation of new minerals. Chemical weathering changes both the chemical composition and physical appearance of the rock.

MATHPRACTICE

Rates of Weathering
Limestone is dissolved by chemical weathering at a rate of 0.2 cm every 100 years. At this rate, after how many years would a layer of limestone 15 m thick completely dissolve?

Oxidation

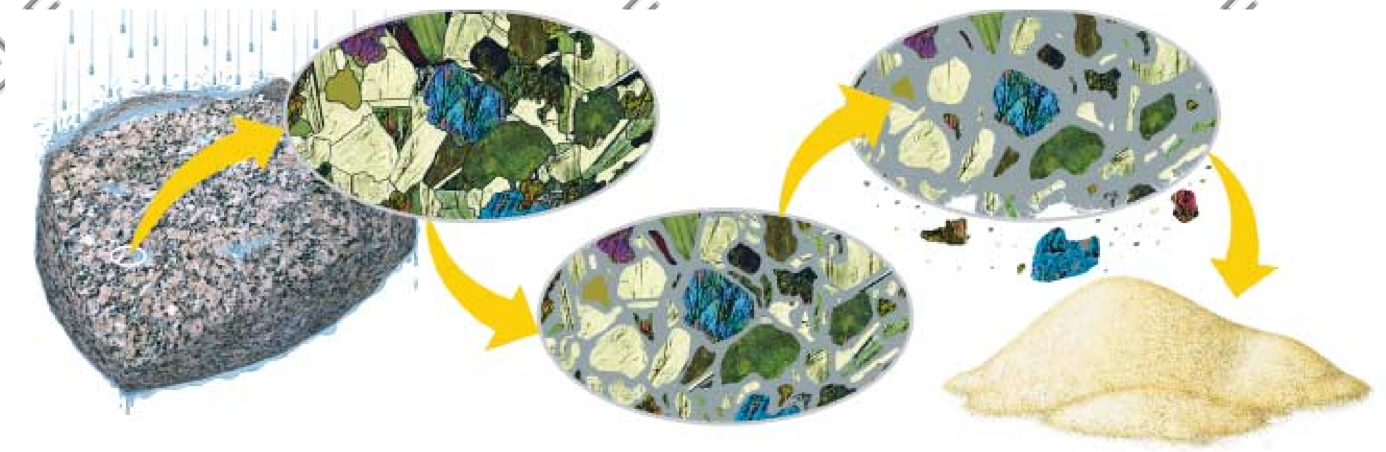
The process by which elements combine with oxygen is called **oxidation.** Oxidation commonly occurs in rock that has iron-bearing minerals, such as hematite and magnetite. Iron, Fe, in rocks and soil combines quickly with oxygen, O_2, that is dissolved in water to form rust, or iron oxide, Fe_2O_3:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

The red color of much of the soil in the southeastern United States, as shown in **Figure 4,** is due to mainly the presence of iron oxide produced by oxidation. Similarly, the color of many red-colored rocks is caused by oxidized, iron-rich minerals.

Reading Check **Describe two effects of chemical weathering. (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ The red tint of the soil surrounding this farmhouse in Georgia is caused by the chemical interaction of iron-bearing minerals in the soil with oxygen in the atmosphere.



Rain, weak acids, and air chemically weather granite.

The bonds between mineral grains weaken as weathering proceeds.

Sediment forms from the weathered granite.

Figure 5 ▶ Thousands of years of chemical weathering processes, such as hydrolysis and carbonation, can turn even a hard rock such as granite into sediment.

Hydrolysis

Water plays a crucial role in chemical weathering, as shown in **Figure 5.** The change in the composition of minerals when they react chemically with water is called **hydrolysis.** For example, a type of feldspar combines with water and produces a common clay called *kaolin*. In this reaction, hydronium ions displace the potassium and calcium atoms in the feldspar crystals, which changes the feldspar into clay.

Minerals that are affected by hydrolysis often dissolve in water. Water can then carry the dissolved minerals to lower layers of rock in a process called *leaching*. Ore deposits, such as bauxite, the aluminum ore, sometimes form when leaching causes a mineral to concentrate in a thin layer beneath Earth's surface.

hydrolysis a chemical reaction between water and another substance to form two or more new substances

carbonation the conversion of a compound into a carbonate

Carbonation

When carbon dioxide, CO_2, from the air dissolves in water, H_2O, a weak acid called *carbonic acid,* H_2CO_3, forms:

$$H_2O + CO_2 \quad H_2CO_3$$

Carbonic acid has a higher concentration of hydronium ions than pure water does, which speeds up the process of hydrolysis. When certain minerals come in contact with carbonic acid, they combine with the acid to form minerals called carbonates. The conversion of minerals into a carbonate is called **carbonation.**

One example of carbonation occurs when carbonic acid reacts with calcite, a major component of limestone, and converts the calcite into calcium bicarbonate. Calcium bicarbonate dissolves easily in water, so the limestone eventually weathers away.

Organic Acids

Acids are produced naturally by certain living organisms. Lichens and mosses grow on rocks and produce weak acids that can weather the surface of the rock. The acids seep into the rock and produce cracks that eventually cause the rock to break apart.

Figure 6 ▶ This stone lion sits outside Leeds Town Hall in England. It was damaged by acid precipitation, which fell regularly in Europe and North America for more than 50 years.

Acid Precipitation

Rainwater is slightly acidic because it combines with small amounts of carbon dioxide. But when fossil fuels, especially coal, are burned, nitrogen oxides and sulfur dioxides are released into the air. These compounds combine with water in the atmosphere to produce nitric acid, nitrous acid, or sulfuric acid. When these acids fall to Earth, they are called **acid precipitation.**

acid precipitation precipitation, such as rain, sleet, or snow, that contains a high concentration of acids, often because of the pollution of the atmosphere

Acid precipitation weathers rock faster than ordinary precipitation does. In fact, many historical monuments and sculptures have been damaged by acid precipitation, as shown in **Figure 6.** Between 1940 and 1990, acid precipitation fell regularly in some cities in the United States. In 1990, the Acid Rain Control Program was added to the Clean Air Act of 1970. These regulations gave power plants 10 years to decrease sulfur dioxide emissions. The occurrence of acid precipitation has been greatly reduced since power plants have installed scrubbers that remove much of the sulfur dioxide before it can be released.

Section 1 Review

1. **Identify** three agents of mechanical weathering.
2. **Describe** how ice wedging weathers rock.
3. **Explain** how two activities of plants or animals help weather rocks or soil.
4. **Compare** mechanical and chemical weathering processes.
5. **Identify** and describe three chemical processes that weather rock.
6. **Compare** hydrolysis, carbonation, and oxidation.
7. **Summarize** how acid precipitation forms.

CRITICAL THINKING

8. **Making Connections** What two agents of weathering would be rare in a desert? Explain your reasoning.
9. **Understanding Relationships** Automobile exhaust contains nitrogen oxides. How might these pollutants affect chemical weathering processes?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *weathering, oxidation, mechanical weathering, ice wedging, hydrolysis, abrasion, chemical weathering, carbonation,* and *acid precipitation.*

Section 2 Rates of Weathering

The processes of mechanical and chemical weathering generally work very slowly. For example, carbonation dissolves limestone at an average rate of only about one-twentieth of a centimeter (0.2 cm) every 100 years. At this rate, it could take up to 30 million years to dissolve a layer of limestone that is 150 m thick.

The pinnacles in Nambung National Park in Australia are shown in **Figure 1.** These large, jutting pieces of limestone are all that remains of a thick limestone formation that covered the area millions of years ago. Most of the limestone was weathered away by agents of both chemical and mechanical weathering until only the pinnacles remained. The rate at which rock weathers depends on a number of factors, including rock composition, climate, and topography.

OBJECTIVES

- **Explain** how rock composition affects the rate of weathering.
- **Discuss** how surface area affects the rate at which rock weathers.
- **Describe** the effects of climate and topography on the rate of weathering.

KEY TERM

differential weathering

Differential Weathering

The composition of rock greatly affects the rate at which rock weathers. The process by which softer, less weather-resistant rock wears away and leaves harder, more resistant rock behind is called **differential weathering.** When igneous rocks that are rich in the mineral quartz are exposed on Earth's surface, they remain basically unchanged, even after all of the surrounding sedimentary rock has weathered away. They remain unchanged because the chemical composition and crystal structure of quartz make quartz resistant to chemical weathering. These same characteristics make quartz a very hard mineral, so it also resists mechanical weathering.

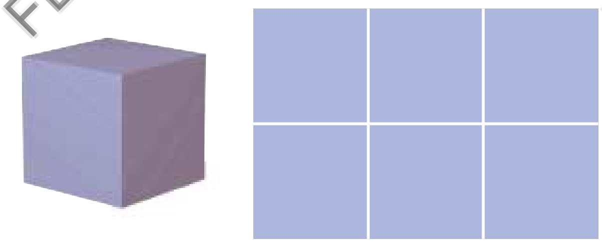
differential weathering the process by which softer, less weather resistant rocks wear away at a faster rate than harder, more weather resistant rocks do

Rock Composition

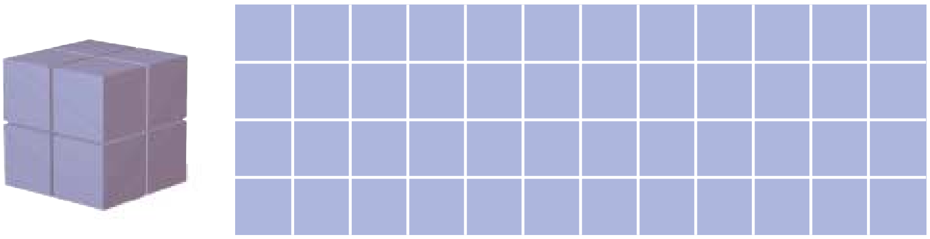
Limestone and other sedimentary rocks that contain calcite are weathered most rapidly. They weather rapidly because they commonly undergo carbonation. Other sedimentary rocks are affected mainly by mechanical weathering processes. The rates at which these rocks weather depend mostly on the material that holds the sediment grains together. For example, shales and sandstones that are not firmly cemented together gradually break up to become clay and sand particles. However, conglomerates and sandstones that are strongly cemented by silicates resist weathering. Some of these strongly cemented sedimentary rocks can resist weathering longer than some igneous rocks do.

Figure 1 ▶ Differences in rock composition and structure are the reasons for the different rates of weathering that formed these limestone pinnacles at Nambung National Park in Australia.

Figure 2 ▶ **The Ratio of Total Surface Area to Volume**



All cubes have both volume and surface area. The total surface area is equal to the sum of the areas of each of the six sides, or the length of each side multiplied by the width of each side.



If you split the first cube into eight smaller cubes, you have the same amount of material (volume), but the surface area doubles. If you split the eight small cubes in the same way, the original surface area is doubled again.

Amount of Exposure

The more exposure to weathering agents a rock receives, the faster the rock will weather. The amount of time the rock is exposed and the amount of the rock's surface area that is available for weathering are important factors in determining the rate of weathering.

Surface Area

Both chemical and mechanical weathering may split rock into a number of smaller rocks. The part of a rock that is exposed to air, water, and other agents of weathering is called the rock's *surface area*. As a rock breaks into smaller pieces, the surface area that is exposed increases. For example, imagine a block of rock as a cube that has six sides exposed. Splitting the block into eight smaller blocks, as shown in **Figure 2**, doubles the total surface area available for weathering.

Fractures and Joints

Most rocks on Earth's surface contain natural fractures and joints. These structures are natural zones of weakness within the rock. Fractures and joints increase the surface area of a rock and allow weathering to take place more rapidly. They also form natural channels through which water flows. Water may penetrate the rock through these channels and break the rock by ice wedging. As water moves through these channels, it chemically weathers the rock that is exposed in the fracture or joint. The chemical weathering removes rock material and makes the jointed or fractured area weaker.

Reading Check **How do fractures and joints affect surface area? (See the Appendix for answers to Reading Checks.)**

QuickLAB 10 min

Surface Areas

Procedure

1. Fill **two small containers** about half full with **water.**
2. Add **one sugar cube** to one container.
3. Add **1 tsp of granulated sugar** to the other container.
4. Use **two different spoons** to stir the water and sugar in each container at the same rate.
5. Use a **stopwatch** to measure how long the sugar in each container takes to dissolve.

Analysis

1. Did the sugar dissolve at the same rate in both containers?
2. Which do you think would wear away faster—a large rock or a small rock? Explain your answer.

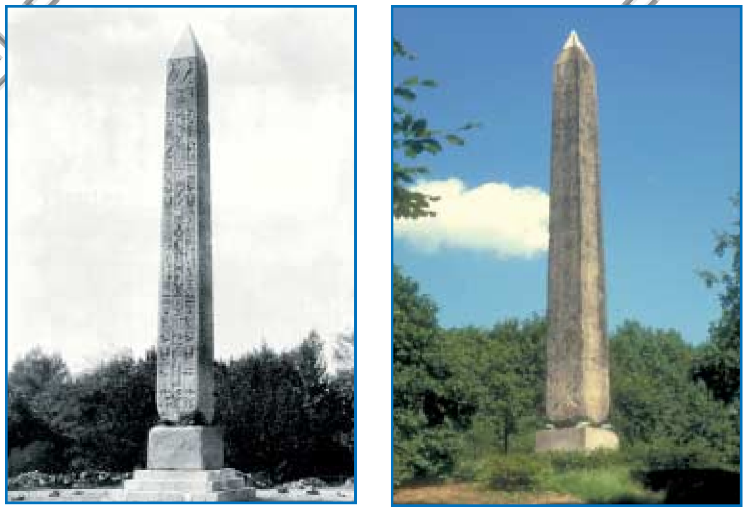


Figure 3 ▶ The photo on the left shows Cleopatra's Needle before it was moved to New York City. The photograph on the right shows the 3,000 year old carving after only one century in New York City.

Climate

In general, climates that have alternating periods of hot and cold weather allow the fastest rates of weathering. Freezing and thawing can cause the mechanical breakdown of rock by ice wedging. Chemical weathering can then act quickly on the fractured rock. When temperatures rise, the rate at which chemical reactions occur also accelerates. In warm, humid climates, chemical weathering is also fairly rapid. The constant moisture is highly destructive to exposed surfaces.

The slowest rates of weathering occur in hot, dry climates. The lack of water limits many weathering processes, such as carbonation and ice wedging. Weathering is also slow in very cold climates.

The effects of climate on weathering rates can be seen on Cleopatra's Needle, which is shown in **Figure 3.** Cleopatra's needle is an obelisk that is made of granite. For 3,000 years, the obelisk stood in Egypt, where the hot, dry climate scarcely changed its surface. Then, in 1880, Cleopatra's Needle was moved to New York City. After the obelisk was exposed to more than 100 years of moisture, the pollution, ice wedging, and acid precipitation caused more weathering than was caused in the preceding 3,000 years in the Egyptian desert.

Topography

Topography, or the elevation and slope of the land surface, also influences the rate of weathering. Because temperatures are generally cold at high elevations, ice wedging is more common at high elevations than at low elevations. On steep slopes, such as mountainsides, weathered rock fragments are pulled downhill by gravity and washed out by heavy rains. As the rocks slide down the mountain or are carried away by mountain streams, rocks smash against each other and break apart. As a result of the removal of these surface rocks, new surfaces of the mountain are continually exposed to weathering.

Figure 4 ▶ All-terrain vehicles cause mechanical weathering on exposed surfaces. Because of this weathering, these vehicles are banned from some areas where erosion is a concern.

Human Activities

Rock can be chemically and mechanically broken down by the action of humans. Mining and construction often expose rock surfaces to agents of weathering. Mining also often exposes rock to strong acids and other chemical compounds that are used in mining processes. Construction often removes soil and exposes previously unexposed rock surfaces. Recreational activities such as hiking or riding all-terrain vehicles, as shown in **Figure 4,** can also speed up weathering by exposing new rock surfaces. Rock that is disturbed or broken by human activities weathers more rapidly than undisturbed rock does.

Plant and Animal Activities

Rock that is disturbed or broken by plants or animals also weathers more rapidly than undisturbed rock does. The roots of plants and trees often break apart rock. Burrowing animals dig holes into rock and soil. Some biological wastes of animals can cause chemical weathering. For example, caves that have large populations of bats also have large amounts of bat guano on the cave floors. Bat guano attracts small animals such as millipedes and other insects. The presence of these insects speeds up mechanical weathering, and the presence of the guano speeds up certain chemical weathering processes.

Section 2 Review

1. **Explain** how rock composition affects the rate of weathering.
2. **Discuss** how the surface area of a rock can affect the rock's weathering rate.
3. **Identify** two ways that climate can influence weathering rates.
4. **Describe** two ways the topography of a region affects weathering rates.
5. **Summarize** three ways human actions can affect the rate of weathering.
6. **Explain** two ways that animals can affect the rate of weathering.

CRITICAL THINKING

7. **Applying Concepts** Imagine that there is an area of land where mechanical weathering has caused damage. Describe two ways to reduce the rate of mechanical weathering.
8. **Identifying Relationships** How would Cleopatra's Needle probably have been affected if it had been in the cold, dry climate of Siberia for 100 years?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *composition, exposure, precipitation, surface area, climate, temperature, topography, weathering, elevation,* and *human activities.*

Section 3 Soil

One result of weathering is the formation of *regolith*, the layer of weathered rock fragments that covers much of Earth's surface. *Bedrock* is the solid, unweathered rock that lies beneath the regolith. The lower regions of regolith are partly protected by those above and thus do not weather as rapidly as the upper regions do. The uppermost rock fragments weather to form a layer of very fine particles. This layer of small rock particles provides the basic components of soil. **Soil** is a complex mixture of minerals, water, gases, and the remains of dead organisms.

OBJECTIVES

- **Summarize** how soils form.
- **Explain** how the composition of parent rock affects soil composition.
- **Describe** the characteristic layers of mature residual soils.
- **Predict** the type of soil that will form in arctic and tropical climates.

KEY TERMS

soil
soil profile
horizon
humus

Characteristics of Soil

The characteristics of soil depend mainly on the rock from which the soil was weathered, which is called the soil's *parent rock*. Soil that forms and stays directly over its parent rock is called *residual soil*. However, the weathered mineral grains that form soil may be carried away from the location of the parent rock by water, wind, or glaciers. Soil that results from the deposition of this material is called *transported soil*, and this soil may have different characteristics than the bedrock on which it rests.

soil a loose mixture of rock fragments and organic material that can support the growth of vegetation

Soil Composition

Parent rock that is rich in feldspar or other minerals that contain aluminum weathers to form soils that contain large amounts of clay. Rocks that contain large amounts of quartz, such as granite, weather to form sandy soils. Soil composition refers to the materials of which it is made. The color of soil is related to the composition of the soil. Black soils are commonly rich in organic material, while red soils may form from iron-rich parent rocks. Soil moisture can also affect color, as shown in **Figure 1.**

Figure 1 ▶ These soil scientists are testing soil moisture to determine whether irrigation will be needed. Moister soils are generally darker than drier soils are.

Soil Texture

Rock material in soil consists of three main types: clay, silt, and sand. Clay particles have a diameter of less than 0.004 mm. Silt particles have diameters from 0.004 to 0.06 mm. Silt particles are too small to be seen easily, but they make soil feel gritty. Sand particles have diameters from 0.06 to 2 mm. The proportion of clay, silt, and sand in soil depends on the soil's parent rock.

Soil Profile

soil profile a vertical section of soil that shows the layers of horizons

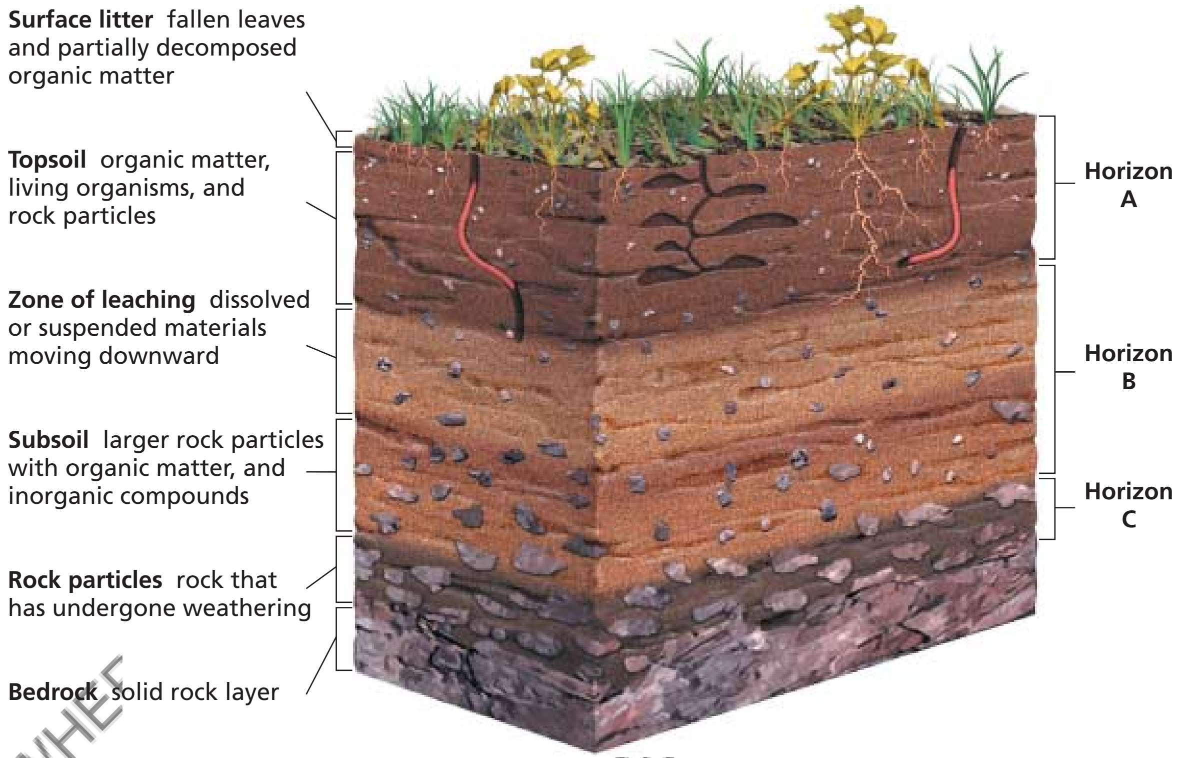
horizon a horizontal layer of soil that can be distinguished from the layers above and below it; *also* a boundary between two rock layers that have different physical properties

humus dark, organic material formed in soil from the decayed remains of plants and animals

Transported soils are commonly deposited in unsorted masses by water or wind. However, residual soils commonly develop distinct layers over time. To determine a soil's composition, scientists study a soil profile. A **soil profile** is a cross section of the soil and its bedrock. The different layers of soil are called **horizons.**

Residual soils generally consist of three main horizons. The *A horizon,* or *topsoil,* is a mixture of organic materials and small rock particles. Almost all organisms that live in soil inhabit the A horizon. As organisms die, their remains decay and produce **humus,** a dark, organic material. The A horizon is also the zone from which surface water leaches minerals. The *B horizon* or *subsoil,* contains the minerals leached from the topsoil, clay, and, sometimes, humus. In dry climates, the B horizon also may contain minerals that accumulate as water in the soil evaporates. The *C horizon* consists of partially-weathered bedrock. The first stages of mechanical and chemical change happen in this bottom layer. **Figure 2** shows the relationships between the three soil horizons.

Figure 2 ▶ Soil Horizons of Residual Soils



Soil and Climate

Climate is one of the most important factors that influences soil formation. Climate determines the weathering processes that occur in a region. These weathering processes, in turn, help determine the composition of soil.

Tropical Soils

In humid tropical climates, where much rain falls and where temperatures are high, chemical weathering causes thick soils to develop rapidly. These thick, tropical soils, called *laterites* (LAT uhr IETS), contain iron and aluminum minerals that do not dissolve easily in water. Leached minerals from the A horizon sometimes collect in the B horizon. Heavy rains, which are common in tropical climates, cause a lot of leaching of the topsoil, and thus keep the A horizon thin. But because of the dense vegetation in humid, warm climates, organic material is continuously added to the soil. As a result, a thin layer of humus usually covers the B horizon, as shown in **Figure 3.**

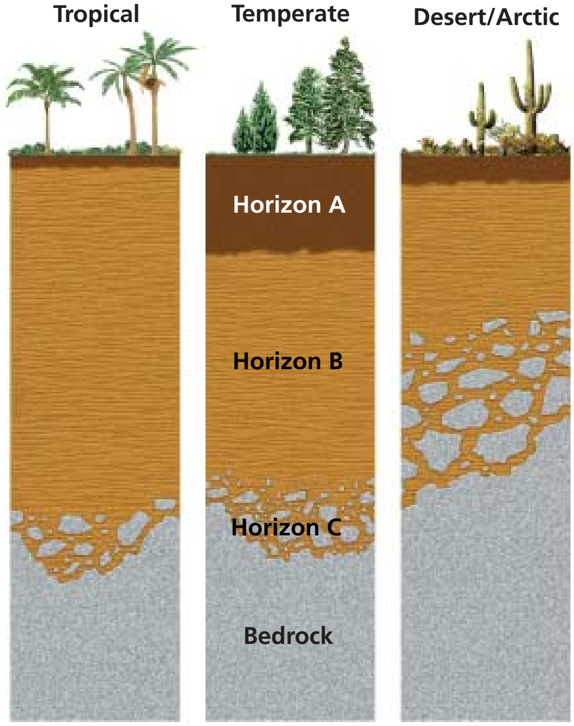


Figure 3 ▶ Tropical climates produce thick, infertile soils. Temperate climates produce thick, fertile soils. Desert and arctic climates produce thin soils.

Temperate Soils

In temperate climates, where temperatures range between cool and warm and where rainfall is not excessive, both mechanical and chemical weathering occur. All three soil horizons in temperate soils may reach a thickness of several meters, as shown in **Figure 3.**

Two main soil types form in temperate climates. In areas that receive more than 65 cm of rain per year, a type of soil called *pedalfer* (pi DAL fuhr) forms. Pedalfer soils contain clay, quartz, and iron compounds. The Gulf Coast states and states east of the Mississippi River have pedalfer soils. In areas that receive less than 65 cm of rain per year, a soil called *pedocal* (PED oh KAL) forms. Pedocal soils contain large amounts of calcium carbonate, which makes pedocal soil very fertile and less acidic than pedalfer soil. The southwestern states and most states west of the Mississippi River have pedocal soils.

Reading Check **Compare the formation of tropical soils and temperate soils. (See the Appendix for answers to Reading Checks.)**

Desert and Arctic Soils

In desert and arctic climates, rainfall is minimal and chemical weathering occurs slowly. As a result, the soil is thin and consists mostly of regolith—evidence that soil in these areas forms mainly by mechanical weathering. Desert and arctic climates are also often too warm or too cold to sustain life, so their soils have little humus.

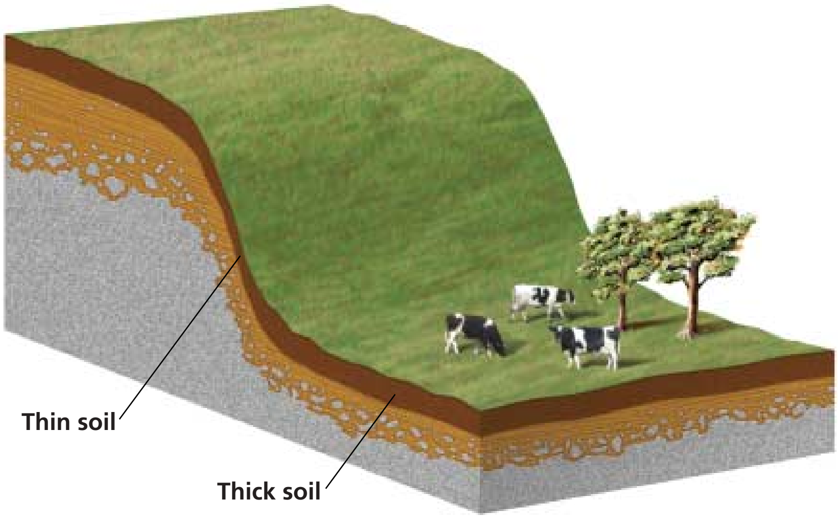


Figure 4 ▶ Soil is thick at the top and bottom of a slope. Soil is thin along the slope.

Soil and Topography

The shape of the land, or topography, also affects soil formation. Because rainwater runs down slopes, much of the topsoil of the slope washes away. Therefore, as shown in **Figure 4,** the soil at the top and bottom of a slope tends to be thicker than the soil on the slope.

One study of soil in Canada showed that A horizons on flat areas were more than twice as thick as those on 10° slopes. Topsoil that remains on a slope is often too thin to support dense plant growth. The lack of vegetation contributes to the development of a poor-quality soil that lacks humus. The soils on the sides of mountains are commonly thin and rocky, and the soils have few nutrients. Lowlands that retain water tend to have thick, wet soils and a high concentration of organic matter, which forms humus. A fairly flat area that has good drainage provides the best surface for formation of thick, fertile layers of residual soil.

Section 3 Review

1. **Summarize** how soils form.
2. **Explain** how the composition of parent rock affects soil composition.
3. **Describe** the three horizons of a residual soil.
4. **Predict** the type of soil that will form in arctic and tropical climates.

CRITICAL THINKING

5. **Applying Ideas** What combination of soil and climate would be ideal for growing deep-rooted crops? Explain your answer.
6. **Analyzing Relationships** Would you expect crop growth to be more successful on a farm that has an uneven topography or on a farm that has level land? Explain your answer.
7. **Analyzing Ideas** Why would tropical soil not be good for sustained farming?
8. **Making Comparisons** Although desert and arctic climates are extremely different, their soils may be somewhat similar. Explain why.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *soil, bedrock, regolith, humus, parent rock, residual soil, transported soil, horizon, soil profile, climate,* and *topography*.

Section 4 Erosion

OBJECTIVES

- **Define** erosion, and list four agents of erosion.
- **Identify** four farming methods that conserve soil.
- **Discuss** two ways gravity contributes to erosion.
- **Describe** the three major landforms shaped by weathering and erosion.

KEY TERMS

erosion
sheet erosion
mass movement
solifluction
creep
landform

When rock weathers, the resulting rock particles do not always stay near the parent rock. Various forces may move weathered fragments of rock away from where the weathering occurred. The process by which the products of weathering are transported is called **erosion.** The most common agents of erosion are gravity, wind, glaciers, and water. Water can move weathered rock in several different ways including by ocean waves and currents, by streams and runoff, and by the movements of groundwater.

erosion a process in which the materials of Earth's surface are loosened, dissolved, or worn away and transported from one place to another by a natural agent, such as wind, water, ice, or gravity

Soil Erosion

As rock weathers, it eventually becomes very fine particles that mix with water, air, and humus to form soil. The erosion of soil occurs worldwide and is normally a slow process. Ordinarily, new soil forms about as fast as existing soil erodes. However, some forms of land use and unusual climatic conditions can upset this natural balance. Once the balance is upset, soil erosion often accelerates.

Some farming and ranching practices increase soil erosion. For example, plants anchor soil with their roots and prevent wind and water from eroding the soil. Clearing plants or allowing animals to overgraze destroys this groundcover and increases erosion rates. Soil erosion is considered by some scientists to be the greatest environmental problem that faces the world today. As shown in **Figure 1,** vulnerability to erosion affects fertile topsoil around the world. This erosion prevents some countries from growing the crops needed to prevent widespread famine.

Figure 1 ▶ This map shows the vulnerability of soils worldwide to erosion by water.

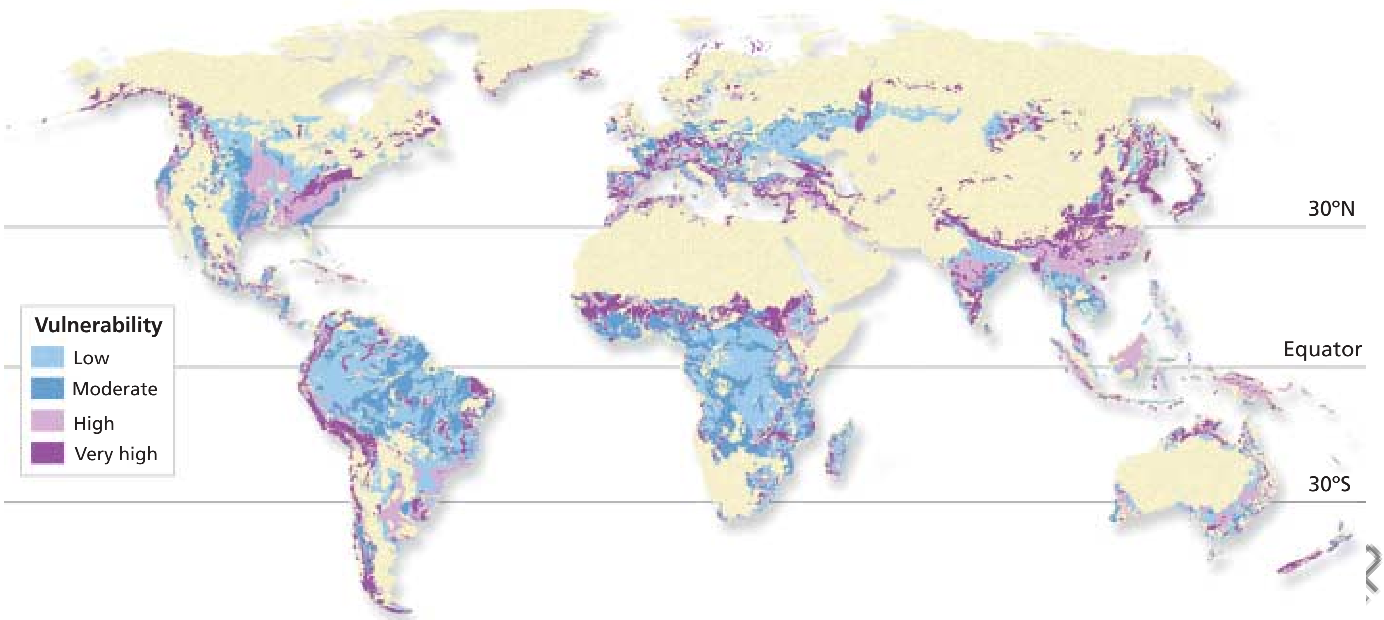


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Figure 2 ▶ This land in Madagascar can no longer be used for farming because of a form of rapid erosion called *gullying*.

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For a variety of links related to this subject, go to www.scilinks.org

Topic: Soil Erosion
SciLinksCode: HQ61410
Topic: Soil Conservation
SciLinksCode: HQ61409

Gullying and Sheet Erosion

One farming technique that can accelerate soil erosion is the plowing of furrows, or long, narrow rows. Furrows that are plowed up and down slopes allow water to run swiftly over soil. As soil is washed away with each rainfall, a furrow becomes larger and forms a small gully. Eventually, land that is plowed in this way can become covered with deep gullies. This type of accelerated soil erosion is called *gullying*. The farmland shown in **Figure 2** has been ruined by gullying.

Another type of soil erosion strips away parallel layers of topsoil. Eventually, erosion can expose the surface of the subsoil. This process is called **sheet erosion.** Sheet erosion may occur where continuous rainfall washes away layers of the topsoil. Wind also can cause sheet erosion during unusually dry periods. The soil, which is made dry and loose by a lack of moisture, is carried away by the wind as clouds of dust and drifting sand. These wind-borne particles may produce large dust storms.

sheet erosion the process by which water flows over a layer of soil and removes the topsoil

Reading Check **Describe one way a dust storm may form, and explain how a dust storm can affect the fertility of land. (See the Appendix for answers to Reading Checks.)**

Results of Soil Erosion

Constant erosion reduces the fertility of the soil by removing the A horizon, which contains the fertile humus. The B horizon, which does not contain much organic matter, is difficult to farm because it is much less fertile than the A horizon. Without plants, the B horizon has nothing to protect it from further erosion. So, within a few years, all of the soil layers could be removed by continuous erosion.

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Soil Conservation

Figure 3 ▶ This housing development in England is encroaching on cropland. The clearing of land for development can accelerate topsoil erosion.

Erosion rates are affected not only by natural factors but also by human activities. Certain farming and grazing techniques and construction projects can also increase the rate of erosion. In developing urban areas, vegetation is removed to build houses and roads, such as those shown in **Figure 3.** This land clearing removes protective ground cover plants and accelerates topsoil erosion. In some areas, such as deserts or mountainous regions, it may take hundreds or thousands of years for the topsoil to be replenished.

But rapid, destructive soil erosion can be prevented by soil conservation methods. People, including city planners and some land developers, have begun to recognize the environmental impact of land development and are beginning to implement soil conservation measures. Some land development projects are leaving trees and vegetation in place whenever possible. Other projects are planting cover plants to hold the topsoil in place. Farmers are also looking for new ways to prevent soil erosion to preserve fertile topsoil.

Connection to ENVIRONMENTAL SCIENCE

Land Degradation

Soil that can support the growth of healthy plants is called *fertile soil*. Land that can be used to grow crops is called *arable land*. A limited area of arable land is available on Earth. As humans use this land for agriculture, they plow, fertilize, irrigate, and otherwise change the natural processes of soil formation.

Human activity and natural processes may damage land to the point that it can no longer support the local ecosystem. This process is called *land degradation*. Several activities may lead to land degradation. Three common factors in land degradation are urbanization, overgrazing, and deforestation.

Urbanization is the movement of people from rural areas to cities. As cities expand rapidly, people begin to develop the surrounding area, in a process called *urban sprawl*. As a result, arable land is paved and demand for resources may overwhelm the water and land resources in the area.

Overgrazing occurs when more animals are allowed to graze an area than the plants in that area can support. When animals overgraze, too many plants are eaten or trampled and too few plants are left to protect the soil from eroding.

If this clearcut in Willamette National Forest in Oregon was not reclaimed, the land may have continued to undergo degradation.

Deforestation is the clearing of trees from an area without replacing them. This process destroys wildlife habitat and results in accelerated soil erosion.

Extreme land degradation may cause desertification. *Desertification* is the process by which land in dry areas becomes more desertlike because of human activity or climate change. Desertification can cause land to become useless for farming or human habitation.

Many government and independent organizations are working to develop laws and guidelines to protect both wilderness and agricultural land. These groups hope that by protecting these lands now, the resources will be available for future generations.

Contour Plowing These fields are plowed in contours (or curves) that follow the shape of the land.

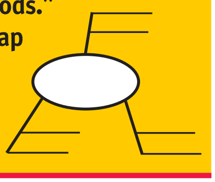
Strip-Cropping These fields were planted with alternating strips of different crops.

Terracing These terraced fields help slow runoff and prevent rapid soil erosion.

Figure 4 ▶ Soil Conservation Methods

Graphic Organizer **Spider Map**

Create the **Graphic Organizer** entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Soil conservation methods." Then, fill in the map with at least four methods for soil conservation.



Contour Plowing

Farmers in countries around the world use planting techniques to reduce soil erosion. In one method, called *contour plowing*, soil is plowed in curved bands that follow the contour, or shape, of the land. This method of planting, shown in **Figure 4,** prevents water from flowing directly down slopes, so the method prevents gullying.

Strip-Cropping

In *strip-cropping*, crops are planted in alternating bands, also shown in **Figure 4.** A crop planted in rows, such as corn, may be planted in one band, and another crop that fully covers the surface of the land, such as alfalfa, will be planted next to it. The *cover crop* protects the soil by slowing the runoff of rainwater. Strip-cropping is often combined with contour plowing. The combination of these two methods can reduce soil erosion by 75%.

Terracing

The construction of steplike ridges that follow the contours of a sloped field is called *terracing*, as shown in **Figure 4.** Terraces, especially those used for growing rice in Asia, prevent or slow the downslope movement of water and thus prevent rapid erosion.

Crop Rotation

In *crop rotation*, farmers plant one type of crop one year and a different type of crop the next. For example, crops that expose the soil to the full effects of erosion may be planted one year, and a cover crop will be planted the next year. Crop rotation stops erosion in its early stages, which allows small gullies that formed during one growing season to fill with soil during the next one.

Gravity and Erosion

Gravity causes rock fragments to move down inclines. This movement of fragments down a slope is called **mass movement.** Some mass movements occur rapidly, and others occur very slowly.

mass movement the movement of a large mass of sediment or a section of land down a slope

Rockfalls and Landslides

The most dramatic and destructive mass movements occur rapidly. The fall of rock from a steep cliff is called a *rockfall*. A rockfall is the fastest kind of mass movement. Rocks in rockfalls often range in size from tiny fragments to giant boulders.

When masses of loose rock combined with soil suddenly fall down a slope, the event is called a *landslide*. Large landslides, in which loosened blocks of bedrock fall, generally occur on very steep slopes. You may have seen a small landslide on cliffs and steep hills overlooking highways, such as the one shown in **Figure 5.** Heavy rainfall, spring thaws, volcanic eruptions, and earthquakes can trigger landslides.

Reading Check **What is the difference between a rockfall and a landslide? (See the Appendix for answers to Reading Checks.)**

Mudflows and Slumps

The rapid movement of a large amount of mud creates a *mudflow*. Mudflows occur in dry, mountainous regions during sudden, heavy rainfall or as a result of volcanic eruptions. Mud churns and tumbles as it moves down slopes and through valleys, and it frequently spreads out in a large fan shape at the base of the slope. The mass movements that sometimes occur in hillside communities, such as the one shown in **Figure 5,** are often referred to as landslides, but they are actually mudflows.

Sometimes, a large block of soil and rock becomes unstable and moves downhill in one piece. The block of soil then slides along the curved slope of the surface. This type of movement is called a *slump*. Slumping occurs along very steep slopes. Saturation by water and loss of friction with underlying rock causes loose soil to slip downhill over the solid rock.

Figure 5 ▶ An earthquake in El Salvador caused this dramatic landslide (left). Heavy rains in the Philippines caused this destructive mudflow (right).

Solifluction

Although most slopes appear to be unchanging, some slow mass movement commonly occurs. Catastrophic landslides are the most hazardous mass movement. However, more rock material on the whole is moved by the greater number of slow mass movements than by catastrophic landslides.

solifluction the slow, downslope flow of soil saturated with water in areas surrounding glaciers at high elevations

creep the slow downhill movement of weathered rock material

One form of slow mass movement is called solifluction. **Solifluction** is the process by which water-saturated soil slips over hard or frozen layers. Solifluction occurs in arctic and mountainous climates where the subsoil is permanently frozen. In spring and summer, only the top layer of soil thaws. The moisture from this layer cannot penetrate the frozen layers beneath. So, the surface layer becomes muddy and slowly flows downslope, or downhill. Solifluction can also occur in warmer regions, where the subsoil consists of hard clay. The clay layer acts like the frozen subsoil in arctic climates by forming a waterproof barrier.

Creep

The extremely slow downhill movement of weathered rock material is known as **creep.** Soil creep moves the most soil of all types of mass movements. But creep may go unnoticed unless buildings, fences, or other surface objects move along with soil.

Many factors contribute to soil creep. Water separates rock particles, which allows them to move freely. Growing plants produce a wedgelike pressure that separates particles and loosens the soil. The burrowing of animals and repeated freezing and thawing loosen rock particles and allow gravity to slowly pull the particles downhill.

As rock fragments accumulate at the base of a slope, they form piles called *talus* (TAY luhs), as shown in **Figure 6.** Talus weathers into smaller fragments, which move farther down the slope. The fragments wash into gullies, are carried into successively larger waterways, and eventually flow into rivers.

Figure 6 ▶ The movement of rock fragments downslope formed these talus cones at the base of the Canadian Rockies.

Figure 7 ▶ The mountains in the Patagonian Andes, shown on the left, are still being uplifted and are more rugged than the more eroded Appalachian mountains on the right.

Erosion and Landforms

Through weathering and erosion, Earth's surface is shaped into different physical features, or **landforms.** There are three major landforms that are shaped by weathering and erosion—*mountains, plains,* and *plateaus*. Minor landforms include hills, valleys, and dunes. The shape of landforms is also influenced by rock composition.

All landforms are subject to two opposing processes. One process bends, breaks, and lifts Earth's crust and thus creates elevated, or uplifted, landforms. The other process is weathering and erosion, which wears down land surfaces.

landform a physical feature of Earth's surface

Erosion of Mountains

During the early stages in the history of a mountain, the mountain undergoes uplift. Generally, while tectonic forces are uplifting the mountain, it rises faster than it is eroded. Mountains that are being uplifted tend to be rugged and have sharp peaks and deep, narrow valleys. When forces stop uplifting the mountain, weathering and erosion wear down the rugged peaks to rounded peaks and gentle slopes. The formations in **Figure 7** show how the shapes of mountains are influenced by uplift and erosion.

Over millions of years, mountains that are not being uplifted become low, featureless surfaces. These areas are called *peneplains* (PEE nuh PLAYNZ), which means "almost flat." A peneplain commonly has low, rolling hills, as seen in New England.

Reading Check **Describe how a mountain changes after it is no longer uplifted. (See the Appendix for answers to Reading Checks.)**

Figure 8 ▶ Ancient rivers carved plateaus into mesas, which eventually eroded into the buttes of Monument Valley in Arizona.

Erosion of Plains and Plateaus

A *plain* is a relatively flat landform near sea level. A *plateau* is a broad, flat landform that has a high elevation. A plateau is subject to much more erosion than a plain. Young plateaus, such as the Colorado Plateau in the southwestern United States, commonly have deep stream valleys that separate broad, flat regions. Older plateaus, such as those in the Catskill region in New York State, have been eroded into rugged hills and valleys.

The effect of weathering and erosion on a plateau depends on the climate and the composition and structure of the rock. In dry climates, resistant rock produces plateaus that have flat tops. As a plateau ages, erosion may dissect the plateau into smaller, tablelike areas called *mesas* (MAY suhz). Mesas ultimately erode to small, narrow-topped formations called *buttes* (BYOOTS). In dry regions, such as in the area shown in **Figure 8,** mesas and buttes have steep walls and flat tops. In areas that have wet climates, humidity and precipitation weather landforms into round shapes.

Section 4 Review

1. **Define** erosion.
2. **List** four agents of erosion.
3. **Summarize** two processes of soil erosion.
4. **Identify** four farming methods that result in soil conservation.
5. **Discuss** two ways gravity contributes to erosion.
6. **Compare** rapid mass movements and slow mass movements.
7. **Describe** the erosion of the three major landforms.

CRITICAL THINKING

8. **Analyzing Relationships** Describe an experiment that could help you determine whether a nearby hill is undergoing creep.
9. **Applying Ideas** Suppose you wanted to grow grapevines on a hillside in Italy. What farming methods would you use? Explain your answer.
10. **Predicting Consequences** Describe two ways a small butte would change if it was in a wet climate, rather than a dry climate.
11. **Drawing Conclusions** A hillside community has asked you to help brainstorm ways to prevent future mudflows. Describe three of your ideas.

CONCEPT MAPPING

12. Use the following terms to create a concept map: *erosion, gullying, sheet erosion, landslide, mudflow, slump, solifluction, creep, talus, landform, mountain, plain, plateau, mesa,* and *butte.*

Chapter 14 Highlights

Sections

1 Weathering Processes

Key Terms

weathering, 343
mechanical weathering, 343
abrasion, 344
chemical weathering, 346
oxidation, 346
hydrolysis, 347
carbonation, 347
acid precipitation, 348

Key Concepts

- Agents of mechanical weathering break rock into smaller pieces but do not change its chemical composition.
- Chemical weathering changes the mineral composition of rock.
- Types of chemical weathering include hydrolysis, carbonation, oxidation, and acid precipitation.

2 Rates of Weathering

differential weathering, 349

- Rock weathers at different rates, which depend partly on its mineral composition.
- The greater the amount of exposure a rock has, the faster a rock weathers.
- Rock weathers more rapidly in regions where rainfall is abundant and where alternating freezes and thaws occur.

3 Soil

soil, 353
soil profile, 354
horizon, 354
humus, 354

- The parent rock from which soil forms is the major factor that determines the composition of the soil.
- Thick soils form in tropical climates and temperate climates. Thin soils form in arctic climates and desert climates, where rainfall is minimal.

4 Erosion

erosion, 357
sheet erosion, 358
mass movement, 361
solifluction, 362
creep, 362
landform, 363

- Natural agents often move weathered rock away from where the weathering occurred. This movement leads to erosion.
- Planting crops helps to conserve soil.
- Slow and rapid mass movements of rock, soil, and mud cause massive amounts of soil erosion.
- Erosion wears away landforms as it levels Earth's surface.

Chapter 14 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *abrasion*
2. *humus*
3. *landform*

For each pair of terms, explain how the meanings of the terms differ.

4. *weathering* and *erosion*
5. *mechanical weathering* and *chemical weathering*
6. *oxidation* and *carbonation*
7. *soil profile* and *horizon*
8. *solifluction* and *creep*

Understanding Key Concepts

9. A common kind of mechanical weathering is called
   a. oxidation. **c.** carbonation.
   b. ice wedging. **d.** leaching.

10. Oxides of sulfur and nitrogen that combine with water vapor cause
    a. hydrolysis.
    b. acid rain.
    c. mechanical weathering.
    d. carbonation.

11. The surface area of rocks exposed to weathering is increased by
    a. burial. **c.** leaching.
    b. accumulation. **d.** jointing.

12. Chemical weathering is most rapid in
    a. hot, dry climates.
    b. cold, dry climates.
    c. cold, wet climates.
    d. hot, wet climates.

13. The chemical composition of soil depends to a large extent on
    a. topography.
    b. the soil's A horizon.
    c. the parent material.
    d. soil's B horizon.

14. The soil in tropical climates is often
    a. thick. **c.** dry.
    b. thin. **d.** fertile.

15. All of the following farming methods prevent gullying, *except*
    a. terracing. **c.** contour plowing.
    b. strip-cropping. **d.** irrigation.

16. The type of mass movement that moves the most soil is
    a. a landslide. **c.** a rockfall.
    b. a mudflow. **d.** creep.

17. The grinding away of rock surfaces through the mechanical action of rock or sand particles is called
    a. carbonation. **c.** abrasion.
    b. hydrolysis. **d.** erosion.

18. The process by which softer rocks wear away and leave harder rocks behind is
    a. chemical weathering.
    b. mechanical weathering.
    c. differential weathering.
    d. erosion.

Short Answer

19. What is the difference between natural rain and acid precipitation?
20. Explain two reasons why soil conservation is important.
21. Describe how a mountain changes from a rugged mountain to a peneplain.
22. Describe three landforms that are shaped by weathering and erosion.

23. Explain two ways that weathering and erosion are related.

24. Identify three ways that climate affects the rate of weathering.

25. Name three landforms that you would expect to find in a desert.

Critical Thinking

26. Making Comparisons Compare the weathering processes that affect a rock on top of a mountain and those that affect a rock beneath the ground surface.

27. Understanding Relationships Which do you think would weather faster, a sculpted marble statue or a smooth marble column? Explain your answer.

28. Making Inferences Mudflows in the southern California hills are usually preceded by a dry summer and widespread fires, which are followed by torrential rainfall. Explain why these phenomena are followed by mudflows.

29. Evaluating Ideas How can differential weathering help you determine whether a rock is harder or softer than the rock that surrounds it?

30. Inferring Relationships Suppose that a mountain has been wearing down at the rate of about 2 cm per year for 10 years. After 10 years, scientists find that the mountain is no longer losing elevation. Why do you think the mountain is no longer losing elevation?

Concept Mapping

31. Use the following terms to create a concept map: *composition, mechanical weathering, chemical weathering, topography, erosion, conservation, exposure, weathering, surface area,* and *climate.*

Math Skills

32. Making Calculations A group of scientists calculates that an acre of land has crept 18 cm in 15 years. What is the average rate of creep in millimeters per year?

33. Making Calculations For a given area of land, the average rate of creep is 14 mm per year. How long will it take the area to move 1 m?

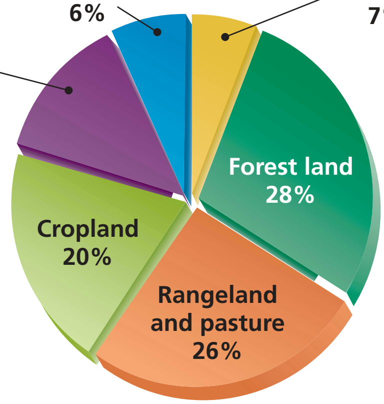
Writing Skills

34. Writing from Research Research a mudslide or landslide that occurred in the past. Describe the conditions that led to that mass movement and the impact it had.

35. Communicating Ideas You are in charge of preserving a precious marble statue. Write a paragraph that describes how you would protect the statue from weathering.

Interpreting Graphics

The graph below shows land use in the United States. Use the graph to answer the questions that follow.



36. How much more land is rangeland and pasture than is urban land?

37. If cropland increased to 25% and all other categories remain the same except for forests, what would the percentage of forests be?

Chapter 14 Standardized Test Prep

Understanding Concepts

***Directions (1–5):* For *each* question, write on a separate sheet of paper the letter of the correct answer.**

1 The processes of physical weathering and erosion shape Earth's landforms by
- **A.** expanding the elevation of Earth's surface
- **B.** decreasing the elevation of Earth's surface
- **C.** changing the composition of Earth's surface
- **D.** bending rock layers near Earth's surface

2 Which of the following rocks is most likely to weather quickly?
- **F.** a buried rock in a mountain
- **G.** an exposed rock on a plain
- **H.** a buried rock in a desert
- **I.** an exposed rock on a slope

3 The red color of rocks and soil containing iron-rich minerals is caused by
- **A.** chemical weathering
- **B.** mechanical weathering
- **C.** abrasion
- **D.** erosion

4 In which of the following climates does chemical weathering generally occur most rapidly?
- **F.** cold, wet climates
- **G.** cold, dry climates
- **H.** warm, humid climates
- **I.** warm, dry climates

5 Which of the following has the greatest impact on soil composition?
- **A.** activity of plants and animals
- **B.** characteristics of the parent rock
- **C.** amount of precipitation
- **D.** shape of the land

***Directions (6–7):* For *each* question, write a short response.**

6 In what type of decomposition reaction do hydrogen ions from water displace elements in a mineral?

7 Sand carried by wind is responsible for what type of mechanical weathering?

Reading Skills

***Directions (8–10):* Read the passage below. Then, answer the questions.**

How Rock Becomes Soil

Earthworms are crucial for forming soil. As they search for food by digging tunnels, they expose rocks and minerals to the effects of weathering. Over time, this process creates new soil.

Worms are not the only living things that help create soil. Plants also play a part in the weathering process. As the roots of plants grow and seek out water and nutrients, they help break large rock fragments into smaller ones. Have you ever seen a plant growing in a sidewalk? As the plant grows, its roots spread into tiny cracks in the sidewalk. These roots apply pressure to the cracks, and over time, the cracks become larger. As the plants make the cracks larger, ice wedging can occur more readily. As the cracks expand, more water can flow into them. When the water freezes, it expands and presses against the walls of the crack, which makes the crack larger. Over time, the weathering caused by water, plants, and worms helps break down rock to form soil.

8 Which of the following statements can be inferred from the passage?
- **A.** Weathering can occur only when water freezes in cracks in rocks.
- **B.** Only large plants have roots that are powerful enough to increase the rate of weathering.
- **C.** Local biological activity may increase the rate of weathering in a given area.
- **D.** Plant roots often prevents weathering by filling cracks and keeping water out of cracks.

9 Ice wedging, as described in the passage, is an example of which of the following?
- **F.** oxidation
- **G.** mechanical weathering
- **H.** chemical weathering
- **I.** hydrolysis

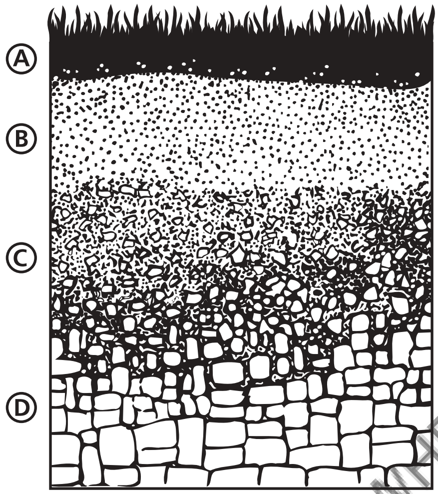
10 What are some ways not mentioned in the passage in which the activity of biological organisms may increase weathering?

Interpreting Graphics

Directions (11–13): **For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram shows the soil profile of a mature soil. Use this diagram to answer questions 11 and 12.

Mature Soil Profile



11 Which of the layers in the soil profile above contains the greatest number of soil organisms?

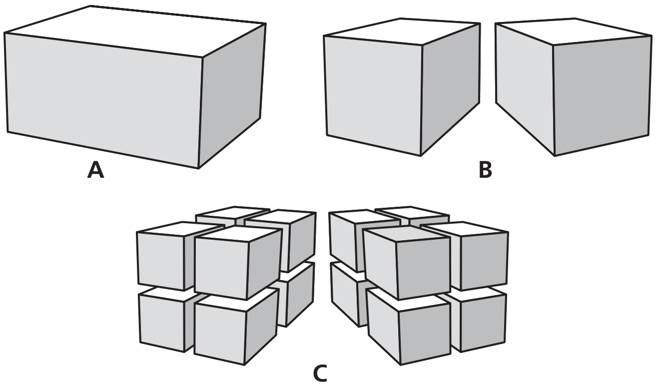
A. layer A
B. layer B
C. layer C
D. layer D

12 Which two layers in the soil profile above are least likely to contain the dark, organic material humus?

F. layers A and B
G. layers B and C
H. layers C and D
I. layers A and D

Use the diagram stone blocks below to answer question 13.

Blocks of Identical Volume



13 If the blocks shown in diagrams A, B, and C above contain identical volumes and are made of the same types of minerals, will they weather at the same rate? Explain your answer.

Test TIP

Whenever possible, highlight or underline important numbers or words that are critical to correctly answering a question.

Skills Practice Lab

Soil Chemistry

Objectives

- **Test** the acidity of soil samples.
- **Identify** the composition of soil samples.

Materials

- ammonia solution
- stoppers, cork (9)
- hydrochloric acid, dilute
- medicine dropper
- pH paper
- subsoil sample (B and C horizons)
- test tubes, 9
- test-tube rack
- topsoil sample (A horizon)
- water

Safety

Different soil types contain different kinds and amounts of minerals. To support plant life, soil must have a proper balance of minerals and nutrients. For plants to take in the minerals they need, the soil must also have the proper acidity.

Acidity is measured on a scale called the *pH scale*. The pH scale ranges from 0 (acidic) to 14 (alkaline). A pH of 7 is neutral (neither acidic nor alkaline). In this lab, you will test the acidity of soil samples.

PROCEDURE

1. pH paper changes color in the presence of an acidic or alkaline substance. Wet a strip of pH paper with tap water. Compare the color of the wet pH paper with the pH color scale. What is the pH of the tap water?
2. Fill a clean test tube to 1/8 full with a small amount of the topsoil. Add water to the test tube until it is 3/4 full. Place a cork stopper on the test tube, and shake the test tube.
3. Set the soil and water mixture aside in the test-tube rack to settle. When the water is fairly clear, test it with a piece of pH paper. What is the pH of the soil sample? Is the soil acidic or alkaline?
4. Repeat step 2 and step 3 with the subsoil sample.
5. Pedalfer soils tend to become acidic. Pedocal soils tend to become alkaline. Based on the pH results in steps 3 and 4, predict whether your soil is pedalfer or pedocal.

Step 3

6 To test your prediction, you will need to test the soil's composition. Take five rock particles from the subsoil sample. Place each particle in a separate test tube. Use the dropper to add two drops of hydrochloric acid, HCl, to the test tubes. **CAUTION** If you spill any acid on your skin or clothing, rinse immediately with cool water and alert your teacher.

7 HCl has little or no effect on silicates, but HCl decomposes calcium carbonate and causes CO_2 gas to bubble out of solution. How many of the rock particles were silicates? How many were calcium carbonate?

8 Fill a test tube 1/8 full with the subsoil. Slowly add HCl to the test tube until it is about 2/3 full. Cork the tube, and gently shake it. **CAUTION** Always shake the test tube by pointing it away from yourself and other students.

9 After shaking the test tube, remove the stopper and set the test tube in the rack. Record your observations. After the mixture has settled, draw the test tube and its contents. Label each layer. If iron is present, the solution may look brown. What color is the liquid above the soil sample?

10 Use a medicine dropper to place 10 drops of the liquid in a clean test tube. Carefully add 12 drops of ammonia to the test tube. Test the pH of the solution. If the pH is greater than 8, any iron should settle out as a reddish-brown residue. The remaining solution will be colorless.

11 If the pH is less than 8, add two more drops of ammonia and test the pH again. Continue adding ammonia until the pH reaches 8 or higher. Record your observations, and draw a diagram of the test tube. Label each layer of material in the test tube.

Step 6

ANALYSIS AND CONCLUSION

1 **Analyzing Results** Is your soil sample most likely pedalfer or pedocal? Explain your answer.

2 **Drawing Conclusions** What type of soil, pedalfer or pedocal, would you treat with acidic substances, such as phosphoric acid, sulfur, or ammonium sulfate, to help plant growth? Explain your answer.

3 **Recognizing Relationships** Explain why acidic substances are usually spread on the surface of the soil.

Extension

1 **Research** Use the library or the Internet to learn why the use of phosphate and nitrate detergents has been banned in some areas. Report your findings to the class.

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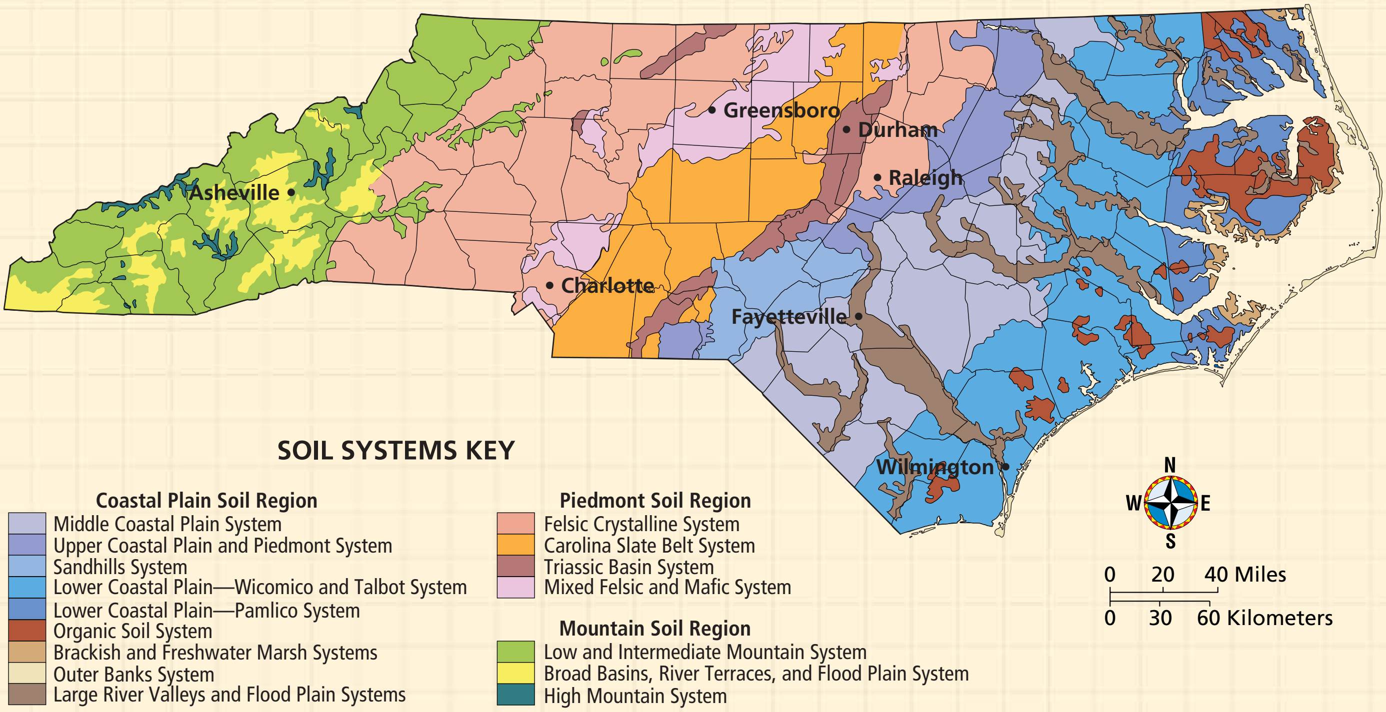
MAPS in Action

Soil Map of North Carolina



Map Skills Activity

This map shows soil systems in the state of North Carolina, including the Outer Banks barrier island system. Use the map to answer the questions below.

1. **Using a Key** How many colors on the map represent soil systems in the Piedmont Soil Region?
2. **Using a Key** What soil systems are present along the eastern shore of North Carolina?
3. **Analyzing Data** What city is located on the banks of a large river or in a river valley? Explain your answer.
4. **Inferring Relationships** What landforms would you expect to surround the town of Asheville? Explain your answer.
5. **Analyzing Relationships** Brackish water is water that is somewhat salty but is not as salty as sea water. How does this fact explain the location of the Brackish and Freswater Marsh soil systems?
6. **Identifying Trends** How would you describe the change in elevation of North Carolina from west to east based on the locations of soil systems? Explain your answer.

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CAREER FOCUS

Soil Conservationist

"Everything ties back to the soil."

—Lewis Nichols

One hundred and fifty years ago, Boone County, Illinois, consisted mainly of rolling prairies. Today, farms and homes have replaced much of the prairies. As a soil conservationist, Lewis Nichols helps farmers and homeowners to more effectively manage their land.

Down-to-Earth Solutions

"Erosion is our number one issue here," says Nichols. "Gully erosion, the kind of erosion that forms large trenches, is the most visible kind. Farmers also have problems with sheet erosion, which can remove topsoil from entire fields." Nichols helps farmers implement conservation practices to keep valuable soil in the fields and to keep the soil out of streams and rivers. As more rural areas give way to housing developments, Nichols also visits new neighborhoods. Though most of his work is done in the field, Nichols returns to his office to develop specific conservation practices for the problems he is studying.

For Nichols, the career path to soil conservation began in a high school greenhouse. Nichols turned his interests into a profession. He earned a bachelor's degree in agronomy, which is the study of crop production and soil management.

Hamburger and the Farmer

Like other soil conservationists, Nichols reaches out to communities and schools to teach the value of natural resources and to encourage conservation efforts. "We go to schools to talk to kids about conservation. We want kids to know the connection between a hamburger and the farmer that produced it," says Nichols. "I find it very rewarding to know I'm able to help society by looking out for the future and providing a better world for our children—a world where the words *natural resources* still have meaning."

◀ Irrigation in this peanut field in Oklahoma has caused soil erosion. Soil conservationists work with farmers to reduce erosion when possible.

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Topic: Careers in Earth Science

SciLinksCode: HQ60222

Chapter 15 River Systems

Sections

1 The Water Cycle
2 Stream Erosion
3 Stream Deposition

What You'll Learn

- How water moves between Earth's land, oceans, and atmosphere
- How rivers shape the land by erosion
- How rivers shape the land by deposition

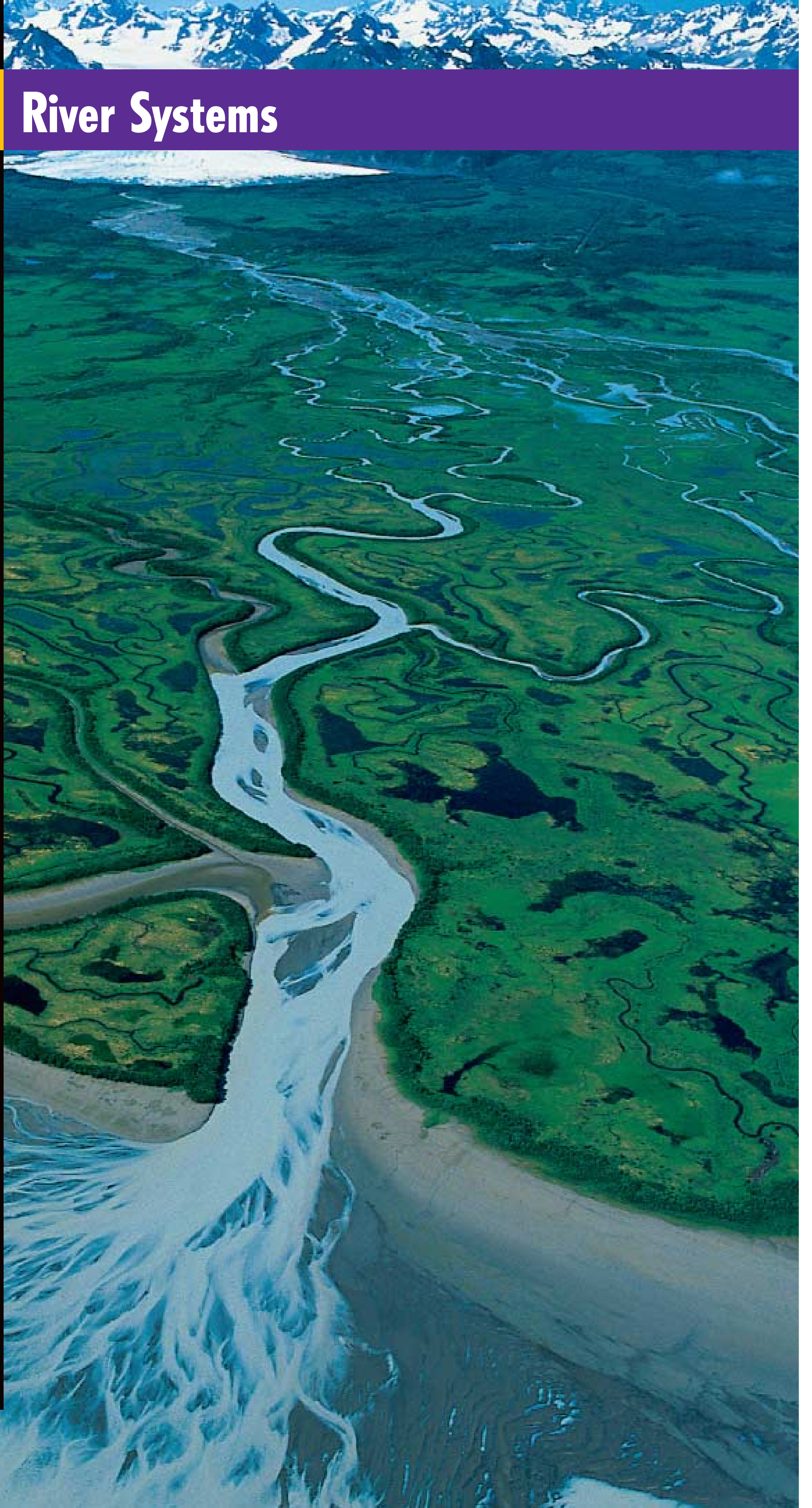
Why It's Relevant

The continuous movement of water is necessary for the survival of humans and other lifeforms on Earth. Water movement also shapes the land by erosion and deposition.

PRE-READING ACTIVITY

FOLDNOTES

Layered Book Before you read this chapter, create the **FoldNote** entitled "Layered Book" described in the Skills Handbook section of the Appendix. Label the tabs of the layered book with "Evapotranspiration," "Condensation," "Precipitation," and "Conservation." As you read the chapter, write information you learn about each category under the appropriate tab.



▶ Rivers, such as the Copper River in Alaska shown here, are major forces in eroding sediment from one place and depositing sediment in another.

Section 1 The Water Cycle

The origin of Earth's water supply has puzzled people for centuries. Aristotle and other ancient Greek philosophers believed that rivers such as the Nile and the Danube could be supplied by rain and snow alone. It was not until the middle of the 17th century that scientists could accurately measure the amount of water received on Earth and the amount flowing in rivers. These measurements showed that Earth's surface receives up to 5 times as much water as rivers carry off. So, a more puzzling question than "Where does Earth's water come from?" is "Where does the water go?"

OBJECTIVES

- **Outline** the stages of the water cycle.
- **Describe** factors that affect a water budget.
- **List** two approaches to water conservation.

KEY TERMS

water cycle
evapotranspiration
condensation
precipitation
desalination

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Topic: Water Cycle
SciLinks code: HQ61626

Movement of Water on Earth

Water is essential for humans and all other organisms. Its availability in different forms is critical for the continuation of life on Earth. More than two-thirds of Earth's surface is covered with water. Water flows in streams and rivers. It is held in lakes, oceans, and icecaps at Earth's poles. It even flows through the rock below Earth's surface as groundwater. Water is found not only in these familiar bodies of water but also in the tissues of all living creatures. In the atmosphere, water occurs as an invisible gas. This gas is called *water vapor*. Liquid water also exists in the atmosphere as small particles in clouds and fog, as shown in **Figure 1.**

Earth's water is constantly changing from one form to another. Water vapor falls from the sky as rain. Glaciers melt to form streams. Rivers flow into oceans, where liquid water escapes into the atmosphere as water vapor. This continuous movement of water on Earth's surface from the atmosphere to the land and oceans and back to the atmosphere is called the **water cycle.**

water cycle the continuous movement of water between the atmosphere, the land, and the oceans

Figure 1 ▶ The snow, the fog, and the river water in this photo are three of the forms that water takes on Earth. Invisible water vapor is also present in the air.

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Evapotranspiration

The process by which liquid water changes into water vapor is called *evaporation*. Each year, about 500,000 km^3 of water evaporates into the atmosphere. About 86% of this water evaporates from the ocean. The remaining water evaporates from lakes, streams, and the soil. Water vapor also enters the air by *transpiration,* the process by which plants and animals release water vapor into the atmosphere. The total loss of water from an area, which equals the sum of the water lost by evaporation from the soil and other surfaces and the water lost by transpiration from organisms, is called **evapotranspiration.** Evapotranspiration is one part of the water cycle, which is shown in **Figure 2.**

evapotranspiration the total loss of water from an area, which equals the sum of the water lost by evaporation from the soil and other surfaces and the water lost by transpiration from organisms

condensation the change of state from a gas to a liquid

precipitation any form of water that falls to Earth's surface from the clouds; includes rain, snow, sleet, and hail

Condensation

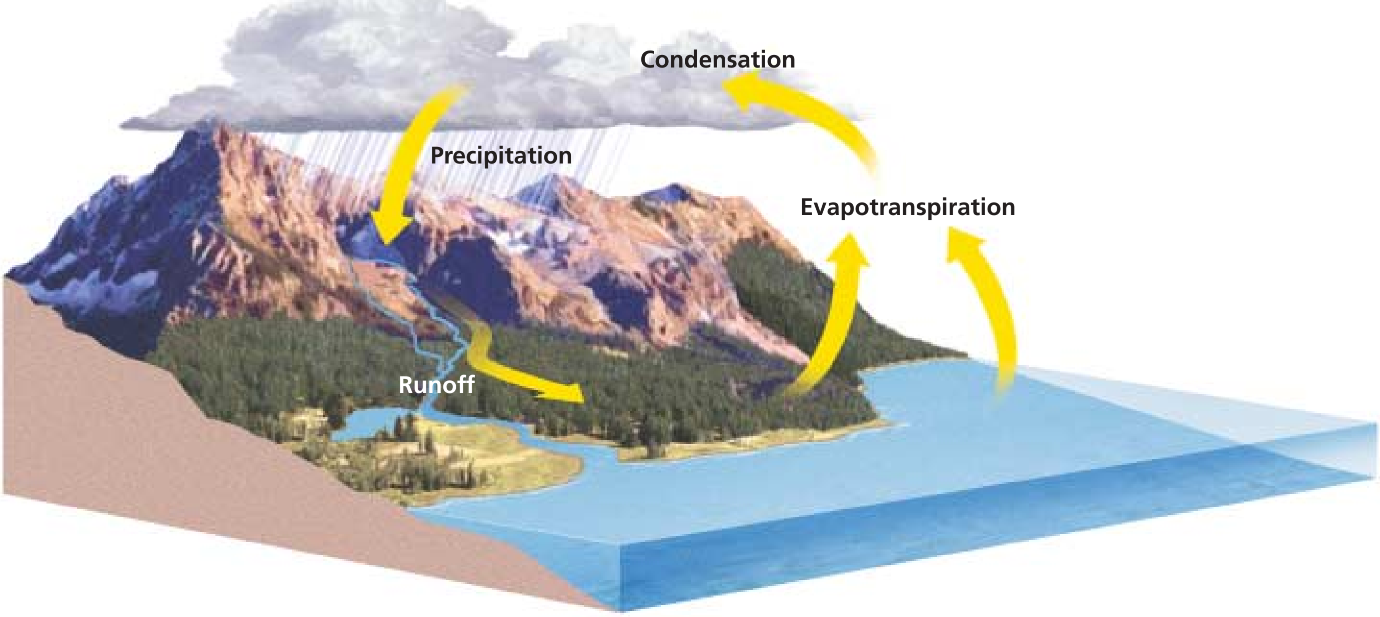
Another process of the water cycle is condensation. **Condensation** is the change of state from a gas to a liquid. When water vapor rises in the atmosphere, it expands and cools. As the vapor becomes cooler, some of it condenses, or changes into tiny liquid water droplets, and forms clouds.

Precipitation

The third process of the water cycle is precipitation. **Precipitation** is any form of water that falls to Earth's surface from the clouds and includes rain, snow, sleet, and hail. About 75% of all precipitation falls on Earth's oceans. The rest falls on land and becomes runoff or groundwater. Eventually, all of this water returns to the atmosphere by evapotranspiration, condenses, and falls back to Earth's surface to begin the cycle again.

Reading Check **List the forms of precipitation. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Evapotranspiration, condensation, and precipitation make up the continuous process called the *water cycle.*



Water Budget

The continuous cycle of evapotranspiration, condensation, and precipitation establishes Earth's *water budget.* A financial budget is a statement of expected income—money coming in—and expenses—money going out. In Earth's water budget, precipitation is the income. Evapotranspiration and runoff are the expenses. The water budget of Earth as a whole is balanced because the amount of precipitation is equal to the amount of evapotranspiration and runoff. However, the water budget of a particular area, called the *local water budget,* usually is not balanced.

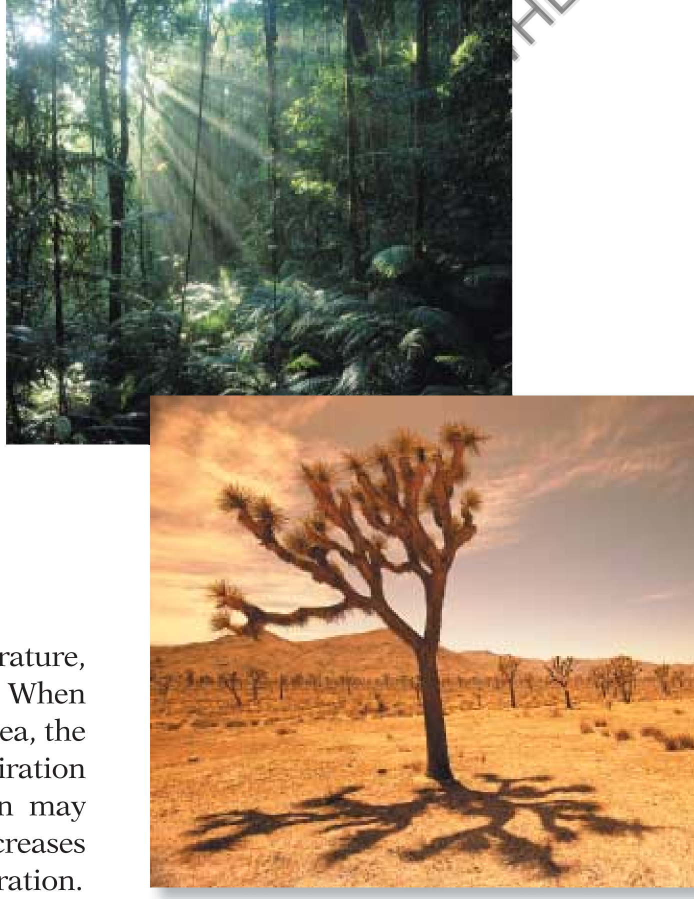


Figure 3 ▶ Tropical rain forests, such as the one in Queensland, Australia (top photo), require large amounts of rainfall annually. Deserts, such as the Mojave Desert in California (bottom photo), receive small amounts of rainfall each year.

Factors That Affect the Water Budget

Factors that affect the local water budget include temperature, vegetation, wind, and the amount and duration of rainfall. When precipitation exceeds evapotranspiration and runoff in an area, the result is moist soil and possible flooding. When evapotranspiration exceeds precipitation, the soil becomes dry and irrigation may be necessary. Vegetation reduces runoff in an area but increases evapotranspiration. Wind increases the rate of evapotranspiration.

The factors that affect the local water budget vary geographically. For example, the Mojave Desert in California receives much less precipitation than do the tropical rain forests of Queensland, Australia, as **Figure 3** shows.

The local water budget also changes with the seasons in most areas of Earth. In general, cooler temperatures slow the rate of evapotranspiration. During the warmer months, evapotranspiration increases. As a result, streams generally transport more water in cooler months than they do in warmer months.

Quick LAB 35 min

Modeling the Water Cycle

Procedure

1. Place a **short glass** inside a **large plastic mixing bowl.** Add cold water to the mixing bowl until about three-fourths of the glass is covered with water. Make sure to keep the inside of the glass dry.
2. Add drops of **food coloring** (red, blue, or green) to the water in the bowl until the water has a strong color.
3. Now, add about 1 cup of dry **dirt** to the water, and stir gently until the water is muddy as well as colored.
4. Cover the bowl tightly with a **piece of plastic wrap** secured to the bowl with a **rubber band,** and place a **coin or stone** in the middle of the plastic wrap above the glass.
5. Set the bowl in the sun or under a **heat lamp** for 30 minutes to several hours. Then, observe the water that has collected in the glass.

Analysis

1. What are the processes that have taken place to allow water to collect in the glass?
2. Why is the water in the glass not muddy?
3. Is the water in the glass colored? What does this say about pollutants in water systems and the water cycle?

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Figure 4 ▶ Waste from this paper mill has polluted the Qingai River in China.

Water Use

On average, each person in the United States uses about 95,000 L (20,890.5 gal) of water each year. Water is used for bathing, washing clothes and dishes, watering lawns, carrying away wastes, and drinking. Agriculture and industry also use large amounts of water. As the population of the United States increases, so does the demand for water.

About 90% of the water used by cities and industry is returned to rivers or to the oceans as wastewater. Some of this wastewater contains harmful materials, such as toxic chemicals and metals, as shown in **Figure 4.** These toxic materials can pollute rivers and can harm plants and animals in the water.

Conservation of Water

While Earth holds a lot of water, only a small percentage of that water is fresh water that can be used by humans. Scientists have identified two ways to ensure that enough fresh water is available today and in the future. One way is through conservation, or the wise use of water resources. Individuals can conserve water by limiting their water use as much as possible. Governments can help conserve water by enforcing conservation laws and antipollution laws that prohibit the dumping of waste into bodies of water.

A second way to protect the water supply is to find alternative methods of obtaining fresh water. One such method is called **desalination,** which is the process of removing salt from ocean water. However, this method is expensive and is impractical for supplying water to large populations. Currently, the best way of maintaining an adequate supply of fresh water is the wise use and conservation of the fresh water that is now available.

desalination a process of removing salt from ocean water

Section 1 Review

1. **List** two ways in which water reaches the oceans.
2. **Outline** the major stages of the water cycle.
3. **Explain** the difference between condensation and precipitation.
4. **Explain** why most local water budgets are not balanced.
5. **Describe** how vegetation and rainfall affect the local water budget.
6. **List** two ways to ensure the continued supply of fresh water.

CRITICAL THINKING

7. **Applying Concepts** Describe five ways that you can conserve water at home.
8. **Analyzing Processes** Why are the oceans the location of most evaporation and precipitation?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *water cycle, evaporation, transpiration, evapotranspiration, condensation, precipitation,* and *water budget.*

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Section 2 Stream Erosion

A river system begins to form when precipitation exceeds evapotranspiration in a given area. After the soil in the area soaks up as much water as the soil can hold, the excess water moves downslope as runoff. As runoff moves across the land surface, it erodes rock and soil and eventually may form a narrow ditch, called a *gully*. Eventually, the processes of precipitation and erosion form a fully developed valley with a permanent stream.

OBJECTIVES

- **Summarize** how a river develops.
- **Describe** the parts of a river system.
- **Explain** factors that affect the erosive ability of a river.
- **Describe** how erosive factors affect the evolution of a river channel.

KEY TERMS

tributary
watershed
stream load
discharge
gradient
meander
braided stream

Parts of a River System

A river system is made up of a main stream and **tributaries,** which are all of the feeder streams that flow into the main stream. The land from which water runs off into these streams is called a **watershed.** The ridges or elevated regions that separate watersheds are called *divides*. A river system is shown in **Figure 1.**

The relatively narrow depression that a stream follows as it flows downhill is called its *channel*. The edges of a stream channel that are above water level are called the stream's *banks*. The part of the stream channel that is below the water level is called the stream's *bed*. A stream channel gradually becomes wider and deeper as it erodes its banks and bed.

tributary a stream that flows into a lake or into a larger stream

watershed the area of land that is drained by a river system

Channel Erosion

River systems change continuously because of erosion. In the process of *headward erosion,* channels lengthen and branch out at their upper ends, where runoff enters the streams. Erosion of the slopes in a watershed can also extend a river system and can add to the area of the watershed. In the process known as *stream piracy,* a stream from one watershed is "captured" by a stream from another watershed that has a higher rate of erosion. The captured stream then drains into the river system that has done the capturing.

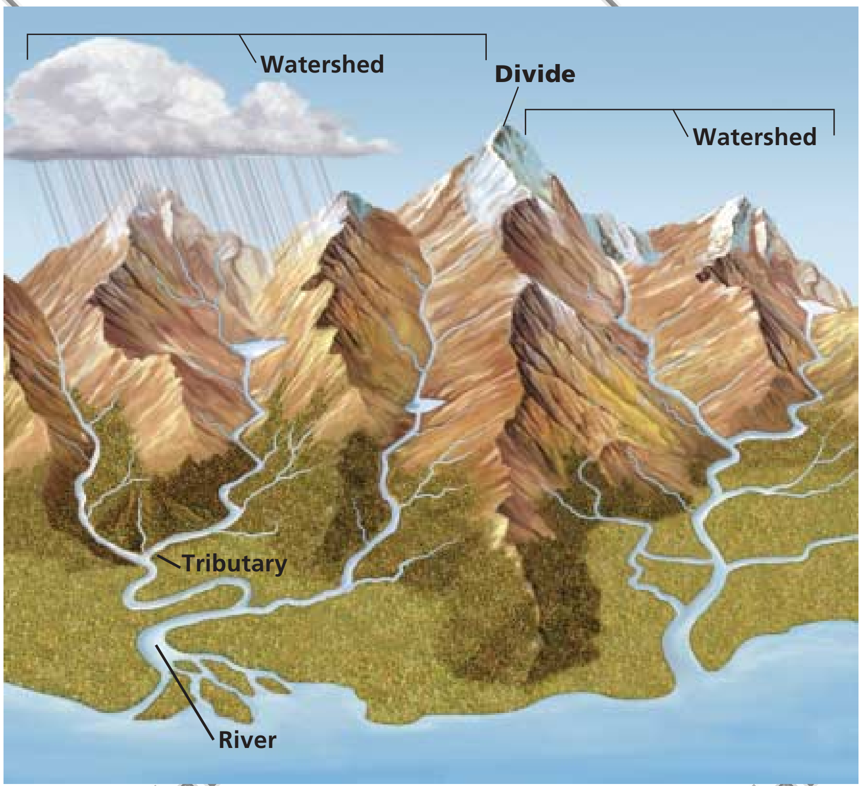

Figure 1 ▶ The tributaries that run into this river are fed by runoff from surrounding land. All of the land that drains into a single river makes up the watershed of the river.

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Stream Load

A stream transports soil, loose rock fragments, and dissolved minerals as it flows downhill. The materials carried by a stream are called the **stream load.** Stream load takes three forms: suspended load, bed load, and dissolved load. The *suspended load* consists of particles of fine sand and silt. The velocity, or rate of downstream travel, of the water keeps these particles suspended, so they do not sink to the stream bed. The *bed load* is made up of larger, coarser materials, such as coarse sand, gravel, and pebbles. This material moves by sliding and jumping along the bed. The *dissolved load* is mineral matter transported in liquid solution.

stream load the materials other than the water that are carried by a stream

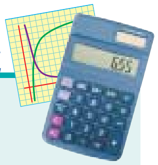
discharge the volume of water that flows within a given time

gradient the change in elevation over a given distance

Stream Discharge

The volume of water moved by a stream in a given time period is the stream's **discharge.** The faster a stream flows, the higher its discharge and the greater the load that the stream can carry. Thus, a swift stream carries more sediment and larger particles than a slow stream does. A stream's velocity also affects how the stream cuts down and widens its channel. Swift streams erode their channels more quickly than slow-moving streams do.

MATHPRACTICE



Water Discharge of a River River channels can carry an enormous volume of water. The water that rivers discharge can be calculated by using the following equation:

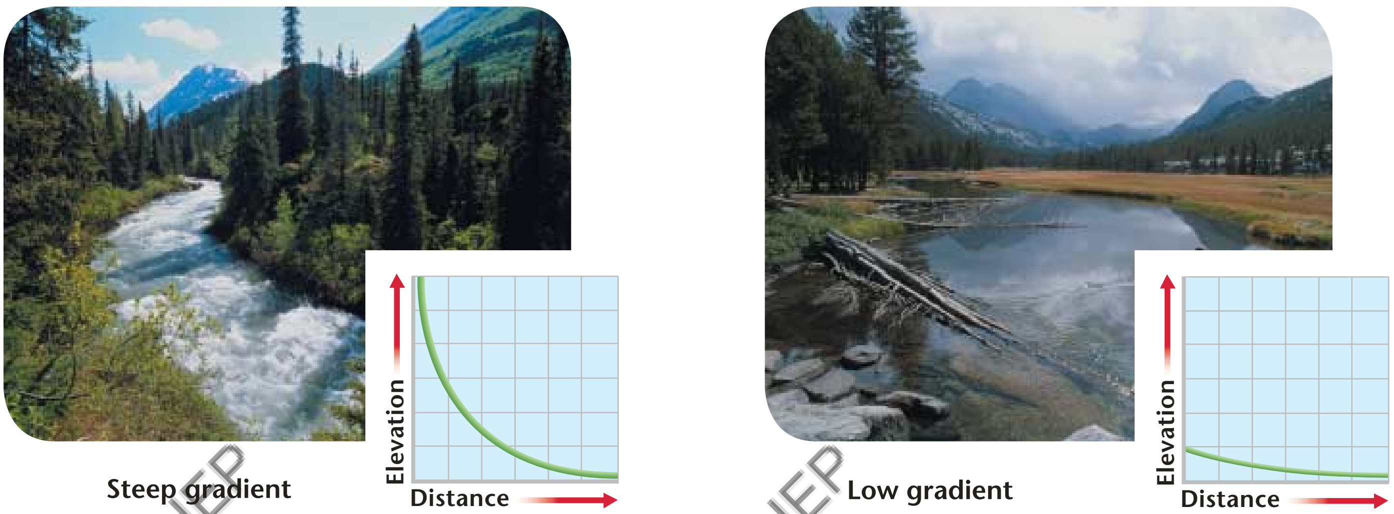
$$\textit{discharge} = \textit{velocity of the water} \times \textit{cross-sectional area of the river channel}$$

In cubic meters per second (m^3/s), what is the discharge of water carried by a river that moves 1.5 m/s through a cross-sectional area of 520 m^2?

Stream Gradient

The velocity of a stream depends mainly on gradient. **Gradient** is the change in elevation of a stream over a given horizontal distance. In other words, gradient is the steepness of the stream's slope. Near the *headwaters,* or the beginning of a stream, the gradient generally is steep. This area of the stream has a high velocity, which causes rapid channel erosion. As the stream nears its *mouth,* where the stream enters a larger body of water, its gradient often becomes flatter. As a result, the river's velocity and erosive power decrease. The stream channel eventually is eroded to a nearly flat gradient by the time the stream channel reaches the sea. Streams with different gradients are shown in **Figure 2.**

Figure 2 ▶ Streams that have steep gradients, such as the stream on the left, have a higher velocity than streams that have low gradients, such as the stream on the right, do.



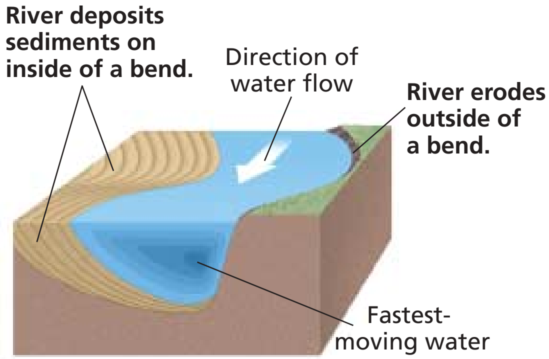


Figure 3 ▶ Decreased velocity on the inside of a river's curve leads to the deposition of sediment, as this photo of a river in the Banff National Park in Alberta, Canada, shows.

Evolution of River Channels

As the stream's load, discharge, and gradient decrease, the erosive power of the stream decreases, which influences the evolution of the stream's channel. Over time, as the channel erodes, it becomes wider and deeper. When the stream becomes longer and wider, it is called a *river*.

Meandering Channels

As a river evolves, it may develop curves and bends. A river that has a low gradient tends to have more bends than a river that has a steep gradient does. A winding pattern of wide curves, called **meanders,** develops because as the gradient decreases, the velocity of the water decreases. When the velocity of the water decreases, the river is less able to erode down into its bed. As the water flows through the channel, more energy is directed against the banks, which causes erosion of the banks.

meander one of the bends, twists, or curves in a low-gradient stream or river

When a river rounds a bend, the velocity of the water on the outside of the curve increases. The fast-moving water on the outside of a river bend erodes the outer bank of that bend. However, on the inside of the curve, the velocity of the water decreases. This decrease in velocity leads to the formation of a *bar* of deposited sediment, such as sand or gravel, as shown in **Figure 3.**

As this process continues, the curve enlarges while further sediment deposition takes place on the opposite bank, where the water is moving more slowly. Meanders can become so curved that they almost form a loop, separated by only a narrow neck of land. When the river cuts across this neck, the meander can become isolated from the river, and an *oxbow lake* forms.

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Topic: River Systems
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Reading Check **How would you describe the gradient of a river that has meanders? (See the Appendix for answers to Reading Checks.)**

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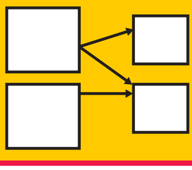
Figure 4 ▶ Braided streams, such as the Chisana River in Alaska, divide into multiple channels.

Graphic Organizer **Cause-and-Effect Map**

Create the Graphic Organizer entitled "Cause-and-Effect Map" described in the Skills Handbook section of the Appendix. Label the effects with "Meandering streams" and "Braided streams." Then, fill in the map with causes of meandering streams and braided streams and details about the causes and effects.



Braided Streams

Most rivers are single channels. However, under certain conditions, the presence of sediment bars between a river's banks can divide the flow of the river into multiple channels. A stream or river that is composed of multiple channels that divide and rejoin around sediment bars is called a **braided stream.** Braided streams are a direct result of a large sediment load, particularly when a high percentage of the load is composed of coarse sand and gravel. The bars form on the channel floor when the river is unable to move all of the available load.

Although braided streams, such as those in **Figure 4,** look very different from meandering channels, they can cause just as much erosion. The channel location shifts constantly such that bars between channels erode and new bars form. Sometimes, a single river can change from a braided stream to a meandering stream as the gradient and discharge change.

braided stream a stream or river that is composed of multiple channels that divide and rejoin around sediment bars

Section 2 Review

1. **Summarize** how a river develops.
2. **Describe** the parts of a river system.
3. **Explain** the processes of headward erosion and stream piracy.
4. **List** the three types of stream load.
5. **Explain** how stream discharge and gradient affect the erosive ability of a river.
6. **Describe** the factors that control whether a river is braided or meandering.
7. **Summarize** the process that forms an oxbow lake.

CRITICAL THINKING

8. **Predicting Consequences** If geologic forces were to cause an uplift of the land surface, what would the effect on stream channel erosion be?
9. **Analyzing Processes** Explain how the velocity of a stream affects the suspended load.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *braided channels, stream load, suspended load, dissolved load, bed load, meanders, stream gradient,* and *headwaters.*

Section 3 Stream Deposition

The total load that a stream can carry is greatest when a large volume of water is flowing swiftly. When the velocity of the water decreases, the ability of the stream to carry its load decreases. As a result, part of the stream load is deposited as sediment.

OBJECTIVES

- **Explain** the two types of stream deposition.
- **Describe** one advantage and one disadvantage of living in a floodplain.
- **Identify** three methods of flood control.
- **Describe** the life cycle of a lake.

KEY TERMS

delta
alluvial fan
floodplain

Deltas and Alluvial Fans

A stream may deposit sediment on land or in water. For example, the load carried by a stream can be deposited when the stream reaches an ocean or a lake. As a stream empties into a large body of water, the velocity of the stream decreases sharply. The load is usually deposited at the mouth of the stream in a triangular shape. A triangular-shaped deposit that forms where the mouth of a stream enters a larger body of water is called a **delta.** The exact shape and size of a delta are determined by waves, tides, offshore depths, and the sediment load of the stream.

When a stream descends a steep slope and reaches a flat plain, the speed of the stream suddenly decreases. As a result, the stream deposits some of its load on the level plain at the base of the slope. A fan-shaped deposit called an **alluvial fan** forms on land, and its tip points upstream. In arid and semi-arid regions, temporary streams commonly form alluvial fans. Alluvial fans differ from deltas in that alluvial fans form on land instead of being deposited in water. This difference is shown in **Figure 1.**

delta a fan-shaped mass of rock material deposited at the mouth of a stream; for example, deltas form where streams flow into the ocean at the edge of a continent

alluvial fan a fan-shaped mass of rock material deposited by a stream when the slope of the land decreases sharply; for example, alluvial fans form when streams flow from mountains to flat land

Figure 1 ▶ A delta, such as this one in Alaska's Prince William Sound (above), forms when a stream deposits sediment into another body of water. An alluvial fan, such as this one in California's Death Valley (right), forms when a stream deposits sediment on land.