Figure 2 ▶ People who live in the Tonle Sap Floodplain in Cambodia have adapted to frequent flooding by building houses that are raised above the water level on stilts.

floodplain an area along a river that forms from sediments deposited when the river overflows its banks

Floodplains

The volume of water in nearly all streams varies depending on the amount of rainfall and snowmelt in the watershed. A dramatic increase in volume can cause a stream to overflow its banks and to wash over the valley floor. The part of the valley floor that may be covered with water during a flood is called a **floodplain.**

Natural Levees

When a stream overflows its banks and spreads out over the floodplain, the stream loses velocity and deposits its coarser sediment load along the banks of the channel. The accumulation of these deposits along the banks eventually produces raised banks, called *natural levees*.

Finer Flood Sediments

Not all of the load deposited by a stream in a flood will form levees. Finer sediments are carried farther out into the floodplain by the flood waters and are deposited there. A series of floods produces a thick layer of fine sediment, which becomes a source of rich floodplain soils. Swampy areas are common on floodplains because drainage is usually poor in the area between the levees and the outer walls of the valley. Despite the hazards of periodic flooding, people choose to live on floodplains, as shown in **Figure 2.** Floodplains provide convenient access to the river for shipping, fishing, and transportation. The rich soils, which are good for farming, also draw people to live on floodplains.

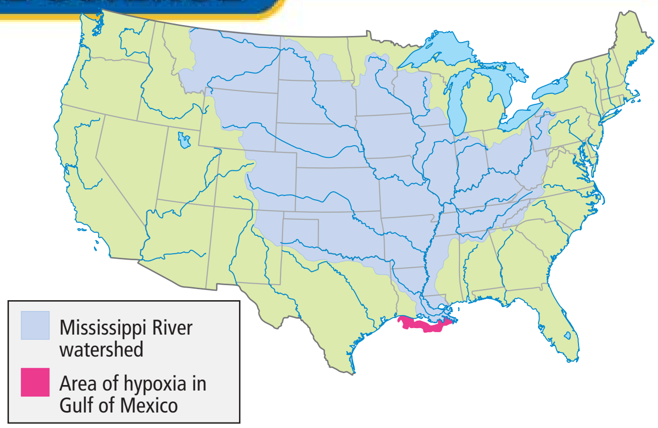
Connection to ENVIRONMENTAL SCIENCE

The Dead Zone

Oceanographers have discovered that water in the Gulf of Mexico west of the mouth of the Mississippi River delta has a low level of oxygen during the summer. This condition, known as *hypoxia,* can suffocate crabs, shrimp, and other fish that live on the sea floor. For this reason, the area has been dubbed the Dead Zone. Hypoxia has severely affected the marine food chain in this area as well as the fishing industry.

What is the origin of the Dead Zone? Studies indicate that water flowing from the Mississippi River to the Gulf of Mexico has a high level of dissolved nitrogen and phosphorus from fertilizers that are used to grow crops in the watershed. These substances increase the growth of phytoplankton—small floating marine plants—in shallow gulf waters where the river water ends up. When these plants die and sink to the sea floor, they are broken down by bacteria that use oxygen in the process. As a result, the ocean water becomes depleted of oxygen. This process usually occurs in the summer when river flow is high, more sunlight is available for plant growth, and shallow gulf waters are poorly mixed with offshore water by winds.

To reduce the effects of hypoxia in the Gulf of Mexico, government officials are considering regulating the amount and type of fertilizers that can be used in the Mississippi watershed.



Quick LAB 40 min

Soil Erosion

Procedure

1. Fill a **23 cm × 33 cm pan** about half full with **moist, fine sand.**
2. Place the pan in a **sink** so that one end of the pan is resting on a **brick** and is under the water faucet.
3. Position an **additional pan or container** such that it catches any sand and water that flow out of the first pan.
4. Slowly open the faucet until a gentle trickle of water falls onto the sand in the raised end of the pan. Let the water run for 15 to 20 s.
5. Turn off the water, and draw the pattern of water flow over the sand.
6. Press the sand back into place, and carefully smooth the surface by using a **ruler.** Repeat steps 4 and 5 three more times. Each time, increase the rate of water flow slightly without splashing the sand.

Analysis

1. Describe how the rate of water flow affects erosion.
2. How does the rate of water flow affect gullies?
3. How could erosion on a real hillside be reduced without changing the rate of water flow?
4. How does the shape of a river bend change as water flows?

Human Impacts on Flooding

Human activity can contribute to the size and number of floods in many areas. Vegetation, such as trees and grass, protects the ground surface from erosion by taking in much of the water that would otherwise run off. Where this natural ground cover is removed, water can flow more freely across the surface. As a result, the likelihood of flooding increases. Logging and the clearing of land for agriculture or housing development can increase the volume and speed of runoff, which leads to more frequent flooding. Natural events, such as forest fires, can also increase the likelihood of flooding.

Flood Control

Indirect methods of flood control include forest and soil conservation measures that prevent excess runoff during periods of heavy rainfall. More-direct methods include the building of artificial structures that redirect the flow of water.

The most common method of direct flood control is the building of *dams*. The artificial lakes that form behind dams act as reservoirs for excess runoff. The stored water can be used to generate electricity, supply fresh water, and irrigate farmland. Another direct method of flood control is the building of *artificial levees*. However, artificial levees must be protected against erosion by the river. As **Figure 3** shows, when artificial levees break, flooding and property damage can result. Permanent overflow channels, or floodways, can also help prevent flooding. When the volume of water in a river increases, floodways carry away excess water and keep the river from overflowing.

Reading Check **Describe two ways that floods can be controlled. (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Week-long storms in Modesto, California, in 1997 broke this levee and caused flooding.

Precipitation collects in a depression and forms a lake.

A lake loses its water as the water drains away or evaporates.

As water is lost, the lake basin may eventually become dry land.

Figure 4 ▶ Compared to rivers, lakes are short lived, and some lakes may eventually dry up.

The Life Cycle of Lakes

Not all streams flow from the land to the ocean. Sometimes, water from streams collects in a depression in the land and forms a lake. Most lakes are located at high latitudes and in mountainous areas. Most of the water in lakes comes from precipitation and the melting of ice and snow. Springs, rivers, and runoff coming directly from the land are also sources of lake water.

Most lakes are relatively short lived in geologic terms. Many lakes eventually disappear because too much of their water drains away or evaporates, as shown in **Figure 4.** A common cause of excess drainage is an outflowing stream that erodes its bed below the level of a lake basin. Lakes may also lose water if the climate becomes drier and evaporation exceeds precipitation.

Lake basins may also disappear if they fill with sediments. Streams that feed a lake deposit sediments in the lake. Sediments also are carried into the lake by water that runs off the land but does not enter a stream. Most of these sediments are deposited near the shore. These sediments build up over time, which creates new shorelines and gradually fills in the lake. Organic deposits from vegetation also may accumulate in the bottom of a shallow lake. As these deposits grow denser, a bog or swamp may form. The lake basin may eventually become dry land.

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

Topic: Flooding and Society
SciLinks code: HQ60585
Topic: Stream Deposition
SciLinks code: HQ61457

Section 3 Review

1. **Identify** the differences between a delta and an alluvial fan.
2. **Explain** the differences between the deposition of sediment in deltas and alluvial fans with the deposition of sediment on a floodplain.
3. **Describe** the advantages and disadvantages of living in a floodplain.
4. **Summarize** how human activities can affect the size and number of floods.
5. **Identify** three methods of flood control.
6. **Explain** why lakes are usually short lived.

CRITICAL THINKING

7. **Analyzing Ideas** Why are spring floods common in rivers where the headwaters are in an area of cold, snowy winters?
8. **Making Inferences** If you were picking a material to make an artificial levee, what major characteristic would you look for? Explain your answer.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *stream deposition, delta, alluvial fan, floodplain, natural levee, dam, artificial levee,* and *lake.*

Chapter 15 Highlights

Sections

1 The Water Cycle

Key Terms

water cycle, 375
evapotranspiration, 376
condensation, 376
precipitation, 376
desalination, 378

Key Concepts

- The continuous movement of water from the atmosphere to the land and oceans and back to the atmosphere is called the *water cycle*.
- A region's water budget is affected by temperature, vegetation, wind, and the amount and duration of rainfall.
- The availability of fresh water can be enhanced through conservation efforts.

2 Stream Erosion

tributary, 379
watershed, 379
stream load, 380
discharge, 380
gradient, 380
meander, 381
braided stream, 382

- A river system is made of a main stream and feeder streams, called *tributaries*.
- A watershed is the area of land that is drained by a river system.
- The erosive ability of a river is affected by stream load, stream discharge, and stream gradient.
- A bend in a low-gradient stream or river is called a *meander*.
- A river that is composed of multiple channels that divide and rejoin around sediment bars is called a *braided stream*.

3 Stream Deposition

delta, 383
alluvial fan, 383
floodplain, 384

- Where a stream slows significantly, it can deposit its stream load to form deltas and alluvial fans.
- In floodplains, flooding commonly brings in new, rich soil for farming but can cause property damage.
- Floods can be controlled through forest and soil conservation and by building structures such as levees and dams.

Chapter 15 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *water cycle*
2. *gradient*
3. *evapotranspiration*
4. *floodplain*

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

5. *condensation* and *precipitation*
6. *watershed* and *tributary*
7. *stream load* and *discharge*
8. *delta* and *alluvial fan*

Understanding Key Concepts

9. The change of water vapor into liquid water is called
   - **a.** runoff.
   - **b.** desalination.
   - **c.** evaporation.
   - **d.** condensation.

10. In a water budget, the income is precipitation and the expense is
    - **a.** evapotranspiration and runoff.
    - **b.** condensation and saltation.
    - **c.** erosion and conservation.
    - **d.** conservation and sedimentation.

11. The land area from which water runs off into a stream is called a
    - **a.** tributary.
    - **b.** watershed.
    - **c.** divide.
    - **d.** gully.

12. Tributaries branch out and lengthen as a river system develops by
    - **a.** headward erosion.
    - **b.** condensation.
    - **c.** saltation.
    - **d.** runoff.

13. The stream load that includes gravel and large rocks is the
    - **a.** suspended load.
    - **b.** runoff load.
    - **c.** dissolved load.
    - **d.** bed load.

14. A fan-shaped formation that develops when a stream deposits its sediment at the base of a steep slope is called a(n)
    - **a.** delta.
    - **b.** meander.
    - **c.** oxbow lake.
    - **d.** alluvial fan.

15. The part of a valley floor that may be covered during a flood is the
    - **a.** floodway.
    - **b.** floodplain.
    - **c.** meander.
    - **d.** artificial levee.

16. One way to control floods indirectly is through
    - **a.** soil conservation.
    - **b.** dams.
    - **c.** floodways.
    - **d.** artificial levees.

Short Answer

17. How does a local water budget differ from the water budget of the whole Earth?
18. How is reducing the pollution in streams and groundwater linked to water conservation?
19. Describe how bank erosion can cause a river to meander.
20. Why do most rivers that have a large sediment load also have high water velocity?
21. Describe how lakes fill with sediment.
22. What is the difference between direct and indirect methods of flood control?

Critical Thinking

23. Evaluating Ideas How would Earth's water cycle be affected if a significant percentage of the sun's rays were blocked by dust or other contaminants in the atmosphere?

24. Making Comparisons Use an atlas to determine the geographic location of Calcutta, India, and Stockholm, Sweden. How might the local water budgets of these two cities differ? Explain your answer.

25. Making Inferences The Colorado River is usually grayish brown as it flows through the Grand Canyon. What causes this color?

26. Making Predictions What do you think would happen to cities in the southwestern U.S. if rivers in that area could not be dammed?

Concept Mapping

27. Use the following terms to create a concept map: *water vapor, condensation, precipitation, channel, stream load, watershed, bar, alluvial fan, delta, divides, watersheds, tributaries, floodplains, dams,* and *artificial levees*.

Math Skills

28. Making Calculations If a river is 3,705 km long from its headwaters to its delta and the average downstream velocity of its water is 200 cm/s, use the equation *time* = *distance* ÷ *velocity* to determine how many days a water molecule takes to make the trip.

29. Using Equations You wish to examine the annual water budget for the state of Colorado. If p = total precipitation, e = total evapotranspiration, r = total stream runoff, and g = total water soaking into the ground, what equation will allow you to determine whether Colorado experiences a net loss or net gain of water over the course of a year?

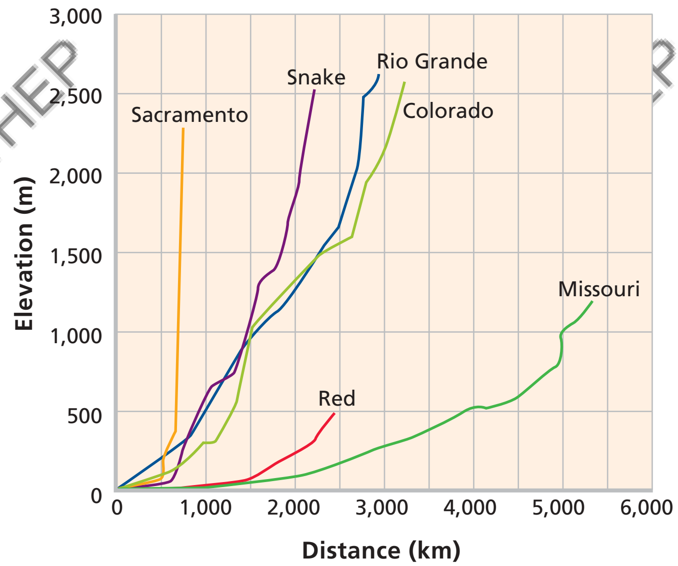
Writing Skills

30. Writing Persuasively Write a persuasive essay of at least 300 words that suggests ways in which your community can conserve water and reduce water pollution.

31. Communicating Main Ideas Discuss the dangers and advantages of living in a river floodplain. Outline the options for adapting to living in a river floodplain.

Interpreting Graphics

The graph below shows the gradients of several rivers of the United States. Use the graph to answer the questions that follow.



32. Which river has the shallowest average gradient over its entire course?

33. Which river has the steepest average gradient over its entire course?

34. Based only on gradient, how would the velocity of the Snake River compare with the velocity of the Missouri River?

35. Which end of each line on the graph represents the headwaters of the river system? Explain your answer.

Chapter 15 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 Condensation is often triggered as water vapor rising in the atmosphere
A. cools
B. warms
C. contracts
D. breaks apart

2 The continuous movement of water from the ocean, to the atmosphere, to the land, and back to the ocean is
F. condensation.
G. the water cycle.
H. precipitation.
I. evapotranspiration.

3 Which of the following formations drains a watershed?
A. floodplains
B. a recharge zone
C. an artesian spring
D. streams and tributaries

4 Like rivers, lakes have life cycles. Most lakes have short life cycles and eventually disappear. Which of the following conditions may cause a lake to disappear?
F. when evaporation exceeds precipitation
G. when precipitation exceeds evaporation
H. when sediments are removed from the lake
I. when a local water budget is balanced

Directions (5–8): **For *each* question, write a short response.**

5 What is the term for a volume of water that is moved by a stream during a given amount of time?

6 The gradient of a river is defined as a change in what over a given distance?

7 Streams are said to have varying loads. What makes up a stream's load?

8 Desalination removes what naturally occurring compound from ocean water?

Reading Skills

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

The Mississippi Delta

In the Mississippi River Delta, long-legged birds step lightly through the marsh and hunt fish or frogs for breakfast. Hundreds of species of plants and animals start another day in this fragile ecosystem. This delta ecosystem, like many other ecosystems, is in danger of being destroyed.

The threat to the Mississippi River Delta ecosystem comes from efforts to make the river more useful. Large parts of the river bottom have been dredged to deepen the river for ship traffic. Underwater channels were built to control flooding. What no one realized was that the sediments that once formed new land now pass through the channels and flow out into the ocean. Those river sediments had once replaced the land that was lost every year to erosion. Without them, the river could no longer replace land lost to erosion. So, the Mississippi River Delta began shrinking. By 1995, more than half of the wetlands were already gone—swept out to sea by waves along the Lousiana coast.

9 Based on the passage, which of the following statements about the Mississippi River is true?
A. The Mississippi River never floods.
B. The Mississippi River is not wide enough for ships to travel on it.
C. The Mississippi River's delicate ecosystem is in danger of being lost.
D. The Mississippi River is disappearing.

10 Based on the passage, which of the following statements is true?
F. By 1995, more than half of the Mississippi River was gone.
G. Underwater channels control flooding.
H. Channels help form new land.
I. Sediment cannot replace lost land.

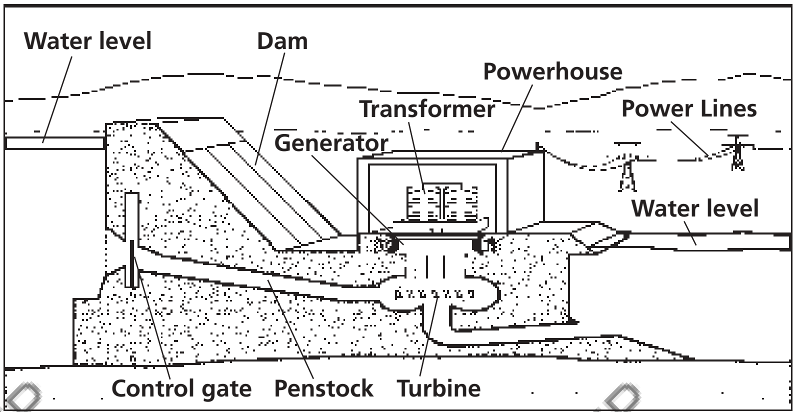
11 The passage mentions that damage to the ecosystem came from efforts to make the river more useful. For who or what was the river being made more useful?

Interpreting Graphics

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

The diagram below shows how a hydropower plant works. Use this diagram to answer questions 12 and 13.

Hydroelectric Dam



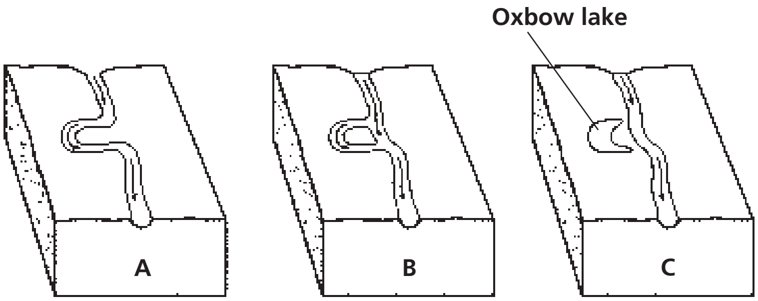
12 Hydroelectric dams are used to generate electricity for human use. As water rushes past the machinery inside, an electric current is generated. What does water rush past to turn the generator, which produces the current?

A. a transformer
B. the control gate
C. an intake
D. a turbine

13 Look at the diagram above. What direction does the water flow? What makes the water flow in this direction?

The graphic below shows the formation of an oxbow lake. Use this graphic to answer questions 14 and 15.

Formation of an Oxbow Lake



14 What is the term for the wide curves whose development causes the formation of oxbow lakes?

F. wonders
G. meanders
H. bows
I. loops

15 How does the speed at which the water flows contribute to the process of forming an oxbow lake?

Test TIP

If you are permitted to, draw a line through each incorrect answer choice as you eliminate it.

Using Scientific Methods

Sediments and Water

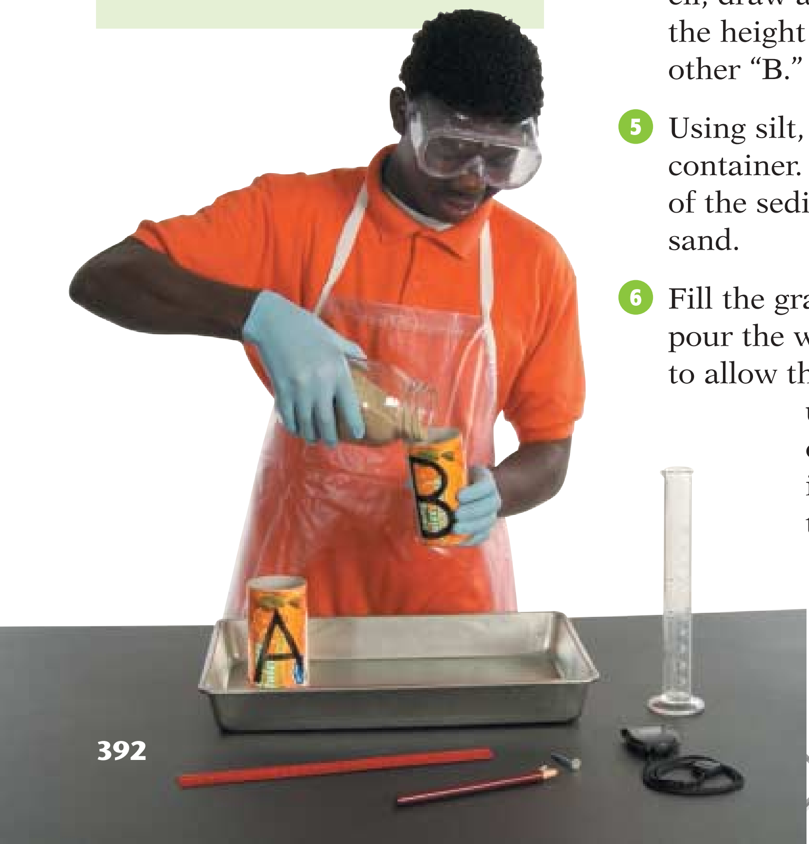
Objectives

- **Measure** the amount of water that sediment can hold.
- **Identify** the properties that affect how sediment interacts with water.

Materials

- graduated cylinder, 100 mL
- grease pencil
- juice containers, 12 oz (2)
- metric ruler
- nail, large
- pan, 23 cm × 33 cm × 5 cm or larger
- sand, dry and coarse
- silt, dry
- stopwatch or clock with second hand
- water

Safety



Step 5

Running water erodes some types of soil more easily than it erodes others. How rapidly a soil erodes depends on how well the soil holds water. In this lab, you will determine the erosive effect of water on various types of sediment.

ASK A QUESTION

1. Which type of soil would hold more water: sandy soil or silty soil? Which soil would water flow through faster and thus would erode more rapidly: sandy soil or silty soil?

FORM A HYPOTHESIS

2. Write a hypothesis that is a possible answer to the questions above.

TEST THE HYPOTHESIS

3. Use a graduated cylinder to pour 300 mL of water into each of two juice containers.
4. Place the containers on a flat surface. Using a grease pencil, draw a line around the inside of the containers to mark the height of the water. Label one container "A" and the other "B." Empty and dry the containers.
5. Using silt, fill container A up to the line drawn inside the container. Tap the container gently to even out the surface of the sediment. Repeat this step for container B, but use sand.
6. Fill the graduated cylinder with 100 mL of water. Slowly pour the water into container A. Stop every few seconds to allow the soil to absorb the water. Continue pouring until a thin film of water forms on the surface of the sediment. If more than 100 mL of water is needed, refill the graduated cylinder and continue this step.

7. Record the volume of water poured into the container.
8. Using container B, repeat steps 6 and 7. Record your observations.
9. Use a metric ruler to measure 1 cm above the surface of the sediment in each container. Using the grease pencil, draw a line to mark this height on the inside of each container. Pour water from the graduated cylinder into containers A and B until the water reaches the 1 cm mark.
10. Poke a nail through the very bottom of the side of container A. Place the container inside the pan. At the same time, start recording the time by using a stopwatch and pull the nail out of the container.
11. Observe the water level, and record the amount of time that the water takes to drop to the sediment surface.
12. Using container B, repeat steps 10 and 11. Record your observations.

Step 8

Step 12

ANALYZE THE RESULTS

1. **Analyzing Results** In step 8, which type of sediment held more water?
2. **Analyzing Results** Which type of sediment was the water able to flow through faster?
3. **Summarizing Results** What properties of the sediment do you think affected how the water flowed through the sediment? Explain your answer.

DRAW CONCLUSIONS

4. **Analyzing Results** On the basis of your answers to the questions above, which would water erode more quickly: an area of silt or an area of sand? Explain your answer.
5. **Drawing Conclusions** In which sediment do you think a deep stream channel is most likely to form? In which sediment is a meandering stream likely to form? Explain your answers.

Extension

1. **Applying Conclusions** Describe three ways to make slopes covered with soil more resistant to erosion.

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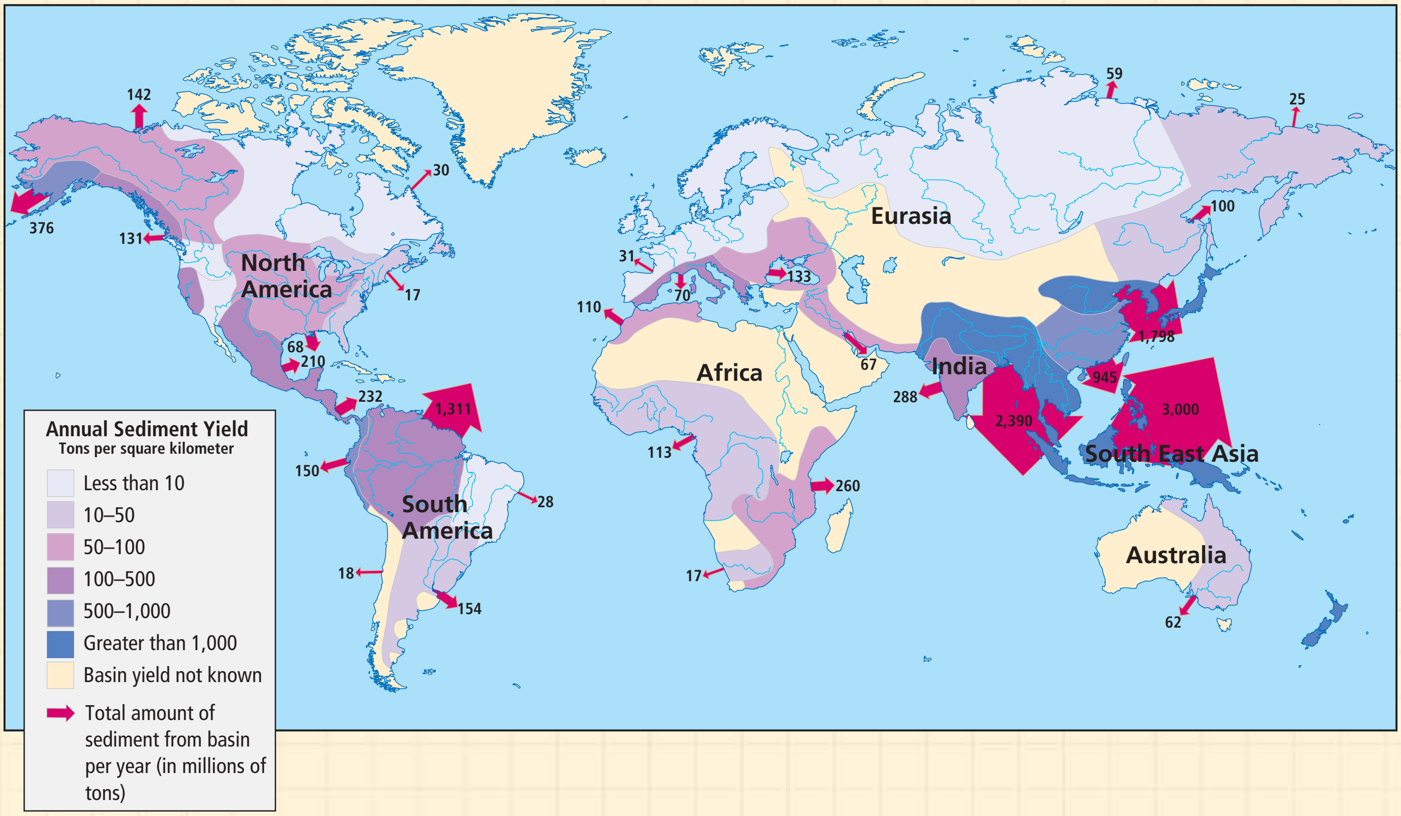
MAPS in Action

World Watershed Sediment Yield



Map Skills Activity

This map shows the world's watersheds and identifies the sediment yield of each watershed basin in tons per square kilometer and the total amount of sediment that each basin dumps into the ocean in millions of tons per year. Use the map to answer the questions below.

1. **Using a Key** What area has the highest total annual sediment yield from one basin?
2. **Using a Key** What is the range of the annual sediment yield in tons per square kilometer for the United States, excluding Alaska?
3. **Analyzing Data** What is the total amount of sediment that basins in South America yield per year?
4. **Analyzing Relationships** Areas that have high relief, where the range of elevations is great, tend to have higher sediment yields than areas that have low relief, where the topography is flatter, do. Which area would you conclude has higher relief: Africa or South East Asia? Explain your answer.
5. **Making Comparisons** Both the Amazon basin, which is in northern South America, and the India basin have an annual sediment yield range of 100 to 500 tons per square kilometer. However, the total amount of sediment per year from the Amazon basin is 1,311 million tons, while the total amount of sediment per year from the India basin is 288 million tons. Explain why these two basins differ so significantly in their total sediment yield per year.

EYE on the Environment

The Three Gorges Dam

China's Yangtze River is the third-longest river in the world. The Yangtze River flows through the Three Gorges region of central China, which is famous for its natural beauty and historical sites. This region is also where the Three Gorges Dam—the largest hydroelectric dam project in the world—is currently being built. When the dam is complete, the Yangtze River will rise to form a reservoir that is 595 km long—as long as Lake Superior. In other words, the reservoir will be about as long as the distance between Los Angeles and San Francisco in California!

Benefits of the Dam

The dam has several purposes, one of which is to control the water level of the Yangtze River to prevent flooding. About 1 million people died in the last century from flooding along the river. The other purpose is to provide millions of people with hydroelectric power. China now burns air-polluting coal to meet 75% of the country's energy needs. Engineers project that when the dam is completed, its turbines will provide enough electrical energy to power a city that is 10 times the size of Los Angeles. When its flow is controlled, the Yangtze River will be deep enough for ships to navigate on it, so the dam will also increase trade in a relatively poor region of China.

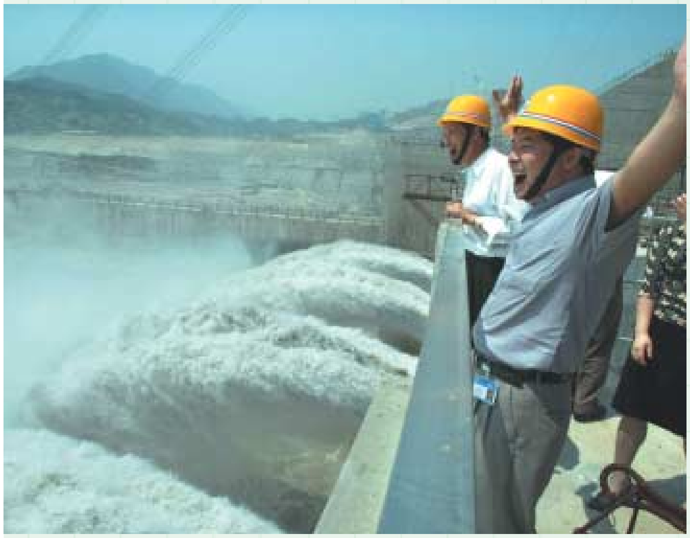
Disadvantages of the Dam

The project has several drawbacks, however. The reservoir behind the dam will flood an enormous area. Almost 2 million people living in the affected areas are being relocated—there are 13 cities and hundreds of villages in the area of the reservoir. As the reservoir's waters rise, fragile ecosystems and valuable archeological sites will be destroyed and scenic recreation areas will be submerged.

▲ A resident on the Yangtze River carries his belongings to higher ground after his home was destroyed when the dam caused the water level to rise.

Opponents of the project also claim that the dam will increase pollution levels in the Yangtze River. Most of the cities and factories along the river dump untreated wastes directly into the water. Some people think the reservoir will become the world's largest sewer when 1 billion tons of sewage flows into the reservoir every year.

Because the dam lies over a fault, scientists question whether the dam will be able to withstand earthquakes. If the dam were to burst, towns and cities downstream would be destroyed by the ensuing flood.



◀ An engineer on the Three Gorges Dam project celebrates the successful test of sluicing, which is the rushing of water through channels in the dam.

Extension

1. **Research** What do you think of the Three Gorges dam? Research other dam projects. After analyzing the benefits and risks of dams, write an essay describing your opinion about dam projects.

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Chapter 16 Groundwater

Sections

1 Water Beneath the Surface

2 Groundwater and Chemical Weathering

What You'll Learn

- How water moves under Earth's surface
- How humans use groundwater
- How groundwater shapes Earth's surface

Why It's Relevant

Groundwater is a major source of drinking water for humans and a source of fresh water for agriculture and industry. Groundwater is also a major force in shaping Earth's landforms.

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.

▶ These macaque monkeys are bathing in hot springs in Jigokudani National Park in Japan. Hot springs form where molten rock in Earth's crust heats surrounding rock and the groundwater in the rock. The water then rises to the surface to form pools and springs.

Section 1 Water Beneath the Surface

Surface water that does not run off into streams and rivers may seep down through the soil into the upper layers of Earth's crust. There, the water fills spaces, or *pores,* between rock particles. Water may also fill fractures or cavities in rock that were caused by erosion. Water that fills and moves through these spaces in rock and sediment is called **groundwater.** Groundwater is an important source of fresh water in the United States.

OBJECTIVES

- **Identify** properties of aquifers that affect the flow of groundwater.
- **Describe** the water table and its relationship to the land surface.
- **Compare** wells, springs, and artesian formations.
- **Describe** two land features formed by hot groundwater.

KEY TERMS

groundwater
aquifer
porosity
permeability
water table
artesian formation

Properties of Aquifers

A body of rock or sediment in which large amounts of water can flow and be stored is called an **aquifer.** For water to flow freely through an aquifer, the pores or fractures in the aquifer must be connected. The ease with which water flows through an aquifer is affected by many factors, including porosity and permeability.

Porosity

In a set volume of rock or sediment, the percentage of the rock or sediment that consists of open spaces is **porosity.** One factor that affects porosity is sorting. *Sorting* is the amount of uniformity in the size of the rock or sediment particles, as **Figure 1** shows. Most particles in a well-sorted sediment are about the same size, and a few smaller particles fill the spaces between them. Poorly sorted sediment contains particles of many sizes. Small particles fill the spaces between large particles, which makes the rock less porous. Particle packing also affects porosity. Loosely packed particles leave many open spaces that can store water, so the rock has high porosity. Rock that has tightly packed particles contains few open spaces and thus has low porosity. Grain shape also affects porosity. In general, the more irregular the grain shape is, the more porous the rock or sediment is.

groundwater the water that is beneath Earth's surface

aquifer a body of rock or sediment that stores groundwater and allows the flow of groundwater

porosity the percentage of the total volume of a rock or sediment that consists of open spaces

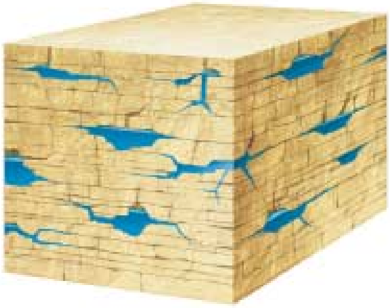
Figure 1 ▶ **Differences in Porosity**

Well-sorted, coarse-grained sediment has high porosity.

Well-sorted, fine-grained sediment has high porosity equal to the porosity of coarse-grained sediment.

Poorly sorted sediment that contains grains of many sizes has low porosity.

Rock is considered porous if it has many empty spaces that can fill with water.



Rock is considered permeable if its empty spaces are connected so that water may flow from one space to the next.

Figure 2 ▶ Porous rocks do not make good aquifers unless water can move freely through the rocks.

permeability the ability of a rock or sediment to let fluids pass through its open spaces, or pores

Permeability

The ease with which water passes through a porous material is called **permeability.** For a rock to be permeable, the open spaces must be connected, as shown in **Figure 2.** A rock that has high porosity is not permeable if the pores or fractures are not connected. Permeability is also affected by the size and sorting of the particles that make up a rock or sediment. The larger and better sorted the particles are, the more permeable the rock or sediment tends to be. The most permeable rocks, such as sandstone, are composed of coarse particles. Other rocks, such as limestone, may be permeable if they have interconnected cracks. Clay is a sediment composed of flat, very fine-grained particles. Because of this characteristic composition, clay is essentially *impermeable,* which means that water cannot flow through it.

QuickLAB 20 min

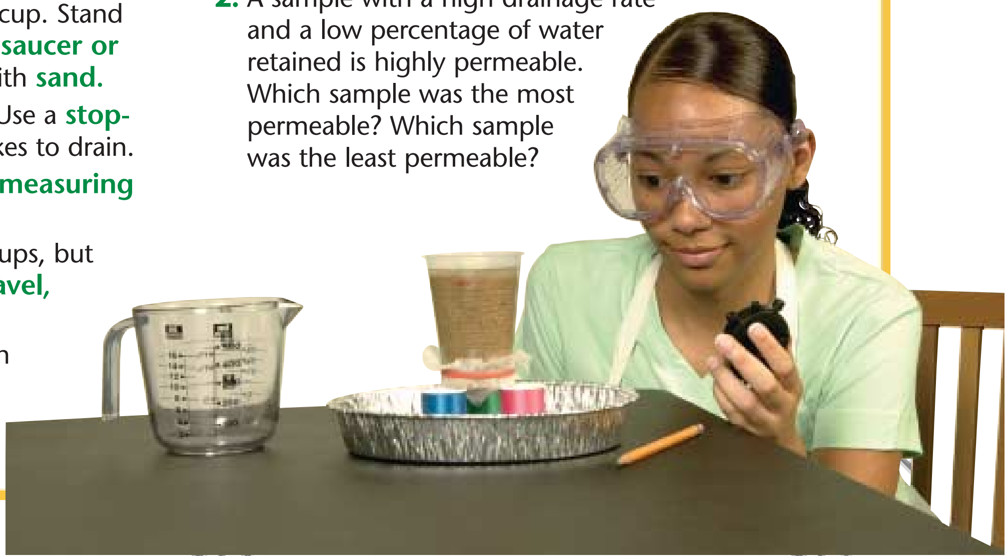
Permeability

Procedure

1. With a **sharpened pencil,** make seven tiny holes in the bottom of each of **three paper or plastic cups.** Stretch **cheesecloth** tightly over the bottom of each cup. Secure the cloth with a **rubber band.**
2. Mark a line 2 cm from the top of one cup. Stand the cup on **three thread spools** in a **saucer or pie pan,** and fill the cup to the line with **sand.**
3. Pour **120 mL of water** into the cup. Use a **stopwatch** to time how long the water takes to drain.
4. Pour the water from the saucer into a **measuring cup.** Record the amount of water.
5. Repeat steps 2–4 with the two other cups, but fill one cup with **soil** and one with **gravel,** not sand.
6. Calculate the rates of drainage for each cup by dividing the amount of water that drained by the time the water took to drain.
7. For each cup, calculate the percentage of water retained by subtracting the amount of water drained from 120 mL. Divide this volume by 120.

Analysis

1. Which cup had the highest drainage rate?
2. A sample with a high drainage rate and a low percentage of water retained is highly permeable. Which sample was the most permeable? Which sample was the least permeable?



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Zones of Aquifers

Gravity pulls water down through soil and rock layers until the water reaches impermeable rock. Water then begins to fill, or saturate, the spaces in the rock above the impermeable layer. As more water soaks into the ground, the water level rises underground and forms two distinct zones of groundwater, as shown in **Figure 3.**

Zone of Saturation

The layer of an aquifer in which the pore space is completely filled with water is the *zone of saturation*. The term *saturated* means "filled to capacity." The zone of saturation is the lower of the two zones of groundwater. The upper surface of the zone of saturation is called the **water table.**

water table the upper surface of underground water; the upper boundary of the zone of saturation

Zone of Aeration

The zone that lies between the water table and Earth's surface is called the *zone of aeration*. The zone of aeration is composed of three regions. The uppermost region of the zone of aeration holds soil moisture—water that forms a film around grains of topsoil. The bottom region, just above the water table, is the capillary fringe. Water is drawn up from the zone of saturation into the capillary fringe by capillary action. *Capillary action* is caused by the attraction of water molecules to other materials, such as soil. For example, when a paper towel soaks up a spill, capillary action draws moisture into the towel. Between the soil moisture region and the capillary fringe is a region that is dry—except during periods of rain—and thus contains air in its pores.

Reading Check What are the two zones of groundwater? (See the Appendix for answers to Reading Checks.)

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

Topic: Groundwater
SciLinks code: HQ60699

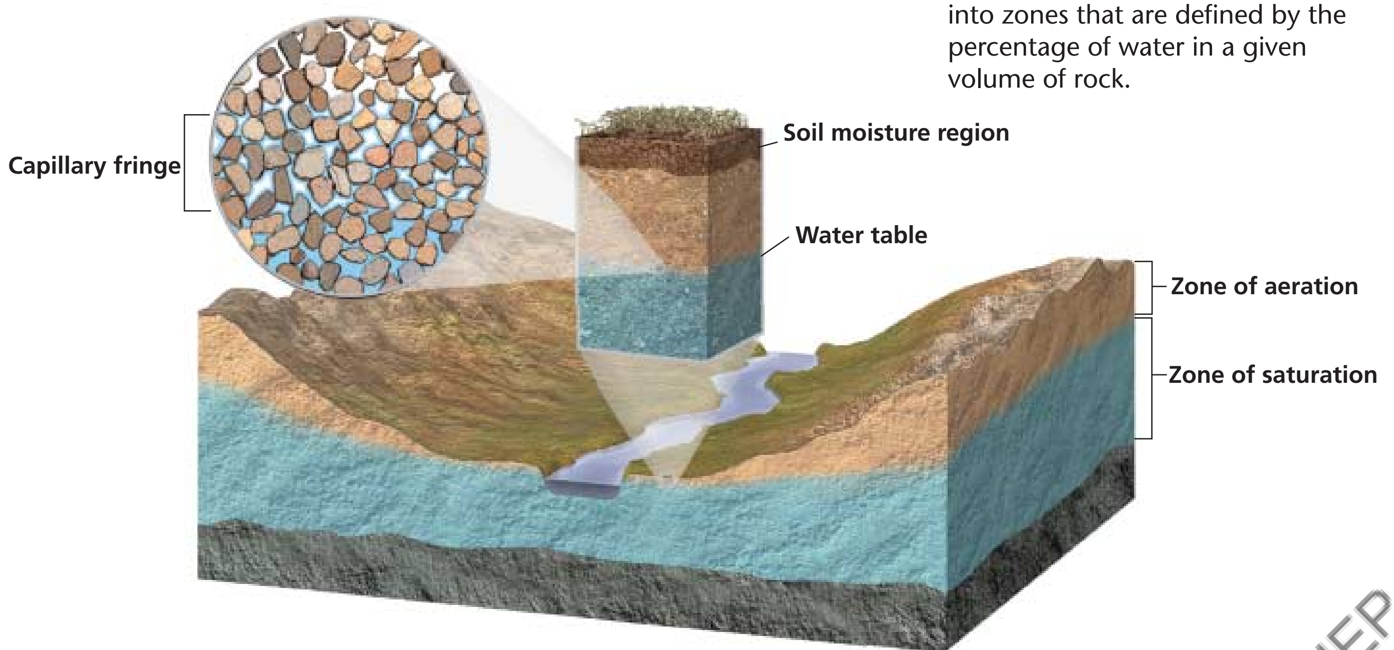


Figure 3 ▶ Groundwater is divided into zones that are defined by the percentage of water in a given volume of rock.

MATHPRACTICE

Rate of Groundwater Depletion In some areas, more groundwater is removed than is naturally replaced. In one area, for example, 575 million cubic meters of water enters the rock every year, while 1,500 million cubic meters of water is removed each year. What is the rate of groundwater depletion in that area? The total amount of groundwater available is 6,475 million cubic meters. If groundwater use continues at the current rate, in how many years will the water be completely depleted?

Movement of Groundwater

Like water on Earth's surface, groundwater flows downward in response to gravity. Water passes quickly through highly permeable rock and slowly through rock that is less permeable. The rate at which groundwater flows horizontally depends on both the permeability of the aquifer and the gradient of the water table. *Gradient* is the steepness of a slope. The velocity of groundwater increases as the water table's gradient increases.

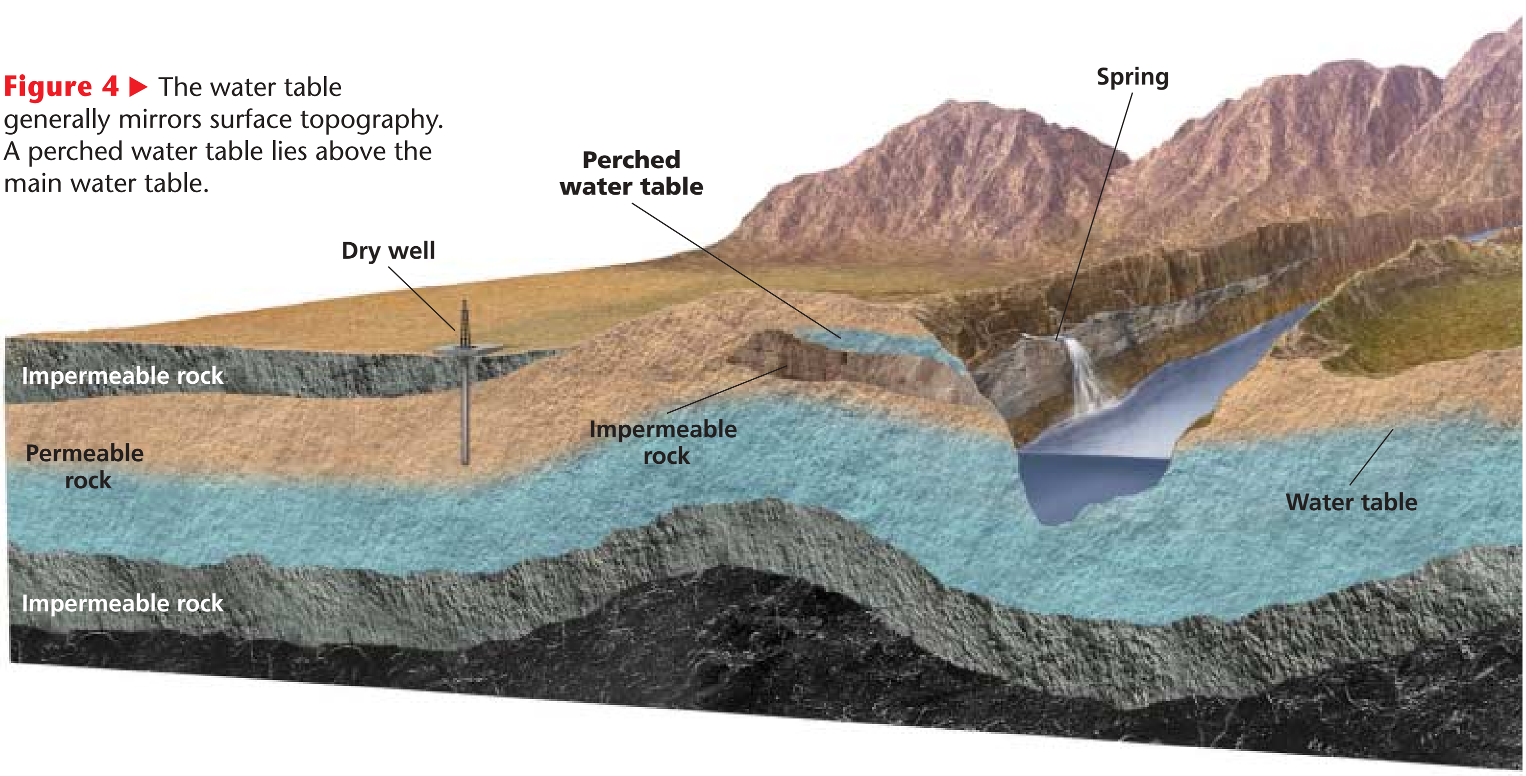
Topography and the Water Table

The depth of the water table below the ground surface depends on surface topography, the permeability of the aquifer, the amount of rainfall, and the rate at which humans use the water. Generally, shallow water tables match the contours of the surface, as shown in **Figure 4.** During periods of prolonged rainfall, the water table rises. During periods of drought, the water table falls and flattens because water that leaves the aquifer is not replaced.

Only one water table exists in most areas. In some areas, however, a layer of impermeable rock lies above the main water table. This rock layer prevents water from reaching the main zone of saturation. Water collects on top of this upper layer and creates a second water table, which is called a *perched water table*.

Reading Check **What four factors affect the depth of a water table? (See the Appendix for answers to Reading Checks.)**

Figure 4 ▶ The water table generally mirrors surface topography. A perched water table lies above the main water table.

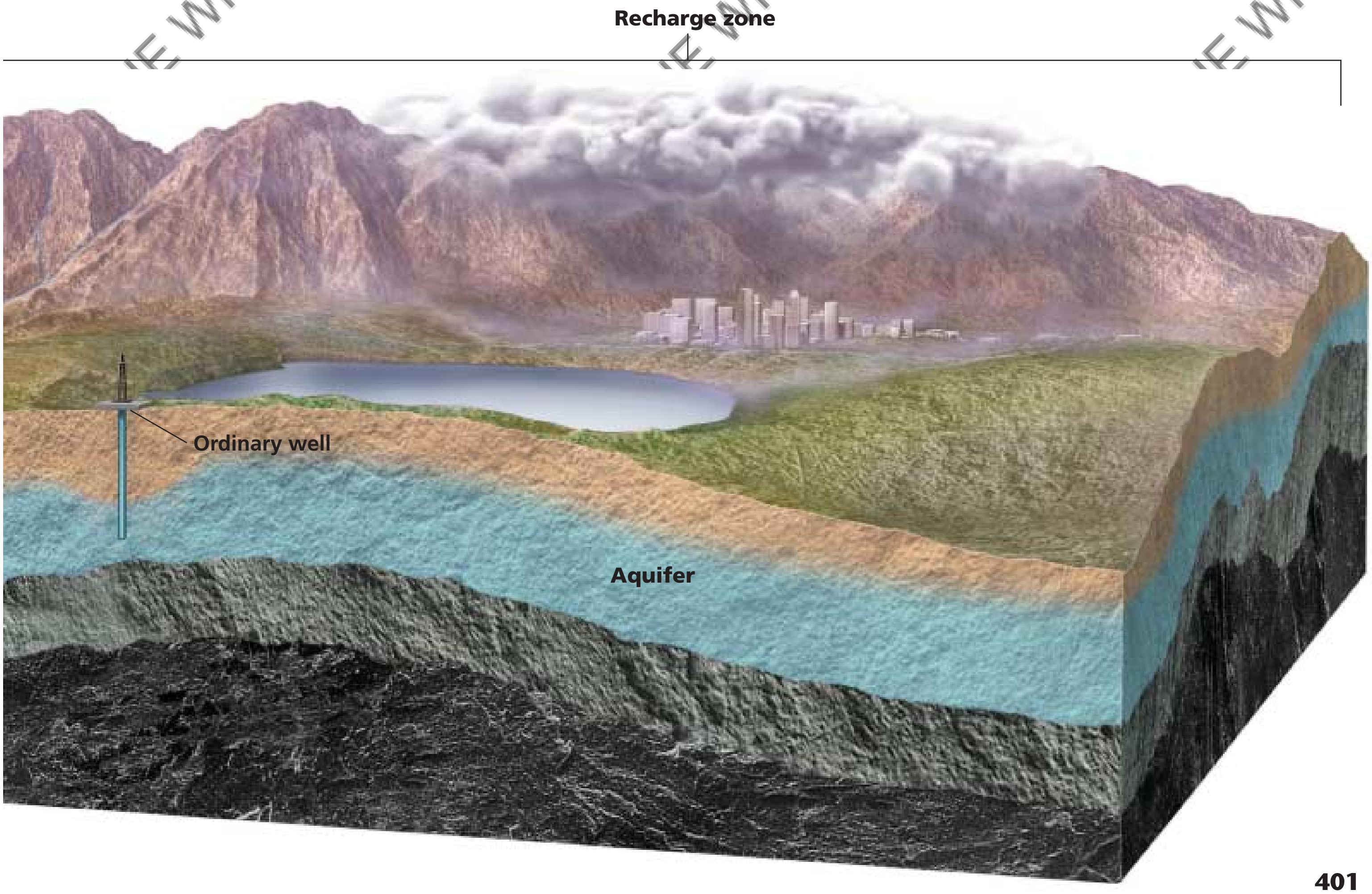


Conserving Groundwater

In many communities, groundwater is the only source of fresh water. Although groundwater is renewable, its long renewal time limits its supply. Groundwater collects and moves slowly, and the water taken from aquifers may not be replenished for hundreds or thousands of years. Communities often regulate the use of groundwater to help conserve this valuable resource. They can monitor the level of the local water table and discourage excess pumping. Some communities recycle used water. This water is purified and may be used to replenish the groundwater supply.

Surface water enters an aquifer through an area called a recharge zone. A *recharge zone* is anywhere that water from the surface can travel through permeable rock to reach an aquifer, as shown in **Figure 4.** Recharge zones are environmentally sensitive areas because pollution in the recharge zone can enter the aquifer. Therefore, recharge zones are often labeled by signs like the one shown in **Figure 5.** Pollution can enter an aquifer from waste dumps and underground storage tanks for toxic chemicals, from fertilizers and pesticides used in agriculture and on lawns, or from leaking sewage systems. If too much groundwater is pumped from an aquifer that is near the ocean, salt water from the ocean can then flow into the aquifer and contaminate the groundwater supply.

Figure 5 ▶ Water that enters this drain runs off into the Charles River and surrounding aquifers in Massachusetts.

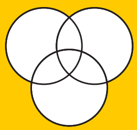


Wells and Springs

Groundwater reaches Earth's surface through wells and springs. A *well* is a hole that is dug to below the level of the water table and through which groundwater is brought to Earth's surface. A *spring* is a natural flow of groundwater to Earth's surface in places where the ground surface dips below the water table. Wells and springs are classified into two groups—ordinary and artesian.

Graphic Organizer **Venn Diagram**

Create the **Graphic Organizer** entitled "Venn Diagram" described in the Skills Handbook section of the Appendix. Label the circles "Ordinary wells" and "Artesian wells." Then, fill in the diagram with characteristics that are common to both types of wells.



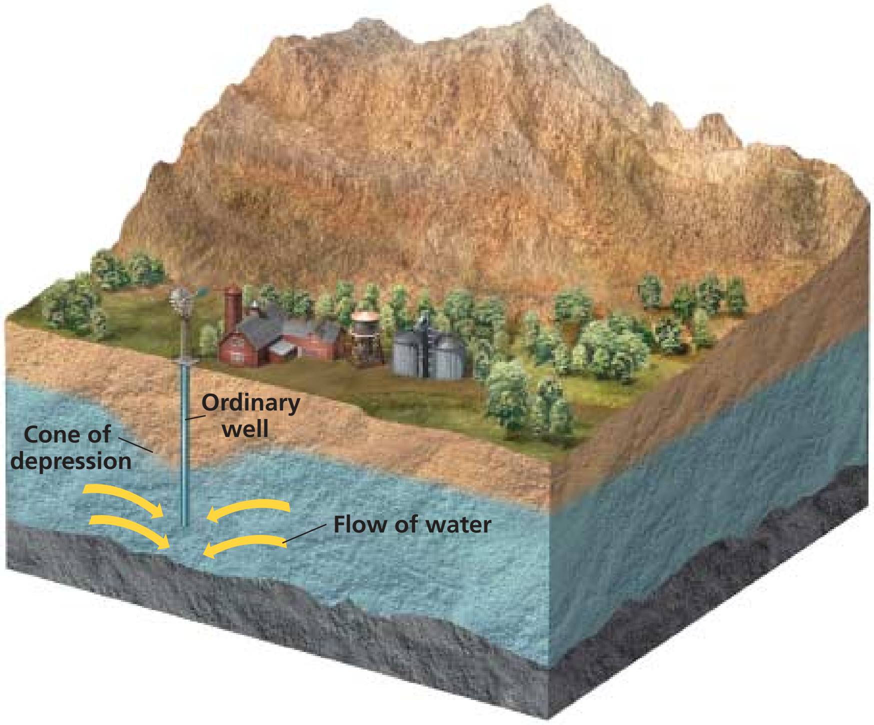
Ordinary Wells and Springs

Ordinary wells work only if they penetrate highly permeable sediment or rock below the water table. If the rock is not permeable enough, groundwater cannot flow into the well quickly enough to replace the water that is withdrawn.

Pumping water from a well lowers the water table around the well and forms a *cone of depression,* as shown in **Figure 6.** If too much water is taken from a well, the cone of depression may drop to the bottom of the well and the well will go dry. The lowered water table may extend several kilometers around the well and may cause surrounding wells to become dry.

Ordinary springs are usually found in rugged terrain where the ground surface drops below the water table. These springs may not flow continuously if the water table in the area has an irregular depth as a result of variable rainfall. Springs that form from perched water tables that intersect the ground surface are very sensitive to the amount of local precipitation. Thus, these springs may go dry during dry seasons or severe droughts.

Figure 6 ▶ A cone of depression develops in the water table around a pumping well.



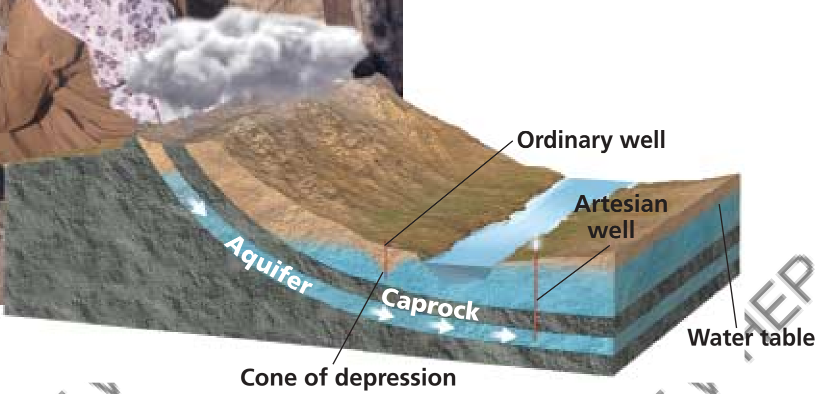


Figure 7 ▶ The aquifer in an artesian formation dips under the impermeable caprock. When a well is drilled into an artesian aquifer, pressure is released and the water rushes upward. These men are testing the quality of water from an artesian well in Pakistan.

Artesian Wells and Springs

The groundwater that supplies many wells comes from local precipitation. However, the water in some wells may come from as far away as hundreds of kilometers. Water may travel through an aquifer to a distant location. Because the aquifer is so extensive, it may become part of an artesian formation, an arrangement of permeable and impermeable rock.

An **artesian formation** is a sloping layer of permeable rock that is sandwiched between two layers of impermeable rock, as shown in **Figure 7.** The permeable rock is the aquifer, and the top layer of impermeable rock is called the *caprock*. Water enters the aquifer at a recharge zone and flows downhill through the aquifer. As the water flows downward, the weight of the overlying water causes pressure in the aquifer to increase. Because the water is under pressure, when a well is drilled through the caprock, the water quickly flows up through the well and may even spout from the surface. An *artesian well* is a well through which water flows freely without being pumped.

artesian formation a sloping layer of permeable rock sandwiched between two layers of impermeable rock and exposed at the surface

Artesian formations are also the source of water for some springs. When cracks occur naturally in the caprock, water from the aquifer flows through the cracks. This flow forms *artesian springs*.

Reading Check **What is the difference between ordinary springs and artesian springs? (See the Appendix for answers to Reading Checks.)**

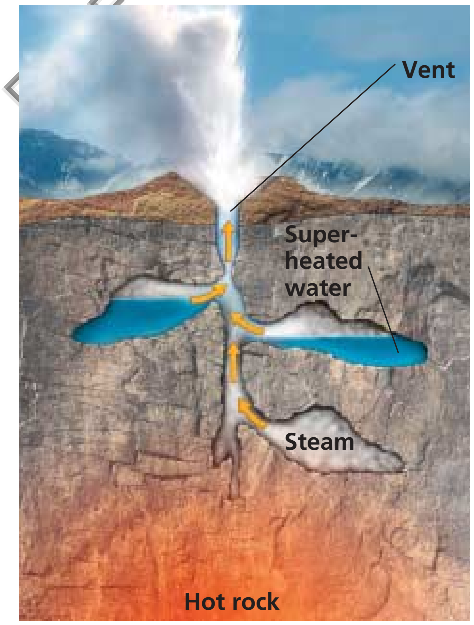


Figure 8 ▶ The vent and underground chambers of a geyser enable water to become superheated and to eventually erupt to the surface.

Hot Springs

Groundwater is heated when it passes through rock that has been heated by magma. Hot groundwater that is at least 37°C and that rises to the surface before cooling produces a *hot spring*. When water in a hot spring cools, the water deposits minerals around the spring's edges. The deposits form steplike terraces of calcite called *travertine*. *Mud pots* form when chemically weathered rock mixes with hot water to form a sticky, liquid clay that bubbles at the surface. Mud pots are called *paint pots* when the clay is brightly colored by minerals or organic materials.

Geysers

Hot springs that periodically erupt from surface pools or through small vents are called *geysers*. A geyser consists of a narrow vent that connects one or more underground chambers with the surface. The hot rocks that make up the chamber walls superheat the groundwater. The water in the vent exerts pressure on the water in the chambers, which keeps the water in the chambers from boiling for a time. When the water in the vent finally begins to boil, the boiling water produces steam that pushes the water above it to the surface. Release of the water near the top of the vent relieves the pressure on the superheated water farther down. With the sudden release of pressure, the superheated water changes into steam and explodes toward the surface, as shown in **Figure 8.** The eruption continues until most of the water and steam are emptied from the vent and chambers. After the eruption, groundwater begins to collect again and the process is repeated, often at regular intervals.

Section 1 Review

1. **Identify** the difference between porosity and permeability, and explain how permeability affects the flow of groundwater.
2. **Name and describe** the two zones of groundwater.
3. **Describe** how the contour of a shallow water table compares with the local topography.
4. **Explain** why ordinary springs often flow intermittently.
5. **Define** the term *cone of depression*.
6. **Compare** the rock layers in an artesian formation with those in an ordinary aquifer.
7. **Compare** artesian wells and ordinary wells.

CRITICAL THINKING

8. **Making Inferences** Which type of well would provide a community with a more constant source of water: an ordinary well or an artesian well? Explain your answer.
9. **Identifying Relationships** Why is protecting the environment from pollution important for communities in recharge zones?
10. **Analyzing Ideas** Why don't shallow pools of hot water erupt the way that geysers erupt?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *groundwater, water table, zone of saturation,* and *zone of aeration.*

Section 2 Groundwater and Chemical Weathering

As groundwater passes through permeable rock, minerals in the rock dissolve. The warmer the rock is and the longer it is in contact with water, the greater the amount of dissolved minerals in the water. Water that contains relatively high concentrations of dissolved minerals, especially minerals rich in calcium, magnesium, and iron, is called *hard water*. Water that contains relatively low concentrations of dissolved minerals is called *soft water*.

Many people think that using hard water is unappealing. For example, more soap is needed to produce suds in hard water than in soft water. Also, many people prefer not to drink hard water because of its metallic taste. Some household appliances or fixtures may be damaged by the buildup of mineral deposits from hard water. **Figure 1** shows some results of the long-term presence of hard water.

Results of Weathering by Groundwater

One way that minerals become dissolved in groundwater is through chemical weathering. As water moves through soil and other organic materials, the water combines with carbon dioxide to form carbonic acid. This weak acid chemically weathers the rock that the acid passes through by breaking down and dissolving the minerals in the rock.

OBJECTIVES

- **Describe** how water chemically weathers rock.
- **Explain** how caverns and sinkholes form.
- **Identify** two features of karst topography.

KEY TERMS

cavern
sinkhole
karst topography

QuickLAB 25 min

Chemical Weathering

Procedure

1. Place **limestone, granite, pyrite,** and **chalk chips** into separate **small beakers.**
2. Cover the rocks in **1% HCL solution.**
3. After 20 min, observe the rocks.

Analysis

1. How have the rocks changed?
2. How is this process of change like the process of chemical weathering by groundwater?

Figure 1 ▶ Soap scum forms when soap reacts with calcium carbonate in hard water (inset). During high-water stages, hard water deposited a residue of calcium carbonate on the canyon walls that border this creek.

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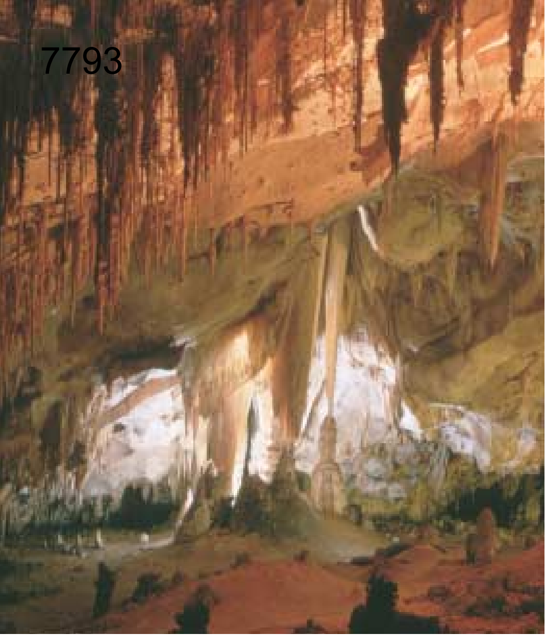


Figure 2 ▶ The formations in Carlsbad Caverns in New Mexico are made of calcite. ***Which formations in this photo are stalagmites?***

cavern a natural cavity that forms in rock as a result of the dissolution of minerals; also a large cave that commonly contains many smaller, connecting chambers

Caverns

Rocks that are rich in the mineral calcite, such as limestone, are especially vulnerable to chemical weathering. Although limestone is not porous, vertical and horizontal cracks commonly cut through limestone layers. As groundwater flows through these cracks, carbonic acid slowly dissolves the limestone and enlarges the cracks. Eventually, a cavern may form. A **cavern** is a large cave that may consist of many smaller connecting chambers. Carlsbad Caverns in New Mexico is a good example of a large limestone cavern, as shown in **Figure 2.**

Stalactites and Stalagmites

Although a cavern that lies above the water table does not fill with water, water still passes through the rock surrounding the cavern. When water containing dissolved calcite drips from the ceiling of a limestone cavern, some of the calcite is deposited on the ceiling. As this calcite builds up, it forms a suspended, cone-shaped deposit called a *stalactite* (stuh LAK TIET). When drops of water fall on the cavern floor, calcite builds up to form an upward-pointing cone called a *stalagmite* (stuh LAG MIET). Often, a stalactite and a stalagmite will grow until they meet and form a calcite deposit called a *column*.

Connection to CHEMISTRY

How Water Dissolves Limestone

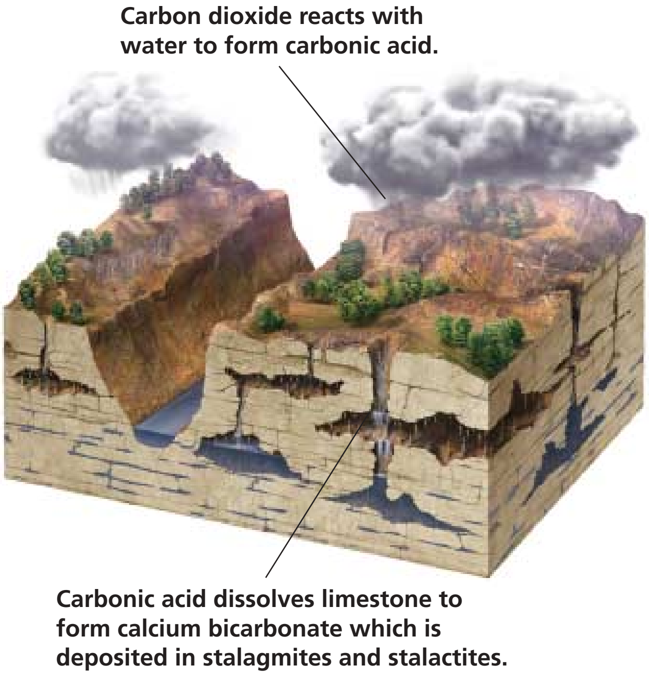
Water that falls as precipitation contains dissolved carbon dioxide, CO_2. This dissolved CO_2 causes the water to be slightly acidic. The formula for the dissolution of CO_2 is shown below.

Carbon dioxide reacts with **water** to form **carbonic acid: $H_2O + CO_2 = H_2CO_3$.**

Water that reaches the ground seeps into the soil. As the water passes through the soil, more CO_2 dissolves and the water becomes more acidic. The slightly acidic water enters fractures in limestone and dissolves the rock as the water moves through. The formula for the dissolution of limestone is shown below.

Carbonic acid dissolves **limestone** to form **calcium bicarbonate: $CaCO_3 + H_2CO_3 = Ca(HCO_3)_2$.**

Fractures widen over time, and caves develop underground. The calcium bicarbonate that forms when the limestone dissolves is deposited as the water drips and flows through the caves. This deposited calcium bicarbonate forms structures such as stalagmites and stalactites.



Sinkholes

A circular depression that forms at the surface when rock dissolves, when sediment is removed, or when caves or mines collapse is a **sinkhole.** Most sinkholes form by dissolution, in which the limestone or other rock dissolves where weak areas in the rock, such as fractures, previously existed. The dissolved material is carried away from the surface, and a small depression forms. *Subsidence sinkholes* form by a similar process except that as rock dissolves, overlying sediments settle into cracks in the rock and a depression forms.

Figure 3 ▶ When land overlying a cavern collapses to form a sinkhole, human-made structures, such as this highway, are often damaged.

Collapse sinkholes may form when sediment below the surface is removed and an empty space forms within the sediment layer. Eventually, the overlying sediments collapse into the empty space below. Collapse sinkholes may also form during dry periods, when the water table is low and caverns are not completely filled with water. Because water no longer supports the roof of the cavern, the roof may collapse. Collapse sinkholes may develop abruptly and cause extensive damage. A collapse sinkhole is shown in **Figure 3.**

sinkhole a circular depression that forms when rock dissolves, when overlying sediment fills an existing cavity, or when the roof of an underground cavern or mine collapses

Natural Bridges

When the roof of a cavern collapses in several places, a relatively straight line of sinkholes forms. The uncollapsed rock between each pair of sinkholes forms an arch of rock called a *natural bridge*, such as the one shown in **Figure 4.** When a natural bridge first forms, it is thick, but erosion causes the bridge to become thinner. Eventually, the natural bridge may collapse.

Reading Check **How are sinkholes related to natural bridges? (See the Appendix for answers to Reading Checks.)**

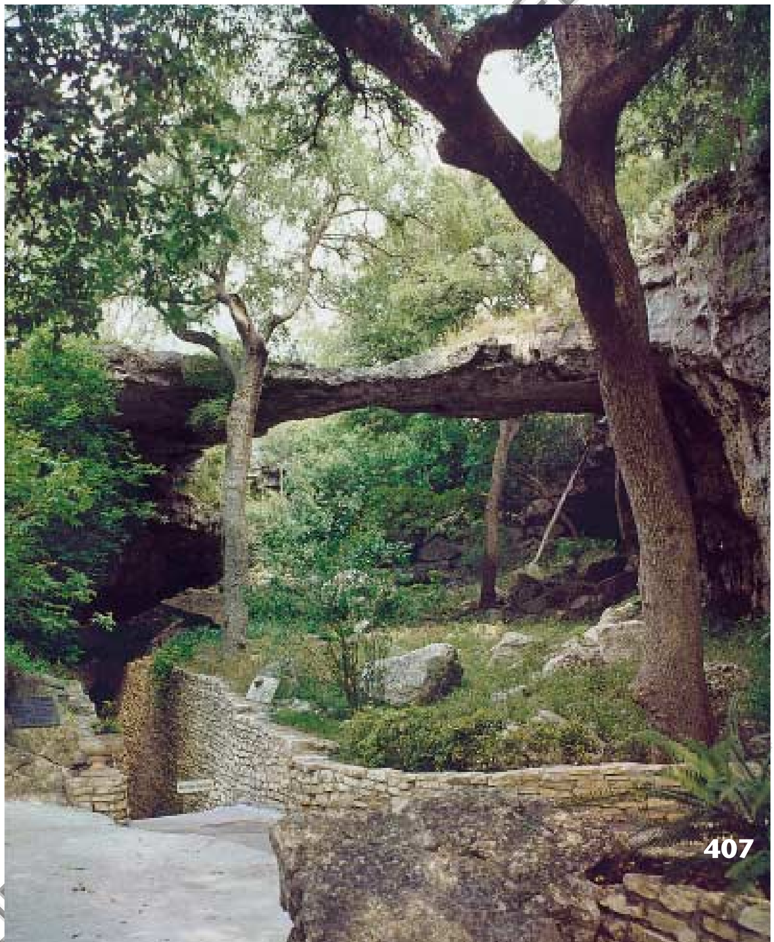


Figure 4 ▶ This natural bridge near San Marcos, Texas, formed when the roofs of two adjoining caverns collapsed.

Figure 5 ▶ The Stone Forest in Yunnan, China, is a dramatic example of karst topography.

Karst Topography

Irregular topography caused by the chemical weathering of limestone or other soluble rock by groundwater is called **karst topography.** Common features of karst topography include many closely spaced sinkholes and caverns. In karst regions, streams often disappear into cracks in the rock and then emerge in caves or through other cracks many kilometers away. In the United States, there is karst topography in Kentucky, Tennessee, southern Indiana, northern Florida, and Puerto Rico.

karst topography a type of irregular topography that is characterized by caverns, sinkholes, and underground drainage and that forms on limestone or other soluble rock

Generally, karst topography forms in regions where the climate is humid and where limestone formations exist at or near the surface. The plentiful precipitation in these regions commonly becomes groundwater. The groundwater flows through the limestone and reacts chemically with the calcite in the limestone. As the groundwater dissolves the limestone, cracks in the rock enlarge to form cave systems. Features of karst topography can form in dry regions, too. In these areas, sinkholes may form very close together and leave dramatic arches and spires, as shown in **Figure 5.** Karst topography in dry regions may indicate that the climate in those regions is becoming drier.

Section 2 Review

1. **Describe** how water chemically weathers rock.
2. **Explain** how caverns form.
3. **Explain** the difference between stalactites and stalagmites.
4. **Identify** three common features of karst topography.
5. **Describe** two ways in which a natural bridge might form.
6. **Compare** sinkholes and caverns.

CRITICAL THINKING

7. **Making Inferences** If an area has a dry climate, how can the area have karst topography?
8. **Identifying Relationships** Why might you expect to find springs in regions that have karst topography?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *groundwater, stalagmite, stalactite, natural bridge, cavern,* and *sinkhole*.

Chapter 16 Highlights

Sections

1 Water Beneath the Surface

Key Terms

- **groundwater,** 397
- **aquifer,** 397
- **porosity,** 397
- **permeability,** 398
- **water table,** 399
- **artesian formation,** 403

Key Concepts

- Porosity and permeability determine how water moves through rock or sediment.
- Aquifers have two main zones—the zone of aeration and the zone of saturation. The upper surface of the zone of saturation is called the *water table*.
- The depth of the water table depends on the topography of the land, the permeability of the rock, the amount of rainfall, and the rate at which groundwater is used by humans.
- Groundwater can be polluted by wastes, agricultural and lawn fertilizers, agricultural and lawn pesticides, and sea water.
- Wells and springs may be ordinary or artesian. Artesian formations are the source of artesian wells and springs.
- Hot springs and geysers form when hot rock beneath Earth's surface heats groundwater.

2 Groundwater and Chemical Weathering

Key Terms

- **cavern,** 406
- **sinkhole,** 407
- **karst topography,** 408

Key Concepts

- Caverns form as a result of the chemical weathering of limestone.
- Stalagmites are calcite formations that form on the floor of a cavern. Stalactites are calcite formations that form on the roof of a cavern.
- Sinkholes form when rock dissolves, when sediment is removed, or when the roof of a cavern or mine collapses.
- Karst topography features closely spaced sinkholes, caverns, and streams that disappear into cracks in the rock and then emerge several kilometers away.

Chapter 16 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *groundwater*
2. *water table*
3. *karst topography*

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

4. *geyser* and *hot spring*
5. *porosity* and *permeability*
6. *well* and *spring*
7. *ordinary well* and *artesian well*
8. *stalactite* and *stalagmite*

Understanding Key Concepts

9. Any body of rock or sediment in which water can flow and be stored is called a(n)
   a. well.
   b. aquifer.
   c. sinkhole.
   d. artesian formation.

10. The percentage of open space in a given volume of rock is the rock's
    a. viscosity.
    b. capillary fringe.
    c. permeability.
    d. porosity.

11. The ease with which water can pass through a rock or sediment is called
    a. permeability.
    b. carbonation.
    c. porosity.
    d. velocity.

12. The slope of a water table is called the
    a. gradient.
    b. porosity.
    c. permeability.
    d. aquifer.

13. A natural flow of groundwater that has reached the surface is a(n)
    a. spring.
    b. well.
    c. aquifer.
    d. travertine.

14. Pumping water from a well causes a local lowering of the water table known as a
    a. cone of depression.
    b. horizontal fissure.
    c. hot spring.
    d. sinkhole.

15. Calcite formations that hang from the ceiling of a cavern are called
    a. stalagmites.
    b. sinks.
    c. stalactites.
    d. aquifers.

16. Regions where the results of weathering by groundwater are clearly visible have
    a. sink topography.
    b. karst topography.
    c. limestone topography.
    d. artesian formations.

17. When the roofs of several caverns collapse, the uncollapsed rock between sinkholes can form
    a. natural bridges.
    b. stalactites.
    c. limestone topography.
    d. artesian formations.

18. A layer of permeable rock that is sandwiched between layers of impermeable rock is called
    a. a natural bridge.
    b. karst topography.
    c. limestone topography.
    d. an artesian formation.

Short Answer

19. In regions where the water table is at the surface of the land, what type of terrain would you expect to find?

20. Explain the process that forms stalactites and stalagmites. Name another process in nature that produces shapes similar to the shapes of stalactites.

21. How does a mud pot form?

22. Describe the zones of an aquifer.

23. What are two ways that groundwater reaches Earth's surface?

24. How are caverns and sinkholes related?

25. What causes a geyser to erupt?

26. Why does polluted groundwater take a long time to become pure enough for human use?

Critical Thinking

27. Making Inferences In what type of location might pumping too much water from an aquifer lead to contamination of the groundwater supply? Explain how the water becomes contaminated.

28. Analyzing Relationships Describe an artesian formation, and explain how the water in an artesian well may have entered the ground many hundreds of kilometers away.

29. Analyzing Ideas Explain how a rock can be both porous and impermeable.

30. Identifying Relationships Do you think that an area that has karst topography would have many surface streams or few surface streams? Explain your answer.

Concept Mapping

31. Use the following terms to create a concept map: *porosity, sorting, permeability, ordinary well, artesian formation, highly permeable rock,* and *impermeable rock*.

Math Skills

32. Evaluating Data People in Oklahoma use 11 billion gallons of water every day. The renewable water supply in Oklahoma is 68.7 billion gallons per day. What percentage of the renewable water supply do Oklahomans use every day?

33. Making Conversions In an average aquifer, groundwater moves about 50 m per year. At this rate, how long would the groundwater take to flow 1 km?

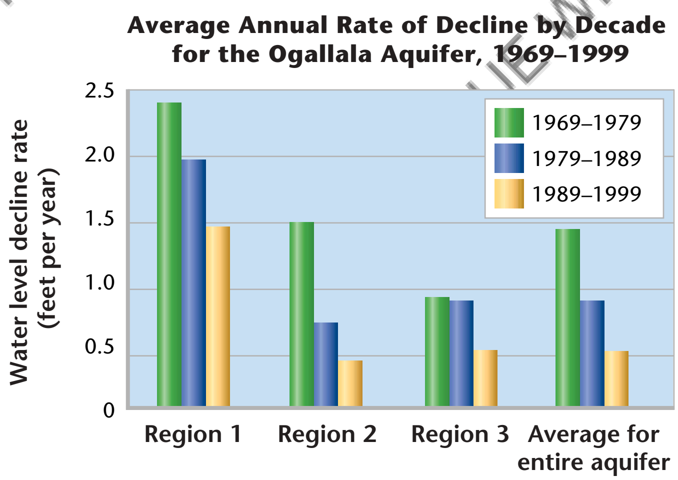
Writing Skills

34. Writing Persuasively Write a persuasive essay about the importance of conserving groundwater.

35. Communicating Main Ideas Explain how overpumping at one well can affect groundwater availability in surrounding areas.

Interpreting Graphics

The graph below shows the average annual decline in water level for the Ogallala Aquifer over 30 years. Use the graph below to answer the questions that follow.



36. Which region had the highest rate of decline from 1969 to 1999?

37. Over which decade did the aquifer have the lowest rate of decline?

38. Which years would you expect to have a higher rate of decline: the years 1999 to 2009 or the years 1989 to 1999? Explain your answer.

Chapter 16 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 Which of the following statements is false?
A. Permeability affects flow through an aquifer.
B. Groundwater can be stored in an aquifer.
C. An aquifer is composed of a single rock layer.
D. Well-sorted sediment holds the most water.

2 The amount of surface water that seeps into the pores between rock particles is influenced by which of the following factors?
F. rock type, land slope, and climate
G. rock type, land slope, and capillary fringe
H. rock type, land slope, and sea level
I. rock type, land slope, and recharging

3 Shanghai removed 96.03 million cubic meters of groundwater in 2002 but replaced only 13.75 million cubic meters. What was the rate of groundwater depletion in Shanghai that year?
A. 109.78 million cubic meters per year
B. 1,320.41 million cubic meters per year
C. 6.98 million cubic meters per year
D. 82.28 million cubic meters per year

4 How does karst topography form in dry regions?
F. Limestone dissolves, and caves form.
G. Sinkholes form close together.
H. Soluble rock is chemically weathered.
I. Soluble rock is physically weathered.

5 What quality distinguishes an ordinary well from an artesian well?
A. Water flows freely from an ordinary well.
B. Water is pressurized in an ordinary well.
C. Water must be pumped from an ordinary well.
D. Water comes from rainfall in an ordinary well.

Directions **(6–7): For** ***each*** **question, write a short response.**

6 What is a watershed?

7 What is the term for a local lowering of the water table caused by the pumping water from a well?

Reading Skills

Directions **(8–10): Read the passage below. Then answer the questions.**

Land Subsidence

Land subsidence is the settling or sinking of earth in response to the movement of materials under its surface. The greatest contributor to land subsidence is aquifer depletion. As groundwater is removed, the surface above may sink. Rocks may settle and pores may close close, which leaves less area for water to be stored. In areas where aquifers are replenished, the surface of Earth may subside and then return almost to its previous level. However, in areas where water is not pumped back into aquifers, subsidence is substantial and whole regions may sink. Human activites can contribute to land subsidence. These activities include the pumping of water, gas, and oil from underground reservoirs and the collapse of mine tunnels.

8 According to the passage, which of the following statements is not true?
A. Land subsidence is the settling or sinking of earth.
B. As groundwater is removed, the earth above may sink.
C. The greatest contributor to land subsidence is aquifer depletion.
D. Rocks settle and pores close, which leaves more area for water to be stored.

9 Which of the following statements can be inferred from the information in the passage?
F. Subsidence sinkholes occur most often in rural areas.
G. The majority of all subsidence sinkholes are formed through natural processes
H. Subsidence sinkholes form both naturally and because of the activities of humans.
I. Older sinkholes are easily recovered by refilling the area with water.

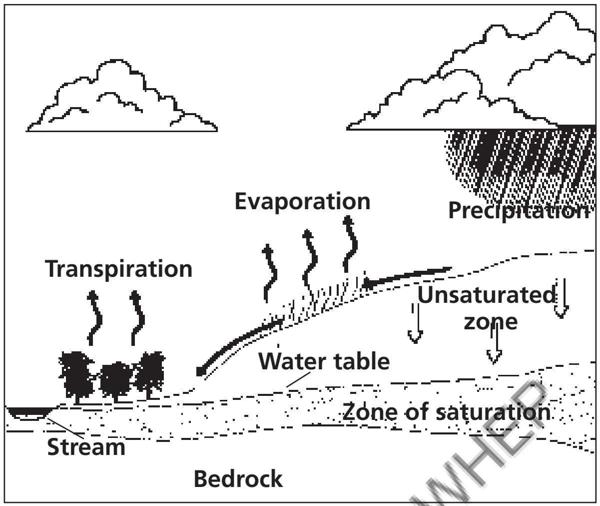
10 Subsidence due to groundwater depletion may occur slowly or very abruptly. Which type of subsidence presents a greater chance for recovery? Why?

Interpreting Graphics

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

This graphic shows an example of the water cycle. Use this graphic to answer question 11.

The Water Cycle

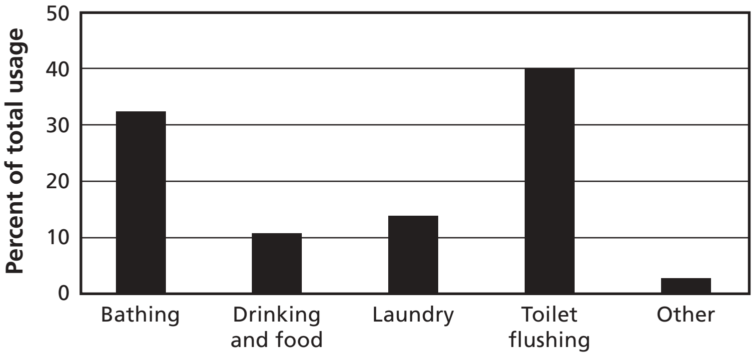


11 Which process occurs where the water table intersects the surface?

A. stream formation
B. runoff
C. groundwater movement
D. saturation

The graph below shows indoor water use for a typical family in the United States. Use this graph to answer questions 12 and 13.

Water Use for a Family of Four



12 According to the graph, what is the largest use of indoor water for a family in the United States? Name some ways that people can reduce the amount of water consumed by this task.

13 What total percentage of household indoor water is consumed by the two largest uses of indoor water? Round your answer to the nearest 10. How could this knowledge be used to help people reduce water usage?

Test TIP

Remember that if you can eliminate two of four answer choices, your chances of choosing the correct answer will double.

Chapter 16

Skills Practice Lab

Objectives

- USING SCIENTIFIC METHODS **Measure** the porosity of a given volume of beads for each of three samples: large beads, small beads, and a mix of large and small beads.
- **Describe** how particle size and sorting of a material affect porosity.

Materials

- beads, plastic, 4 mm (400)
- beads, plastic, 8 mm (200)
- beaker, 100 mL
- graduated cylinder, 100 mL

Safety

Porosity

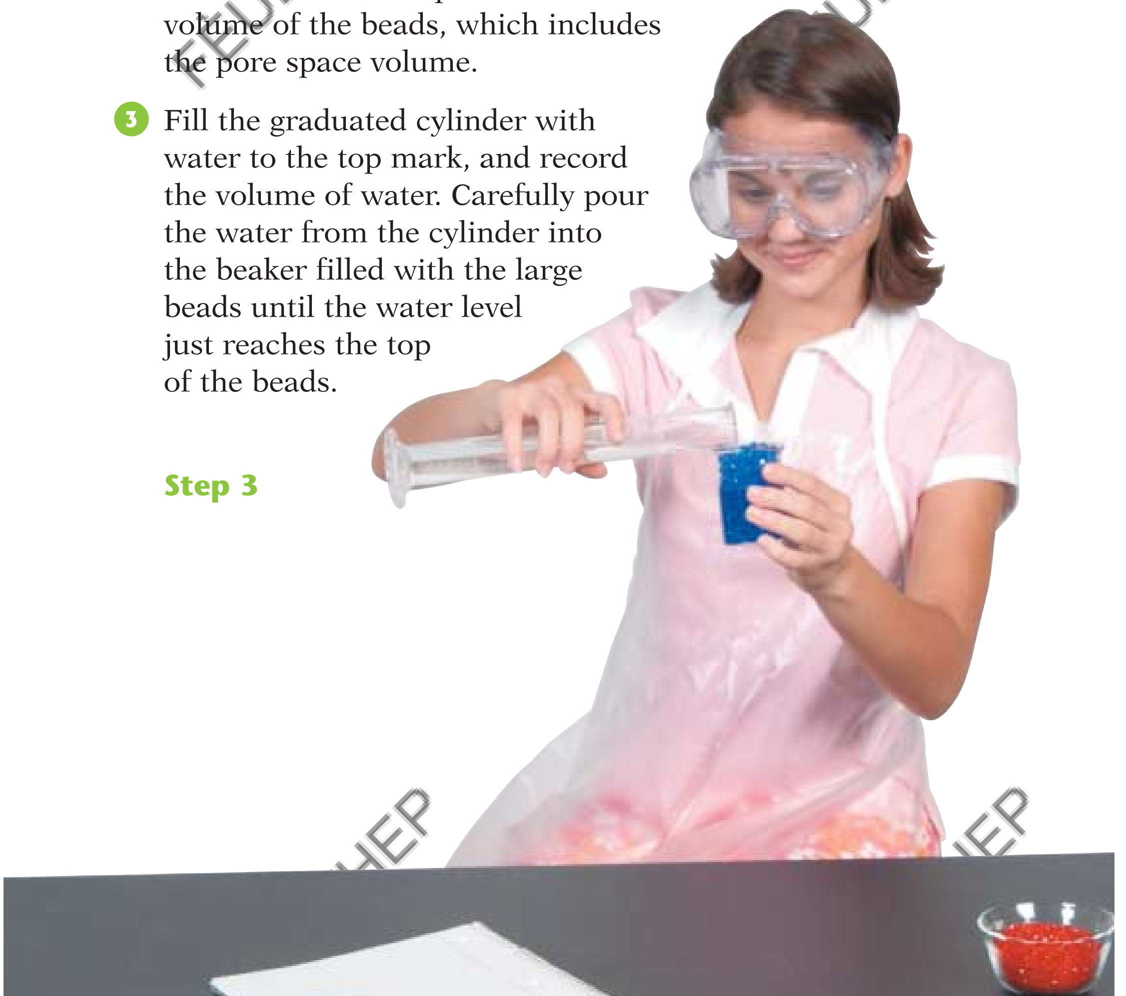
Whether soil is composed of coarse pieces of rock or very fine particles, some pore space remains between the pieces of solid material. Porosity is calculated by dividing the volume of the pore space by the total volume of the soil sample. Thus, if 50 cm^3 of soil contains 5.0 cm^3 of pore space, the porosity of the soil sample is

$$5.0\ cm^3/50\ cm^3 = 0.10 \times 100 = 10\%.$$

The result is generally written as a percentage. In this lab, you will measure and compare the porosity of three samples that represent rock particles.

PROCEDURE

1. Fill a beaker to the top with water. Pour the water into a graduated cylinder and record the volume of water.
2. Dry the beaker, and fill it to the top with large (8 mm) plastic beads. Gently tap the beaker to settle and compact the beads. Add more beads to fill the beaker until the beads are level with the top. Record the total volume of the beads, which includes the pore space volume.
3. Fill the graduated cylinder with water to the top mark, and record the volume of water. Carefully pour the water from the cylinder into the beaker filled with the large beads until the water level just reaches the top of the beads.



Step 3

4. To determine the amount of water that you added to the beaker, subtract the volume of water in the graduated cylinder from the volume that you recorded in step 3. This difference is the volume of the pore space between the beads. Record the volume of the pore space.
5. Calculate the porosity of the beads. Record the porosity as a decimal and as a percentage.
6. Repeat steps 2–5 using small (4 mm) beads.
7. Drain and dry both sets of beads. Mix together equal volumes of the small and large beads. Using the mixed-size beads, repeat steps 2–5.

Step 4

ANALYSIS AND CONCLUSION

1. **Analyzing Methods** Do the 8 mm beads in step 2 represent well-sorted large rock particles, well-sorted small rock particles, or unsorted rock particles?
2. **Analyzing Methods** Do the 4 mm beads in step 6 represent well-sorted large rock particles, well-sorted small rock particles, or unsorted rock particles?
3. **Analyzing Methods** Do the mixed beads in step 7 represent well-sorted or unsorted rock particles?
4. **Making Graphs** Compare the porosity of the large beads with the porosity of the small beads. Make a graph that shows bead size on the *x*-axis and porosity on the *y*-axis.
5. **Drawing Conclusions** In well-sorted sediment, does porosity depend on particle size? Explain your answer.
6. **Determining Cause and Effect** How did mixing the bead sizes affect the porosity? Explain the effect.

Extension

1. **Designing Experiments** How would mixing coarse gravel with fine sand affect the porosity of the gravel? Conduct an experiment to find out if your answer is correct.

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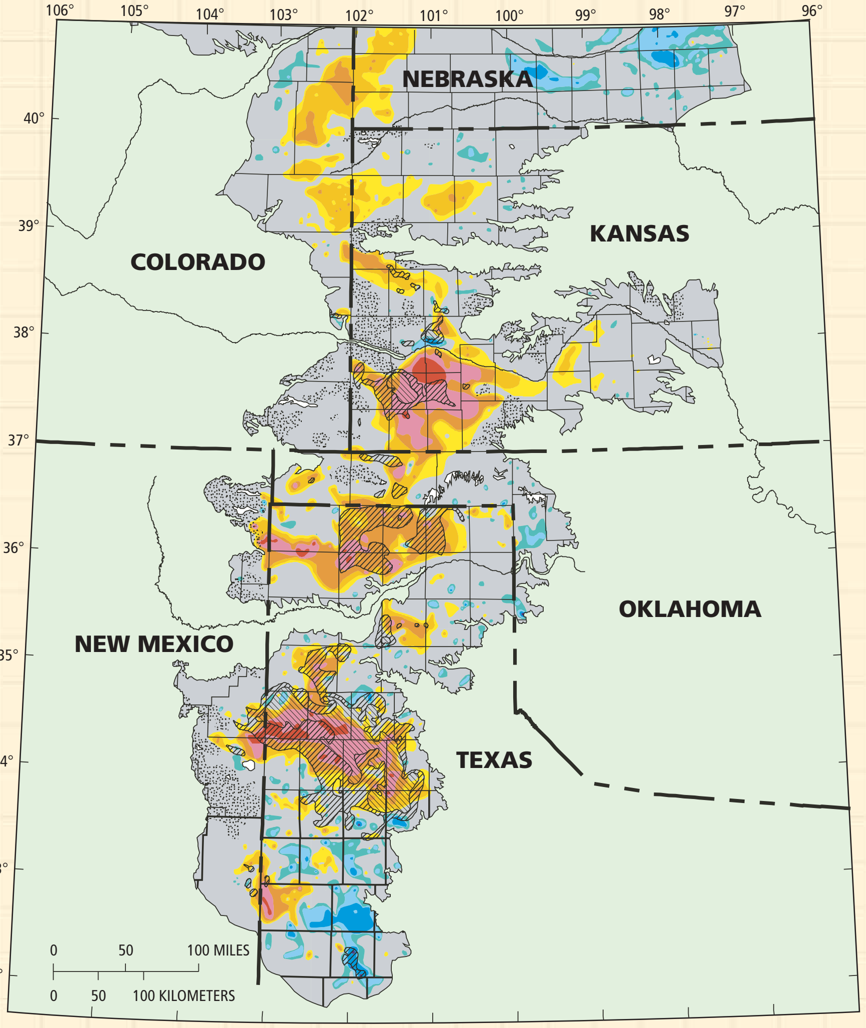
MAPS in Action

Water Level in the Southern Ogallala



Map Skills Activity

This map shows water-level change in regions of the Ogallala Aquifer, which supplies much of the drinking water in the midwestern United States. Use the map to answer the questions below.

1. **Using a Key** From predevelopment to 1980, how many areas had a decline in water level of 50 to 100 ft?
2. **Using a Key** From 1980 to 1999, how many areas had a decline in water level of more than 60 ft?
3. **Making Comparisons** Is the area in which the water level declined 50 to 100 ft before 1980 larger than or smaller than the area in which the water level declined more than 60 ft from 1980 to 1999?
4. **Identifying Trends** Has the overall amount of decline in the water-table level increased or decreased since 1980?
5. **Analyzing Relationships** What may have caused the trend that you identified in question 4? What may have changed between 1980 and 1999 that could account for the trend?

Disappearing Land

On May 8, 1981, in Winter Park, Florida, a resident saw a sycamore tree disappear. A sinkhole had swallowed the tree, and that disappearance was only the beginning.

When it first appeared, at about 8:00 P.M., the cone-shaped sinkhole was 13 m wide and 7 m deep. Overnight, the hole expanded to a diameter of 27 m. Before noon the next day, the hole expanded to a size of 300 m in diameter—the size of a football field—and 37 m deep. In the process, it consumed about 160,000 m^3 of ground.

The Winter Park Sinkhole

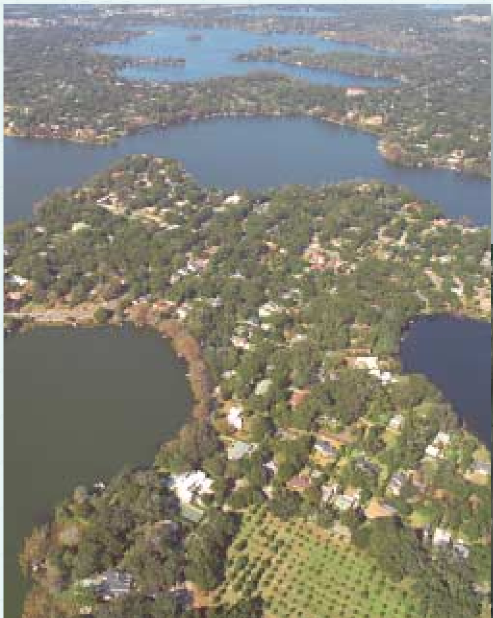
This destructive sinkhole resulted from a combination of natural processes and human activities. Collapse sinkholes, such as the one in Winter Park, occur when the sediment overlying a cavern collapses into a cavity formed by groundwater. However, the rapid expansion of this sinkhole may have been the result of the collapse of the cavern roof. Such a collapse may have resulted from the removal of too much water from an aquifer that was already depleted after a two-year drought.

The Money Pit

Eventually, the Winter Park sinkhole swallowed up several houses, part of a four-lane highway, a swimming pool, a parking lot, five cars, and a truck. The cost of the damage reached about $2 million. When the sinkhole finally stabilized, the city of Winter Park turned the hole into a municipal lake.

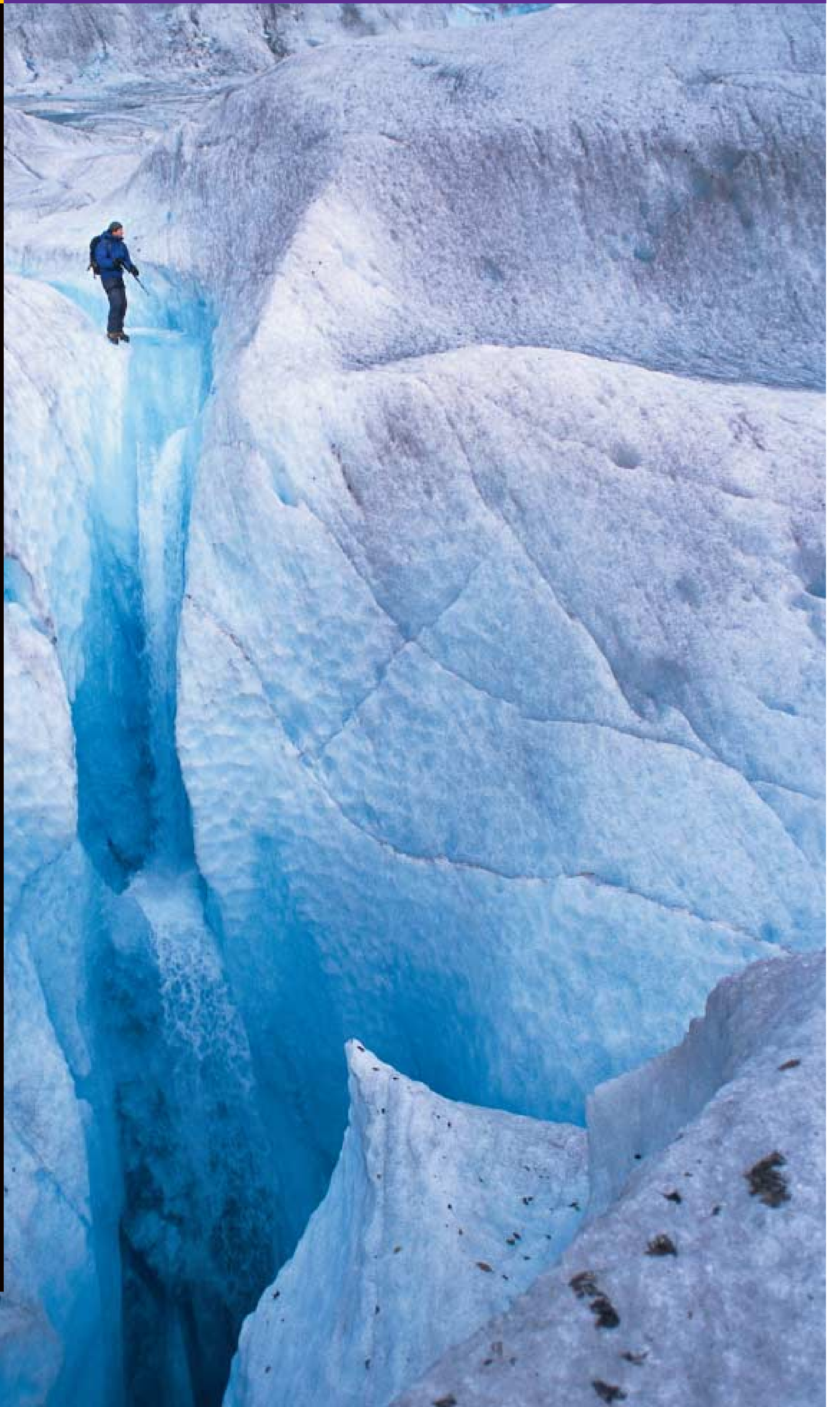
Extension

1. **Applying Ideas** What might Winter Park residents do to prevent the formation of more sinkholes?



▲ Florida's landscape is dotted with small sinkhole lakes.

Chapter 17 Glaciers



Sections

What You'll Learn

- How glaciers form and move
- What landforms glaciers create
- What factors drive glacial cycles

Why It's Relevant

Earth's surface was reshaped by glaciers during the last glacial period. Glaciers provide information about past and present climates and are key indicators of current climatic change.

PRE-READING ACTIVITY

FOLDNOTES

Double Door Before you read the chapter, create the **FoldNote** entitled "Double Door" described in the Skills Handbook section of the Appendix. Write "Alpine glaciers" on one flap of the double door and "Continental glaciers" on the other flap. As you read the chapter, write the characteristics of each type of glacier under the appropriate flap.

▶ The brilliant blue color of Alaska's Mendenhall Glacier is characteristic of glacial ice. Ice crystals in the glacier scatter more blue light than any other color, which makes the ice look blue.

ENVIRONMENTAL CONNECTION

Section 1 Glaciers: Moving Ice

A single snowflake is lighter than a feather. However, if you squeeze a handful of snow, you make a firm snowball. In a process similar to making a snowball, natural forces compact snow to make a large mass of moving ice called a **glacier.**

Formation of Glaciers

At high elevations and in polar regions, snow may remain on the ground all year and form an almost motionless mass of permanent snow and ice called a *snowfield*. Snowfields form as ice and snow accumulate above the snowline. The *snowline* is the elevation above which ice and snow remain throughout the year, as shown in **Figure 1.**

Average temperatures at high elevations and in polar regions are always near or below the freezing point of water. So, snow that falls there accumulates year after year. Cycles of partial melting and refreezing change the snow into grainy ice called *firn*.

In deep layers of snow and firn, the pressure of the overlying layers flattens the ice grains and squeezes the air from between the grains. The continued buildup of snow and firn forms a glacier that moves downslope or outward under its own weight.

The size of a glacier depends on the amount of snowfall received and the amount of ice lost. When new snow is added faster than ice and snow melt, the glacier gets bigger. When the ice melts faster than snow is added, the glacier gets smaller. Small differences in average yearly temperatures and snowfall may upset the balance between snowfall and ice loss. Thus, changes in the size of a glacier may indicate climatic change.

OBJECTIVES

- **Describe** how glaciers form.
- **Compare** two main kinds of glaciers.
- **Explain** two processes by which glaciers move.
- **Describe** three features of glaciers.

KEY TERMS

glacier
alpine glacier
continental glacier
basal slip
internal plastic flow
crevasse

glacier a large mass of moving ice

Figure 1 ▶ The snowline on the Grand Teton Mountains at Grand Teton National Park, Wyoming, is more than 3000 m above sea level.

Figure 2 ▶ An alpine glacier (above) descends through Thompson Pass in Alaska. A continental glacier (right) covers much of the land surface in Greenland.

alpine glacier a narrow, wedge-shaped mass of ice that forms in a mountainous region and that is confined to a small area by surrounding topography; examples include valley glaciers, cirque glaciers, and piedmont glaciers

continental glacier a massive sheet of ice that may cover millions of square kilometers, that may be thousands of meters thick, and that is not confined by surrounding topography

Types of Glaciers

The two main categories used to classify glaciers are alpine and continental. An **alpine glacier** is a narrow, wedge-shaped mass of ice that forms in a mountainous region and that is confined to a small area by surrounding topography, as shown in **Figure 2.** Alpine glaciers are located in Alaska, the Himalaya Mountains, the Andes, the Alps, and New Zealand.

Continental glaciers are massive sheets of ice that may cover millions of square kilometers, that may be thousands of meters thick, and that are not confined by surrounding topography, as shown in **Figure 2.** Today, continental glaciers, also called *ice sheets*, exist only in Greenland and Antarctica. The Antarctic ice sheet covers an area of more than 13 million km^2 and is more than 4,000 m thick in some places. The Greenland ice sheet covers 1.7 million km^2 of land, and its maximum thickness is more than 3,000 m. If these ice sheets melted, the water they contain would raise the worldwide sea level by more than 80 m.

Reading Check **Where can you find continental glaciers today? (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: Glaciers

SciLinks code: HQ60675

Movement of Glaciers

Glaciers are sometimes called “rivers of ice.” Gravity causes both glaciers and rivers to flow downward. However, glaciers and rivers move in different ways. Unlike water in a river, glacial ice cannot move rapidly or flow easily around barriers. In a year, some glaciers may travel only a few centimeters, while others may move a kilometer or more. Glaciers move by two basic processes—basal slip and internal plastic flow.

Basal Slip

One way that glaciers move is by slipping over a thin layer of water and sediment that lies between the ice and the ground. The weight of the ice in a glacier exerts pressure that lowers the melting point of ice. As a result, the ice melts where the glacier touches the ground. The water mixes with sediment at the base of the glacier. This mixture acts as a lubricant between the ice and the underlying surface. The process that lubricates a glacier's base and causes the glacier to slide forward is called **basal slip.**

Basal slip also allows a glacier to work its way over small barriers in its path by melting and then refreezing. For example, if the ice pushes against a rock barrier, the pressure causes some of the ice to melt. The water from the melted ice travels around the barrier and freezes again as the pressure is removed.

basal slip the process that causes the ice at the base of a glacier to melt and the glacier to slide

internal plastic flow the process by which glaciers flow slowly as grains of ice deform under pressure and slide over each other

Internal Plastic Flow

Glaciers also move by a process called **internal plastic flow.** In this process, pressure deforms grains of ice under a glacier. As the grains deform, they slide over each other and cause the glacier to flow slowly. However, the rate of internal plastic flow varies for different parts of a glacier, as shown in **Figure 3.** The slope of the ground and the thickness and temperature of the ice determine the rate at which ice flows at a given point. The edges of a glacier move more slowly than the center because of friction with underlying rock. For this same reason, a glacier moves more quickly near its surface than near its base.

QuickLAB 15 min

Slipping Ice

Procedure

1. Squeeze flat a handful of **snow** or **shaved ice** until you notice a change in the particles.
2. Place the squeezed ice on a **tray.** Place a **heavy weight** on the squeezed ice.
3. Lift one end of the tray to a 30° incline, and record your observations.

Analysis

1. What does squeezing do to the particles of snow or ice?
2. How is squeezing the snow or ice similar to the formation of a glacier?
3. What did you observe when you placed the squeezed ice on the tray? What glacial movement process is modeled here?

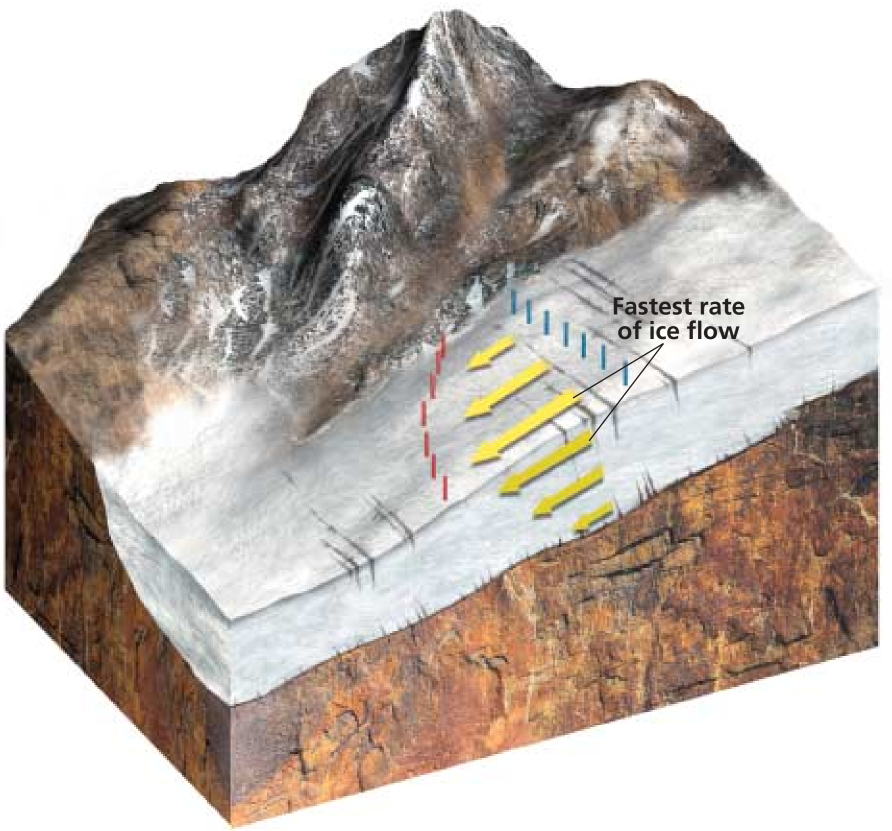
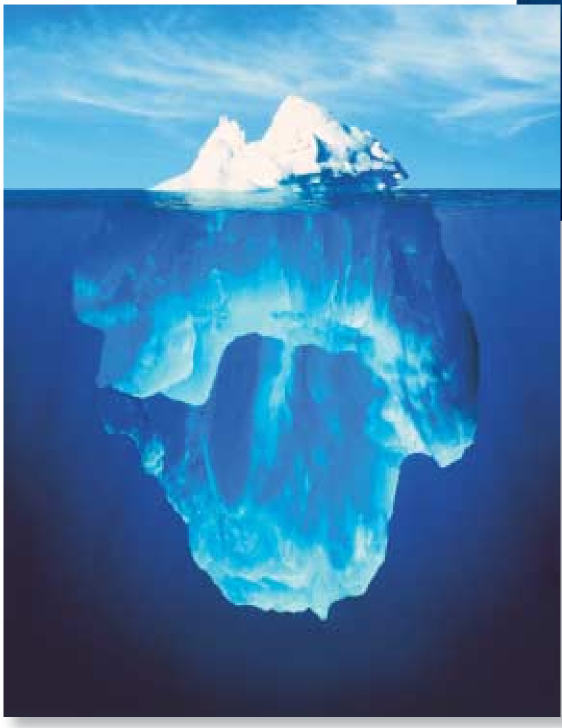


Figure 3 ▶ A line of blue stakes driven into a alpine glacier moves to the position of the red stakes as the glacier flows. This measurement shows that the central part of the glacier moves faster than its edges.

Figure 4 ▶ Crevasses (right) are large cracks in a glacier. The composite photograph below shows what an iceberg might look like if you could see the entire iceberg.



crevasse in a glacier, a large crack or fissure that results from ice movement

Features of Glaciers

While the interior of a glacier moves by internal plastic flow and the entire glacier moves by basal slip, the low pressure on the surface ice causes the surface ice to remain brittle. The glacier flows unevenly beneath the surface, and regions of tension and compression build under the brittle surface. As a result, large cracks, called **crevasses** (kruh VAS uhz), form on the surface, as shown in **Figure 4.** Some crevasses may be as deep as 50 m!

Continental glaciers move outward in all directions from their centers toward the edges of their landmasses. Some parts of the ice sheets may move out over the ocean and form *ice shelves*. When the tides rise and fall, large blocks of ice, called *icebergs,* may break from the ice shelves and drift into the ocean. Because most of an iceberg is below the surface of the water, as shown in **Figure 4,** icebergs pose a hazard to ships. The area above water of one of the largest icebergs ever observed in the Antarctic was twice the size of Connecticut!

Section 1 Review

1. **Identify** two regions in which snow accumulates year after year.
2. **Describe** the process by which glaciers form.
3. **Compare** an alpine glacier and a continental glacier.
4. **Explain** how internal plastic flow and basal slip move glaciers.
5. **Describe** two features of glaciers.
6. **Compare** a glacier and a snowfield.
7. **Explain** how a crevasse forms.

CRITICAL THINKING

8. **Making Inferences** If glaciers could move only by internal plastic flow, what might happen to the rate at which glaciers move? Explain your answer.
9. **Identifying Relationships** How can changes in the size of a glacier indicate climate change?
10. **Analyzing Ideas** If icebergs are visible at sea level, why do they pose a hazard to ships?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *glacier, firn, snowline, snowfield, alpine glacier, continental glacier, basal slip, internal plastic flow, ice shelf, iceberg,* and *crevasse.*

Section 2 Glacial Erosion and Deposition

Many of the landforms in Canada and in the northern United States were created by glaciers. Large lakes, solitary boulders on flat plains, and jagged ridges are just a few examples of landforms created by glaciers. Glaciers created these landforms through the processes of erosion and deposition.

OBJECTIVES

- **Describe** the landscape features that are produced by glacial erosion.
- **Name** and describe five features formed by glacial deposition.
- **Explain** how glacial lakes form.

KEY TERMS

cirque
arête
horn
erratic
glacial drift
till
moraine
kettle
esker

Glacial Erosion

Like rivers, glaciers are agents of erosion. Both a river and a glacier can pick up and carry rock and sediment. However, because of the size and density of glaciers, landforms that result from glacial action are very different from those that rivers form. For example, deep depressions in rock form when a moving glacier loosens and dislodges, or plucks, a rock from the bedrock at the base or side of the glacier. The rock plucked by the glacier is then dragged across the bedrock and causes abrasions. As shown in **Figure 1,** long parallel grooves in the bedrock are left behind and show the direction of the glacier's movement.

Figure 1 ▶ As a glacier moves, it picks up and carries rocks from the bedrock. These grooves at Kelly's Island in Ohio were carved by a glacier 35,000 years ago.

7811

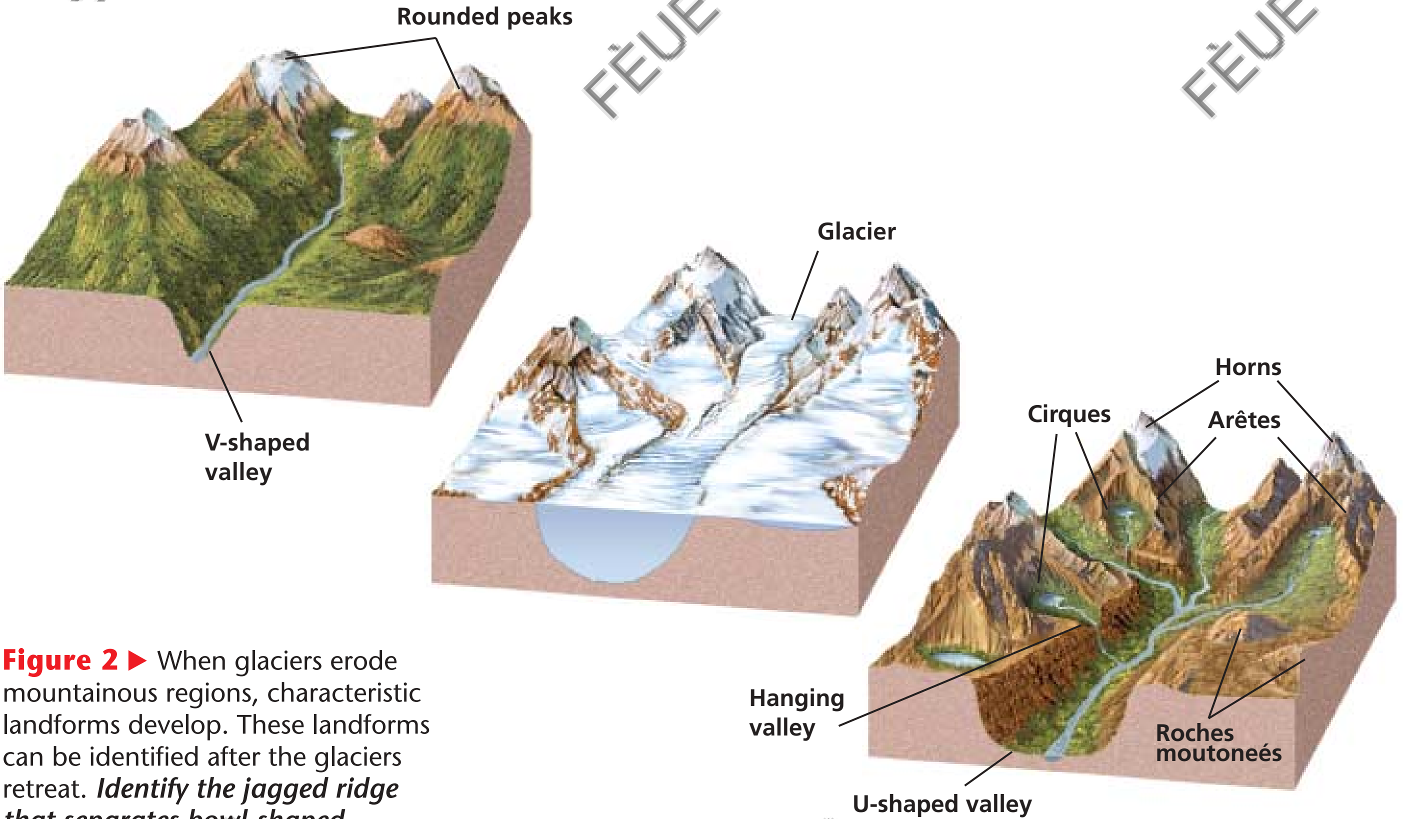


Figure 2 ▶ When glaciers erode mountainous regions, characteristic landforms develop. These landforms can be identified after the glaciers retreat. ***Identify the jagged ridge that separates bowl-shaped depressions.***

Landforms Created by Glacial Erosion

Glaciers have shaped many mountain ranges and have created unique landforms by erosive processes. The glacial processes that change the shape of mountains begin in the upper end of the valley where an alpine glacier forms. As a glacier moves through a narrow, V-shaped river valley, rock from the valley walls breaks off and the walls become steeper. The moving glacier also pulls blocks of rock from the floor of the valley. These actions create a bowl-shaped depression called a **cirque** (SUHRK). A sharp, jagged ridge called an **arête** (uh RAYT) forms between cirques. When several arêtes join, they form a sharp, pyramid-like peak called a **horn,** as shown in **Figure 2.**

As the glacier flows down through an existing valley, the glacier picks up large amounts of rock. These rock fragments, which range in size from microscopic particles to large boulders, become embedded in the ice.

Rock particles embedded in the ice may polish solid rock as the ice moves over the rock. Large rocks carried by the ice may gouge deep grooves in the bedrock. Glaciers may also round large rock projections. These rounded projections usually have a smooth, gently sloping side facing the direction from which the glacier came. The other side is steep and jagged because rock is pulled away as the ice passes. The resulting rounded knobs of rock are called *roches moutonnées* (ROHSH MOO tuh NAY), which means "sheep rocks" in French.

cirque a deep and steep bowl-like depression produced by glacial erosion

arête a sharp, jagged ridge that forms between cirques

horn a sharp, pyramid-like peak that forms because of the erosion of cirques

Reading Check **How does a glacier form a cirque? (See the Appendix for answers to Reading Checks.)**

U-Shaped Valleys

A stream forms the V shape of a valley. As a glacier scrapes away a valley's walls and floor, this original V shape becomes a U shape, as shown in **Figure 3.** Because glacial erosion is the only way by which U-shaped valleys form, scientists can use this feature to determine whether a valley has been glaciated in the past.

Small tributary glaciers in adjacent valleys may flow into a main alpine glacier. Because a small tributary glacier has less ice and less cutting power than the main alpine glacier does, the small glacier's U-shaped valley is not cut as deeply into the mountains. When the ice melts, the tributary valley is suspended high above the main valley floor and is called a *hanging valley*. When a stream flows from a hanging valley, a waterfall forms.

Figure 3 ▶ Jollie Valley, a U-shaped glaciated valley, is located in the Southern Alps of New Zealand.

Erosion by Continental Glaciers

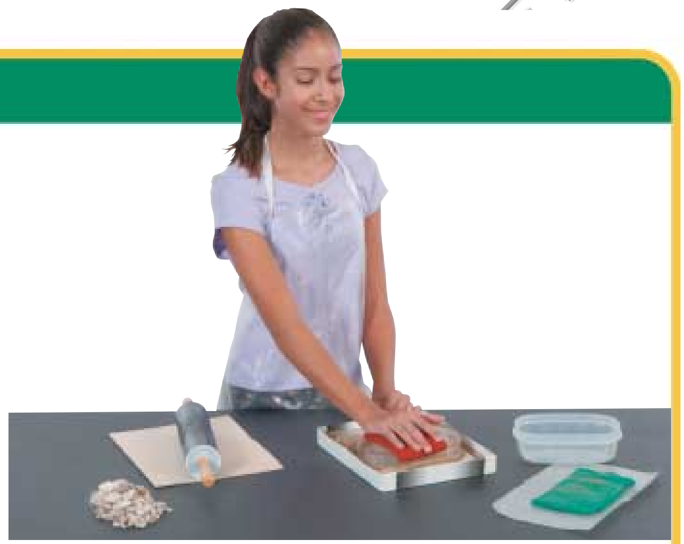
The landscape eroded by continental glaciers differs from the sharp, rugged features eroded by alpine glaciers. Continental glaciers erode by leveling landforms to produce a smooth, rounded landscape. Continental glaciers smooth and round exposed rock surfaces in a way similar to the way that bulldozers flatten landscapes. Rock surfaces are also scratched and grooved by rocks carried at the base of the ice sheet. These scratches and grooves are parallel to the direction of glacial movement.

Quick LAB 25 min

Glacial Erosion

Procedure

1. Put a **mixture of sand, gravel,** and **rock** in the bottom of a **15 cm × 10 cm × 5 cm plastic container.** Fill the container with **water** to a depth of about 4 cm. Freeze the container until the water is solid. Remove the **ice block** from the container.
2. Use a **rolling pin** or **large dowel** to flatten some **modeling clay** into a rectangle about 20 cm × 10 cm × 1 cm.
3. Grasp the ice block firmly with a **hand towel.** Place the block with the gravel-and-rock side down at one end of the clay. Press down on the ice block, and push it along the length of the flat clay surface.
4. Sketch the pattern made in the clay by the ice block.
5. Next, press a 2 cm layer of **damp sand** into the bottom of a **shallow, rectangular box.** As in step 3, push the ice block along the surface of the sand, but press down lightly.
6. Repeat steps 3 and 4, but use a **soft, wooden board** in place of the clay.



Analysis

1. Describe the effects of the ice block on the clay, on the sand, and on the wood.
2. Did any clay, sand, or wood become mixed with material from the ice block? Did the ice deposit material on any surface?
3. What glacial land features are represented by the features of the clay model? the sand model? the wood model?

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Glacial Deposition

Glaciers are also agents of deposition. Deposition occurs when a glacier melts. A glacier will melt if it reaches low, warm elevations or if the climate becomes warmer. As the glacier melts, it deposits all of the material that it has accumulated, which may range in size from fine sediment to large rocks.

Large rocks that a glacier transports from a distant source are called **erratics.** Because a glacier carries an erratic a long distance, the composition of an erratic usually differs from that of the bedrock over which the erratic lies.

Various other landforms develop as glaciers melt and deposit sediment, as shown in **Figure 4.** The general term for all sediments deposited by a glacier is **glacial drift.** Unsorted glacial drift that is deposited directly from a melting glacier is called the **till.** Till is composed of sediments from the base of the glacier and is commonly left behind when glacial ice melts. Another type of glacial drift is stratified drift. *Stratified drift* is material that has been sorted and deposited in layers by streams flowing from the melted ice, or *meltwater*.

erratic a large rock transported from a distant source by a glacier

glacial drift rock material carried and deposited by glaciers

till unsorted rock material that is deposited directly by a melting glacier

Figure 4 ▶ Moraines, glacial lakes, drumlins, meltwater streams, and outwash plains are some examples of landforms created by glacial deposition.

Till Deposits

Landforms that result when a glacier deposits till are called *moraines*. **Moraines** are ridges of unsorted sediment on the ground or on the glacier itself. There are several types of moraines, as shown in **Figure 4.** A *lateral moraine* is a moraine that is deposited along the sides of an alpine glacier, usually as a long ridge. When two or more alpine glaciers join, their adjacent lateral moraines combine to form a *medial moraine*.

The unsorted material left beneath the glacier when the ice melts is the *ground moraine*. The soil of a ground moraine is commonly very rocky. An ice sheet may mold ground moraine into clusters of drumlins. *Drumlins* are long, low, tear-shaped mounds of till. The long axes of the drumlins are parallel to the direction of glacial movement.

Terminal moraines are small ridges of till that are deposited at the leading edge of a melting glacier. These moraines have many depressions that may contain lakes or ponds. Large terminal moraines, some of which are more than 100 km long, can be seen across the Midwest, especially south of the Great Lakes.

Reading Check **Which glacial deposit is a tear-shaped mound of sediment? (See the Appendix for answers to Reading Checks.)**

moraine a landform that is made from unsorted sediments deposited by a glacier

Graphic Organizer **Spider Map**

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

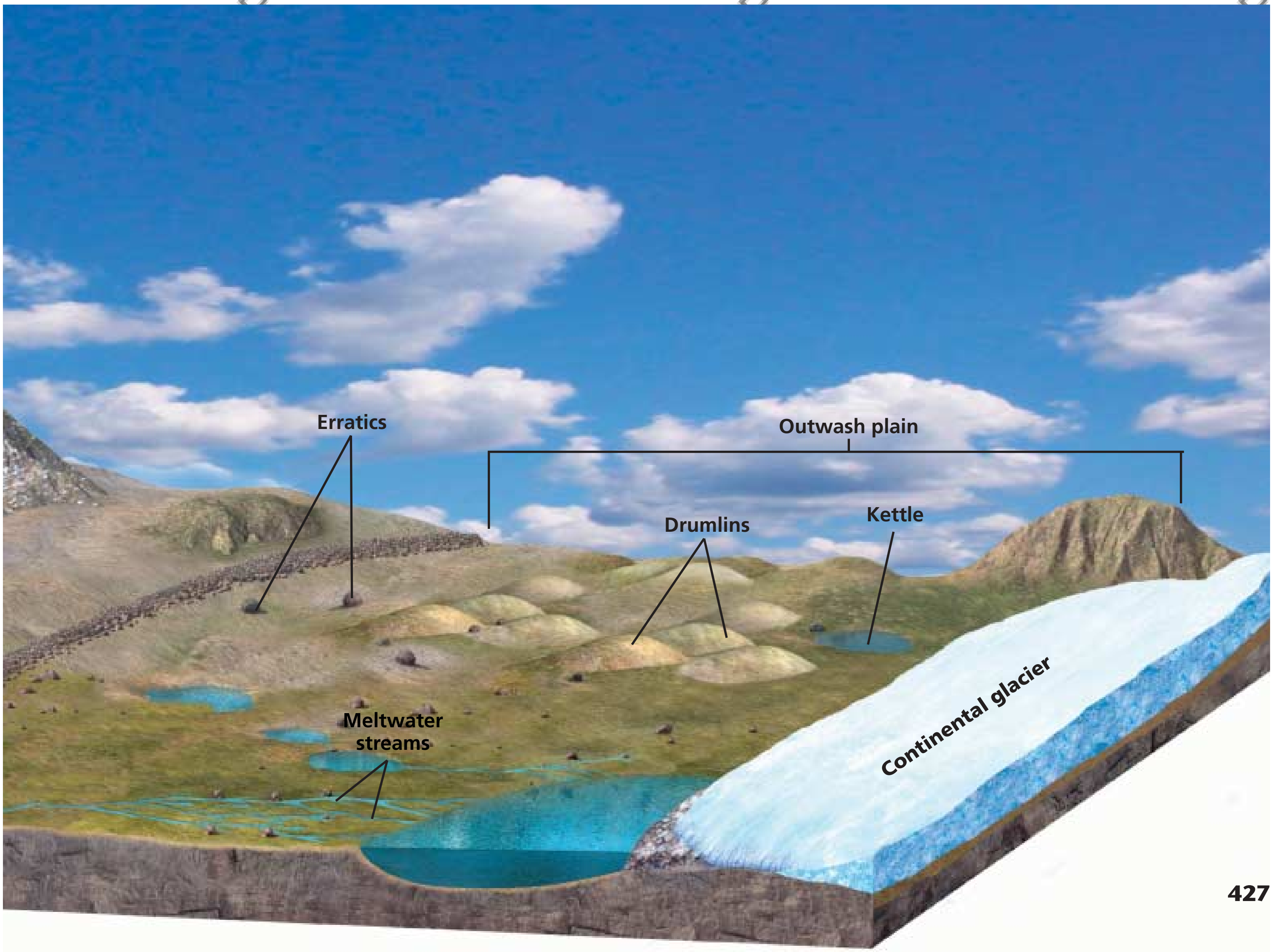

Figure 5 ▶ This kettle lake in Saskatchewan, Canada, formed as a result of glacial deposition.

Outwash Plains

When a glacier melts, streams of meltwater flow from the edges, the surface, and beneath the glacier. Glacial meltwater may have beautiful colors, such as milky white, emerald green, or turquoise blue, because it carries very fine sediment. The meltwater carries drift as well as rock particles and deposits them in front of the glacier as a large outwash plain. An *outwash plain* is a deposit of stratified drift that lies in front of a terminal moraine and is crossed by many meltwater streams.

kettle a bowl-like depression in a glacial drift deposit

esker a long, winding ridge of gravel and coarse sand deposited by glacial meltwater streams

Kettles

Most outwash plains are pitted with depressions called **kettles.** A kettle forms when a chunk of glacial ice is buried in drift. As the ice melts, a cavity forms in the drift. The drift collapses into the cavity and produces a depression. Kettles commonly fill with water to form kettle lakes, such as the one shown in **Figure 5.**

Eskers

When continental glaciers recede, **eskers** (ES kuhrz)—long, winding ridges of gravel and sand—may be left behind. These ridges consist of stratified drift deposited by streams of meltwater that flow through ice tunnels within the glaciers. Eskers may extend for tens of kilometers, like raised, winding roadways.

Reading Check How do eskers form? (See the Appendix for answers to Reading Checks.)

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Glacial Lakes

Lake basins commonly form where glaciers erode surfaces and leave depressions in the bedrock. Thousands of lake basins in Canada and the northern United States were gouged from solid rock by a continental glacier. Thousands of other glacial lakes form as a result of deposition rather than as a result of erosion. Many lakes form in the uneven surface of ground moraine deposited by glaciers. These lakes exist in many areas of North America and Europe.

Long, narrow *finger lakes,* such as those in western New York, form where terminal and lateral moraines block existing streams. The area south of the Great Lakes, from Minnesota to Ohio, has belts of moraines and lakes. Minnesota, also called the “Land of 10,000 Lakes,” was completely glaciated and has evidence of all types of glacial lakes.

Figure 6 ▶ Many streams and rivers carry dissolved minerals to the Great Salt Lake in Utah. However, because there is no outlet, the lake becomes concentrated with these minerals as continual evaporation removes water.

Formation of Salt Lakes

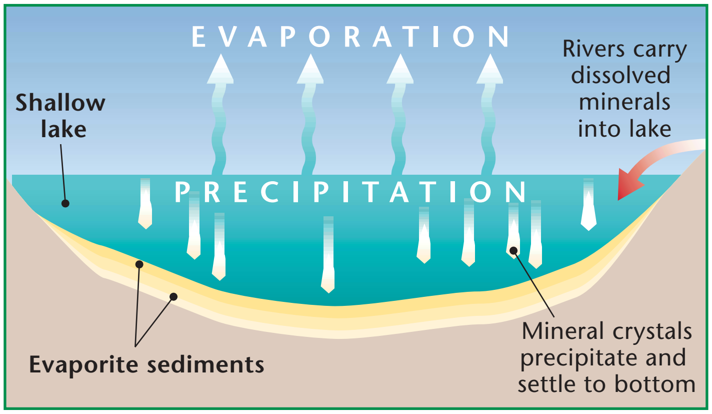
Many lakes existed during the last glacial advance. But because of topographic and climatic changes, outlet streams no longer leave these lakes. Water leaves the lakes only by evaporation. When the water evaporates, salt that was dissolved in the water is left behind, which makes the water increasingly salty. Salt lakes, such as the one shown in **Figure 6,** commonly form in dry climates, where evaporation is rapid and precipitation is low.

Connection to CHEMISTRY

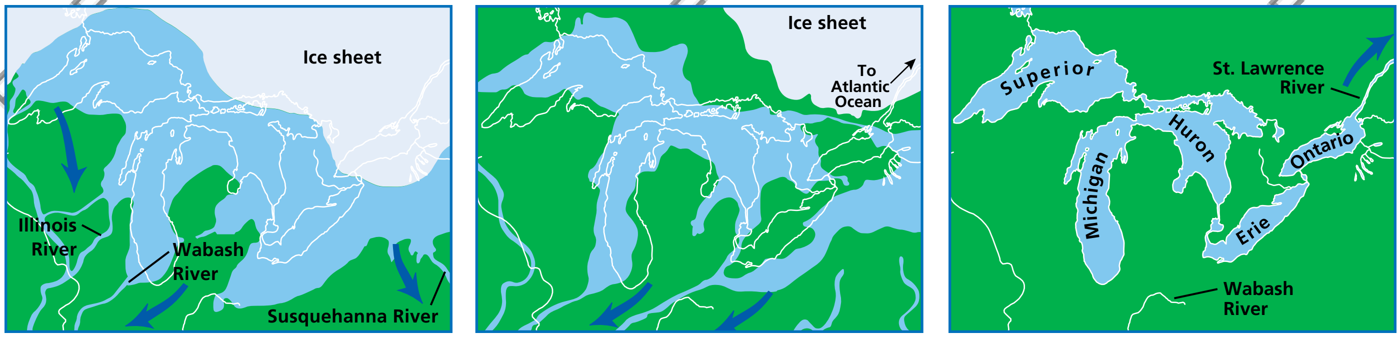
Precipitation of Minerals

Salt lakes form when a high rate of evaporation removes only water from the lake and leaves the dissolved minerals, such as salt, in the lake. Water can dissolve a limited amount of minerals. Therefore, when the concentration of minerals in the lake water becomes too high, the minerals crystallize in a process called *precipitation*. The crystallized minerals then settle to the bottom of the lake.

The minerals that precipitate from evaporating water are called *evaporites*. Common evaporite minerals include halite, or salt (NaCl); gypsum ($CaSO_4 \bullet 2H_2O$); calcite ($CaCO_3$); and borax ($Na_2B_4O_7 \bullet 10H_2O$).



When the minerals settle out of the water, the concentration of chemicals in the water changes. This change in concentration causes different minerals to precipitate at different times. The first minerals to precipitate as water evaporates are carbonates, such as calcite. Continued evaporation leads to the formation of gypsum. Finally, salts such as halite begin to form. This process leads to the characteristic sequences of mineral deposits found in natural salt formations.



Early Ice Retreat The ice sheet that covered the northern part of North America formed enormous lakes.

Late Ice Retreat As the ice sheet retreated, the lakes became smaller and the drainage pattern changed.

Today's Great Lakes Uplifting of the land reduced the Great Lakes to their present sizes.

Figure 7 ▶ The Great Lakes in the northern United States were formed by a massive continental glacier.

History of the Great Lakes

The Great Lakes of North America formed as a result of erosion and deposition by a continental glacier, as shown in **Figure 7.** Glacial erosion widened and deepened existing river valleys. Moraines to the south blocked off the ends of these valleys. As the ice sheet melted, the meltwater was trapped in the valleys by the moraines and lakes formed.

In their early stages, the lakes emptied to the south into the Wabash and Illinois Rivers, which flowed into the Mississippi River. Later, the lakes grew larger and also drained into the Atlantic Ocean through the Susquehanna, Mohawk, and Hudson River valleys.

After the glacial period, the crust rose as the weight of the ice was removed. The lake beds uplifted and shrank. The uplift of the land caused the lakes to drain to the northeast through the St. Lawrence River. As a result of this northeasterly flow, Niagara Falls formed between Lake Erie and Lake Ontario.

Section 2 Review

1. **Describe** the following landscape features: a cirque, an arête, and a horn.
2. **List** five features that form by glacial deposition.
3. **Explain** how terminal and lateral moraines can form glacial lakes.
4. **Compare** the process of glacial deposition with the process of glacial erosion.
5. **Describe** how a kettle forms.
6. **Explain** how an alpine glacier can change the topography of a mountainous area.
7. **Compare** the process of erosion by glaciers with the process of erosion by rivers.

CRITICAL THINKING

8. **Making Comparisons** Compare the processes that form ground moraines with the processes that form eskers.
9. **Analyzing Predictions** On a field trip, you find rock that has long, parallel grooves. Form a hypothesis that explains this feature. What other landforms would you try to find to test this hypothesis?
10. **Making Comparisons** Compare glacial sediment deposited directly by glacial ice with the sediment deposited by glacial meltwater.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *cirque, stratified drift, roches moutonnées, moraine, till, glacial drift, kettle, outwash plains,* and *glacier*.

Section 3 Ice Ages

Today, continental glaciers are located mainly in latitudes near the North and South Poles. However, thousands of years ago, ice sheets covered much more of Earth's surface. An **ice age** is a long period of climatic cooling during which the continents are glaciated repeatedly. Several major ice ages have occurred during Earth's geologic history, as shown in **Figure 1.** The earliest known ice age began about 800 million years ago. The most recent ice age began about 4 million years ago. The last advance of this ice age's massive ice sheets started to retreat about 15,000 years ago. Ice ages probably begin with a long, slow decrease in Earth's average temperatures. A drop in average global temperature of only about 5°C may be enough to start an ice age.

OBJECTIVES

- **Describe** glacial and interglacial periods within an ice age.
- **Summarize** the theory that best accounts for the ice ages.

KEY TERMS

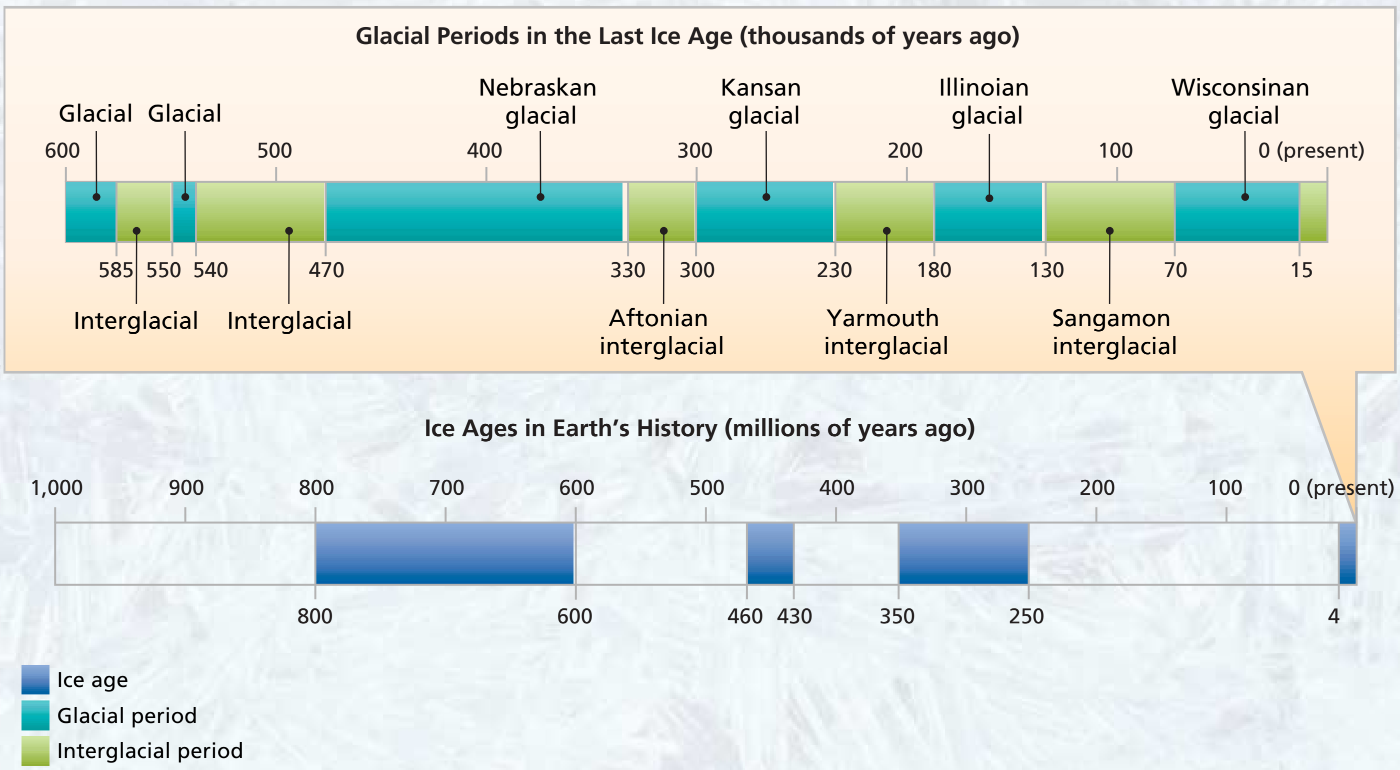
ice age
Milankovitch theory

ice age a long period of climatic cooling during which the continents are glaciated repeatedly

Glacial and Interglacial Periods

Continental glaciers advance and retreat several times during an ice age. The ice sheets advance during colder periods and retreat during warmer periods. A period of cooler climate that is characterized by the advancement of glaciers is called a *glacial period*. A period of warmer climate that is characterized by the retreat of glaciers is called an *interglacial period*. Currently, Earth is in an interglacial period of the most recent ice age.

Figure 1 ▶ Glacial and Interglacial Periods



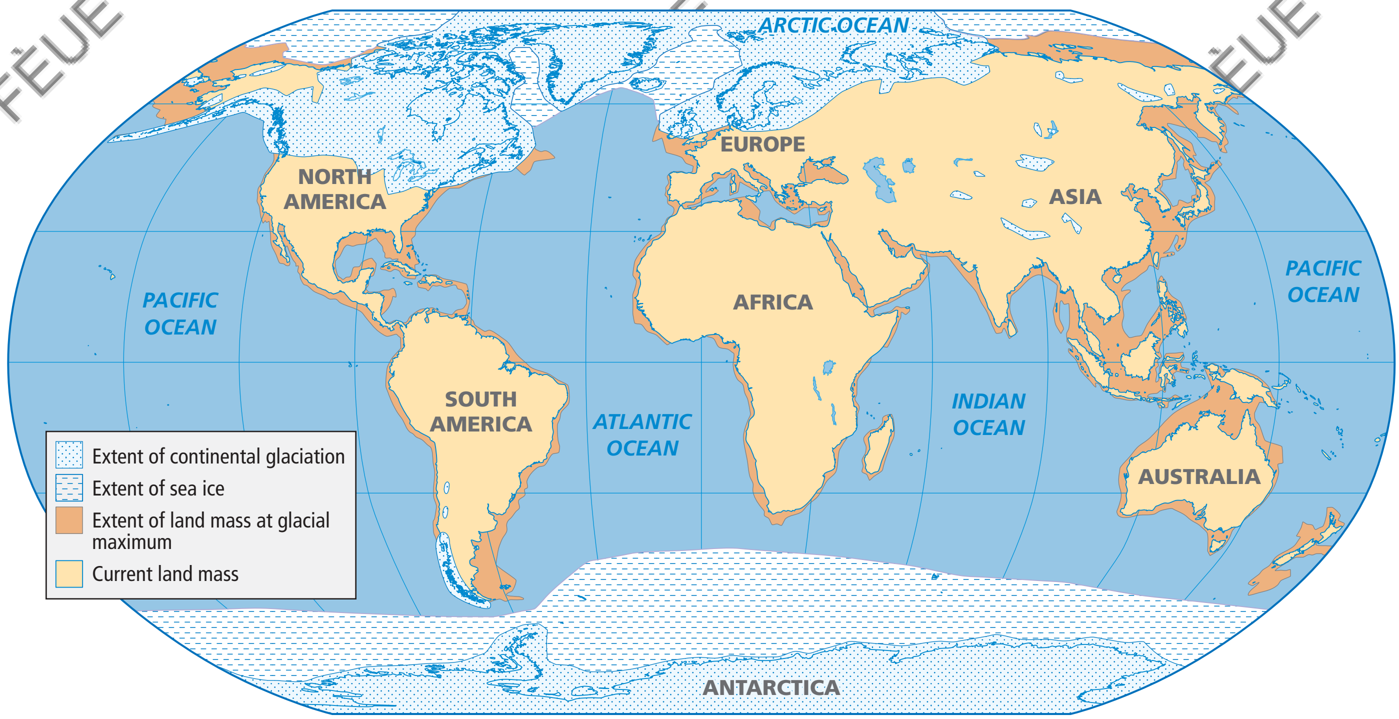


Figure 2 ▶ During the last glacial period, about 30% of Earth's surface was covered with ice.

Glaciation in North America

Glaciers covered about one-third of Earth's surface during the last glacial period. Most glaciation took place in North America and Eurasia. In some parts of North America, the ice was several kilometers thick. So much water was locked in ice during the last glacial period that sea level was as much as 140 m lower than it is today. As a result, the coastlines of the continents extended farther than they do today, as shown in **Figure 2.**

Canada and the mountainous regions of Alaska were buried under ice. In the mountains of the western United States, numerous small alpine glaciers joined to form larger glaciers. These large glaciers flowed outward from the Rocky Mountains and the Cascade and Sierra Nevada Ranges. A great continental ice sheet that was centered on what is now the Hudson Bay region of Canada spread as far south as the Missouri and Ohio Rivers.

Reading Check **How did glaciation in the last glacial period affect the sea level? (See the Appendix for answers to Reading Checks.)**

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

Topic: Ice Ages
SciLinks code: HQ60781

Glaciation in Eurasia and the Southern Hemisphere

In Europe, a continental ice sheet that was centered on what is now the Baltic Sea spread south over Germany, Belgium, and the Netherlands and west over Great Britain and Ireland. It flowed eastward over Poland and Russia. Long alpine glaciers formed in the Alps and the Himalayas. A continental ice sheet formed in Siberia. In the Southern Hemisphere, the Andes Mountains in South America and much of New Zealand were covered by mountainous ice fields and alpine glaciers. Many land features that formed during the last glacial period are still recognizable.

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Causes of Ice Ages

Scientists have proposed a number of theories to explain ice ages. Each theory explains why Earth experienced the gradual cooling that brought on the advancement of the glaciers. The theories also explain why the glaciers retreated during the interglacial periods.

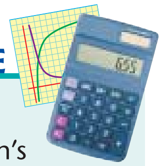
The Milankovitch Theory

A Serbian scientist named Milutin Milankovitch proposed a theory to explain the cause of ice ages. Milankovitch noticed that ice ages occurred in cycles. He thought that these cycles could be linked to cycles in Earth's movement relative to the sun. The **Milankovitch theory** is the theory that cyclical changes in Earth's orbit and in the tilt of Earth's axis occur over thousands of years and cause climatic changes.

Three periodic changes occur in the way that Earth moves around the sun, as **Figure 3** shows. First, the shape of Earth's orbit, or *eccentricity,* changes from nearly circular to elongated and back to nearly circular every 100,000 years. The second change occurs in the tilt of Earth's axis. Every 41,000 years, the tilt of Earth's axis varies between about 22.2° and 24.5°. A third periodic change is caused by the circular motion, or *precession,* of Earth's axis. Precession causes the axis to change its position, which is often described as a wobble. The axis of Earth traces a complete circle every 25,700 years.

Milankovitch calculated how these three factors may affect the distribution of solar energy that reaches Earth's surface. Changes in the distribution of solar energy affects global temperatures, which may cause an ice age.

MATHPRACTICE

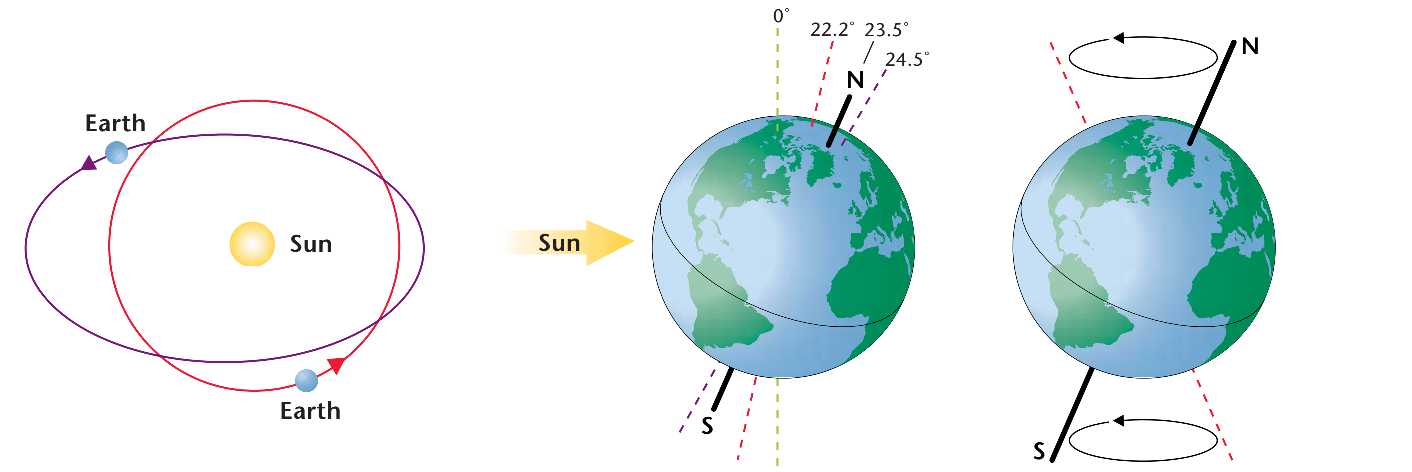


Earth's Tilt

The current angle of Earth's tilt is 23.5°. That angle is decreasing. If the tilt moves from 24.5° to 22.2° over 41,000 years, estimate how many years will pass before Earth's tilt reaches 22.2°.

Milankovitch theory the theory that cyclical changes in Earth's orbit and in the tilt of Earth's axis occur over thousands of years and cause climatic changes

Figure 3 ▶ According to the Milankovitch theory, the distribution of solar radiation that Earth receives varies because of three kinds of changes in Earth's position relative to the sun.



Eccentricity Changes in orbital eccentricity cause an increase in seasonality in one hemisphere and reduce seasonality in the other hemisphere.

Tilt Over a period of 41,000 years, the tilt of Earth's axis varies between 22.2° and 24.5°. The poles receive more solar energy when the tilt angle is greater.

Precession The wobble of Earth's axis affects the amount of solar radiation that reaches different parts of Earth's surface at different times of the year.

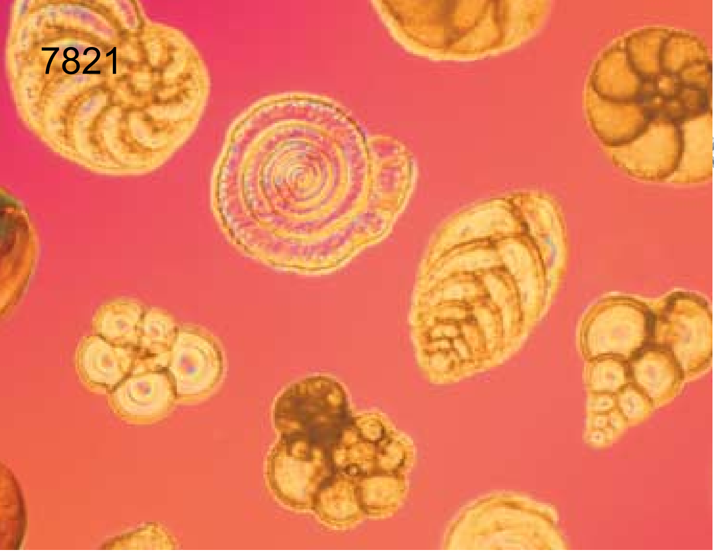


Figure 4 ▶ The microscopic shells of organisms from the order Foraminifera give clues to climate change.

Evidence for Multiple Ice Ages

Evidence for past ice ages has been discovered in the shells of dead marine animals found on the ocean floor. The formation of the shells of organisms from the order Foraminifera, shown in **Figure 4,** is affected by the temperature of the ocean water. Temperature of the ocean water affects the amount of oxygen that the water dissolves. The amount of oxygen in turn affects how these organisms form their shells. Organisms that lived in ocean waters that were warmer than 8°C coiled their shells to the right. Organisms that lived in ocean waters that were much cooler coiled their shells to the left.

By studying Foraminifera shells in the layers of sediment on the ocean floor, scientists have discovered evidence of different ice ages. Scientists have found that the record of ice ages in marine sediments closely follows the cycle of cooling and warming predicted by the Milankovitch theory.

Other Explanations for Ice Ages

Other explanations for the causes of ice ages have been suggested. However, unlike the Milankovitch theory, most of these explanations indicate that the ice ages were caused by a change in the amount of solar energy that reached Earth's surface. Some scientists propose that changes in solar energy are caused by varying amounts of energy produced by the sun. Other scientists suggest that ice ages start when volcanic dust blocks the sun's rays. Yet another explanation proposes that plate tectonics may cause ice ages, because changes in the positions of continents cause changes in global patterns of warm and cold air and ocean circulation.

Section 3 Review

1. **Describe** glacial periods and interglacial periods.
2. **Explain** what happens to global sea level during a glacial period.
3. **Identify** the areas of Earth's surface that were covered by ice during the last glacial period.
4. **Summarize** the Milankovitch theory.
5. **Explain** how fossils of marine animals provide evidence of past ice ages.
6. **Describe** three explanations of ice ages other than the Milankovitch theory.

CRITICAL THINKING

7. **Evaluating Hypotheses** Use the information that you learned about glacial periods within an ice age to explain why volcanic eruptions and plate tectonics may not be among the causes of ice ages.
8. **Predicting Consequences** If Earth's orbit were always circular, would Earth be more likely to experience ice ages or less likely to experience ice ages? Explain your answer.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *ice age, glacial period, interglacial period, Milankovitch theory, eccentricity, tilt, volcanic eruption,* and *precession.*

Chapter 17 Highlights

Sections

1 Glaciers: Moving Ice

Key Terms

glacier, 419
alpine glacier, 420
continental glacier, 420
basal slip, 421
internal plastic flow, 421
crevasse, 422

Key Concepts

- A glacier is a large mass of moving ice formed by the compaction of snow.
- The two main types of glaciers are alpine glaciers and continental glaciers.
- Glaciers move by basal slip and by internal plastic flow.
- Three features of glaciers are crevasses, ice shelves, and icebergs.

2 Glacial Erosion and Deposition

cirque, 424
arête, 424
horn, 424
erratic, 426
glacial drift, 426
till, 426
moraine, 427
kettle, 428
esker, 428

- Glaciers create land features by eroding the land and by depositing rock and sediment.
- Glaciers erode the valleys through which they flow and produce characteristic landforms such as cirques, arêtes, horns, hanging valleys, and roches moutonneés.
- When glaciers melt, they deposit sediments called *glacial drift*.
- Glacial deposits may form erratics, kettles, eskers, drumlins, and moraines.
- Glaciers may form lake basins by eroding the land or by depositing sediments.

3 Ice Ages

ice age, 431
Milankovitch theory, 433

- An ice age occurs when a long period of climatic cooling causes continental glaciers to cover large areas of Earth's surface.
- During an ice age, cooler glacial periods alternate with warmer interglacial periods.
- The Milankovitch theory suggests that ice ages are caused by changes in the amount of solar energy Earth receives. These changes are caused by regular changes in the eccentricity of Earth's orbit, the tilt of Earth's axis, and precession.
- Variations in solar activity, volcanic activity, and plate tectonics may also affect climate.

Chapter 17 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *glacier*
2. *crevasse*
3. *ice age*

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

4. *alpine glacier* and *continental glacier*
5. *till* and *moraine*
6. *basal slip* and *internal plastic flow*
7. *cirque* and *arête*
8. *glacial period* and *interglacial period*

Understanding Key Concepts

9. Glaciers that form in mountainous areas are called
   - **a.** continental glaciers.
   - **b.** alpine glaciers.
   - **c.** icebergs.
   - **d.** ice shelves.

10. A glacier will move by sliding when the base of the ice and the underlying rock are separated by a thin layer of
   - **a.** water and sediment.
   - **b.** snow.
   - **c.** pebbles.
   - **d.** drift.

11. What part of a glacier moves fastest when the glacier moves by internal plastic flow?
   - **a.** The center of the glacier moves fastest.
   - **b.** The bottom of the glacier moves fastest.
   - **c.** The edges of the glacier move fastest.
   - **d.** The whole ice mass moves at the same speed.

12. Icebergs form when ice breaks off of a(n)
   - **a.** crevasse.
   - **b.** ice shelf.
   - **c.** alpine glacier.
   - **d.** esker.

13. As a glacier moves through a valley, it carves out a(n)
   - **a.** U shape.
   - **b.** esker.
   - **c.** V shape.
   - **d.** moraine.

14. A deposit of stratified drift is called a(n)
   - **a.** drumlin.
   - **b.** outwash plain.
   - **c.** ground moraine.
   - **d.** roche moutonnée.

15. One component of the Milankovitch theory is
   - **a.** the circular motion of Earth's axis.
   - **b.** continental drift.
   - **c.** volcanic activity.
   - **d.** landslide activity.

16. Which of the following is *not* a theory for the cause of ice ages?
   - **a.** volcanic eruptions
   - **b.** variations in Earth's orbit
   - **c.** Foraminifera shell coils
   - **d.** changes in tectonic plate position

Short Answer

17. How does climate change during an ice age?
18. What are the four types of moraines, and how are they different from each other?
19. Identify three types of landforms created by alpine glaciers.
20. In what two ways do glacial lakes form?
21. How do the processes of basal slip and internal plastic flow differ?

Critical Thinking

22. Identifying Relationships Why is it important for scientists to monitor and study the continental ice sheets that cover Greenland and Antarctica?

23. Applying Concepts Antarctic explorers need special training to travel safely over the ice sheet. Besides the cold, what structural aspects of the glaciers may be dangerous?

24. Evaluating Data What phenomenon other than decreased temperature and increased snowfall might signal the beginning of a glacial period?

Concept Mapping

25. Use the following terms to create a concept map: *snowfield, erosion, deposition, glacier, horn, arête, kettle, moraine, basal slip,* and *internal plastic flow.*

Math Skills

26. Using Equations The area of Earth's surface that is covered with water is 361,000,000 km^2. The volume of water locked in ice in the Antarctic ice sheet is about 26,384,368 km^3. Use the following equation to find the average worldwide rise in sea level, in meters, that would occur if the Antarctic ice sheet melted.

$$\text{rise in water level} = \frac{\text{volume of water in ice sheet}}{\text{area of Earth covered by water}}$$

27. Evaluating Data New York City has an elevation of 27 m above sea level. What would happen to the city if the Antarctic ice sheet melted and raised the worldwide sea level by 50 m?

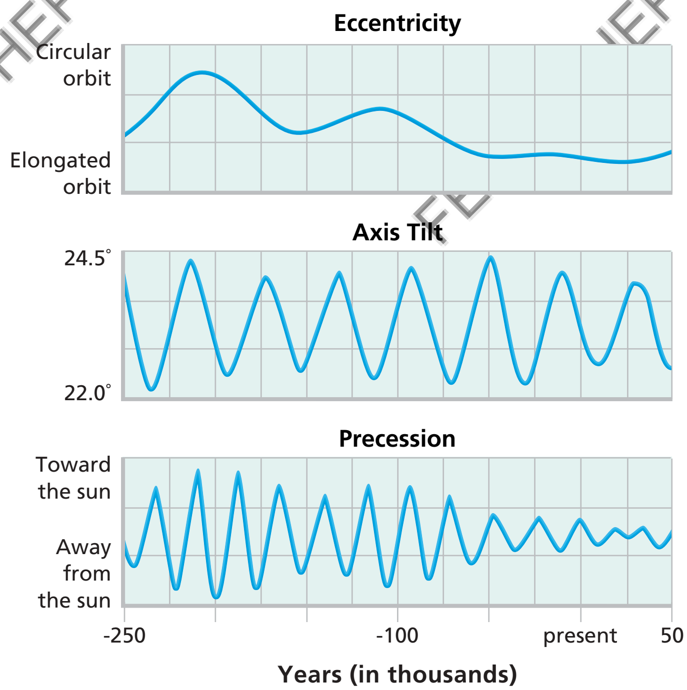
Writing Skills

28. Writing Persuasively Write a research proposal to the National Science Foundation that details a plan of action and reasons for studying the ice sheet in Greenland.

29. Writing from Research Research how ocean currents affect the polar icecaps. Write a short essay that describes global ocean currents and explains how they affect the formation and advancement of polar icecaps.

Interpreting Graphics

The graph below shows the relationship between cycles of eccentricity, tilt, and precession. Use the graph to answer the questions that follow.



30. What was the angle of Earth's tilt 50,000 years ago?

31. Describe the shape of Earth's orbit 200,000 years ago.

32. How would the seasons 50,000 years from now be different from the seasons 50,000 years ago?

Chapter 17 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 Which statement *best* compares the movement of glacial ice to the movement of river water?
- **A** Glacial ice moves more rapidly than water.
- **B.** Glacial ice cannot easily flow around barriers.
- **C.** Glacial ice moves in response to gravity.
- **D.** Glacial ice moves in the same way as water.

2 What landform created by glaciers has a bowl-like shape?
- **F.** cirque
- **G.** arête
- **H.** horn
- **I.** roches moutonnée

3 What is the unsorted material left beneath a glacier when the ice melts?
- **A.** lateral moraine
- **B.** ground moraine
- **C.** medial moraine
- **D.** terminal moraine

4 Which of the following statements *best* describes how crevasses form on the surface of a glacier?
- **F.** Movement of the glacier's ice from the center toward the edges forms large cracks on the surface of the glacier.
- **G.** As the ice flows unevenly beneath the surface of the glacier, tension and compression on the surface form large cracks.
- **H.** Breakage of large blocks of ice from the edges of ice shelves forms large cracks.
- **I.** Narrow, wedge-shaped masses of ice confined to a small area form large cracks.

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

5 What is the term for all types of sediments deposited by a glacier?

6 What is the name of a jagged ridge that is formed between two or more cirques that cut into the same mountain?

Reading Skills

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

Glacial and Interglacial Periods

Ice ages are periods during which ice collects in high latitudes and moves toward lower latitudes. During an ice age, there are periods of cold and of warmth. These periods are called *glacial and interglacial periods.* During glacial periods, enormous sheets of ice advance, grow bigger, and cover a large area. Because a large amount of sea water is frozen during glacial periods, the sea level around the world drops.

Warmer time periods that occur between glacial periods are known as interglacial periods. During an interglacial period, the large ice sheets begin to melt and the sea levels begin to rise again. Scientists believe that the last interglacial period began approximately 10,000 years ago and is still happening. For nearly 200 years, scientists have been debating what the current interglacial period might mean for humans and the possibility of a future glacial period.

7 According to the passage, which of the following statements is true?
- **A.** The last interglacial period began approximately 1,000 years ago.
- **B.** Scientists have been thinking about the next glacial period for two centuries.
- **C.** Ice ages are periods during which ice collects in the lower latitudes and moves toward higher latitudes.
- **D.** During glacial periods, enormous sheets of ice tend to melt, so they become smaller and cover less area.

8 Which of the following statements can be inferred from the information in the passage?
- **F.** On average, ice ages occur every 50,000 years and always start with a glacial period.
- **G.** Interglacial periods always last 10,000 years.
- **H.** Glacial periods always last 10,000 years.
- **I.** The current interglacial period will likely be followed by a glacial period.

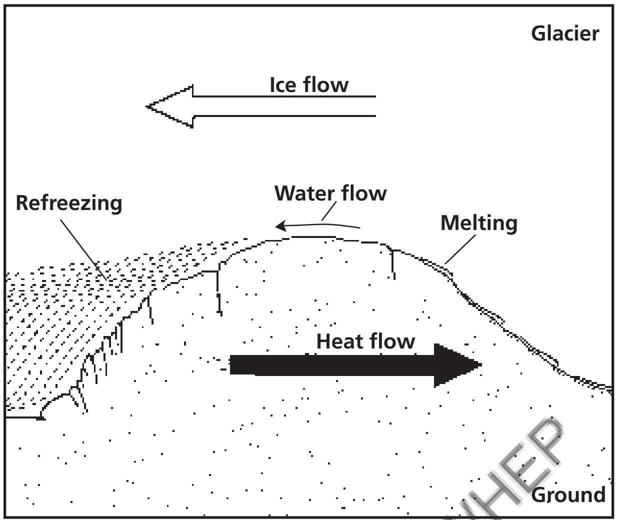
9 If a new glacial period began tomorrow, what might happen to coastal cities

Interpreting Graphics

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

Base your answers to questions 10 through 11 on the diagram below.

Basal Slip



10 What causes the ice to melt in the diagram above?
A. Pressure decreases the melting point of the ice.
B. Pressure increases the melting point of the ice.
C. The ground heats the ice until it melts.
D. Ice at the base of a glacier does not melt.

11 How does meltwater influence basal slip?

Base your answers to question 12 on the table below.

World Cities and Their Elevations

City	Elevation (m)
New York City	27
Kiev, Ukraine	168
Buenos Aries, Argentina	25
Amsterdam, Netherlands	2

12 What would happen to each of the cities listed in the table if the Antarctic ice sheet were to melt and raise the sea level by 50 m?

13 The movement of a glacier was recorded over a period of 180 days. During that time, the glacier moved a total of 36 m. What was the average speed of the glacier each day?
F. 0.20 m/day
G. 0.50 m/day
H. 2.00 m/day
I. 5.00 m/day

Test TIP

For a group of questions that refer to a diagram, graph, or table, read all of the questions quickly to determine what information you will need to glean from the graphic.

Chapter 17

Making Models Lab

Objectives

- **Model** the melting of an ice sheet.
- USING SCIENTIFIC METHODS **Analyze** the effects of melting ice on sea level.

Materials

- block, ice, 5 cm × 5 cm × 5 cm
- block, wooden, 5 cm × 5 cm × 5 cm
- pan, 30 cm × 40 cm × 10 cm
- pebbles (1 kg)
- ruler, metric
- sand (1 kg)
- water

Safety

Glaciers and Sea Level Change

Today, glaciers hold only about 2.2% of Earth's water. But if the polar ice sheets melted, the coastal areas of many countries would flood. Many major cities, such as New York, New Orleans, Houston, and Los Angeles, would flood if the sea level rose only a few meters. In this lab, you will construct a model to simulate what would happen if the Antarctic ice sheet melted.

PROCEDURE

1. Calculate and record the approximate surface area of the bottom of the pan. Area (A) is equal to length (l) times width (w), or $A = l \times w$, and is expressed in square units.
2. Calculate and record the overall volume of the ice block and the area of one side of the ice block. Volume (V) is equal to length (l) times width (w) times height (h), or $V = l \times w \times h$, and is expressed in cubic units.
3. Add the sand and small pebbles to one end of the pan so that they cover about half of the area of the pan and slope toward the middle of the pan. Use the wooden block to elevate the end of the pan containing the sand and pebbles.
4. Slowly add water to the opposite end of the pan. Be sure that the water does not cover the sand and pebbles and touches only the edge of the sand.

Step 3

5. Measure and record the depth of the water at the deepest point.
6. Measure and record the distance from the end of the pan covered with sand to the point where the sand touches the water.
7. Place the block of ice in the pan on top of the sand. Calculate and record the percentage of the total area of the pan that is covered by ice.
8. As the ice begins to melt, pick up the ice block. Note the appearance of the bottom of the ice block and the appearance of the sand under the ice block. Record what is happening to the ice block and what is happening to the sand under the ice block. Place the ice block back on the sand.
9. While the ice is melting, calculate the expected rise in the pan's water level by using the following formula:

$$\textit{rise in water level} = \frac{\textit{volume of water in ice block}}{\textit{area of pan covered by water}}$$

10. When the ice is completely melted, measure and record the depth of water at the deepest point.
11. Measure and record the distance from the end of the pan covered with sand to the point where the sand touches the water.

Step 4

ANALYSIS AND CONCLUSION

1. **Making Comparisons** Compare the depth of water at the beginning of the lab with the depth at the end of the lab. Explain any differences.
2. **Analyzing Results** How did the distance from the end of the pan covered with sand to the point where the sand touches the water change? Explain your answer.
3. **Compare and Contrast** How does the ice-block model differ from a glacier on Earth?
4. **Drawing Conclusions** How does the ice-block model represent what would happen on Earth if the Antarctic polar ice sheet melted?

Extension

1. **Evaluating Models** In this lab, you used a physical model to simulate an occurrence in nature. In what other ways do scientists use models? What kinds of errors can occur when models are used?

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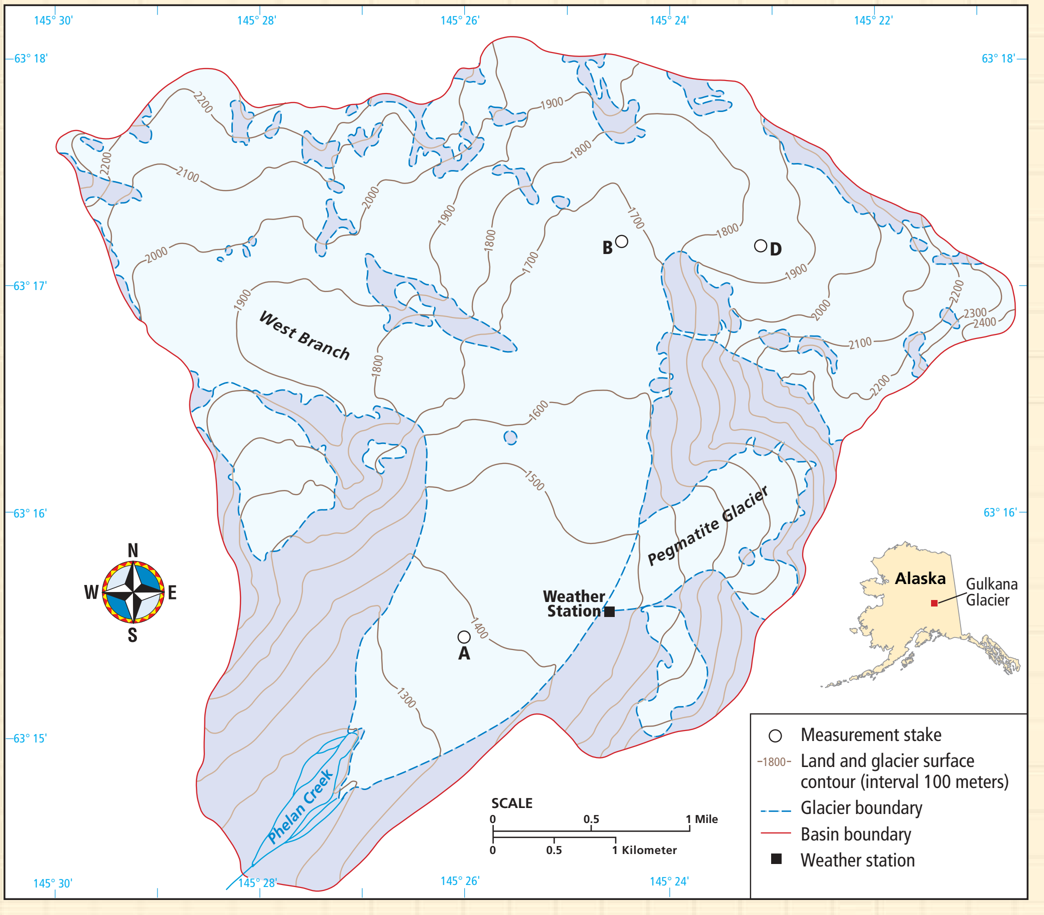
MAPS in Action

Gulkana Glacier



Map Skills Activity

This contour map shows the elevation and boundaries of the Gulkana Glacier located in Alaska. Use the map to answer the questions below.

1. **Using the Key** Estimate the length of the Gulkana Glacier from its northernmost point to its southernmost point.

2. **Analyzing Data** Estimate the latitude and longitude of the glacier's highest point.

3. **Identifying Trends** In which direction do you think Gulkana Glacier is moving at measurement stake D?

4. **Identifying Trends** In which direction do you think Gulkana Glacier is moving at measurement stake A?

5. **Predicting Consequences** Why might you think that the glacier moves in different directions at measurement stake A and measurement stake B?

6. **Analyzing Data** What do you think the scientists are measuring at the measurement stakes?

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The Missoula Floods

In an area called the Channeled Scablands in Washington State, scientists discovered numerous gravel bars and ridges that are roughly parallel to each other. The ridges are 10 m high, extend about 115 m from crest to crest, and can be more than 3 km long. The scientists were puzzled and set out to determine how the ridges formed.

Mystery Ripples

After extensive research and some aerial photography, scientists realized that the gravel ridges are giant ripple marks that formed as a huge amount of water poured across the land. Scientists had observed similar ripples created by the movement of flowing water in rivers and on beaches, but no one had ever seen ripples of this size!

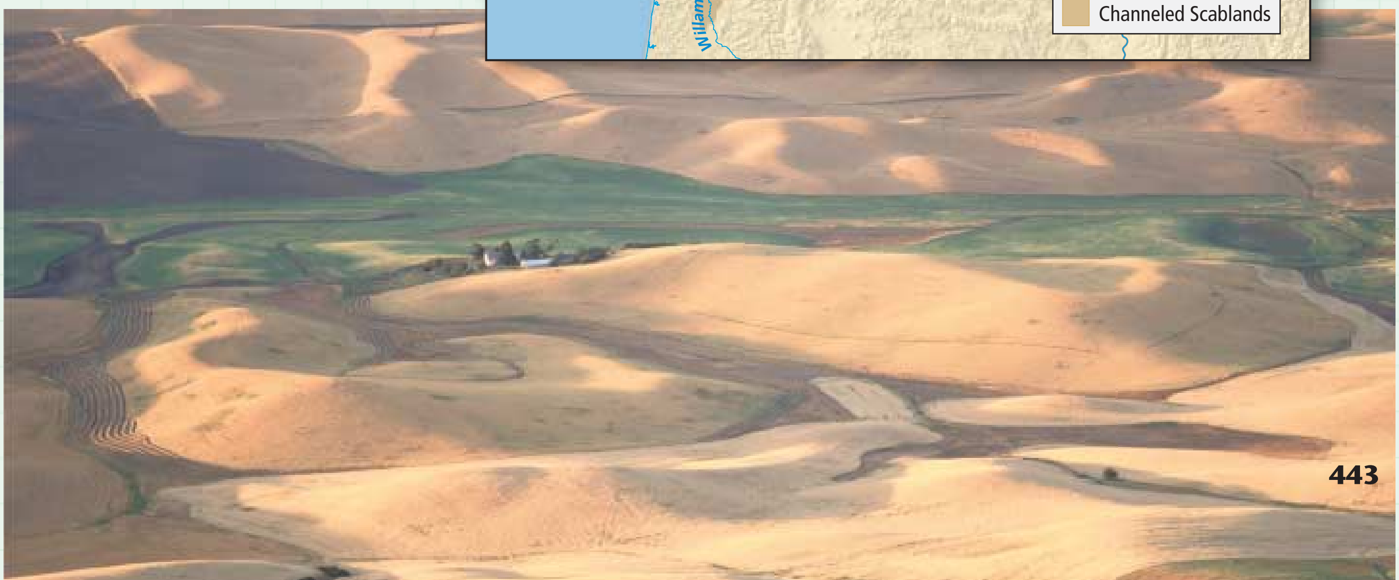
Catastrophic Floods

What caused such enormous ripples? During the last glacial period, a series of ice dams formed across the Clark Fork River, and a giant glacial lake—Lake Missoula—periodically formed. This lake was as big as Lake Erie and Lake Ontario combined! About 14,000 years ago, the last ice dam broke, and a wave 650 m tall raced across eastern Washington at a speed of about 90 km/h. The wave left huge piles of gravel and ripple marks in its wake. Scientists estimate that the water rushed through the region as fast as 400 million cubic feet per second and emptied the entire lake in only two days.

Extension

1. **Research and Communications** Research the type of sediment that makes up the gravel ridges in the Channeled Scablands. Write a brief essay that explains whether the type of sediment in the gravel ridges supports the hypothesis of a giant flood.

▼ The Channeled Scablands formed when an ice dam broke 14,000 years ago.



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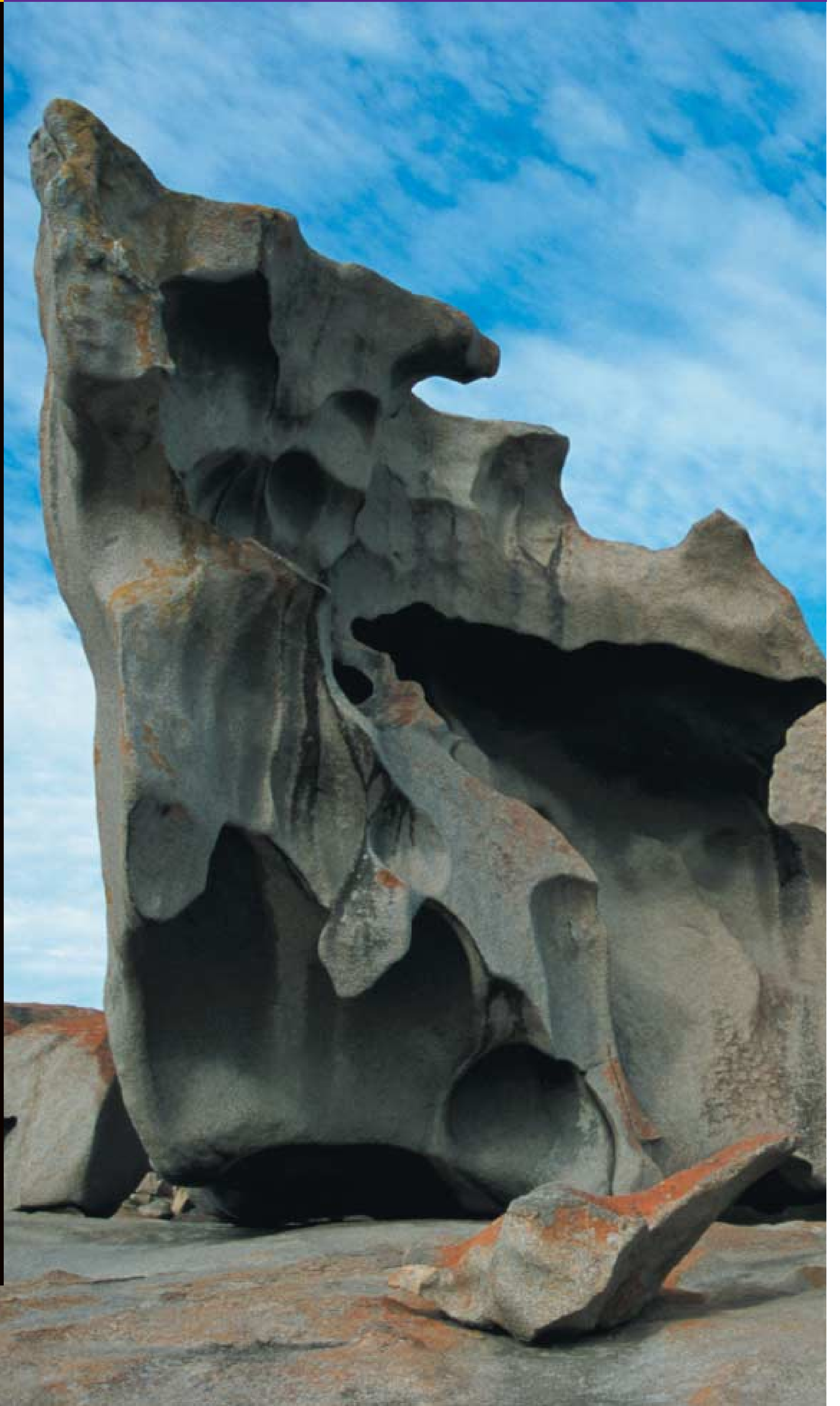
Chapter 18 Erosion by Wind and Waves



Sections

1 Wind Erosion

2 Wave Erosion

3 Coastal Erosion and Deposition

What You'll Learn

- How wind erodes the land
- How waves erode shorelines
- How coastlines change

Why It's Relevant

Wind and wave erosion change features of Earth's surface. Soil that is needed for farming is carried away by wind. Wave action affects beaches and coasts, which have high economic and recreational value.

PRE-READING ACTIVITY

FOLDNOTES

Pyramid Before you read the chapter, create the **FoldNote** entitled "Pyramid" described in the Skills Handbook section of the Appendix. Label the sides of the pyramid with "Wind erosion," "Wave erosion," and "Coastal erosion and deposition." As you read the chapter, define each type of erosion, and write characteristics of each type on the appropriate pyramid side.

▶ This unusual rock sits on Kangaroo Island, which is located off the southern shore of Australia. This rock, like many other rocks, has been shaped by the forces of the wind and the waves.

Section 1 Wind Erosion

Wind contains energy. Some of this energy can move a sailboat or turn a wind turbine, but this energy can also erode the land. As wind passes over the land, the wind can carry sand or dust. Sand is loose fragments of weathered rocks and minerals. Most grains of sand are made of quartz. Other common minerals that make up sand are mica, feldspar, and magnetite.

Dust consists of particles that are smaller than the smallest sand grain. Most dust particles are microscopic fragments of rocks and minerals that come from the soil or volcanic eruptions. Other sources of dust are plants, animals, bacteria, pollution from the burning of fuels, and certain manufacturing processes.

OBJECTIVES

- **Describe** two ways that wind erodes land.
- **Compare** the two types of wind deposits.

KEY TERMS

saltation
deflation
ventifact
dune
loess

How Wind Moves Sand and Dust

Wind cannot keep sand aloft. Instead, sand grains are moved by a series of jumps and bounces called **saltation.** Saltation occurs when wind speed is high enough to roll sand along the ground. When rolling sand grains collide, some sand grains bounce up, as shown in **Figure 1.** Once in the air, a sand grain moves ahead a short distance and then falls. As a sand grain falls, it strikes other sand grains. Saltating sand grains move in the same direction that the wind blows. However, the grains rarely rise more than 1 m above the ground, even in very strong winds.

saltation the movement of sand or other sediments by short jumps and bounces that is caused by wind or water

Because dust particles are very small and light, even gentle air currents can keep dust particles suspended in the air. Dust from volcanic eruptions can remain in the atmosphere for several years. Strong winds may lift large amounts of dust and create dust storms, such as the one shown in **Figure 1.** Some dust storms cover hundreds of square kilometers and darken the sky for several days.

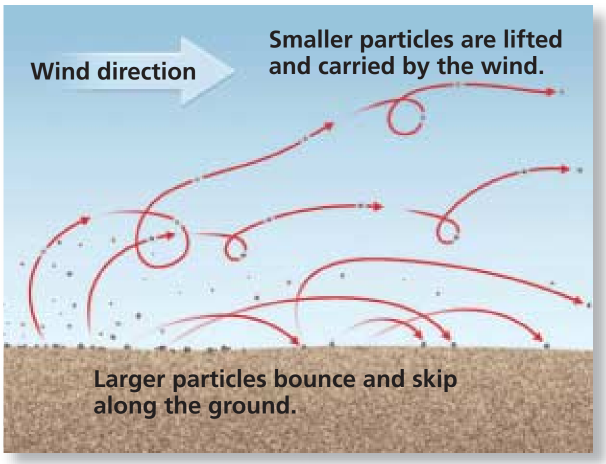


Figure 1 ▶ Heavy sand grains move by making low, arcing jumps when blown by the wind (above). Dust is light enough to be aloft for days, as shown in this dust storm in Phoenix, Arizona (left).

Figure 2 ▶ Desert pavement, such as the example above from Calico Hills, California, prevents erosion of the material beneath it.

Effects of Wind Erosion

While wind erosion happens everywhere there is wind, the landscapes that are most dramatically shaped by wind erosion are deserts and coastlines. In these areas, fewer plant roots anchor soil and sand in place to reduce the amount of wind erosion. Also, in the desert, where there is little moisture, soil layers are thin and are likely to be swept away by the wind. Moisture makes soil heavy and causes some soil and rock particles to stick together, which makes them difficult to move.

Reading Check **Why does wind erosion happen faster in dry climates than in moist climates? (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: Wind Erosion

SciLinks code: HQ61669

Desert Pavement

deflation a form of wind erosion in which fine, dry soil particles are blown away

One common form of wind erosion is deflation. **Deflation** is the process by which wind removes the top layer of fine, very dry soil or rock particles and leaves behind large rock particles. These remaining rock particles often form a surface of closely packed small rocks called *desert pavement,* or *stone pavement*, as shown in **Figure 2.** Desert pavement protects the underlying land from erosion by forming a protective barrier over underlying soil.

Deflation Hollows

Deflation is a serious problem for farmers because it blows away the best soil for growing crops. Deflation may form shallow depressions in areas where the natural plant cover has been removed. As the wind strips off the topsoil, a shallow depression called a *deflation hollow* forms. A deflation hollow may expand to a width of several kilometers and to a depth of 5 to 20 m.

Ventifacts

When pebbles and small stones in deserts and on beaches are exposed to wind abrasion, the surfaces of the rocks become flattened and polished on two or three sides. Rocks that have been pitted or smoothed by wind abrasion are called **ventifacts.** The word *ventifact* comes from the Latin word *ventus,* which means "wind." The direction of the prevailing wind in an area can be determined by the appearance of ventifacts.

Scientists once thought that large rock structures, such as desert basins, natural bridges, rock pinnacles, and rocks perched on pedestals, were formed by wind erosion. However, scientists now think that it is more likely that such large features were produced by erosion due to surface water and weathering. Erosion of large masses of rock by wind-blown sand happens very slowly and happens only close to the ground, where saltation occurs.

ventifact any rock that is pitted, grooved, or polished by wind abrasion

dune a mound of wind-deposited sand that moves as a result of the action of wind

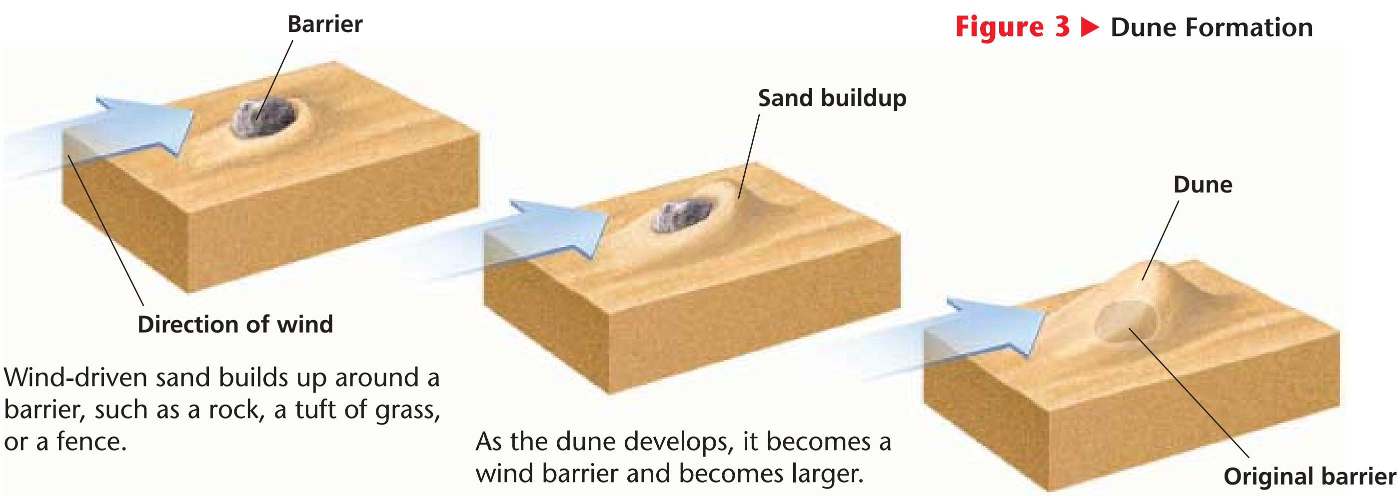
Wind Deposition

The wind drops particles when it slows down and can no longer carry them. These deposited particles are continually covered by additional deposits. Eventually, cementation and pressure from overlying layers bind the fragments together. This process is one way that sedimentary rocks form.

Dunes

The best-known wind deposits are **dunes,** which are mounds of wind-deposited sand. Dunes form where the soil is dry and unprotected and where the wind is strong, such as in deserts and along the shores of oceans and large lakes. A dune begins to form when a barrier slows the speed of the wind. When wind speed slows, sand accumulates on both sides of the barrier, as shown in **Figure 3.** As more sand is deposited, the dune itself acts as a barrier, grows, and buries the original barrier.

Figure 3 ▶ Dune Formation



Wind-driven sand builds up around a barrier, such as a rock, a tuft of grass, or a fence.

As the dune develops, it becomes a wind barrier and becomes larger.

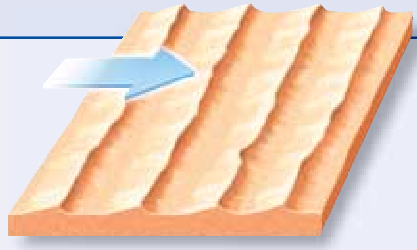
The fully formed dune covers the original barrier.

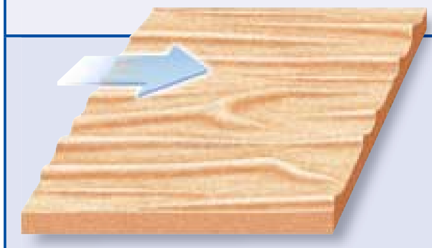
Types of Dunes

Barchan dunes
When sand is limited, strong winds form these crescent-shaped dunes.

Parabolic dunes
U-shaped parabolic dunes can form when plants anchor the edges of barchan dunes and invert their shape.

Transverse dunes
When sand is plentiful, barchan dunes can join together in long ridges to form transverse dunes.





Longitudinal dunes
These dunes are similiar to transverse dunes except they lie parallel to the direction of the wind.

Types of Dunes

The force and direction of the wind shapes sand dunes. Commonly, the gentlest slope of a dune is the side that faces the wind. Sand that is blown over the crest of the dune tumbles down the opposite side, which is called the *slipface*. The slipface has a steeper slope than the windward side does. Two long, pointed extensions may form as wind sweeps around the ends of the dune and gives the dune a crescent shape. Crescent-shaped dunes that have an open side facing away from the wind are called *barchan dunes* (BAHR kahn doonz). A *parabolic dune* is a crescent-shaped dune whose open side faces into the wind. These dunes often form as sand collects around the rim of a deflation hollow.

In desert or coastal areas that have a large amount of sand, a series of ridges of sand may form in long, wavelike patterns. These ridges are called *transverse dunes*. Transverse dunes form at right angles to the wind direction. A type of dune that is similar to a transverse dune, called a *longitudinal dune,* also forms in the shape of a ridge. But longitudinal dunes lie parallel to the direction the wind blows. **Table 1** illustrates several types of dunes and explains how the shape of dunes relates to wind direction.

Reading Check **How do barchan dunes differ from transverse dunes? (See the Appendix for answers to Reading Checks.)**

Graphic Organizer **Comparison Table**

Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Barchan dunes," "Parabolic dunes," "Transverse dunes," and "Longitudinal dunes." Label the rows with "Shape" and "Formation." Then, fill in the table with details about the four kinds of dunes.

Figure 4 ▶ Wind erodes sand from the windward side of the dune and deposits it on the slipface. ***Which direction is this sand dune migrating?***

Dune Migration

The movement of dunes is called *dune migration*. If the wind usually blows from the same direction, dunes will move downwind. Dune migration occurs as sand is blown over the crest from the windward side and builds up on the slipface, as shown in **Figure 4.** In mostly level areas, dunes migrate until they reach a barrier. To prevent dunes from drifting over highways and farmland, people often build fences or plant grasses, trees, and shrubs.

QuickLAB 20 min

Modeling Desert Winds

Procedure

1. Spread a mixture of **dust, sand,** and **gravel** on a table placed outdoors.
2. Place an **electric fan** at one end of the table.
3. Put on **safety goggles** and a **filter mask.** Aim the fan across the sediment you have laid out. Start the fan on the lowest speed. Record any observations.
4. Turn the fan to a medium speed and record any observations. Then, turn the fan to its highest speed to imitate a desert windstorm. Record any observations.

Analysis

1. In what direction did the sediment move?
2. What was the relationship between the wind speed and the sediment size that was moved?
3. How does the remaining sediment compare to desert pavement?
4. How did the sand move in this activity? How do your observations relate to dune migration?
5. Using the same materials, how would you model dune migration? How would you model the formation of the different kinds of dunes?

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Figure 5 ▶ These loess deposits are located in Vicksburg, Mississippi. Much of the surrounding land is fertile farmland.

loess fine-grained sediments of quartz, feldspar, hornblende, mica, and clay deposited by the wind

Loess

The wind carries dust higher and much farther than it carries sand. Fine dust may be deposited in such thin layers that it is not noticed. However, thick deposits of yellowish, fine-grained sediment, called **loess** (LOH ES), can form by the accumulation of windblown dust. Although loess is soft and easily eroded, it sometimes forms steep bluffs, such as those shown in **Figure 5.**

A large area in northern China is covered in a deep layer of loess. The material in this deposit came from the Gobi Desert, in Mongolia. Deposits of loess are also located in central Europe. In North America, loess is located in the midwestern states, along the eastern border of the Mississippi River valley, and in eastern Oregon and Washington State. These deposits probably formed as dust from dried beds of glacial lakes and from outwash plains blew across the region. Loess deposits are extremely fertile and provide excellent soil for grain-growing regions.

Section 1 Review

1. **Describe** how wind transports sediment by saltation.
2. **Define** *deflation,* and explain how *deflation hollows* form.
3. **Describe** how desert pavement forms.
4. **Describe** how sand dunes form and how dunes migrate.
5. **Explain** how the wind moves loess.
6. **Identify** two reasons why wind erosion has a major affect on deserts.
7. **Compare** the four main shapes of dunes.

CRITICAL THINKING

8. **Analyzing Processes** Explain how scientists know that desert pavement forms by wind erosion.
9. **Determining Cause and Effect** Why does planting grass, trees, or shrubs help prevent dunes from covering roads?
10. **Analyzing Processes** Explain why the position of dunes would not be helpful for navigation in the desert.

CONCEPT MAPPING

11. Use the following terms to create a concept map: *saltation, deflation, dune, deflation hollow, desert pavement, wind, sand particle, top soil layer,* and *migration.*

Section 2 Wave Erosion

As wind moves over the ocean, the wind produces waves and currents that erode the coastline. Wave erosion changes the shape of shorelines, the places where the ocean and the land meet.

OBJECTIVES

- **Compare** the formation of six features produced by wave erosion.
- **Explain** how beaches form.
- **Describe** the features produced by the movement of sand along a shore.

KEY TERMS

headland
beach
longshore current

Shoreline Erosion

The power of waves striking rock along a shoreline can sometimes shake the ground as much as a small earthquake would. The great force of waves may break off pieces of rock and throw the pieces back against the shore. These sediments grind together in the tumbling water. This abrasive action, which is known as *mechanical weathering,* eventually reduces most of the rock fragments to small pebbles and sand grains.

Much of the erosion along a shoreline takes place during storms, which cause large waves that release tremendous amounts of energy, as shown in **Figure 1.** A severe storm can noticeably change the appearance of a shoreline in a single day.

Chemical weathering also affects the rock along a shoreline. The waves force salt water and air into small cracks in the rock. Chemicals in the air and water react with the rock and enlarge the cracks. Enlarged cracks expose more of the rock to mechanical and chemical weathering.

Figure 1 ▶ Large waves break apart rock on shorelines and change the shoreline's appearance. ***Where is erosion occurring in the photo shown here?***

Sea Cliffs

In places where waves strike directly against rock, the waves slowly erode the base of the rock. The waves cut under the overhanging rock, until the rock eventually collapses to form a steep *sea cliff*. The rate at which sea cliffs erode depends on the amount of wave energy and on the resistance of the rock along the shoreline. Soft rock, such as limestone, erodes very rapidly. Harder rock, such as granite, shows little change over hundreds of years. Resistant rock formations that project out from shore are called **headlands.** Areas that have less resistant rock form *bays*. **Figure 2** shows bays and several other coastal landforms produced by wave erosion.

headland a high and steep formation of rock that extends out from shore into the water

Sea Caves, Arches, and Stacks

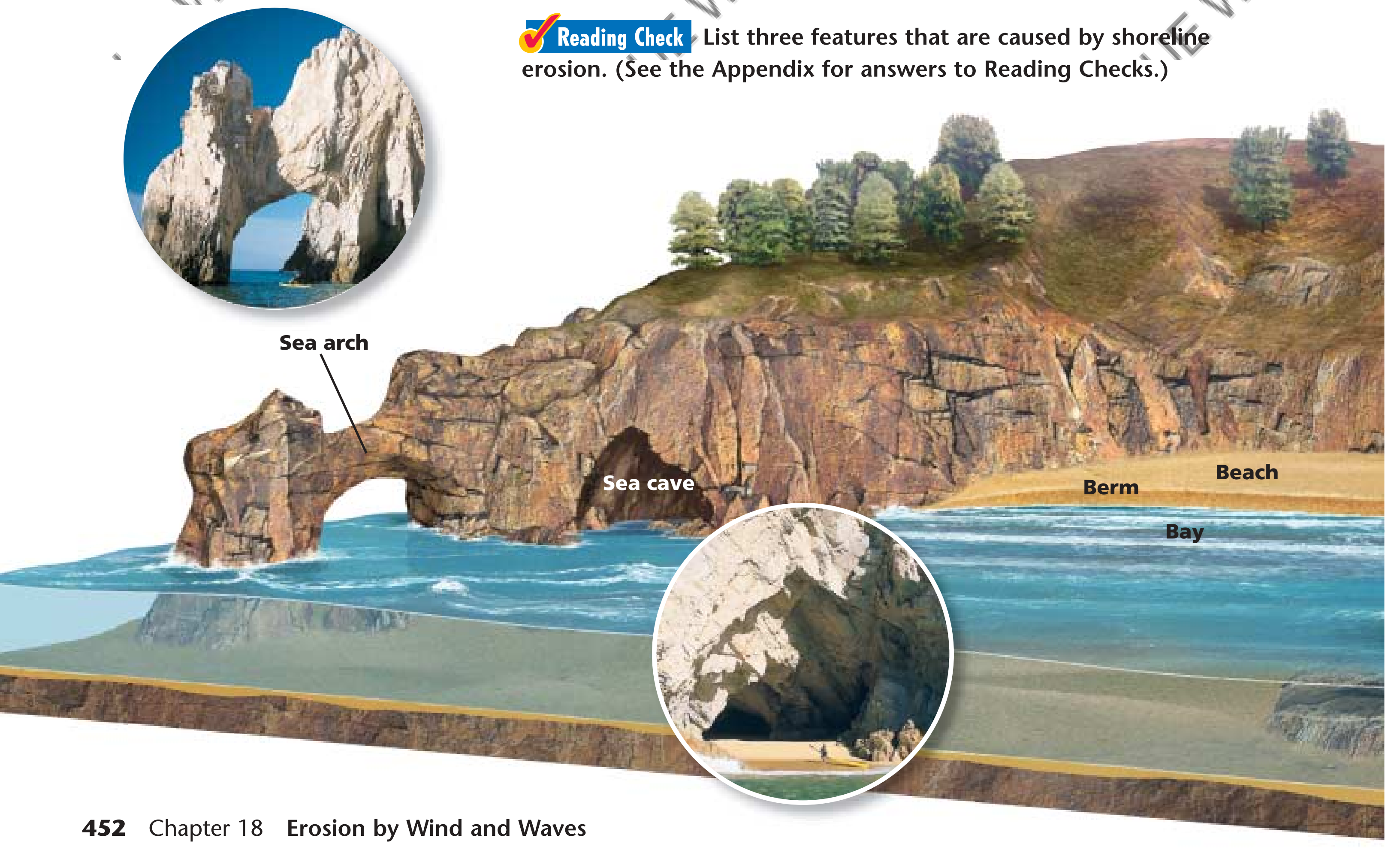
Waves often cut deep into fractured and weak rock along the base of a cliff to form a large hole, or a *sea cave*. When waves cut completely through a headland, a *sea arch* forms. Offshore columns of rock that once were connected to a sea cliff or headland, are called *sea stacks*.

Terraces

As a sea cliff is worn, a nearly level platform, called a *wave-cut terrace,* usually remains beneath the water at the base of the cliff. Eroded material may be deposited offshore to create an extension to the wave-cut terrace called a *wave-built terrace*.

Reading Check **List three features that are caused by shoreline erosion. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Wave erosion of sea cliffs causes cliff retreat and forms isolated sea stacks. Sea cliffs develop where waves strike directly against rock that is along a shoreline.



Beaches

Waves create features by eroding the land and depositing sediment. A deposit of sediment along an ocean or lake shore is called a **beach.** Beaches form where more sediment is deposited than is removed. After a beach forms, the rate at which sediment is deposited and the rate at which sediment is removed may vary.

beach an area of the shoreline that is made up of deposited sediment

Composition of Beaches

The sizes and kinds of materials that make up beaches vary. In general, the smaller the particle is, the farther it traveled before it was deposited. The composition of beach materials depends on the minerals in the source rock. Some beaches may consist of fragments of shells and coral that are washed ashore. In other locations, sand beaches form from sediment deposited by rivers or glaciers. Other beaches are composed of large pebbles.

MATHPRACTICE

Wave Depth A wave will break when the depth of the wave is equal to 3/2 the height of the wave. This statement is represented by the formula $D = 3/2\ H$. If the tallest wave in a specific area is 6 m, what is the maximum depth at which wave erosion would occur in that area?

The Berm

Each wave that reaches the shore moves sand slightly. The sand piles up to produce a sloping surface. During high tides or large storms, sand is deposited at the back of this slope. So, most beaches have a raised section called the *berm,* as shown in **Figure 2.** The berm is high and steep during the winter because large storms remove sand from the beach on the seaward side of the berm. The sand that is removed may be deposited offshore to form a long underwater ridge called a *sand bar*. In the summer, waves may move the sand back to the shore to widen the beach.

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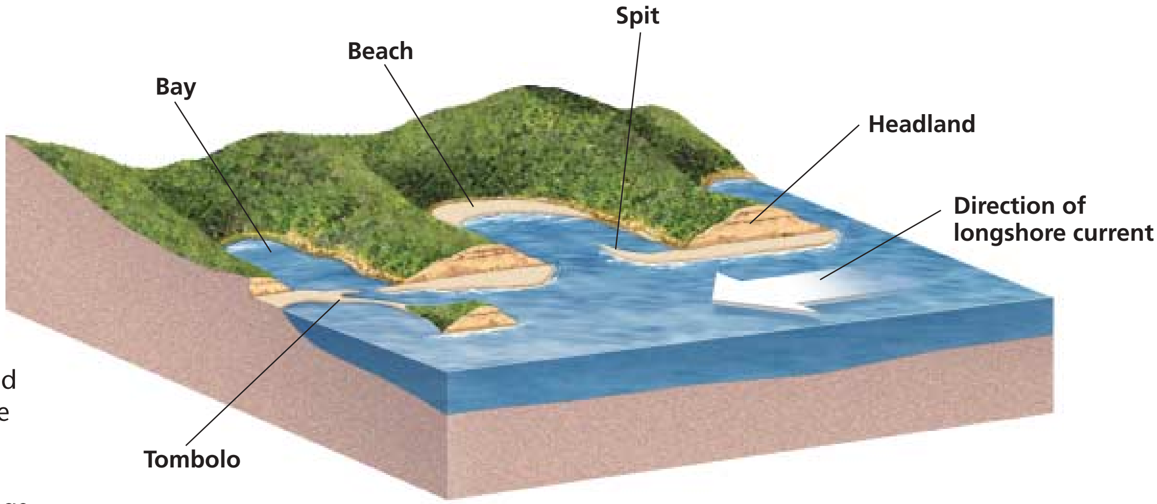


Figure 3 ▶ Spits and tombolos form where longshore currents deposit sand at headlands, at openings to a bay, or on offshore islands.

longshore current a water current that travels near and parallel to the shoreline

Longshore-Current Deposits

The direction in which a wave approaches the shore determines how the wave will move sediment. Most waves approach the beach at an angle and retreat in a direction that is more perpendicular to the shore. So, waves move individual sand grains in a zig-zag motion. The general movement of sand along the beach is in the direction in which the waves strike the shore.

Waves moving at an angle to the shoreline often create longshore currents. A **longshore current** is a movement of water parallel to and near the shoreline. Longshore currents transport sand parallel to the shoreline, as shown in **Figure 3.**

Along a relatively straight coastline, sand keeps moving until the shoreline changes direction at bays and headlands. The longshore current slows, and sand is deposited at the far end of the headland. A long, narrow deposit of sand connected at one end to the shore is called a *spit*. Currents and waves may curve the end of a spit into a hook shape. Beach deposits may also connect an offshore island to the mainland. Such connecting ridges of sand are called *tombolos*.

Section 2

1. **Compare** the formation of six features that are produced by shoreline erosion.
2. **Identify** two factors that determine the composition of beach materials.
3. **Explain** how beaches form.
4. **Compare** sea arches, sea caves, and sea stacks.
5. **Describe** three features produced by the movement of sand along a shore.

CRITICAL THINKING

6. **Making Inferences** How do seasonal changes affect beaches?
7. **Identifying Relationships** How does the speed at which water moves affect the deposition of materials of differing sizes?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *shoreline erosion, sea arch, sea cave, sea cliff, wave-cut terrace, wave-built terrace,* and *terrace.*

Section 3 Coastal Erosion and Deposition

The boundaries between land and the ocean are among the most rapidly changing parts of Earth's surface. Coastal areas extend from relatively shallow water to several kilometers inland. Coastlines are affected by the long-term rise and fall of sea level and by the long-term uplifting or sinking of the land that borders the water. These and other more rapid processes, such as wave erosion and deposition, constantly change the appearance of coastlines.

OBJECTIVES

- **Explain** how changes in sea level affect coastlines.
- **Describe** the features of a barrier island.
- **Analyze** the effect of human activity on coastal land.

KEY TERMS

estuary
barrier island
lagoon

Absolute Sea-Level Changes

A change in the amount of ocean water causes sea level to rise or fall, so coastlines are covered or exposed. During the last glacial period, which ended about 15,000 years ago, some of the water that is now in the ocean existed as continental ice sheets. Scientists estimate that the ice sheets held about 70 million cubic kilometers of ice. Now, the ice sheets in Antarctica and Greenland hold only about 25 million cubic kilometers of ice.

During the last glacial period, the water that made up the additional 45 million cubic kilometers of ice is thought to have come from the oceans. As a result, sea level was as much as 140 m lower during the last glacial period than it is today. Since the last glacial period, the ice sheets have been melting and sea level has been rising at a rate of about 1 mm per year, as shown in **Figure 1.** If the polar icecaps were to melt completely, the oceans would rise about 60 m and submerge low-lying coastal regions, including many large cities, such as New York, Los Angeles, Miami, and Houston.

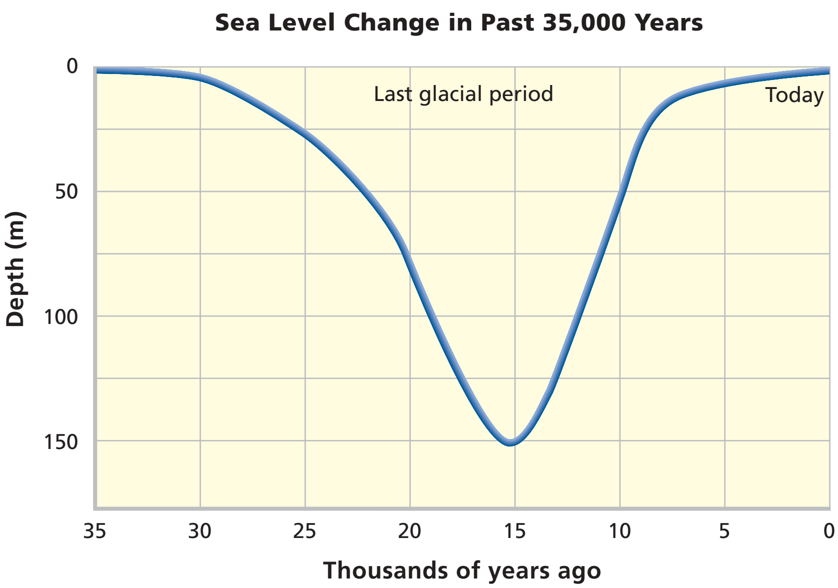


Figure 1 ▶ This graph shows how sea level has changed during the past 35,000 years.

QuickLAB 35 min

Graphing Tides

Procedure

1. Research the daily tidal data for a certain area for a calendar month.
2. Graph the tide measurements on a line graph.

Analysis

1. When was high tide? When was low tide?
2. What kind of sea-level changes do tides represent?
3. Research the full and new moon dates for the time period you graphed. How does the moon correspond with your high- and low-tides?

Relative Sea-Level Changes

Absolute sea level changes when the amount of water in the ocean changes. Relative sea level changes when the land or features near the coast change. These changes can be caused by large-scale geologic processes or by localized coastal changes. For example, movements of Earth's crust can cause coastlines to sink or to rise. Coastlines near a tectonic plate boundary may change as tectonic plates move. When coastlines change, the relative sea-level of that area also changes.

Submergent Coastlines

When sea level rises or when land sinks, a *submergent coastline* forms. Divides between neighboring valleys become headlands separated by bays and inlets, and submerged peaks may form offshore islands, as shown in **Figure 2.** Beaches are generally short, narrow, and rocky. When U-shaped glacial valleys become flooded with ocean water as sea level rises, spectacular narrow, deep bays that have steep walls, called *fiords* (FYAWRDZ), form.

The mouth of a river valley that is submerged by ocean water may become a wide, shallow bay that extends far inland. This type of bay, where salt water and fresh water mix, is called an **estuary** (ES tyoo er ee).

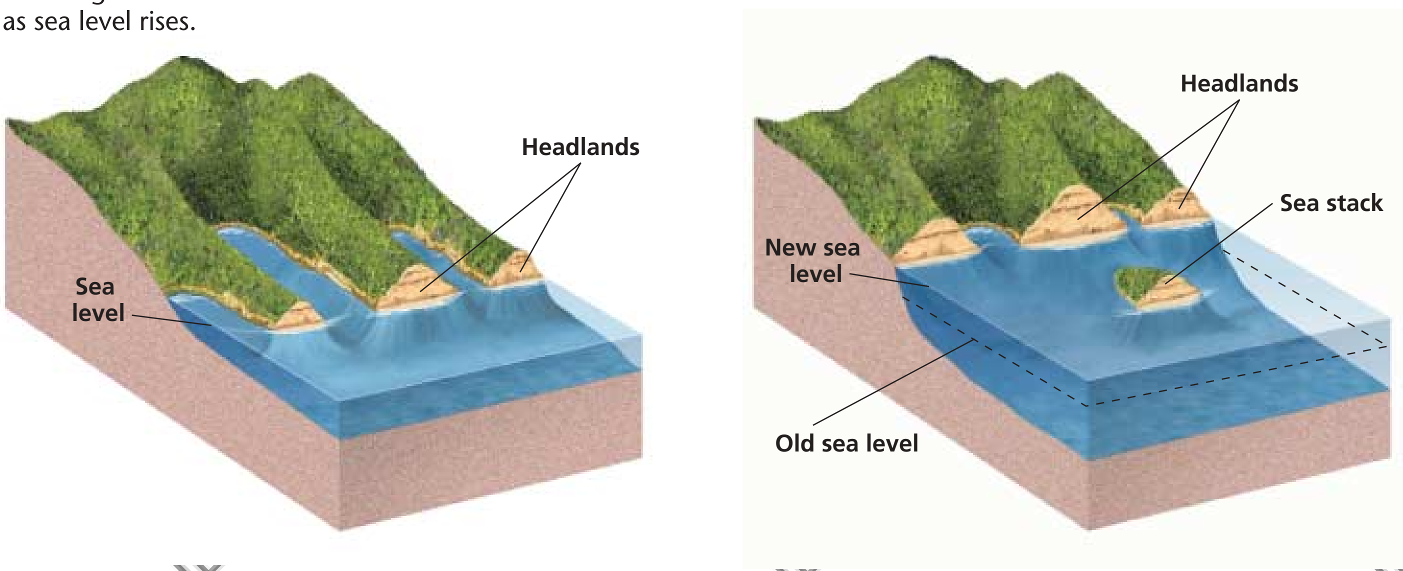
estuary an area where fresh water from rivers mixes with salt water from the ocean; the part of a river where the tides meet the river current

Emergent Coastlines

When the land rises or when sea level falls, an *emergent coastline* forms. If an emergent coastline has a steep slope and is exposed rapidly, the coastline will erode to form sea cliffs, narrow inlets, and bays. A series of wave-cut terraces may be exposed as well.

A gentle slope forms when part of the continental shelf is slowly lifted and exposed. The gentle slope forms a smooth coastal plain that has few bays or headlands and that has many long, wide beaches.

Figure 2 ▶ The features of a submergent coastline erode over time as sea level rises.



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Barrier Islands

As sea level rises over a flat coastal plain, the shoreline moves inland and isolates dunes from the old shoreline to form barrier islands, such as the one shown in **Figure 3.** **Barrier islands** are long, narrow ridges of sand that lie nearly parallel to the shoreline. Barrier islands can be 3 to 30 km offshore and can be more than 100 km long. Between a barrier island and the shoreline is a narrow region of shallow water called a **lagoon.**

Barrier islands also form when sand spits are separated from the land by storms or when waves pile up ridges of sand that were scraped from the shallow, offshore sea bottom. These deposits are then moved toward the shore by waves, currents, and winds. This motion causes most barrier islands to migrate toward the shoreline. Winds blowing toward the land often create a line of dunes that are 3 to 6 m high on the side of the island that faces the shore.

Large waves from storms, especially waves from hurricanes, may severely erode barrier islands. During a storm, sand washes from the ocean side toward the inland side of the island. Some barrier islands are eroding at a rate of about 20 m per year.

Reading Check **How do barrier islands form? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Santa Rosa Island is a long, narrow barrier island that is located off the coast of Florida.

barrier island a long ridge of sand or narrow island that lies parallel to the shore

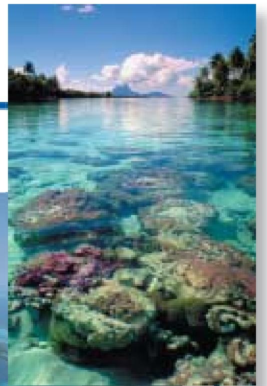
lagoon a small body of water separated from the sea by a low, narrow strip of land

Connection to BIOLOGY

Coral Reefs

A common coastal feature called a *reef* forms when small marine animals called *corals*, which live in warm, shallow sea water, grow. Corals extract calcium carbonate from ocean water and use it to build a hard outer skeleton. Corals attach to each other to form a large colony made of millions of coral skeletons.

Fringing reefs form when a coral colony grows in the shallow water around a tropical volcanic island. As the sea floor bends under the weight of the volcano, both the volcano and the reef sink. The coral builds higher to form a *barrier reef* around the remnant of the volcanic island. When the island is completely submerged, a nearly circular coral reef, called an *atoll,* remains around a shallow lagoon.



A coral reef completely surrounds the island of Bora Bora in French Polynesia.

7845

Figure 4 ▶ Engineers inspect beach erosion caused by hurricane Bonnie, which struck Wrightsville Beach, North Carolina.

Preserving the Coastline

Coastal lands are used for commercial fishing, shipping, industrial and residential development, and recreation. While development of coastal areas is economically important, it can also damage coastal areas in several ways. Pollution is a serious threat to coastal resources. Oil spills are a threat because tankers travel near shorelines and because oil wells are drilled offshore. Garbage, pollution from industry, and sewage from towns on the coast can pollute the coastline. This pollution can damage habitats and kill marine birds and other animals.

To preserve the coastal zone, private owners and government agencies often work together to set guidelines for coastal protection. Some coastal towns have brought sand from other places to rebuild beaches eroded by severe storms as shown in **Figure 4.** Coastal development in some environmentally sensitive areas, such as the North Carolina coast has been slowed or stopped completely in an attempt to protect these important areas.

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

Topic: Coastal Changes
SciLinks code: HQ60307

Section 3 Review

1. **Explain** how changes in sea level affect coastlines.
2. **Explain** how the formation of a submergent coastline differs from the formation of an emergent coastline.
3. **Describe** two features of a barrier island.
4. **Explain** why barrier islands are particularly sensitive to erosion.
5. **Describe** two ways in which human activity affects coastlines.

CRITICAL THINKING

6. **Making Predictions** Predict the effect that a season of heavy storms would have on a barrier island.
7. **Identifying Relationships** If Earth were to enter a new glacial period, how might coastlines around the world change?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *coastline, emergent coastline, submergent coastline, barrier island,* and *lagoon.*

Chapter 18 Highlights

Sections

1 Wind Erosion

Key Terms

saltation, 445
deflation, 446
ventifact, 447
dune, 447
loess, 450

Key Concepts

- Wind transports sediment by saltation and by deflation. Saltation is the movement of particles by a series of jumps or bounces. Deflation is the process of carrying small particles that are suspended in air currents.
- Wind erosion forms desert pavement, deflation hollows, and ventifacts.
- The two types of wind deposits are dunes, which are generally made of sand, and loess, which is made of dust particles.

2 Wave Erosion

headland, 452
beach, 453
longshore current, 454

- Waves weather and erode the shoreline and produce characteristic features, such as sea cliffs, sea caves, sea arches, sea stacks, terraces, and beaches.
- Beaches form from the deposition of sediments by waves.
- Longshore currents move sediments parallel to a shoreline.

3 Coastal Erosion and Deposition

estuary, 456
barrier island, 457
lagoon, 457

- Coastlines are exposed or submerged as sea level changes.
- Barrier islands are long, narrow offshore ridges of sand.
- Human activities, including development and pollution, affect land along the coasts.

Chapter 18 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *ventifact*
2. *longshore current*
3. *loess*

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

4. *saltation* and *deflation*
5. *headland* and *beach*
6. *barrier island* and *lagoon*

Understanding Key Concepts

7. Wind forms desert pavement by removing fine sediment and by leaving large rocks behind in a process called
   a. saltation. **c.** deflation.
   b. abrasion. **d.** ventifact.

8. Wind moves sand by
   a. saltation. **c.** abrasion.
   b. emergence. **d.** depression.

9. Dunes move primarily by the process called
   a. abrasion. **c.** deflation.
   b. migration. **d.** submergence.

10. Thinly layered, yellowish, fine-grained deposits are called
    a. beaches.
    b. loess.
    c. dunes.
    d. desert pavement.

11. The most important erosion agent along shorelines is
    a. wave action. **c.** wind.
    b. weathering. **d.** the tide.

12. Which of the following shoreline features is *not* produced by wave erosion of sea cliffs?
    a. spits **c.** wave-cut terraces
    b. sea stacks **d.** sea arches

13. Longshore-current deposition of sand at the end of a headland produces a
    a. sand bar. **c.** dune.
    b. spit. **d.** sea cliff.

14. Sea level is now
    a. stationary.
    b. falling about 1 mm per year.
    c. rising about 1 cm per year.
    d. rising about 1 mm per year.

15. Barrier islands tend to migrate
    a. away from the shore.
    b. along the shore.
    c. in the summer.
    d. toward the shore.

Short Answer

16. What is the difference between an emergent coastline and a submergent coastline?

17. Explain what may happen if shoreline resources are not protected.

18. What factors affect the composition of a beach?

19. Explain the difference between the four main types of dunes.

20. Explain the difference between absolute sea-level change and relative sea-level change.

Critical Thinking

21. **Identifying Relationships** The deserts of the southwestern United States contain many tall, sculpted rock formations. Was wind or water erosion the most likely agent responsible for these formations? Explain.

22. **Making Inferences** Suppose that one time each month for a year a satellite orbiting Earth takes a photograph of the same sandy, 1 km^2 area of the Sahara. Would the surface features shown in these 12 photographs remain essentially the same, or would they vary? Explain your answer.

23. **Inferring Relationships** Wave energy decreases when waves travel through shallow water. Based on this information, what effect do you think development of a wave-built terrace has on erosion of the shoreline? Explain your answer.

Concept Mapping

24. Use the following terms to create a concept map: *wave erosion, beaches, spit, berm,* and *tombolos.*

Math Skills

25. **Making Calculations** Suppose that sea level continuously rises at the rate of 1 mm per year and that other factors affecting the coastlines do not change. How many kilometers will sea level rise in 1 million years?

26. **Applying Quantities** Every year, 25 km^3 of sand is deposited on a beach by a nearby river, and 28 km^3 of sand is removed by wave action. Is the size of the beach increasing or decreasing? Explain.

Writing Skills

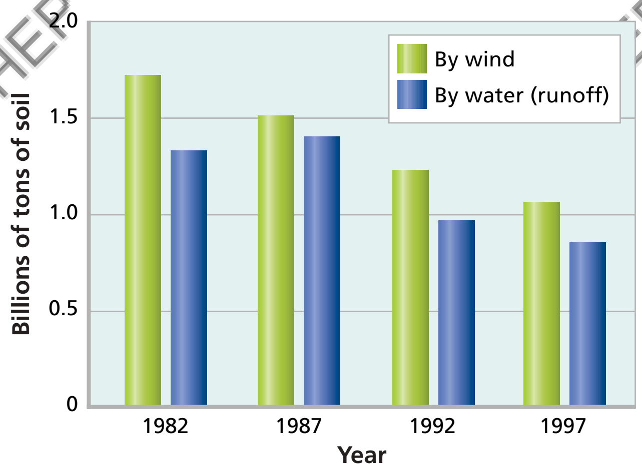
27. **Creative Writing** Imagine that you are a newspaper reporter who has traveled to another planet. Scientists know that, at one time, both wind and water eroded the surface of the planet. Prepare a news release that describes the landscape you see and explains the processes that produced it.

28. **Writing Persuasively** You have learned that beautifully colored sunsets and sunrises are the result of dust in the atmosphere. Write a letter or essay to your doubting friend to convince him or her that sunsets and sunrises are caused by dust. Use the evidence that remarkable sunsets were visible around the world for two years after the 1883 eruption of Krakatau, a volcanic island in Indonesia, in your essay.

Interpreting Graphics

The graph below shows soil erosion in the United States by wind and water from 1982 to 1997. Use this graph to answer the questions that follow.

Soil Erosion in the United States, 1982–1997



29. Which year had the most combined soil erosion?

30. Which year had the most soil erosion due to water?

31. Do you predict more or less soil erosion by wind in future years? Explain your answer.

32. Would you expect that the amount of soil erosion in the United States would ever be zero? Explain your answer.

Chapter 18 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 Which of the following factors most affects the rate at which waves erode land features along the shore?
- **A** temperature of the waves
- **B.** direction in which waves approach shores
- **C.** shape of the rock formation
- **D.** compostion of the rock formation

2 Why are dust particles more likely to remain in the atmosphere longer and travel farther than sand particles?
- **F.** Sand grains are carried higher and fall.
- **G.** Dust particles are smaller and lighter.
- **H.** Sand grains are made from rocks.
- **I.** Dust is moved by the process of saltation.

3 What is the term for rocks or pebbles that have flat, polished surfaces caused by wind abrasion?
- **A.** bedrock
- **B.** compaction
- **C.** pinnacles
- **D.** ventifacts

4 What is the name for a submerged river valley mouth that forms a bay where salt and fresh water mix?
- **F.** estuary
- **G.** fiord
- **H.** atoll
- **I.** lagoon

5 Why is erosion by wind more common in arid climates than in other regions of the world?
- **A.** arid climates have much thicker soil layers
- **B.** arid climates have less frequent dust storms
- **C.** arid climates have less plant cover to anchor soil
- **D.** arid climates have more moisture to hold soil

Directions (6–7): **For *each* question, write a short response.**

6 What is the primary method of dune movement?

7 What factor is most important in determining the composition of beach materials?

Reading Skills

Directions (8–10): **Read the passage below. Then, answer the questions.**

Black Blizzards

The area that covers parts of Colorado, Kansas, New Mexico, Oklahoma, and Texas had been converted from natural grassland to farmland in the early 1900s. Many of the plants brought in to replace the natural prairie grasses had shallow root systems that could not hold soil in place. Much of the rest of the grassland was turned over to grazing land for hungry livestock.

During the 1930s, a long period of drought set in and the already dry soil turned to dust. In the spring of 1934, high winds blew black dust clouds across the dry wheat fields of these states. Some of the dust settled only when it reached Boston and New York City. The sky turned black at mid-day. And when the dust fell, houses were coated with thick layers of dust. Roads and fences were covered by dust. The remaining crops that had survived the droughts suffocated on the ground as the dust blocked the sunlight and other nutrients. Millions of people left their farms in search of a better life.

8 According to the passage, how far did some of the dust travel during the dust storms of 1934?
- **A.** all the way to the Pacific Ocean
- **B.** all the way to the Atlantic Ocean
- **C.** only as far as the Rocky Mountains
- **D.** only as far as the Great Smokey Mountains

9 Which of the following statements can be inferred from the information in the passage?
- **A.** The dust storms from the 1930s continued well into the 1940s.
- **B.** Black blizzards are common occurances in the states of Texas and Colorado.
- **C.** One of the main causes of the dust storms of the 1930s was misuse of land by humans.
- **D.** Damage from the dust storms of the 1930s can still be seen today in states such as Texas and Oklahoma.

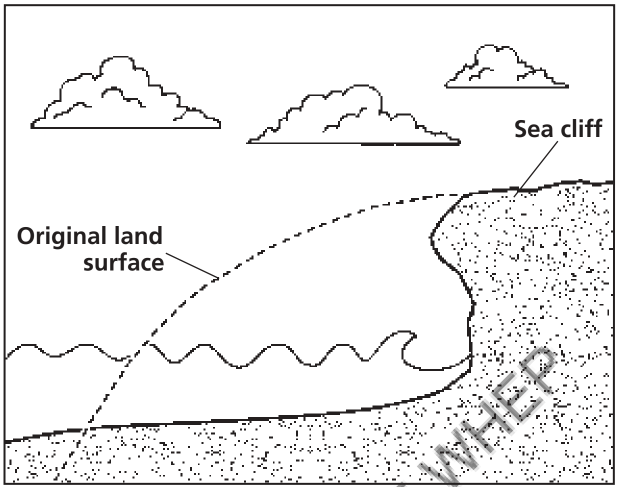
10 Briefly describe how high winds and an extensive drought could combine to produce the terrible conditions seen during the 1930s.

Interpreting Graphics

Directions (11–12): **For *each* question below, record the correct answer on a separate sheet of paper.**

Base your answers to question 11 on the image of an eroding sea cliff . The projecting headland of the cliff is composed of granite, and the hillside below is made of limestone.

Erosion of a Sea Cliff

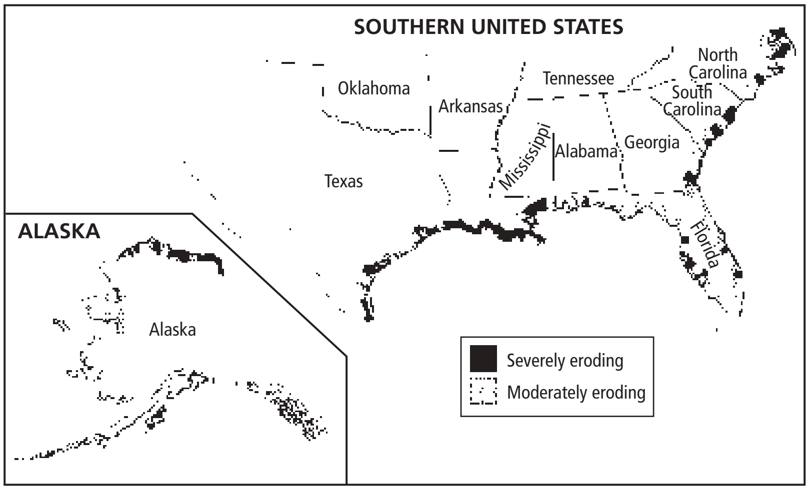


11 The coastal landforms shown were most likely formed as a result of the action of

A. glacial movements
B. seismic activity
C. sea level changes
D. waves and weathering

Base your answers to question 12 on the map below, which shows shoreline changes across the United States.

Map of Coastal Erosion Patterns



12 How might human activities along the rivers that empty into the Gulf of Mexico and the coastal shoreline play a part in the increasing rate of erosion that is affecting the region?

Test TIP

Do not spend a long period of time on any single question. Mark a question that you cannot answer quickly, and come back to it.

7851

Chapter 18

Inquiry Lab

Using Scientific Methods

Objectives

- **Model** the effects of wave action and longshore currents on a beach.
- **Identify** ways to decrease the effects of wave action on beach sand.

Materials

block, plaster (2)
block, wooden, large
container, plastic, large
pebbles
ruler, metric
sand, 5 to 10 lb
water

Safety

Beaches

Coastal management is a growing concern because beaches are increasingly used for resources and recreation. The supply of sand for many beaches has been cut off by dams built on rivers and streams that are used to carry sand to the sea. Waves generated by storms also continuously wear away beaches. In some places, breakwaters have been built offshore to protect beaches from washing away. In this lab, you will examine how wave action may change the shape of beaches and how these changes can be reduced.

ASK A QUESTION

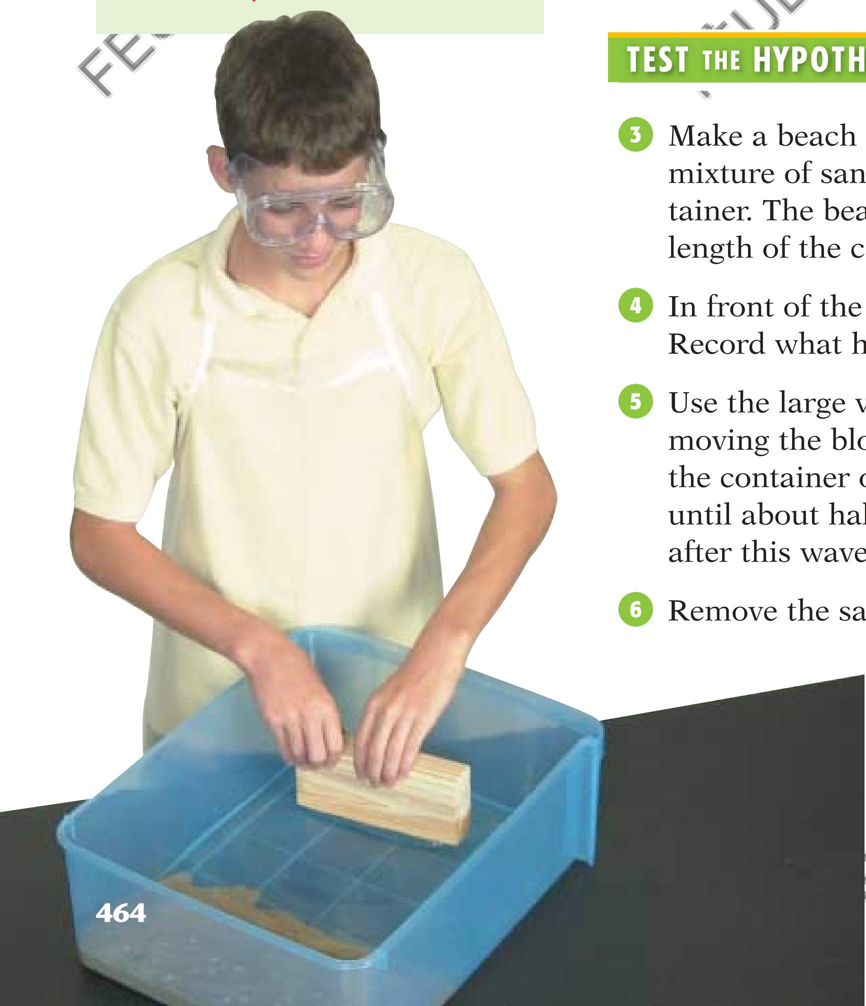
1. How does wave action affect the amount of sand on a beach? How can these effects be reduced?

FORM A HYPOTHESIS

2. Form a hypothesis that answers your question. Explain your reasoning.

TEST THE HYPOTHESIS

3. Make a beach in a large, shallow container by placing a mixture of sand and small pebbles at one end of the container. The beach should occupy about one-fourth of the length of the container.
4. In front of the sand, add water to a depth of 2 to 3 cm. Record what happens.
5. Use the large wooden block to generate several waves by moving the block up and down in the water at the end of the container opposite the beach. Continue this wave action until about half the beach has moved. Describe the beach after this wave action has taken place.
6. Remove the sand, and rebuild the beach.



Step 5

7. Design three breakwaters that change the flow of water along the beach. Draw your designs on a piece of paper. The two top photos at right are samples of some breakwater arrangements.
8. Have your teacher approve your designs before you build them into your model beach.
9. Use the two plaster blocks to model the first breakwater that you designed. Use a wooden block to generate waves as in step 5. Record your observations.
10. Use the wooden block to generate waves that move parallel to the beach. Record your observations.
11. Repeat steps 9 and 10 for each of your other two designs. Record your observations.

Step 7

Step 7

Step 10

ANALYZE THE RESULTS

1. **Making Comparisons** How does wave action build up a beach? How does wave action wear away a beach?
2. **Explaining Events** Describe what happened to the shape of the waves along the beach in step 10.
3. **Analyzing Results** How do breakwaters modify the effect that longshore currents have on the shape of a beach?

DRAW CONCLUSIONS

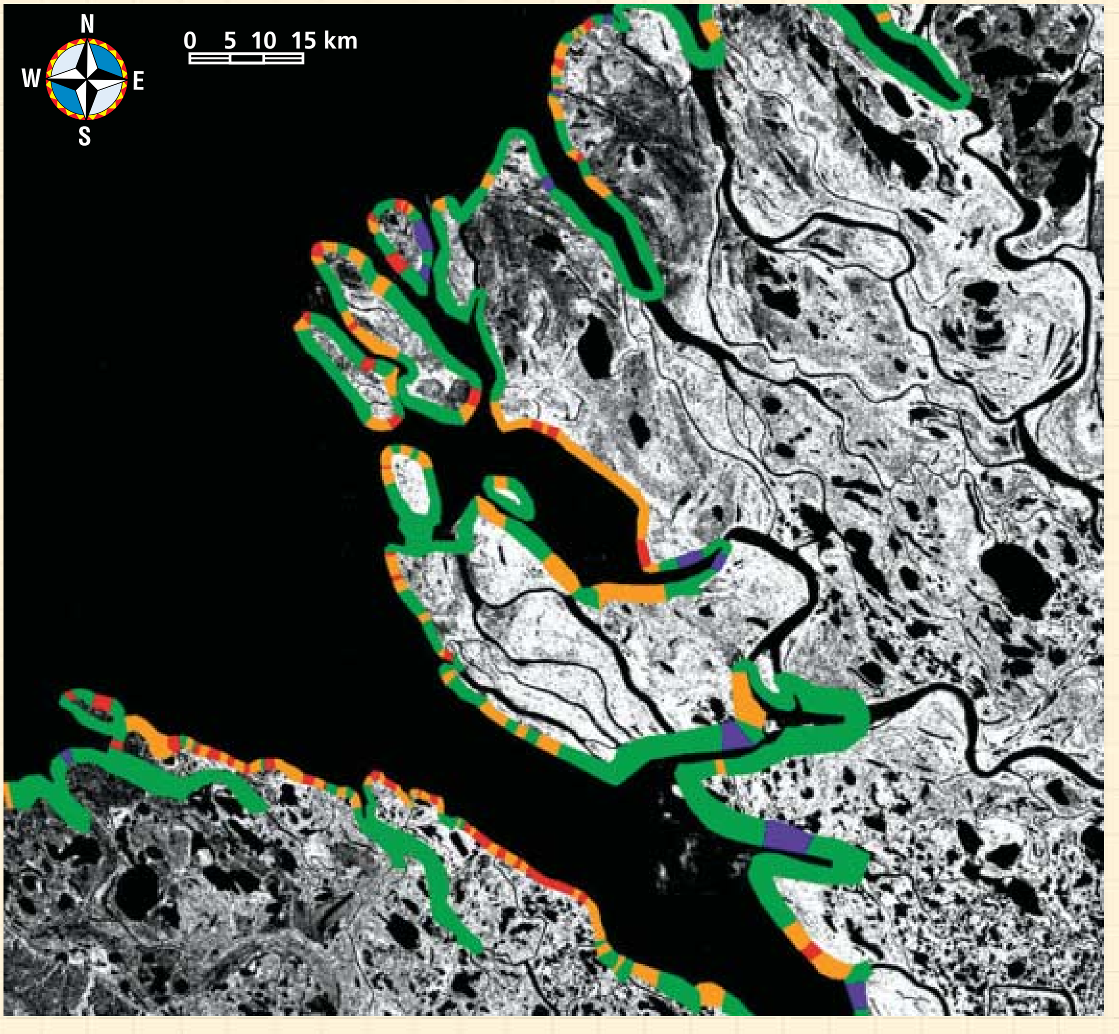
4. **Making Predictions** Predict what will happen to a beach that is affected by wave action if it had no source of additional sand.
5. **Drawing Conclusions** What effect would a series of jetties have on a beach?

Extension

1. **Research and Communications** Research what can be done to preserve a recreational beach from erosion that is caused by excessive use by people. Write a letter to a local authority outlining a plan of action to protect that beach.

MAPS in Action

Coastal Erosion Near the Beaufort Sea



Rapid erosion
(>5 m/per year)

Moderate erosion
(1 to 5 m/per year)

No detectable erosion
(–1 to 1 m/per year)

Deposition
(<–1 m/per year)

Areas of accretion are shown in blue. Accretion occurs when more material is deposited than is eroded.

Map Skills Activity

This map shows the coastline of the Beaufort Sea in Canada along with computed amounts of shoreline erosion and accretion. Use the map to answer the questions below.

1. **Using the Key** How many areas of accretion are shown on the map?
2. **Using the Key** What is the level of erosion that is present in most areas shown?
3. **Analyzing Data** Is the estimated overall shoreline change for the entire area shown a positive value (accretion) or a negative value (erosion)?
4. **Making Comparisons** Is there more erosion on the coastal area toward the north or on the area toward the south?
5. **Inferring Relationships** Is the area shown in the map more significantly affected by the effects of waves along the shoreline or by the depositional actions of rivers that enter the ocean? Explain your answer.
6. **Identifying Trends** If present conditions remain the same, what would you expect to happen to the five small islands that are located on the northwest area of the map.

IMPACT on Society

The Flooding of Venice

The city of Venice, Italy, is famous for its canals and priceless art treasures. Venice is built on about 120 islands in the Adriatic Sea.

◀ Flooding in St. Mark's square invites residents to be creative about their transportation.

A City Underwater

The waters of the Adriatic Sea constantly threaten Venice. Every year, winter storms cause sea water to flood the city's public squares, walkways, and buildings. Venice's famous St. Mark's Square may flood more than 100 times per year. Overexposure to floodwaters is slowly eroding the foundations of the city's Byzantine and Renaissance architecture. The city's sidewalks are buckled because the water has eroded the ground underneath them.

These floods are the result of three factors: erosion, rising sea level, and sinking land. Erosion of barrier beaches and sandbars allows high tides to reach farther into Venice. Also, the Adriatic Sea is rising. Its average sea level has risen 11 cm over the last 100 years, and Venice has sunk 13 cm.

The weight of added sediments is causing the city to sink about 1 mm per year. Removal of too much groundwater and the weight of the buildings within the city have caused additional sinkage.

An Uncertain Future

To prevent future and permanent damage to Venice, the city restricts the pumping of groundwater. Pavement is often raised to help keep the city above water and to minimize erosion caused by floodwaters. Massive floodgates have been built to block high tides that threaten the city. In addition, city planners are constructing a system to pump fluids into the aquifer below the lagoon to raise the level of water in the aquifer.

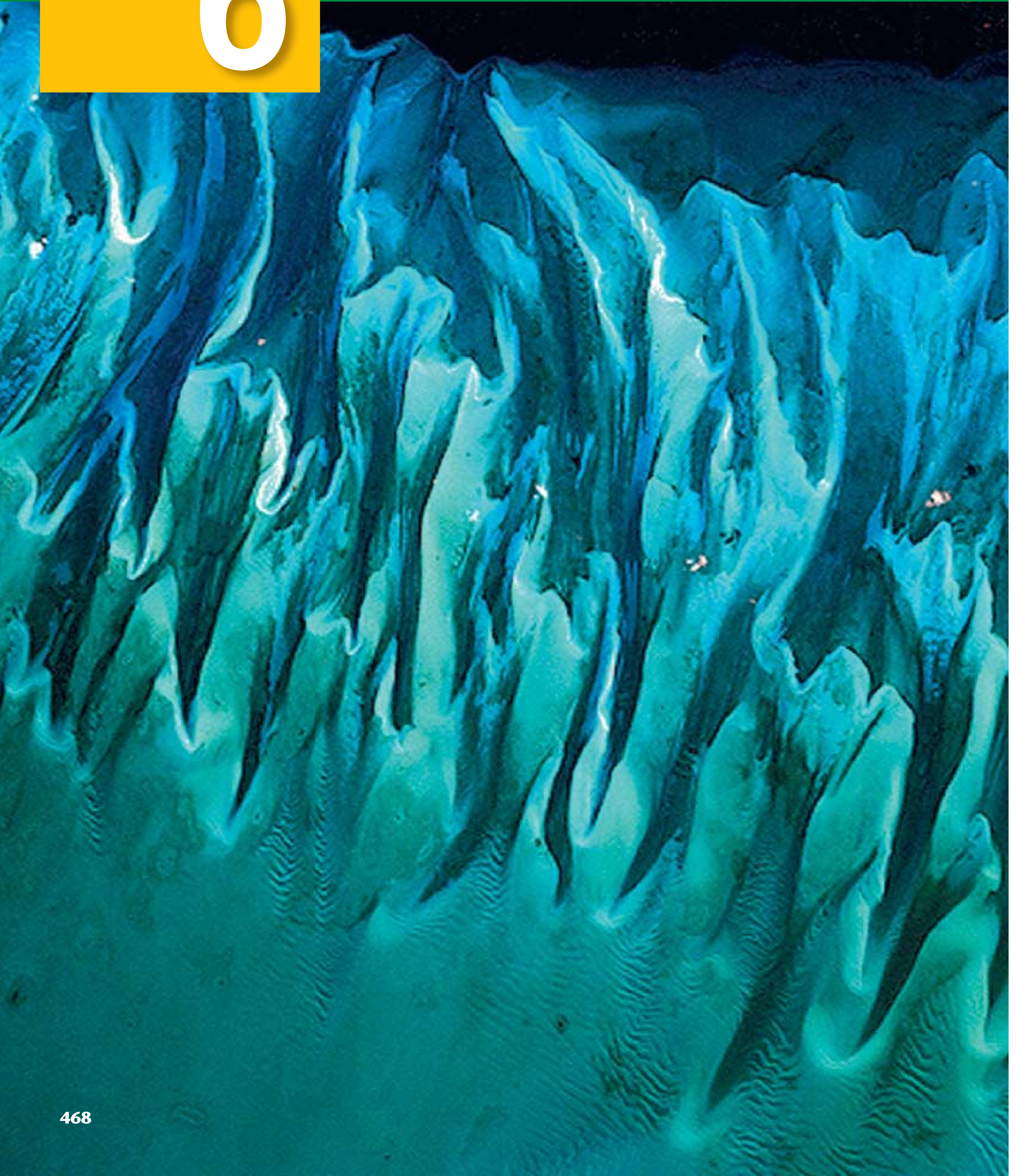
◀ Flooding causes erosion in wood, brick, and stone. Many building foundations are slowly dissolving into the waters of the Adriatic Sea.

Extension

1. **Researching Trends** Research another area of the world that is grappling with regular flooding. How is that city or town dealing with the erosion that is caused by flooding?

7855

Unit 6 OCEANS



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Unit 6 Outline

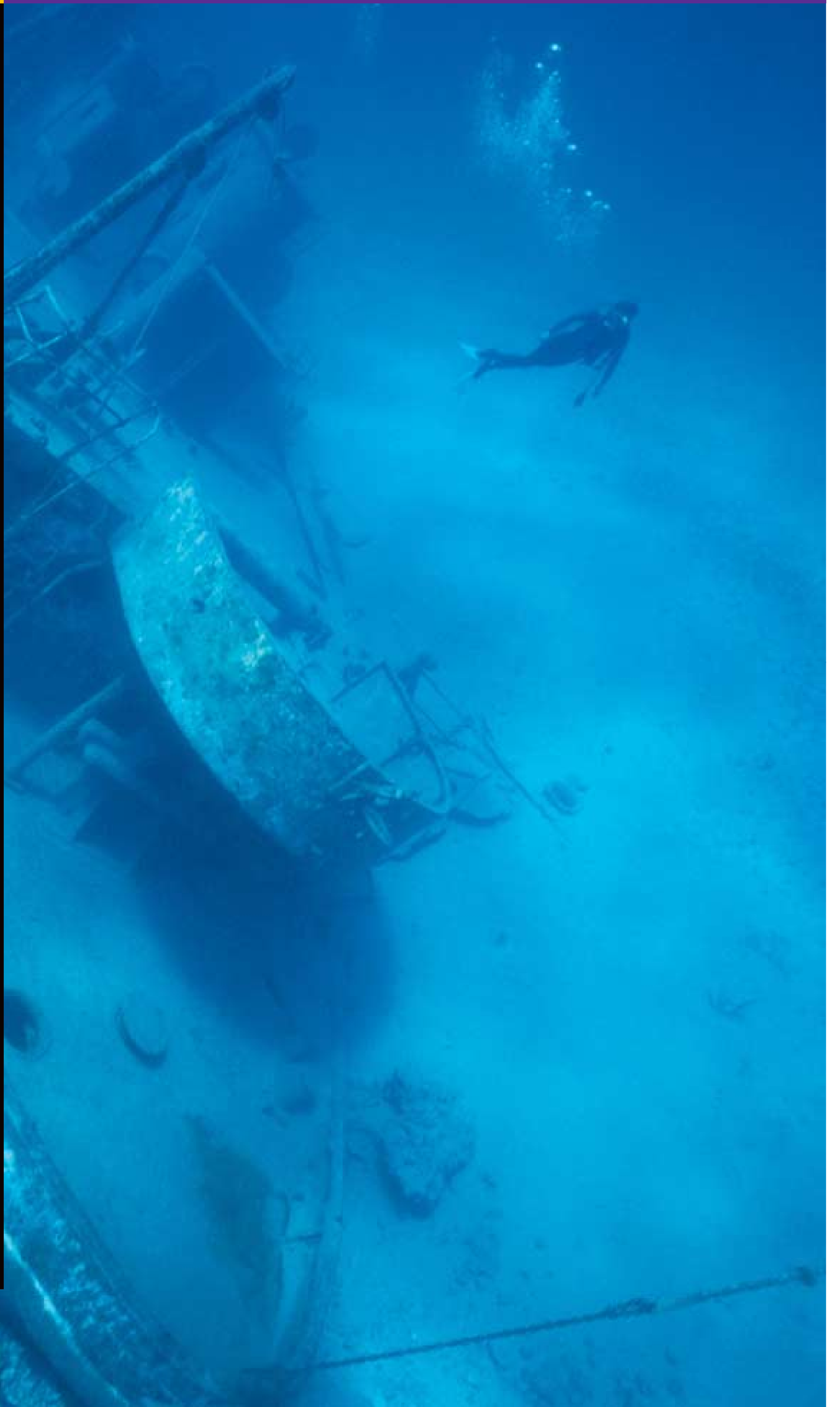
CHAPTER 19
The Ocean Basins

CHAPTER 20
Ocean Water

CHAPTER 21
Movements of the Ocean

▶ Oceans affect coastlines, climates, and aquatic life around the world. As shown in this satellite image of the Bahamas in the Caribbean Sea, ocean currents and tides have shaped the sand and seaweed beds so that from space the beds appear to be blue flames of a fire.

Chapter 19 The Ocean Basins



Sections

What You'll Learn

- Why scientists study the ocean
- What the features of the ocean basins are
- How ocean-floor sediments are classified

Why It's Relevant

The oceans interact with the atmosphere and the land to affect weather, climate, and the shape of continents. Exploration of the oceans explains how these interactions shape Earth's surface.

PRE-READING ACTIVITY

FOLDNOTES

Booklet Before you read the chapter, create the **FoldNote** entitled "Booklet" described in the Skills Handbook section of the Appendix. Label each page of the booklet with a main idea from the chapter. As you read the chapter, write what you learn about each main idea on the appropriate page of the booklet.

▶ The ocean floors contain evidence of changes in Earth over time and of human endeavors. This is the wreckage of the *Ora Verde,* a ship that was lost near the Grand Cayman Islands.

Section 1 The Water Planet

Nearly three-quarters of Earth's surface lies beneath a body of salt water called the **global ocean.** No other known planet has a similar covering of liquid water. Only Earth can be called the *water planet*.

The global ocean contains more than 97% of all of the water on Earth. Although the ocean is the most prominent feature of Earth's surface, the ocean is only about 1/4,000 of Earth's total mass and only 1/800 of Earth's total volume.

OBJECTIVES

- **Name** the major divisions of the global ocean.
- **Describe** how oceanographers study the ocean.
- **Explain** how sonar works.

KEY TERMS

global ocean
sea
oceanography
sonar

Divisions of the Global Ocean

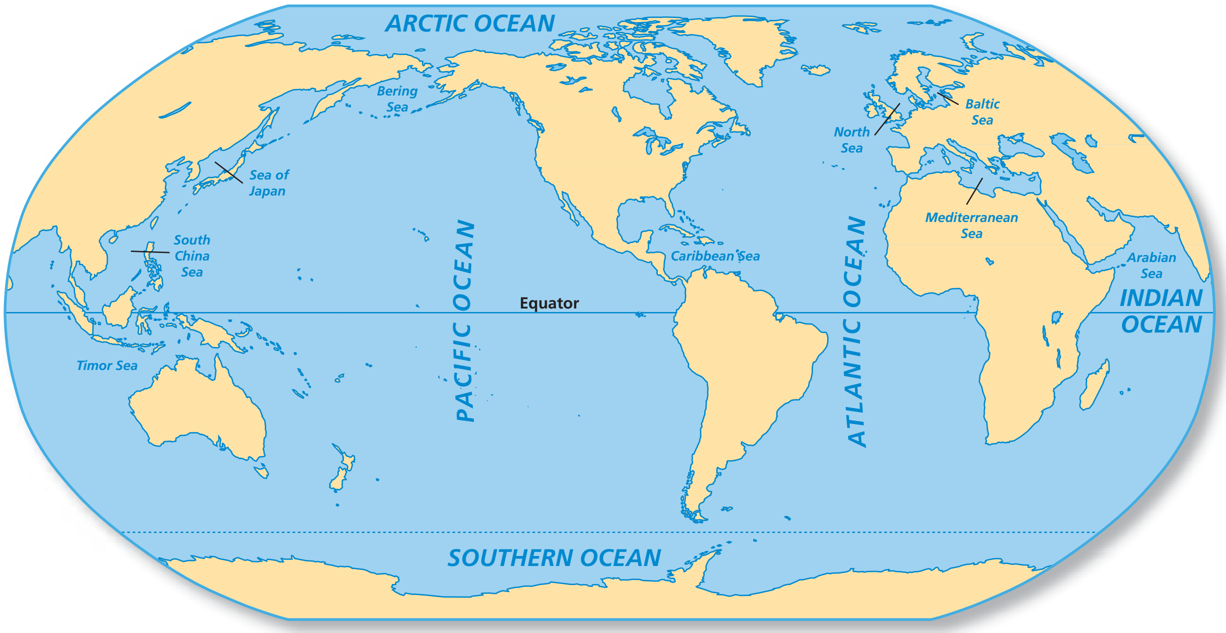
As shown in **Figure 1,** the global ocean is divided into five major oceans. These major oceans are the Atlantic, Pacific, Indian, Arctic, and Southern Oceans. Each ocean has special characteristics. The Pacific Ocean is the largest ocean on Earth's surface. It contains more than one-half of the ocean water on Earth. With an average depth of 4.3 km, the Pacific Ocean is also the deepest ocean. The next largest ocean is the Atlantic Ocean. The Atlantic Ocean has an average depth of 3.9 km. The Indian Ocean is the third-largest ocean and has an average depth of 3.9 km. The Southern Ocean extends from the coast of Antarctica to 60°S latitude. The Arctic Ocean is the smallest ocean, and it surrounds the North Pole.

A **sea** is a body of water that is smaller than an ocean and that may be partially surrounded by land. Examples of major seas include the Mediterranean, Caribbean, and South China Seas.

global ocean the body of salt water that covers nearly three-fourths of Earth's surface

sea a large, commonly saline body of water that is smaller than an ocean and that may be partially or completely surrounded by land

Figure 1 ▶ The global ocean is divided into oceans and seas. ***How many oceans are on Earth?***



Exploration of the Ocean

oceanography the scientific study of the ocean, including the properties and movement of ocean water, the characteristics of the ocean floor, and the organisms that live in the ocean

The study of the physical characteristics, chemical composition, and life-forms of the ocean is called **oceanography.** Although some ancient civilizations studied the ocean, modern oceanography did not begin until the 1850s.

The Birth of Oceanography

An American naval officer named Matthew F. Maury used records from navy ships to learn about ocean currents, winds, depths, and weather conditions. In 1855, he published these observations as one of the first textbooks about the oceans. Then, from 1872 to 1876, a team of scientists aboard the British Navy ship HMS *Challenger* crossed the Atlantic, Indian, and Pacific Oceans. The scientists measured water temperatures at great depths and collected samples of ocean water, sediments, and thousands of marine organisms. The voyages of the HMS *Challenger* laid the foundation for the modern science of oceanography.

Today, many ships perform oceanographic research. In the 1990s and in the beginning of the 21st century, the research ship *JOIDES Resolution* was the world's largest and most sophisticated scientific drilling ship. Samples drilled by *JOIDES Resolution*, shown in **Figure 2,** provide scientists with valuable information about plate tectonics and the ocean floor. The Japanese ship *CHIKYU*, which is operated by the Integrated Ocean Drilling Program, is one of the most advanced drilling ship now in use.

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Topic: The Oceans
SciLinks code: HQ61069

Reading Check **List three characteristics of the ocean that oceanographers study.** **(See the Appendix for answers to Reading Checks.)**

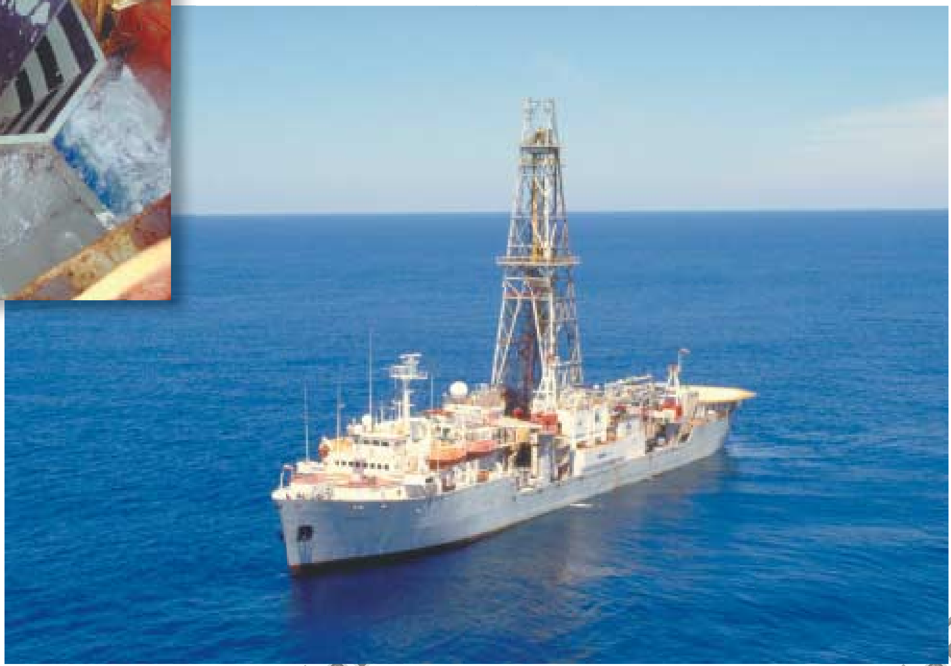


Figure 2 ▶ Reentry cones (above) are used so that core samples can later be taken from the same place on the ocean floor. Scientists aboard the research ship *JOIDES Resolution* (right) perform scientific studies of the ocean floor.

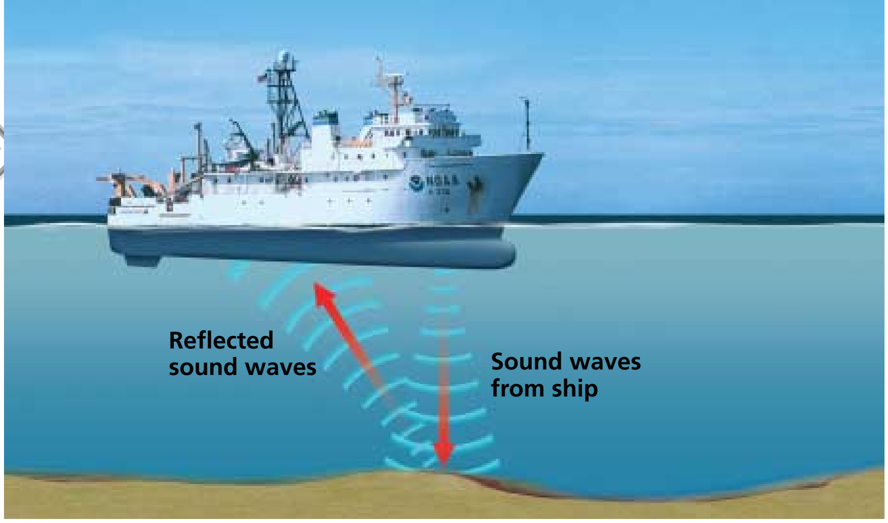


Figure 3 ▶ Active sonar sends out a pulse of sound. The pulse, called a *ping* because of the way it sounds, reflects when it strikes a solid object.

Sonar

Oceanographic research ships are often equipped with sonar. **Sonar** is a system that uses acoustic signals and returned echoes to determine the location of objects or to communicate. Sonar is an acronym for ***so****und* ***n****avigation* ***a****nd* ***r****anging*. A sonar transmitter sends out a continuous series of sound waves from a ship to the ocean floor, as shown in **Figure 3.** The sound waves travel about 1,500 m/s through sea water and bounce off the solid ocean floor. The waves reflect back to a receiver. Scientists measure the time that the sound waves take to travel from the transmitter, to the ocean floor, and to the receiver in order to calculate the depth of the ocean floor. Scientists then use this information to make maps and profiles of the ocean floor.

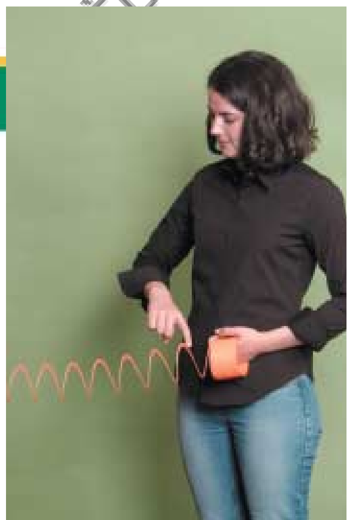
sonar *sound navigation and ranging,* a system that uses acoustic signals and returned echoes to determine the location of objects or to communicate

QuickLAB 30 min

Sonar

Procedure

1. Use **heavy string** to tie one end of a **spring** securely to a **doorknob.** Pull the spring taut and parallel to the floor. You will need to keep the tension of the spring constant throughout the lab.
2. Use **masking tape** to mark the floor directly beneath the hand that is holding the spring taut. Use a **meterstick** to measure and record the distance from that hand to the doorknob.
3. Note the time on a **stopwatch or clock with a second hand.** Hold the spring taut, and hit the spring horizontally to create a compression wave.
4. Check the time again to see how long the pulse takes to travel to the doorknob and back to your hand. Record the time.
5. Repeat steps 2–4 three times. Each time, hold the spring 60 cm closer to the doorknob. Keep tension constant by gathering coils as necessary.
6. Calculate the rate of travel for each trial by multiplying the distance between your hand and the doorknob by 2. Then, divide by the number of seconds the pulse took to travel to the doorknob and back.



Analysis

1. Did the rate the pulse traveled change during the course of the investigation?
2. If a pulse took 3 s to travel to the doorknob and back to your hand, what is the distance from the doorknob to your hand?
3. How is the apparatus you used similar to sonar? How is the apparatus different than sonar? Explain.

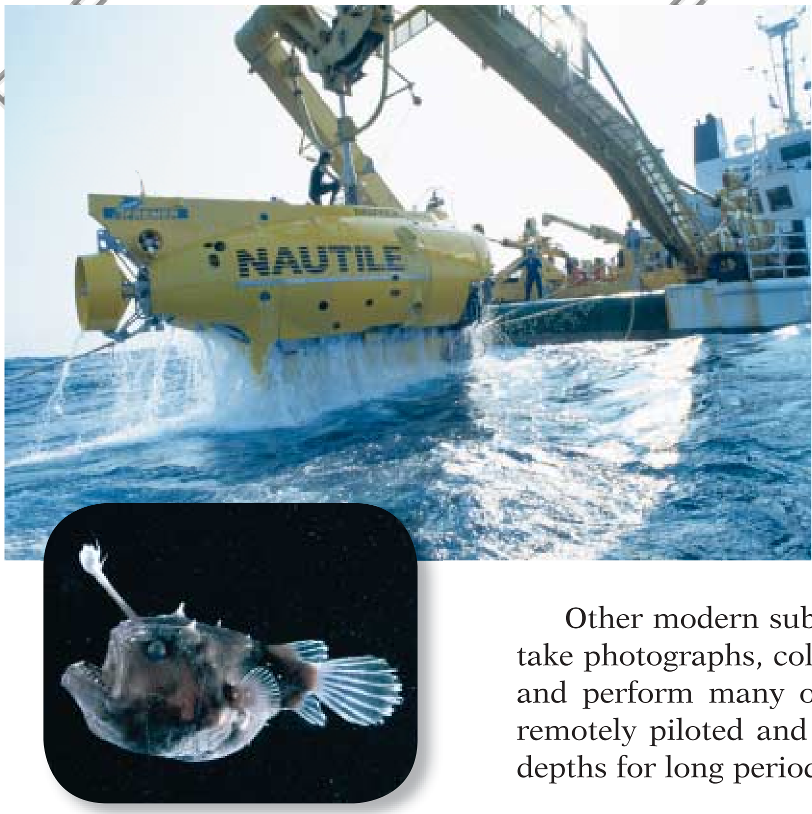


Figure 4 ▶ The submersible *Nautile* (top) carries enough oxygen to keep a three-person crew underwater for more than five hours. Deep-sea submersibles have discovered many strange organisms in the deep ocean, such as this angler fish (bottom).

Submersibles

Underwater research vessels, called *submersibles,* also enable oceanographers to study the ocean depths. Some submersibles are piloted by people. One such submersible is the *bathysphere,* a spherical diving vessel that remains connected to the research ship for communications and life support. Another type of piloted submersible, called a *bathyscaph,* is a self-propelled, free-moving submarine. One of the most well-known bathyscaphs is the *Alvin*. Another modern submersible, called *Nautile* (NOH teel), is shown in **Figure 4.**

Other modern submersibles are submarine robots. They can take photographs, collect mineral samples from the ocean floor, and perform many other tasks. These robot submersibles are remotely piloted and allow oceanographers to study the ocean depths for long periods of time.

Underwater Research

Submersibles have helped scientists make exciting discoveries about the deep ocean. During one dive in a submersible, startled oceanographers saw communities of unusual marine life living at depths and temperatures where scientists thought that almost no life could exist. Giant clams, blind white crabs, and giant tube worms were some of the strange life-forms that were discovered. Many of these life-forms have unusual adaptations that allow them to live in hostile environments. The angler fish, shown in **Figure 4,** can produce its own light, which attracts prey.

Section 1 Review

1. **Name** the five major divisions of the global ocean.
2. **Explain** the difference between an ocean and a sea.
3. **Define** *oceanography*.
4. **Describe** two ways that oceanographers study the ocean.
5. **Explain** how sonar works.
6. **Describe** two aspects of the ocean that submersibles are used to study.
7. **List** three types of submersibles.

CRITICAL THINKING

8. **Evaluating Ideas** Most submarines use sonar as a navigation aid. How would sonar enable an underwater vessel to move through the ocean depths?
9. **Analyzing Methods** Why are submarine robots more practical for deep-ocean research than submersibles designed to carry people are?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *oceanography, submersible, bathysphere, bathyscaph, robot submersible,* and *sonar*.

Section 2 Features of the Ocean Floor

The ocean floor can be divided into two major areas, as shown in **Figure 1.** The **continental margins** are shallow parts of the ocean floor that are made of continental crust and a thick wedge of sediment. The other major area is the **deep-ocean basin,** which is made of oceanic crust and a thin sediment layer, is the deep part of the ocean beyond the continental margin.

OBJECTIVES

- **Describe** the main features of the continental margins.
- **Describe** the main features of the deep-ocean basin.

KEY TERMS

continental margin
deep-ocean basin
trench
abyssal plain

Continental Margins

The line that divides the continental crust from the oceanic crust is not abrupt or distinct. Shorelines are not the true boundaries between the oceanic crust and the continental crust. The boundaries are actually some distance offshore and beneath the ocean and the thick sediments of the continental margin.

Continental Shelf

Continents are outlined in most places by a zone of shallow water where the ocean covers the edge of the continent. The part of the continent that is covered by water is called a *continental shelf*. The shelf usually slopes gently from the shoreline and drops about 0.12 m every 100 m. The average depth of the water covering a continental shelf is about 60 m. Although it is underwater, a continental shelf is part of the continental margin, not the deep-ocean basin.

Changes in sea level affect the continental shelves. During glacial periods, continental ice sheets hold large amounts of water. So, sea level falls and exposes more of the continental shelf to weathering and erosion. But if ice sheets melt adding water to the oceans, sea level rises and covers the continental shelf.

continental margin the shallow sea floor that is located between the shoreline and the deep-ocean bottom

deep-ocean basin the part of the ocean floor that is under deep water beyond the continent margin and that is composed of oceanic crust and a thin layer of sediment

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

Topic: Ocean-Floor Features
SciLinks code: HQ61067

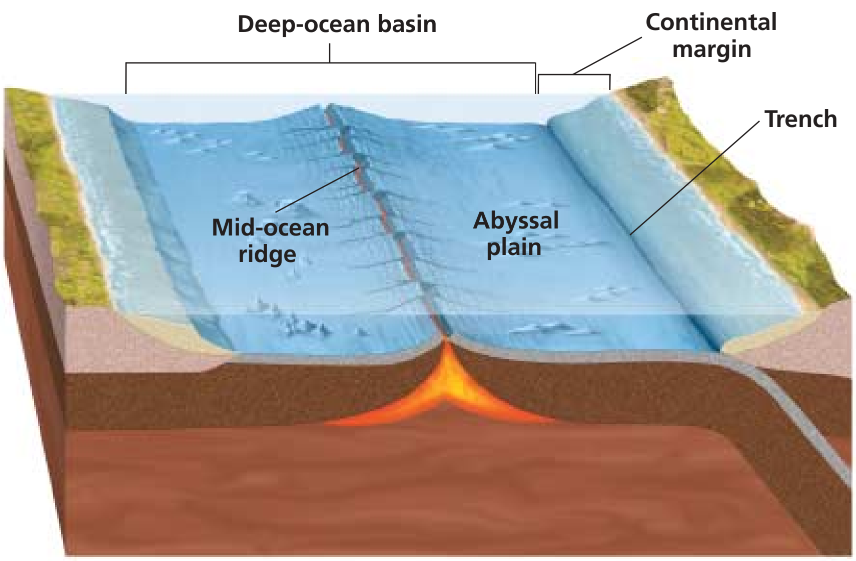


Figure 1 ▶ The ocean floor includes the continental margins and the deep-ocean basin. ***What are three other major features of the ocean floor?***

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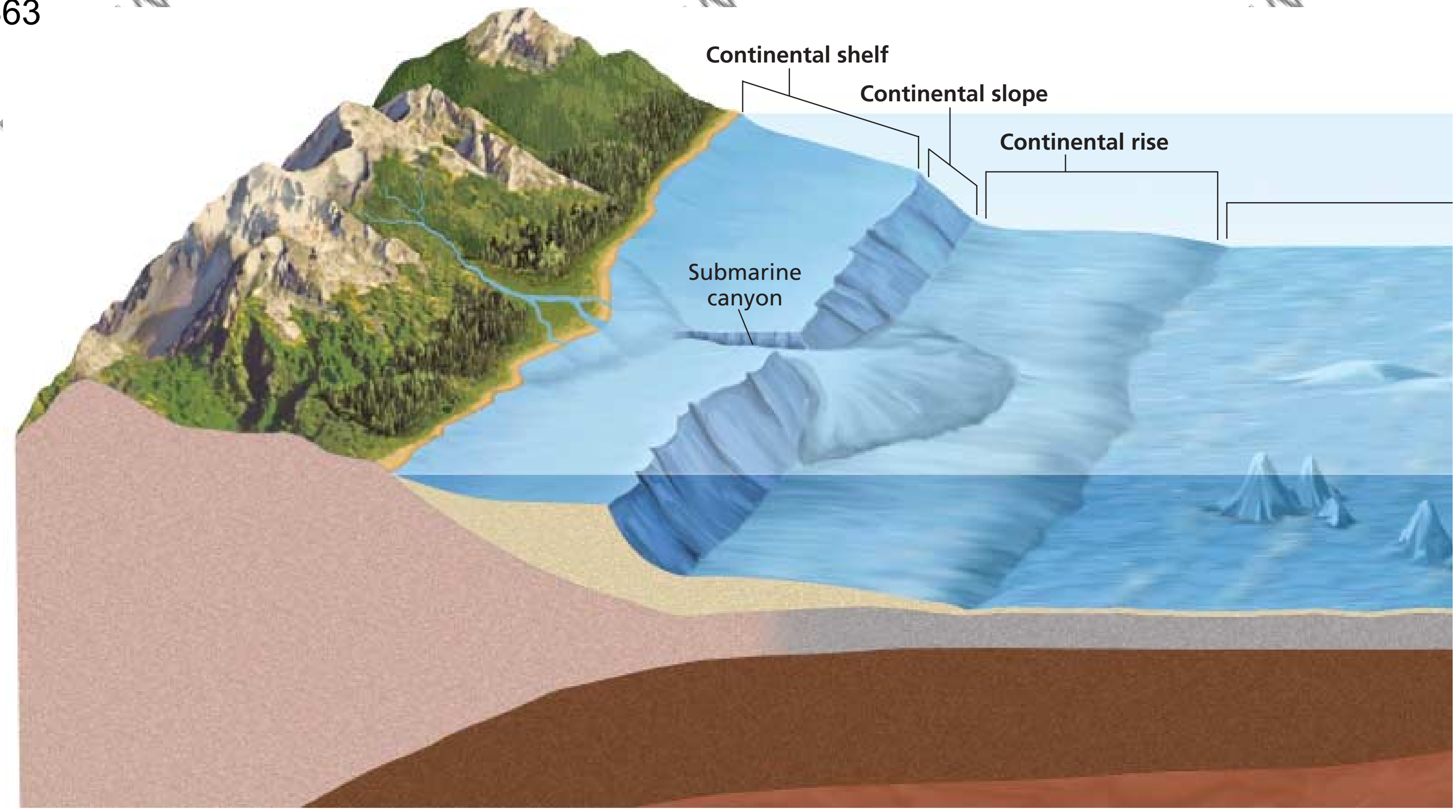


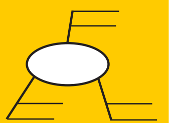
Figure 2 ▶ The ocean floor is made of distinct areas and features.

Continental Slope and Continental Rise

At the seaward edge of a continental shelf is a steep slope called a *continental slope*. The boundary between the continental crust and the oceanic crust is located at the base of the continental slope. Along the continental slope, the ocean depth increases by several thousand meters within a distance of a few kilometers, as shown in **Figure 2.** The continental shelf and continental slope may be cut by deep V-shaped valleys. These deep valleys are called *submarine canyons*. These deep canyons are often found near the mouths of major rivers. Other canyons may form over time as very dense currents called *turbidity currents* carry large amounts of sediment down the continental slopes. Turbidity currents form when earthquakes cause underwater landslides or when large sediment loads run down a slope. These sediments form a raised wedge at the base of the continental slope called a *continental rise*.

Graphic Organizer **Spider Map**

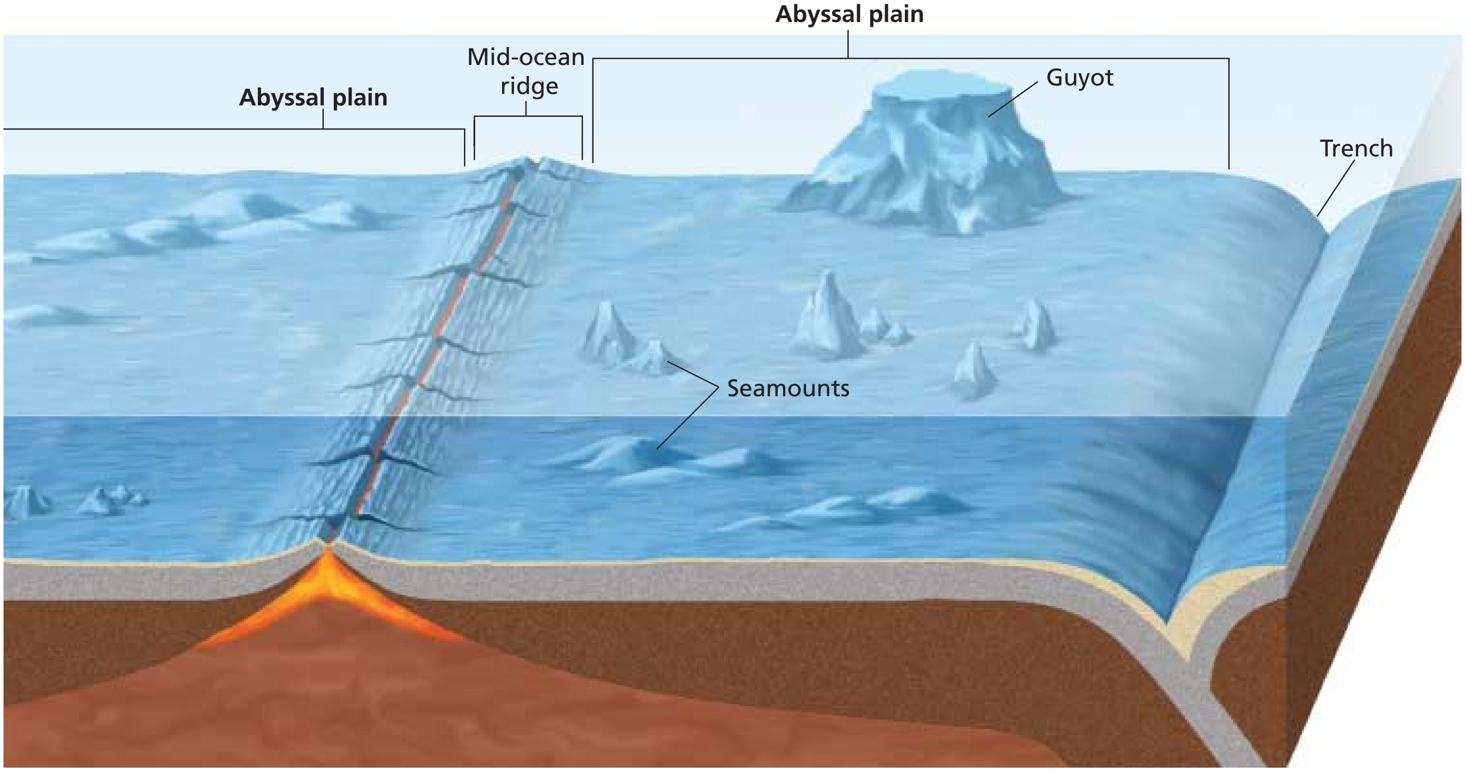
Create the Graphic Organizer entitled "Spider Map" described in the Skills Handbook section of the Appendix. Label the circle "Ocean Basin Features." Create a leg for each ocean basin feature. Then, fill in the map with details about each ocean basin feature.



Deep-Ocean Basins

Deep-ocean basins also have distinct features, as shown in **Figure 2.** These features include broad, flat plains; submerged volcanoes; gigantic mountain ranges; and deep trenches. In the deep-ocean basins, the mountains are higher and the plains are flatter than any features found on the continents are.

Reading Check **What features are located in the deep-ocean basins?** **(See the Appendix for answers to Reading Checks.)**



Trenches

Long, narrow depressions located in the deep-ocean basins are called **trenches.** At more than 11,000 m deep, the Mariana Trench, in the western Pacific Ocean, is the deepest place in Earth's crust. Trenches form where one tectonic plate subducts below another plate. Earthquakes occur near trenches. Volcanic mountain ranges and volcanic island arcs also form near trenches.

Abyssal Plains

The vast, flat areas of the deep-ocean basins where the ocean is more than 4 km deep are called **abyssal plains** (uh BIS uhl PLAYNZ). Abyssal plains cover about half of the deep-ocean basins and are the flattest regions on Earth. In some places, the ocean depth changes less than 3 m over more than 1,300 km.

Layers of fine sediment cover the abyssal plains. Ocean currents and wind carry some sediments from the continental margins. Other sediment is made by organisms that live in the ocean and settle to the ocean floor when they die.

The thickness of sediments on the abyssal plains is determined by three factors. The age of the oceanic crust is one factor. Older crust is generally covered with thicker sediments than younger crust is. The distance from the continental margin to the abyssal plain also determines how much sediment reaches the plain from the continent. Third, the sediment cover on abyssal plains that are bordered by trenches is generally thinner than the sediment cover on abyssal plains that are not bordered by trenches.

trench a long, narrow, and steep depression that forms on the ocean floor as a result of subduction of a tectonic plate, that runs parallel to the trend of a chain of volcanic islands or the coastline of a continent, and that may be as deep as 11 km below sea level; also called an *ocean trench* or a *deep-ocean trench*

abyssal plain a large, flat, almost level area of the deep-ocean basin

Figure 3 ▶ The white ridges in this photo are coral reefs of an atoll that formed in the shallow waters around a volcanic island. Erosion is changing the island into a guyot.

Mid-Ocean Ridges

The most prominent features of ocean basins are the *mid-ocean ridges,* which form underwater mountain ranges that run along the floors of all oceans. Mid-ocean ridges rise above sea level in only a few places, such as in Iceland. Mid-ocean ridges form where plates pull away from each other. A narrow depression, or rift, runs along the center of the ridge. Through this rift, magma reaches the sea floor and forms new lithosphere. This new lithosphere is less dense than the old lithosphere. As the new lithosphere cools, it becomes denser and begins to sink as it moves away from the rift. Fault-bounded blocks of crust that form parallel to the ridges as the lithosphere cools and contracts are called *abyssal hills*.

As ridges adjust to changes in the direction of plate motions, they break into segments that are bounded by faults. These faults create areas of rough topography called *fracture zones*, which run perpendicular across the ridge.

Seamounts

Submerged volcanic mountains that are taller than 1 km are called *seamounts*. Seamounts form in areas of increased volcanic activity called *hot spots*. Seamounts that rise above the ocean surface form oceanic islands. As tectonic plate movements carry islands away from a hot spot, the islands sink and are eroded by waves to form flat-topped, submerged seamounts called *guyots* (GEE OHZ) or *tablemounts*. An intermediate stage in this process, called an *atoll*, is shown in **Figure 3.**

Section 2 Review

1. **Describe** the three main sections of the continental margins.
2. **Describe** where the boundary between the oceanic crust and the continental crust is located.
3. **Explain** how turbidity currents are related to submarine canyons.
4. **List** four main features of the deep-ocean basins, and describe one characteristic of each feature.
5. **Compare** seamounts, guyots, and atolls.
6. **Explain** the difference between the meanings of the terms *continental margin, continental shelf, continental slope,* and *continental rise.*

CRITICAL THINKING

7. **Making Inferences** The Pacific Ocean is surrounded by trenches, but the Atlantic Ocean is not. In addition, the Pacific Ocean is wider than the Atlantic Ocean, and much of the crust under the Pacific Ocean is very young. Which ocean's abyssal plain has thicker sediments? Explain your answer.
8. **Determining Cause and Effect** If sea level were to fall significantly, what would happen to the continental shelves?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *continental margin, deep-ocean basin, continental shelf, continental slope, continental rise, trench, abyssal plain,* and *mid-ocean ridge.*

Section 3 Ocean-Floor Sediments

Continental shelves and slopes are covered with sediments. Sediments are carried into the ocean by rivers, are washed away from the shoreline by wave erosion, or settle to the ocean bottom when the organisms that created them die. The composition of ocean sediments varies and depends on which part of the ocean floor the sediments form in. The sediments are fairly well sorted by size. Coarse gravel and sand are usually found close to shore because these heavier sediments do not move easily offshore. Lighter particles are suspended in ocean water and are usually deposited at a great distance from shore.

OBJECTIVES

- **Describe** the formation of ocean-floor sediments.
- **Explain** how ocean-floor sediments are classified by their physical composition.

KEY TERMS

core sample
nodule

Sources of Deep Ocean–Basin Sediments

Sediments found in the deep-ocean basin, which is beyond the continental margin, are generally finer than those found in shallow water. Samples of the sediments in the deep-ocean basins can be gathered by scooping up sediments or by taking core samples. **Core samples** are cylinders of sediment that are collected by drilling into sediment layers on the ocean floor. **Figure 1** shows a core sample being studied aboard the research vessel *JOIDES Resolution*.

core sample a cylindrical piece of sediment, rock, soil, snow, or ice that is collected by drilling

The study of sediment samples shows that most of the sediments in the deep-ocean basins are made of materials that settle slowly from the ocean water above. These materials may come from organic or inorganic sources.

Figure 1 ▶ A scientist studies a core sample that was brought up from the drill aboard the research ship *JOIDES Resolution*.

Figure 2 ▶ This picture of sediment emptying out of the Mahakam River in Indonesia was taken by astronauts aboard the space shuttle *Columbia*.

Inorganic Sediments

Some ocean-basin sediments are rock particles that were carried from land by rivers. When a river empties into the ocean, the river deposits its sediment load, as shown in **Figure 2.** Most of these sediments are deposited along the shore and on the continental shelf. However, large quantities of these sediments occasionally slide down continental slopes to the ocean floor below. The force of the slide creates powerful turbidity currents that spread the sediments over the deep-ocean basins. Other deep ocean–basin sediments consist of fine particles of rock, including volcanic dust, that have been blown great distances out to sea by the wind. These particles land on the surface of the water, sink, and gradually settle to the bottom of the ocean.

Icebergs also provide sediments that can end up on the ocean basins. As a glacier moves across the land, the glacier picks up rock. The rock becomes embedded in the ice and moves with the glacier. When an iceberg breaks from the glacier, drifts out to sea, and melts, the rock material sinks to the ocean floor.

Even meteorites contribute to deep ocean-basin sediments. Much of a meteorite vaporizes as it enters Earth's atmosphere. The remaining cosmic dust falls to Earth's surface. Because most of Earth's surface is ocean, most meteorite fragments fall into the ocean and become part of the sediments on the ocean floor.

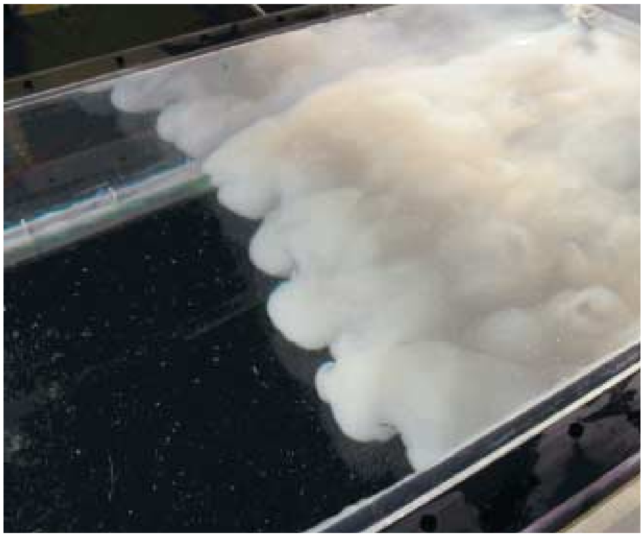
Connection to PHYSICS

Turbidity Currents

Underwater landslides can be caused by earthquakes or can happen when the sediment-water mixture becomes denser than the surrounding water. These landslides form currents called *turbidity currents*.

Gravity powers turbidity currents. As the dense sediment mixture moves downhill, it picks up sediment. This added sediment increases the current's density, which increases the current's speed. Turbidity currents can travel at speeds of more than 100 km/h.

The speed and composition of these currents make them powerful agents of erosion. One turbidity current may move billions of kilograms of mud, rock, and sand down a slope. Sediments are deposited as the speed of the current decreases. A turbidity current may gain enough momentum that it does not stop at the continental rise. Thus, it may spread sediment hundreds of kilometers onto the abyssal plain.



This simulated turbidity current was created in a laboratory. The density of the sediment-filled water causes it to move downhill like a landslide does.

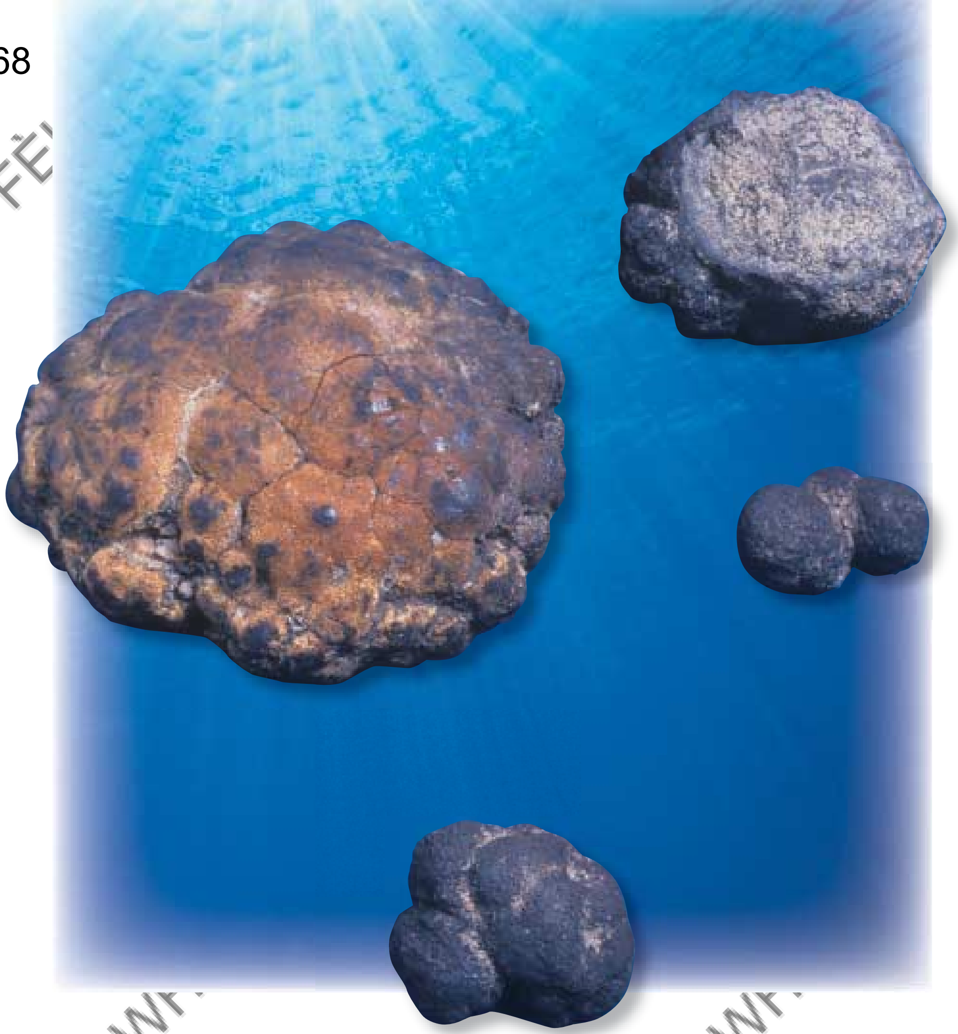


Figure 3 ▶ Nodules, such as these mined from the East Pacific Rise, are rich in a variety of minerals.

MATHPRACTICE

Ocean-floor Sediments Ocean-floor sediments are composed of an average of 54% biogenic sediments, 45% Earth rocks and dust, less than 1% precipitation of dissolved materials (nodules and phosphorite), and less than 1% of rocks and dust from space. If you collected 10,000 kg of ocean-floor sediment, how many kilograms of each type of ocean-floor sediment would you expect to find?

Biogenic Sediments

In many places on the ocean floor, almost all of the sediments are biogenic. The word *biogenic* comes from the Latin words *bios*, which means "life," and *genus*, which means "origin." Biogenic sediments are the remains of marine plants and animals. The two most common compounds found in organic sediments are silica, SiO_2, and calcium carbonate, $CaCO_3$. Silica comes primarily from microscopic organisms called *diatoms* and *radiolarians*. Calcium carbonate comes mostly from the skeletons of tiny organisms called *foraminiferans*.

Chemical Deposits

When chemical reactions take place in the ocean, solid materials can form. When substances that are dissolved in ocean water crystallize, these materials settle to the ocean floor as potato-shaped lumps of minerals called **nodules.** Nodules, such as the ones shown in **Figure 3,** are commonly located on the abyssal plains. Nodules are composed mainly of the oxides of manganese, nickel, copper, and iron. Other minerals, such as phosphorite, are carried in the ocean water before they precipitate and settle to the ocean floor.

Reading Check **How do nodules form? (See the Appendix for answers to Reading Checks.)**

QuickLAB 20 min

Diatoms

Procedure

1. Observe **diatoms** under a **microscope.**
2. Sketch what you see. Make sure to note the magnification.

Analysis

1. What characteristics of the diatoms did you observe?
2. Propose one possible function for each of the structures you observed.

nodule a lump of minerals that is made of oxides of manganese, iron, copper, or nickel and that is found in scattered groups on the ocean floor

Figure 4 ▶ The remains of diatoms (left) and radiolarians (right), both magnified hundreds of times in these photos, are important components of biogenic sediments on the ocean floor.

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

Topic: Ocean-Floor Sediments
SciLinks code: HQ61068

Physical Classification of Sediments

Deep ocean-floor sediments can be classified into two basic types. *Muds* are very fine silt- and clay-sized particles of rock. One common type of mud on the abyssal plains is red clay. Red clay is made of at least 40% clay particles and is mixed with silt, sand, and biogenic material. This clay can vary in color from red to gray, blue, green, or yellow-brown. About 40% of the ocean floor is covered with soft, fine sediment called *ooze*. At least 30% of the ooze is biogenic materials, such as the remains of microscopic sea organisms. The remaining material is fine mud.

Ooze can be classified into two types. *Calcareous ooze* is ooze that is made mostly of calcium carbonate. Calcareous ooze is never found below a depth of 5 km, because at depths between 3 km and 5 km, calcium carbonate dissolves in the deep, cold ocean water. *Siliceous ooze*, which can be found at any depth, is made of mostly silicon dioxide, which comes from the shells of radiolarians and diatoms. Examples of remains of these organisms are shown in **Figure 4.** Most siliceous ooze is found in the cool, nutrient-rich ocean waters around Antarctica because of the abundance of diatoms and radiolarians in that location.

Section 3 Review

1. **Describe** the formation of two different types of ocean-floor sediments.
2. **Summarize** how icebergs contribute to deep ocean-basin sediments.
3. **Explain** how substances that are dissolved in ocean water travel to the ocean floor.
4. **Explain** how ocean-floor sediments are classified by physical composition.
5. **Describe** how scientists define the word *mud.*
6. **Compare** the compositions of calcareous ooze and siliceous ooze.

CRITICAL THINKING

7. **Making Inferences** What could you infer from a core sample of a layer of sediment that contains volcanic ash and dust?
8. **Applying Ideas** Some businesses have tried to develop methods of extracting nodules from the ocean. Name two factors that businesses should consider when they are determining whether extracting nodules is profitable.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *nodule, inorganic sediment, biogenic sediment, diatom, chemical deposit,* and *ocean-floor sediment.*

Chapter 19 Highlights

Sections

1 The Water Planet

Key Terms

global ocean, 471
sea, 471
oceanography, 472
sonar, 473

Key Concepts

- The global ocean can be divided into five major oceans—the Pacific, Atlantic, Indian, Arctic, and Southern Oceans—and many smaller seas.
- Oceanography is the study of the oceans and the seas. Oceanographers study the ocean using research ships, sonar, and submersibles.
- Sonar is a system that uses acoustic signals and echo returns to determine the location of objects or to communicate.

2 Features of the Ocean Floor

continental margin, 475
deep-ocean basin, 475
trench, 477
abyssal plain, 477

- The areas around continents that are shallow parts of the ocean floor are called *continental margins*.
- Continental margins include the continental shelf, the continental slope, and the continental rise.
- Features of deep-ocean basins include trenches, abyssal plains, mid-ocean ridges, and seamounts.

3 Ocean-Floor Sediments

core sample, 479
nodule, 481

- Core samples are taken by drilling into sediment layers. Scientists study core samples to learn about the composition and characteristics of ocean-floor sediments.
- Ocean-floor sediments form from inorganic and biogenic materials as well as from chemical deposits.
- Based on physical characteristics, deep ocean–floor sediments are classified as mud or as ooze.

Chapter 19 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *oceanography*
2. *sonar*
3. *core sample*

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

4. *ocean* and *sea*
5. *submersible* and *nodule*
6. *continental margin* and *deep-ocean basin*
7. *global ocean* and *sea*
8. *mud* and *ooze*

Understanding Key Concepts

9. A self-propelled, free-moving submarine that is equipped for ocean research is a
   - **a.** turbidity.
   - **b.** bathysphere.
   - **c.** bathyscaph.
   - **d.** guyot.

10. A system that is used for determining the depth of the ocean floor is
    - **a.** a guyot.
    - **b.** radiolarians.
    - **c.** a bathysphere.
    - **d.** sonar.

11. The parts of the ocean floor that are made up of continental crust are called
    - **a.** continental margins.
    - **b.** abyssal plains.
    - **c.** mid-ocean ridges.
    - **d.** trenches.

12. The accumulation of sediments at the base of the continental slope is called the
    - **a.** trench.
    - **b.** turbidity current.
    - **c.** continental margin.
    - **d.** continental rise.

13. The deepest parts of the ocean are called
    - **a.** trenches.
    - **b.** submarine canyons.
    - **c.** abyssal plains.
    - **d.** continental rises.

14. Large quantities of the inorganic sediment that makes up the continental rise come from
    - **a.** turbidity currents.
    - **b.** earthquakes.
    - **c.** diatoms.
    - **d.** nodules.

15. Potato-shaped lumps of minerals on the ocean floor are called
    - **a.** guyots.
    - **b.** nodules.
    - **c.** foraminiferans.
    - **d.** diatoms.

16. Very fine particles of silt and clay that have settled to the ocean floor are called
    - **a.** muds.
    - **b.** seamounts.
    - **c.** guyots.
    - **d.** nodules.

Short Answer

17. What is the differences between a seamount and a guyot?
18. Explain how sonar is used to study the oceans.
19. List four ways that scientists can learn about the deep ocean.
20. How do fine sediments reach the deep-ocean bottom?
21. What effects do deep-ocean trenches have on the sediment thickness of the abyssal plain?
22. List the three main types of ocean-floor sediments, and describe how they are deposited.

Critical Thinking

23. Making Comparisons The exploration of the ocean depths has been compared with the exploration of space. What similarities exist between these two environments and the attempts by people to explore them?

24. Making Predictions What may be the eventual fate of seamounts as they are carried along the spreading oceanic crust?

25. Analyzing Ideas A type of fish is known to exist only in one river in the central United States. Explain how the fossilized remains of this fish might become part of the sediments on the ocean floor.

26. Analyzing Relationships Explain how it is possible that scientists have found some red clays on the ocean floor that contain material from outer space.

Concept Mapping

27. Use the following terms to create a concept map: *deep-ocean basin, continental shelf, mud, ooze, calcareous ooze, siliceous ooze,* and *sediment*.

Math Skills

28. Making Calculations The total area of Earth is approximately 511,000,000 km^2. About 71% of Earth's surface is covered with water. Calculate the area of Earth, in square kilometers, that is covered with water.

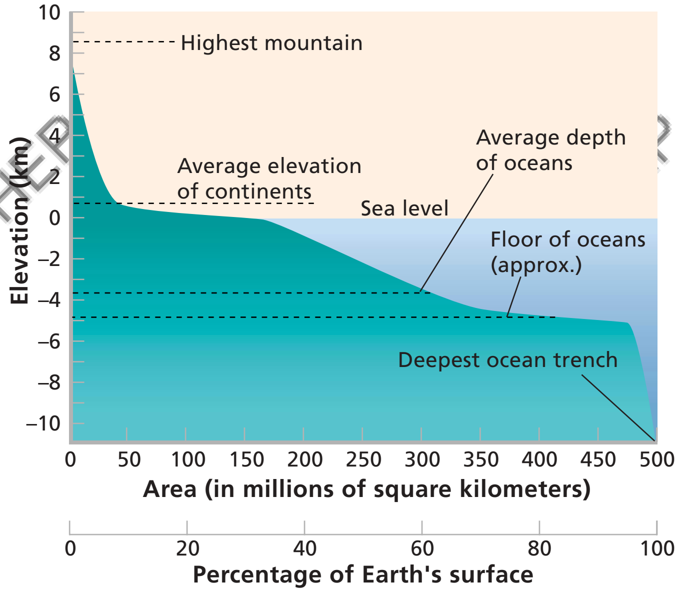
Writing Skills

29. Writing from Research Prepare a brief report on the different types of submersibles. Your report should explain the special features of each type of submersible as well as how each type has contributed to oceanographers' knowledge of the oceans.

30. Creative Writing Create an imaginary walking tour of the ocean basins. Your tour should begin at the edge of a continent—perhaps at a beach on the east coast of Florida. Explain exactly what tourists should look for along the continental margin and the ocean floor on their way to the western coast of Africa.

Interpreting Graphics

The graph below compares elevations of land and depths of oceans on Earth's surface. Use the graph to answer the questions that follow.



31. What percentage of Earth's surface is covered by land?

32. Which is greater: the elevation of the highest mountain above sea level or the depth of the deepest ocean trench below sea level?

33. Relative to sea level, how many times greater is the average depth of the ocean than the average elevation of land?

34. According to this diagram, how many millions of square kilometers of crust is under ocean water?

Chapter 19 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 global ocean is divided into which of the following oceans, in order of decreasing size?
A. Atlantic, Pacific, Arctic, Indian
B. Arctic, Indian, Atlantic, Pacific
C. Pacific, Arctic, Indian, Atlantic
D. Pacific, Atlantic, Indian, Arctic

2 What in the name for a vast, flat area of a deep-ocean basin?
F. trench
G. seamount
H. abyssal plain
I. mid-ocean ridge

3 What are very fine, silt- and clay-sized particles of rock found on the ocean floor called?
A. muds
B. calcareous ooze
C. siliceous ooze
D. sand

4 The study of deep-ocean sediment samples shows that
F. most of the sediments came from the crust.
G. most of the sediments settled from above.
H. sediments cannot be organic.
I. sediments cannot be inorganic.

5 Which of the following affects the ocean's salinity?
A. number of fish
B. wave size
C. evaporation
D. wave speed

***Directions (6–7):* For *each* question, write a short response.**

6 The surface area of Earth is about 511,000,000 km^2. About 70% of the Earth's surface is covered by water and the Pacific Ocean makes up 50% of this amount. Calculate the surface area of Earth that is covered by the Pacific Ocean.

7 What is the name of the process used to remove salt from seawater?

Reading Skills

***Directions (8–10):* Read the passage below. Then, answer the questions.**

Life on a Continental Shelf

While fish, mammals, and other forms of life can be found throughout these ocean waters, most life in the ocean is concentrated near the continental shores. The shallow waters of the continental shelf, which make up less than 10% of the ocean's total surface area, are home to an amazing array of plants, animals, and microscopic organisms.

Organisms such as coral and seaweed can grow on the ocean floor and still receive much needed sunlight that cannot penetrate deeper waters. The sunlight also makes the shallow waters much warmer than deeper abyssal waters. Algae flourishes in these warm, nutrient-rich waters and serves as food for many small ocean organisms. These organisms are in turn eaten by larger organisms. Even humans have become part of the food chain on the shelf. The vast majority of fish caught for human consumption are caught in waters above a continental shelf.

8 Which of the following statements about why humans catch so many fish in the waters over a continental shelf can be inferred from the information in the passage?
A. There are no fish in deeper waters.
B. Fish from deeper waters are inedible.
C. Humans do not have the technological ability to catch fish in deeper ocean waters.
D. There are larger and more varied fish populations over a continental shelf.

9 Coral reefs stop actively growing at depths of aboout 70 m. According to the passage, why might this be true?
F. Coral feed on algae in shallow waters.
G. Coral need sunlight to live, and sunlight can penetrate water only to a certain depth.
H. Coral need warmth, and the deeper ocean waters are too cold for them to survive.
I. Coral at greater depths are eaten by fish.

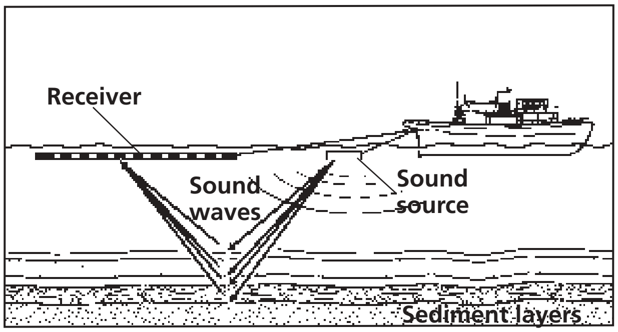
10 Why might the waters of a continental shelf have more nutrients than abyssal waters?

Interpreting Graphics

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

Base your answer to question 11 on this image which shows how sonar equipment works.

Studying the Ocean Floor with Sonar

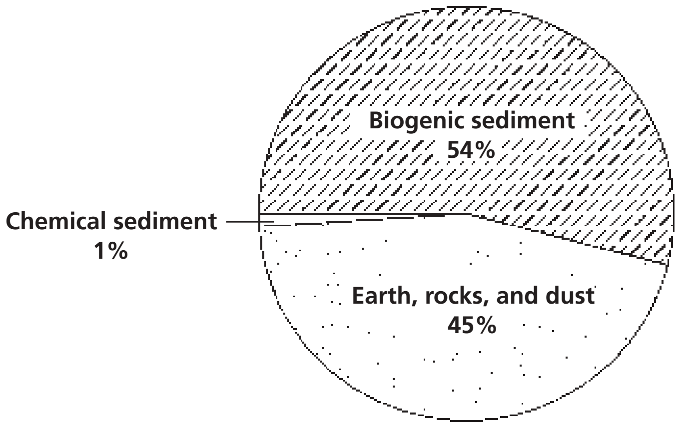


11 Which of the following best summarizes how sound waves are used?

A. A sound source dragged behind the boat emits waves that penetrate the different layers of the sea floor and bounce back to the receiver.
B. A sound source in front of the boat emits waves that penetrate the different layers of the sea floor and then bounce back to the receiver.
C. A receiver dragged behind the boat emits waves that penetrate the different layers of the sea floor and then bounce back to the receiver.
D. A receiver in front of the boat emits waves that penetrate the different layers of the sea floor and then bounce back to the receiver.

Base your answers to questions 12 and 13 on the pie graph below, which shows the composition of ocean-floor sediments.

Composition of Ocean-Floor Sediments



12 Why is there such a large difference between the percentage of biogenic sediment and the percentage of chemical sediment?

13 How did the inorganic materials in the two kinds of inorganic sediment shown on the pie graph above form and become part of the ocean floor?

Test TIP

Before choosing an answer to a question, try to answer the question without looking at the answer choices on the test.

Skills Practice Lab

Objectives

- **USING SCIENTIFIC METHODS** **Observe and record** the settling rates of four different sediments.
- **Draw conclusions** about how particle size affects settling rate.
- **Identify** factors that affect settling rate of sediments besides particle size.

Materials

balance, metric
column, clear plastic, 80 cm × 4 cm
cup, paper
pencil, grease
ring stand with clamp
ruler, metric
sieve, 4 mm, 2 mm, 0.5 mm
soil, coarse, medium, medium-fine, and fine grain
stopper, rubber
stopwatch
tape, adhesive
teaspoon
towels, paper
water

Safety

Ocean-Floor Sediments

Most of the ocean floor is covered with a layer of sediment that varies in thickness from 0.3 km to more than 1 km. Much of this sediment is thought to have originated on land through the process of weathering. Through erosion, the sediment has made its way to the deep-ocean basins. In this lab, you will use sediment samples of four particle sizes to determine the relationship between the size of particles and the settling rate of the particles in water.

PROCEDURE

1. Take one sample of sediment from each of the following size ranges: coarse, medium, medium-fine, and fine.
2. Plug one end of the plastic column with a rubber stopper, and secure the stopper to the column with tape. Place the column in a vertical position using the ring stand and clamp. Carefully fill the column with water to a level about 5 cm from the top, and allow the water to stand until all large air bubbles have escaped.
3. Use the grease pencil to mark the water level on the column. This will be the starting line.
4. Next, draw a line about 5 cm from the bottom of the column. This will be the finish line.
5. Have a member of your lab group put 1 tsp of the coarse sample into the water column. The other group member should record three time measurements as follows:

   a. Using a stopwatch, start timing when the first particles hit the start line on the column, and stop timing when they reach the finish line. Perform this procedure three times. Record the time for each trial in a table similar to the one shown below.

Soil samples	Trial 1	Trial 2	Trial 3	Average
Coarse	First time measurment:			
	Second time measurement:			
Medium	First time measurement:			
	Secont time measurement:			

b. Next, use the stopwatch to determine how long it takes the last particle in the sample to travel from the start line to the finish line. Perform this procedure three times. Record the time for each trial in your table.

6. Determine the average time of the three trials for the first measurement. Do the same for the second measurement. Record the averages.
7. Pour the soil and water from the column into the container provided by your teacher. (Note: Do not pour the soil into the sink.)
8. Refill the plastic column with water up to the original level marked with the grease pencil.
9. Repeat steps 5, 6, and 7 for the remaining sediment sizes. Record the measurements and the averages in your table.
10. With the plastic column filled with water, pour 20 g of unsieved soil into the column, and allow the soil to settle for 5 minutes. After 5 minutes, look at the column and record your observations of both the settled sediment and the water. Repeat step 7, and then answer the questions below.

Step 5

ANALYSIS AND CONCLUSION

1. **Organizing Data** Which particles settled fastest? Which particles settled slowest?
2. **Making Comparisons** Compare the settling time of the medium particles with the settling time of the medium-fine particles. Do similar-sized particles fall at the same rate?
3. **Making Inferences** In step 10, why did the water remain slightly cloudy even after most of the particles had settled?
4. **Evaluating Methods** How do the results in step 10 help to explain why the deep-ocean basins are covered with a very fine layer of sediment while areas near the shore are covered with coarse sediment?
5. **Making Predictions** Other than size, what factors do you think would influence the speed at which particles fall in water? Explain your answer.

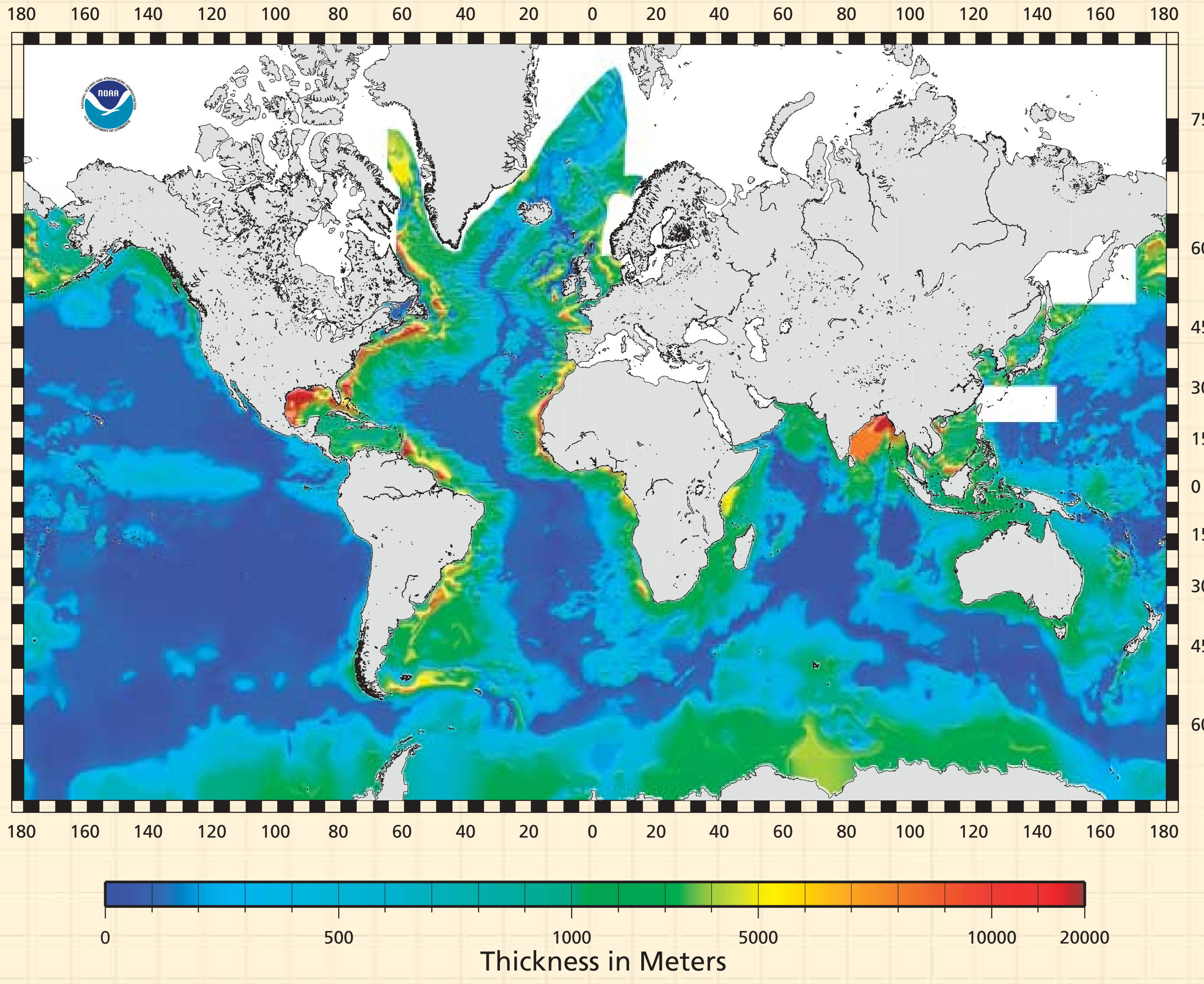
Extension

1. **Analyzing Predictions** Obtain particles of different shapes, such as long, cylindrical grains; flat, disk-shaped grains; round grains; and angular grains. Test the settling times of these grains, and write a brief paragraph that explains how grain shape affects the settling rate of particles in water.

7877

MAPS in Action

Total Sediment Thickness of Earth's Oceans



Map Skills Activity

This map shows the total thicknesses of sediments on Earth's ocean floors. Use the map to answer the questions below.

1. **Using the Key** What is the approximate thickness of the sediment located at 45°S and 45°W?
2. **Analyzing Data** Use latitude and longitude to identify two areas that have the thickest sediments.
3. **Comparing Areas** Compare the amount of sediment near the middle of the oceans with the amount of sediment on the continental margins.
4. **Identifying Trends** Rivers deposit massive amounts of sediment when they reach the ocean. Based on this map, at what locations would you expect to find mouths of major rivers?
5. **Inferring Relationships** Which coast of South America—east or west—is most likely bordered by a trench?
6. **Analyzing Relationships** Why does this map contain white spaces even though the key lists no thickness that corresponds with the color white?

Career Focus

Oceanographer

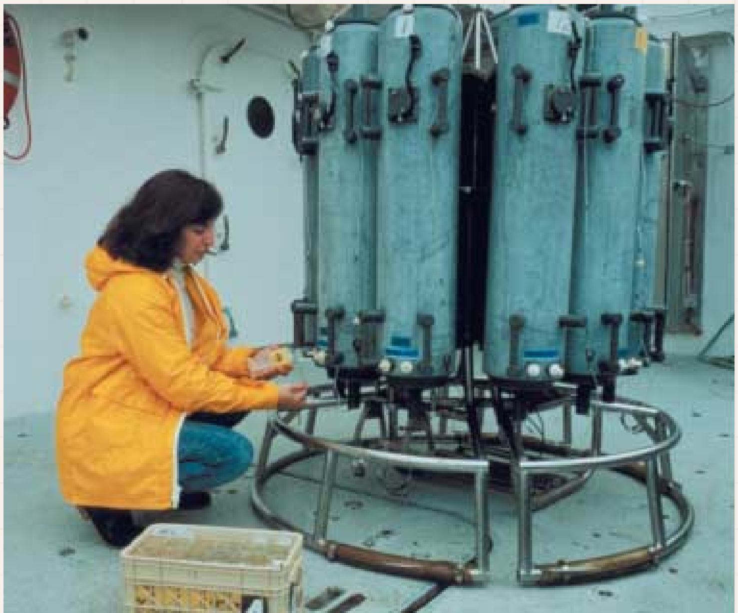
Lynne Talley is a physical oceanographer. Physical oceanographers study waves, tides, and currents in the ocean and the interactions between the ocean and the atmosphere. Talley's research focuses on large-scale patterns of ocean circulation that govern the worldwide movement of ocean waters. Her oceanography career began with a love for physics. Scientists also enter the field of oceanography from the fields of mathematics, geology, engineering, chemistry, biology, or ecology.

Going to Sea

Unlike the many oceanographers who use remote-sensing aircraft and Earth-orbiting satellites to collect data, Talley is a seagoing oceanographer. She uses direct measurement techniques to collect data. Every two years, she goes to sea on a month-long research cruise. Scientists on the cruise measure the temperature, salinity, and dissolved oxygen of ocean waters at various depths. Water samples are analyzed for chemical "fingerprints," such as the isotope helium-3. The presence of helium-3 may indicate that the sampled waters were near the surface during thermonuclear weapons testing that began in the 1950s.

After each cruise, Talley uses computer programs to analyze the data collected on the cruise. "Because oceans cover almost three-fourths of the world's surface, they have a huge impact on climate," says Talley. By studying the global movements of ocean waters, Talley can trace the global movement of heat. She uses her data as a basis for building numerical models that help scientists predict future oceanic and atmospheric conditions.

▼ Lynne Talley uses this rosette sampler to take samples of ocean water at various depths.



"I chose oceanography because it's so environmental and large scale. You can see it and touch it."

—Lynne Talley Ph.D.

Predicting Future Climate

Discovering how heat moves around Earth gives scientists a better understanding of global warming. Nations around the world are developing regulations to control global warming. Talley says that it is critical that such regulations be based on accurate data. "You must understand the actual processes occurring right now in order to predict change. You can't make up a model unless you understand the system."

7879

Chapter 20 Ocean Water

Sections

What You'll Learn

- What the properties of ocean water are
- How life survives in the ocean
- Why ocean resources are important

Why It's Relevant

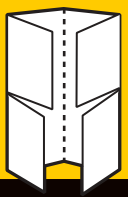
Earth's oceans play a vital role in Earth's ecology. Resources from the ocean provide humans with food, fuel, and fresh water.

PRE-READING ACTIVITY

FOLDNOTES

Four-Corner Fold

Before you read the chapter, create the **FoldNote** entitled "Four-Corner Fold" described in the Skills Handbook section of the Appendix. Label each flap of the four-corner fold with a topic. Write what you know about each topic under the appropriate flap. As you read the chapter, add other information that you learn.



▶ To avoid predators, chevron barracuda school in a spiraling tornado near the ocean surface in Kimbe Bay, Papua New Guinea. These fish get all of the nutrients they need for life from the ocean water in which they live.

Section 1 Properties of Ocean Water

Pure liquid water is tasteless, odorless, and colorless. However, the water in the ocean is not pure. Many solids and gases are dissolved in the ocean. In addition to dissolved substances, small particles of matter and tiny organisms are also suspended in ocean water. Ocean water is a complex mixture of chemicals that sustains a variety of plant and animal life.

Scientists describe ocean water by using a variety of properties, such as the presence of dissolved gases and the presence of dissolved solids, salinity, temperature, density, and color. Scientists study all of these properties to understand the complex interactions between the oceans, the atmosphere, and the land.

OBJECTIVES

- **Describe** the chemical composition of ocean water.
- **Describe** the salinity, temperature, density, and color of ocean water.

KEY TERMS

salinity
pack ice
thermocline
density

Dissolved Gases

The two principal gases in the atmosphere are nitrogen, N_2, and oxygen, O_2. These two gases are also the main gases dissolved in ocean water. While carbon dioxide, CO_2, is not a major component of the atmosphere, a large amount of this gas is dissolved in ocean water. Other atmospheric gases are also present in the ocean in small amounts.

Ocean water dissolves gases from a variety of sources, as shown in **Figure 1.** Gases may enter ocean water from water in streams and rivers. Some of the gases in ocean water come from volcanic eruptions beneath the ocean. Gases are also released directly into ocean water by organisms that live in the ocean. For example, many plants in the ocean make oxygen as a product of photosynthesis. However, most oxygen in the ocean enters at the surface of the ocean from the atmosphere.

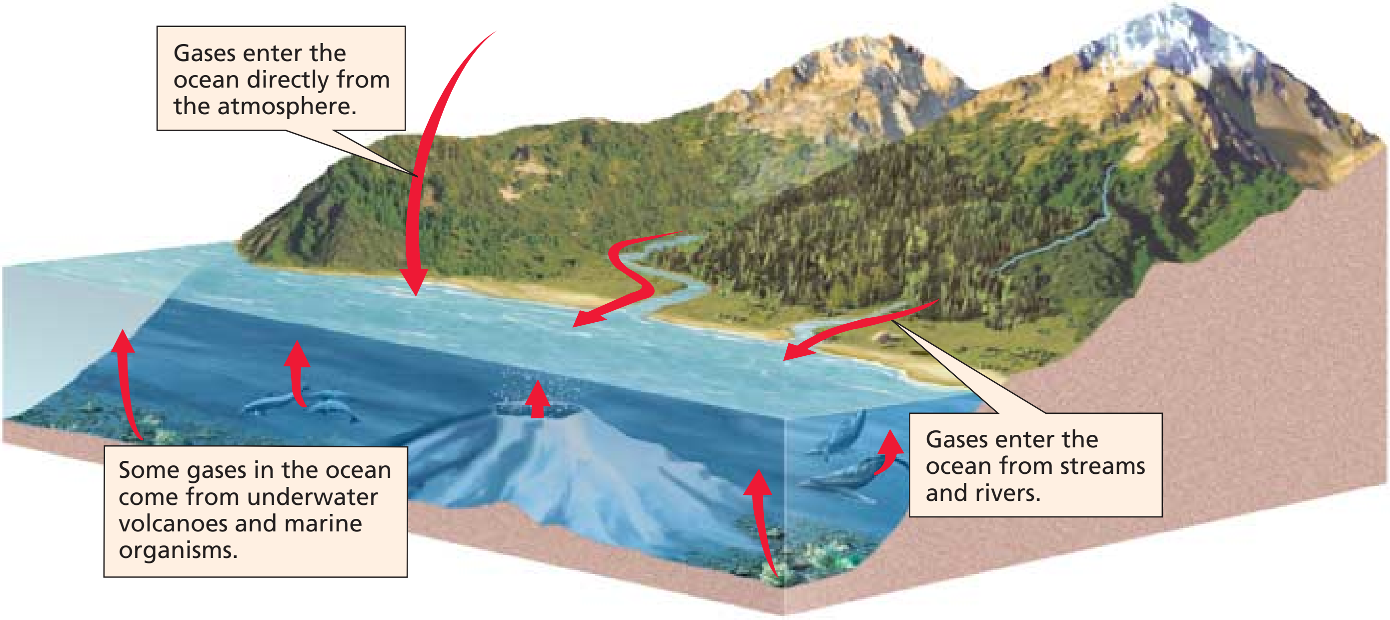


Figure 1 ▶ Gases can enter the ocean from streams, volcanoes, organisms, and the atmosphere.

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

Topic: Properties of Ocean Water
SciLinks code: HQ61232

Temperature and Dissolved Gases

The temperature of water affects the amount of gas that dissolves in water. Gases dissolve more readily in cold water than in warm water. You may have noticed this phenomenon when your glass of soda quickly goes "flat" on a warm day. The soda goes flat quickly because the CO_2 that makes the soda bubbly escapes into the air. But if the soda is kept in the refrigerator, the soda will retain its fizz longer. Because cold water dissolves gases more readily, water at the surface of the ocean in cold regions dissolves larger amounts of gases than water in warm tropical regions does.

Gases also can return to the atmosphere from the ocean. If the water temperature rises, less gas will remain dissolved, and the excess gas will be released into the atmosphere. For example, warm equatorial ocean waters tend to release CO_2 into the atmosphere, but ocean waters at cooler, higher latitudes take up large amounts of CO_2. Therefore, the ocean and the atmosphere are continuously exchanging gases as water temperatures change.

The Oceans as a Carbon Sink

Oceans contain more than 60 times as much carbon as the atmosphere does. Dissolved CO_2 may be trapped in the oceans for hundreds to thousands of years. Because of this ability to dissolve and contain a large amount of CO_2, the oceans are commonly referred to as a *carbon sink*. Because gaseous CO_2 affects the atmosphere's ability to trap thermal energy from the sun, the oceans are important in the regulation of climate.

Connection to CHEMISTRY

How Substances Dissolve

A water molecule is one oxygen atom bonded to two hydrogen atoms. The oxygen atom pulls electrons away from the hydrogen atoms, which gives the hydrogen atoms a partial positive charge and gives the oxygen atom a partial negative charge. This uneven distribution of charges allows the water molecule to attract both positive and negative ions.

The figure at right shows how a sodium chloride, NaCl, crystal dissolves in water. The partially negative oxygen atoms in water molecules attract the positively charged sodium ions of the salt. The partially positive hydrogen atoms in the water molecules attract the negatively charged chloride ions of the salt. When the force of attraction between the ions and the water molecules becomes stronger than the force of attraction between the sodium and chloride atoms, the ions are pulled away from the crystal. The ions are then surrounded by water molecules. Eventually, all of the ions in the crystal are pulled into solution, and the substance is completely dissolved.

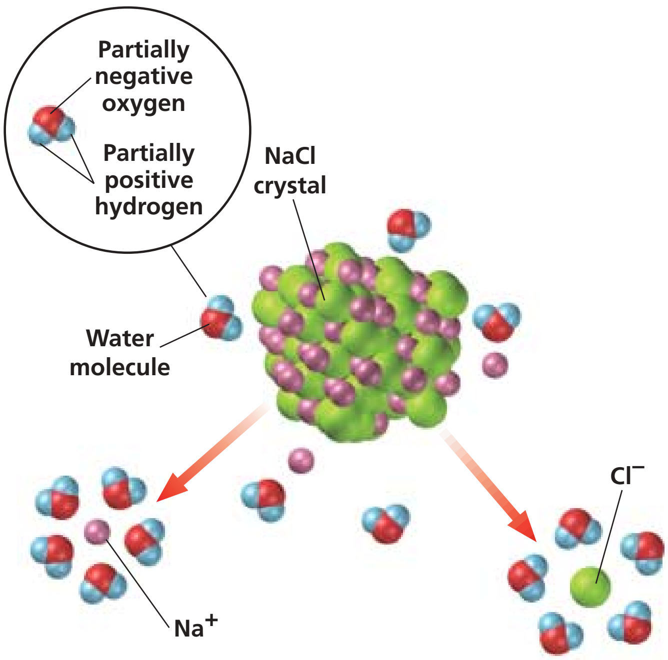
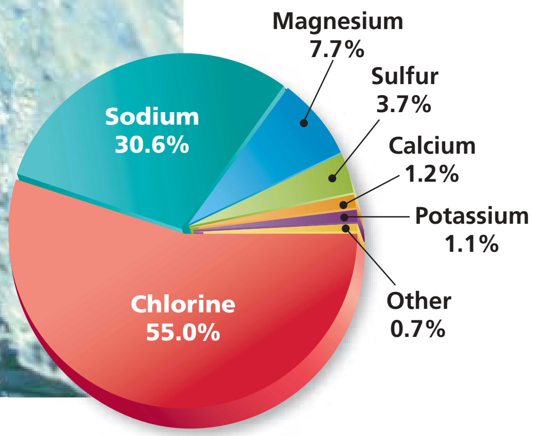


Figure 2 ▶ Dissolved solids make up 3.5% of the mass of ocean water. More than 85% of these dissolved solids are sodium and chlorine.



Dissolved Solids

Ocean water is 96.5% pure water, or H_2O. Dissolved solids make up about 3.5% of the mass of ocean water. These dissolved solids, commonly called *sea salts*, give the ocean its salty taste.

Most Abundant Elements

Solids dissolved in ocean water are composed of about 75 chemical elements. The six most abundant elements in ocean water are chlorine, sodium, magnesium, sulfur, calcium, and potassium. The salt halite, which is made of sodium and chloride ions, makes up more than 85% of the ocean's dissolved solids. The remaining dissolved solids consist of various other salts and minerals, as shown in **Figure 2.** *Trace elements* are elements that exist in very small amounts. Gold, zinc, and phosphorus are some of the trace elements that are found in the ocean.

Sources of Dissolved Solids

Most of the elements that form sea salts come from three main sources—volcanic eruptions, chemical weathering of rock on land, and chemical reactions between sea water and newly formed sea-floor rocks. Each year, rivers carry about 400 billion kilograms of dissolved solids into the ocean. Most of these dissolved solids are salts. As water evaporates from the ocean, salts and other minerals remain in the ocean. Only a small fraction of these salts and minerals are returned to the land in the water that falls as rain and snow during the water cycle.

Reading Check **How do dissolved solids enter the ocean? (See the Appendix for answers to Reading Checks.)**

Quick LAB 10 min

Dissolving Solids

Procedure

1. Heat **200 ml of water** in a **beaker** over a **hot plate** until the water is about 60°C.
2. Dissolve **table salt** in the water 1 tsp at a time until no more salt will dissolve. Record the total amount of salt that dissolves.
3. Dissolve table salt 1 tsp at a time into **200 ml of water** that has been chilled in the refrigerator to about 5°C. Record the total amount of salt that dissolves.

Analysis

1. Which water sample dissolved the most salt?
2. Describe what would happen to the dissolved salt in the hot water if the hot water was chilled to 10°C.

salinity a measure of the amount of dissolved salts in a given amount of liquid

Salinity of Ocean Water

One of the biggest differences between ocean water and fi is the high concentration of salts in ocean water. **Salinity** sure of the amount of dissolved salts and other solids liquid. Salinity is measured by the number of grams of solids in 1,000 g of ocean water. For example, if 1,000 g water contained 35 g of solids, the salinity of the sam be about 35 parts salt per 1,000 parts ocean water. This ment is written as *salinity* = 35 parts per thousand, Thus, the ocean is about 3.5% salts. However, fresh wa than 0.1% salt or has a salinity of 1‰.

Factors That Change Salinity

Evaporation and freezing remove only water molecules liquid part of the ocean; dissolved salts and other solid Where the rate of evaporation is high, the salinity water increases. Therefore, tropical waters have a hig ity at the surface than polar waters do. Salinity also as depth increases. Because water evaporates and free surface, surface water generally has a higher salinity water does.

Over most of the surface of the ocean, salinity ra 33‰ to 36‰. The global ocean has an average salinity However, salinity at particular locations can vary shown in **Figure 3.** The salinity of the Red Sea, for ex more than 40‰. The high salinity is due to the hot, d around the Red Sea, which causes high levels of evapo

Figure 3 ▶ The average surface salinity of the global ocean varies from one location to another. ***What effect do river mouths tend to have on the salinity of the surrounding ocean water?***

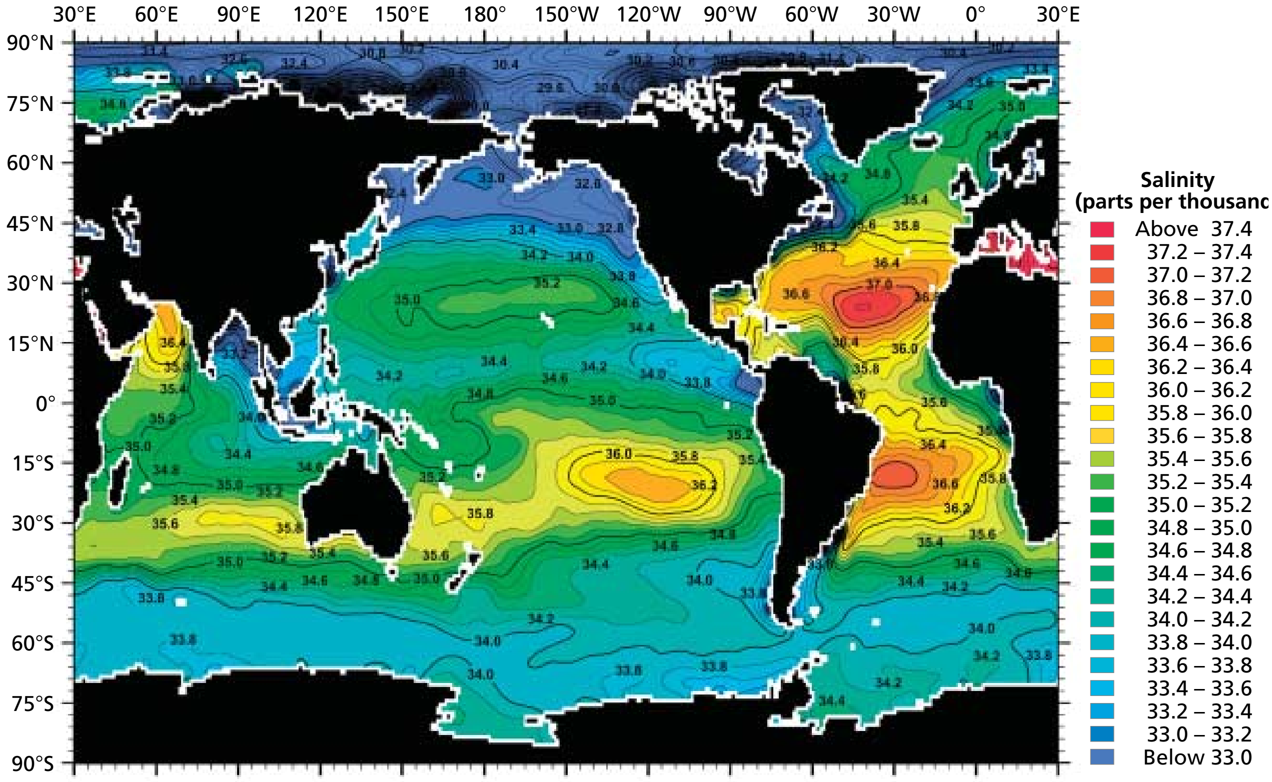


Figure 4 ▶ The surface temperature of tropical ocean water (right) can be as high as 30°C. However, the surface temperature of polar ocean water (left) is below the freezing point of fresh water.

Temperature of Ocean Water

Like ocean salinity, ocean temperature varies depending on depth and location on the surface of the oceans. The range of ocean temperatures is affected by the amount of solar energy an area receives and by the movement of water in the ocean.

Surface Water

The mixing of the ocean's surface water distributes heat downward to a depth of 100 to 300 m. Thus, the temperature of this zone of surface water is relatively constant and decreases only slightly as depth increases. However, the temperature of surface water does decrease as latitude increases. Therefore, polar surface waters are much cooler than the surface waters in the Tropics, as shown in **Figure 4.**

The total amount of solar energy that reaches the surface of the ocean is much greater at the equator than in areas near the North and South Poles. In tropical waters, surface temperatures of about 30°C are common. Surface temperatures in polar oceans, however, usually drop below –2°C. Because ocean water freezes at about –2°C, vast areas of sea ice exist in polar oceans. A floating layer of sea ice that completely covers an area of the ocean surface is called **pack ice.** Usually, pack ice is no more than 5 m thick because the ice insulates the water below and prevents it from freezing. In the middle latitudes, the ocean surface temperature varies depending on the seasons. In some areas, the ocean surface temperature may vary by as much as 10°C to 20°C between summer and winter.

pack ice a floating layer of sea ice that completely covers an area of the ocean surface

Reading Check **What factors affect the surface temperature of the ocean? (See the Appendix for answers to Reading Checks.)**

The Thermocline

Because the sun cannot directly heat ocean water below the surface layer, the temperature of the water decreases sharply as depth increases. In most places in the ocean, this sudden decrease in temperature begins close to the surface. The layer in a body of water in which water temperature drops with increased depth faster than it does in other layers is called the **thermocline.**

thermocline a layer in a body of water in which water temperature drops with increased depth faster than it does in other layers

The thermocline exists because the water near the surface becomes less dense as energy from the sun warms the water. This warm water cannot mix easily with the cold, dense water below. Thus, a thermocline marks the distinct separation between the warm surface water and the cold deep water. Below the thermocline, the temperature of the water continues to decrease, but it decreases very slowly, as shown in **Figure 5.** Changing temperature or shifting currents may alter the depth of the thermocline or cause the thermocline to disappear. Nevertheless, a thermocline is usually present beneath much of the ocean surface.

Deep Water

In the deep zones of the ocean, the temperature of the water is usually about 2°C. The colder the water is, the denser it is. The density of cold, deep water controls the slow movement of deep ocean currents. This movement occurs when the cold, dense water at the poles sinks and flows beneath warm water toward the equator. Cold, deep ocean water also holds more dissolved gases than warm, shallow ocean water does.

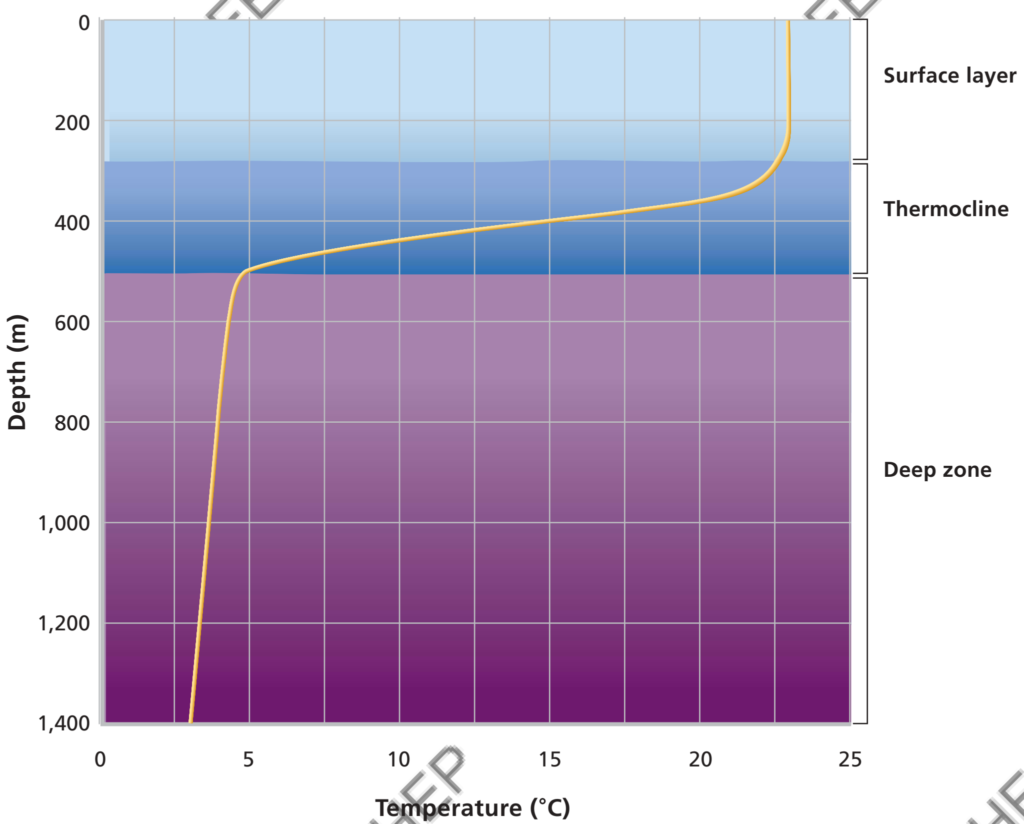


Figure 5 ▶ The temperature of ocean water decreases as depth increases. Just below the surface is a thermocline, an area where the water temperature decreases sharply.

Density of Ocean Water

The mass of a substance per unit volume is that substance's **density.** For example, 1 cm^3 of pure water has a mass of 1 g. So, the density of pure water is 1 g/cm^3. Different liquids have different densities, as shown in **Figure 6.** Two factors affect the density of ocean water: salinity and the temperature of the water. Dissolved solids, which are mainly salts, add mass to the water. The large amount of dissolved solids in ocean water makes it denser than pure fresh water. Ocean water has a density between 1.026 g/cm^3 and 1.028 g/cm^3.

Ocean water becomes denser as it becomes colder and less dense as it becomes warmer. Water temperature affects the density of ocean water more than salinity does. Therefore, the densest ocean water is found in the polar regions, where the ocean surface is coldest. This cold, dense water sinks and moves through the ocean basins near the ocean floor.

Figure 6 ▶ This graduated cylinder contains six liquids that have different densities. From top to bottom they are corn oil, water, shampoo, dish detergent, anti-freeze, and maple syrup. ***Which liquid has the lowest density?***

density the ratio of the mass of a substance to the volume of the substance; commonly expressed as grams per cubic centimeter for solids and liquids and as grams per liter for gases

Reading Check **Explain why ocean water is denser than fresh water. (See the Appendix for answers to Reading Checks.)**

QuickLAB 20 min

Density Factors

Procedure

1. Fill a **deep, clear plastic container** half full with **room temperature water.**
2. In a **1 L beaker,** mix **1/8 cup of table salt,** a **few drops of red food coloring,** and 1 L of room temperature water. Stir the mixture until the salt is dissolved.
3. Add the red saltwater mixture to the water in the clear plastic container. Record your observations.
4. In the **1 L beaker,** mix a **few drops of blue food coloring** with water that is 8°C.
5. Slowly add the cold, blue water to the clear plastic container in step 3. Record your observations.

Analysis

1. Describe what happened when you added the red salt water to the fresh water. Which is denser: fresh water or salt water?
2. What happened when you added the cold water to the room temperature water? Which is denser: cold water or room temperature water?
3. What would you expect to happen if the blue water was heated, instead of cooled?
4. Based on your observations, where would you expect the water in the ocean to be the least dense? the most dense?
5. Describe water layering where a river empties into the ocean.

Figure 7 ▶ Ocean water appears blue as far as 100 m below the surface.

Color of Ocean Water

Have you ever wondered why the ocean appears blue, as shown in **Figure 7**? The color of ocean water is determined by the way it absorbs or reflects sunlight. White light from the sun contains light from all the visible wavelengths of the electromagnetic spectrum. Much of the sunlight penetrates the surface of the ocean and is absorbed by the water. Water absorbs most of the wavelengths, or colors, of visible light. Only the blue wavelengths tend to be reflected. The reflection of this blue light makes ocean water appear blue.

Why Is Ocean Color Important?

Substances or organisms in ocean water, such as phytoplankton, can affect the color of the water. *Phytoplankton* are microscopic plants in the ocean that provide food to many of the ocean's organisms. Phytoplankton absorb red and blue light, but reflect green light. Therefore, the presence and amount of phytoplankton can affect the shade of blue of the ocean.

By studying variations in the color of the ocean, scientists can determine the presence of phytoplankton in the ocean. Because phytoplankton require nutrients, the presence or absence of phytoplankton can indicate the health of the ocean. If the color of an area of the ocean indicates that no phytoplankton is present, pollution may have prevented phytoplankton growth.

Section 1 Review

1. **Describe** how water temperature affects the ability of the ocean water to dissolve gasses.
2. **Summarize** how freezing and evaporation affect salinity.
3. **Describe** the composition of ocean water.
4. **Define** *thermocline*.
5. **Describe** how temperature and salinity affect the density of ocean water.
6. **Explain** how the density of ocean water drives the movement of deep ocean currents.
7. **Explain** why shallow ocean water appears to be blue in color.

CRITICAL THINKING

8. **Making Inferences** Why does the surface temperature of ocean water in middle latitudes vary during the year?
9. **Understanding Relationships** Why would surface water in the North Sea be more likely to contain a high percentage of dissolved gases than the surface water in the Caribbean Sea would?
10. **Predicting Consequences** If global temperatures increase, how would this change affect the ability of the oceans to absorb CO_2?
11. **Identifying Relationships** If an area of the ocean has a large decrease in phytoplankton, how would this change affect other ocean organisms? Explain your answer.

CONCEPT MAPPING

12. Use the following terms to create a concept map: *ocean water, salinity, temperature, density, dissolved solids,* and *dissolved gas.*

Section 2 Life in the Oceans

Most marine organisms depend on two major factors for their survival—the essential nutrients available in ocean water and sunlight. Variations in either of these factors affect the ability of aquatic organisms to survive and flourish.

OBJECTIVES

- **Explain** how marine organisms alter the chemistry of ocean water.
- **Explain** why plankton can be called *the foundation of life in the ocean*.
- **Describe** the major zones of life in the ocean.

KEY TERMS

upwelling
plankton
nekton
benthos
benthic zone
pelagic zone

Ocean Chemistry and Marine Life

The chemistry of the ocean is a balance of dissolved gases and solids that are essential to marine life. Marine organisms help maintain the chemical balance of ocean water. They do this by removing nutrients and gases from the ocean while returning other nutrients and gases to the ocean. For example, marine plants absorb large amounts of carbon, hydrogen, oxygen, and sulfur. They also absorb other elements such as nitrogen, phosphorus, and silicon. Marine organisms also return nutrients and gases to the ocean. For example, photosynthetic marine plants remove carbon dioxide from ocean water to produce oxygen.

Marine organisms, such as the sea horse shown in **Figure 1**, also help recycle nutrients in the ocean. During a marine organism's lifetime, the organism absorbs and stores nutrients from the ocean. These nutrients are eventually returned to the water when the organism dies. For example, bacteria in the water digest the remains of the dead organisms. The bacteria then release the essential nutrients from the dead organisms into the ocean.

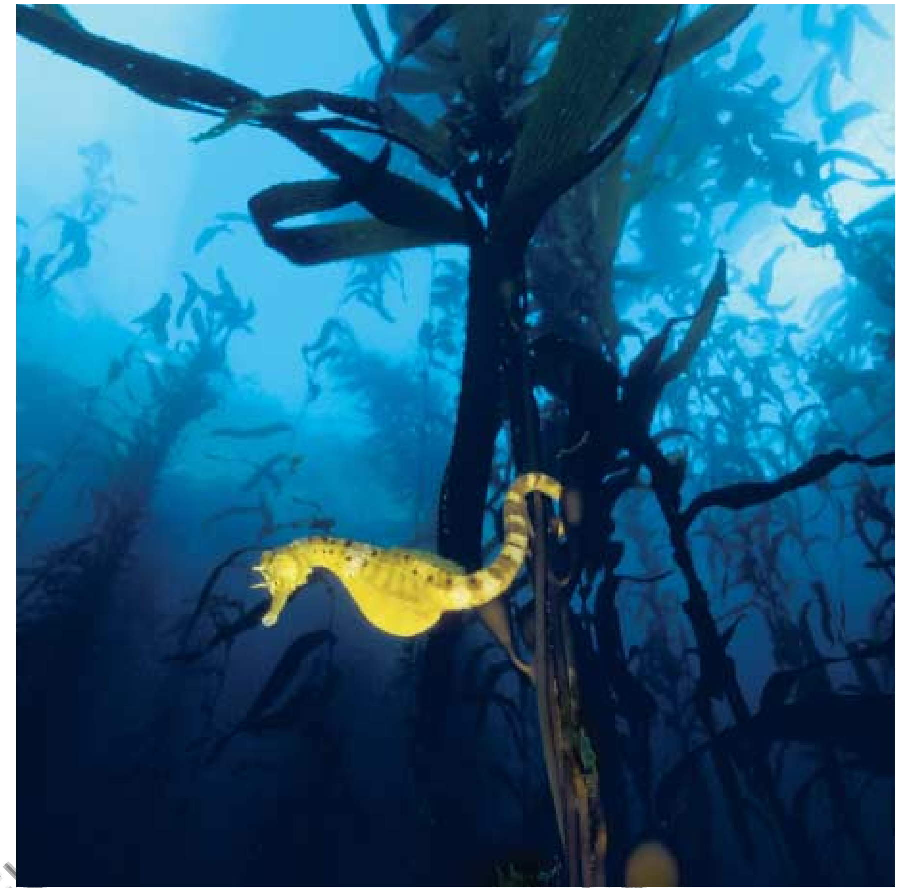


Figure 1 ▶ Like many marine organisms, this sea horse gets many of the nutrients it needs from the ocean water.

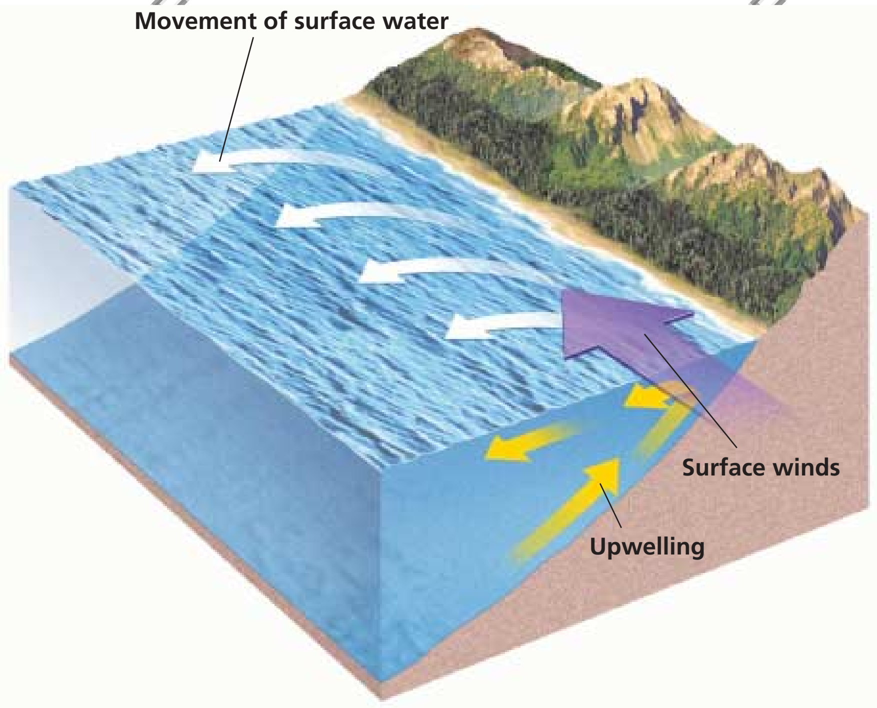


Figure 2 ▶ Upwelling is caused by offshore movement of surface water. ***How might stormy weather affect the process of upwelling?***

Upwelling

The distribution of life in the ocean depends on the way life-supporting nutrients cycle in the ocean water. In general, all of the elements necessary for life are consumed by organisms near the surface. Elements are then released back into the ocean water when organisms die, sink to lower depths, and decay. Thus, deep water is a storage area for the nutrients needed for life. These nutrients must, however, return to the surface before most organisms in the ocean can use them.

One way that nutrients return to the surface is through a process called upwelling. **Upwelling** is the movement of deep, cold, and nutrient-rich water to the surface, as shown in **Figure 2.** When wind blows steadily parallel to a coastline, surface water moves farther offshore. The deep, cold water then rises to replace the surface water that has moved away from the shore.

upwelling the movement of deep, cold, and nutrient-rich water to the surface

plankton the mass of mostly microscopic organisms that float or drift freely in the waters of aquatic (freshwater and marine) environments

nekton all organisms that swim actively in open water, independent of currents

benthos organisms that live at the bottom of oceans or bodies of fresh water

Marine Food Webs

Because most marine organisms need sunlight as well as nutrients, most marine organisms live in the upper 100 m of water. Free-floating, microscopic plants and animals called **plankton** live within the sunlit zone. Plankton, shown in **Figure 3,** form the base of the complex food webs in the ocean. The plankton are consumed primarily by small marine organisms, which, in turn, become food for larger marine animals. These larger animals fall into two groups. All organisms that swim actively in open water, such as fish, dolphins, and squid, are called **nekton.** The organisms that live on the ocean floor are called **benthos.** Benthos include marine plants and animals, such as oysters, sea stars, and crabs, that live in sunlit, shallow waters.

Figure 3 ▶ Plankton are so tiny that you need a microscope to see them.

Ocean Environments

The ocean can be divided into two basic environments, as shown in **Figure 4.** These zones are the bottom region, or **benthic zone,** and the upper region, or **pelagic zone.** The amount of sunlight, the water temperature, and the water pressure determine the distribution of marine life within these zones.

benthic zone the bottom region of oceans and bodies of fresh water

pelagic zone the region of an ocean or body of fresh water above the benthic zone

Benthic Zones

The shallowest benthic zone lies between the low-tide and high-tide lines and is called the *intertidal zone*. Shifting tides and breaking waves make this zone a continually changing environment for the marine organisms that flourish there.

Most of the organisms that live in the benthic zone live in the shallow *sublittoral zone*. This continuously submerged zone is located on the continental shelves and is populated by organisms such as sea stars, brittle stars, and sea lilies.

The *bathyal zone* begins at the continental slope and extends to a depth of 4,000 m. Because little or no sunlight reaches this zone, plant life is scarce. Examples of animals that live in the bathyal zone are octopuses, sea stars, and brachiopods.

The *abyssal zone* has no sunlight because it begins at a depth of 4,000 m and extends to a depth of 6,000 m. Organisms that live in the abyssal darkness include sponges and worms.

The *hadal zone* is confined to the ocean trenches, which are deeper than 6,000 m below the surface of the water. This zone is virtually unexplored, and scientists think that life in the hadal zone is sparse.

Reading Check **Which benthic zone has the most marine life? Why?** **(See the Appendix for answers to Reading Checks.)**

Graphic Organizer **Comparison Table**

Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with the different benthic zones. Label the rows with "Depth," "Marine life," and "Sunlight." Then, fill in the table with details about the different benthic zones.

Figure 4 ▶ This diagram shows the classification and location of marine environments.

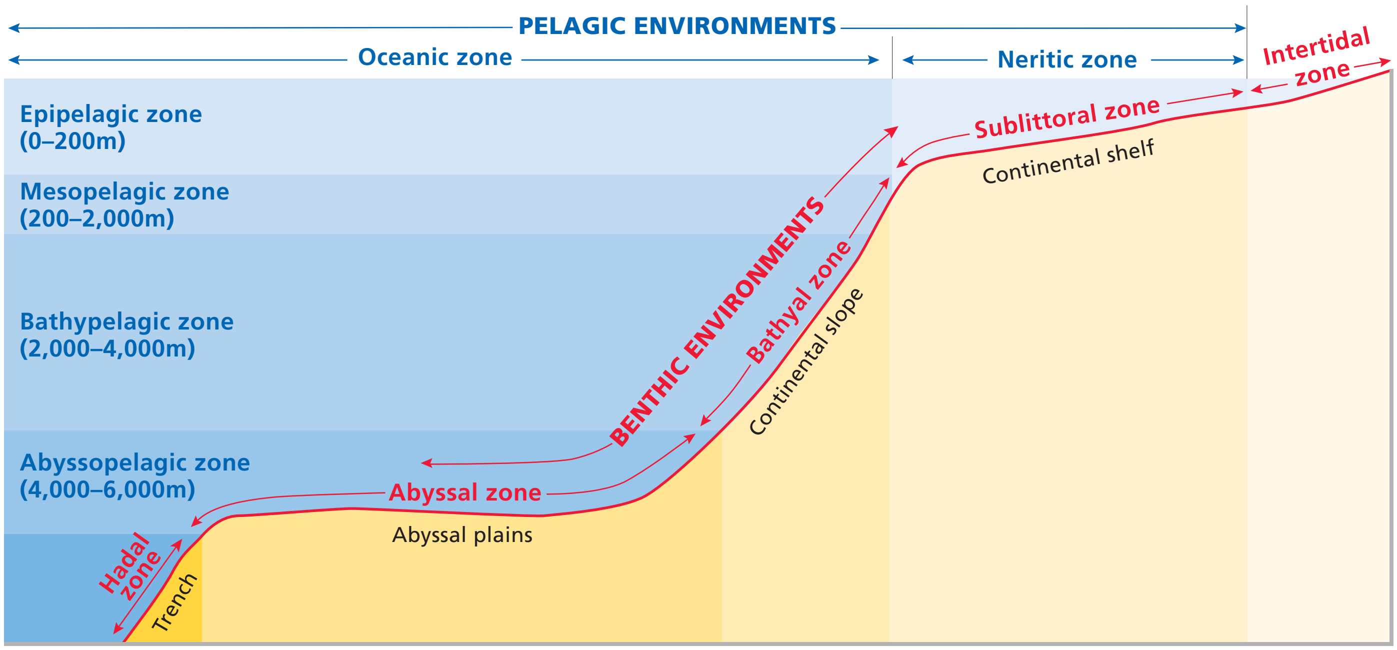


Figure 5 ▶ Fish and marine mammals are examples of organisms that live in the pelagic zone.

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Topic: Marine Life
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Pelagic Zones

The region of the ocean above the benthic zone is the pelagic zone. The area of the pelagic zone above the continental shelves is called the *neritic zone*. The neritic zone has abundant sunlight, moderate temperatures, and relatively low water pressure, which are ideal factors for marine life. Nekton fill the zone's waters and are the source of much of the fish and seafood that humans eat.

The *oceanic zone* extends into the deep waters beyond the continental shelf. It is divided into four zones, based on depth. The epipelagic zone is the uppermost area of the oceanic zone. It is sunlit and populated by marine life, such as the dolphins shown in **Figure 5**. The mesopelagic, bathypelagic, and abyssopelagic zones occur at increasingly greater depths. The amount of marine life in the pelagic zone decreases as depth increases.

Section 2 Review

1. **Explain** the effects marine organisms have on the chemistry of ocean water.
2. **Summarize** the process of upwelling, and describe its importance to marine organisms.
3. **Explain** how plankton form the base of ocean food webs.
4. **Identify** the two major zones of the ocean environment.
5. **Compare** the sublittoral and neritic zones, and name some organisms found in each zone.

CRITICAL THINKING

6. **Analyzing Processes** How can the movement of wind currents alter the chemistry of a given area of the ocean?
7. **Making Predictions** How would life in the ocean change if the area of all regions of upwelling decreased?

CONCEPT MAPPING

8. Use the following terms to create a concept map: *pelagic zone, neritic zone, benthic zone, ocean environment,* and *oceanic zone.*

Section 3 Ocean Resources

The ocean supplies humans with a number of natural resources. It is a major source of food and minerals, and it provides a means of transportation. Furthermore, the growth of Earth's population has created new interest in the sea as a source of fresh water.

OBJECTIVES

- **Describe** three important resources of the ocean.
- **Explain** the threat water pollution poses to marine organisms.

KEY TERMS

desalination
aquaculture

Fresh Water from the Ocean

The increasing demand for fresh water for things such as drinking water, industry, and irrigation can be met by converting ocean water to fresh water. One way of increasing the freshwater supply is through desalination, as shown in **Figure 1.** **Desalination** is the extraction of fresh water from salt water. Although desalination may provide needed fresh water, the process is generally costly.

Methods of Desalination

One method of desalination is distillation. During *distillation,* ocean water is heated to remove salt. Heat causes liquid water to evaporate and leaves dissolved salts behind. When the water vapor condenses, the result is pure fresh water. However, the process of evaporating liquid water often requires a large amount of costly heat energy.

Another method of desalination is *freezing*. When water freezes, the first ice crystals that form do not contain salt. The ice can be removed and melted to obtain fresh water. This process requires about one-sixth the energy needed for distillation.

Reverse osmosis desalination is a popular method for desalinating ocean water. It includes the use of special membranes that allow water under high pressure to pass through and that block the dissolved salts.

desalination a process of removing salt from ocean water

Figure 1 ▶ Thousands of gallons of water from the Persian Gulf is converted into fresh water through the towers of this desalination plant in Kuwait.

Figure 2 ▶ Offshore oil rigs, such as this one in the Gulf of Mexico, produce about one-fourth of the world's oil.

Mineral and Energy Resources

Salt is one mineral resource that can be obtained from the ocean. Other minerals and energy resources can also be extracted from the oceans. While some valuable minerals are easily extracted from the oceans, others are costly or difficult to extract.

Petroleum

The most valuable resource in the ocean is the petroleum found beneath the sea floor. Offshore oil and natural gas deposits exist along continental margins around the world. About one-fourth of the world's oil is now obtained from offshore wells, such as the one shown in **Figure 2.** As a result of new drilling techniques, oil and gas can be extracted far offshore and from great depths.

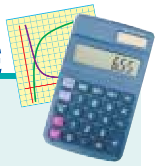
Nodules

Potato-shaped lumps of minerals, called *nodules,* are found on the abyssal floor of the ocean. Nodules are a valuable source of manganese, iron, copper, nickel, cobalt, and phosphates. However, the recovery of nodules is expensive and difficult because they are located in very deep water. Because country borders are observed only close to land, the question of who has the right to mine minerals from the ocean floor has not been answered.

Trace Minerals

The ocean is also the main source of magnesium and bromine. However, the concentration of most other useful chemicals that are dissolved in the oceans is very small. The extraction of minerals found only in trace amounts is too costly to be practical.

MATHPRACTICE



Ocean's Gold One cubic kilometer of ocean water contains about 6 kg of gold. If you must process 4 million liters of ocean water to get an amount of gold worth 4¢, how many liters of water would have to be processed to get gold worth $1?

Food from the Ocean

Of all of the resources that the ocean supplies, the one in greatest demand is food. Seafood, which is an important source of protein, can be harvested through fishing or through aquaculture.

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Topic: Ocean Resources

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Fishing

Because fish are a significant food source for people around the world, fishing has become an important industry. But when the ocean is overfished, or overharvested, over a long period of time, fish populations can collapse. A collapse may damage the ecosystem and threaten the fishing industry. To prevent overharvesting, many governments have passed laws to manage fishing.

Aquaculture

Another way to deal with the high demand for seafood is by farming aquatic life. **Aquaculture** is the raising of aquatic plants and animals for human use or consumption. Catfish, salmon, oysters, and shrimp are already grown on large aquatic farms. Similar methods may be used to breed fish and seaweed in ocean farms, such as the one shown in **Figure 3.** A major problem for aquaculturalists is that the ocean farms are susceptible to pollution and that the farms may be a local source of pollution.

aquaculture the raising of aquatic plants and animals for human use or consumption

Under the best conditions, an ocean farm could produce more food than an agricultural farm of the same size does. For example, in agriculture, only the top layers of soil can be used. In contrast, ocean farms may use a wide range of depths to produce food. Someday, the nutrient-rich bottom water may be pumped to the surface as a way of fertilizing aquatic farms.

Reading Check **List the benefits and problems of aquaculture. (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Aquaculture establishments, such as this seaweed farm in Madagascar, provide a reliable, economical source of food.

Figure 4 ▶ Pollution can damage the ocean's ecosystem and make seafood unsafe to eat.

Ocean-Water Pollution

The oceans have been used as a dumping ground for many kinds of wastes including garbage, sewage, and nuclear waste. Until recently, most wastes were diluted or destroyed as they spread throughout the ocean. But the growth of the world population and the increased use of more-toxic substances have reduced the ocean's ability to absorb wastes and renew itself.

Productive coastal areas and beaches are in the greatest danger of being polluted because they are closest to sources of pollution, as shown in **Figure 4.** Pollution has destroyed clam and oyster beds, sea birds have become tangled in plastic products, and beaches have been closed because of sewage and oil spills.

Besides being found in coastal waters, pollutants can be found in most other areas of the oceans. Traces of mercury, of the insecticide DDT, and of lead from gasoline have been detected in the ocean. In some areas of the world, concentrations of pollutants are so high that the fish have become unsafe for humans to eat. Recognizing the affects of dumping waste in the ocean, scientists and governments have been working to reduce pollution. For example, the use of DDT has been banned in the United States and the use of leaded gasoline has been reduced.

Section 3 Review

1. **Describe** three methods of desalinating ocean water.
2. **Explain** why distillation can be an expensive method of desalination.
3. **List** two important mineral resources in the ocean.
4. **Identify** the most valuable resource that can be obtained from the ocean.
5. **Define** the term *aquaculture,* and explain why aquaculture is important.
6. **Explain** why beaches are especially vulnerable to ocean pollution.

CRITICAL THINKING

7. **Making Inferences** Describe how the mining of nodules may create problems between countries.
8. **Predicting Consequences** How would pollution of oceans affect the fishing industry?
9. **Analyzing Relationships** How could humans be affected if microscopic marine organisms absorb small amounts of mercury?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *desalination, distillation, freezing, reverse osmosis, petroleum, aquaculture, fishing, salt, ocean resource,* and *pollution.*

Chapter 20 Highlights

Sections

1 Properties of Ocean Water

Key Terms

salinity, 496
pack ice, 497
thermocline, 498
density, 499

Key Concepts

- Cold ocean water dissolves gases more readily than warm ocean water does.
- The ocean is a carbon sink that dissolves CO_2 from the atmosphere.
- Dissolved solids make up 3.5% of the mass of ocean water.
- Salinity is a measure of the amount of dissolved salts in ocean water.
- Temperature of ocean water is dependent on depth and latitude.
- Density of ocean water is dependent on temperature and salinity.
- The color of ocean water is affected by the presence of phytoplankton.

2 Life in the Oceans

upwelling, 502
plankton, 502
nekton, 502
benthos, 502
benthic zone, 503
pelagic zone, 503

- Marine organisms help maintain the chemical balance of ocean water by using nutrients for life processes and by returning the nutrients to the water after death.
- Plankton form the base of complex ocean food webs by acting as food for other marine organisms.
- There are two major zones of life in the ocean: benthic and pelagic. Each zone supports different types of organisms.

3 Ocean Resources

desalination, 505
aquaculture, 507

- The ocean is valuable as a source of fresh water, minerals, and food.
- Fresh water can be obtained from the ocean by the methods of desalination, freezing, and reverse osmosis desalination.
- Ocean-water pollution threatens both marine organisms and humans by damaging food resources in the ocean.

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Chapter 20 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *thermocline*
2. *upwelling*
3. *desalination*

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

4. *salinity* and *density*
5. *plankton* and *nekton*
6. *benthic zone* and *pelagic zone*
7. *upwelling* and *aquaculture*

Understanding Key Concepts

8. The amount of dissolved salts in ocean water is called the water's
   - a. salinity.
   - b. nekton.
   - c. plankton.
   - d. density.

9. When liquid water is warmed, its density
   - a. increases.
   - b. decreases.
   - c. remains the same.
   - d. doubles.

10. Although most of the various wavelengths of visible light are absorbed by ocean water, the one wavelength that is most often reflected is the color
    - a. violet.
    - b. green.
    - c. yellow.
    - d. blue.

11. Drifting marine plants and animals are known as
    - a. plankton.
    - b. benthos.
    - c. nekton.
    - d. sea stars.

12. Marine animals that can swim to search for food and avoid predators are called
    - a. phytoplankton.
    - b. zooplankton.
    - c. nekton.
    - d. benthos.

13. Which of the following ocean environments experiences the most change?
    - a. intertidal zone
    - b. abyssal zone
    - c. bathyal zone
    - d. neritic zone

14. Which of the following methods is *not* used for producing fresh water by desalinating ocean water?
    - a. distillation
    - b. evaporation
    - c. reverse osmosis
    - d. aquaculture

15. Lumps of minerals on the ocean floor are called
    - a. nekton.
    - b. nodules.
    - c. benthos.
    - d. plankton.

16. Aquaculture is another name for
    - a. desalination.
    - b. distillation.
    - c. ocean farming.
    - d. rapid temperature changes.

Short Answer

17. Describe the process of upwelling, and explain its effects on marine life.

18. What are the six most abundant elements dissolved in ocean water?

19. How are temperature, salinity, and density related?

20. Describe how an oil spill would affect a fishing industry.

21. List three important resources from the ocean, and describe how they are obtained.

22. What effects does ocean pollution have on humans?

Critical Thinking

23. Predicting Consequences If climatic conditions over Earth's oceans caused upwelling and wave action to stop, what would happen to marine life? Explain your answer.

24. Identifying Relationships How would a significant and global decrease in sunlight affect plankton and other marine organisms?

25. Applying Concepts If you were to start an aquatic farm, in which of the zones of marine life would you locate your farm? Explain your answer.

26. Making Inferences When oceanographers first explored the deep-ocean basin along mid-ocean ridges, they discovered a variety of marine life, including sightless crabs. Explain why sightlessness is not a disadvantage to these crabs.

Concept Mapping

27. Use the following terms to create a concept map: *fishing, marine life, plankton, fish, color, dissolved gas, dissolved solid, desalination, salt, ocean water characteristics,* and *aquaculture*.

Math Skills

28. Using Equations Using the equation *density* = *mass* ÷ *volume,* determine the mass of a 3 cm^3 sample of ocean water if the water's density is 1.027 g/cm^3.

29. Making Calculations What percentage of dissolved salts would be present in water that has a salinity of 40‰?

30. Making Calculations A 1,000 g sample of ocean water contains 35 g of dissolved solids. Magnesium makes up 7.7% of the 35 g of dissolved solids. How many grams of magnesium are in the 1,000 g sample of ocean water?

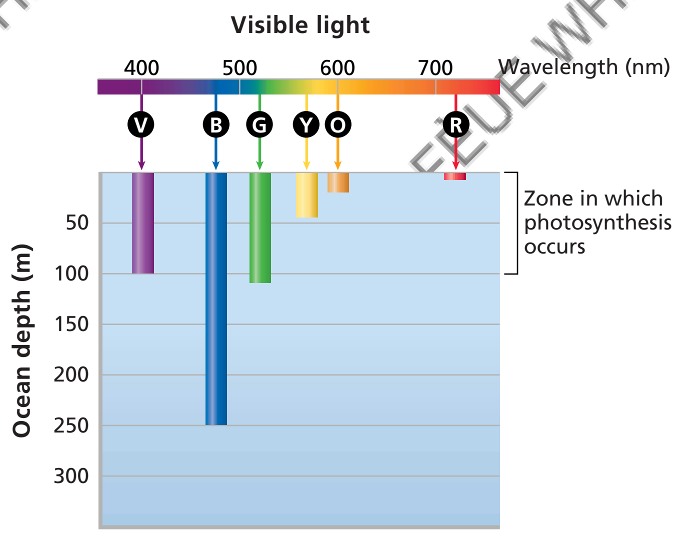
Writing Skills

31. Creative Writing Write a descriptive essay about the deep-ocean waters of the oceanic zone. The essay should include a description of the marine organisms in this zone as well as a description of what life is like for the marine organisms in this zone.

32. Writing from Research Research the new foods that are being produced through aquaculture and the nations that are investing in this method of farming. Write a short essay that describes these foods, where they are grown, and their nutritional values.

Interpreting Graphics

The graph shows the depths at which different wavelengths of light penetrate ocean water. Use this graph to answer the questions that follow.



33. Estimate the depth at which yellow light can no longer penetrate ocean water.

34. Which colors can penetrate the ocean at a depth of 50 m?

35. Would an object that is painted red appear red at a depth of 50 m? Explain your answer.

Chapter 20 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 Organisms that live on the ocean floor are called
A. benthos
B. nekton
C. plankton
D. phytoplankton

2 Which of the following cannot be used to remove salt from sea water to make the water safe for drinking?
F. distillation
G. freezing
H. reverse osmosis
I. adding fresh water

3 The temperature of ocean water is dependent on all of the following except
A. depth
B. the amount of solar energy it receives
C. water movement
D. the number of organisms living in it

4 As the temperature of ocean water increases from 10ºC to 30ºC, how does the water's density change?
F. It increases.
G. It decreases.
H. It remains the same.
I. It is impossible to predict.

5 Barriers to the mining of mineral nodules include
A. that mining rights for the ocean floor have not yet been determined.
B. that they contain only traces of minerals and therefore are not worth the effort to gather.
C. that they are readily accessible and therefore not valuable.
D. that they primarily contain elements that are dangerous to humans.

Directions (6–7): **For *each* question, write a short response.**

6 What is the cause of deep ocean currents?

7 What is the name for the top layer of ocean water that extends to 300 m below sea level?

Reading Skills

Directions (8–10): **Read the passage below. Then answer the questions.**

The Effects of El Niño

The interaction between the ocean and the atmosphere can profoundly affect weather conditions. Occurring, on average, every four years and lasting about 18 months, El Niño is one event that triggers global weather changes. El Niño is characterized by changes in wind patterns that allow warmer water from the western Pacific Ocean to surge eastward. Normally, east-to-west winds cause warm water to accumulate in the western Pacific Ocean. During El Niño, the trade winds shift warm water east. Sea surface temperatures from the coast of Peru to the equatorial central Pacific rise. The warm waters cause the thermocline to sink and contribute to the formation of convective clouds, which cause heavy rains that shift eastward at the same rate as the waters. In areas on the western coast of the Pacific Ocean, droughts become common.

8 According to the passage, which of the following statements is not true?
A. During El Niño, the trade winds shift warm water eastward.
B. El Niño is one event that triggers global weather changes.
C. An El Niño weather event lasts about two years on average.
D. An El Niño event lead to the formation of convective clouds that shift eastward.

9 Which of the following statements can be inferred from the reading passage?
F. An El Niño is usually followed by a weather event that moves cold water westward.
G. The changes caused by El Niño directly affect the weather in the United States.
H. El Niño causes severe disruptions to international trade and travel.
I. El Niño weather cycles are a relatively recent phenomenon.

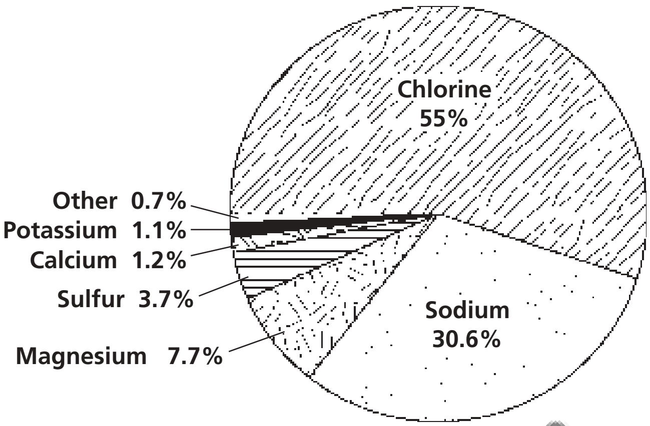
10 During an El Niño weather event, what happens to the thermocline and what effect might this have on upwelling?

Interpreting Graphics

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

Base your answers to questions 11 and 12 on the pie graph below.

Solids Dissolved in Ocean Water



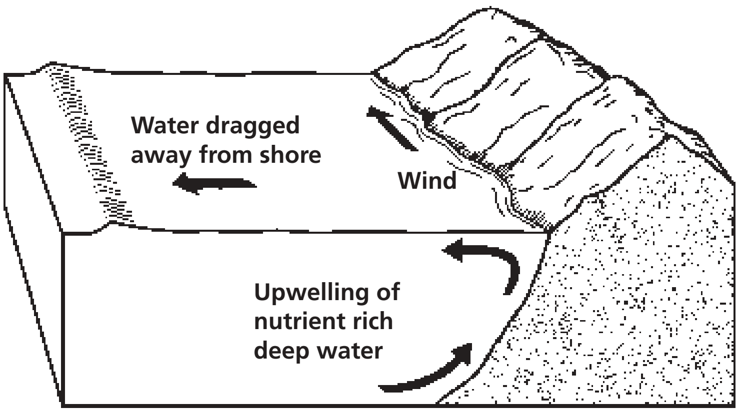
11 The two elements that make up the largest percentage of the dissolved solids combine to make what common solid found in ocean water?

F. sand
G. salt
H. siliceous ooze
I. calcareous ooze

12 While the salinity of ocean waters varies from one area to another, the relative amount of solids dissolved in ocean water does not change. What is the reason for this equilibrium?

Base your answer to question 13 on the diagram below, which shows the basic mechanics of upwelling.

Diagram of Upwelling



13 During summer months, beaches may sometimes close because of the appearance of large phytoplankton blooms. How might an upwelling contribute to these beach closings during warmer months?

Test TIP

Scan the answer set for words such as "never" and "always." Such words are often used in statements that are incorrect because they are too general.

Objectives

- **Measure** the temperature and density of water.
- USING SCIENTIFIC METHODS **Analyze** the effects of temperature and salinity on the density of water.

Materials

beaker, 250 mL
clay, modeling
freezer (optional)
gloves, heat-resistant
graduated cylinder, 100 mL
hot plate
pencil, grease, red
pencil, grease, yellow
ruler, metric
scissors
straw, plastic
table salt
teaspoon
thermometer
water, distilled

Safety

Step 8

Ocean Water Density

The density of ocean water varies. Density is affected by the salinity of the water and the temperature of the water. Furthermore, the salinity of an area of the ocean is affected by the rate of evaporation or freezing and by the addition of fresh water and salts. The temperature of the ocean is determined by the amount of infrared radiation that reaches Earth's surface. In this lab, you will observe the effects of temperature and salinity on the density of salt water.

PROCEDURE

1. Make a hydrometer by filling 5 cm of one end of the straw with modeling clay.
2. Pour 100 mL of distilled water at room temperature into a glass jar or beaker. Float the straw upright in the jar. If the straw does not float upright, cut off the open end at 1 cm intervals until it floats upright.
3. Use a red grease pencil to mark the water level on the straw. Remove the straw from the water, and draw a continuous line around the straw at the mark.
4. Use a yellow grease pencil to draw lines around the straw at 1 cm intervals above and below the red line. The red line will be used as a reference point.
5. Add 2 tsp of salt to the water, and stir until all of the salt has dissolved. Draw a table similar to **Table 1**. Measure and record the water temperature in **Table 1.**
6. Place the hydrometer in the salt water. In **Table 1,** record the density by counting the marks above or below the red line to the water's surface. The higher the hydrometer floats out of the water, the more dense the water.
7. Turn the hot plate on low. Place the beaker of salt water on the hot plate. **CAUTION** Wear heat-resistant gloves.
8. Hold a thermometer in the water. Do not let the thermometer touch the bottom of the beaker.

9. When the water's temperature reaches 25°C, turn off the hot plate. Immediately place the hydrometer in the water. Record the relative density in **Table 1.**

10. Repeat steps 7–9, and heat the water until it is 30°C.

11. Turn the hot plate on high. Heat the salt water until it begins to boil. Boil the water for 5 min. Turn off the hot plate.

12. Place the hydrometer in the water. Draw a table similar to **Table 2**. Measure and record the water's density in **Table 2.**

13. Boil the water for another 5 min. Measure and record the water's density.

14. Repeat step 13. Once the water is cool, measure the amount of water that remains in the beaker.

Temperature (°C)	Density (cm above or below the red line)
25	
30	

Table 1

Minutes of boiling	Density (cm above or below the red line)
5	
10	
15	

Table 2

ANALYSIS AND CONCLUSION

1. **Analyzing Data** In which trial was the water the most dense? the least dense? Explain your answers.

2. **Identifying Trends** As the temperature of the water increases, does the water's density increase or decrease?

3. **Making Inferences** Based on your observations, infer the density of polar ocean waters, and compare it with the density of equally saline water near the equator. Explain your answer.

4. **Analyzing Processes** Why did the amount of water in the beaker change? Explain why boiling the water affected its density.

5. **Forming a Hypothesis** How would you expect the density of the water to change if the water was frozen instead of boiled? Explain your answer.

Extension

1. **Evaluating Hypotheses** Place a beaker of salt water in a freezer until a crust of ice forms. Break up and remove the ice from the water, and record the density of the remaining water. Is the water denser or less dense than before it was frozen? Explain.

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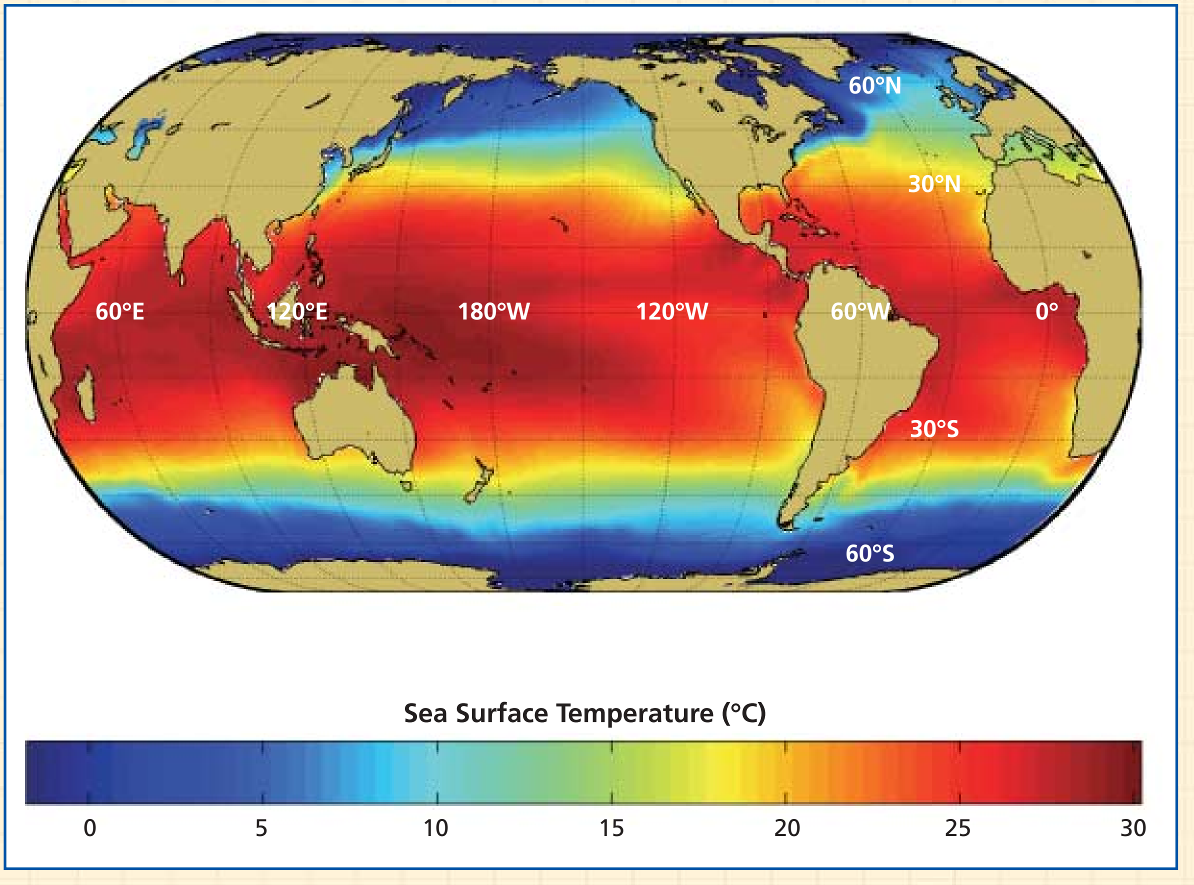
MAPS in Action

Sea Surface Temperatures in August



Map Skills Activity

This map shows global sea surface temperatures in the month of August. Latitude and longitude are shown in 10° intervals. The latitude of New York City is 41°N and 74°W. Use the map to answer the questions below.

1. **Analyzing Data** Estimate the sea surface temperatures off the east coast of Florida.
2. **Identifying Relationships** Identify areas of the globe that receive the most solar energy.
3. **Inferring Relationships** At which locations would you most likely find pack ice?
4. **Making Comparisons** Where would you expect to find higher surface salinity values, off the coast of North Africa or off the coast of the southern tip of South America?
5. **Analyzing Relationships** As latitude increases, surface temperatures decrease. How would you expect the density of surface water to change as latitude increases? Explain your answer.
6. **Making Predictions** Off the coast of New York City in December, would you expect the density of the ocean waters to increase or decrease compared to the density of the waters in August? Explain.

EYE on the Environment

A Harbor Makes a Comeback

Not long ago, the harbor in Boston, Massachusetts, was known as the most polluted harbor in the world. In recent years, however, Boston Harbor has made one of the most impressive comebacks in history.

Polluted Since Colonial Times

During America's colonial period, residents of the city of Boston dealt with their sewage by dumping it directly into Boston Harbor. They hoped that the tides would carry the sewage out to sea. However, much of the raw sewage remained in the harbor. For hundreds of years, waste and sewage washed up along the shore and sometimes caused outbreaks of disease. Over time, most of the species of marine life disappeared from the harbor.

In the late 1960s, a sewage-treatment plant was built to treat the city's sewage before it was dumped into the harbor. Unfortunately, the plant could not meet the demands of the fast-growing city. Even as late as the 1980s, millions of tons of sewage flowed directly into the harbor every year. Beaches were closed, and the shell-fishing industry in Boston Harbor was shut down. Divers reported that a "gray, mayonnaise-like substance" covered the harbor's floor.

Taking Action

In the mid 1980s, a new sewage-treatment complex was built at Deer Island, which lies in the outskirts of the harbor. By 1995, the beaches were reopened and were significantly safer. Plants, fish, and other organisms returned to the harbor, and the ocean floor improved.

The task of protecting the harbor is far from over, however. Officials continue to monitor the sewage-treatment process. In addition, officials are working to expand the cleanup project to include surrounding watersheds.

▲ For many years, Boston Harbor was known as the most polluted harbor in the world.

◀ The Deer Island sewage-treatment facility is one of the largest facilities of its kind in the world. The large, egg-shaped tanks are used in the primary treatment of sewage.

Extension

1. **Determining Cause and Effect** Why would the health of Boston Harbor depend on the health of the surrounding watersheds?
2. **Research** Write a brief summary of how sewage from your area is treated and disposed and how long the current sewage-treatment system has been used.

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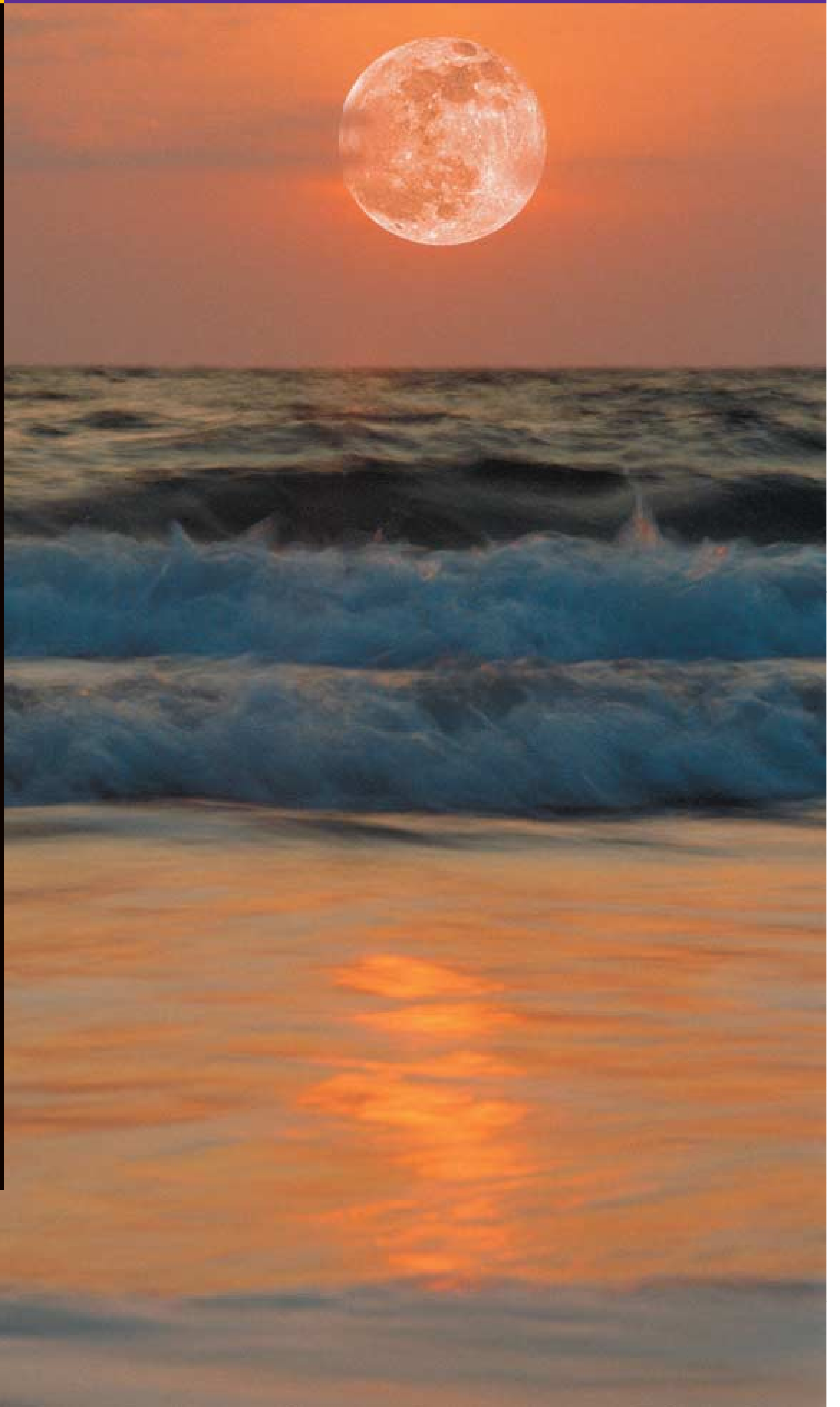
Chapter 21 Movements of the Ocean



Sections

What You'll Learn

- What factors cause surface and deep currents
- How waves form and move
- How the moon affects tides

Why It's Relevant

Ocean water moves in currents. Ocean currents are a major method of heat transport that affects climate around the globe.

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 "Surface currents," "Deep currents," "Waves," and "Tides." As you read the chapter, write information you learn about each category under the appropriate tab.

▶ Tides are caused by the moon's gravitational pull on the oceans. In some places, the moon can cause tides that are as high as 15 m above the low tide.

Section 1 Ocean Currents

The water in the ocean moves in giant streams called **currents.** Many ocean currents are complex and difficult to trace. Oceanographers identify ocean currents by studying the physical and chemical characteristics of the ocean water. They also identify currents by mapping the paths of debris that is dumped or washed overboard from ships, as shown in **Figure 1.** From these data, scientists have mapped a detailed pattern of ocean currents around the world. Scientists place ocean currents into two major categories: surface currents and deep currents.

OBJECTIVES

- **Describe** how wind patterns, the rotation of Earth, and continental barriers affect surface currents in the ocean.
- **Identify** the major factor that determines the direction in which a surface current circulates.
- **Explain** how differences in the density of ocean water affect the flow of deep currents.

KEY TERMS

current
surface current
Coriolis effect
gyre
Gulf Stream
deep current

Factors That Affect Surface Currents

Currents that move on or near the surface of the ocean and are driven by winds are called **surface currents.** Surface currents are controlled by three factors: air currents, Earth's rotation, and the location of the continents.

All surface currents are affected by winds. Winds are caused by the uneven heating of the atmosphere. Variations in air temperature lead to variations in air density and pressure. Colder, denser air sinks and forms areas of high pressure. Air moves away from high-pressure areas to lower pressure areas. This movement gives rise to wind.

Because *wind* is moving air, wind has kinetic energy. The wind passes this energy to the ocean as the air moves across the ocean surface. As energy is transferred from the air to the ocean, the water at the ocean's surface begins to move.

current in geology, a horizontal movement of water in a well-defined pattern, such as a river or stream

surface current a horizontal movement of ocean water that is caused by wind and that occurs at or near the ocean's surface

Figure 1 ▶ Glass floats, which are used to hold up Japanese fishing nets, have been carried by surface currents from off the coasts of Japan to this beach in northwest Hawaii.

Global Wind Belts

Global wind belts, such as the trade winds and westerlies shown in **Figure 2**, are a major factor affecting the flow of ocean surface water. The *trade winds* are located just north and south of the equator. In the Northern Hemisphere, trade winds blow from the northeast. In the Southern Hemisphere, they blow from the southeast. In both hemispheres, trade-wind belts push currents westward across the tropical latitudes of all three major oceans.

The *westerlies* are located in the middle latitudes. In the Northern Hemisphere, westerlies blow from the southwest. In the Southern Hemisphere, they blow from the northwest. Westerlies push ocean currents eastward in the higher latitudes of the Northern and Southern Hemispheres.

Coriolis effect the apparent curving of the path of a moving object from an otherwise straight path due to Earth's rotation

gyre a huge circle of moving ocean water found above and below the equator

Continental Barriers

The continents are another major influence on surface currents. The continents act as barriers to surface currents. When a surface current flows against a continent, the current is deflected and divided.

The Coriolis Effect

Global wind belts and ocean currents do not flow in straight lines. Wind belts and ocean currents follow a curved or circular pattern that is caused by Earth's rotation. As Earth spins on its axis, ocean currents and wind belts curve. The curving of the path of oceans and winds due to Earth's rotation is called the **Coriolis effect**. The wind belts and the Coriolis effect cause huge circles of moving water, called **gyres,** to form. In the Northern Hemisphere, water flow in gyres is to the right, or clockwise. In the Southern Hemisphere, the flow is to the left, or counterclockwise.

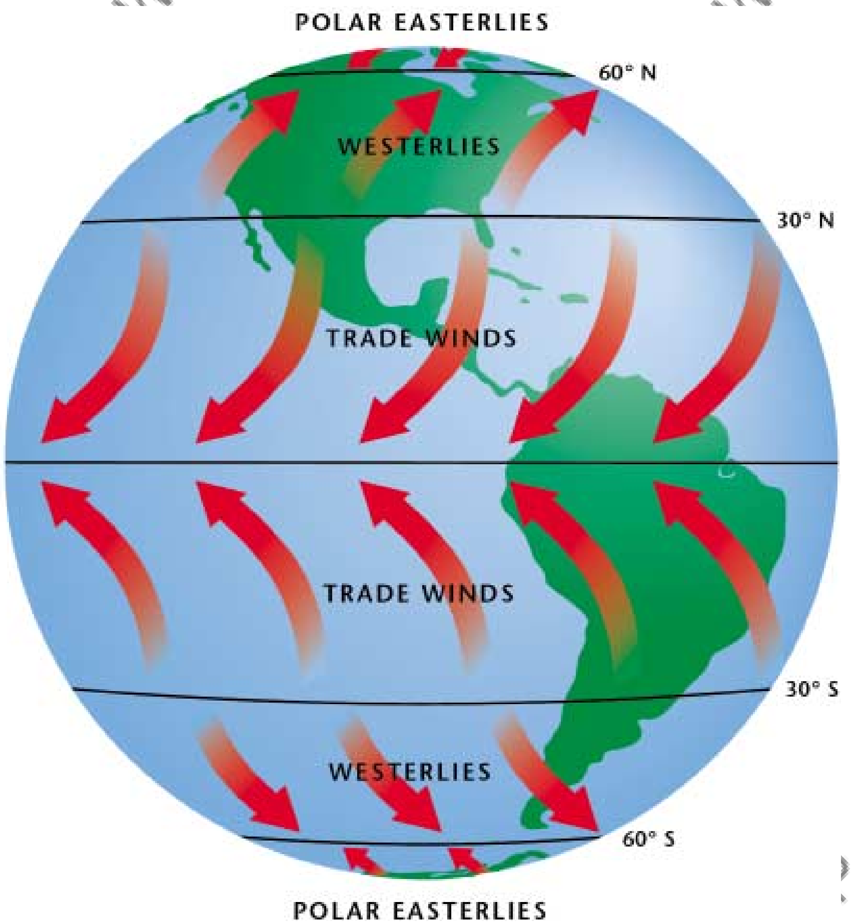


Figure 2 ▶ Global winds and the Coriolis effect together drive the surface currents of the oceans in great circular patterns. The photo at right shows a gyre in the Pacific Ocean off the east coast of Japan.

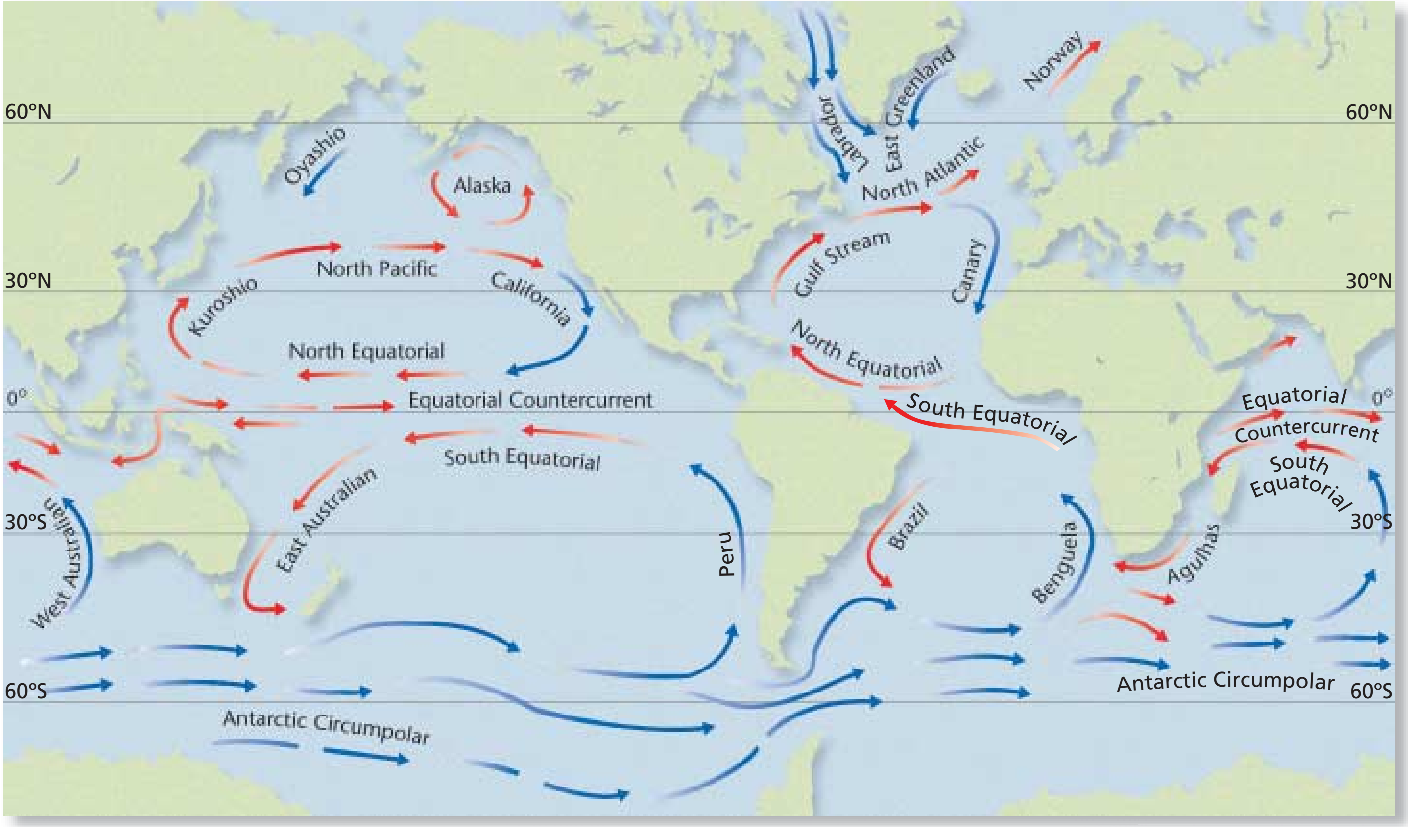


Figure 3 ▶ This map shows the major surface currents of the oceans of the world. Warm-water currents are shown in red; cold-water currents are shown in blue.

Major Surface Currents

The major surface currents of the world are shown in **Figure 3.** The major currents in the equatorial region and in the Northern and Southern Hemispheres are described below.

Equatorial Currents

Warm equatorial currents are located in the Atlantic, Pacific, and Indian Oceans. Each of these oceans has two warm-water equatorial currents that move in a westward direction. Between these westward-flowing currents lies a weaker, eastward-flowing current called the *Equatorial Countercurrent.*

Currents in the Southern Hemisphere

In the Southern Hemisphere, the currents in gyres move counterclockwise. In the most southerly regions of the oceans, constant westward winds produce the world's largest current, the *Antarctic Circumpolar Current,* also known as *West Wind Drift.* No continents interrupt the movement of this current that completely circles Antartica and crosses all three major oceans.

The Indian Ocean surface currents follow two patterns. Currents in the southern Indian Ocean follow a circular, counterclockwise gyre. Currents in the northern Indian Ocean are governed by *monsoons,* winds whose directions change seasonally.

Reading Check **What is the world's largest ocean current? (See the Appendix for answers to Reading Checks.)**

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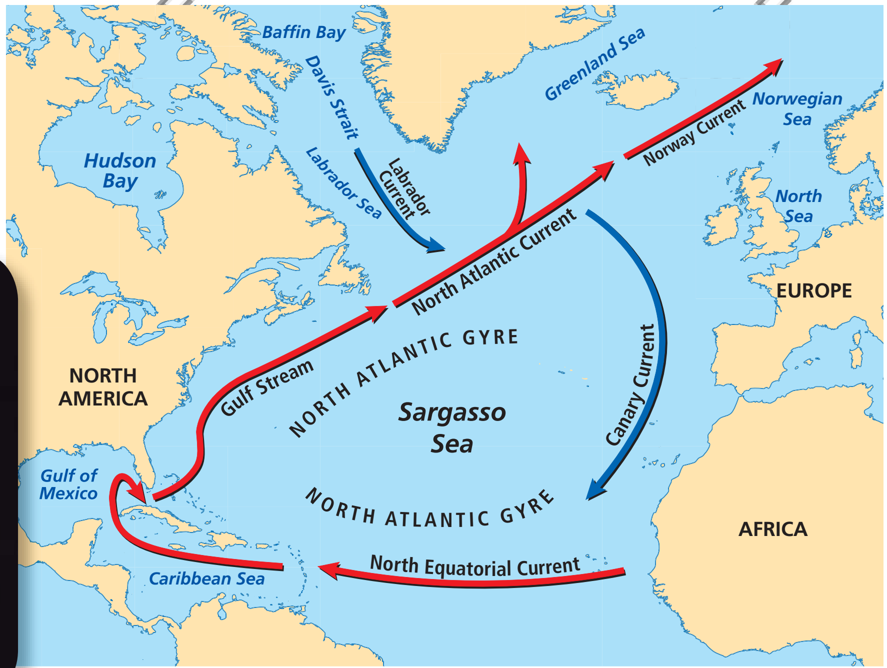
For a variety of links related to this subject, go to www.scilinks.org

Topic: Ocean Currents
SciLinks code: HQ61061

Figure 4 ▶ Surface currents in the Atlantic Ocean form the North Atlantic Gyre. The Sargasso Sea in the center of the gyre results from this pattern of currents. The organisms below are commonly found in the Sargasso Sea.



Currents in the North Atlantic

In the North Atlantic Ocean, warm water moves through the Caribbean Sea and Gulf of Mexico and north along the east coast of North America in a swift, warm current called the **Gulf Stream.** Farther north, the cold-water Labrador Current, which flows south, joins the Gulf Stream. South of Greenland, the Gulf Stream widens and slows until it becomes a vast, slow-moving warm current known as the *North Atlantic Current*. Near western Europe, the North Atlantic Current splits. One part becomes the Norway Current, which flows northward along the coast of Norway and keeps that coast ice-free all year. The other part is deflected southward and becomes the cool Canary Current, which eventually warms and rejoins the North Equatorial Current.

Gulf Stream the swift, deep, and warm Atlantic current that flows along the eastern coast of the United States toward the north

As **Figure 4** shows, the Gulf Stream, the North Atlantic Current, the Canary Current, and the North Equatorial Current form the North Atlantic Gyre. At the center of this gyre lies a vast area of calm, warm water called the *Sargasso Sea*. The Sargasso Sea is named after *sargassum,* the brown seaweed that floats on the sea's surface in this area. The pattern of winds and currents around the Sargasso Sea concentrates all kinds of floating debris, such as orange peels and plastic cups, in this area.

QuickLAB 10 min

Ocean Currents

Procedure

1. Fill a **shallow pan** with **water.**
2. Sprinkle **paper confetti** on the surface of the water.
3. Blow across the surface of the water through a **drinking straw** to produce a clockwise current.
4. Blow through the straw to make a counterclockwise current. Try to make two currents.

Analysis

1. Draw a diagram of the currents. Draw the straw's positions, and use arrows to show air and water direction.
2. How does this activity relate to what happens in ocean currents?

Currents in the North Pacific

The pattern of currents in the North Pacific is similar to that in the North Atlantic. The warm Kuroshio Current, the Pacific equivalent of the Gulf Stream, flows northward along the east coast of Asia. This current then flows toward North America as the North Pacific Drift. It eventually flows southward along the California coast as the cool California Current.

Deep Currents

In addition to having wind-driven surface currents, the ocean has **deep currents,** cold, dense currents far below the surface. Deep currents move much more slowly than surface currents do. Deep currents form as cold, dense water of the polar regions sinks and flows beneath warmer ocean water.

The movement of polar waters is a result of differences in density. When water cools, it contracts and the water molecules move closer together. This contraction makes the water denser, and the water sinks. When water warms, it expands and the water molecules move farther apart. The warm water is less dense, so it rises above the cold water. Temperature determines density.

Salinity, too, determines the density of water. The water in polar regions has high salinity because of the large amount of water frozen in icebergs and sea ice. When water freezes, the salt in the water does not freeze but stays in the unfrozen water. So, unfrozen polar water has a high salt concentration and is denser than water that has a lower salinity. This dense polar water sinks and forms a deep current that flows beneath less dense surface currents, as shown in **Figure 5.**

deep current a streamlike movement of ocean water far below the surface

Graphic Organizer **Comparison Table**

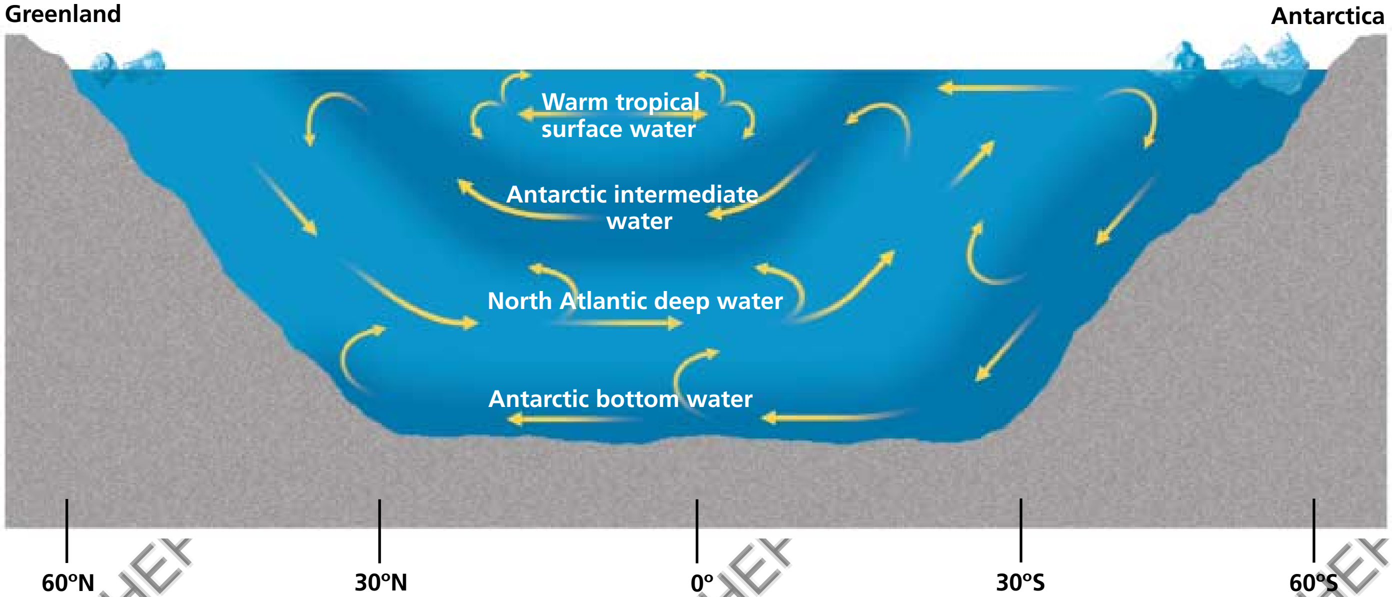
Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Surface currents" and "Deep currents." Label the rows with "Salinity," "Temperature," and "Density." Then, fill in the table with details about the salinity, temperature, and density of each current.

Antarctic Bottom Water

The temperature of the water near Antarctica is very cold, –2°C. The water's salinity is high. These two factors make the water off the coast of Antarctica the densest and coldest ocean water in the world. This dense, cold water sinks to the ocean bottom and forms a deep current called the *Antarctic Bottom Water.* The Antarctic Bottom Water moves slowly northward along the ocean bottom for thousands of kilometers to a latitude of about 40°N. It takes hundreds of years for the current to make the trip.

Reading Check **Why is Antarctic Bottom Water the densest in the world? (See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ The very dense and highly saline Antarctic Bottom Water travels beneath less dense North Atlantic Deep Water.



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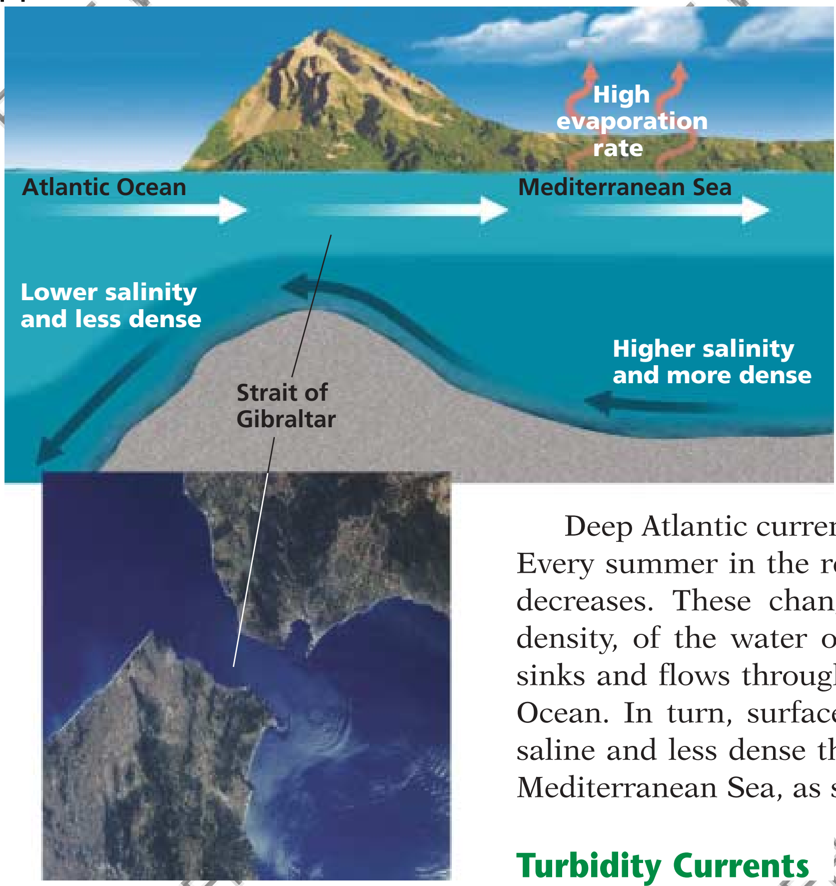


Figure 6 ▶ The dense, highly saline water of the Mediterranean Sea forms a deep current as it flows through the strait of Gibraltar and into the less dense Atlantic Ocean.

North Atlantic Deep Water

In the North Atlantic, south of Greenland, the water is very cold and has a high salinity. This cold, salty water forms a deep current that moves southward under the northward-flowing Gulf Stream. Near the equator, this deep current divides. One part begins to rise, reverse direction, and flow northward again. The rest of the current continues southward toward Antarctica and flows over the colder, denser Antarctic Bottom Water.

Deep Atlantic currents exist near the Mediterranean Sea, too. Every summer in the region, evaporation increases and rainfall decreases. These changes increase the salinity, and thus the density, of the water of the Mediterranean. This denser water sinks and flows through the strait of Gibraltar into the Atlantic Ocean. In turn, surface water from the Atlantic, which is less saline and less dense than deep current water is, flows into the Mediterranean Sea, as shown in **Figure 6.**

Turbidity Currents

A turbidity current is a strong current caused by an underwater landslide. A turbidity current occurs when large masses of sediment that have accumulated along a continental shelf or continental slope suddenly break loose and slide downhill. The landslide mixes the nearby water with sediment. The sediment causes the water to become cloudy, or turbid, and denser than the surrounding water. The dense water mass of the turbidity current moves beneath the less dense, clear water.

Section 1 Review

1. **Describe** the force that drives most surface currents.
2. **Identify** the winds that affect the surface currents on either side of the equator.
3. **Identify** the winds that affect the surface currents in the middle latitudes.
4. **Describe** how density affects the flow of deep currents.
5. **List** the factors that affect the density of ocean water.
6. **List** three major surface currents and two major deep currents.

CRITICAL THINKING

7. **Predicting Consequences** Describe how surface currents would be affected if Earth did not rotate.
8. **Identifying Relationships** Explain how the distribution of solar energy around Earth affects ocean surface currents.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *ocean currents, surface currents, deep currents, Gulf Stream, North Atlantic Current, Antarctic Bottom Water, gyres,* and *Coriolis effect.*

Section 2 Ocean Waves

A **wave** is a periodic disturbance in a solid, liquid, or gas as energy is transmitted through the medium. One kind of wave is described as the periodic up-and-down movement of water. Such a wave has two basic parts—a *crest* and a *trough,* as shown in **Figure 1.** The crest is the highest point of a wave. The trough is the lowest point between two crests. The *wave height* is the vertical distance between the crest and the trough of a wave. The *wavelength* is the horizontal distance between two consecutive crests or between two consecutive troughs. The **wave period** is the time required for two consecutive wave crests to pass a given point. The speed at which a wave moves is calculated by dividing the wave's wavelength by its period.

$$\textit{wave speed} = \frac{\textit{wavelength}}{\textit{wave period}}$$

OBJECTIVES

- **Describe** the formation of waves and the factors that affect wave size.
- **Explain** how waves interact with the coastline.
- **Identify** the cause of destructive ocean waves.

KEY TERMS

wave
wave period
fetch
refraction

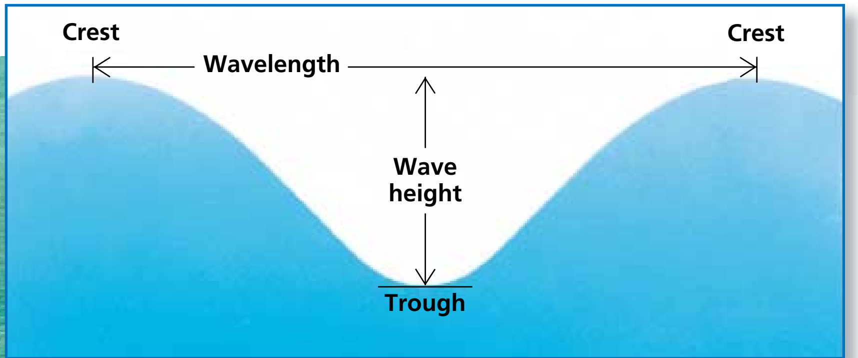
Wave Energy

The uneven heating of Earth's atmosphere causes pressure differences that make air move. This moving air is called *wind*. Wind then transfers the energy received from the sun to the ocean and forms waves. Small waves, or ripples, form as a result of friction between the moving air and water. As a ripple receives more energy from wind, the ripple grows into a larger wave. The longer that wind blows from a given direction, the more energy is transferred from wind to water and the larger the wave becomes.

The smoothness of the ocean's surface is generally disrupted by many small waves moving in different directions. Because of their large surface area, larger waves receive more energy from the wind than smaller waves do. Thus, larger waves grow larger, and smaller waves die out.

wave a periodic disturbance in a solid, liquid, or gas as energy is transmitted through a medium

wave period the time required for two consecutive wave crests to pass a given point



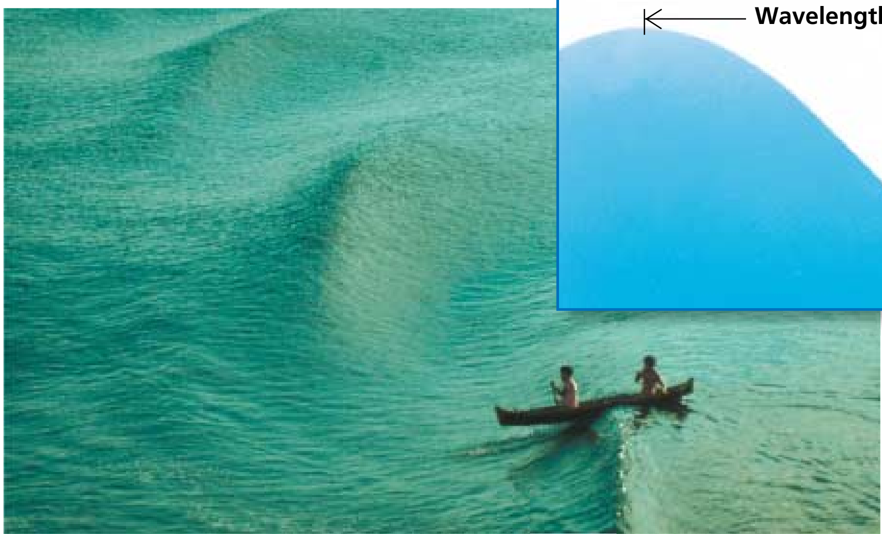


Figure 1 ▶ The vertical distance between the crest and the trough of a wave is the wave height. In a series of waves, the wave height may be similar for all of the waves, as shown in the photo at left.

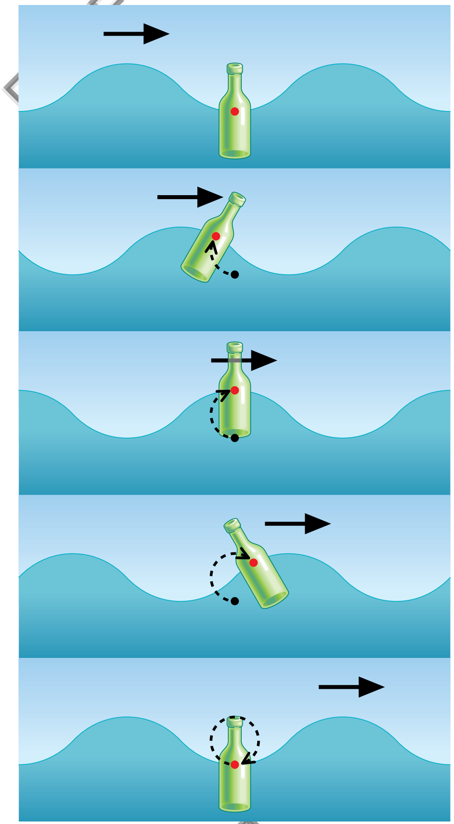


Figure 2 ▶ Like the bottle in this diagram, water molecules do not travel horizontally through the water with the wave.

Water Movement in a Wave

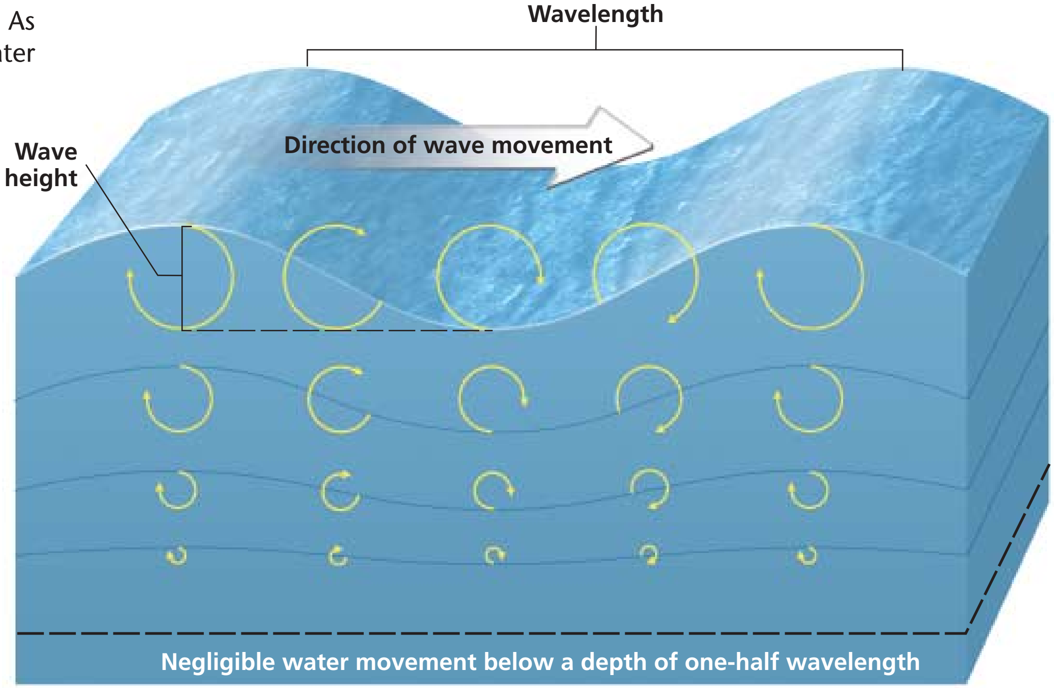
Although the energy of a wave moves from water molecule to water molecule in the direction of the wave, the water itself moves very little. This fact can be demonstrated by observing the movement of a bottle floating on the water as a wave passes. The bottle appears to move up and down, but it moves in a circular path, as shown in **Figure 2.** As the wave passes, the bottle returns to where it started.

As a wave moves across the surface of the ocean, only the energy of the wave, not the water, moves in the direction of the wave. The water molecules within the wave move in a circular motion. During a single wave period, each water particle moves in one complete circle. At the end of the wave period, a circling water particle ends up almost exactly where it started.

As a wave passes a given point, the circle traced by a water particle on the ocean surface has a diameter that is equal to the height of the wave. Because waves receive their energy from wind pushing against the surface of the ocean, the energy received decreases as the depth of the water increases. As a result, water at various depths receives varying amounts of energy. Thus, the diameter of a water molecule's circular path decreases as water depth increases, as shown in **Figure 3.** Below a depth of about one-half the wavelength, there is almost no circular motion of water molecules.

Reading Check **Why does the diameter of a water molecule's circular path in a wave decrease as depth increases? (See the Appendix for answers to Reading Checks.)**

Figure 3 ▶ Wave energy decreases as depth increases. As a result, the diameter of a water molecule's circular path in the wave also decreases.



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Wave Size

Three factors determine the size of a wave. These factors are the speed of the wind, the length of time the wind blows, and fetch. **Fetch** is the distance that the wind can blow across open water. Very large waves are produced by strong, steady winds blowing across a long fetch.

During a storm, steady high winds can cause some waves to gather enough energy to reach great size. Strong, gusty winds, on the other hand, produce choppy water that has waves of various heights and lengths and which may come from various directions. Nevertheless, the size of a wave will increase to only a certain height-to-length ratio before the wave collapses.

On calm days, small, smooth waves move steadily across the ocean's surface. One of a group of long, rolling waves that are of similar size is called a *swell*. Swells move in groups in which one wave follows another. Swells that reach the shore may have formed thousands of kilometers out in the ocean.

Figure 4 ▶ Whitecaps, such as the ones shown here off the coast of North Carolina, may form during storms.

fetch the distance that wind blows across an area of the sea to generate waves

Whitecaps

When winds blow the crest of a wave off, *whitecaps* form, as shown in **Figure 4.** Because whitecaps reflect solar radiation, they allow less radiation to reach the ocean. Scientists have been studying how this characteristic may affect climate.

QuickLAB 15 min

Waves

Procedure

1. Fill a **rectangular pan** (40 cm × 30 cm × 10 cm) with **water** to a depth of 7 cm.
2. Float a **cork** near the center of the pan. On each side of the pan, mark the location of the cork with a small piece of **tape.**
3. Hold a **spoon** in the water at one end of the pan. Carefully move the spoon up and down in the water to make a slow, regular pattern of waves.
4. Observe the movement of the cork for 1 minute. Sketch how the cork moves in relation to the waves.
5. Remove the cork from the pan.
6. Use the spoon to make a strong, steady series of waves.
7. Remove the spoon from the pan. Observe what happens when the waves reach the edges of the pan. Write down or sketch what you observe.

Analysis

1. Describe the motion of the cork when a wave passes.
2. How does the cork move relative to the tape on the sides of the pan? Explain your answer.
3. When a wave breaks on the shore, the water is carried in the direction of the wave. Based on your observations in step 4, does this statement contradict your model? Explain your answer.

Waves and the Coastline

In shallow water near the coastline, the bottom of a wave touches the ocean floor. A wave touches the ocean bottom where the depth of the water is about half the wavelength. Contact with the ocean floor creates friction, which causes the wave to slow and eventually break, as shown in **Figure 5.**

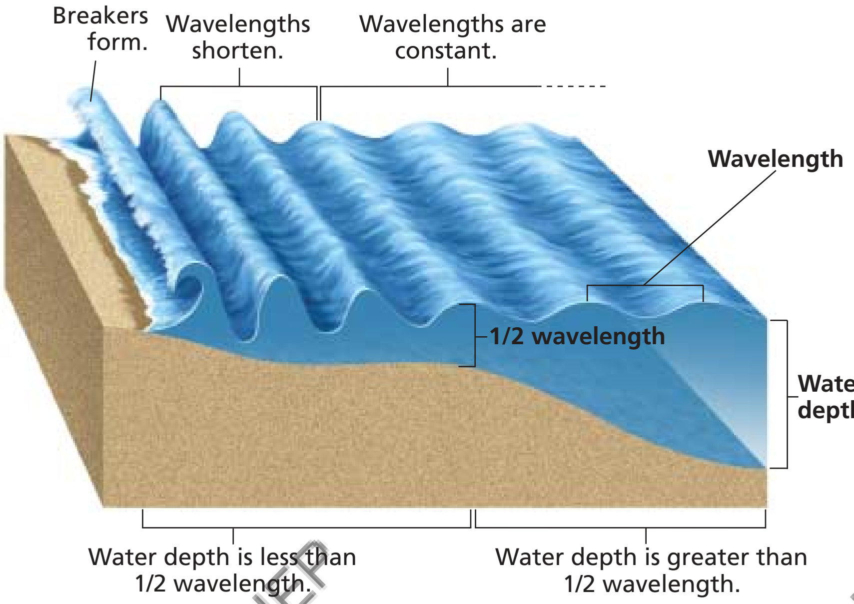
Breakers

The height of a wave changes as the wave approaches the coastline. The water involved in the motion of a wave extends to a depth of one-half wavelength. As the wave moves into shallow water, the bottom of the wave is slowed by friction. The top of the wave, however, continues to move at its original speed. The top of the wave gets farther and farther ahead of the bottom of the wave. Finally, the top of the wave topples over and forms a *breaker,* a foamy mass of water that washes onto the coastline. The height of the wave when the wave topples over is 1 to 2 times the height of the original wave.

Breaking waves scrape sediments off the ocean floor and move the sediments along the coastline. The waves also erode rocky coastlines. The size and force of breakers are determined by the original wave height, wavelength, and the steepness of the ocean floor close to the coastline. If the slope of the ocean floor is steep, the height of the wave increases rapidly and the wave breaks with great force. If the coastline slopes gently, the wave rises slowly. The wave spills forward with a rolling motion that continues as the wave advances up the coastline.

Reading Check **As a wave moves into shallow water, what causes the top of the wave to break and topple over? (See the Appendix for answers to Reading Checks.)**

Figure 5 ▶ Breakers begin to form as the wave approaches the coastline. As a wave nears the coastline, wave height increases and wavelength decreases.



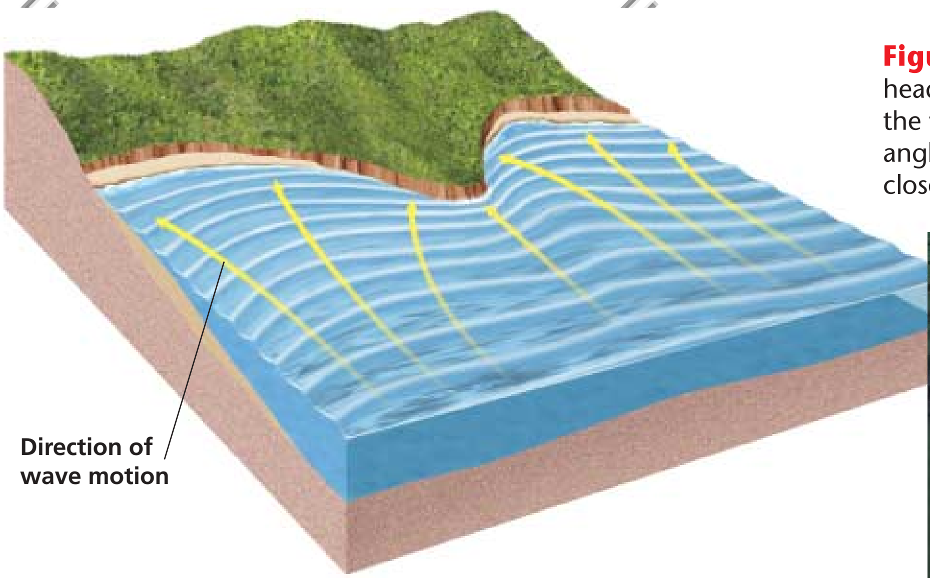


Figure 6 ▶ Waves strike the shore head-on as a result of refraction. Notice the waves approaching the shore at an angle. These waves bend as they draw closer to the shore.

Refraction

Most waves approach the coastline at an angle. When a wave reaches shallow water, however, the wave bends. This bending is called refraction. **Refraction** is the process by which ocean waves bend toward the coastline as they approach shallow water. As a wave approaches the coastline, the part of the wave that is in shallower water slows, and the part of the wave that is in deeper water maintains its speed. The wave gradually bends toward the beach and strikes the shore head-on, as shown in **Figure 6.**

refraction the process by which ocean waves bend directly toward the coastline as they approach shallow water, the part of the wave that is traveling in shallow water travels more slowly than the part of the wave that is still advancing in deeper water

Undertows and Rip Currents

Water carried onto a beach by breaking waves is pulled back into deeper water by gravity. This motion forms an irregular current called an *undertow.* An undertow is seldom strong, and only along shorelines that have steep drop-offs do undertows create problems for swimmers.

The generally weak undertow is often confused with the more dangerous *rip current*. Rip currents form when water from large breakers returns to the ocean through channels that cut through underwater sandbars that are parallel to the beach. Rip currents flow perpendicularly to shore through those channels and may be strong enough to quickly carry a swimmer away from shore. The presence of rip currents can usually be detected by a gap in a line of breakers or by turbid water, water in which sand has been stirred up by the current.

Longshore Currents

Longshore currents form when waves approach the beach at an angle. Longshore currents flow parallel to the shore. Great quantities of sand are carried by longshore currents. If there is a bay or inlet along the shoreline where waves refract, sand will be deposited as the energy of the waves decreases. These sand deposits form low ridges of sand called *sandbars*.

Figure 7 ▶ A tsunami caused wide-spread damage on the coastline of the Waiakea area of Hilo, Hawaii, in 1960.

Tsunamis

The most destructive waves in the ocean are not powered by the wind. *Tsunamis* are giant seismic ocean waves. Most tsunamis are caused by earthquakes on the ocean floor, but some can be caused by volcanic eruptions and underwater landslides. Tsunamis are commonly called *tidal waves,* which is misleading because tsunamis are not caused by tides.

Tsunamis have a long wavelength. In deep water, the wave height of a tsunami is usually less than 1 m, but the wavelength may be as long as 500 km. A tsunami commonly has a wave period of about 1 hour and may travel at speeds of up to 890 km/h (as fast as a jet airplane). Because the wave height of a tsunami is so low in the open ocean, the tsunami cannot be felt by people aboard ships.

Tsunami as a Destructive Force

A tsunami has a tremendous amount of energy. Because its wavelength is so great, the entire depth of the water is involved in the wave motion of a tsunami. All of the energy of this mass of water is released against the shore and causes a great deal of destruction, as shown in **Figure 7.** Near the shore, the height of the tsunami greatly increases as the tsunami's speed decreases. As it approaches the shore, the wave may reach a height of 30 to 40 m. The arrival of a tsunami may be signaled by the sudden pulling back of the water along the shore. This pulling back occurs when the trough of the tsunami arrives before the crest. If the crest arrives first, a sudden, rapid rise in the water level occurs.

The tsunami triggered by the earthquake in Chile in 1960 caused destruction to many countries in the Pacific Ocean. It struck the coast of South America and then Hawaii and crossed 17,000 km of ocean to strike Japan.

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

Topic: Tsunamis
SciLinks code: HQ61561

Section 2 Review

1. **Explain** how wavelength and wave period can be used to calculate wave speed.
2. **Describe** the formation of waves.
3. **List** three factors that determine the size of a wave.
4. **Explain** why incoming waves refract toward the beach until they strike the shore head-on.
5. **Describe** what factors cause tsunamis.
6. **Explain** why waves slow down in shallow water.

CRITICAL THINKING

7. **Analyzing Processes** Would the breakers at a specific beach always form at the same distance from shore? Explain your answer.
8. **Predicting Consequences** Explain how whitecaps could affect climate.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *wave, wave height, whitecap, trough, crest, fetch, swell,* and *tsunami.*

Section 3 Tides

The periodic rise and fall of the water level in the oceans is called the **tide**. *High tide* is when the water level is highest. *Low tide* is when the water level is lowest. The tide change is most noticeable on the coastline. If you stand on a beach long enough, you can see how the ocean retreats and returns with the tides.

OBJECTIVES

- **Describe** how the gravitational pull of the moon causes tides.
- **Compare** spring tides and neap tides.
- **Describe** how tidal oscillations affect tidal patterns.
- **Explain** how the coastline affects tidal currents.

KEY TERMS

tide
tidal range
tidal oscillation
tidal current

The Causes of Tides

In the late 1600s, Isaac Newton identified the force that causes the rise and fall of tides along coastlines. According to Newton's law of gravitation, the gravitational pull of the moon on Earth and Earth's waters is the major cause of tides. The sun also causes tides, but they are smaller because the sun is so much farther from Earth than the moon is.

As the moon revolves around Earth, the moon exerts a gravitational pull on the entire Earth. However, because the force of the moon's gravity decreases with distance from the moon, the gravitational pull of the moon is strongest on the side of Earth that is nearest to the moon. As a result, the ocean on Earth's near side bulges slightly, which causes a high tide within the area of the bulge.

tide the periodic rise and fall of the water level in the oceans and other large bodies of water

At the same time, another tidal bulge forms on the opposite side of Earth. This tidal bulge forms because the solid Earth, which acts as though all of its mass were at Earth's center, is pulled more strongly toward the moon than the ocean water on Earth's far side is. The result is a smaller tidal bulge on Earth's far side. **Figure 1** shows the Earth-moon system and the position of the moon in relation to the tidal bulges.

Low tides form halfway between the two high tides. Low tides form because as ocean water flows toward the areas of high tide, the water level in other areas of the oceans drops.

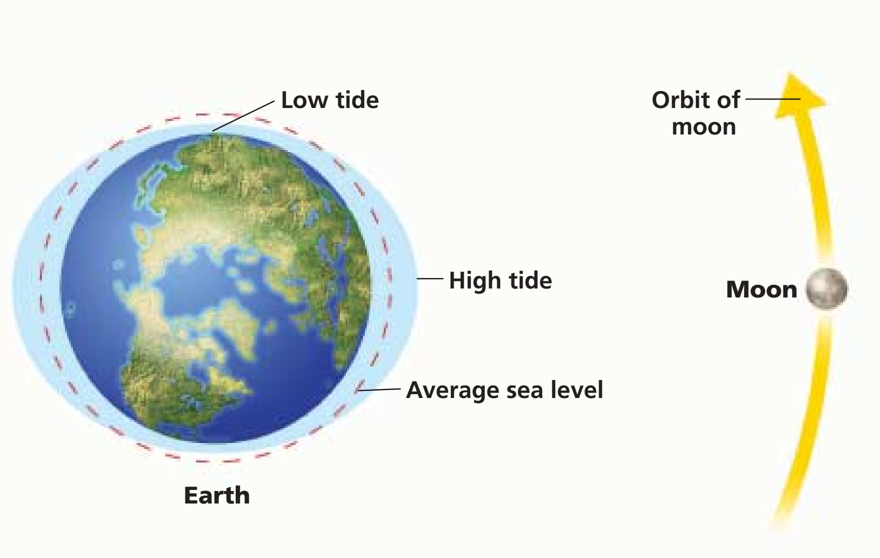
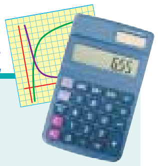


Figure 1 ▶ Tides form because the gravitational pull of the moon decreases with distance from the moon. Because of Earth's rotation, most locations in the ocean have two high tides and two low tides daily.



MATHPRACTICE

Tidal Friction As the tidal bulges move around Earth, friction between the water and the ocean floor slows Earth's rotation slightly. Scientists estimate that the average length of a day has increased by 10.8 min in the last 65 million years. How many years does it take for Earth's rotation to slow by 1 s?

Behavior of Tides

Earth rotates on its axis once every 24 h. In that 24 h, the moon moves through about 1/29 of its orbit. Because the moon orbits Earth in the same direction that Earth rotates, all areas of the ocean pass under the moon every 24 h 50 min. As seen from above the North Pole, Earth rotates counterclockwise and the tidal bulges appear to move westward around Earth.

Because there are two tidal bulges, most locations in the ocean have two high tides and two low tides daily. The difference in levels of ocean water at high tide and low tide is called the **tidal range.** The tidal range can vary widely from place to place. Because the moon rises about 50 minutes later each day, the times of high and low tides are about 50 minutes later each day.

tidal range the difference in levels of ocean water at high tide and low tide

Spring Tides

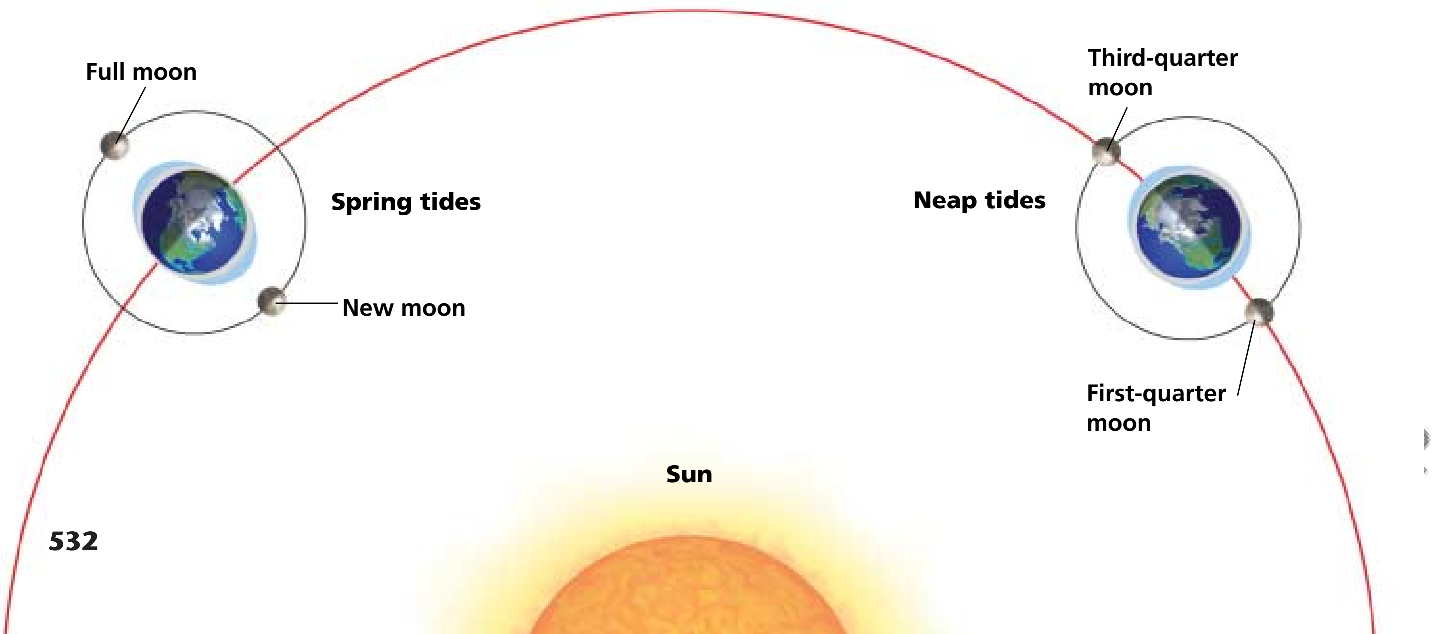
The sun's gravitational pull can strengthen or weaken the moon's influence on the tides. During the new moon and the full moon, Earth, the sun, and the moon are aligned, as shown in **Figure 2.** The combined gravitational pull of the sun and the moon results in higher high tides and lower low tides. So, the daily tidal range is greatest during the new moon and the full moon. During these two monthly periods, tides are called *spring tides*.

Neap Tides

During the first- and third-quarter phases of the moon, the moon and the sun are at right angles to each other in relation to Earth, also shown in **Figure 2.** The gravitational forces of the sun and moon work against each other. As a result, the daily tidal range is small. Tides that occur during this time are called *neap tides*.

Reading Check **Describe the location of the sun and moon in relation to Earth when the tidal range is small. (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ The alignment of the sun, moon, and Earth during spring tides differs from their alignment during neap tides. ***How often do spring tides occur?***



Tidal Variations

Although the global ocean is one body of water, continents and irregularities in the ocean floor divide the ocean into several basins. Tidal patterns are greatly influenced by the size, shape, depth, and location of the ocean basin in which the tides occur.

Along the Atlantic Coast of the United States, two high tides and two low tides occur each day and have a fairly regular tidal range. Along the shore of the Gulf of Mexico, however, only one high tide and one low tide occur each day. Along the Pacific Coast, the tides follow a mixed pattern of tidal ranges. Pacific Coast tides commonly have a very high tide followed by a very low tide and then a lower high tide, followed by a higher low tide.

Tidal Oscillations

Tidal patterns are also affected by tidal oscillations. **Tidal oscillations** (TIE duhl AHS uh LAY shunz) are slow, rocking motions of ocean water that occur as the tidal bulges move around the ocean basins. Along straight coastlines and in the open ocean, the effects of tidal oscillations are not very obvious. In some enclosed seas, such as the Baltic and Mediterranean Seas, tidal oscillations reduce the effects of the tidal bulges. As a result, these seas have a very small tidal range. However, in small basins and narrow bays located off major ocean basins, tidal oscillations may amplify the effects of the tidal bulges. An example of the effects of tidal oscillations is shown in **Figure 3.**

Figure 3 ▶ A great tidal range of as much as 15 m in the V-shaped Bay of Fundy in Canada is caused by tidal oscillations.

tidal oscillation the slow, rocking motion of ocean water that occurs as the tidal bulges move around the ocean basins

Connection to ASTRONOMY

The Earth-Moon System

The force of attraction that exists between all matter in the universe is called *gravity*. The force of attraction between any two objects depends on their masses and the distance between them. Earth's mass is estimated to be 6.0×10^{24} kg, and the moon's mass is estimated to be 7.3×10^{22} kg. The average distance between Earth and the moon is 384,000 km. These masses and distance make the attractive force of gravity strong between Earth and the moon. Because the gravitational forces between these two bodies is strong, the moon causes tides on Earth's surface. At the same time, Earth's gravity affects the rate at which the moon rotates.

Earth rotates on its axis once every 24 hours. While Earth completes one rotation, the moon travels only 1/29 of the way around Earth relative to the sun. As a result, the moon rises and sets about 50 minutes later each day. However, relative to the stars, the moon revolves around Earth once every 27.3 days.

In addition to orbiting Earth and revolving around the sun, the moon spins very slowly on its axis. It rotates on its axis once every 27.3 days, or about once every lunar cycle. Because the rotation and revolution of the moon take the same amount of time, observers on Earth always see the same side of the moon.

Figure 4 ▶ The photo to the right shows a tidal bore in early spring at Turnagain Arm of Cook Inlet, Alaska.

Tidal Currents

tidal current the movement of water toward and away from the coast as a result of the rise and fall of the tides

As ocean water rises and falls with the tides, it flows toward and away from the coast. This movement of the water is called a **tidal current.** When the tidal current flows toward the coast, it is called *flood tide*. When the tidal current flows toward the ocean, it is called *ebb tide*. When there are no tidal currents, the time period between flood tide and ebb tide is called *slack water*.

Tidal currents in the open ocean are much smaller than those at the coastline. Tidal currents are strongest between two adjacent coastal regions that have large differences in the height of the tides. In bays and along other narrow coastlines, tides may create rapid currents. Some tidal currents may reach speeds of 20 km/h.

Where a river enters the ocean through a long bay, the tide may enter the river mouth and create a *tidal bore*, a surge of water that rushes upstream, such as the one shown in **Figure 4.** In some cases, the tidal bore rushes upstream in the form of a large wave up to 5 m high that eventually loses energy. The tidal bores in the River Severn in England travel almost 20 km/h and reach as far as 33 km inland.

Section 3 Review

1. **Describe** how the moon causes tides.
2. **Explain** how the sun can influence the moon's effect on tides.
3. **Compare** spring tides and neap tides.
4. **Describe** how ocean basins affect tidal patterns.
5. **Explain** how tidal oscillations in an enclosed sea would affect tidal patterns in that sea.
6. **Compare** the movement of ocean water in the open ocean with the movement of ocean water in narrow bays.
7. **Describe** how a tidal bore forms.

CRITICAL THINKING

8. **Predicting Consequences** Predict where tidal currents may be of concern to ships that are approaching the land.
9. **Identifying Relationships** Describe ways in which tides could be affected if Earth had two moons.

CONCEPT MAPPING

10. Use the following terms to create a concept map: *tide, tidal range, spring tide, neap tide, tidal oscillation, tidal current, flood tide,* and *ebb tide.*

Chapter 21 Highlights

Sections

1 Ocean Currents

Key Terms

current, 519
surface current, 519
Coriolis effect, 520
gyre, 520
Gulf Stream, 522
deep current, 523

Key Concepts

- Surface currents of the ocean are the result of global wind belts, the Coriolis effect, and continental land barriers.
- Major ocean currents, such as the Gulf Stream and the Canary Current, help create gyres.
- Deep currents are produced as dense water near the North and South Poles sinks and moves toward the equator beneath less-dense water.
- The Antarctic Bottom Water current is a deep-water current that moves slowly north along the ocean bottom.

2 Ocean Waves

wave, 525
wave period, 525
fetch, 527
refraction, 529

- The speed of a wave can be calculated by dividing the wavelength by the wave period.
- Wind is the primary source of wave energy.
- Wave size is determined by wind speed, by the length of time wind blows, and fetch.
- As a wave comes into contact with the ocean floor, the wave may undergo refraction or form breakers.
- Waves near the shoreline can cause currents such as an undertow and rip current.
- Tsunamis are giant, destructive waves.

3 Tides

tide, 531
tidal range, 532
tidal oscillation, 533
tidal current, 534

- The gravitational effects of the moon and, to a lesser extent, the sun cause tides.
- Tidal ranges are greatest during spring tides and smallest during neap tides.
- Variations in the tides are influenced by the size, shape, depth, and location of the ocean basins or seas in which the tides occur.
- Tidal currents are generally small in the open ocean but may create rapid currents in narrow bays along the coastline.

Chapter 21 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *current*
2. *gyre*
3. *tide*
4. *wave*

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

5. *surface current* and *deep current*
6. *Coriolis effect* and *gyre*
7. *fetch* and *refraction*
8. *tidal range* and *tidal oscillation*

Understanding Key Concepts

9. The water in the ocean moves in giant streams called
   a. currents.
   b. westerlies.
   c. waves.
   d. tides.

10. The effect of Earth's rotation on winds and ocean currents is called the
    a. neap-tide effect.
    b. refraction effect.
    c. Coriolis effect.
    d. tsunami effect.

11. Which of the following currents is the westward warm-water current in the North Atlantic Gyre?
    a. Canary Current
    b. North Atlantic Current
    c. North Equatorial Current
    d. Gulf Stream

12. Deep currents are the result of
    a. the Coriolis effect.
    b. changes in the density of ocean water.
    c. the trade winds.
    d. neap tides.

13. The periodic disturbance in water as energy is transmitted through the water is a
    a. current. **c.** fetch.
    b. breaker. **d.** wave.

14. The highest point of a wave is the
    a. trough. **c.** crest.
    b. period. **d.** length.

15. The distance that wind blows across an area of the sea to generate waves is the
    a. trough.
    b. sargassum.
    c. fetch.
    d. wave period.

16. The movement of water toward and away from the coasts due to tidal forces is called a
    a. tidal bore.
    b. tidal current.
    c. tidal range.
    d. tidal oscillation.

Short Answer

17. Describe how a breaker forms.
18. Define *tide,* and explain why tides form.
19. What factors control most ocean surface currents?
20. How does the depth of the ocean floor affect the shape and speed of a wave?
21. How do deep currents form?
22. Explain how wind is the primary source for wave energy.
23. What is a tidal bore?

Critical Thinking

24. Determining Cause and Effect During winter in the northern Indian Ocean, winds called *monsoons* blow in a direction opposite to the direction that they blow during summer. What effect do these winds have on surface currents?

25. Analyzing Processes Suppose that a retaining wall is built along a shoreline. What will happen to waves as they pass over the retaining wall?

26. Making Inferences Imagine that you are fishing from a small boat anchored off the shore of the Gulf of Mexico. You are lulled to sleep by the gently rocking boat but wake up to find your boat on wet sand. What happened?

27. Making Predictions What effect would Earth's rotating in the direction opposite that in which it now rotates have on the movement of ocean currents?

Concept Mapping

28. Use the following terms to create a concept map: *currents, surface currents, trade winds, deep currents, Coriolis effect, wave, breaker, rip current, tide, Antarctic Bottom Water* and *tidal current*.

Math Skills

29. Applying Quantities The Gulf Stream can move 100 million cubic meters of water per second. The Mississippi River moves 15,400 m^3 of water per second. How many times more water per second does the Gulf Stream move than the Mississippi River does?

30. Making Calculations If a wave has a wavelength of 216 m and a period of 12 s, what is the wave's speed?

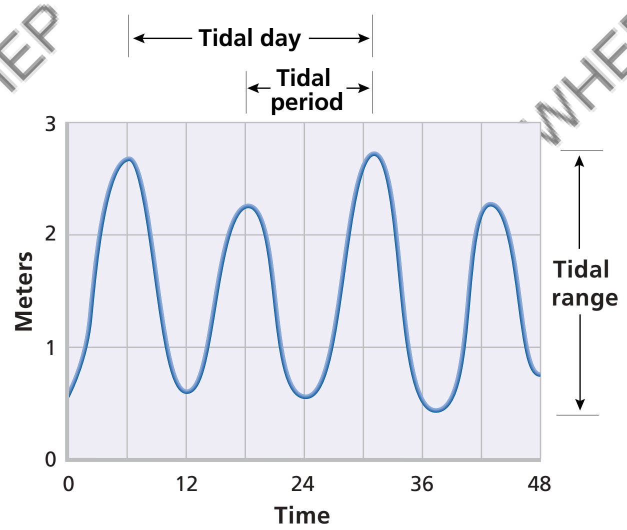
Writing Skills

31. Writing from Research Write a report that describes the La Rance, France, tidal power plant project, the amount of electricity provided by the project, and the impact of the project on the environment of the area.

32. Outlining Topics Create an outline that shows the steps of tide formation. Provide diagrams as needed to illustrate the steps.

Interpreting Graphics

The graph below shows the measurements of tides in one location on the Atlantic coast of North America. Use the graph to answer the questions that follow.



33. How many high tides occur every day in this location?

34. How many hours is the tidal period?

35. How many hours apart are the low tides?

36. What is the average tidal range in meters?

37. What is the difference in height (in meters) between the first high tide and the second high tide?

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Chapter 21 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. Which of the following factors is a cause of surface currents?
   A. Earth's rotation on its axis
   B. water salinity
   C. human activity
   D. sea-floor spreading

2. What is the speed of an ocean wave that has 12 s between crests and a wavelength of 36 m?
   F. 6 m/s
   G. 3 km
   H. 3 m/s
   I. 12 m

3. When an ocean wave travels 100 m west, which of the following also travels 100 m west?
   A. the energy in the wave
   B. the water molecules in the wave
   C. both the water molecule and the energy
   D. neither the water molecule nor the energy

4. What role do convection currents in the ocean and atmosphere have in regulating climate?
   F. They set up atmospheric circulation.
   G. They prevent deep-water currents.
   H. They restrict energy to local use.
   I. They ensure a balance of precipitation.

5. The vertical distance from the trough of a wave to the crest of a wave is called the
   A. wave height
   B. wave length
   C. wave speed
   D. wave distance

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

6. What is a main factor that causes the movements of deep-water currents?

7. What happens to a wave's height as the wave approaches the shore?

8. Most waves are generated by energy transferred to water from what?

Reading Skills

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

Tsunamis

Tsunamis are the most destructive waves in the ocean. Most tsunamis are caused by earthquakes on the ocean floor, but some can be caused by volcanic eruptions and underwater landslides. Tsunamis are sometimes called *tidal waves,* which is misleading because tsunamis have no connections to tides.

Tsunamis commonly have a wave period of about 1 hour and a wave speed of about 890 km/h, which is about as fast as a commercial airplane. By the time the tsunami reaches the shore, the tsunami's height may be 40 m.

Tsunamis can travel thousands of kilometers. One tsunami was triggered by an earthquake off the coast of South America in 1960. The tsunami was so powerful that it crossed the Pacific Ocean and hit the city of Hilo, on the coast of Hawaii, approximately 10,000 km away. The same tsunami then continued and struck Japan.

9. Why is the word *misleading* used to describe the use of the term *tidal waves* in the reading passage?
   A. Tsunamis are really large tides.
   B. Tsunamis can cause extensive damage to coastal areas.
   C. Tsunamis are related to earthquakes.
   D. Tsunamis are not related to tides.

10. Which of the following statements is a fact from the passage?
    F. All tsunamis are caused by earthquakes.
    G. A tsunami can travel as fast as an airplane.
    H. The tsunami of 1960 only struck Japan.
    I. Tsunamis are caused by surface currents.

11. Once triggered, how far can a tsunami travel?
    A. Tsunamis are short-lived and usually dissipate within just a few kilometers.
    B. Tsunamis travel about 100 km before dissipating in the ocean.
    C. Tsunamis travel about 1,000 km before dissipating in the ocean.
    D. Tsunamis can travel thousands of kilometers before dissipating or striking land.

Interpreting Graphics

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

Base your answers to questions 12 and 13 on the diagrams of the Earth, moon, and sun system below.

Effect of Sun and Moon on Earth's Tides

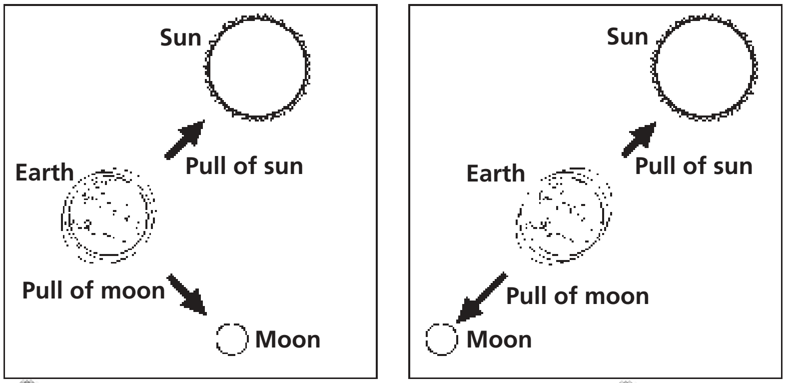


Diagram A   Diagram B

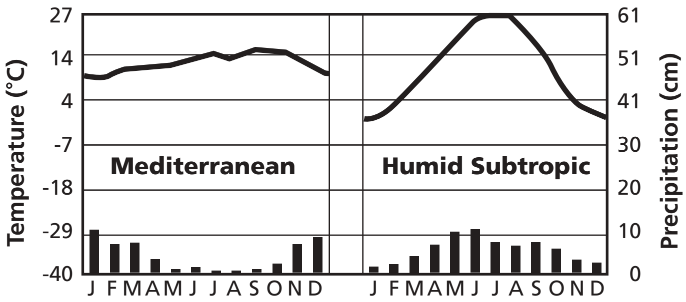
12 What type of tide is produced by the arrangement in Diagram B?

F. spring tide   **H.** winter tide
G. neap tide   **I.** weak tide

13 Using the diagrams above, explain in general terms how the gravitational effects of astronomical bodies cause tides on Earth.

Base your answers to questions 14 and 15 on the climate graphs shown below, which combine temperature and precipitation data for San Francisco, California and Wichita, Kansas.

Average Yearly Weather Data for San Francisco and Wichita



14 Which location shows the most extreme climate variation?

A. Wichita, Kansas shows the most extreme climate variation.
B. San Francisco, California shows the most extreme climate variation.
C. Both climates are equally mild.
D. Both climates are equally variable.

15 How do the location of these cities and the nearby currents help explain the differences in their climates?

Test TIP

Allow a few minutes at the end of the test-taking period to check for careless mistakes such as marking two answers for a single question.

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Chapter 21

Making Models Lab

Objectives

- **Model** the movement of waves.
- **Compare** the characteristics of waves when wave speed changes.

Materials

- cloth ties, about 50 cm in length (2)
- marker
- meterstick
- paper, 2 m × 1 m
- paper, graph
- pen or pencil, colored (3)
- rope, thin, 2.5 m in length

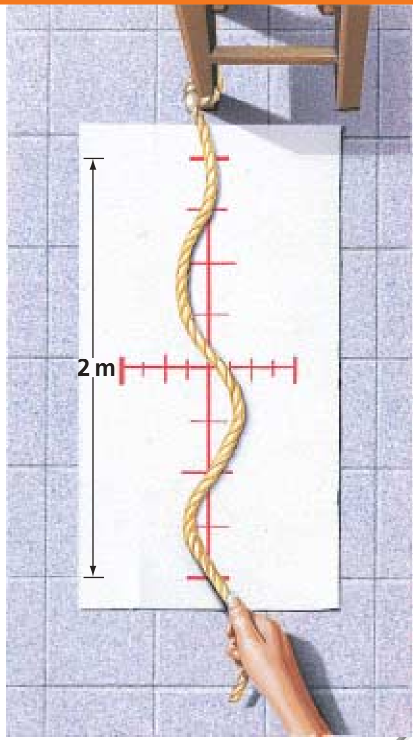
Wave Motion

The source of wave movement in water is energy, which is generated primarily from wind. Waves of water appear to move horizontally. However, only the energy of the waves moves horizontally; the water moves horizontally very little. In this lab, you will work with two partners to simulate wave motion and to observe how energy generates wave motion in water. You will also observe the properties of waves.

PROCEDURE

1. Tie one end of the rope securely to the leg of a chair or table.
2. On the large sheet of paper, use the meterstick to draw a grid like the one shown in the illustration on the next page. Draw and label the grid using the measurements shown.
3. Place the sheet of paper on the floor, and line up the rope along the 2 m line of the grid.
4. To make waves, move the free end of the rope from side to side. (Note: Be sure to maintain a constant motion with the rope.)
5. While one person moves the rope, another person marks the paper where a crest of a wave hits. The third group member marks the paper where a trough of a wave hits.
6. On the graph paper, make a graph that has wavelength (in meters) as the x-axis and wave height (in meters) as the y-axis.

Step 5



7 Plot a wave that represents the wave that you observed in step 5. Plot the wave height and the wavelength. Indicate the direction of the wave's motion.

8 Move the rope at a fast speed. Do not change the side-to-side distance that you move the free end of the rope.

9 As soon as a constant motion has been established, repeat steps 5 and 6. Plot a wave that represents the wave that you observed when repeating step 5. Use a pen or pencil whose color differs from the color of the first wave plot.

10 Next, generate very small waves. Repeat steps 5 and 6 using a third color of pen or pencil.

11 On your graph, label a crest and a trough on each of the waves that you plotted. Measure the wave height and wavelengths of each wave that you plotted.

12 Use the following formula to calculate the wave speeds of the three waves represented on the graph if each wave period is 6 s:

$$\textit{wave speed} = \frac{\textit{wavelength}}{\textit{wave period}}$$

13 Tie the two pieces of cloth around the middle of the rope about 15 cm apart.

14 Make waves by moving the end of the rope from side to side. Observe and record the motion of the cloth ties relative to the motion of the waves.

ANALYSIS AND CONCLUSION

1 **Examining Data** How do the wave motions of the waves shown on your graph differ from each other? If these waves were real water waves, what might be the cause(s) of the differences in motion?

2 **Recognizing Relationships** How is the movement of the rope similar to wave movement in water?

3 **Analyzing Relationships** How do the motions of the cloth ties differ from the wave's motion?

4 **Drawing Conclusions** What do the motions of the cloth ties tell you about wave movement in water?

Extension

1 **Making Comparisons** Use a 4 m rope to repeat the investigation. Construct a graph similar to your first graph, but extend the *x*-axis to provide room to plot a 4 m length. Observe and plot five waves of varying speeds and heights. Compare waves generated on a 2 m rope with those generated on a 4 m rope. Describe your results. Using 6 s as the wave period for each wave that you plot, calculate wave speeds.

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MAPS in Action

Roaming Rubber Duckies

Map Skills Activity

This map shows the estimated route taken by bathtub toys spilled from a cargo ship in the North Pacific Ocean. Use the map to answer the questions below:

1. **Analyzing Data** Describe where the toys started their journey.
2. **Evaluating Data** How long did it take the toys to travel to Sitka, Alaska, by the most direct route?
3. **Identifying Relationships** Compare the map above with the map of the major surface currents in the section entitled *Ocean Currents.* Then, name the current that carried the toys past Hawaii.
4. **Evaluating Sources** Is the current that carries the toys along the coast of the western United States cold or warm? Explain your answer.
5. **Predicting Consequences** Predict where the toys might have been located in December 2003 if tracking data were plotted on the map.
6. **Identifying Relationships** What is the name of the current that carried the toys south along the coast of Siberia?
7. **Evaluating Data** How long did it take the toys to travel from the location where they were dumped to their location on the coast of China on July 26, 2003?

Energy from the Ocean

The search for renewable energy sources has led to some ingenious ways of tapping the ocean for energy. Scientists have found ways to generate electricity from three ocean features: waves, tides, and heat.

Wave Energy

Most wave-power systems use buoys and the up-and-down motion of waves to run pumps that force water or air through turbine generators. A newer design uses piezoelectric plastic (pie EE zoh ee LEK trik PLAS tik), a material that produces electricity when stretched.

Tidal Energy

Tides can generate electricity in a way similar in principle to the way that hydroelectric plants on rivers generate electricity. At high tide, a dam built across a bay or inlet traps water. As the tide ebbs, this water is released through the dam's turbines to drive electric generators.

Thermal Energy

The process of producing electricity from the heat energy contained in ocean water is called *ocean thermal energy conversion* (OTEC). OTEC plants rely on steam to turn their turbine generators. Warm surface water is pumped through a vacuum chamber, which turns the water to steam. The steam then turns special low-pressure turbines.

Ocean power is not as cost effective as electricity from fuel-burning or nuclear power plants is. However, as ocean power technology becomes more reliable and more efficient, the ocean's renewable energy may become more affordable.

Extension

1. **Determining Cause and Effect** What do all three types of ocean power have in common?
2. **Research** Write a short report that explains how using energy from waves, tides, or heat in the ocean could help reduce pollution of the air and ocean.

▼ Tidal power plants, such as this one in France, rely on the flow of tides to turn turbines that generate electricity.

◀ This wave-power energy station in Scotland generates 500 kilowatts of electricity, enough to power 300 homes.

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Unit 7 ATMOSPHERIC FORCES

Unit 7 Outline

CHAPTER 22
The Atmosphere

CHAPTER 23
Water in the Atmosphere

CHAPTER 24
Weather

CHAPTER 25
Climate

▶ Wall clouds, such as this one near Adrian, Texas, are small clouds that form underneath large storm clouds. The beginning of a tornado can be seen in the circulation of dust on the ground under this wall cloud. Tornadoes tend to form under wall clouds.

Chapter 22 The Atmosphere

Sections
1 Characteristics of the Atmosphere
2 Solar Energy and the Atmosphere
3 Atmospheric Circulation

What You'll Learn
- Which gases make up the atmosphere
- How solar energy interacts with the atmosphere
- What causes wind

Why It's Relevant
The atmosphere affects all living things on Earth. It provides the air that we breathe, protection from solar radiation, and the insulation that maintains the global temperature of Earth.

PRE-READING ACTIVITY

FOLDNOTES

Booklet Before you read this chapter, create the FoldNote entitled "Booklet" described in the Skills Handbook section of the Appendix. Label each page of the booklet with a main idea from the chapter. As you read the chapter, write what you learn about each main idea on the appropriate page of the booklet.

▶ This image was captured by a satellite that was monitoring a large storm over the Atlantic Ocean. Storms are only one small feature of Earth's dynamic atmosphere.

Section 1 Characteristics of the Atmosphere

The layer of gases that surrounds Earth is called the **atmosphere**. The atmosphere is made up of a mixture of chemical elements and compounds that is commonly called *air*. The atmosphere protects Earth's surface from the sun's radiation and helps regulate the temperature of Earth's surface.

OBJECTIVES

- **Describe** the composition of Earth's atmosphere.
- **Explain** how two types of barometers work.
- **Identify** the layers of the atmosphere.
- **Identify** two effects of air pollution.

KEY TERMS

atmosphere
ozone
atmospheric pressure
troposphere
stratosphere
mesosphere
thermosphere

Composition of the Atmosphere

As the graph in **Figure 1** shows, the most abundant elements in air are the gases nitrogen, oxygen, and argon. The composition of dry air is nearly the same everywhere on Earth's surface and up to an altitude of about 80 km. The two most abundant compounds in air are the gases carbon dioxide, CO_2, and water vapor, H_2O. In addition to containing gaseous elements and compounds, the atmosphere commonly carries various kinds of tiny solid particles, such as dust and pollen.

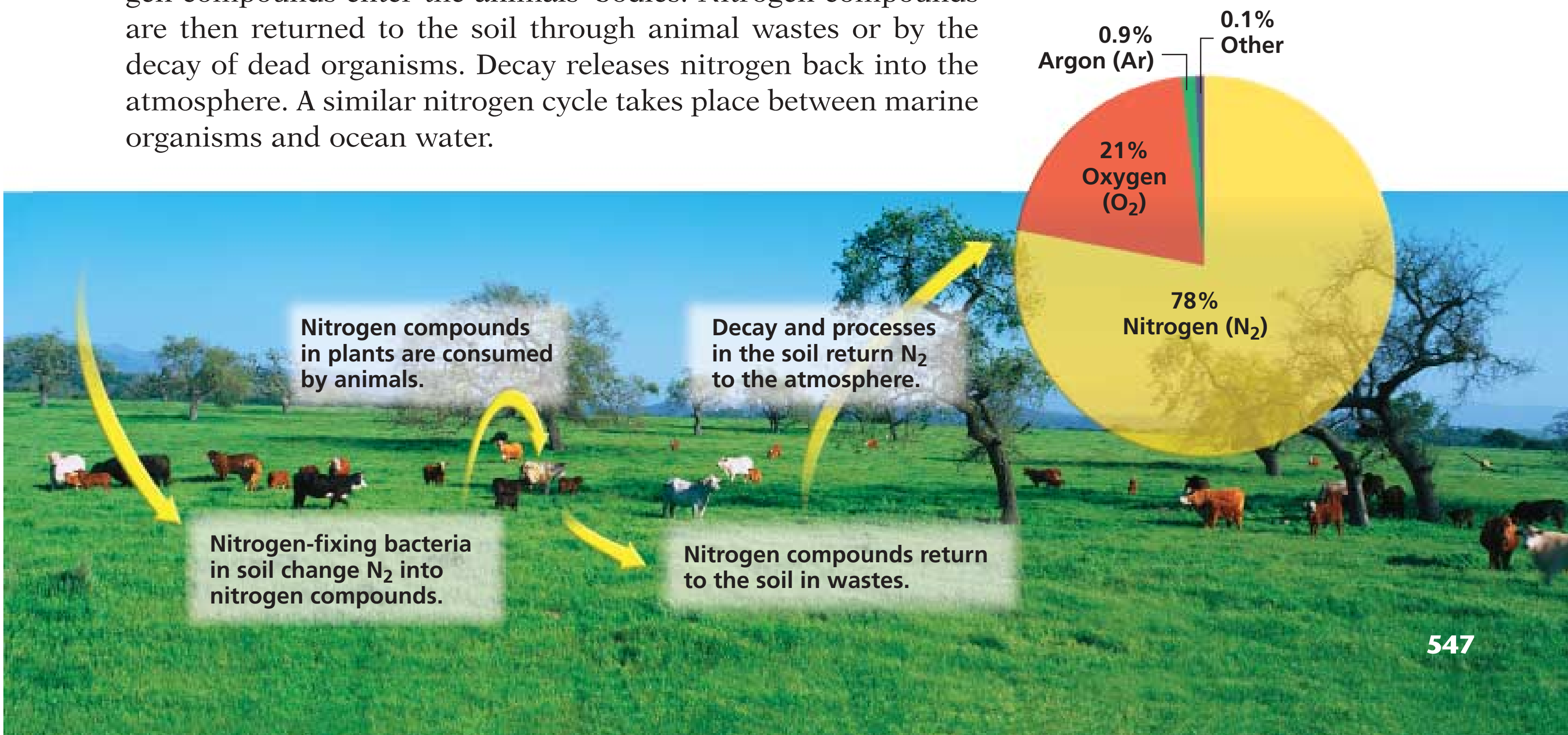
Nitrogen in the Atmosphere

Nitrogen makes up about 78% of Earth's atmosphere. Nitrogen in the atmosphere is maintained through a process called the *nitrogen cycle*. During the nitrogen cycle, nitrogen moves from air to the soil and then to plants and animals and eventually returns to the air, as shown in **Figure 1.**

Nitrogen is removed from the air mainly by the action of nitrogen-fixing bacteria. These microscopic organisms live in the soil and on the roots of certain plants. The bacteria chemically change nitrogen from the air into nitrogen compounds that are vital to the growth of all plants. When animals eat plants, nitrogen compounds enter the animals' bodies. Nitrogen compounds are then returned to the soil through animal wastes or by the decay of dead organisms. Decay releases nitrogen back into the atmosphere. A similar nitrogen cycle takes place between marine organisms and ocean water.

atmosphere a mixture of gases that surrounds a planet, such as Earth

Figure 1 ▶ The pie graph shows the composition of dry air by volume at sea level. Nitrogen in the atmosphere is kept at a relatively constant level by the nitrogen cycle.



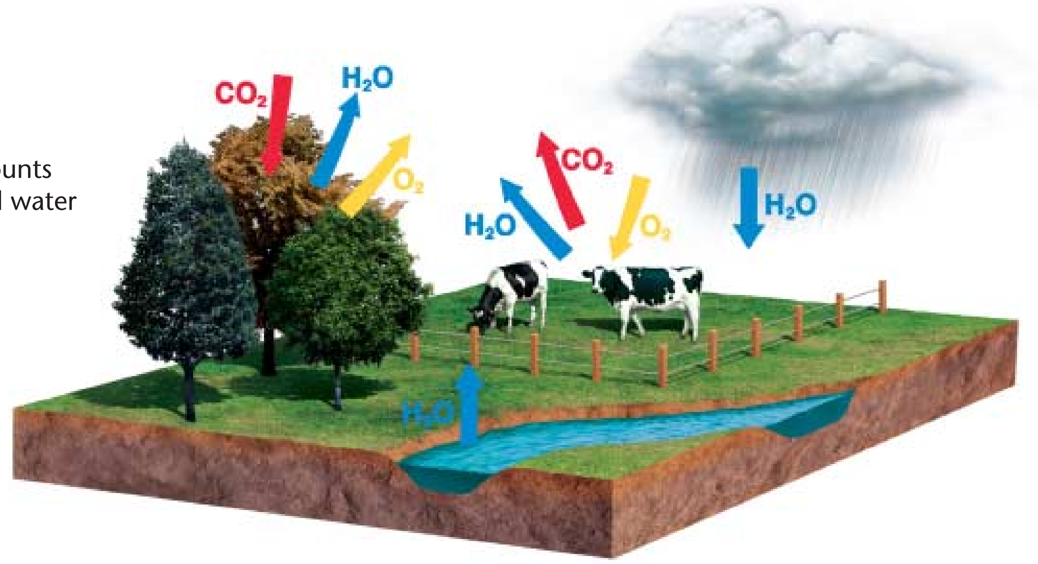


Figure 2 ▶ Several processes interact to maintain stable amounts of oxygen, carbon dioxide, and water in the atmosphere.

Oxygen in the Atmosphere

Oxygen makes up about 21% of Earth's atmosphere. As shown in **Figure 2,** natural processes maintain the chemical balance of oxygen in the atmosphere. Animals, bacteria, and plants remove oxygen from the air as part of their life processes. Forest fires, the burning of fuels, and the weathering of some rocks also remove oxygen from air. These processes would quickly use up most atmospheric oxygen if various processes that add oxygen to air did not take place.

Land and ocean plants produce large quantities of oxygen in a process called *photosynthesis*. During photosynthesis, plants use sunlight, water, and carbon dioxide to produce their food, and they release oxygen as a byproduct. The amount of oxygen produced by plants each year equals the amount consumed by all animal life processes. Thus, the oxygen content of the air has not changed significantly for millions of years.

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Topic: The Atmosphere
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Water Vapor in the Atmosphere

As water evaporates from oceans, lakes, streams, and soil, it enters air as the invisible gas *water vapor*. Plants and animals give off water vapor during transpiration, one of their life processes. But as water vapor enters the atmosphere, it is removed by the processes of condensation and precipitation. The percentage of water vapor in the atmosphere varies depending on factors such as time of day, location, and season. Because the amount of water vapor in air varies, the composition of the atmosphere is usually given as that of dry air. Dry air has less than 1% water vapor. Moist air may contain as much as 4% water vapor.

Reading Check **Does transpiration increase the amount of water vapor in the atmosphere or decrease the amount of water vapor in the atmosphere? (See the Appendix for answers to Reading Checks.)**

Ozone in the Atmosphere

Although it is present only in small amounts, a form of oxygen called **ozone** is an important component of the atmosphere. The oxygen that we breathe, O_2, has two atoms per molecule, but ozone, O_3, has three atoms. Ozone in the upper atmosphere forms the *ozone layer,* which absorbs harmful ultraviolet radiation from the sun. Without the ozone layer, living organisms would be severely damaged by the sun's ultraviolet rays. Unfortunately, a number of human activities damage the ozone layer. Compounds known as *chlorofluorocarbons,* or CFCs, which were previously used in refrigerators and air conditioners, and exhaust compounds, such as nitrogen oxide, break down ozone and have caused parts of the ozone layer to weaken, as **Figure 3** shows.

ozone a gas molecule that is made up of three oxygen atoms

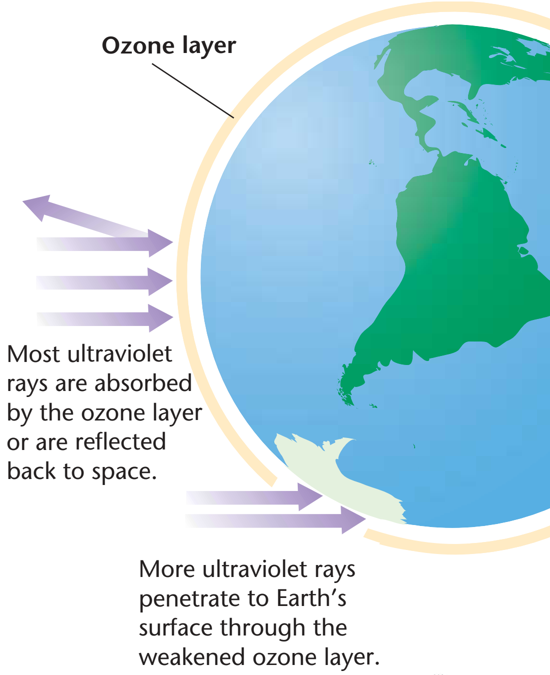


Figure 3 ▶ Harmful ultraviolet radiation can reach Earth's surface through the weakened ozone layer over Antarctica.

Particulates in the Atmosphere

In addition to containing gases, the atmosphere contains various tiny solid particles, called *particulates*. Particulates can be volcanic dust, ash from fires, microscopic organisms, or mineral particles lifted from soil by winds. Pollen from plants and particles from meteors that have vaporized are also particulates. When tiny drops of ocean water are tossed into the air as sea spray, the drops evaporate. Left behind in the air are tiny crystals of salt, another type of particulate. Four common sources of particulates are shown in **Figure 4.** Large, heavy particles remain in the atmosphere only briefly, but tiny particles can remain suspended in the atmosphere for months or years.

Figure 4 ▶ **Sources of Particulates**

Volcanic ash and dust can remain in the atmosphere for years.

The wind carries pollen from plant to plant.

Tornadoes and windstorms carry dirt and dust high into the atmosphere.

As seaspray evaporates, salt particles are left in the atmosphere.

Figure 5 ▶ At high altitudes, climbers must carry a supply of oxygen to breathe from because the density of the atmosphere there is very low. So, oxygen levels in the air are too low to supply the climber. In 2001, Eric Weihenmeyer (shown above) was the first blind person to reach the summit of Mount Everest.

Atmospheric Pressure

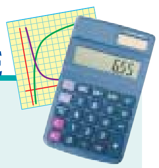
Gravity holds the gases of the atmosphere near Earth's surface. As a result, the air molecules are compressed together and exert force on Earth's surface. The pressure exerted on a surface by the atmosphere is called **atmospheric pressure.** Atmospheric pressure is exerted equally in all directions—up, down, and sideways.

Earth's gravity keeps 99% of the total mass of the atmosphere within 32 km of Earth's surface. The remaining 1% extends upward for hundreds of kilometers but gets increasingly thinner at high altitudes, as shown in **Figure 5.** Because the pull of gravity is not as strong at higher altitudes, the air molecules are farther apart and exert less pressure on each other at higher altitudes. Thus, atmospheric pressure decreases as altitude increases.

Atmospheric pressure also changes as a result of differences in temperature and in the amount of water vapor in the air. In general, as temperature increases, atmospheric pressure at sea level decreases. The reason is that molecules move farther apart when the air is heated. So, fewer particles exert pressure on a given area, and the pressure decreases. Similarly, air that contains a lot of water vapor is less dense than drier air because water vapor molecules have less mass than nitrogen or oxygen molecules do. The lighter water vapor molecules replace an equal number of heavier oxygen and nitrogen molecules, which makes the volume of air less dense.

atmospheric pressure the force per unit area that is exerted on a surface by the weight of the atmosphere

MATHPRACTICE



Force of the Air

On average, a column of air 1 m^2 at its base that reaches upward from sea level has a mass of 10,300 kg and exerts a force of 101,325 N (newtons) on the ground. So, at sea level, on every square meter of Earth's surface, the atmosphere presses down with an average force of 101,325 N. What would the average force of a column of air that has a 3 m^2 base be?

Measuring Atmospheric Pressure

Meteorologists use three units for atmospheric pressure: atmospheres (atm), millimeters or inches of mercury, and millibars (mb). *Standard atmospheric pressure,* or 1 atmosphere, is equal to 760 mm of mercury, or 1000 millibars. The average atmospheric pressure at sea level is 1 atm. Meteorologists measure atmospheric pressure by using an instrument called a *barometer.*

7938

Mercurial Barometers

Meteorologists use two main types of barometers. One type is the *mercurial barometer,* a model of which is shown in **Figure 6.** Atmospheric pressure presses on the liquid mercury in a well at the base of the barometer. The pressure holds the mercury up to a certain height inside a tube. The height of the mercury inside the tube varies with the atmospheric pressure. The greater the atmospheric pressure is, the higher the mercury rises.

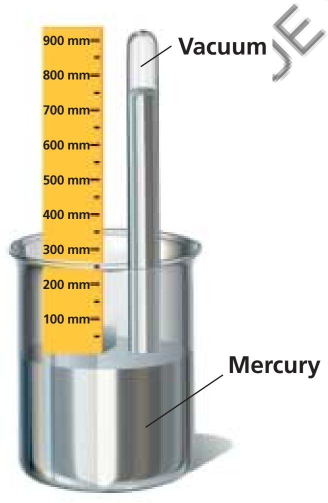


Figure 6 ▶ The height of the mercury in this mercurial barometer indicates barometric pressure. ***What is the barometric pressure shown?***

Aneroid Barometers

The type of barometer most commonly used today is called an *aneroid barometer.* Inside an aneroid barometer is a sealed metal container from which most of the air has been removed to form a partial vacuum. Changes in atmospheric pressure cause the sides of the container to bend inward or bulge out. These changes move a pointer on a scale. Aneroid barometers can be constructed to keep a continuous record of atmospheric pressure.

An aneroid barometer can also measure altitude above sea level. When used for this purpose, an aneroid barometer is called an *altimeter*. The scale on an altimeter registers altitude instead of pressure. At high altitudes, the atmosphere is less dense and exerts less pressure than at low altitudes. So, a lowered pressure reading can be interpreted as an increased altitude reading.

Reading Check **What is inside an aneroid barometer? (See the Appendix for answers to Reading Checks.)**

QuickLAB 25 min (over 5 days)

Barometric Pressure

Procedure

1. Use a **rubber band** to secure **plastic wrap** tightly over the open end of a **coffee can**.
2. Use **tape** to secure one end of a **10 cm drinking straw** onto the plastic wrap near the center of the can.
3. Use **scissors** and a **metric ruler** to cut a piece of **cardboard** 10 cm wide. The cardboard should also be at least 13 cm taller than the can.
4. Fold the cardboard so that it stands upright and extends at least 3 cm above the top of the straw.
5. Place the cardboard near the can so that the free end of the straw just touches the front of the cardboard. Mark an *X* where the straw touches.
6. Draw three horizontal lines on the cardboard: one that is level with the *X*, one that is 2 cm above the *X*, and one that is 2 cm below the *X*.
7. Position the cardboard so that the straw touches the *X*. Tape the base of the cardboard in place.
8. Observe the level of the straw at least once per day over a 5-day period. Record any changes that you see.

Analysis

1. What factors affect how your model works? Explain.
2. What does an upward movement of the straw indicate? What does a downward movement indicate?
3. Compare your results with the barometric pressures listed in your local newspaper. What may have caused your results to differ from the newspaper's?

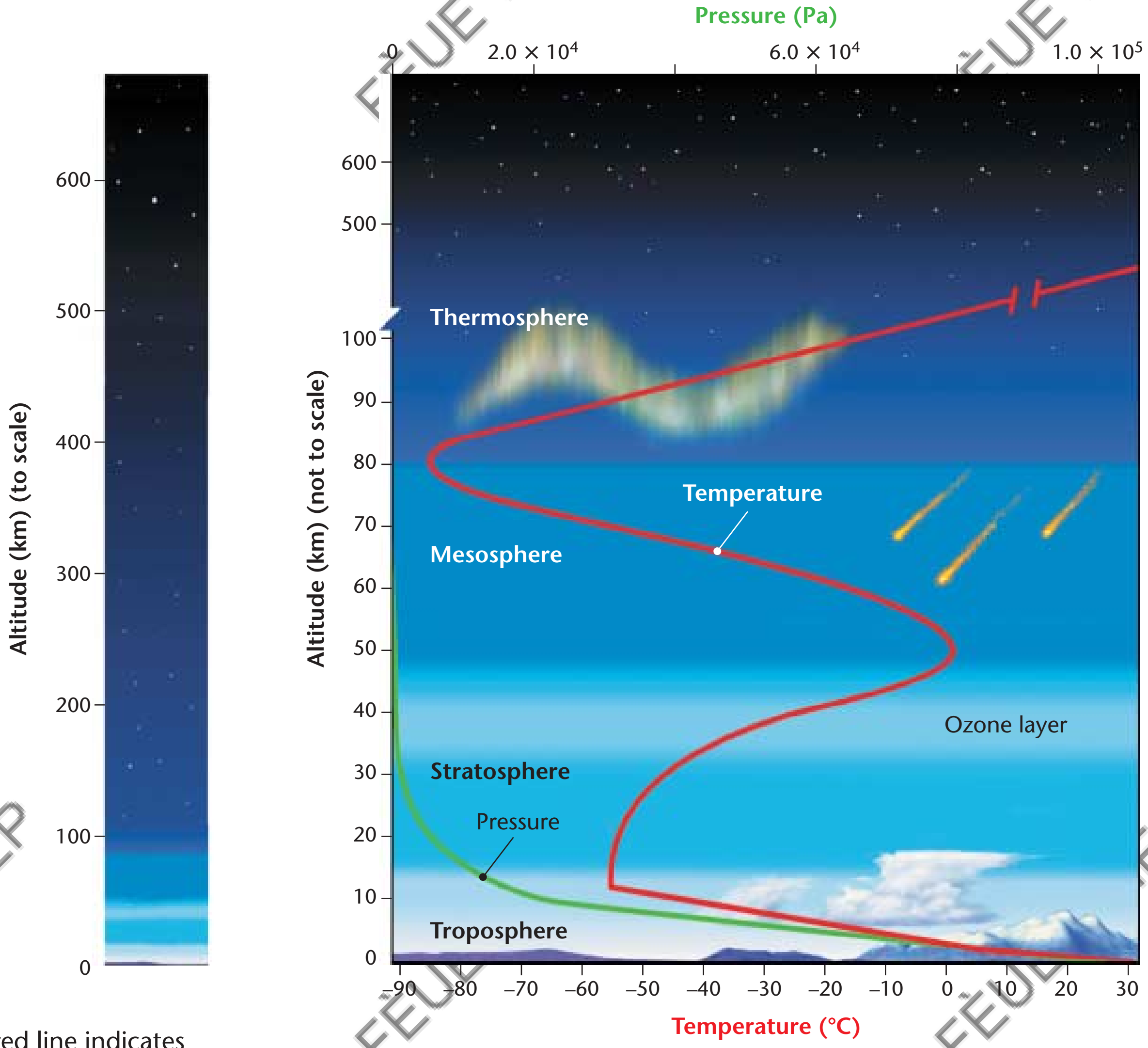


Figure 7 ▶ The red line indicates the temperature at various altitudes in the atmosphere. The green line indicates atmospheric pressure at various altitudes.

Layers of the Atmosphere

Earth's atmosphere has a distinctive pattern of temperature changes with increasing altitude, as shown in **Figure 7.** The temperature differences mainly result from how solar energy is absorbed as it moves through the atmosphere. Scientists identify four main layers of the atmosphere based on these differences.

The Troposphere

troposphere the lowest layer of the atmosphere, in which temperature drops at a constant rate as altitude increases; the part of the atmosphere where weather conditions exist

The atmospheric layer that is closest to Earth's surface and in which nearly all weather occurs is called the **troposphere.** Almost all of the water vapor and carbon dioxide in the atmosphere is found in this layer. Temperature within the troposphere decreases as altitude increases because air in this layer is heated from below by thermal energy that radiates from Earth's surface. The temperature within the troposphere decreases at the average rate of 6.5°C per kilometer as the distance from Earth's surface increases. However, at an average altitude of 12 km, the temperature stops decreasing. This zone is called the *tropopause* and represents the upper boundary of the troposphere. The altitude of this boundary varies with latitude and season.

The Stratosphere

The layer of the atmosphere called the **stratosphere** extends from the tropopause to an altitude of nearly 50 km. Almost all of the ozone in the atmosphere is concentrated in this layer. In the lower stratosphere, the temperature is almost –60°C. In the upper stratosphere, the temperature increases as altitude increases because air in the stratosphere is heated from above by absorption of solar radiation by ozone. The temperature of the air in this layer rises steadily to a temperature of about 0°C at an altitude of about 50 km above Earth's surface. This zone, called the *stratopause*, marks the upper boundary of the stratosphere.

stratosphere the layer of the atmosphere that lies between the troposphere and the mesosphere and in which temperature increases as altitude increases; contains the ozone layer

mesosphere the coldest layer of the atmosphere, between the stratosphere and the thermosphere, in which temperature decreases as altitude increases

thermosphere the uppermost layer of the atmosphere, in which temperature increases as altitude increases; includes the ionosphere

The Mesosphere

Located above the stratopause and extending to an altitude of about 80 km is the **mesosphere.** In this layer, temperature decreases as altitude increases. The upper boundary of the mesosphere, called the *mesopause*, has an average temperature of nearly –90°C, which is the coldest temperature in the atmosphere. Above this boundary temperatures again begin to increase.

The Thermosphere

The atmospheric layer above the mesopause is called the **thermosphere.** In the thermosphere, temperature increases steadily as altitude increases because nitrogen and oxygen atoms absorb solar radiation. Because air particles in the thermosphere are very far apart, they do not strike a thermometer often enough to produce an accurate temperature reading. Therefore, special instruments are needed. These instruments have recorded temperatures of more than 1,000°C in the thermosphere.

The lower region of the thermosphere, at an altitude of 80 to 400 km, is commonly called the *ionosphere*. In the ionosphere, solar radiation that is absorbed by atmospheric gases causes the atoms of gas molecules to lose electrons and to produce ions and free electrons. Interactions between solar radiation and the ionosphere cause the phenomena known as *auroras,* which are shown in **Figure 8.**

There are not enough data about temperature changes in the thermosphere to determine its upper boundary. However, above the ionosphere is the region where Earth's atmosphere blends into the almost complete vacuum of space. This zone of indefinite altitude, called the *exosphere,* extends for thousands of kilometers above the ionosphere.

Reading Check **What is the lower region of the thermosphere called? (See the Appendix for answers to Reading Checks.)**

Figure 8 ▶ Auroras can be seen from space as well as from the ground.

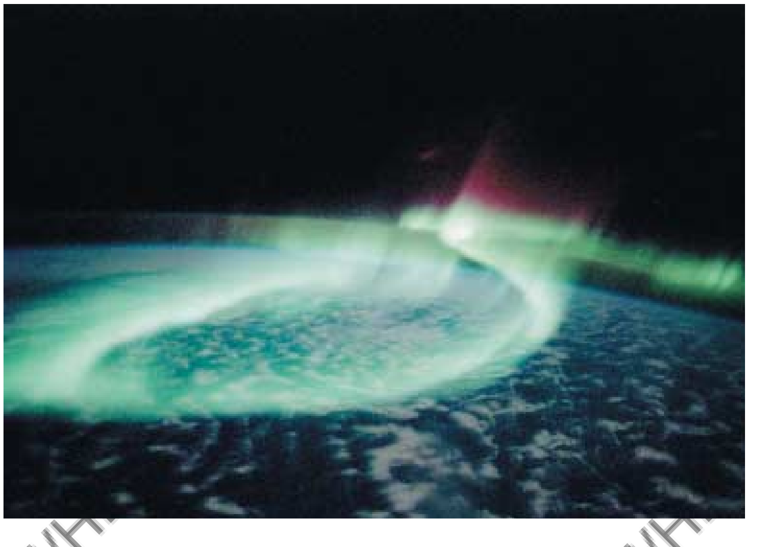


Figure 9 ▶ During a temperature inversion, polluted cool air becomes trapped beneath a warm-air layer.

Temperature Inversions

Any substance that is in the atmosphere and that is harmful to people, animals, plants, or property is called an *air pollutant*. Today, the main source of air pollution is the burning of fossil fuels, such as coal and petroleum. As these fuels burn, they may release harmful chemical substances, such as sulfur dioxide gas, hydrocarbons, nitrogen oxides, carbon monoxide, and lead, into the air.

Certain weather conditions can make air pollution worse. One such condition is a *temperature inversion*, the layering of warm air on top of cool air. Warm air, which is less dense than cool air is, can trap cool, polluted air beneath it. In some areas, topography may make air pollution even worse by keeping the polluted inversion layer from dispersing, as **Figure 9** shows. Under conditions in which air cannot circulate up and away from an area, trapped automobile exhaust can produce *smog*, a general term for air pollution that indicates a combination of smoke and fog.

Air pollution can be controlled only by preventing the release of pollutants into the atmosphere. International, federal, and local laws have been passed to reduce the amount of air pollutants produced by automobiles and industry.

Section 1 Review

1. **Describe** the composition of dry air at sea level.
2. **Identify** five main components of the atmosphere.
3. **Explain** the cause of atmospheric pressure.
4. **Explain** how the two types of barometers measure atmospheric pressure.
5. **Identify** the layer of the atmosphere in which weather occurs.
6. **Compare** the four main layers of the atmosphere.
7. **Identify** the two atmospheric layers that contain air as warm as 25°C.

CRITICAL THINKING

8. **Drawing Conclusions** Why is atmospheric pressure generally lower beneath a mass of warm air than beneath a mass of cold air?
9. **Making Calculations** Calculate how much colder air is at the top of Mount Everest, which is almost 9 km above sea level, than air is at the Indian coastline. (Hint: On average, the temperature in the troposphere decreases by 6.5°C per kilometer of altitude.)
10. **Applying Ideas** Which industrial city would have fewer air-pollution incidents related to temperature inversions: one on the Great Plains or one near the Rocky Mountains? Explain your answer.
11. **Applying Concepts** In 1982, Larry Walters rose to an altitude of approximately 4,900 m on a lawn chair attached to 45 helium-filled weather balloons. Give two reasons why Walters' trip was dangerous.

CONCEPT MAPPING

12. Use the following terms to create a concept map: *oxygen, atmosphere, air, nitrogen, water vapor, ozone,* and *particulates*.

Section 2 Solar Energy and the Atmosphere

Earth's atmosphere is heated by the transfer of energy from the sun. Some of the heat in the atmosphere comes from the absorption of the sun's rays by gases in the atmosphere. Some heat enters the atmosphere indirectly as ocean and land surfaces absorb solar energy and then give off that energy as heat.

Radiation

All of the energy that Earth receives from the sun travels through space between Earth and the sun as radiation. *Radiation* includes all forms of energy that travel through space as waves. Visible light is the form of radiation that human eyes can detect. However, there are many other forms of radiation that humans cannot see, such as ultraviolet light, X rays, and radio waves.

Radiation travels through space in the form of waves at a very high speed—approximately 300,000 km/s. The distance from any point on a wave to the identical point on the next wave, for example from crest to crest, is called the *wavelength* of a wave. The various types of radiation differ in the length of their waves. Visible light, for example, consists of waves that have various wavelengths that are seen as different colors. The wavelengths of ultraviolet rays, X rays, and gamma rays are shorter than those of visible light. Infrared waves and radio waves have relatively long wavelengths. The waves that make up all forms of radiation are called *electromagnetic waves*. Almost all of the energy that reaches Earth from the sun is in the form of electromagnetic waves. The **electromagnetic spectrum,** shown at the bottom of **Figure 1,** consists of the complete range of wavelengths of electromagnetic waves.

OBJECTIVES

- **Explain** how radiant energy reaches Earth.
- **Describe** how visible light and infrared energy warm Earth.
- **Summarize** the processes of radiation, conduction, and convection.

KEY TERMS

electromagnetic spectrum
albedo
greenhouse effect
conduction
convection

electromagnetic spectrum all of the frequencies or wavelengths of electromagnetic radiation

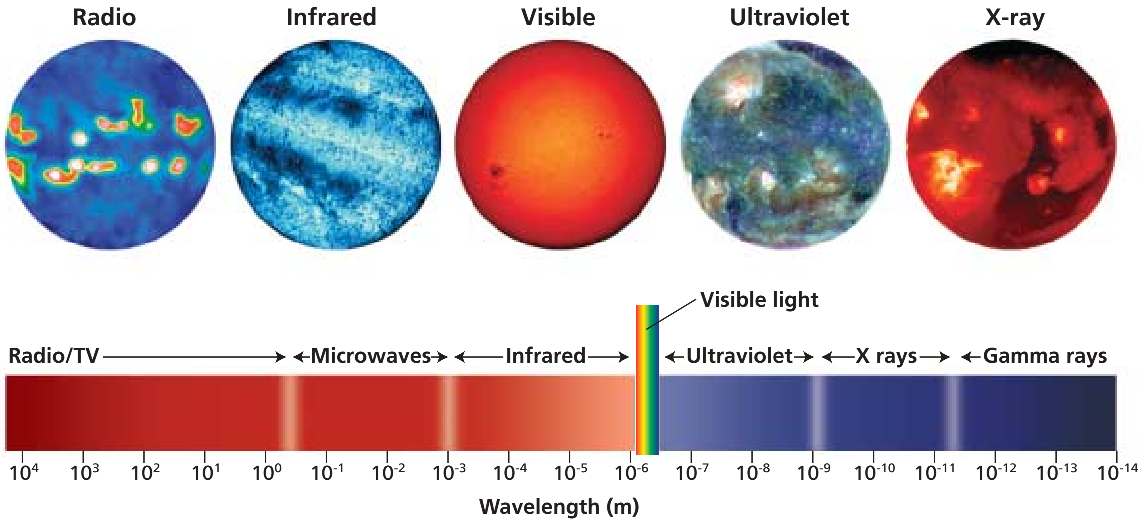


Figure 1 ▶ The sun emits radiation whose wavelengths range throughout the electromagnetic spectrum. Five images of the sun are shown above. Each image shows radiation emitted at different wavelengths.

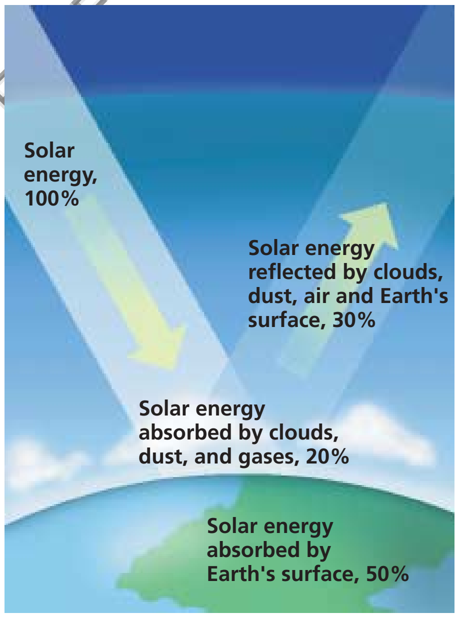


Figure 2 ▶ About 70% of the solar energy that reaches Earth is absorbed by Earth's land and ocean surfaces and by the atmosphere. The remainder is reflected back into space.

The Atmosphere and Solar Radiation

As solar radiation passes through Earth's atmosphere, the atmosphere affects the radiation in several ways. The upper atmosphere absorbs almost all radiation that has a wavelength shorter than the wavelengths of visible light. Molecules of nitrogen and oxygen in the thermosphere and mesosphere absorb the X rays, gamma rays, and ultraviolet rays. In the stratosphere, ultraviolet rays are absorbed and act upon oxygen molecules to form ozone.

Most of the solar rays that reach the lower atmosphere, such as visible and infrared waves, have longer wavelengths. Most incoming infrared radiation is absorbed by carbon dioxide, water vapor, and other complex molecules in the troposphere. As visible light waves pass through the atmosphere, only a small amount of this radiation is absorbed. **Figure 2** shows the percentage of solar energy that is reflected and absorbed by the atmosphere.

Scattering

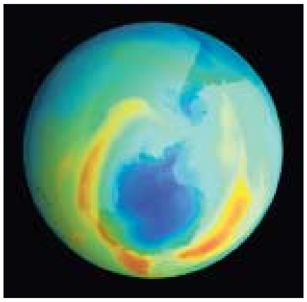
Clouds, dust, water droplets, and gas molecules in the atmosphere disrupt the paths of radiation from the sun and cause scattering. Scattering occurs when particles and gas molecules in the atmosphere reflect and bend the solar rays. This deflection causes the rays to travel out in all directions without changing their wavelengths. Scattering sends some of the radiation back into space. The remaining radiation continues toward Earth's surface. As a result of scattering, sunlight that reaches Earth's surface comes from all directions. In addition, scattering makes the sky appear blue and makes the sun appear red at sunrise and sunset.

Connection to PHYSICS

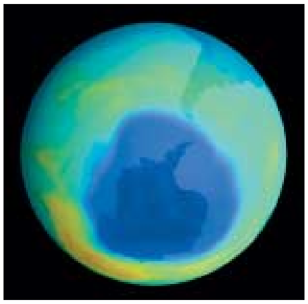
The Ozone "Hole"

Ozone, O_3, is a naturally occurring gas that is present primarily in the stratosphere. The thin layer of ozone that surrounds Earth prevents most of the sun's ultraviolet (UV) radiation from reaching Earth's surface. Overexposure to UV radiation is dangerous to living things because it damages DNA. DNA is the genetic material that carries the information for inherited characteristics. UV radiation also makes the body more susceptible to skin cancer.

The protective ozone layer is not distributed around Earth evenly. Scientists have observed that ozone concentrations vary with latitude and with the time of year. In 1985, scientists discovered that the ozone layer was unusually thin in regions over Antarctica. This "ozone hole" allows greater amounts of UV radiation to reach Earth's surface. Scientists discovered that chemicals called chlorofluorocarbons (CFCs) were causing the ozone layer to break down. CFCs were used as coolants in refrigerators and air conditioners.



Satellite image of the ozone "hole" (purple) in 1980



Satellite image of the same ozone "hole" in 2000

CFCs were also used in spray cans such as those used for household products and paint. The discovery of a connection between CFCs and the weakening ozone layer led to an international ban on CFCs.

CFCs can act to destroy ozone continuously for 60 to 120 years. So, CFCs released 30 years ago may still be destroying ozone today. It will take many years for the ozone layer to completely recover.

Table 1 ▼

Percentage of Solar Radiation		
Surface	Reflected	Absorbed
Soils (dark colored)	5–10	90–95
Desert	20–40	60–80
Grass	5–25	75–95
Forest	5–10	90–95
Snow	50–90	10–50
Water (high sun angle)	5–10	90–95
Water (low sun angle)	50–80	20–50

Table 1 ▶ Reflection and Absorption Rates of Various Materials

Reflection

When solar energy reaches Earth's surface, the surface either absorbs or reflects the energy. The amount of energy that is absorbed or reflected depends on characteristics such as the color, texture, composition, volume, mass, transparency, state of matter, and specific heat of the material on which the solar radiation falls. The intensity and amount of time that a surface material receives radiation also affects how much energy is reflected or absorbed.

The fraction of solar radiation that is reflected by a particular surface is called the **albedo.** Because 30% of the solar energy that reaches Earth's atmosphere is either reflected or scattered, Earth is said to have an albedo of 0.3. **Table 1** shows the amount of incoming solar radiation that is absorbed and reflected by various surfaces.

albedo the fraction of solar radiation that is reflected off the surface of an object

Absorption and Infrared Energy

The sun constantly emits radiation. Solar radiation that is not reflected is absorbed by rocks, soil, water, and other surface materials. When Earth's surface absorbs solar radiation, the radiation's short-wavelength infrared rays and visible light heat the surface materials. Then, the heated materials convert the energy into infrared rays of longer-wavelengths and reemit it as those waves. Gas molecules, such as water vapor and carbon dioxide, in the atmosphere absorb these infrared rays. The absorption of thermal energy from the ground heats the lower atmosphere and keeps Earth's surface much warmer than it would be if there were no atmosphere. Sometimes, warm air near Earth's surface bends light rays to produce an effect called a *mirage,* as **Figure 3** shows.

Figure 3 ▶ Hot air near the surface of this road bends light rays. ***What objects in this photo appear to be reflected?***

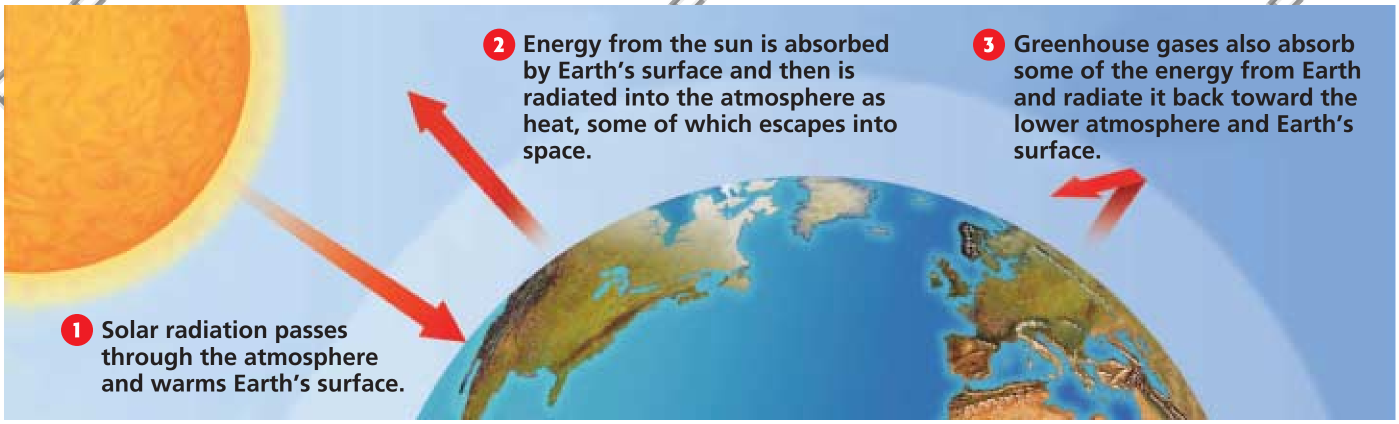


Figure 4 ▶ One process that helps heat Earth's atmosphere is similar to the process that heats a greenhouse.

The Greenhouse Effect

One of the ways in which the gases of the atmosphere absorb and reradiate infrared rays, shown in **Figure 4,** can be compared to the process that keeps a greenhouse warm. The glass of a greenhouse allows visible light and infrared rays from the sun to pass through and warm the surfaces inside of the greenhouse. But the glass prevents the infrared rays that are emitted by the warmed surfaces within the greenhouse from escaping. Similarly, Earth's atmosphere slows the escape of energy that radiates from Earth's surface. Because this process is similar to the process that heats a greenhouse, it is called the **greenhouse effect.**

greenhouse effect the warming of the surface and lower atmosphere of Earth that occurs when carbon dioxide, water vapor, and other gases in the air absorb and reradiate infrared radiation

Human Impact on the Greenhouse Effect

Generally, the amount of solar energy that enters Earth's atmosphere is about equal to the amount that escapes into space. However, human activities may change this balance and may cause the average temperature of the atmosphere to increase. For example, measurements indicate that the amount of carbon dioxide in the atmosphere has been increasing in recent years. These increases have been attributed to the burning of more fossil fuels. These increases seem likely to continue in the future. Increases in the amount of carbon dioxide may intensify the greenhouse effect and may cause Earth to become warmer in some areas and cooler in others.

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Topic: Greenhouse Effect
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Variations in Temperature

Radiation from the sun does not heat Earth equally at all places at all times. In addition, a slight delay occurs between the absorption of energy and an increase in temperature. Earth's surface must absorb energy for a time before enough heat has been absorbed and reradiated from the ground to change the temperature of the atmosphere. For a similar reason, the warmest hours of the day are usually mid- to late afternoon even though solar radiation is most intense at noon. The temperature of the atmosphere in any region on Earth's surface depends on several factors, including latitude, surface features, and the time of year and day.

Latitude and Season

Latitude is the primary factor that affects the amount of solar energy that reaches any point on Earth's surface. Because Earth is a sphere, the sun's rays do not strike all areas at the same angle, as shown in **Figure 5.** The rays of the sun strike the ground near the equator at an angle near 90°. At the poles, the sunlight strikes the ground at a much smaller angle. When sunlight hits Earth's surface at an angle smaller than 90°, the energy is spread out over a larger area and is less intense. Thus, the energy that reaches the equator is more intense than the energy that strikes the poles, so average temperatures are higher near the equator than near the poles.

Temperature varies seasonally because of the tilt of Earth's axis. As Earth revolves around the sun once each year, the portion of Earth's surface that receives the most intense sunlight changes. For part of the year, the Northern Hemisphere is tilted toward the sun and receives more direct sunlight. During this time of year, temperatures are at their highest. For the other part of the year, the Southern Hemisphere is tilted toward the sun. During this time, the Northern Hemisphere receives less direct sunlight, and the temperatures there are at their lowest.

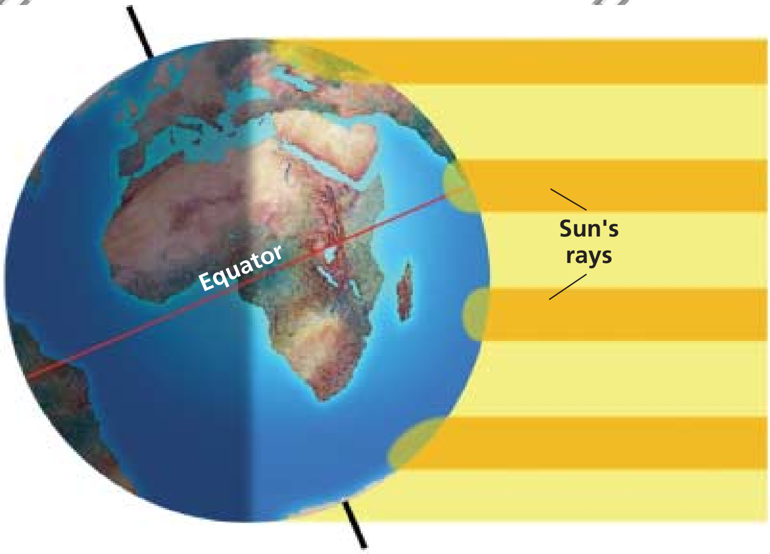

Figure 5 ▶ Temperatures are higher at the equator because solar energy is concentrated in a small area. Farther north and south, the same amount of solar energy is spread out over a larger area.

Water in the Air and on the Surface

Because water vapor stores heat, the amount of water in the air affects the temperature of a region. The thinner air at high elevations contains less water vapor and carbon dioxide to absorb the heat. As a result, those areas become warm during the day but cool very quickly at night. Similarly, desert temperatures may vary widely between day and night because little water vapor is present to hold the heat of the day.

Land areas close to large bodies of water generally have more moderate temperatures. In other words, these areas will be cooler during the day and warmer at night than inland regions that have the same general weather conditions are. The reason for these moderate temperatures is that water heats up and cools down faster than air does, so the temperature of water changes less than the temperature of land does.

The wind patterns in an area also affect temperature. A region that receives winds off the ocean waters has more moderate temperatures than does a similar region in which the winds blow from the land.

Reading Check **Why are deserts generally colder at night than other areas are? (See the Appendix for answers to Reading Checks.)**

QuickLAB 5 min

Light and Latitude

Procedure

1. Hold a **flashlight** so that the beam shines directly down on a **white piece of paper.** Use a **pencil** to trace the outline of the beam of light.
2. Move the flashlight so that the light shines on the paper at an angle. Trace the outline of the beam of light.

Analysis

1. How does the area of the direct beam differ from the area of the angled beam?
2. How does this exercise illustrate how latitude affects incoming solar radiation?

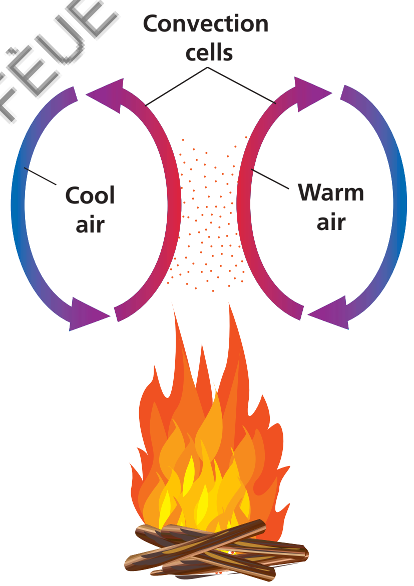

Figure 6 ▶ During convection, energy is carried away by heated air as it rises above cooler, denser air.

Conduction

The molecules in a substance move faster as they become heated. These fast-moving molecules cause other molecules to move faster. Collisions between the particles result in the transfer of energy, which warms the substance. The transfer of energy as heat from one substance to another by direct contact is called **conduction**. Solid substances, in which the molecules are close together, make relatively good conductors. Because the molecules of air are far apart, air is a poor conductor. Thus, conduction heats only the lowest few centimeters of the atmosphere, where air comes into direct contact with the warmed surface of Earth.

conduction the transfer of energy as heat through a material

convection the movement of matter due to differences in density that are caused by temperature variations; can result in the transfer of energy as heat

Convection

The heating of the lower atmosphere is primarily the result of the distribution of heat through the troposphere by convection. **Convection** is the process by which air, or other matter, rises or sinks because of differences in temperature. Convection occurs when gases or liquids are heated unevenly. As air is heated by radiation or conduction, it becomes less dense and is pushed up by nearby cooler air. In turn, this cooler air becomes warmer, and the cycle repeats, as shown in **Figure 6.**

The continuous cycle in which cold air sinks and warm air rises warms Earth's atmosphere evenly. Because warm air is less dense than cool air is, warm air exerts less pressure than the same volume of cooler air does. So, the atmospheric pressure is lower beneath a mass of warm air. As dense, cool air moves into a low-pressure region, the less dense, warmer air is pushed upward. These pressure differences, which are the result of the unequal heating that causes convection, create winds.

Section 2 Review

1. **Explain** how radiant energy reaches Earth.
2. **List and describe** the types of electromagnetic waves.
3. **Describe** how gases and particles in the atmosphere interact with light rays.
4. **Describe** how visible light and infrared energy warm Earth.
5. **Explain** how variations in the intensity of sunlight can cause temperature differences on Earth's surface.
6. **Summarize** the processes of conduction and convection.

CRITICAL THINKING

7. **Making Inferences** Why do scientists study all wavelengths of the electromagnetic spectrum?
8. **Applying Concepts** Explain how fans in convection ovens help cook food more evenly.
9. **Applying Conclusions** You decide not to be outside during the hottest hours of a summer day. When will the hottest hours probably be? How do you know?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *electromagnetic waves, infrared waves, greenhouse effect, ultraviolet waves, visible light, scattering,* and *absorption.*

Section 3 Atmospheric Circulation

Pressure differences in the atmosphere cause the movement of air worldwide. The air near Earth's surface generally flows from the poles toward the equator. The reason for this flow is that air moves from high-pressure regions to low-pressure regions. High-pressure regions form where cold air sinks toward Earth's surface. Low-pressure regions form where warm air rises away from Earth's surface.

OBJECTIVES

- **Explain** the Coriolis effect.
- **Describe** the global patterns of air circulation, and name three global wind belts.
- **Identify** two factors that form local wind patterns.

KEY TERMS

Coriolis effect
trade winds
westerlies
polar easterlies
jet stream

The Coriolis Effect

The circulation of the atmosphere and of the oceans is affected by the rotation of Earth on its axis. Earth's rotation causes its diameter to be greatest through the equator and smallest through the poles. Because each point on Earth makes one complete rotation every day, points near the equator travel farther and faster in a day than points closer to the poles do. When air moves toward the poles, it travels east faster than the land beneath it does. As a result, the air follows a curved path. The tendency of a moving object to follow a curved path rather than a straight path because of the rotation of Earth is called the **Coriolis effect**, which is shown in **Figure 1**.

Coriolis effect the curving of the path of a moving object from an otherwise straight path due to Earth's rotation

Winds that blow from high-pressure areas to lower-pressure areas curve as a result of the Coriolis effect. The Coriolis effect deflects moving objects along a path that depends on the speed, latitude, and direction of the object. Objects are deflected to the right in the Northern Hemisphere and are deflected to the left in the Southern Hemisphere.

The faster an object travels, the greater the Coriolis effect on that object is. The Coriolis effect also noticeably changes the paths of large masses that travel long distances, such as air or ocean currents. In general, the Coriolis effect is detectable only on objects that move very fast or that travel over long distances.

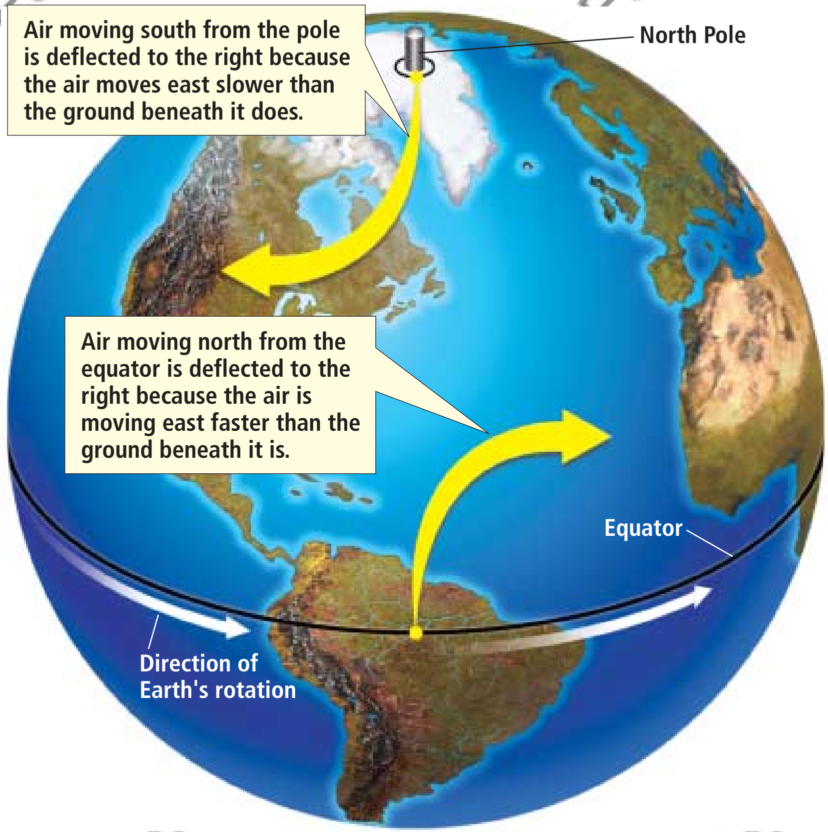

Figure 1 ▶ Because of Earth's rotation, an object that travels north from the equator will curve to the east. This curving is called the *Coriolis effect*.

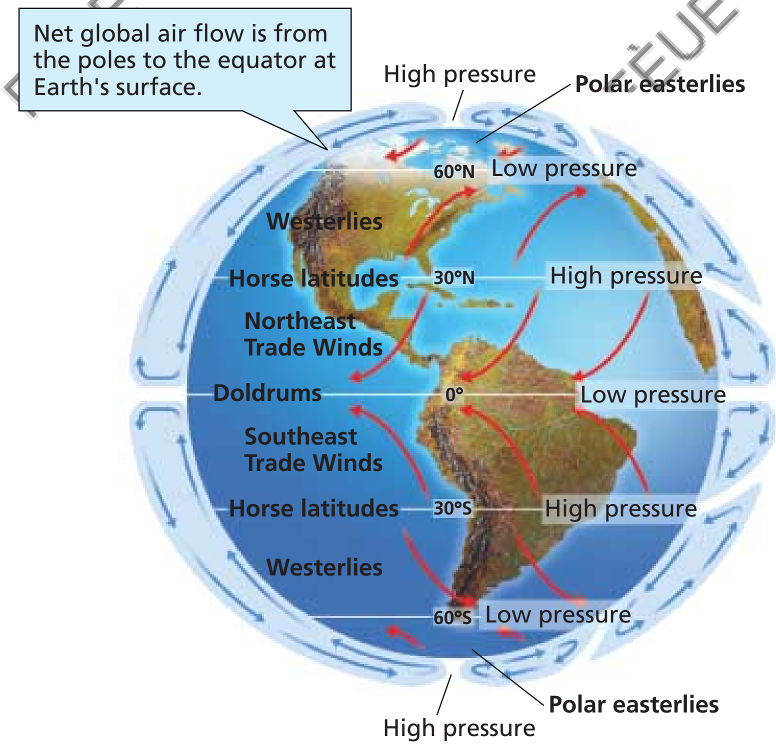

Figure 2 ▶ Each hemisphere has three wind belts. Wind belts are the result of pressure differences at the equator, the subtropics, the subpolar regions, and the poles. Winds in the belts curve because of the Coriolis effect. ***Do winds in the Northern Hemisphere curve clockwise or counterclockwise?***

Global Winds

The air that flows from the poles toward the equator does not flow in a single, straight line. Each hemisphere contains three looping patterns of flow called *convection cells*. Each of these convection cells correlates to an area of Earth's surface, called a *wind belt*, that is characterized by winds that flow in one main direction. These winds are called *prevailing winds*. All six wind belts are shown in **Figure 2.**

Trade Winds

In both hemispheres, the winds that flow toward the equator between 30° and 0° latitude are called **trade winds.** Like all winds, the trade winds are named according to the direction from which they flow. In the Northern Hemisphere, the trade winds flow from the northeast and are called the *northeast trade winds*. In the Southern Hemisphere, the trade winds are called the *southeast trade winds*. These wind belts are called *trade winds* because many trading ships sailed on these winds from Europe in the 18th and 19th centuries.

Westerlies

Between 30° and 60° latitude, some of the descending air moving toward the poles is deflected by the Coriolis effect. This flow creates the **westerlies,** which exist in another wind belt in each hemisphere. In the Northern Hemisphere, the westerlies are southwest winds. In the Southern Hemisphere, they are northwest winds. The westerlies blow throughout the contiguous United States.

Reading Check **Name two ways in which the trade winds of the Northern Hemisphere differ from the westerlies of the Northern Hemisphere. (See the Appendix for answers to Reading Checks.)**

Polar Easterlies

Toward the poles, or poleward, of the westerlies—at about 60° latitude—is a zone of low pressure. This zone of low pressure separates the westerlies from a third wind belt in each hemisphere. Over the polar regions themselves, descending cold air creates areas of high pressure. Surface winds created by the polar high pressure are deflected by the Coriolis effect and become the **polar easterlies.** The polar easterlies are strongest where they flow off Antarctica. Where the polar easterlies meet warm air from the westerlies, a stormy region known as a *front* forms.

trade winds prevailing winds that blow from east to west from 30° latitude to the equator in both hemispheres

westerlies prevailing winds that blow from west to east between 30° and 60° latitude in both hemispheres

polar easterlies prevailing winds that blow from east to west between 60° and 90° latitude in both hemispheres

The Doldrums and Horse Latitudes

As **Figure 2** shows, the trade wind systems of the Northern Hemisphere and Southern Hemisphere meet at the equator in a narrow zone called the *doldrums*. In this warm zone, most air movement is upward and surface winds are weak and variable. As the air approaches 30° latitude, it descends and a high-pressure zone forms. These subtropical high-pressure zones are called the *horse latitudes*. Here, too, surface winds are weak and variable.

Wind and Pressure Shifts

As the sun's rays shift northward and southward during the changing seasons of the year, the positions of the pressure belts and wind belts shift. Although the area that receives direct sunlight can shift by up to 47° north and south of the equator, the average shift for the pressure belts and wind belts is only about 10° of latitude. However, even this small change causes some areas of Earth's surface to be in different wind belts during different times of the year. In southern Florida, for example, westerlies prevail in the winter, but trade winds dominate in the summer.

Jet Streams

Narrow bands of high-speed winds that blow in the upper troposphere and lower stratosphere are **jet streams.** These winds exist in the Northern Hemisphere and Southern Hemisphere.

One type of jet stream is a polar jet stream. Polar jet streams form as a result of density differences between cold polar air and the warmer air of the middle latitudes. These bands of winds, which are about 100 km wide and 2 to 3 km thick, are located at altitudes of 10 to 15 km. Polar jet streams can reach speeds of 500 km/h and can affect airline routes and the paths of storms.

Another type of jet stream is a subtropical jet stream. In the subtropical regions, very warm equatorial air meets the cooler air of the middle latitudes, and the *subtropical jet streams* form. Unlike the polar jet streams, the subtropical jet streams do not change much in speed or position. A subtropical jet stream is shown in **Figure 3.**

Graphic Organizer **Comparison Table**

Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Trade winds," "Westerlies," "Polar easterlies," and "Jet streams." Label the rows with "Latitude" and "Direction.". Then, fill in the table with details about each type of wind.

jet stream a narrow band of strong winds that blow in the upper troposphere

Figure 3 ▶ Clouds in this jet stream are traveling high over Egypt. This remarkable photograph was taken by *Gemini 12* astronauts.

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Figure 4 ▶ Sea breezes keep these kites aloft during the afternoon. Overnight, land breezes will blow the flags toward the ocean.

Local Winds

Winds also exist on a scale that is much smaller than a global scale. Movements of air are influenced by local conditions, and local temperature variations commonly cause local winds. Local winds are not part of the global wind belts. Gentle winds that extend over distances of less than 100 km are called *breezes*.

Land and Sea Breezes

Equal areas of land and water may receive the same amount of energy from the sun. However, land surfaces heat up faster than water surfaces do. Therefore, during daylight hours, a sharp temperature difference develops between a body of water and the land along the water's edge. This temperature difference is apparent in the air above the land and water. The warm air above the land rises as the cool air from above the water moves in to replace the warm air. A cool wind moving from water to land, called a *sea breeze,* generally forms in the afternoon, as shown in **Figure 4.** Overnight, the land cools more rapidly than the water does, and the sea breeze is replaced by a *land breeze*. A land breeze flows from the cool land toward the warmer water.

Mountain and Valley Breezes

During the daylight hours in mountainous regions, a gentle valley breeze blows upslope. This *valley breeze* forms when warm air from the valleys moves upslope. At night, the mountains cool more quickly than the valleys do. At that time, cool air descends from the mountain peaks to create a *mountain breeze*. Areas near mountains may experience a warm afternoon that turns to a cold evening soon after sunset. This evening cooling happens because cold air flows down mountain slopes and settles in valleys.

Section 3 Review

1. **Describe** the pattern of air circulation between an area of low pressure and an area of high pressure.
2. **Explain** how the Coriolis effect affects wind flow.
3. **Name and describe** Earth's three global wind belts.
4. **Summarize** the importance of the jet streams.
5. **Identify** two factors that create local wind patterns.

CRITICAL THINKING

6. **Applying Concepts** Determine whether wind moving south from the equator will curve eastward or westward because of the Coriolis effect.
7. **Inferring Relationships** Which has a lower pressure: the air in your lungs as you inhale or the air outside your body? Explain.
8. **Applying Ideas** While visiting the Oregon coast, you decide to hike toward the ocean, but you are not sure of the direction. The time is 4:00 P.M. How might the breeze help you find your way?

CONCEPT MAPPING

9. Use the following terms to create a concept map: *wind, sea breeze, global winds, trade winds, westerlies, local winds, polar easterlies, land breeze, mountain breeze,* and *valley breeze.*

Chapter 22

Highlights

Sections

1 Characteristics of the Atmosphere

Key Terms

- **atmosphere,** 547
- **ozone,** 549
- **atmospheric pressure,** 550
- **troposphere,** 552
- **stratosphere,** 553
- **mesosphere,** 553
- **thermosphere,** 553

Key Concepts

- Earth's atmosphere is the mixture of gases, called *air*, that surrounds Earth. Mixed with the gases that make up air are solid particles called *particulates*.
- Atmospheric pressure is the force exerted on Earth's surface by the weight of the atmosphere. It is measured by using a barometer.
- The atmosphere is divided into four major layers whose temperature and pressure vary.
- Air pollution can be harmful to people, animals, plants, and property.

2 Solar Energy and the Atmosphere

Key Terms

- **electromagnetic spectrum,** 555
- **albedo,** 557
- **greenhouse effect,** 558
- **conduction,** 560
- **convection,** 560

Key Concepts

- Most of the energy that reaches Earth from the sun is in the form of electromagnetic radiation.
- Visible light and infrared rays from the sun penetrate Earth's atmosphere and heat materials on the surface.
- The upper atmosphere is heated by absorption of radiation from the sun. The lower atmosphere is heated by conduction from Earth's surface and by convection of air.

3 Atmospheric Circulation

Key Terms

- **Coriolis effect,** 561
- **trade winds,** 562
- **westerlies,** 562
- **polar easterlies,** 562
- **jet stream,** 563

Key Concepts

- Air-pressure differences due to the unequal heating of Earth in combination with Earth's rotation cause the global wind belts.
- A surface feature, such as a body of water, a mountain, or a valley, can influence local wind patterns.

Chapter 22 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *atmosphere*
2. *electromagnetic spectrum*
3. *Coriolis effect*

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

4. *troposphere* and *stratosphere*
5. *mesosphere* and *thermosphere*
6. *conduction* and *convection*
7. *trade winds* and *westerlies*
8. *polar easterlies* and *westerlies*

Understanding Key Concepts

9. During one part of the nitrogen cycle, nitrogen is removed from the air mainly by nitrogen-fixing
- **a.** bacteria.
- **b.** waves.
- **c.** minerals.
- **d.** crystals.

10. The atmosphere contains tiny solid particles called
- **a.** gases.
- **b.** particulates.
- **c.** meteors.
- **d.** nitrogen.

11. A barometer measures
- **a.** atmospheric pressure.
- **b.** wind speed.
- **c.** ozone concentration.
- **d.** wavelengths.

12. Almost all of the water and carbon dioxide in the atmosphere is in the
- **a.** exosphere.
- **b.** ionosphere.
- **c.** troposphere.
- **d.** stratosphere.

13. The process by which the atmosphere slows Earth's loss of heat to space is called the
- **a.** greenhouse effect.
- **b.** Coriolis effect.
- **c.** doldrums.
- **d.** convection cell.

14. Energy as heat can be transferred within the atmosphere in three ways—radiation, conduction, and
- **a.** transpiration.
- **b.** temperature inversion.
- **c.** weathering.
- **d.** convection.

15. A vertical looping pattern of airflow is known as
- **a.** the Coriolis effect.
- **b.** a convection cell.
- **c.** a trade wind.
- **d.** a westerly.

16. A gentle wind that covers less than 100 km is called
- **a.** a jet stream.
- **b.** the doldrums.
- **c.** a breeze.
- **d.** a trade wind.

17. Which of the following layers of the atmosphere is closest to the ground?
- **a.** troposphere
- **b.** thermosphere
- **c.** mesosphere
- **d.** exosphere

18. Which of the following layers of the atmosphere is closest to space?
- **a.** troposphere
- **b.** ionosphere
- **c.** mesosphere
- **d.** exosphere

Short Answer

19. List the three main elemental gases that compose the atmosphere.

20. What is atmospheric pressure, and how is it measured?

21. List and describe the four main layers of the atmosphere.

22. What happens to visible light that enters Earth's atmosphere?

23. How is heat energy transferred by Earth's atmosphere?

24. How does latitude affect the temperature of a region?

25. Explain how the greenhouse effect helps warm the atmosphere.

26. What causes the Coriolis effect?

27. Name and describe the three main wind belts in both hemispheres.

28. How do surface features influence local wind patterns?

Critical Thinking

29. **Making Inferences** If a breeze is blowing from the ocean to the land on the coast of Maine, about what time of day is it? Explain your answer.

30. **Evaluating Ideas** What effect might jet streams have on airplane travel?

31. **Inferring Relationships** Most aerosol sprays that contain CFCs have been banned in the United States. Which of the four layers of the atmosphere does this ban help protect? Explain your answer.

32. **Evaluating Information** You hear a report about Earth's weather. The reporter says that visible light rays coming from Earth's surface heat the atmosphere in a way similar to the way a greenhouse is heated. Explain why the reporter's statement is incorrect.

Concept Mapping

33. Use the following terms to create a concept map: *atmosphere, troposphere, stratosphere, temperature, mesosphere, thermosphere, atmospheric pressure, altitude,* and *exosphere*.

Math Skills

34. **Applying Quantities** The albedo of the moon is 0.07. What percent of the total solar radiation that reaches the moon is reflected?

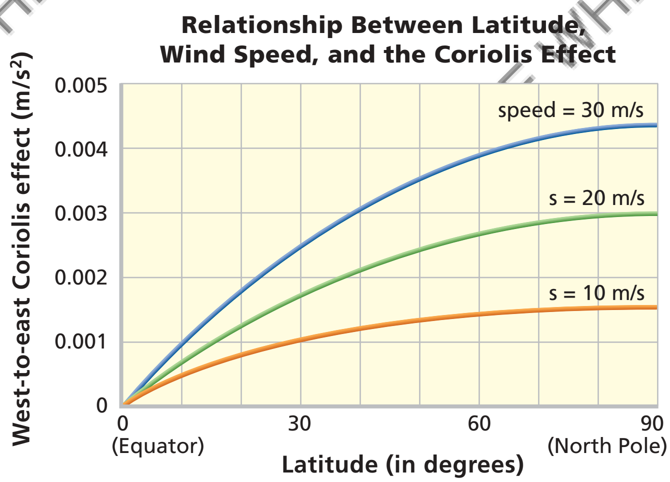
35. **Making Calculations** Maximum local wind speeds for each of the last seven days were 12 km/h, 20 km/h, 11 km/h, 6 km/h, 8 km/h, 19 km/h, and 17 km/h. What was the average maximum wind speed?

Writing Skills

36. **Writing from Research** Research the debate about global warming. Write one paragraph that includes evidence that supports global warming and one paragraph that includes evidence that does not support global warming.

Interpreting Graphics

The graph below shows how the Coriolis effect changes as latitude and wind speed change. Use the graph to answer the questions that follow.



37. At what wind speed is the Coriolis effect the greatest?

38. At what latitude is the Coriolis effect the smallest?

39. At 90° latitude, is there a direct relationship between the Coriolis effect and wind speed?

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Chapter 22 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 Which of the following processes is the source of the oxygen gas found in Earth's atmosphere?
- **A.** oxidation
- **B.** combustion
- **C.** respiration
- **D.** photosynthesis

2 Which of the following statements best describes the relationship of atmospheric pressure to altitude?
- **F.** The atmospheric pressure increases as the altitude increases.
- **G.** The atmospheric pressure increases as the altitude decreases.
- **H.** The atmospheric pressure varies unpredictably at different altitudes.
- **I.** The atmospheric pressure is constant at all altitudes.

3 Approximately how much of the solar energy that reaches Earth is absorbed by the atmosphere, land surfaces, and ocean?
- **A.** 30%
- **B.** 50%
- **C.** 70%
- **D.** 100%

4 In the Northern Hemisphere, the Coriolis effect causes winds moving toward the North Pole to be deflected in which of the following ways?
- **F.** Winds are deflected to the right.
- **G.** Winds are deflected to the left.
- **H.** Winds are deflected in unpredictable patterns.
- **I.** Winds are not deflected by the Corilois effect.

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

5 What is the most abundant gas in Earth's atmosphere?

6 In which atmospheric layer do interactions between gas molecules and solar radiation produce the aurora borealis phenomenon?

Reading Skills

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

The Snow Eater

The chinook, or "snow eater," is a dry wind that blows down the eastern side of the Rocky Mountains from New Mexico to Alaska. Arapaho gave the chinook its name because of its ability to melt large amounts of snow very quickly. Chinooks form when moist air is forced over a mountain range. The air cools as it rises. As the air cools, it releases moisture in the form of rain or snow, which nourishes the local flora. As the dry air flows over the mountaintop, they air compresses and heats the air below. The warm, dry wind that results can melt half of a meter of snow in just a few hours.

The temperature change caused when a chinook rushes down a mountainside can be dramatic. In 1943, in Spearfish, South Dakota, the temperature at 7:30 A.M. was –4°F. But only two minutes later, a chinook caused the temperature to soar to 45°F.

7 Why are the chinook winds of the Rocky Mountains called "snow eaters?"
- **A.** Chinook winds pick up snow and carry it to new locations.
- **B.** Chinook winds drop all of their snow on the western side of the mountains.
- **C.** Chinook winds cause the temperature to decrease, which causes snow to accumulate.
- **D.** Chinook winds cause the temperature to increase rapidly, which causes snow to melt.

8 Which of the following statements can be inferred from the information in the passage?
- **F.** Chinook winds are a relatively new phenomenon related to global warming.
- **G.** The Rocky Mountains are more arid on their eastern side than on their western side.
- **H.** The only type of wind that blows down from mountaintops are chinook winds.
- **I.** When they blow up the western side of the Rocky Mountains, chinook winds are very hot.

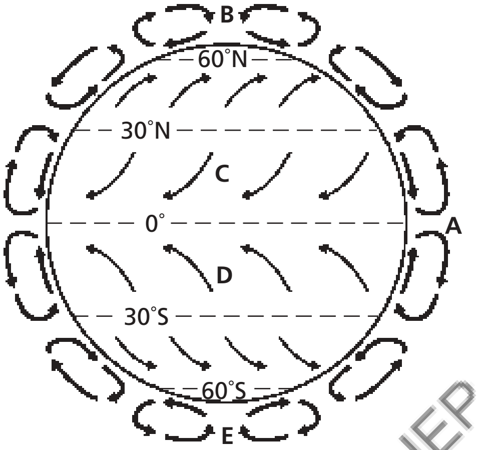
9 How might chinook winds affect agriculture on the eastern side of the Rocky Mountains?

Interpreting Graphics

***Directions (10–12):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram below shows global wind belts and convection cells at different latitudes. Use this diagram to answer questions 10 and 11.

Global Wind Belts



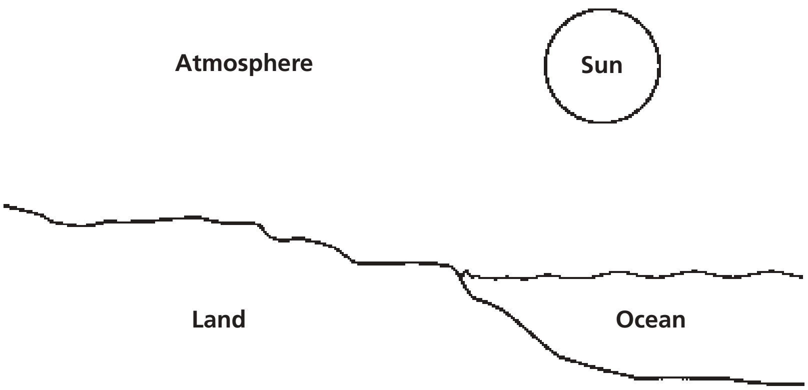
10 What happens to the air around location A as the air warms and decreases in density?

A. It rises.
B. It sinks.
C. It stagnates.
D. It contracts.

11 Compare and contrast the wind patterns in the global wind belts labeled C and D. Why do the winds move in the directions shown?

The graphic below shows a typical coastal area. Use this graphic to answer question 12.

Coastal Land Area on a Summer Day



12 Would the direction of local winds be the same during the night as they would during the day in this location? Explain your answer in terms of the wind's direction and cause during the day and during the night.

Test TIP

Do not be fooled by answers that may seem correct to you just because they contain unfamiliar words.

Chapter 22 **Inquiry Lab** Using Scientific Methods

Energy Absorption and Reflection

When solar energy reaches Earth's surface, the energy is either reflected or absorbed by the material that the surface is made of. Whether the material absorbs or reflects energy, and the amount of energy that is reflected or absorbed, depends on several characteristics of the material. These characteristics include the material's composition, its color and texture, how transparent the material is, the mass and volume of the substance, and the specific heat of the substance. In this lab, you will study these characteristics to determine which material is best suited for use as roofing material.

Objectives

- **Determine** which material would keep the inside of a house coolest.
- **Explain** which properties of that material determine whether it is a conductor or an insulator.

Materials

- cardboard, 4 cm × 4 cm × 1 cm (4 pieces)
- paint, black, white, and light blue tempera
- metal, 4 cm × 4 cm × 1 cm
- rubber, beige or tan, 4 cm × 4 cm × 1 cm
- sandpaper, 4 cm × 4 cm × 1 cm
- thermometers, Celsius (4)
- watch, or clock
- wood, beige or tan, 4 cm × 4 cm × 1 cm

Safety

ASK A QUESTION

1. Which material would keep the interior of a house coolest?

FORM A HYPOTHESIS

2. Identify the material that you think will keep the inside of a house coolest. List the characteristics of that material that caused you to choose that material.

TEST THE HYPOTHESIS

3. Brainstorm with a partner or with a small group of classmates to design a procedure that will help you determine which materials absorb the most energy and which materials keep the surface below them coolest. You do not have to test all of the materials, if you can explain why you think those materials would not be coolest. Write down your experimental procedure.

Step 3

4. Have your teacher approve your experimental design.

5. Create a table like the one shown at right. Use this table to record the data you collect as you perform your experiment.

6. Following your design, measure the temperatures that the materials and the surfaces beneath them reach.

Material	Color	Surface temperature (°C)	Temperature below material (°C)
Cardboard	white		
Rubber	beige		
Sandpaper	beige		

ANALYZE THE RESULTS

1. **Graphing Data** Use the data you collected to create a bar graph whose *x*-axis you label with the materials you tested and *y*-axis you label with a range of temperatures.

2. **Analyzing Data** Which material reached the highest temperature on its surface? Which material caused the surface below it to reach the highest temperature?

3. **Analyzing Data** Which material stayed the lowest temperature at its surface? Which material kept the temperature of the surface beneath it lowest?

4. **Evaluating Results** Did the color of the materials affect whether they absorbed or reflected solar energy? Explain your answer.

DRAW CONCLUSIONS

5. **Drawing Conclusions** Based on your results, which material would you use for the roof of a house? Did your experimental results support your original hypothesis?

6. **Inferring Relationships** What properties of the material you identified in question 5 do you think make it best for this purpose? Explain your answer.

7. **Making Predictions** Do you think the material you chose would keep the inside of a house warm in colder weather? Explain your answer.

8. **Analyzing Methods** Name two changes in your experimental design that you would make if you were going to repeat the experiment. Explain why you would make each change.

Extension

1. **Applying Ideas** Use the materials you tested in this lab to create a model of Earth's surface that represents how different parts of Earth's surface absorb or reflect solar energy. Which areas of Earth's surface absorb the least energy?

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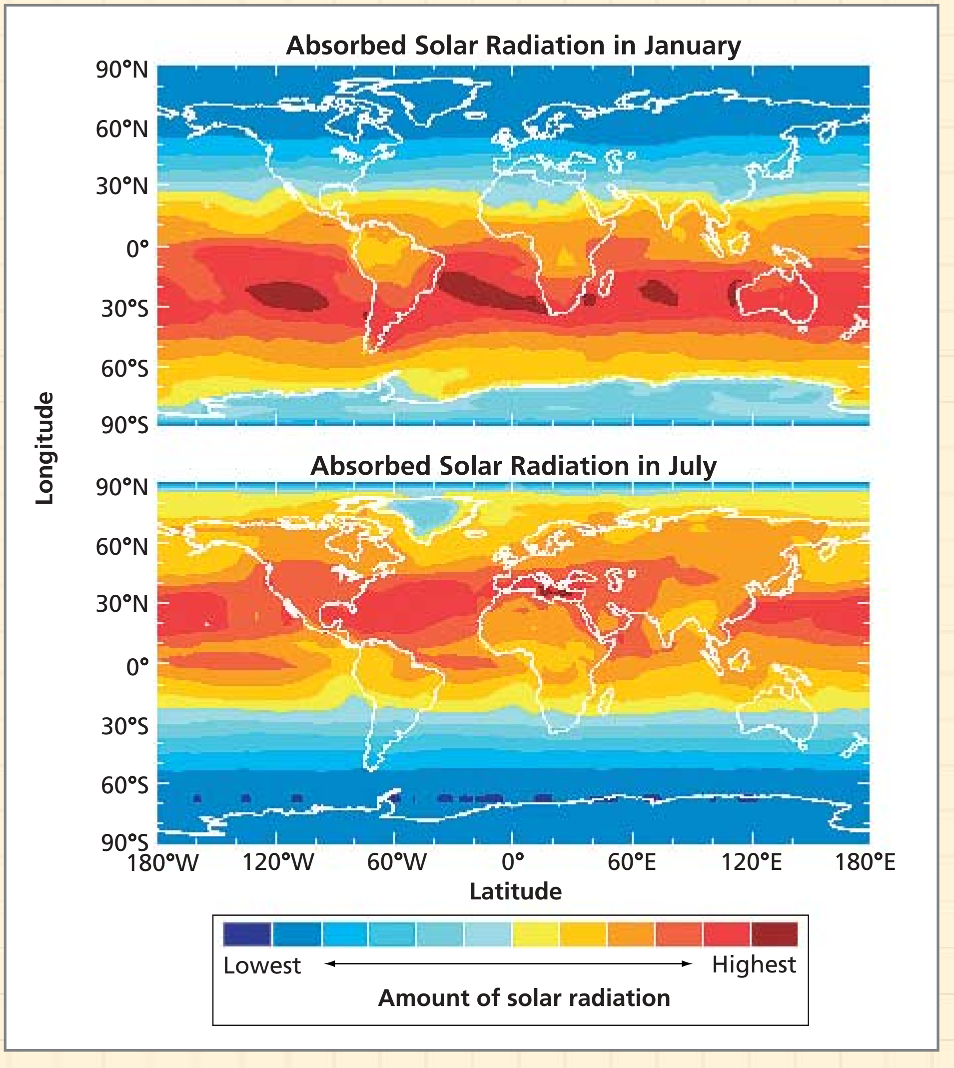
MAPS in Action

Absorbed Solar Radiation



Map Skills Activity

These maps show the total amount of solar radiation that is absorbed by Earth in January and July. Use the maps to answer the questions below.

1. **Using a Key** In January, which region has the highest amount of absorbed solar radiation?

2. **Using a Key** In July, which region has the highest amount of absorbed solar radiation?

3. **Comparing Areas** Which area has the greatest difference between the amount of absorbed solar radiation in January and the amount in July: southern Australia or northeastern South America?

4. **Analyzing Data** At what latitudes are January's and July's amounts of absorbed solar radiation similar?

5. **Inferring Relationships** How do these maps explain the differences between the Northern Hemisphere's weather in January and its weather in July?

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Energy from the Wind

For more than a thousand years, people have used windmills for tasks such as grinding grain or pumping water. Today, more and more people are rediscovering the benefits of wind power, and the number of wind turbines used to generate electricity continues to grow.

A New Take on an Old Idea

One result of the renewed interest in wind power is the reintroduction of the Darrieus turbine. Invented in 1920, the Darrieus turbine resembles an upside-down eggbeater. The Darrieus turbine is designed to catch winds blowing from all directions, and most of its moving parts are located on the ground. The bend in the blades can be changed to maximize efficiency, and the turbine's shape—taller than it is wide—minimizes land use.

Other, more recent technological advances in wind turbines include the use of lighter and less costly materials and the use of faster airfoil blades. Instead of being flat like earlier blades, an airfoil blade is shaped like an airplane wing. This shape allows air to flow smoothly over the blades and enables the airfoil to use the lifting force of the wind more effectively.

Energy of the Future

Using the wind to generate electricity consumes no fuels and produces no wastes. Also, wind itself costs nothing and is available in certain areas in a limitless supply. However, wind power has some disadvantages. One disadvantage is the unpredictability of wind speed and wind direction. Wind farms can also be noisy, unattractive, and deadly to migrating birds.

Thousands of wind turbines have been installed in California, Texas, and other states. Because of the steady increase in wind power use in European countries such as the Netherlands, Denmark, Germany, and England, wind power is quickly becoming the sustainable energy source of choice for utility companies worldwide.

Extension

1. **Making Predictions** What problems might arise in wind turbines placed between 20° and 40° latitude?

▲ A modern Darrieus turbine

▼ A modern wind farm

Chapter 23 Water in the Atmosphere

Sections

What You'll Learn

- How water enters the atmosphere
- How clouds form
- How precipitation forms

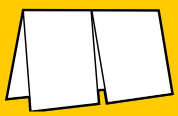
Why It's Relevant

Severe weather conditions can put lives in danger. Understanding how water moves through the atmosphere provides a basis for understanding weather.

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 "Clouds" and "Precipitation." As you read the chapter, write information you learn about each category under the appropriate flap.



▶ Dark clouds, such as the clouds near Rosston, Oklahoma, shown here, usually signal the coming of a thunderstorm. The clouds look dark because they are so thick that little solar radiation passes through them.

Section 1 Atmospheric Moisture

Water in the atmosphere exists in three states, or *phases*. One phase is known as a gas called *water vapor*. The other two phases of water are the solid phase known as *ice* and the liquid phase known as *water*.

OBJECTIVES

- **Explain** how heat energy affects the changing phases of water.
- **Explain** what absolute humidity and relative humidity are, and describe how they are measured.
- **Describe** what happens when the temperature of air decreases to the dew point or below the dew point.

KEY TERMS

latent heat
sublimation
dew point
absolute humidity
relative humidity

Changing Forms of Water

Water changes from one phase to another when heat energy is absorbed or released, as shown in **Figure 1.** Molecules of ice are held almost stationary in a definite crystalline arrangement. However, when energy is absorbed by the ice, the molecules move more rapidly. They break from their fixed positions and slide past each other in the fluid form of a liquid.

When more energy is absorbed by liquid water, the water changes from a liquid to a gas. Because the additional energy causes the movement of molecules in liquid water to speed up, the molecules collide more frequently with each other. Such collisions can cause the molecules to move so rapidly that the fastest-moving molecules escape from the liquid to form invisible water vapor in a process called *evaporation*.

Latent Heat

The heat energy that is absorbed or released by a substance during a phase change is called **latent heat.** When liquid water evaporates, the water absorbs energy from the environment. This energy becomes potential energy between the molecules. When water vapor changes back into a liquid through the process of *condensation*, energy is released to the surrounding air and the molecules move closer together. Likewise, latent heat is absorbed when ice thaws, and latent heat is released when water freezes.

latent heat the heat energy that is absorbed or released by a substance during a phase change

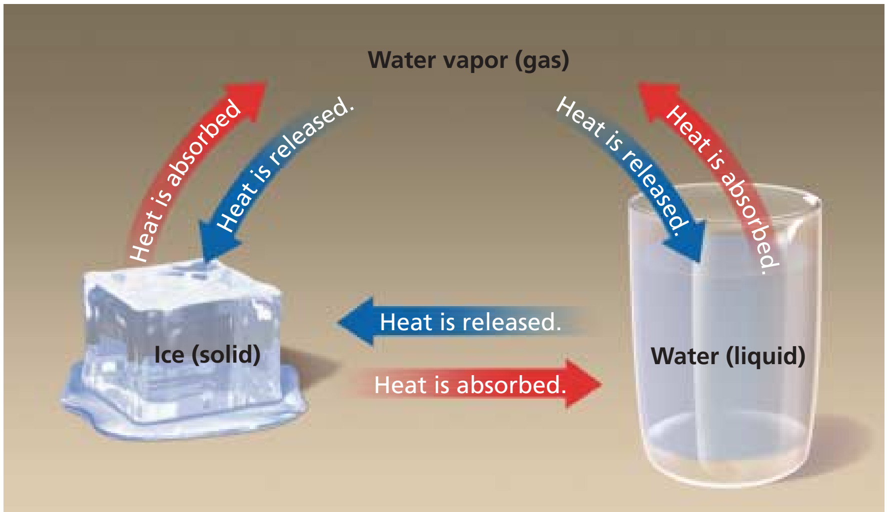


Figure 1 ▶ Water exists in three states, called *phases*. As it changes from one phase to another, water either absorbs or releases heat energy.

Evaporation

Most water enters the atmosphere through the process of evaporation. Because the largest amounts of solar energy reach Earth near the equator, most evaporation takes place in the oceans of the equatorial region. However, water vapor also enters the atmosphere by evaporation from lakes, ponds, streams, and soil. Plants release water into the atmosphere in a process called transpiration. Volcanoes and burning fuels also release small amounts of water vapor into the atmosphere.

Sublimation

sublimation the process in which a solid changes directly into a gas (the term is sometimes also used for the reverse process)

Ice commonly changes into a liquid before changing into a gas. However, in some cases, ice can change directly into water vapor without becoming a liquid. The process by which a solid changes directly into a gas is called **sublimation.** When the air is dry and the temperature is below freezing, ice and snow may sublimate into water vapor. Water vapor can also turn directly into ice without becoming a liquid.

Reading Check **Summarize the conditions under which sublimation commonly occurs. (See the Appendix for answers to Reading Checks.)**

Connection to PHYSICS

Light and Water in the Atmosphere

The interaction of water and light in the atmosphere can create a number of visual effects. When visible light passes through raindrops, the raindrops *refract*, or bend the light rays, which separates the white light into the colors that make up the entire visible spectrum. You can see these colors in rainbows, glories, and coronas. *Coronas* are small, multicolored circles that surround the sun or moon. *Glories* are small, multicolored circles that surround the shadow of an object on which light is shining.

Sun dogs, sun pillars, halos, and rings are caused by the interaction of light rays and ice crystals in the atmosphere. In general, the ice crystals do not separate the light into different colors, so these phenomena involve white light. *Sun dogs* are bright spots that appear in the sky, often on either side of the sun. *Sun pillars* are bright shafts of light that extend up and down from the sun or moon. *Halos* and *rings* are fuzzy or bright rings that are commonly seen around the sun and the moon.

Crepuscular rays are slanting sunbeams that form when sunlight is intermittently interrupted by clouds or fog. The clouds cast shadows that appear to break up the sunlight to form smaller, individual rays.

A *mirage* is one of two types of optical illusions that form when light rays are refracted as they pass through a boundary between hot air and cool air. The first type, called an *inferior mirage,* occurs when light passes from a layer of cool air to a layer of hot air close to the ground. When the light rays enter the hot air, they bend upward and cause the sky to appear as a pool of water on the ground. The other type, a *superior mirage,* is an image of an object that seems to be suspended in the sky. This type occurs when light rays pass through a layer of warm air into a layer of cool air below.

Sun dogs, such as these below, are caused when ice crystals in the atmosphere interact with light rays.

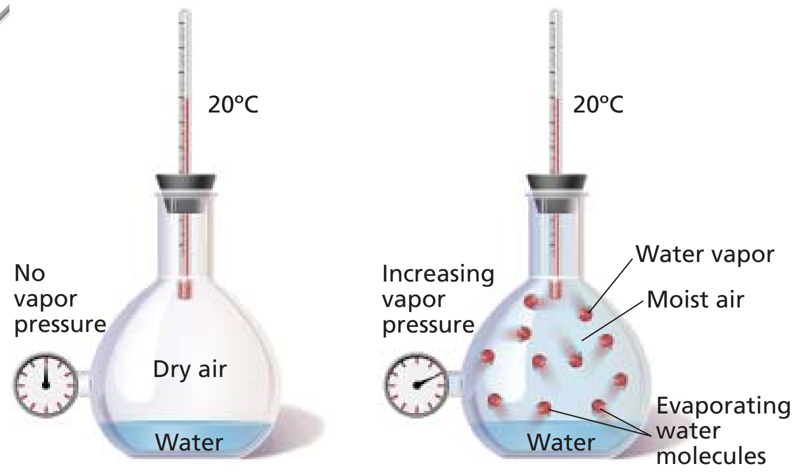


Figure 2 ▶ When water comes into contact with dry air, some of the water molecules evaporate into the dry air. The addition of the water molecules to the air causes the air pressure to increase. This increase in pressure is due to vapor pressure.

Humidity

Water vapor in the atmosphere is known as *humidity*. Humidity is controlled by rates of condensation and evaporation. The rate of evaporation is determined by the temperature of the air. The higher the temperature is, the higher the rate of evaporation is. The rate of condensation is determined by vapor pressure. Vapor pressure is the part of the total atmospheric pressure that is caused by water vapor, as shown in **Figure 2.** When vapor pressure is high, the condensation rate is high.

When the rate of evaporation and the rate of condensation are in equilibrium, the air is said to be "saturated." The temperature at which the condensation rate equals the evaporation rate is called the **dew point.** At temperatures below the dew point, net condensation occurs, and liquid water droplets form.

dew point at constant pressure and water vapor content, the temperature at which the rate of condensation equals the rate of evaporation

absolute humidity the mass of water vapor per unit volume of air that contains the water vapor, usually expressed as grams of water vapor per cubic meter of air

Absolute Humidity

One way to express the amount of moisture in air is by absolute humidity. **Absolute humidity** is the mass of water vapor contained in a given volume of air. In other words, absolute humidity is a measure of the actual amount of water vapor in the air. Absolute humidity is calculated by using the following equation:

$$\textit{absolute humidity} = \frac{\textit{mass of water vapor (grams)}}{\textit{volume of air (cubic meters)}}$$

However, as air moves, its volume changes as a result of temperature and pressure changes. Therefore, meteorologists prefer to describe humidity by using the mixing ratio of air. The *mixing ratio* is the mass of water vapor in a unit of air relative to the mass of the dry air. For example, the very moist air in tropical regions might have 18 g of water vapor in 1 kg of air, or a mixing ratio of 18 g/kg. On the other hand, the cold, dry air in polar regions commonly has a mixing ratio of less than 1 g/kg. Because this measurement uses only units of mass, it is not affected by changes in temperature or pressure.

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Topic: Atmospheric Moisture
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Figure 3 ▶ Dew forms on surfaces such as grass and spider webs when the temperature of air reaches the dew point.

relative humidity the ratio of the amount of water vapor in the air to the amount of water vapor needed to reach saturation at a given temperature

Relative Humidity

A more common way to express the amount of water vapor in the atmosphere is by *relative humidity*. **Relative humidity** is a ratio of the actual water vapor content of the air to the amount of water vapor needed to reach saturation. In other words, relative humidity is a measure of how close the air is to reaching the dew point. For example, at 25ºC, air is saturated when it contains 20 g of water vapor per 1 kg of air. If air that is 25ºC contains 5 g of water vapor, the relative humidity is expressed as 5/20, or 25%.

If the temperature does not change, the relative humidity will increase if moisture enters the air. Relative humidity can also increase if the moisture in the air remains constant but the temperature decreases. If the temperature increases as the moisture in the air remains constant, the relative humidity will decrease.

MATHPRACTICE

Relative Humidity
Relative humidity can be calculated by using the following equation:

$$\text{relative humidity} = \left[\frac{\text{amount of water vapor in air}}{\text{amount of water vapor needed to reach saturation}}\right] \times 100$$

Air at 20°C is saturated when it contains 14 g/kg of water vapor. What is the relative humidity of a volume of air that is 20°C and that contains 10 g/kg of water vapor?

Reaching the Dew Point

When the air is nearly saturated with a relative humidity of almost 100%, only a small temperature drop is needed for air to reach its dew point. Air may cool to its dew point by conduction when the air is in contact with a cold surface. During the night, grass, leaves, and other objects near the ground lose heat. Their surface temperatures often drop to the dew point of the surrounding air. Air, which normally remains warmer than surfaces near the ground do, cools to the dew point when it comes into contact with cooler objects, such as grass. The resulting form of condensation, shown in **Figure 3**, is called *dew*. Dew is most likely to form on cool, clear nights when there is little wind.

If the dew point falls below the freezing temperature of water, water vapor may change directly into solid ice crystals, or *frost*. Because frost forms when water vapor turns directly into ice, frost is not frozen dew. Frozen dew is relatively uncommon. Unlike frost, frozen dew forms as clear beads of ice.

Reading Check **How does dew differ from frost? (See the Appendix for answers to Reading Checks.)**

Measuring Humidity

Meteorologists are interested in measuring humidity so that they can better predict weather conditions. Relative humidity can be measured by using a variety of instruments, such as a thin polymer film, a psychrometer, a dew cell, and a hair hygrometer.

Using Thin Polymer Film to Measure Humidity

Humidity is commonly measured by a humidity sensor that uses a *thin polymer film.* The relative humidity of the surrounding air affects the ability of the thin polymer film to absorb or release water vapor. The amount of water vapor the thin polymer film contains changes the film's ability to conduct electricity. The polymer film's ability to conduct electricity is affected by the relative humidity of the surrounding air. Thus, by measuring the polymer film's ability to store electricity, relative humidity can be determined.

Using Psychrometers to Measure Humidity

A *psychrometer,* shown in **Figure 4,** is another instrument that is used to measure relative humidity. It consists of two identical thermometers. The bulb of one thermometer is covered with a damp wick, while the bulb of the other thermometer remains dry. When the psychrometer is held by a handle and whirled through the air, the air circulates around both thermometers. As a result, the water in the wick of the wet-bulb thermometer evaporates. Evaporation requires heat, so heat escapes from the thermometer. Consequently, the temperature of the wet-bulb thermometer is lower than that of the dry-bulb thermometer. The difference between the dry-bulb temperature and the wet-bulb temperature is used to calculate relative humidity. If there is no difference between the wet-bulb temperature and dry-bulb temperature, no water evaporated from the wet-bulb thermometer. Thus, the air is saturated and the relative humidity is 100%.

QuickLAB **10 min**

Dew Point

Procedure

1. Pour **room-temperature water** into a **glass container,** such as a drinking glass, until the water level is near the top of the cup.
2. Observe the outside of the glass container, and record your observations.
3. Add **one or two ice cubes** to the container of water.
4. Watch the outside of the container for 5 min for any changes.

Analysis

1. What happened to the outside of the container?
2. What is the liquid on the container?
3. Where did the liquid come from? Explain your answer.

Figure 4 ▶ A psychrometer is commonly used with a table that lists relative humidity based on differences between wet-bulb and dry-bulb readings.

7967

Figure 5 ▶ Scientists use weather balloons, such as this one in Antarctica, to send electric hygrometers into the high altitudes of the atmosphere.

Other Methods for Measure Humidity

Another instrument that has been used to measure relative humidity is the *dew cell*. Dew cells consist of a ceramic cylinder with electrodes attached to it and treated with lithium chloride, LiCl. When LiCl absorbs water from the air, the dew cells ability to conduct electricity increases. By detecting the electrical resistance of LiCl as it is heated and cooled, the dew cell can determine the dew point.

The *hair hygrometer* determines relative humidity based on the principle that hair becomes longer as relative humidity increases. As relative humidity decreases, hair becomes shorter.

Measuring Humidity at High Altitudes

To measure humidity at high altitudes, scientists use an electric hygrometer. The hygrometer may be carried up into the atmosphere in an instrument package known as a *radiosonde*. The radiosonde is attached to a weather balloon, such as the one shown in **Figure 5**. The electric hygrometer is triggered by passing an electric current through a moisture-attracting chemical substance. The amount of moisture changes the electrical conductivity of the chemical substance. The change can then be expressed as the relative humidity of the surrounding air.

Section 1 Review

1. **Explain** how most water vapor enters the air.
2. **Identify** the principal source from which most water vapor enters the atmosphere.
3. **Identify** the process by which ice changes directly into a gas.
4. **Define** *humidity*.
5. **Compare** relative humidity with absolute humidity.
6. **Describe** what happens when the temperature of air decreases to the dew point or below the dew point.
7. **Identify** four instruments that are used to measure relative humidity.

CRITICAL THINKING

8. **Predicting Consequences** Explain what would happen to a sample of air whose relative humidity is 100% if the temperature decreased.
9. **Identifying Relationships** Which region of Earth would you expect to have a higher absolute humidity: the equatorial region or the polar regions?

CONCEPT MAPPING

10. Use the following terms to create a concept map: *humidity*, *water vapor*, *dew point*, *absolute humidity*, *dew cell*, *psychrometer*, *hygrometer*, *evaporation*, *condensation*, and *relative humidity*.

Section 2 Clouds and Fog

Clouds are collections of small water droplets or ice crystals that fall slowly through the air. Ice crystals and water droplets form when condensation or sublimation occurs more rapidly than evaporation does. People commonly think that clouds are high in the sky and fog is close to the ground. However, clouds are not limited to high altitudes. Fog is actually a cloud that forms near or on Earth's surface.

OBJECTIVES

- **Describe** the conditions that are necessary for clouds to form.
- **Explain** the four processes of cooling that can lead to the formation of clouds.
- **Identify** the three types of clouds.
- **Describe** four ways in which fog can form.

KEY TERMS

cloud
condensation nucleus
adiabatic cooling
advective cooling
stratus cloud
cumulus cloud
cirrus cloud
fog

cloud a collection of small water droplets or ice crystals suspended in the air, which forms when the air is cooled and condensation occurs

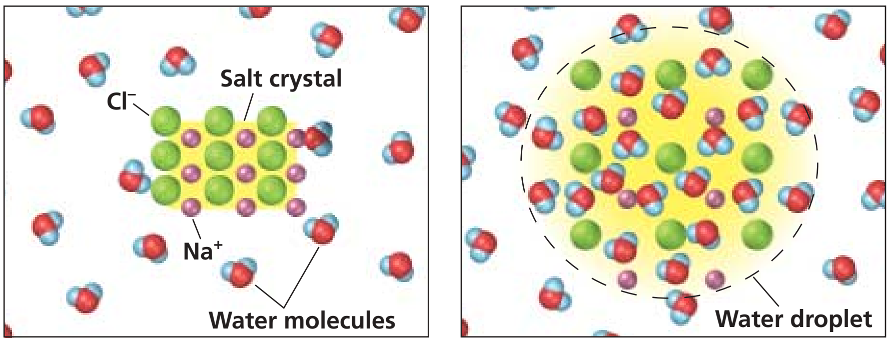
condensation nucleus a solid particle in the atmosphere that provides the surface on which water vapor condenses

Cloud Formation

For water vapor to condense and form a cloud, a solid surface on which condensation can take place must be available. Although the lowest layer of the atmosphere, the *troposphere,* does not contain any large solid surfaces, it contains millions of suspended particles of ice, salt, dust, and other materials. Because the particles are so small—less than 0.001 mm in diameter—they remain suspended in the atmosphere for a long time. The suspended particles that provide the surfaces necessary for water vapor to condense are called **condensation nuclei.** As water molecules collect on the nuclei, water droplets form, as **Figure 1** shows.

In addition, for clouds to form, the rate of evaporation must initially be in equilibrium with the rate of condensation. When this condition occurs, the air is said to be "saturated" with water vapor. When the temperature of the saturated air drops, condensation occurs more rapidly than evaporation does. As a result of this net condensation, clouds begin to form. Because the rate of evaporation decreases as temperature decreases, cooling of air may lead to net condensation. Four major processes can cause the cooling that is necessary for clouds to form.

Figure 1 ▶ **Formation of a Water Droplet**



Water molecules are electrically attracted to the sodium ions, Na^+, and the chlorine ions, Cl^-, in a salt crystal.

The water molecules and ions form a solution. Additional water molecules are attracted to the solution, and the droplet gets bigger.

7969

Adiabatic Cooling

As a mass of air rises, the surrounding atmospheric pressure decreases. Because of the lower pressure, the molecules in the rising air move farther apart. Thus, fewer collisions between the molecules happen. The resulting decrease in the amount of energy that transfers between molecules decreases the temperature of the air. The process by which the temperature of a mass of air decreases as the air rises and expands is called **adiabatic cooling** (AD ee uh BAT ik KOOL ing).

adiabatic cooling the process by which the temperature of an air mass decreases as the air mass rises and expands

Adiabatic Lapse Rate

The rate at which the temperature of a parcel of air changes as the air rises or sinks is called the *adiabatic lapse rate*. The adiabatic lapse rate of clear air is about –1°C for every 100 m that the air rises. Air that is below the dew point—and thus is cloudy—cools more slowly, however. The average adiabatic lapse rate for cloudy air varies between –0.5°C and –0.9°C per 100 m that the air rises. The slower rate of cooling of moist air results from the release of latent heat as the water condenses.

Condensation Level

The process through which clouds form by adiabatic cooling is shown in **Figure 2**. Earth's surface absorbs energy from the sun and then reradiates that energy as heat. The air close to Earth's surface absorbs the heat. As the air warms, it rises, expands, and then cools. When the air cools to a temperature that is below the dew point, net condensation causes clouds to form. The altitude at which this net condensation begins is called the *condensation level*. The condensation level is marked by the base of the clouds. Further condensation allows clouds to rise and expand above the condensation level.

Reading Check **What is the source of heat that warms the air and leads to cloud formation? (See the Appendix for answers to Reading Checks.)**

Figure 2 ▶ Notice in this illustration that temperature and dew point are the same at an altitude of 1,000 m. Above that altitude, condensation begins and clouds, such as the clouds in the image on the right, form.

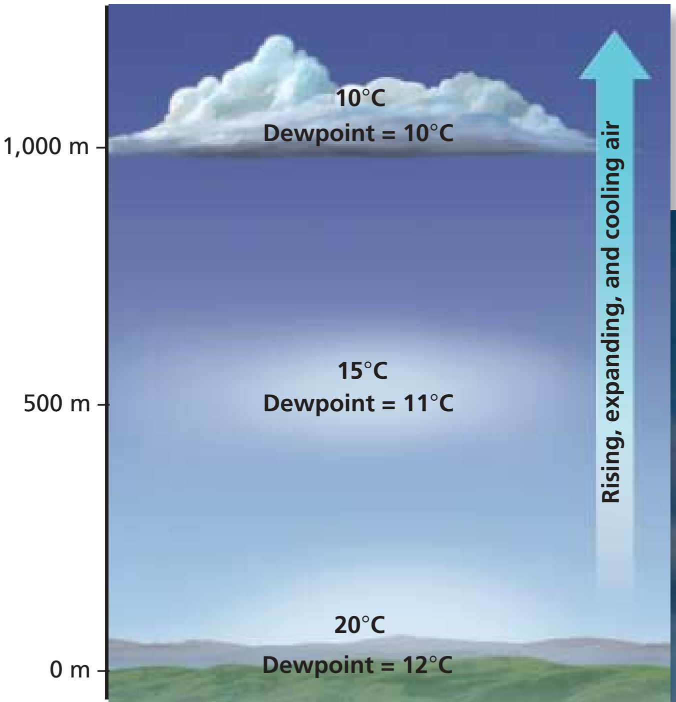


Figure 3 ▶ Clouds can form as air is pushed up along a mountain slope and is cooled to below the dew point.

Mixing

Some clouds form when one body of moist air mixes with another body of moist air that has a different temperature. The combination of the two bodies of air causes the temperature of the air to change. This temperature change may cool the combined air to below its dew point, which results in cloud formation.

Lifting

The forced upward movement of air commonly results in the cooling of air and in cloud formation. Air can be forced upward when a moving mass of air meets sloping terrain, such as a mountain range. As the rising air expands and cools, clouds form. As **Figure 3** shows, entire mountaintops can be covered with clouds that formed in this way.

The large cloud formations associated with storm systems also form by lifting. These clouds form when a mass of cold, dense air enters an area and pushes a less dense mass of warmer air upward.

Advective Cooling

Another cooling process that is associated with cloud formation is advective cooling. **Advective cooling** is the process by which the temperature of an air mass decreases as the air mass moves over a cold surface, such as a cold ocean or land surface. As air moves over a surface that is colder than the air is, the cold surface absorbs heat from the air and the air cools. If the air cools to below its dew point, clouds form.

advective cooling the process by which the temperature of an air mass decreases as the air mass moves over a cold surface

stratus cloud a gray cloud that has a flat, uniform base and that commonly forms at very low altitudes

Classification of Clouds

Clouds are classified by their shape and their altitude. The three basic cloud forms are stratus clouds, cumulus clouds, and cirrus clouds. There are also three altitude groups: low clouds (0 to 2,000 m), middle clouds (2,000 to 6,000 m), and high clouds (above 6,000 m). This classification system is shown in **Figure 4.**

Stratus Clouds

Clouds that have a flat, uniform base and that begin to form at very low altitudes are called **stratus clouds.** *Stratus* means "sheet-like" or "layered." The base of stratus clouds is low and may almost touch Earth's surface. Stratus clouds form where a layer of warm, moist air lies above a layer of cool air. When the overlying warm air cools below its dew point, wide clouds appear. Stratus clouds cover large areas of sky and often block out the sun. Usually, very little precipitation falls from stratus clouds.

Two variations of stratus clouds are known as *nimbostratus* and *altostratus*. The prefix *nimbo-* and the suffix *-nimbus* mean "rain." Unlike other stratus clouds, the dark nimbostratus clouds can cause heavy precipitation. Altostratus clouds form at the middle altitudes. They are generally thinner than the low stratus clouds and usually produce very little precipitation.

Quick LAB 15 min

Cloud Formation

Procedure

1. Use a **bottle opener** to puncture one or two holes into the metal lid of a **glass jar.**
2. Pour **1 mL of hot water** into the jar.
3. Place an **ice cube** over the holes in the lid of the jar. Make sure the holes are completely covered.
4. Observe the changes that occur within the jar.

Analysis

1. Draw a diagram of the jar. Label the areas of the diagram where evaporation and condensation take place. Also, label areas where latent heat is released and absorbed.
2. Explain why latent heat was released and absorbed in the areas that you labeled on the diagram.

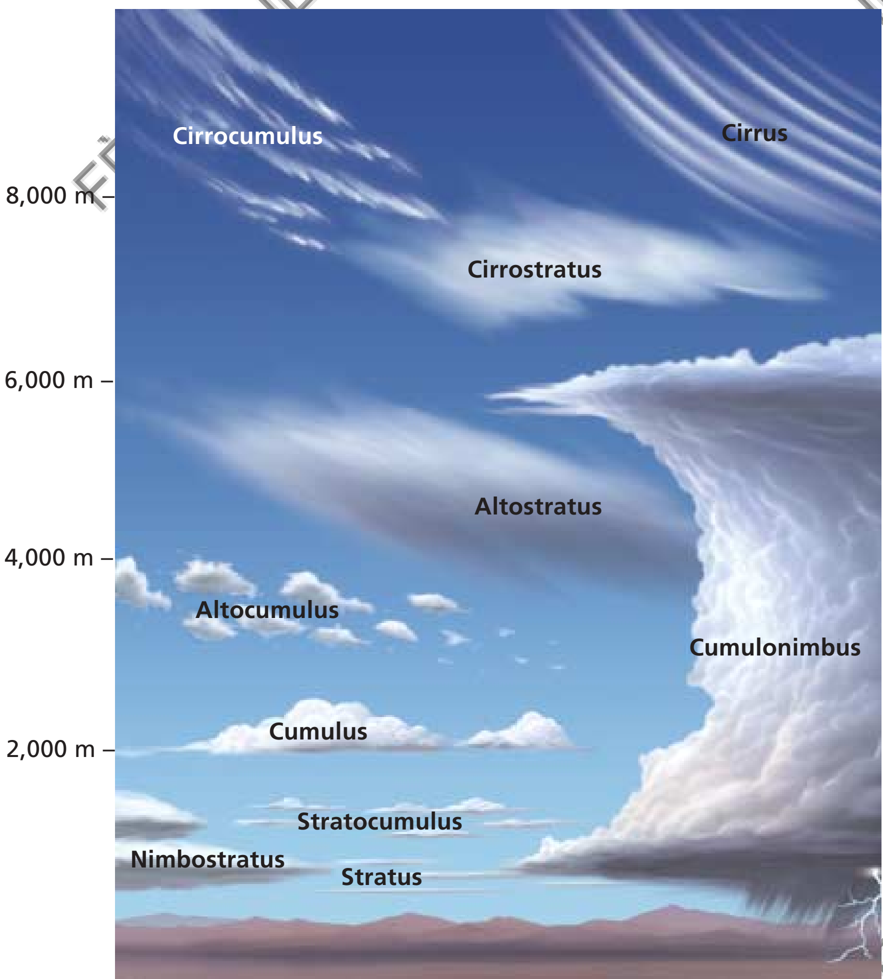


Figure 4 ▶ A variety of cloud types can be identified by their altitude and shape. ***What cloud types form at or above 6,000 m?***

Figure 5 ▶ Cumulus clouds (left) are puffy, vertically growing clouds, while cirrus clouds (right) are wispy.

Cumulus Clouds

Low-altitude, billowy clouds that commonly have a top that resembles cotton balls and a dark bottom are called **cumulus clouds.** *Cumulus* means "piled" or "heaped." Cumulus clouds usually look fluffy, as shown in **Figure 5.** These clouds form when warm, moist air rises and cools. As the cooling air reaches its dew point, the clouds form. The flat base that is characteristic of most cumulus clouds represents the condensation level.

The height of a cumulus cloud depends on the stability of the troposphere, which is the layer of the atmosphere that touches Earth's surface, and on the amount of moisture in the air. On hot, humid days, cumulus clouds reach their greatest heights. High, dark storm clouds known as *cumulonimbus clouds,* or thunderheads, are often accompanied by rain, lightning, and thunder. If the base of cumulus clouds begins at middle altitudes, the clouds are called *altocumulus clouds*. Low clouds that are a combination of stratus and cumulus clouds are called *stratocumulus clouds*.

cumulus cloud a low-level, billowy cloud that commonly has a top that resembles cotton balls and a dark bottom

cirrus cloud a feathery cloud that is composed of ice crystals and that has the highest altitude of any cloud in the sky

Cirrus Clouds

Feathery clouds that are composed of ice crystals and that have the highest altitude of any cloud in the sky are **cirrus clouds.** Cirrus clouds are also shown in **Figure 5.** *Cirro-* and *cirrus* mean "curly." Cirrus clouds form at altitudes above 6,000 m. These clouds are made of ice crystals because the temperatures are low at such high altitudes. Because these clouds are thin, light can easily pass through them.

Cirrocumulus clouds are rare, high-altitude, billowy clouds composed entirely of ice crystals. Cirrocumulus clouds commonly appear just before a snowfall or a rainfall. Long, thin clouds called *cirrostratus clouds* form a high, transparent veil across the sky. A halo may appear around the sun or moon when either is viewed through a cirrostratus cloud. This halo effect is caused by the bending of light rays as they pass through the ice crystals.

Reading Check **Why are cirrus clouds commonly composed of ice crystals? (See the Appendix for answers to Reading Checks.)**

Graphic Organizer **Comparison Table**

Create the Graphic Organizer entitled "Comparison Table" described in the Skills Handbook section of the Appendix. Label the columns with "Stratus clouds," "Cumulus clouds," and "Cirrus clouds." Label the rows with "Altitude" and "Shape." Then, fill in the table with details about the altitude and shape of each cloud.

Figure 6 ▶ Steam fog covers the Yakima River in Washington.

Fog

Like clouds, **fog** is the result of the condensation of water vapor in the air. The obvious difference between fog and clouds is that fog is very near the surface of Earth. However, fog also differs from clouds because of how fog forms.

Radiation Fog

One type of fog forms from the nightly cooling of Earth. The layer of air in contact with the ground becomes chilled to below the dew point, and the water vapor in that layer condenses into droplets. This type of fog is called *radiation fog* because it results from the loss of heat by radiation. Radiation fog is thickest in valleys and low places because dense, cold air sinks to low elevations. Radiation fog is often quite thick around cities, where smoke and dust particles act as condensation nuclei.

fog water vapor that has condensed very near the surface of Earth because air close to the ground has cooled

Other Types of Fog

Another type of fog, *advection fog,* forms when warm, moist air moves across a cold surface. Advection fog is common along coasts, where warm, moist air from above the water moves in over a cooler land surface. Advection fog forms over the ocean when warm, moist air is carried over cold ocean currents.

An *upslope fog* forms by the lifting and cooling of air as air rises along land slopes. *Steam fog* is a shallow layer of fog that forms when cool air moves over an inland warm body of water, such as a river, as shown in **Figure 6.**

Section 2 Review

1. **Describe** the conditions that are necessary for clouds to form.
2. **Explain** the four processes of cooling that can lead to cloud formation.
3. **Identify** the cloud types that form at 8,000 m.
4. **Compare** cirrus, cumulus, and stratus clouds.
5. **Identify** the type of cloud that is known for causing thunderstorms.
6. **Compare** clouds with fog.
7. **Describe** four ways in which fog can form.

CRITICAL THINKING

8. **Applying Ideas** Explain why air expands when it rises.
9. **Making Predictions** How might an increase in pollution affect cloud formation?
10. **Making Comparisons** Which type of cloud has the lowest condensation level? Which type has the highest condensation level?

CONCEPT MAPPING

11. Use the following terms to create a concept map: *cloud, cirrus, condensation level, advective cooling, adiabatic cooling, stratus, cumulus,* and *fog.*

ENVIRONMENTAL CONNECTION

Section 3 Precipitation

Any moisture that falls from the air to Earth's surface is called **precipitation**. The four major types of precipitation are rain, snow, sleet, and hail.

OBJECTIVES

- **Identify** the four forms of precipitation.
- **Compare** the two processes that cause precipitation.
- **Describe** two ways that precipitation is measured.
- **Explain** how rain can be produced artificially.

KEY TERMS

precipitation
coalescence
supercooling
cloud seeding

Forms of Precipitation

Rain is liquid precipitation. Normal raindrops are between 0.5 and 5 mm in diameter. They may vary from a fine mist to large drops in a torrential rainstorm. If the raindrops are smaller than 0.5 mm in diameter, the rain is called *drizzle*. Drizzle results in only a small amount of total precipitation.

The most common form of solid precipitation is *snow,* which consists of ice particles. These particles may fall as small pellets, as individual crystals, or as crystals that combine to form snowflakes. Snowflakes tend to be large at temperatures near 0°C and become smaller at lower temperatures.

When rain falls through a layer of freezing air near the ground, clear ice pellets, called *sleet,* can form. In some cases, the rain does not freeze until it strikes a surface near the ground. There, it forms a thick layer of ice called *glaze ice,* as shown in **Figure 1**. The condition in which glaze ice is produced is commonly referred to as an *ice storm.*

Hail is solid precipitation in the form of lumps of ice. The lumps can be either spherical or irregularly shaped. Hail usually forms in cumulonimbus clouds. Convection currents within the clouds carry raindrops to high levels, where the drops freeze before they fall. If the frozen raindrops are carried upward again, they can accumulate additional layers of ice until they are too heavy for the convection currents to carry them. They then fall to the ground. Large hailstones can damage crops and property.

precipitation any form of water that falls to Earth's surface from the clouds; includes rain, snow, sleet, and hail

Figure 1 ▶ Glaze ice forms as rain freezes on surfaces near the ground, such as on these flowers.

Figure 2 ▶ During coalescence, as cloud droplets fall, they collide and combine with small droplets. The resulting larger droplets fall as rain.

Causes of Precipitation

Most cloud droplets have a diameter of about 20 micrometers, which is smaller than the period at the end of this sentence. Droplets of this size fall very slowly through the air. A droplet must increase in diameter by about 100 times to fall as precipitation. Two natural processes cause cloud droplets to grow large enough to fall as precipitation: coalescence and supercooling.

Coalescence

The formation of a large droplet by the combination of smaller droplets is called **coalescence** (KOH uh LES uhnts) and is shown in **Figure 2.** Large droplets fall much faster through the air than small ones do. As these larger droplets drift downward, they collide and combine with smaller droplets. Each large droplet continues to coalesce until it contains a million times as much water as it did originally.

Supercooling

Precipitation also forms by the process of supercooling. **Supercooling** is a condition in which a substance is cooled to below its freezing point, condensation point, or sublimation point without changing state. Supercooled water droplets may have a temperature as low as –50°C. Yet even at this low temperature, the water droplets do not freeze. They cannot freeze because too few *freezing nuclei* on which ice can form are available. Freezing nuclei are solid particles that are suspended in the air and that have structures similar to the crystal structure of ice. Most water from the supercooled water droplets evaporates. The water vapor then condenses on the ice crystals that have formed on the freezing nuclei. The ice crystals rapidly increase in size until they gain enough mass to fall as snow, as shown in **Figure 3.** If ice crystals melt and turn into rain as they pass through air whose temperature is above freezing, they form the big raindrops that are common in summer thunderstorms.

coalescence the formation of a large droplet by the combination of smaller droplets

supercooling a condition in which a substance is cooled below its freezing point, condensation point, or sublimation point without going through a change of state

Figure 3 ▶ Most of the rain and snow in the middle and high latitudes of Earth are the result of the formation of ice crystals in supercooled clouds.

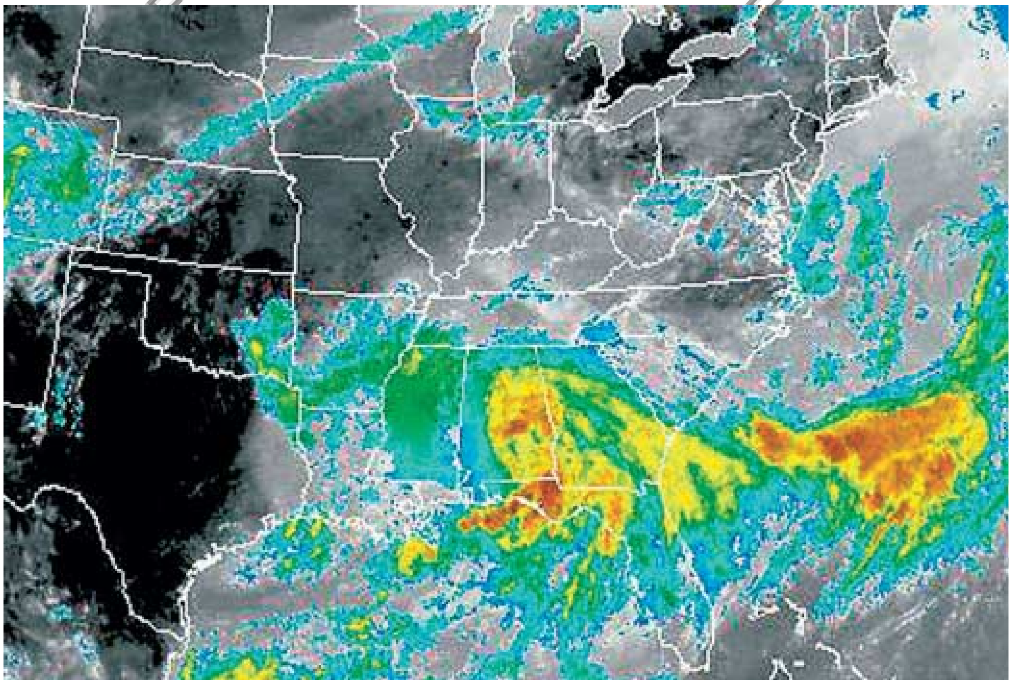


Figure 4 ▶ Doppler radar helps meteorologists track storms, such as Tropical Storm Barry over the southeastern United States. The colors represent the intensity of rainfall. Reds and yellows indicate areas of heaviest rainfall, while blues and greens denote areas of lighter rainfall.

Measuring Precipitation

Meteorologists use a variety of instruments to measure precipitation. For example, a *rain gauge* may be used to measure rainfall.

Amount of Precipitation

In one type of rain gauge, rainwater passes through a funnel into a calibrated container, where the amount of rainfall can then be measured. In another type of rain gauge, rain caught in a funnel fills a bucket. Each time the bucket fills with a given amount of rainwater, the bucket tips and sets off an electrical device that records the amount. As the bucket tips, it activates a switch that releases the water from the bucket.

Snow depth is simply determined with a measuring stick. The water content of the snow is determined by melting a measured volume of snow and by measuring the amount of water that results. On average, 10 cm of snow will melt to produce about 1 cm of water.

Doppler Radar

The intensity of precipitation can be measured using Doppler radar. Doppler radar images, such as the one in **Figure 4,** are commonly used by meteorologists for communicating weather forecasts. Doppler radar works by bouncing radio waves off rain or snow. By timing how long the wave takes to return, meteorologists can detect the location, direction of movement, and intensity of precipitation. This information is very valuable in saving lives because people can be warned of an approaching storm.

Reading Check **What aspects of precipitation can Doppler radar measure? (See the Appendix for answers to Reading Checks.)**

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: Precipitation
SciLinks code: HQ61202

Figure 5 ▶ Special equipment attached to the wings of cloud-seeding planes releases freezing nuclei into clouds. Meteorologists hope that cloud seeding will induce rain to fall on drought-stricken areas.

Weather Modification

In areas suffering from drought, scientists may attempt to induce precipitation through cloud seeding, as shown in **Figure 5**. **Cloud seeding** is the process of introducing freezing nuclei or condensation nuclei into a cloud to cause rain to fall.

cloud seeding the process of introducing freezing nuclei or condensation nuclei into a cloud in order to cause rain to fall

Methods of Cloud Seeding

One method of cloud seeding uses silver iodide crystals, which resemble ice crystals, as freezing nuclei. The silver iodide is released from burners on the ground or from flares dropped from aircraft. Another method of cloud seeding uses powdered dry ice, which is dropped from aircraft to cool cloud droplets and to cause ice crystals to form. As the ice crystals fall, they may melt to form raindrops.

Improving Cloud Seeding

In some cases, seeded clouds produce more precipitation than unseeded clouds do. In other experiments, cloud seeding does not cause a significant increase in precipitation. In some instances, cloud seeding appears to cause less precipitation. Thus, meteorologists have concluded that cloud seeding may increase precipitation under some conditions but decrease it under others. Research is underway to identify the conditions that cause increased precipitation. Eventually, cloud seeding may become a way to overcome many drought-related problems. Cloud seeding could also help control severe storms by releasing precipitation from clouds before a storm can become too large.

Section 3 Review

1. **Identify** four forms of precipitation.
2. **Compare** coalescence and supercooling.
3. **Identify** the instrument that measures amounts of rainfall.
4. **Describe** how the amount of snowfall can be measured.
5. **Explain** how Doppler radar can be used to measure the intensity of precipitation.
6. **Describe** how precipitation can be induced or increased artificially.

CRITICAL THINKING

7. **Predicting Consequences** If water could not remain liquid during supercooling, how would the potential for precipitation in colder climates be affected?
8. **Making Inferences** Explain how cloud seeding could be dangerous if it is not done properly.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *precipitation, rain, snow, glaze ice, hail, coalescence, supercooling, freezing nucleus, sleet,* and *drizzle.*

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Chapter 23 Highlights

Sections

1 Atmospheric Moisture

Key Terms

latent heat, 575
sublimation, 576
dew point, 577
absolute humidity, 577
relative humidity, 578

Key Concepts

- Latent heat is released or absorbed when water changes from one state to another.
- Relative humidity is a ratio of the actual amount of water vapor in the air to the amount of water vapor needed to reach saturation.
- When air reaches the dew point, the rate of condensation equals the rate of evaporation. Below the dew point, net condensation causes dew to form.

2 Clouds and Fog

cloud, 581
condensation nucleus, 581
adiabatic cooling, 582
advective cooling, 583
stratus cloud, 584
cumulus cloud, 585
cirrus cloud, 585
fog, 586

- Clouds form when water vapor cools and condenses on condensation nuclei.
- Water vapor can cool and condense by adiabatic cooling, by the mixing of two bodies of moist air that have different temperatures, by lifting of air, and by advective cooling.
- The three major forms of clouds are stratus clouds, cumulus clouds, and cirrus clouds.
- The four types of fog are radiation fog, advection fog, upslope fog, and steam fog.

3 Precipitation

precipitation, 587
coalescence, 588
supercooling, 588
cloud seeding, 590

- The major forms of precipitation are rain, snow, sleet, and hail.
- Coalescence and supercooling are two processes by which cloud droplets become large enough to fall as precipitation.
- A rain gauge is used to measure liquid precipitation. Snow is measured by its depth and water content.
- Cloud seeding is one way in which meteorologists try to induce precipitation.

Chapter 23 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *latent heat*
2. *condensation nucleus*
3. *precipitation*

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

4. *coalescence* and *supercooling*
5. *stratus cloud* and *cumulus cloud*
6. *adiabatic cooling* and *advective cooling*
7. *relative humidity* and *absolute humidity*
8. *cloud* and *fog*

Understanding Key Concepts

9. When the temperature of the air decreases, the rate of evaporation
   a. increases. **c.** stays the same.
   b. varies. **d.** decreases.

10. The type of fog that results when moist air moves across a cold surface is
   a. radiation fog. **c.** advection fog.
   b. ground fog. **d.** steam fog.

11. Changes in temperature that result from the cooling of rising air or the warming of sinking air are
   a. adiabatic. **c.** advective.
   b. relative. **d.** latent.

12. Clouds form when the water vapor in air condenses as
   a. the air is heated.
   b. the air is cooled.
   c. snow falls.
   d. the air is superheated.

13. The prefix *nimbo-* and suffix *-nimbus* mean
   a. high. **c.** rain.
   b. billowy. **d.** layered.

14. The fog that results from the nightly cooling of Earth is called
   a. steam fog. **c.** radiation fog.
   b. upslope fog. **d.** advection fog.

15. Rain that freezes when it strikes a surface produces
   a. sleet. **c.** hail.
   b. glaze ice. **d.** frost.

16. Clouds in which the water droplets remain liquid below 0°C are said to be
   a. saturated. **c.** superheated.
   b. supersaturated. **d.** supercooled.

17. In one method of cloud seeding, silver iodide crystals are used as
   a. freezing nuclei. **c.** dry ice.
   b. cloud droplets. **d.** latent heat.

18. An instrument that uses the electrical conductance of the chemical lithium chloride to measure relative humidity is the
   a. hygrometer. **c.** psychrometer.
   b. rain gauge. **d.** dew cell.

Short Answer

19. Explain how the transfer of energy affects the changing forms of water.
20. Explain how a psychrometer measures humidity.
21. Describe how frost forms.
22. Describe how precipitation is measured.
23. Describe how cloud seeding may increase precipitation.
24. Explain how clouds are classified.

Critical Thinking

25. Making Inferences Where would air contain more water vapor—over Panama or over Antarctica? Explain your answer.

26. Identifying Relationships One body of air has a relative humidity of 97%. Another has a relative humidity of 44%. At the same temperature, which body of air is closer to its dew point? Explain your answer.

27. Applying Ideas Why would polluted air be more likely to form fog than clean air would?

28. Analyzing Relationships In tropical regions, surface temperatures are very high. However, some precipitation in these regions forms by supercooling. Why might this be true?

29. Predicting Consequences How would a significant decrease in condensation nuclei in the world's atmosphere affect cloud formation and climate?

Concept Mapping

30. Use the following terms to create a concept map: *hygrometer, condensation nucleus, stratus, cirrus, cloud, cumulus, precipitation, relative humidity, saturated, rain, supercooling, snow, sleet, coalescence, dew cell,* and *psychrometer.*

Math Skills

31. Applying Quantities One day in January, 6 cm of snow falls on your area. If all of this snow melts quickly, how deep will the water from the melted snow be? Explain your answer.

32. Making Calculations At 15°C, air reaches saturation when it contains 10 g of water vapor per 1 kg of air. What is the relative humidity of air at 15°C that contains 7 g of water vapor per 1 kg of air?

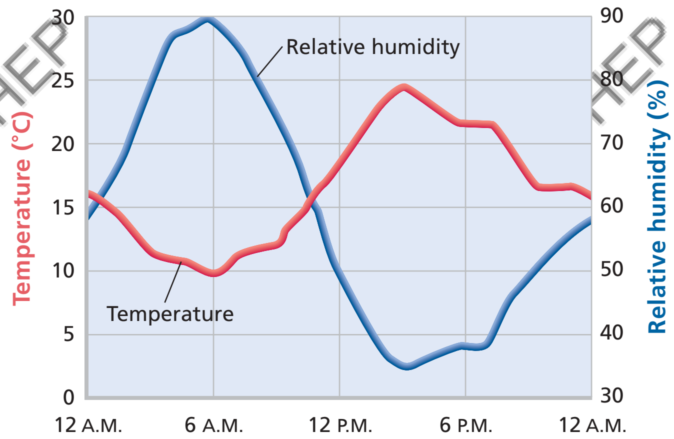
Writing Skills

33. Writing from Research Write a report that describes weather conditions necessary to form each type of cloud. Propose regions and describe climates where each cloud type is most likely to be found.

34. Outlining Topics Create an outline of how clouds form and a separate outline of how precipitation forms. Then, explain how the two differ.

Interpreting Graphics

The graph below shows variations of temperature and humidity in a 24 h period. Use this graph to answer the questions that follow.



35. Estimate the relative humidity at 6:00 A.M.

36. Estimate the temperature at 6:00 A.M.

37. Explain why relative humidity might be highest at 6:00 A.M.

38. When is relative humidity lowest?

39. How does humidity vary relative to temperature?

Chapter 23 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 What type of fog is formed when cool air moves across a warm river or lake?
A. radiation fog
B. advection fog
C. upslope fog
D. steam fog

2 Which of the following processes produces most of the water vapor in the atmosphere?
F. sublimation
G. evaporation
H. advective cooling
I. convective cooling

3 Which of the following is the main source of moisture in Earth's atmosphere?
A. lakes
B. rivers
C. polar icecaps
D. oceans

4 What is relative humidity?
F. a ratio comparing the mass of water vapor in the air at two different locations
G. a ratio comparing the mass of water vapor in the air at two times during the day and in the same location
H. a ratio comparing the actual amount of water vapor in the air with the capacity of the air to hold moisture at a given temperature
I. a ratio comparing the mass of water vapor that air can hold at two different altitudes at noon and at midnight

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

5 What instrument is used to measure atmospheric pressure?

6 Particles called condensation nuclei, which are suspended in the atmosphere, are necessary in allowing what process to take place?

7 Water vapor will turn into what when the dew point falls below the freezing point of water?

Reading Skills

***Directions (8–9):* Read the passage below. Then, answer the questions.**

Acid Precipitation

Thousands of lakes thoughout the world are affected by acid precipitation, often known simply as acid rain. Acid precipitation is precipitation, such as rain, sleet, or snow, that contains high concentrations of acids. When fossil fuels are burned, they release oxides of sulfur and nitrogen. When the oxides combine with water in the atmosphere, they form sulfuric acid and nitric acid, which fall as precipitation. This acidic water flows over and through the ground, and then flows into lakes, rivers, and streams. Acid precipitation can kill living things and can result in the decline or loss of some local animal and plant populations.

A pH (power of hydrogen) number is a measure of how acidic or basic a substance is. The lower the number on the pH scale is, the more acidic a substance is; the highter a pH number is, the more basic a substance is. Each whole number on the pH scale indicates a tenfold change in acidity.

8 According to the passage, which of the following statements is true?
A. Acid precipitation always falls as rain.
B. Acid precipitation seeps into local water supplies and may pose a danger to living things in the area.
C. Sulfur and nitrogen mix with oxygen in the atmosphere and become acids.
D. The amount of acidic precipitation is balanced in nature by an equal amount of basic precipitation.

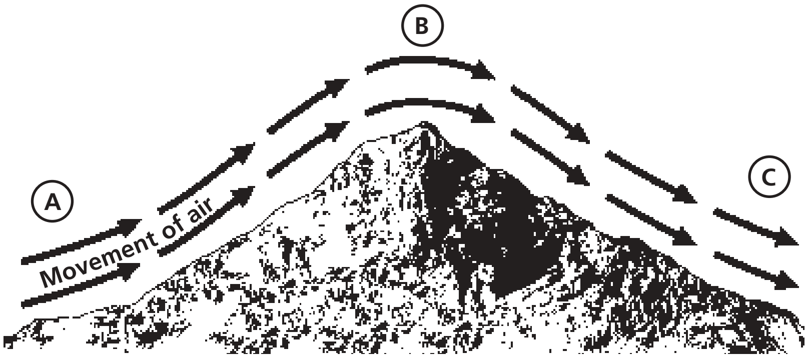
9 Which of the following statements can be inferred from the information in the passage?
F. A reduction in the usage of fossil fuels may help alleviate the problem of acid rain.
G. Local animal and plant species will most likely adapt to acid rain.
H. The acid in precipitation is effectively neutralized once it is in a lake or stream.
I. The amount of acid in a substance can be measured by using a 10-point scale.

Interpreting Graphics

***Directions (10–14):* For *each* question below, record the correct answer on a separate sheet of paper.**

The diagram below shows shows the direction of air movement over a mountain. Use this diagram to answer questions 10 through 12.

Movement of Air Over a Mountain



10 As air moves from point A to point B, the air temperature

A. increases
B. decreases
C. stays the same
D. impossible to predict

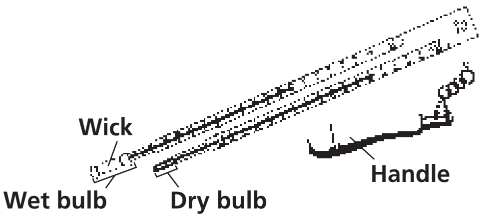
11 Air moving from point B to point C will become compressed and gain energy as it moves down the mountain, which will cause the air to undergo

F. adiabatic warming
G. adiabatic cooling
H. condensation
I. sublimation

12 If moist air moves up the mountain from point A, what process is likely to occur when the moist air moves near point B?

The diagram below shows the parts of a psychrometer. Use this diagram to answer questions 13 and 14.

Parts of a Psychrometer



13 How does a meteorologist use a psychrometer, such as the one shown in the diagram above?

A. It is placed in a pan of water and exposed to the air for one hour.
B. The handle is used to dip it into a body of water such as a lake.
C. It is held by the handle and twirled in the air.
D. It is held until the readings on both thermometers are equal.

14 Why is it necessary to obtain two readings? What measurements of atmospheric moisture can be determined from these readings?

Test TIP

If you are not sure of an answer, go to the next question, but remember to skip that number on your answer sheet.

Skills Practice Lab

Objectives

- **Measure** humidity in the classroom.
- **Calculate** relative humidity.

Materials

- cloth, cotton, at least 8 cm × 8 cm
- container, plastic
- piece of paper
- ring stand with ring
- rubber band
- string
- thermometer, Celsius (2)
- water

Safety

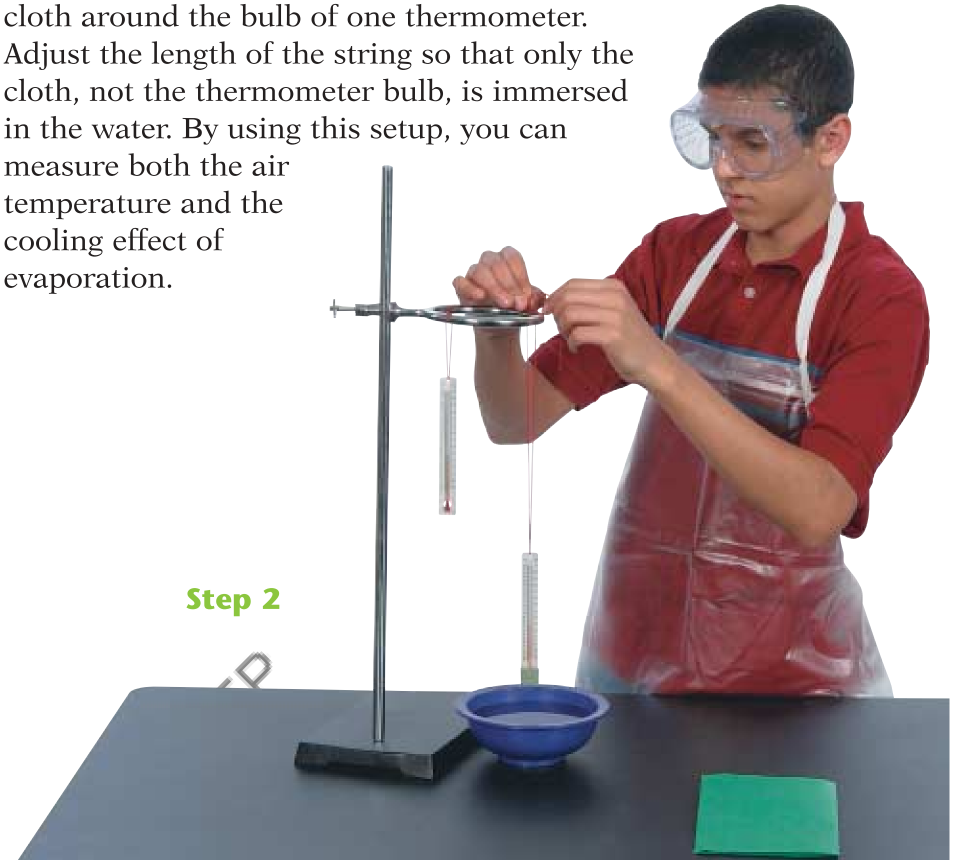
Relative Humidity

Earth's atmosphere acts as a reservoir for water that evaporates from Earth's surface. However, the amount of water vapor in the atmosphere depends on the relative rates of condensation and evaporation. When the rates of condensation and evaporation are equal, the air is said to be "saturated." However, when the rate of condensation exceeds the rate of evaporation, water droplets begin to form in the air or on nearby surfaces. The point at which the condensation rate equals the evaporation rate is called the *dew point* and depends on the temperature of the air and on the atmospheric pressure.

Relative humidity is the ratio of the amount of water vapor in the air to the amount of water vapor that is needed for the air to become saturated. This ratio is most commonly expressed as a percentage. When the air is saturated, the air is said to have a relative humidity of 100%. In this lab, you will use wet-bulb and dry-bulb thermometer readings to determine the relative humidity of the air in your classroom.

PROCEDURE

1. Hang two thermometers from a ring stand, as shown in the illustration below.
2. Using a rubber band, fasten a piece of cotton cloth around the bulb of one thermometer. Adjust the length of the string so that only the cloth, not the thermometer bulb, is immersed in the water. By using this setup, you can measure both the air temperature and the cooling effect of evaporation.



Step 2

3. Predict whether the two thermometers will have the same reading or which thermometer will have the lower reading.

4. Using a piece of paper, fan both thermometers rapidly until the reading on the wet-bulb thermometer stops changing. Read the temperature on each thermometer.
   a. What is the temperature on the dry-bulb thermometer?
   b. What is the temperature on the wet-bulb thermometer?
   c. What is the difference in the two temperature readings?

5. Use the table entitled “Relative Humidity” in the Reference Tables section of the Appendix to find the relative humidity based on your temperature readings in **Step 4.** Look at the left-hand column labeled “Dry-Bulb Temperature.” First, find the temperature that you recorded in **Step 4a.** Follow along to the right in the table until you come to the number that is directly below the column entitled “Difference in Temperature” (top row of the table) and that you recorded in **Step 4c.** This number, expressed as a percentage, is the relative humidity. What is the relative humidity of the air in your classroom?

Step 4

ANALYSIS AND CONCLUSION

1. **Drawing Conclusions** On the basis of the relative humidity you calculated, is the air in your classroom close to or far from the dew point? Explain your answer.

2. **Applying Conclusions** If you wet the back of your hand, would the water evaporate and cool your skin?

Extension

1. **Making Inferences** Suppose that you exercise in a room in which the relative humidity is 100%.
   a. Would the moisture on your skin from perspiration evaporate easily?
   b. Would you be able to cool off readily? Explain your answer.

2. **Applying Ideas** Suppose that you have just stepped out of a swimming pool. The relative humidity is low, about 30%. Would you feel warm or cool? Explain your answer.

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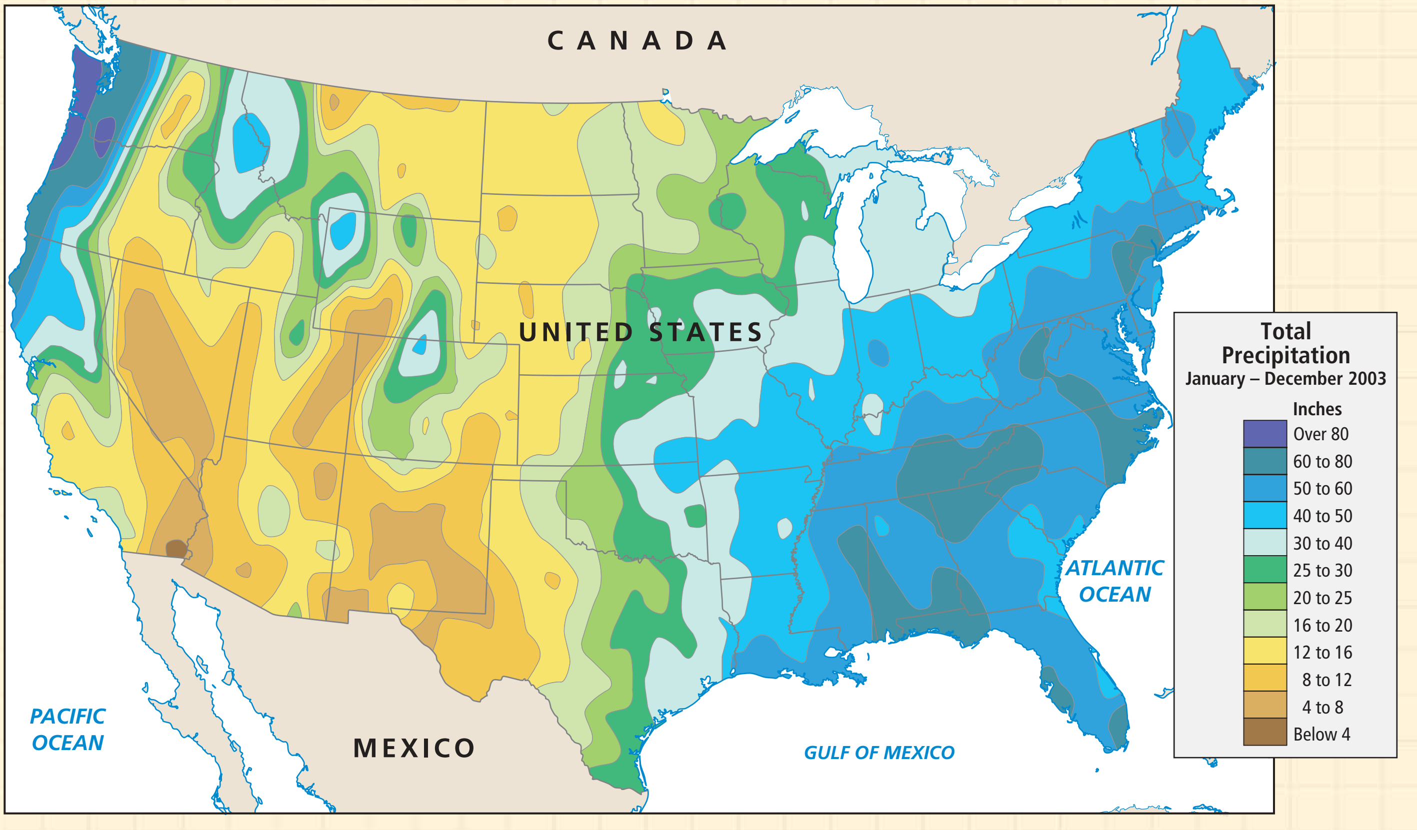
MAPS in Action

Annual Precipitation in the United States



Map Skills Activity

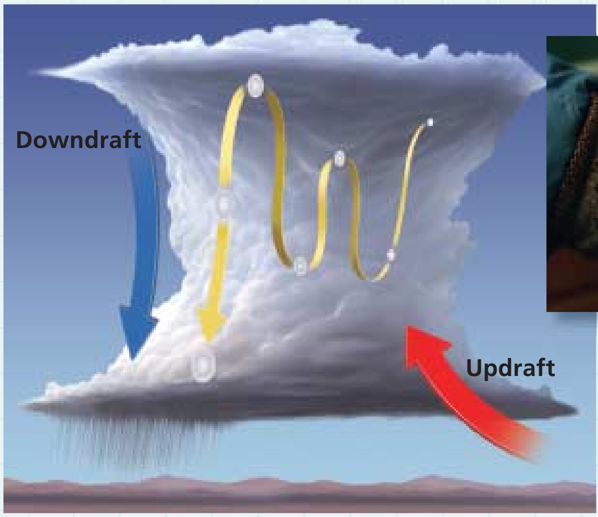
This map shows the total precipitation for the continental United States for the year 2003. Use the map to answer the questions below.

1. **Using a Key** What is the highest total amount of precipitation for any area in your state?
2. **Making Comparisons** Which area of the United States has the highest total annual precipitation?
3. **Analyzing Methods** Using what you have learned about the formation of precipitation, explain why one area of the United States might have a higher total annual precipitation than another area has.
4. **Making Inferences** List the forms of precipitation that occur in the United States. Identify areas of the United States where you would likely encounter each form.
5. **Evaluating Data** Describe the location in the United States that might be classified as desert.
6. **Making Comparisons** Describe the location in the United States that might have the highest rate of evaporation.
7. **Making Comparisons** Describe the location in the United States that you think might have the highest relative humidity.

Hail

Hail is precipitation in the form of a lump of ice that starts as a raindrop falling from clouds. Updraft convection currents carry the raindrop back into freezing cloud regions, where layer after layer of supercooled water is added to the frozen drops. The added water also freezes and increases the sizes of the hailstones. Some hailstones have grown from this process to the size of grapefruits. The largest hailstone ever recorded had a circumference of more than 47 cm.

Hailstones often consist of alternating layers of clear ice and cloudy ice. The clear ice forms as a hailstone passes through a layer of very moist air. The cloudy layer forms when water droplets freeze to the surface of the hailstone and trap air bubbles between them.



▲ Hailstones commonly consist of alternating layers of clear ice and cloudy ice.

Hail's Destructive Power

A hailstorm that lasts only a few minutes can cause tremendous damage. For example, hail has been responsible for some airplane crashes. It has torn holes in the roofs of houses and automobiles and in the cabins of aircraft. Hail has killed people, livestock, and wildlife, and it has stripped plants of their leaves.

In July 1984, a hailstorm in Germany caused $1 billion worth of damage to crops, trees, buildings, and vehicles. Trees were stripped of their bark. Crops were destroyed, and 400 people were injured.

The Cost of Hail

Hail destroys more than $200 million worth of wheat, corn, soybeans, and other crops in the United States each year. Hailstorms can have a devastating effect on individual farmers. Unlike drought, hail does not cause gradual damage. Instead, a family's entire crop, which may represent work over an entire year, can be wiped out within minutes.

◀ A strawberry farmer in Atwater, California, investigates damage to his crop. Seventy-five to eighty percent of his crop was destroyed by a hailstorm.

Extension

1. **Analyzing Processes** If you cut a hailstone in half, you would see layering. Explain why.

Chapter 24 Weather

Sections
1 Air Masses
2 Fronts
3 Weather Instruments
4 Forecasting the Weather

What You'll Learn
- How air masses affect weather
- How fronts lead to severe weather
- How scientists forecast weather

Why It's Relevant
Weather affects many different aspects of our lives every day. Studying the weather helps scientists make forecasts and warn people of dangerous weather.

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.

▶ During a thunderstorm, clouds may discharge a spark of electricity called lightning. This bolt of lightning struck near Sugar Loaf Mountain in Rio De Janeiro, Brazil.

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Section 1 Air Masses

Differences in air pressure are caused by unequal heating of Earth's surface. The region along the equator receives more solar energy than the regions at the poles do. The heated equatorial air rises and creates a low-pressure belt. Conversely, cold air near the poles sinks and creates high-pressure centers. Differences in air pressure at different locations on Earth create wind patterns.

OBJECTIVES

- **Explain** how an air mass forms.
- **List** the four main types of air masses.
- **Describe** how air masses affect the weather of North America.

KEY TERM

air mass

How Air Moves

Air moves from areas of high pressure to areas of low pressure. Therefore, there is a general, worldwide movement of surface air from the poles toward the equator. At high altitudes, the warmed air flows from the equator toward the poles. Temperature and pressure differences on Earth's surface create three wind belts in the Northern Hemisphere and three wind belts in the Southern Hemisphere. The *Coriolis effect,* which occurs when winds are deflected by Earth's rotation, also influences wind patterns. The processes that affect air movement also influence storms, such as the one shown in **Figure 1.**

air mass a large body of air throughout which temperature and moisture content are similar

Formation of Air Masses

When air pressure differences are small, air remains relatively stationary. If the air remains stationary or moves slowly over a uniform region, the air takes on the characteristic temperature and humidity of that region. A large body of air throughout which temperature and moisture are similar is called an **air mass.** Air masses that form over frozen polar regions are very cold and dry. Air masses that form over tropical oceans are warm and moist.

Figure 1 ▶ The motion of Earth's atmosphere can lead to the formation of powerful storms such as Hurricane Florence, which was photographed by astronauts on the shuttle *Atlantis* over the Atlantic Ocean in 1994.

Table 1 ▼

Air Masses		
Source region	**Type of air**	**Symbol**
Continental	dry	c
Maritime	moist	m
Tropical	warm	T
Polar	cold	P

Types of Air Masses

Air masses are classified according to their source regions. The source regions also determine the temperature and the humidity of the air mass. The source regions for cold air masses are polar areas. The source regions for warm air masses are tropical areas. Air masses that form over the ocean are called *maritime*. Air masses that form over land are called *continental*. Maritime air masses are moist, and continental air masses are dry. Air masses and the symbols used to designate them are listed in **Table 1.** The combination of tropical or polar air and continental or maritime air results in air masses that have distinct characteristics.

Continental Air Masses

Continental air masses form over large landmasses, such as northern Canada, northern Asia, or the southwestern United States. Because these air masses form over land, the level of humidity is very low. An air mass may remain over its source region for days or weeks. However, the air mass will eventually move into other regions because of global wind patterns. In general, continental air masses bring dry weather conditions when they move into another region. There are two types of continental air masses: *continental polar* (cP) and *continental tropical* (cT). Continental polar air masses are cold and dry. Continental tropical air masses are warm and dry.

Maritime Air Masses

Maritime air masses form over oceans or other large bodies of water. These air masses take on the characteristics of the water over which they form. The humidity in these air masses tends to be higher than that of the continental air masses. When these very moist masses of air travel to a new location, they commonly bring more precipitation and fog, as shown in **Figure 2.**

The two different maritime air masses are *maritime polar* (mP) and *maritime tropical* (mT). Maritime polar air masses are moist and cold. Maritime tropical air masses are moist and warm.

Figure 2 ▶ A maritime air mass brings fog that rolls in off the coast of California.

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North American Air Masses

The four types of air masses that affect the weather of North America come from six regions. These air masses, their source locations, their movements, and the weather they bring are summarized in **Table 2.** The general directions of the air masses' movements are shown in **Figure 3.** An air mass usually brings the weather of its source region, but an air mass may change as it moves away from its source region. For example, cold, dry air may become warmer and more moist as it moves from land to the warm ocean. As the lower layers of air are warmed, the air rises. This warmed air may then create clouds and precipitation.

Table 2 ▼

Air Masses of North America

Air mass	Source location	Movement	Weather
cP	polar regions in Canada	south-southeast	cold and dry
mP	polar Pacific; polar Atlantic	southeast; southwest-south	cold and moist
cT	U.S. southwest	north-northeast	warm and dry
mT	tropical Pacific; tropical Atlantic	northeast; north-northwest	warm and moist

Tropical Air Masses

Continental tropical air masses form over the deserts of the southwestern United States. These air masses bring dry, hot weather in the summer. They do not form in the winter. Maritime tropical air masses form over the warm water of the tropical Atlantic Ocean. They bring mild, often cloudy weather to the eastern United States in the winter. In the summer, they bring hot, humid weather and thunderstorms. Maritime tropical air masses also form over warm areas of the Pacific Ocean. But these air masses do not usually reach the Pacific coast. In the winter, maritime tropical air masses bring moderate precipitation to the coast and the southwestern deserts.

Reading Check **Which air mass brings dry, hot weather in the summer? (See the Appendix for answers to Reading Checks.)**

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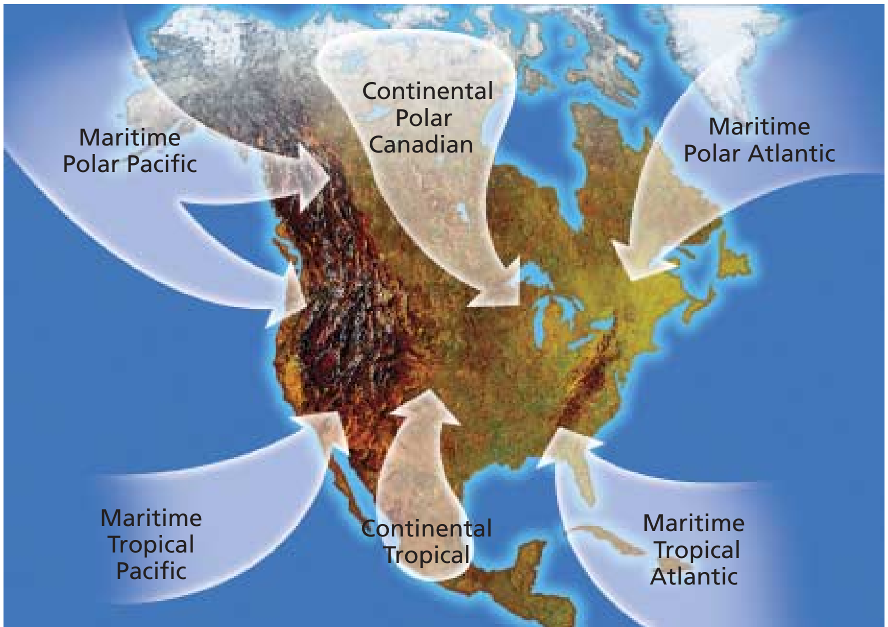

Figure 3 ▶ The four types of air masses that influence the weather in North America come from six regions and are named according to their source regions.

Figure 4 ▶ Maritime polar Atlantic air masses can bring heavy snowfall, such as in this snowstorm that hit New York City in 2003.

Polar Air Masses

Polar air masses from three regions—northern Canada and the northern Pacific and Atlantic Oceans—influence weather in North America. Continental polar air masses form over ice- and snow-covered land. These air masses move into the northern United States and can occasionally reach as far south as the Gulf Coast of the United States. In summer, the air masses usually bring cool, dry weather. In winter, they bring very cold weather to the northern United States.

Maritime polar air masses form over the North Pacific Ocean and are very moist, but they are not as cold as continental polar Canadian air masses. In winter, these maritime polar Pacific air masses bring rain and snow to the Pacific Coast. In summer, they bring cool, often foggy weather. As they move inland and eastward over the Cascades, the Sierra Nevada, and the Rocky Mountains, these cold air masses lose much of their moisture and warm slightly. Thus, they may bring cool and dry weather by the time they reach the central United States.

Maritime polar Atlantic air masses move generally eastward toward Europe. But they sometimes move westward over New England and eastern Canada. In winter, they can bring cold, cloudy weather and snow, as shown in **Figure 4.** In summer, these air masses can produce cool weather, low clouds, and fog.

Section 1 Review

1. **Define** *air mass.*
2. **Explain** how an air mass forms.
3. **Identify** the location where a cold, dry air mass would form.
4. **List** the four main types of air masses.
5. **Describe** how the four main types of air masses affect the weather of North America.
6. **Describe** the air mass that forms over the warm waters of the Atlantic Ocean. What letters designate the source region of this air mass?

CRITICAL THINKING

7. **Making Predictions** How would temperature and humidity at a given location change when a maritime tropical air mass is replaced by a continental polar air mass?
8. **Recognizing Relationships** In which direction would you expect a tropical air mass near the coast of Europe to travel? Explain your answer.

CONCEPT MAPPING

9. Use the following terms to create a concept map: *maritime polar Pacific, maritime polar, continental polar Canadian, air mass, continental polar,* and *maritime polar Atlantic.*

Section 2 Fronts

When two unlike air masses meet, density differences usually keep the air masses separate. A cool air mass is dense and does not mix with the less-dense air of a warm air mass. Thus, a boundary, called a *front,* forms between air masses. A typical front is several hundred kilometers long. However, some fronts may be several thousand kilometers long. Changes in middle-latitude weather usually take place along the various types of fronts. Fronts do not exist in the Tropics because no air masses that have significant temperature differences exist there.

OBJECTIVES

- **Compare** the characteristic weather patterns of cold fronts with those of warm fronts.
- **Describe** how a midlatitude cyclone forms.
- **Describe** the development of hurricanes, thunderstorms, and tornadoes.

KEY TERMS

cold front
warm front
stationary front
occluded front
midlatitude cyclone
thunderstorm
hurricane
tornado

Types of Fronts

For a front to form, one air mass must collide with another air mass. The kind of front that forms is determined by how the air masses move in relationship to each other.

Cold Fronts

When a cold air mass overtakes a warm air mass, a **cold front** forms. The moving cold air lifts the warm air. If the warm air is moist, clouds will form. Large cumulus and cumulonimbus clouds typically form along fast-moving cold fronts. Storms that form along a cold front are usually short-lived and are sometimes violent. A long line of heavy thunderstorms, called a *squall line,* shown in **Figure 1,** may occur in the warm, moist air just ahead of a fast-moving cold front. A slow-moving cold front lifts the warm air ahead of it more slowly than a fast-moving front does. A slow-moving cold front typically produces weaker storms and lighter precipitation than a fast-moving cold front does.

cold front the front edge of a moving mass of cold air that pushes beneath a warmer air mass like a wedge

Figure 1 ▶ As a cold air mass overtakes a warm air mass, a line of thunderstorms called a *squall line* forms. The photo shows a squall line over the North Atlantic Ocean.