CK-12 Earth Science

Middle School

CK-12 Earth Science For Middle School

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Chapter 1 MS What is Earth Science?

Chapter Outline

Earth Science is all about the Earth: its land, its water, its atmosphere. It's about Earth's resources and about the impacts human activities are having on all of those things: the land, water, and atmosphere. Earth Science is even about the vastness that surrounds the planet: the solar system, galaxy, and universe. So can we say Earth Science is about everything? Well, not really, but it is a science that encompasses an awful lot.

Note the word science in that last sentence. Earth Science is a science, or maybe it's made up of a lot of sciences. But what is science? Most people think of science as a bunch of knowledge. And it is. But science is also a way of knowing things. It's different from other ways of knowing because it is based on a method that relies on observations and data. Science can't say how many angels can dance on the end of a pin because that question can't be tested. In fact, science can't even say if there are such things as angels for the same reason. For something to be science, it must be testable. And scientists are the people who do those tests.

1.1 The Nature of Science

Lesson Objectives

- Why is it important to ask questions?
- How can you use the steps of the scientific method to answer questions?
- How do scientists make models?
- What steps should you take to be safe while you are doing science?

Vocabulary

- control
- dependent variable
- hypothesis
- independent variable
- physical model
- theory

Introduction

Sometime in your life you've asked a question about the world around you. Probably you've asked a lot of questions over the years. The best way to answer questions about the natural world is by using science. Scientists ask questions every day, and then use a set of steps to answer those questions. The steps are known as the scientific method. By following the scientific method, scientists come up with the best information about the natural world. As a scientist, you need to do experiments to find out about the world. You also need to wonder, observe, talk, and think. Everything we learn helps us to ask new and better questions.

Scientific Method

The scientific method is a set of steps that help us to answer questions. When we use logical steps and control the number of things that can be changed, we get better answers. As we test our ideas, we may come up with more questions. The basic sequence of steps followed in the scientific method is illustrated in **Figure** 1.1.

Questions

Asking a question is one really good way to begin to learn about the natural world. You might have seen something that makes you curious. You might want to know what to change to produce a better result. Let's say a farmer is having an erosion problem. She wants to keep more soil on her farm. The farmer learns that a farming method

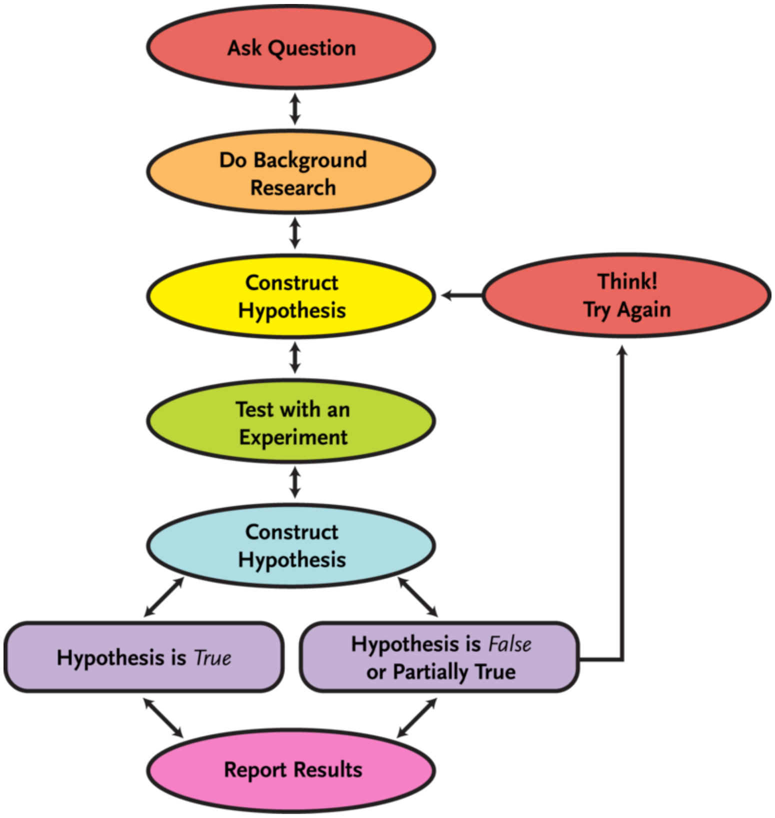

FIGURE 1.1
The Scientific Method.

called "no-till farming" allows farmers to plant seeds without plowing the land. She wonders if planting seeds without plowing will reduce the erosion problem and help keep more soil on her farmland. Her question is this: "Will using the no-till method of farming help me to lose less soil on my farm?" (**Figure** 1.2).

FIGURE 1.2
Soil is often lost from ground that has been plowed.

Research

Before she begins, the farmer needs to learn more about this farming method. She can look up information in books and magazines in the library. She may also search the Internet. A good way for her to learn is to talk to people who have tried this way of farming. She can use all of this information to figure out how she is going to test her question about no-till farming. Farming machines are shown in the **Figure** 1.3.

FIGURE 1.3
Rather than breaking up soil like in this picture, the farmer could try no-till farming methods.

Hypothesis

After doing the research, the farmer will try to answer the question. She might think, "If I don't plow my fields, I will lose less soil than if I do plow the fields. Plowing disrupts the soil and breaks up roots that help hold soil in place." This answer to her question is a **hypothesis**. A hypothesis is a reasonable explanation. A hypothesis can be tested. It may be the right answer, it may be a wrong answer, but it must be testable. Once she has a hypothesis, the next step is to do experiments to test the hypothesis. A hypothesis can be proved or disproved by testing. If a hypothesis is repeatedly tested and shown to be true, then scientists call it a **theory**.

Experiment

When we design experiments, we choose just one thing to change. The thing we change is called the **independent variable**. In the example, the farmer chooses two fields and then changes only one thing between them. She changes how she plows her fields. One field will be tilled and one will not. Everything else will be the same on both fields: the type of crop she grows, the amount of water and fertilizer that she uses, and the slope of the fields she plants on. The fields should be facing the same direction to get about the same amount of sunlight. These are the experimental **controls**. If the farmer only changes how she plows her fields, she can see the impact of the one change. After the experiment is complete, scientists then measure the result. The farmer measures how much soil is lost from each field. This is the **dependent variable**. How much soil is lost from each field "depends" on the plowing method.

Data and Experimental Error

During an experiment, a scientist collects data. The data might be measurements, like the farmer is taking in **Figure** 1.4. The scientist should record the data in a notebook or onto a computer. The data is kept in charts that are clearly labeled. Labeling helps the scientist to know what each number represents. A scientist may also write descriptions of what happened during the experiment. At the end of the experiment the scientist studies the data. The scientist may create a graph or drawing to show the data. If the scientist can picture the data the results may be easier to understand. Then it is easier to draw logical conclusions.

FIGURE 1.4

A pair of farmers take careful measurements in the field.

Even if the scientist is really careful it is possible to make a mistake. One kind of mistake is with the equipment. For example, an electronic balance may always measure one gram high. To fix this, the balance should be adjusted. If it can't be adjusted, each measurement should be corrected. A mistake can come if a measurement is hard to make. For example, the scientist may stop a stopwatch too soon or too late. To fix this, the scientist should run the experiment many times and make many measurements. The average of the measurements will be the accurate answer. Sometimes the result from one experiment is very different from the other results. If one data point is really different, it may be thrown out. It is likely a mistake was made in that experiment.

Conclusions

The scientist must next form a conclusion. The scientist must study all of the data. What statement best explains the data? Did the experiment prove the hypothesis? Sometimes an experiment shows that a hypothesis is correct. Other times the data disproves the hypothesis. Sometimes it's not possible to tell. If there is no conclusion, the scientist may test the hypothesis again. This time he will use some different experiments. No matter what the experiment shows the scientist has learned something. Even a disproved hypothesis can lead to new questions.

The farmer grows crops on the two fields for a season. She finds that 2.2 times as much soil was lost on the plowed field as compared to the unplowed field. She concludes that her hypothesis was correct. The farmer also notices some other differences in the two plots. The plants in the no-till plots are taller. The soil moisture seems higher. She decides to repeat the experiment. This time she will measure soil moisture, plant growth, and the total amount of water the plants consume. From now on she will use no-till methods of farming. She will also research other factors that may reduce soil erosion.

Theory

When scientists have the data and conclusions, they write a paper. They publish their paper in a scientific journal. A journal is a magazine for the scientists who are interested in a certain field. Before the paper is printed, other scientists look at it to try to find mistakes. They see if the conclusions follow from the data. This is called peer review. If the paper is sound it is printed in the journal.

Other papers are published on the same topic in the journal. The evidence for or against a hypothesis is discussed by many scientists. Sometimes a hypothesis is repeatedly shown to be true and never shown to be false. The hypothesis then becomes a theory. Sometimes people say they have a ”theory” when what they have is a hypothesis.

In science, a theory has been repeatedly shown to be true. A theory is supported by many observations. However, a theory may be disproved if conflicting data is discovered. Many important theories have been shown to be true by many observations and experiments and are extremely unlikely to be disproved. These include the theory of plate tectonics and the theory of evolution.

Scientific Models

Scientists use models to help them understand and explain ideas. Models explain objects or systems in a more simple way. Models often only show only a part of a system. The real situation is more complicated. Models help scientists to make predictions about complex systems. Some models are something that you can see or touch. Other types of models use an idea or numbers. Each type is useful in certain ways.

Scientists create models with computers. Computers can handle enormous amounts of data. This can more accurately represent the real situation. For example, Earth’s climate depends on an enormous number of factors. Climate models can predict how climate will change as certain gases are added to the atmosphere. To test how good a model is, scientists might start a test run at a time in the past. If the model can predict the present it is probably a good model. It is more likely to be accurate when predicting the future.

Physical Models

A **physical model** is a representation of something using objects. It can be three-dimensional, like a globe. It can also be a two-dimensional drawing or diagram. Models are usually smaller and simpler than the real object. They most likely leave out some parts, but contain the important parts. In a good model the parts are made or drawn to scale. Physical models allow us to see, feel and move their parts. This allows us to better understand the real system.

An example of a physical model is a drawing of the layers of Earth (**Figure** 1.5). A drawing helps us to understand the structure of the planet. Yet there are many differences between a drawing and the real thing. The size of a model is much smaller, for example. A drawing also doesn’t give good idea of how substances move. Arrows showing the direction the material moves can help. A physical model is very useful but it can’t explain the real Earth perfectly.

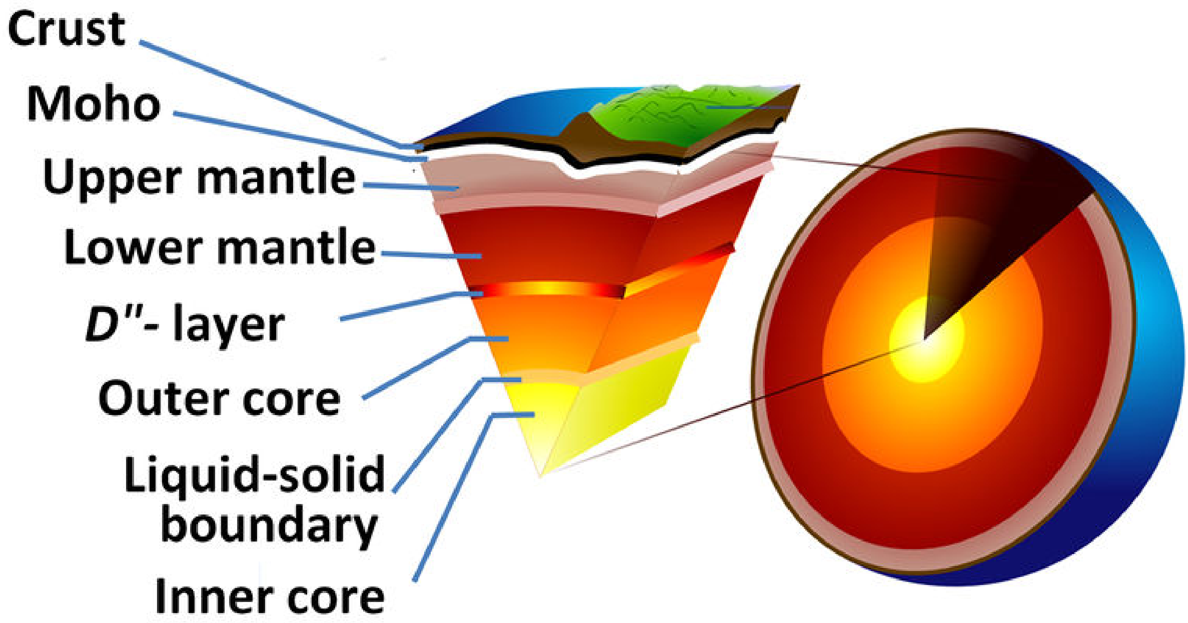

FIGURE 1.5
Earth's Center.

Ideas as Models

Some models are based on an idea that helps scientists explain something. A good idea explains all the known facts. An example is how Earth got its Moon. A Mars-sized planet hit Earth and rocky material broke off of both bodies (**Figure** 1.6). This material orbited Earth and then came together to form the Moon. This is a model of something that happened billions of years ago. It brings together many facts known from our studies of the Moon's surface. It accounts for the chemical makeup of rocks from the Moon, Earth, and meteorites. The physical properties of Earth and Moon figure in as well. Not all known data fits this model, but much does. There is also more information that we simply don't yet know.

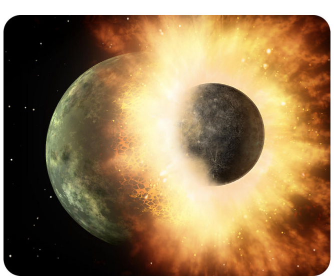

FIGURE 1.6
A collision showing a meteor striking Earth.

Models that Use Numbers

Models may use formulas or equations to describe something. Sometimes math may be the only way to describe it. For example, equations help scientists to explain what happened in the early days of the universe. The universe formed so long ago that math is the only way to describe it. A climate model includes lots of numbers, including temperature readings, ice density, snowfall levels, and humidity. These numbers are put into equations to make a model. The results are used to predict future climate. For example, if there are more clouds, does global temperature go up or down? Models are not perfect because they are simple versions of the real situation. Even so, these models are very useful to scientists. These days, models of complex things are made on computers.

Safety in Science

Accidents happen from time to time in everyday life. Since science involves an adventure into the unknown, it is natural that accidents can happen. Therefore, we must be careful and use proper equipment to prevent accidents (**Figure** 1.7). We must also be sure to treat any injury or accident appropriately.

FIGURE 1.7
Safety Symbols: A. Corrosive , B. Oxidizing Agent, C. Toxic, D. High Voltage.

Inside the Science Laboratory

If you work in the science lab, you may come across dangerous materials or situations. Sharp objects, chemicals, heat, and electricity are all used at times in science laboratories. With proper protection and precautions, almost all accidents can be prevented (**Figure** 1.8). If an accident happens, it can be dealt with appropriately. Below is a list of safety guidelines to follow when doing labs:

- Follow directions at all times.
- A science lab is not a play area.
- Be sure to obey all safety guidelines given in lab instructions or by the lab supervisor.
- Be sure to use the correct amount of each material.
- Tie back long hair.
- Wear closed shoes with flat heels.
- Shirts should have no hanging sleeves, hoods, or drawstrings.
- Use gloves, goggles, or safety aprons as instructed.
- Be very careful when you use sharp or pointed objects, such as knives.
- Clean up broken glass quickly with a dust pan and broom. Never touch broken glass with your bare hands.
- Never eat or drink in the science lab. Table tops and counters could have dangerous substances on them.
- Keep your work area neat and clean. A messy work area can lead to spills and breakage.
- Completely clean materials like test tubes and beakers. Leftover substances could interact with other substances in future experiments.
- If you are using flames or heat plates, be careful when you reach. Be sure your arms and hair are kept far away from heat sources.

- Use electrical appliances and burners as instructed.
- Know how to use an eye wash station, fire blanket, fire extinguisher, and first aid kit.
- Alert the lab supervisor if anything unusual occurs. Fill out an accident report if someone is hurt. The lab supervisor must know if any materials are damaged or discarded.

FIGURE 1.8
A medical researcher protects herself and her work with a net cap, safety goggles, a mask, and gloves.

Outside the Laboratory

Many Earth science investigations are conducted in the field (**Figure** 1.9). Field work needs some additional precautions:

- Be sure to wear appropriate clothing. Hiking requires boots, long pants, and protection from the Sun, for example.
- Bring sufficient supplies like food and water, even for a short trip. Dehydration can occur rapidly.
- Take along first aid supplies.
- Let others know where you are going, what you will be doing, and when you will be returning. Take a map with you if you don't know the area and leave a copy of the map with someone at home.
- Try to have access to emergency services and some way to communicate. Beware that cell phones may not have coverage in all locations.
- Be sure that you are accompanied by a person familiar with the area or is familiar with field work.

Lesson Summary

- Scientists ask questions about the natural world.
- Scientific method is a set of logical steps that can be used to answer these questions.
- A hypothesis is a reasonable explanation of something.
- A theory is a hypothesis that has been shown to be true many times over.
- Models represent real things but are simpler.
- If you are working in a lab, it is very important to be safe.

FIGURE 1.9
Outdoor Excursions.

Lesson Review Questions

Recall

1. Describe three types of scientific models. Under what circumstances would each be used?

2. If you have access to a science laboratory, look around to see what safety symbols there are. What does each mean?

Apply Concepts

3. Write five questions that would get a friend interested in exploring the natural world.

4. A scientist was studying the effects of oil contamination on ocean seaweed. He believed that oil runoff from storm drains would keep seaweed from growing normally. He had two large aquarium tanks of equal size. He kept the amount of dissolved oxygen and the water temperature the same in each tank. He added some motor oil to one tank but not to the other. He then measured the growth of seaweed plants in each tank. In the tank with no oil, the average growth was 2.57cm/day. The average growth of the seaweed in the tank with oil was 2.37cm/day. Based on this experiment, answer the following questions:

- What was the question that the scientist started with?
- What was his hypothesis?
- Identify the independent variable, the dependent variable, and the experimental control(s).
- What did the data show?

Think Critically

5. Design your own experiment based on one of your questions from question 3 above. Include the question, hypothesis, independent and dependent variables, and safety precautions.

Points to Consider

- What parts of Earth do you think are most important and should be better studied?
- Describe a model that you have had experience with. What type of model was it? What did you learn from it?
- What situations are both necessary and dangerous for scientists to study? What precautions do you think they should use when they study them?
- If you could go anywhere, where would it be? What safety equipment or precautions would you take?

1.2 Earth Science and Its Branches

Lesson Objectives

- Describe Earth Science and its branches.
- Identify the field of geology as a branch of Earth Science that deals with the rocks and minerals of Earth.
- Describe the field of oceanography as a branch of Earth Science that explores the ocean.
- Define the field of meteorology as a branch of Earth Science that deals with the atmosphere.
- Understand that astronomy is a branch of Earth Science that studies our solar system and universe.
- List some of the other branches of Earth Science, and how they relate to the study of Earth.

Vocabulary

- astronomy
- geology
- meteorology
- oceanography

Introduction

Earth Science is the study of all aspects of our planet Earth. Earth Science is not just about the molten lava, icy mountain peaks, steep canyons and towering waterfalls of the continents. Earth Science includes the atmosphere and oceans. The field also looks out into the solar system, galaxy, and universe. Earth scientists seek to understand the beautiful planet on which we depend (**Figure** 1.10).

FIGURE 1.10
Earth as seen from Apollo 17.

Different branches of Earth Science study one particular part of Earth. Since all of the branches are connected, specialists work together to answer complicated questions. Let's look at some important branches of Earth Science.

Geology

Geology is the study of the solid Earth. Geologists study how rocks and minerals form. The way mountains rise up is part of geology. The way mountains erode away is another part. Geologists also study fossils and Earth's history. There are many other branches of geology. There is so much to know about our home planet that most geologists become specialists in one area. For example, a mineralogist studies minerals, as seen in (**Figure** 1.11).

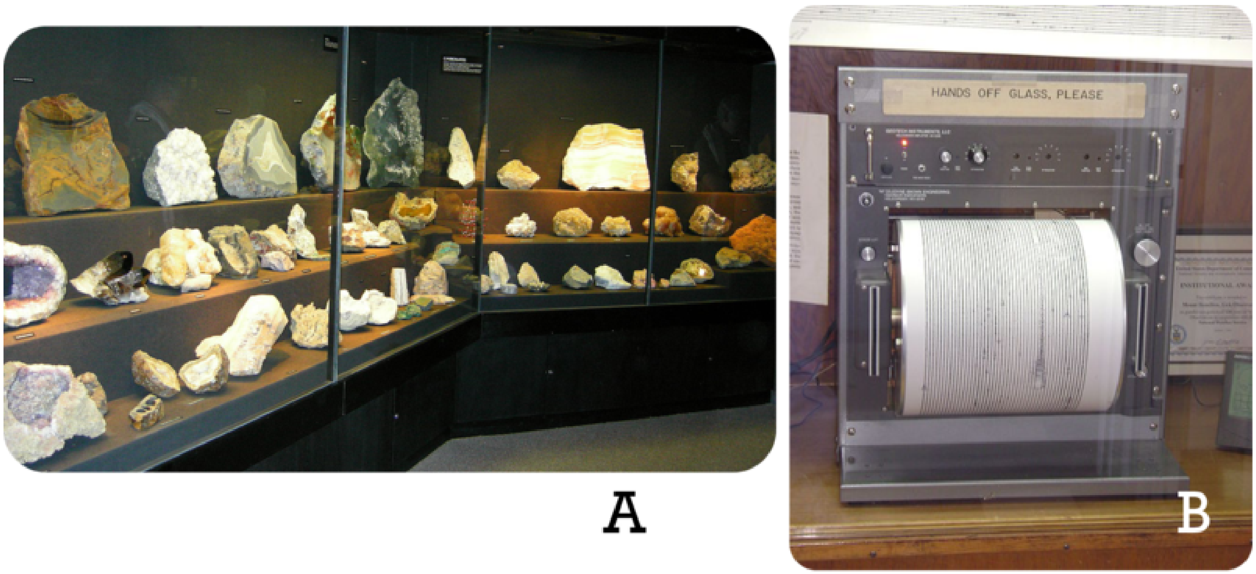

FIGURE 1.11
(A) Mineralogists focus on all kinds of minerals. (B) Seismographs are used to measure earthquakes and pinpoint their origins.

Some volcanologists brave molten lava to study volcanoes. Seismologists monitor earthquakes worldwide to help protect people and property from harm (**Figure** 1.11). Paleontologists are interested in fossils and how ancient organisms lived. Scientists who compare the geology of other planets to Earth are planetary geologists. Some geologists study the Moon. Others look for petroleum. Still others specialize in studying soil. Some geologists can tell how old rocks are and determine how different rock layers formed. There is probably an expert in almost anything you can think of related to Earth!

Geologists might study rivers and lakes, the underground water found between soil and rock particles, or even water that is frozen in glaciers. Earth scientists also need geographers who explore the features of Earth's surface and work with cartographers, who make maps. Studying the layers of rock beneath the surface helps us to understand the history of planet Earth (**Figure** 1.12).

Oceanography

Oceanography is the study of the oceans. The word oceanology might be more accurate, since "ology" is "the study of." "Graph" is "to write" and refers to map making. But mapping the oceans is how oceanography started.

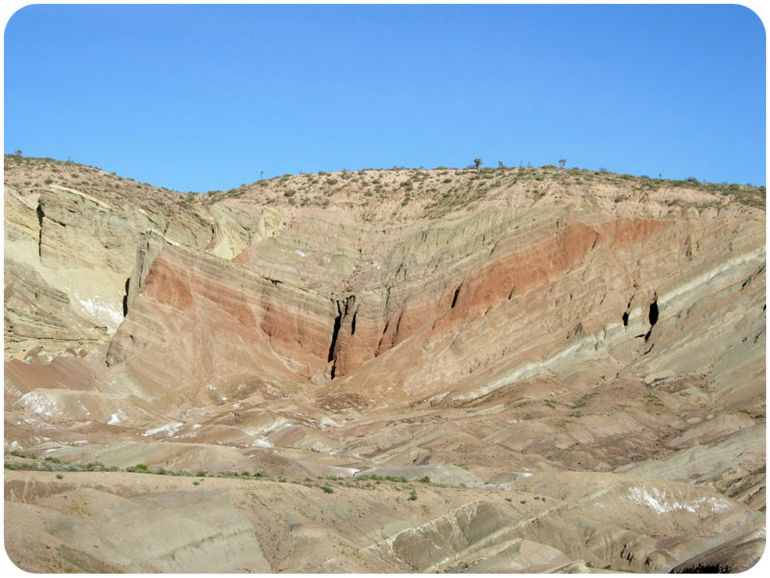

FIGURE 1.12
These folded rock layers have bent over time. Studying rock layers helps scientists to explain these layers and the geologic history of the area.

More than 70% of Earth's surface is covered with water. Almost all of that water is in the oceans. Scientists have visited the deepest parts of the ocean in submarines. Remote vehicles go where humans can't. Yet much of the ocean remains unexplored. Some people call the ocean "the last frontier."

Humans have had a big impact on the oceans. Populations of fish and other marine species have been overfished. Contaminants are polluting the waters. Global warming is melting the thick ice caps and warming the water. Warmer water expands and, along with water from the melting ice caps, causes sea levels to rise.

FIGURE 1.13
This research vessel is specially designed to explore the seas around Antarctica.

There are many branches of oceanography. Physical oceanography is the study of water movement, like waves and ocean currents (**Figure** 1.13). Marine geology looks at rocks and structures in the ocean basins. Chemical oceanography studies the natural elements in ocean water. Marine biology looks at marine life.

Climatology and Meteorology

Meteorologists don't study meteors —they study the atmosphere! The word "meteor" refers to things in the air. **Meteorology** includes the study of weather patterns, clouds, hurricanes, and tornadoes. Meteorology is very important. Using radars and satellites, meteorologists work to predict, or forecast, the weather (**Figure** 1.14).

FIGURE 1.14
Meteorologists can help us to prepare for major storms or know if today is a good day for a picnic.

The atmosphere is a thin layer of gas that surrounds Earth. Climatologists study the atmosphere. These scientists work to understand the climate as it is now. They also study how climate will change in response to global warming.

The atmosphere contains small amounts of carbon dioxide. Climatologists have found that humans are putting a lot of extra carbon dioxide into the atmosphere. This is mostly from burning fossil fuels. The extra carbon dioxide traps heat from the Sun. Trapped heat causes the atmosphere to heat up. We call this global warming (**Figure** 1.15).

FIGURE 1.15
Carbon dioxide released into the atmosphere is causing global warming.

Environmental Science

Environmental scientists study the ways that humans affect the planet we live on. We hope to find better ways of living that can also help the environment. Ecologists study lifeforms and the environments they live in (**Figure** 1.16). They try to predict the chain reactions that could occur when one part of the ecosystem is disrupted.

FIGURE 1.16
In a marine ecosystem, coral, fish, and other sea life depend on each other for survival.

Astronomy

Astronomy and astronomers have shown that the planets in our solar system are not the only planets in the universe. Over 530 planets were known outside our solar system in 2011. And there are billions of other planets! The universe also contains black holes, other galaxies, asteroids, comets, and nebula. As big as Earth seems, the entire universe is vastly more enormous. Earth is just a tiny part of our universe.

Astronomers use many tools to study things in space. Earth-orbiting telescopes view stars and galaxies from the darkness of space (**Figure** 1.17). They may have optical and radio telescopes to see things that the human eye can't see. Spacecraft travel great distances to send back information on faraway places.

Astronomers ask a wide variety of questions. How do strong bursts of energy from the Sun, called solar flares, affect communications? How might an impact from an asteroid affect life on Earth? What are the properties of black holes? Astronomers ask bigger questions too. How was the universe created? Is there life on other planets? Are there resources on other planets that people could use? Astronomers use what Earth scientists know to make comparisons with other planets.

Lesson Summary

- Earth science includes many fields of science related to our home planet.
- Geology is the study of Earth's material and structures and the processes that create them.

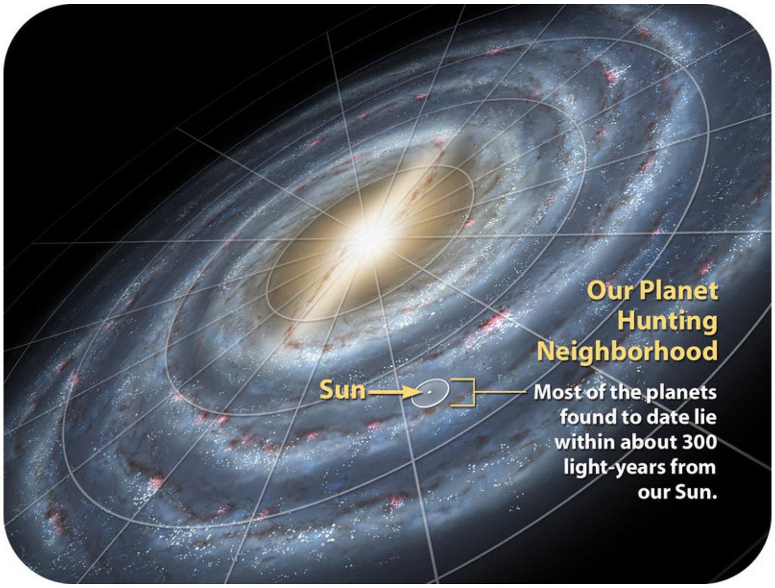

FIGURE 1.17
Scientists are using telescopes to search for other planets that may have conditions favorable for life. The places they can look are near our solar system in our galaxy.

- Oceanography is the study of the oceans: water movement, chemistry and the ocean basins among other things.
- Meteorologists study the atmosphere including climate and weather.
- Environmental science deals with the effects people have on the environment.
- Astronomers study Earth's larger environment: the solar system, galaxy, and universe that our planet resides in.

Lesson Review Questions

Recall

1. What are three major branches of Earth Science?
2. What branch of science deals with stars and galaxies beyond Earth?
3. List important functions of Earth scientists.
4. What does a meteorologist study?

Apply Concepts

5. A glacier is melting. What are all of the scientists you can think of who might be involved in studying this glacier? What would each of them do?

Think Critically

6. Design an experiment that you could conduct in any branch of Earth Science. Identify the independent variable and dependent variable.

Points to Consider

- Why is Earth Science so important?
- Which branch of Earth Science would you most like to explore?
- What is the biggest problem that we face today? Which Earth scientists may help us to solve the problem?
- What other branches of science or society are related to and necessary for Earth Science?

1.3 References

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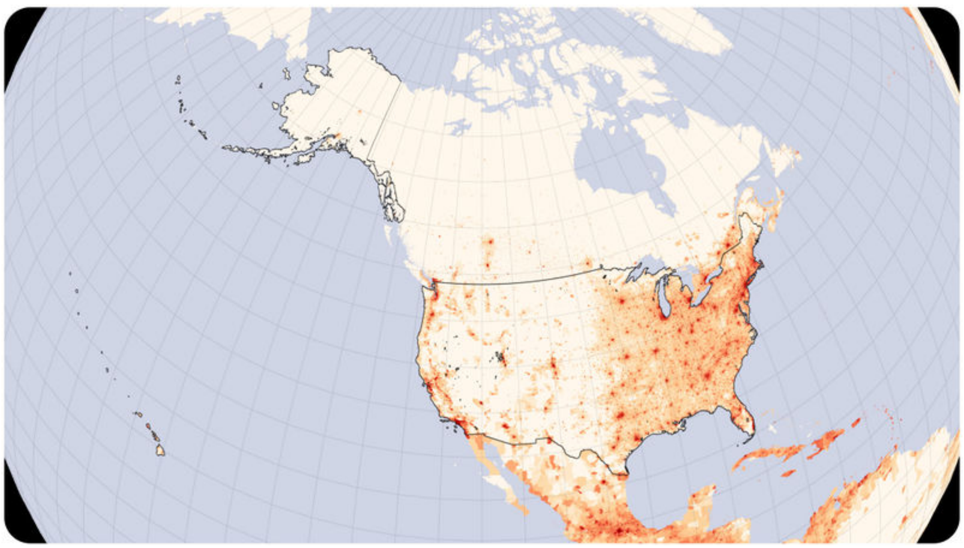
CHAPTER 2 MS Studying Earth's Surface

Chapter Outline



Maps show many types of things. Maps can be on many different scales. Some are large-scale views of large areas. Some are small-scale views of minute features. Maps can have many different types of looks with lots of information or just a little.

The map above shows the population density of the United States, Canada and the northern part of Mexico. It's easy to pick out cities based on population density. It's also interesting to note the different settlement patterns in the eastern and western United States. In the west, much of the population is located in large towns. In the east, there are many large cities. There are also a lot of people spread out across the lands. Very few people live in Canada and most of those live in the southern portion of the country. The gray lines you see are not state boundaries but latitude and longitude lines.

Courtesy of NASA Earth Observatory. earthobservatory.nasa.gov/IOTD/view.php?id=7052. Public Domain.

2.1 Introduction to Earth's Surface

Lesson Objectives

- Describe how you can find a location and direction on Earth's surface.
- Describe topography.
- Identify various landforms and briefly describe how they form.

Vocabulary

- compass
- compass rose
- constructive forces
- continent
- destructive forces
- elevation
- relief
- topography

Introduction

Beautiful mountain ranges, deep canyons, flat plains. These can all be seen on Earth's surface. Beneath the sea are other features that few people have seen directly. Understanding Earth's surface is one of the important things Earth scientists can do. Knowing where they are on the planet is one of the first things they need to describe.

Location

To describe your location wherever you are on Earth's surface, you could use a coordinate system. For example, you could say that you are at 1234 Main Street, Springfield, Ohio. Or you could use a point of reference. If you want to meet up with a friend, you could tell him the distance and direction you are from the reference point. An example is, "I am at the corner of Maple Street and Main Street, about two blocks north of your apartment."

When studying Earth's surface, scientists must be able to pinpoint a feature they are interested in. Scientists and others have a system to describe the location of any feature. Usually they use latitude and longitude as a coordinate system. Lines of latitude and longitude form a grid. The grid is centered on a reference point. You will learn about this type of grid when we discuss maps later in this chapter.

Direction

When an object is moving, it is not enough to describe its location. We also need to know direction. Direction is important for describing moving objects. For example, a wind blows a storm over your school. Where is that storm coming from? Where is it going?

The most common way to describe direction is by using a **compass**. A compass is a device with a floating needle (**Figure** 2.1). The needle is a small magnet that aligns itself with the Earth's magnetic field. The compass needle always points to magnetic north. If you have a compass and you find north, you can then know any other direction. See the directions, such as east, south, west, etc., on a **compass rose**.

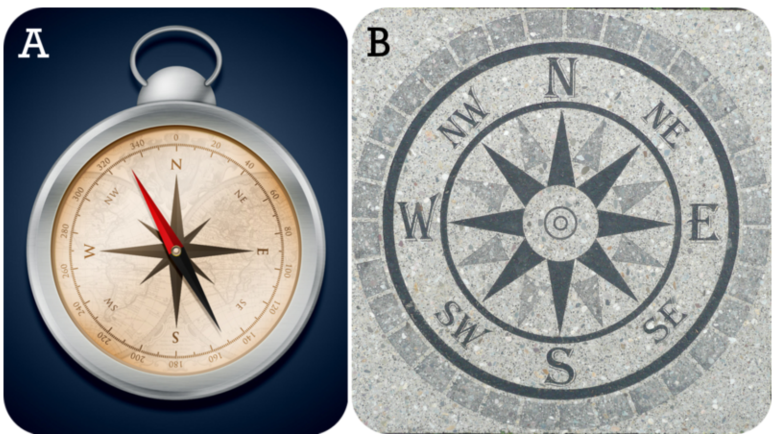


FIGURE 2.1
(A) A compass is a device that is used to determine direction. The needle points to Earth's magnetic north pole. (B) A compass rose shows the four major directions plus intermediates between them.

A compass needle lines up with Earth's magnetic north pole. This is different from Earth's geographic north pole, or true north. The geographic north pole is the top of the imaginary axis around which Earth rotates. The geographic north pole is much like the spindle of a spinning top. The location of the geographic north pole does not change. However, the magnetic north pole shifts in location over time. Depending on where you live, you can correct for the difference between the two poles when you use a map and a compass (**Figure** 2.2).

Some maps have a double compass rose. This allows users to make the corrections between magnetic north and true north. An example is a nautical chart that boaters use to chart their positions at sea (**Figure** 2.3).

Topography

As you know, the surface of Earth is not flat. Some places are high and some places are low. For example, mountain ranges like the Sierra Nevada in California or the Andes in South America are high above the surrounding areas. We can describe the **topography** of a region by measuring the height or depth of that feature relative to sea level (**Figure** 2.4). You might measure your height relative to your classmates. When your class lines up, some kids make high "mountains," while others are more like small hills!

Relief, or terrain, includes all the landforms of a region. A topographic map shows the height, or **elevation**, of features in an area. This includes mountains, craters, valleys, and rivers. For example, **Figure** 2.5 shows the San Francisco Peaks in northern Arizona. Features on the map include mountains, hills and lava flows. You can recognize these features from the differences in elevation. We will talk about some different landforms in the next section.

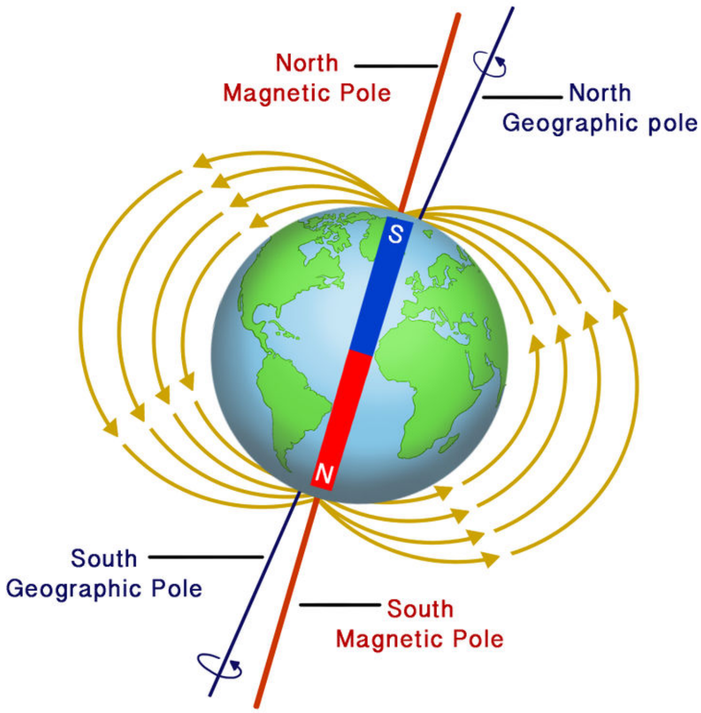


FIGURE 2.2
Earth's magnetic north pole is about 11 degrees offset from its geographic north pole.

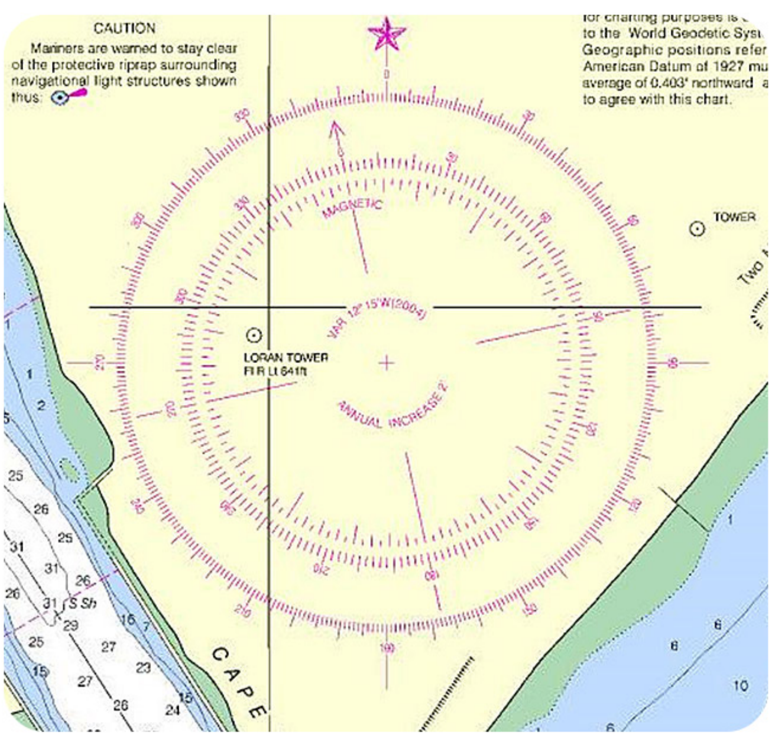


FIGURE 2.3
Nautical maps include a double compass rose that shows both magnetic directions (inner circle) and geographic compass directions (outer circle).

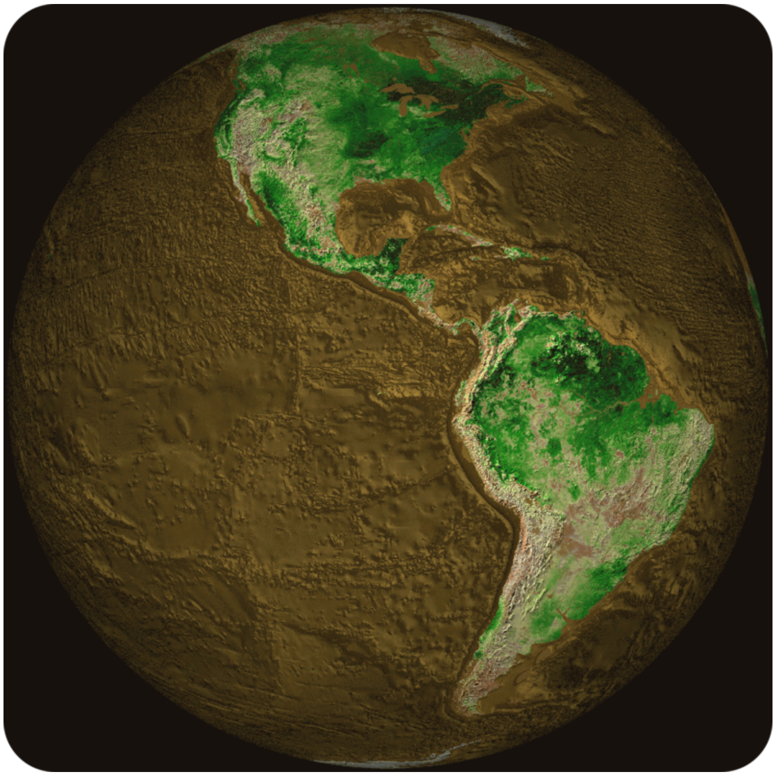


FIGURE 2.4
Topography of Earth showing North America and South America.

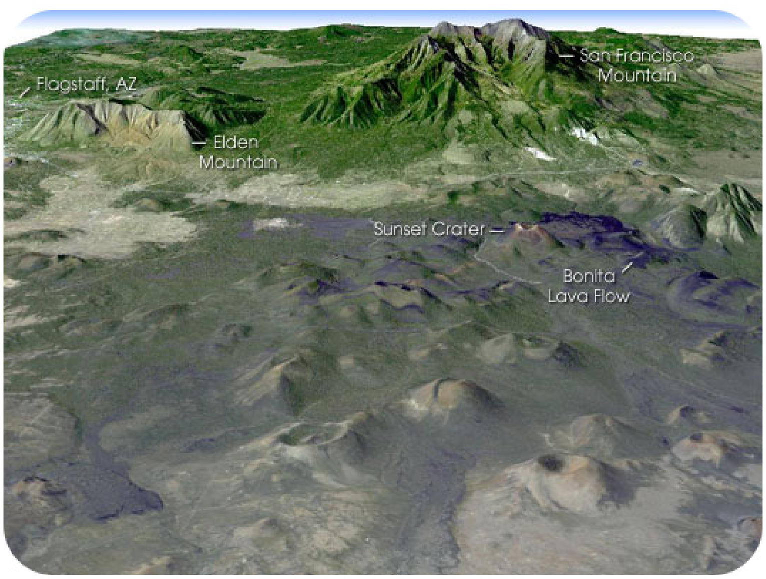


FIGURE 2.5
This image was made from data of the Landsat satellite. It shows the topography of the San Francisco Peaks and surrounding areas.

Continents and Landforms

If you take away the water in the oceans (**Figure** 2.6), Earth looks really different. You see that the surface has two main features: continents and ocean basins. **Continents** are large land areas. **Ocean basins** extend from the edges of continents to the ocean floor and into deep trenches.

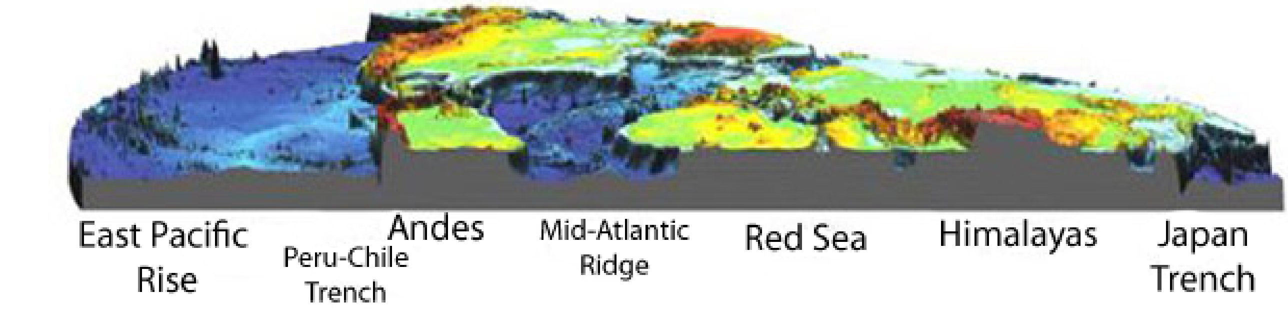


FIGURE 2.6
This image shows Earth with water removed. The red areas are high elevations (mountains). Yellow and green areas are lower elevations. Blue areas are the lowest on the ocean floor.

Continents are much older than ocean basins. Some rocks on the continents are billions of years old. Ocean basins are only millions of years old at their oldest. Because the continents are so old, a lot has happened to them!

As we view the land around us we see landforms. **Landforms** are physical features on Earth's surface. Landforms are introduced in this section but will be discussed more in later chapters. **Constructive forces** cause landforms to grow. Lava flowing into the ocean can build land outward. A volcano can be a constructive force. **Destructive forces** may blow landforms apart. A volcano blowing its top off is a destructive force. The destructive forces of weathering and erosion change landforms more slowly. Over millions of years, mountains are worn down by rivers and streams.

Constructive and destructive forces work together to create landforms. Constructive forces create mountains and erosion may wear them away. Mountains are very large landforms. Mountains may wear away into a high flat area called a plateau, or a lower-lying plain. Interior plains are in the middle of continents. Coastal plains are on the edge of a continent, where it meets the ocean.

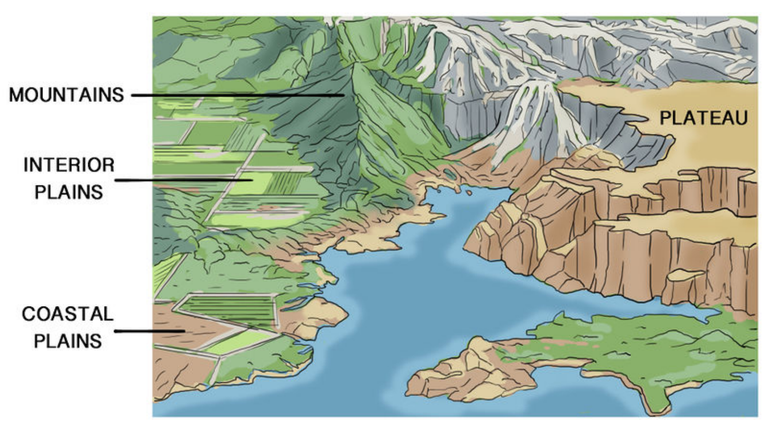


FIGURE 2.7
Features of continents include mountain ranges, plateaus, and plains.

Rivers and streams flow across continents. They cut away at rock, forming river valleys (**Figure** 2.8). These are destructive forces. The bits and pieces of rock carried by rivers are deposited where rivers meet the oceans. These can form deltas, like the Mississippi River delta. They can also form barrier islands, like Padre Island in Texas. Rivers bring sand to the shore, which forms our beaches. These are constructive forces.

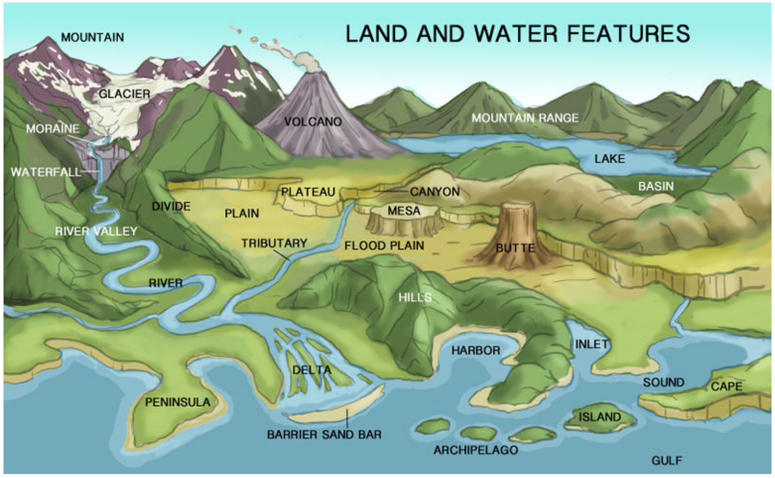


FIGURE 2.8

Summary of major landforms on continents and features of coastlines.

Ocean Basins

The ocean basin begins where the ocean meets the land. The continental margin begins at the shore and goes down to the ocean floor. It includes the continental shelf, slope, and rise. The continental shelf is part of the continent, but it is underwater today. It is about 100-200 meters deep, much shallower than the rest of the ocean. The continental shelf usually goes out about 100 to 200 kilometers from the shore (**Figure** 2.9).

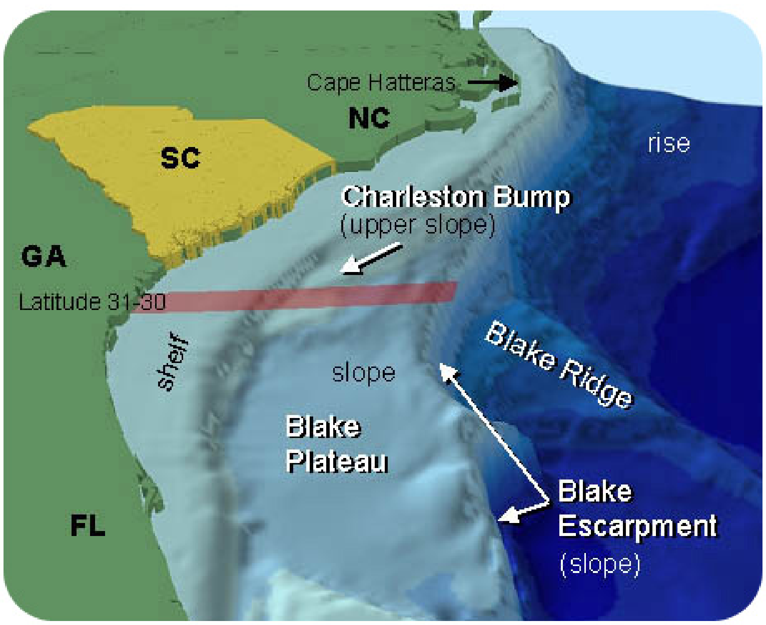


FIGURE 2.9

The continental shelf and slope of the southeastern United States goes down to the ocean floor.

The continental slope is the slope that forms the edge of the continent. It is seaward of the continental shelf. In some places, a large pile of sediments brought from rivers creates the continental rise. The continental rise ends at the ocean floor. Much of the ocean floor is called the abyssal plain.

The ocean floor is not totally flat. In many places, small hills rise above the ocean floor. These hills are undersea volcanoes, called seamounts (**Figure** 2.10). Some rise more than 1000 m above the seafloor.

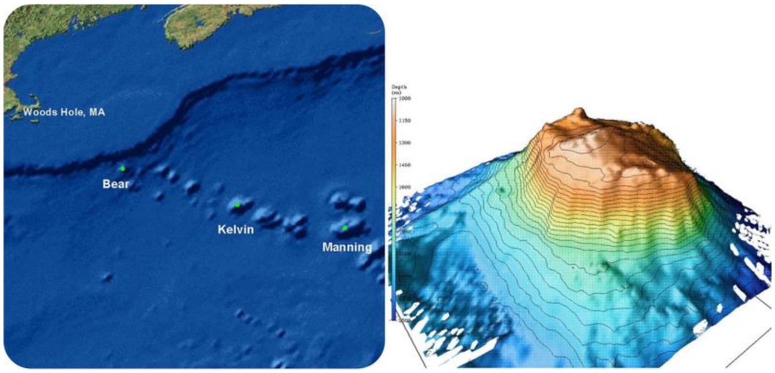


FIGURE 2.10
A chain of seamounts off the coast of New England (left). Oceanographers mapped one of these seamounts, called Bear Seamount, in great detail (right).

Besides seamounts, there are long, very tall (about 2 km) mountain ranges. These ranges are connected so that they form huge ridge systems called mid-ocean ridges (**Figure** 2.11). The mid-ocean ridges form from volcanic eruptions. Lava from inside Earth breaks through the crust and creates the mountains.

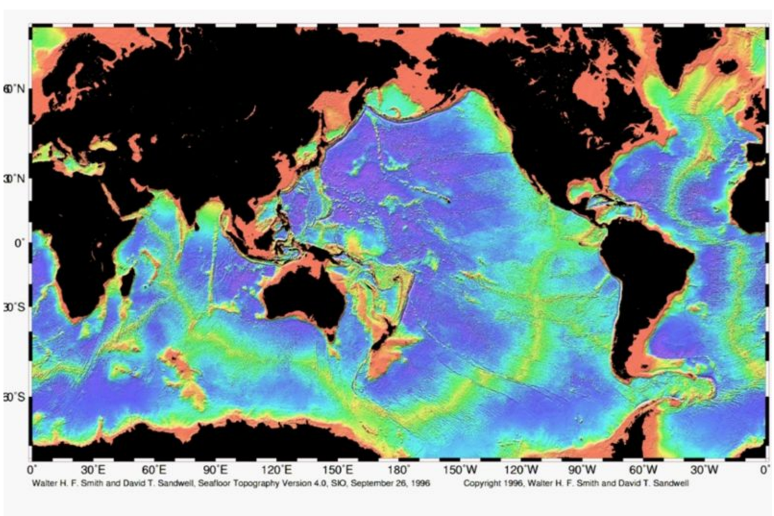


FIGURE 2.11
Map of the mid-ocean ridge system (yellow-green) in Earth's oceans.

The deepest places of the ocean are the ocean trenches. Many trenches line the edges of the Pacific Ocean. The Mariana Trench is the deepest place in the ocean. (**Figure** 2.12). At about 11 km deep, it is the deepest place on Earth! To compare, the tallest place on Earth, Mount Everest, is less than 9 km tall.

Lesson Summary

- Earth scientists must be able to describe the exact locations of features on Earth's surface.
- Locations often include distances and directions.
- A compass has a tiny magnetic needle that points toward Earth's magnetic North Pole. Once you have found north, you can find east, west, and south, using your compass for reference.

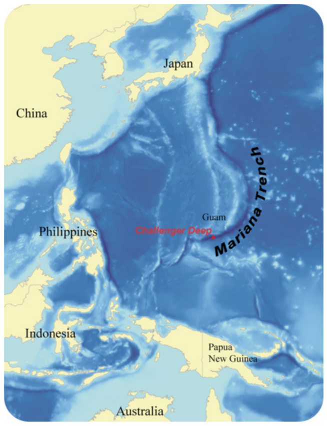


FIGURE 2.12
The Mariana Trench is east of Guam in the Pacific Ocean.

- Topography describes how Earth's surface varies in elevation.
- Constructive forces create landforms. Destructive forces wear landforms down.

Lesson Review Questions

Recall

1. What information might you need to describe the location of a feature on the Earth's surface?

2. On the continents, which landforms rise the highest?

3. What is topography?

Apply Concepts

4. Why would you need to know direction if an object is moving?

5. Why do nautical charts have two compass roses on them?

Think Critically

6. Why do you think that the ocean basins are younger than the continents?

7. Explain what landforms on the continents are created by erosion from wind and water. How does erosion create a landform?

Points to Consider

- A new volcano rises in Mexico. How you would describe its position in a scientific report?
- Can you devise a system to show low areas and high areas on a map?
- Why do you think continents are higher areas on Earth than the ocean basins?

2.2 Modeling Earth's Surface

Lesson Objectives

- Describe what information a map can convey.
- Identify some major types of map projections. Discuss the advantages and disadvantages of each.
- Discuss the advantages and disadvantages of globes.

Vocabulary

- conic map
- coordinate system
- gnomonic map
- latitude
- longitude
- map
- Mercator projection
- projection

Introduction

Maps can convey a lot of different types of information. They can tell you where you are or they can tell you something about a location. Earth scientists often use maps that have coordinates so that they can locate themselves or the features they are interested in. Different types of maps show different things well. For example, some types of maps show the tropical areas really well but do a terrible job depicting the polar regions.

Maps as Models

Imagine you are going on a road trip. Perhaps you are going on vacation. How do you know where to go? Most likely, you will use a map. A **map** is a picture of specific parts of Earth's surface. There are many types of maps. Each map gives us different information. Let's look at a road map, which is the probably the most common map that you use (**Figure** 2.13).

Map Legends

Look for the legend on the top left side of the map. It explains how this map records different features. You can see the following:

FIGURE 2.13

A road map of the state of Florida. What information can you get from this map?

- The boundaries of the state show its shape.
- Black dots represent the cities. Each city is named. The size of the dot represents the population of the city.
- Red and brown lines show major roads that connect the cities.
- Blue lines show rivers. Their names are written in blue.
- Blue areas show lakes and other waterways —the Gulf of Mexico, Biscayne Bay, and Lake Okeechobee. Names for bodies of water are also written in blue.
- A line or scale of miles shows the distance represented on the map —an inch or centimeter on the map represents a certain amount of distance (miles or kilometers).
- The legend explains other features and symbols on the map.
- It is the convention for north to be at the top of a map. For this reason, a compass rose is not needed on most maps.

You can use this map to find your way around Florida and get from one place to another along roadways.

Types of Maps

There are many other types of maps besides road maps. Some examples include:

- Political or geographic maps show the outlines and borders of states and/or countries.
- Satellite view maps show terrains and vegetation —forests, deserts, and mountains.
- Relief maps show elevations of areas, but usually on a larger scale, such as the whole Earth, rather than a local area.
- Topographic maps show detailed elevations of features on the map.
- Climate maps show average temperatures and rainfall.
- Precipitation maps show the amount of rainfall in different areas.
- Weather maps show storms, air masses, and fronts.
- Radar maps show storms and rainfall.
- Geologic maps detail the types and locations of rocks found in an area.

These are but a few types of maps that various Earth scientists might use. You can easily carry a map around in your pocket or bag. Maps are easy to use because they are flat or two-dimensional. However, the world is three-dimensional. So, how do map makers represent a three-dimensional world on flat paper?

Map Projections

Earth is a round, three-dimensional ball. In a small area, Earth looks flat, so it is not hard to make accurate maps of a small place. When map makers want to map the round Earth on flat paper, they use projections. What happens if you try to flatten out the skin of a peeled orange? Or if you try to gift wrap a soccer ball? To flatten out, the orange peel must rip and its shape must become distorted. To wrap around object with flat paper requires lots of extra cuts and folds. A **projection** is a way to represent Earth's curved surface on flat paper (**Figure** 2.14).

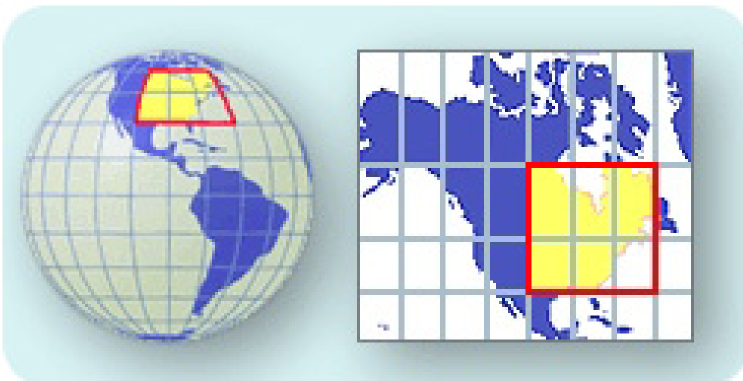


FIGURE 2.14
A map projection translates Earth's curved surface onto two dimensions.

There are many types of projections. Each uses a different way to change three dimensions into two dimensions.

There are two basic methods that the map maker uses in projections:

- The map maker "slices" the sphere in some way and unfolds it to make a flat map, like flattening out an orange peel.
- The map maker can look at the sphere from a certain point and then translate this view onto a flat paper.

Let's look at a few commonly used projections.

Mercator Projection

In 1569, Gerardus Mercator (1512-1594) (**Figure** 2.15) figured out a way to make a flat map of our round world, called the **Mercator projection** (**Figure** 2.16).

Imagine wrapping the round, ball-shaped Earth with a big, flat piece of paper. First you make a tube or a cylinder. The cylinder will touch Earth at its fattest part, the equator. The **equator** is the imaginary line running horizontally around the middle of Earth. The poles are the farthest points from the cylinder. If you shine a light from the inside of your model Earth out to the cylinder, the image projected onto the paper is a Mercator projection. Where does the projection represent Earth best? Where is it worst? Your map would be most correct at the equator. The shapes and sizes of continents become more stretched out near the poles. Early sailors and navigators found the Mercator map useful because most explorations were located near the equator. Many world maps still use the Mercator projection.

The Mercator projection is best within 15 degrees north or south of the equator. Landmasses or countries outside that zone get stretched out of shape. The further the feature is from the equator, the more out of shape it is stretched. For example, if you look at Greenland on a globe, you see it is a relatively small country near the North Pole. Yet, on a Mercator projection, Greenland looks almost as big the United States. Because Greenland is closer to the pole, the continent's shape and size are greatly increased. The United States is closer to its true dimensions.

FIGURE 2.15
Gerardus Mercator developed a map projection used often today, known as the Mercator projection.

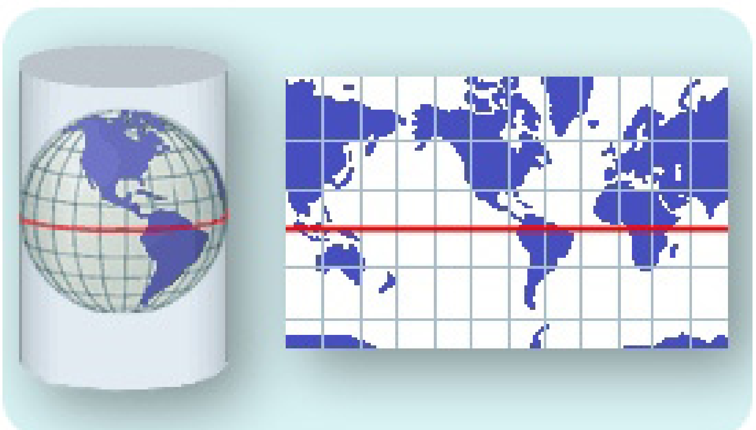


FIGURE 2.16
A Mercator projection translates the curved surface of Earth onto a cylinder.

In a Mercator projection, all compass directions are straight lines. This makes it a good type of map for navigation. The top of the map is north, the bottom is south, the left side is west and the right side is east. However, because it is a flat map of a curved surface, a straight line on the map is not the shortest distance between the two points it connects.

Conic Projection

Instead of a cylinder, you could wrap the flat paper into a cone. **Conic map** projections use a cone shape to better represent regions near the poles (**Figure** 2.17). Conic projections are best where the cone shape touches the globe. This is along a line of latitude, usually the equator.

Gnomonic Projection

What if want to wrap a different approach? Let's say you don't want to wrap a flat piece of paper around a round object? You could put a flat piece of paper right on the area that you want to map. This type of map is called a **gnomonic map** projection (**Figure** 2.18). The paper only touches Earth at one point. The sizes and shapes of countries near that point are good. The poles are often mapped this way to avoid distortion. A gnomic projection is best for use over a small area.

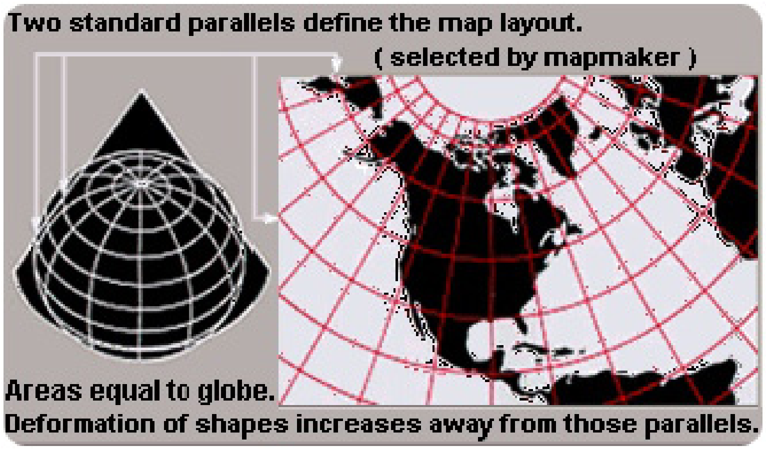


FIGURE 2.17
A conic map projection wraps Earth with a cone shape rather than a cylinder.

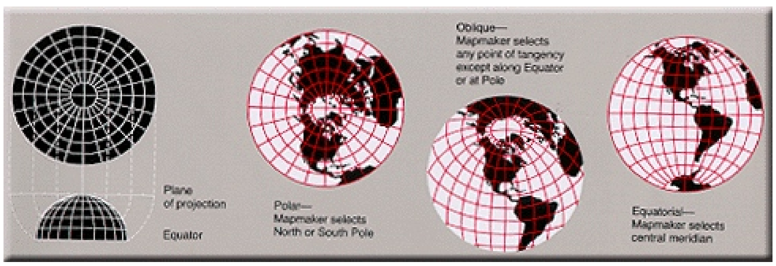


FIGURE 2.18
A gnomonic projection places a flat piece of paper on a point somewhere on Earth and projects an image from that point.

Robinson Projection

In 1963, Arthur Robinson made a map with more accurate sizes and shapes of land areas. He did this using mathematical formulas. The formulas could directly translate coordinates onto the map. This type of projection is shaped like an oval rather than a rectangle (**Figure** 2.19).

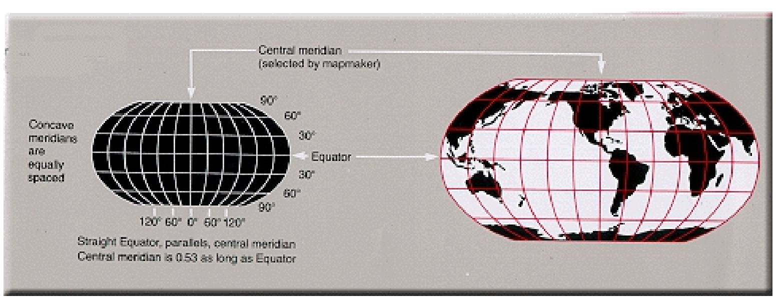


FIGURE 2.19
A Robinson projection better represents the true shapes and sizes of land areas.

Robinson's map is more accurate than a Mercator projection. The shapes and sizes of continents are closer to true. Robinson's map is best within 45 degrees of the equator. Distances along the equator and the lines parallel to it are true. However, the scales along each line of latitude are different. In 1988, the National Geographic Society began to use Robinson's projection for its world maps.

Whatever map projection is used, maps help us find places and to be able to get from one place to another. So how do you find your location on a map?

Map Coordinates

Most maps use a grid of lines to help you to find your location. This grid system is called a geographic **coordinate system**. Using this system you can define your location by two numbers, latitude and longitude. Both numbers are angles between your location, the center of Earth, and a reference line (**Figure** 2.20).

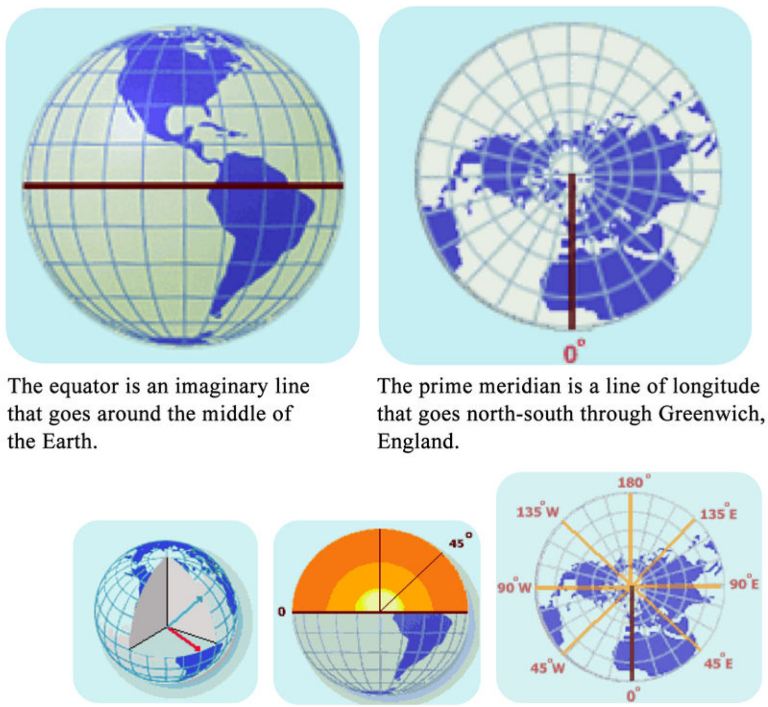


FIGURE 2.20
Lines of latitude start with the equator. Lines of longitude begin at the prime meridian.

Latitude

Lines of **latitude** circle around Earth. The equator is a line of latitude right in the middle of the planet. The equator is an equal distance from both the North and South Pole. If you know your latitude, you know how far you are north or south of the equator.

Longitude

Lines of **longitude** are circles that go around Earth from pole to pole, like the sections of an orange. Lines of longitude start at the Prime Meridian. The Prime Meridian is a circle that runs north to south and passes through Greenwich, England. Longitude tells you how far you are east or west from the Prime Meridian (**Figure** 2.21).

You can remember latitude and longitude by doing jumping jacks. When your hands are above your head and your feet are together, say longitude (your body is long!). When you put your arms out to the side horizontally, say latitude (your head and arms make a cross, like the "t" in latitude). While you are jumping, your arms are going the same way as each of these grid lines: horizontal for latitude and vertical for longitude.

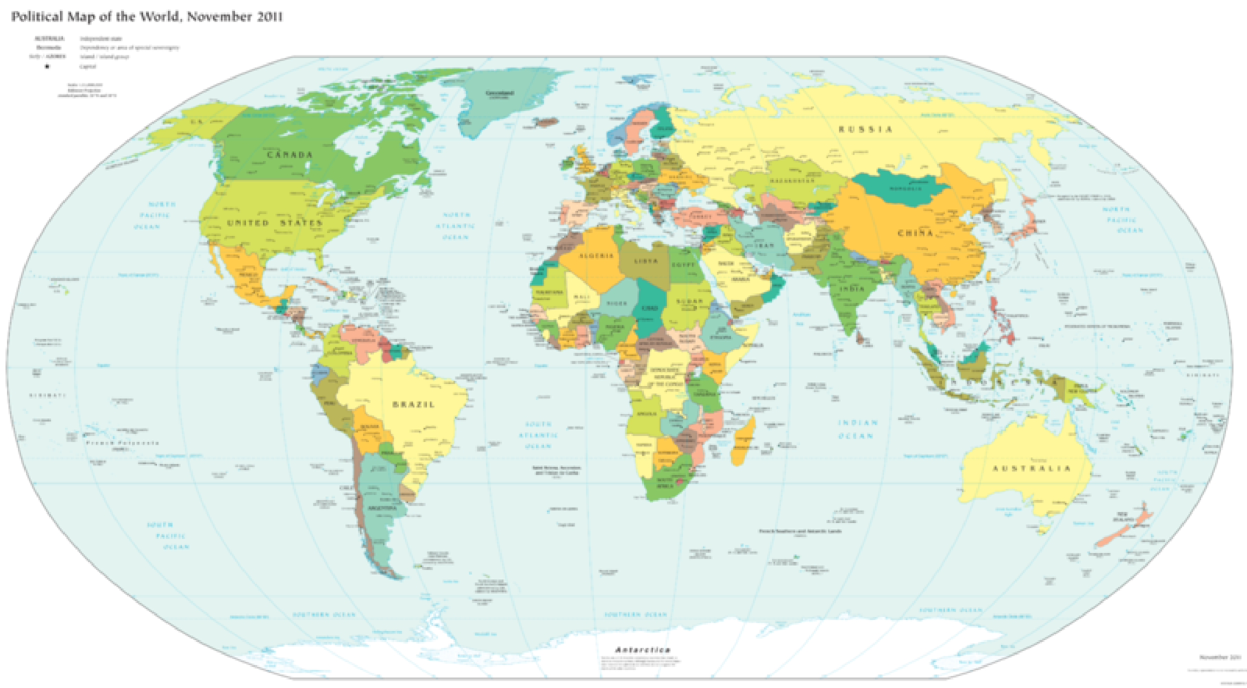


FIGURE 2.21
Lines of latitude and longitude form convenient reference points on a map.

Using Latitude and Longitude on a Map

If you know the latitude and longitude of a place, you can find it on a map. Simply place one finger on the latitude on the vertical axis of the map. Place your other finger on the longitude along the horizontal axis of the map. Move your fingers along the latitude and longitude lines until they meet. For example, say the location you want to find is at 30^oN and 90^oW. Place your right finger along 30^oN at the right of the map. Place your left finger along the bottom at 90^oW. Move your fingers along the lines until they meet. Your location should be near New Orleans, Louisiana, along the Gulf coast of the United States.

What if you want to know the latitude and longitude of your location? If you know where you are on a map, point to the place with your fingers. Take one finger and move it along the latitude line to find your latitude. Then move another finger along the longitude line to find your and longitude.

Polar Coordinate System

You can also use a polar coordinate system. Your location is marked by an angle and distance from some reference point. The angle is usually the angle between your location, the reference point, and a line pointing north. The distance is given in meters or kilometers. To find your location or to move from place to place, you need a map, a compass, and some way to measure your distance, such as a range finder.

Suppose you need to go from your location to a marker that is 20^oE and 500 m from your current position. You must do the following:

- Use the compass and compass rose on the map to orient your map with north.

- Use the compass to find which direction is 20^{o}E.
- Walk 500 meters in that direction to reach your destination.
- Polar coordinates are used in a sport called orienteering. People who do orienteering use a compass and a map with polar coordinates. Participants find their way along a course across wilderness terrain (**Figure** 2.22). They move to various checkpoints along the course. The winner is the person who completes the course in the fastest time.

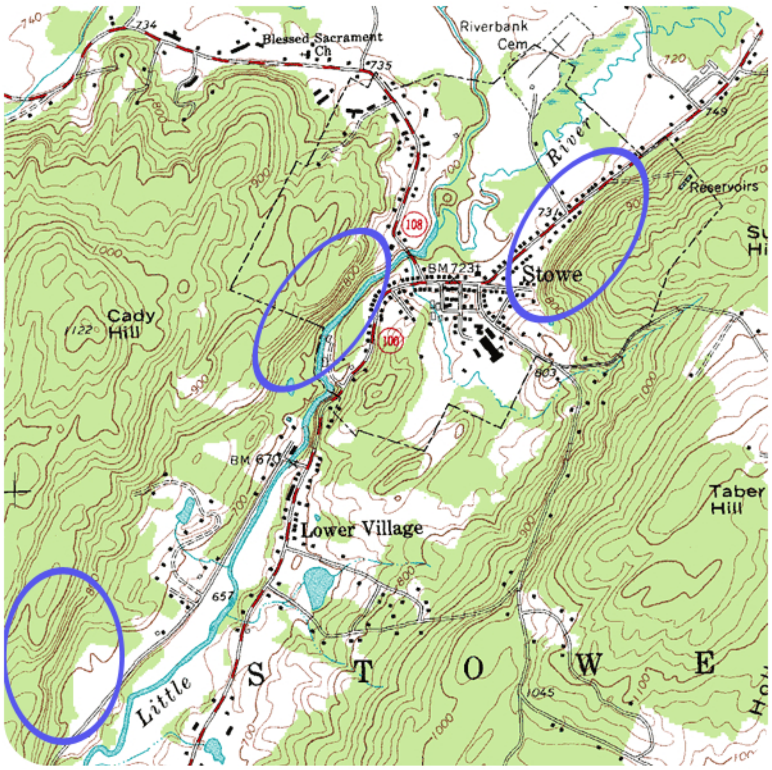


FIGURE 2.22
A topographic map like one that you might use for the sport of orienteering.

Globe

Earth is a sphere and so is a globe. A globe is the best way to make a map of the whole Earth. Because both the planet and a globe have curved surfaces, the sizes and shapes of countries are not distorted. Distances are true to scale. (**Figure** 2.23).

Globes usually have a geographic coordinate system and a scale. The shortest distance between two points on a globe is the length of the portion of a circle that connects them. Globes are difficult to make and carry around. They also cannot be enlarged to show the details of any particular area. Globes are best sitting on your desk for reference.

Google Earth is a neat site to download to your computer. This is a link that you can follow to get there: http://www.earth.google.com/download-earth.html . The maps on this site allow you to zoom in or out, look from above, tilt your image and lots more.

FIGURE 2.23
A globe is the most accurate way to represent Earth's curved surface.

Lesson Summary

- Maps and globes are models of Earth's surface. There are many ways to project the three-dimensional surface of Earth on to a flat map. Each type of map has some advantages as well as disadvantages.
- Most maps use a geographic coordinate system to help you find your location using latitude and longitude.
- Globes are the most accurate representations, because they are round like Earth, but they cannot be carried around easily. Globes also cannot show the details of Earth's surface that maps can.

Lesson Review Questions

Recall

1. Describe each of the following. What is each one good for? What is each one not good for?

- Mercator projection map
- Robinson projection map
- Globe

2. What does it mean to say that your location is 52 degrees south and 143 degrees west?

3. Why were early explorers happy with Mercator projections?

Apply Concepts

4. Use **Figure** 2.24. In what country are you located, if your coordinates are 60^oN and 120^oW?

5. Which of the following map projections gives you the least distortion around the poles?

- Mercator projection map
- Robinson projection map
- Conic projection

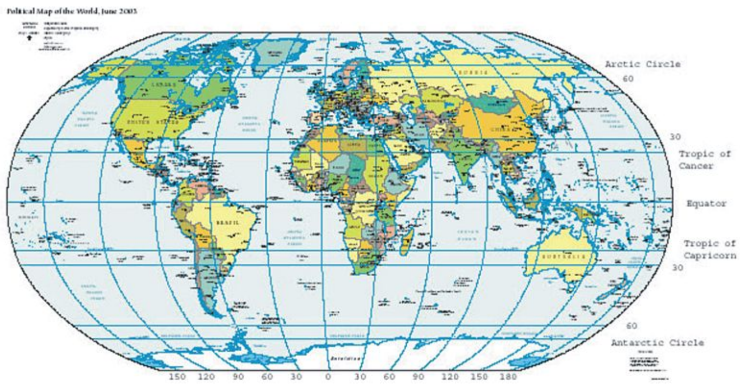


FIGURE 2.24
World map with geographic coordinate system

Think Critically

6. Imagine that you are going out into the field to do geology. What type of Earth model (map projection, globe) would be best to take with you?

7. Would you choose a map that used a Mercator projection if you were going to explore Antarctica? Explain why. Is there another type of map that would be better?

Points to Consider

- How does a flight between two cities drawn on a globe compare with the same flight drawn on a map?
- How do people doing orienteering follow directions across wild terrain?
- Latitude and longitude give your location in two dimensions. How do you give your location in three dimensions? What is that third dimension?

2.3 Topographic Maps

Lesson Objectives

- Describe a topographic map.
- Explain what information a topographic map contains.
- Explain how to read and interpret a topographic map.
- Explain how various Earth scientists use topographic maps to study Earth.

Vocabulary

- contour interval
- contour lines
- topographic map

Introduction

Anyone who knows how to read a topographic map can "see" the landscape of a region without being there. A mountaineer could plan the best route for a mountain climbing trip. An engineer could plan the best location for a road or power plant. A tourist can get an idea of what they are going to see on their vacation. Topographic maps are interesting and fun to use.

What is a Topographic Map?

Mapping is an important part of Earth Science. **Topographic maps** use a line, called a contour line, to show different elevations on a map. **Contour lines** show the location of hills, mountains and valleys. A regular road map shows where a road goes. But a road map doesn't show if the road goes over a mountain pass or through a valley. A topographic map shows you the features the road is going through or past. Let's look at topographic maps.

Look at this view of the Swamp Canyon Trail in Bryce Canyon National Park, Utah (**Figure** 2.25). You can see the rugged canyon walls and valley below. The terrain has many steep cliffs with high and low points between the cliffs.

Now look at the same section of the visitor's map (**Figure** 2.26). You can see a green line that is the main road. The black dotted lines are trails. You see some markers for campsites, a picnic area, and a shuttle bus stop. The map does not show the height of the terrain. Where are the hills and valleys located? What is Natural Bridge? How high are the canyon walls? Which way do streams flow?

A topographic map represents the elevations in an area (**Figure** 2.27). We mentioned topographic maps in the section on orienteering above.

FIGURE 2.25
View of Swamp Canyon in Bryce Canyon National Park.

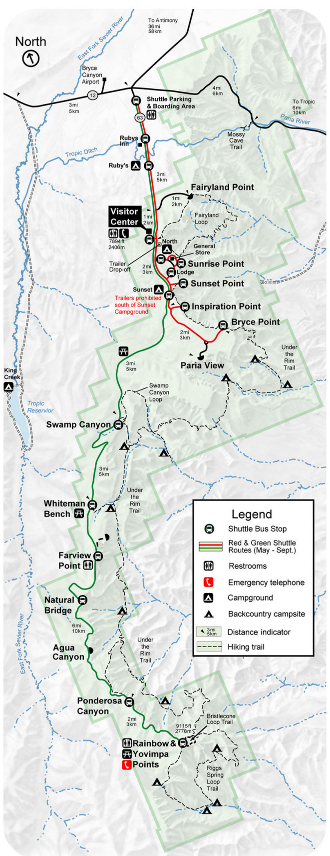


FIGURE 2.26
A map of a portion of Bryce Canyon National Park road map showing Swamp Canyon Loop.

Contour Lines

Contour lines connect all the points on the map that have the same elevation. Let's take a closer look at this (**Figure** 2.27).

Each contour line represents a specific elevation. The contour line connects all the points that are at the same

FIGURE 2.27
Topographic map of Swamp Canyon Trail portion of Bryce Canyon National Park.

elevation. Every fifth contour line is made bold. The bold contour lines have numbers to show elevation. Contour lines run next to each other and NEVER cross one another. If the lines crossed it would mean that one place had two different elevations. This cannot happen.

Contour Intervals

Since each contour line represents a specific elevation, two different contour are separated by the same difference in elevation (e.g. 20 ft or 100 ft.). This difference between contour lines is called the **contour interval**. You can calculate the contour interval by following these steps:

a. Take the difference in elevation between 2 bold lines.

b. Divide that difference by the number of contour lines between them.

Imagine that the difference between two bold lines is 100 feet and there are five lines between them. What is the contour interval? If you answered 20 feet, then you are correct (100 ft/5 lines = 20 ft between lines).

The legend on the map also gives the contour interval.

Interpreting Contour Maps

How does a topographic map tell you about the terrain? Let's consider the following principles:

1. **The spacing of contour lines shows the slope of the land**. Contour lines that are close together indicate a steep slope. This is because the elevation changes quickly in a small area. Contour lines that seem to touch indicate a very steep slope, like a cliff. When contour lines are spaced far apart the slope is gentle. So contour lines help us see the three-dimensional shape of the land.

Look at the topographic map of Stowe, Vermont (**Figure** 2.28). There is a steep hill rising just to the right of the city of Stowe. You can tell this because the contour lines there are closely spaced. The contour lines also show that the hill has a sharp rise of about 200 feet. Then the slope becomes less steep toward the right.

2. **Concentric circles indicate a hill**. **Figure** 2.29 shows another side of the topographic map of Stowe, Vermont. When contour lines form closed loops, there is a hill. The smallest loops are the higher elevations on the hill. The

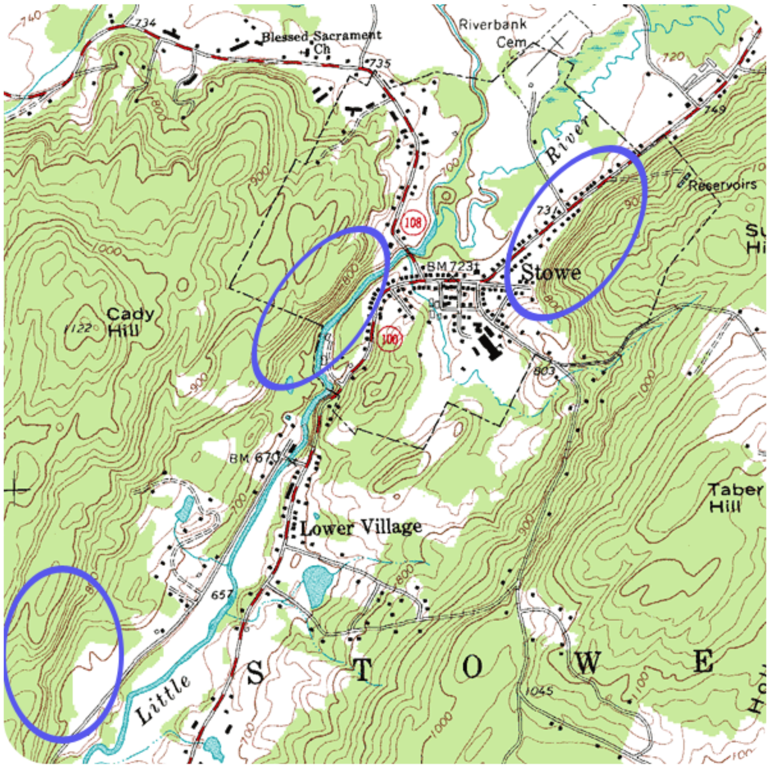


FIGURE 2.28
Portion of a USGS topographic map of Stowe, VT.

larger loops encircling the smaller loops are downhill. If you look at the map, you can see Cady Hill in the lower left and another, smaller hill in the upper right.

3. **Hatched concentric circles indicate a depression**. The hatch marks are short, perpendicular lines inside the circle. The innermost hatched circle represents the deepest part of the depression. The outer hatched circles represent higher elevations (**Figure** 2.30).

4. **V-shaped portions of contour lines indicate stream valleys.** The "V" shape of the contour lines point uphill. There is a V shape because the stream channel passes through the point of the V. The open end of the V represents the downstream portion. A blue line indicates that there is water running through the valley. If there is not a blue line the V pattern indicates which way water flows. In **Figure** 2.31, you can see examples of V-shaped markings. Try to find the direction a stream flows.

5. **Like other maps, topographic maps have a scale so that you can find the horizontal distance**. You can use the horizontal scale to calculate the slope of the land (vertical height/horizontal distance). Common scales used in United States Geological Service (USGS) maps include the following:

- 1:24,000 scale –1 inch = 2000 ft
- 1:100,000 scale –1 inch = 1.6 miles
- 1:250,000 scale –1 inch = 4 miles

Including contour lines, contour intervals, circles, and V-shapes allows a topographic map to show three-dimensional information on a flat piece of paper. A topographic map gives us a good idea of the shape of the land.

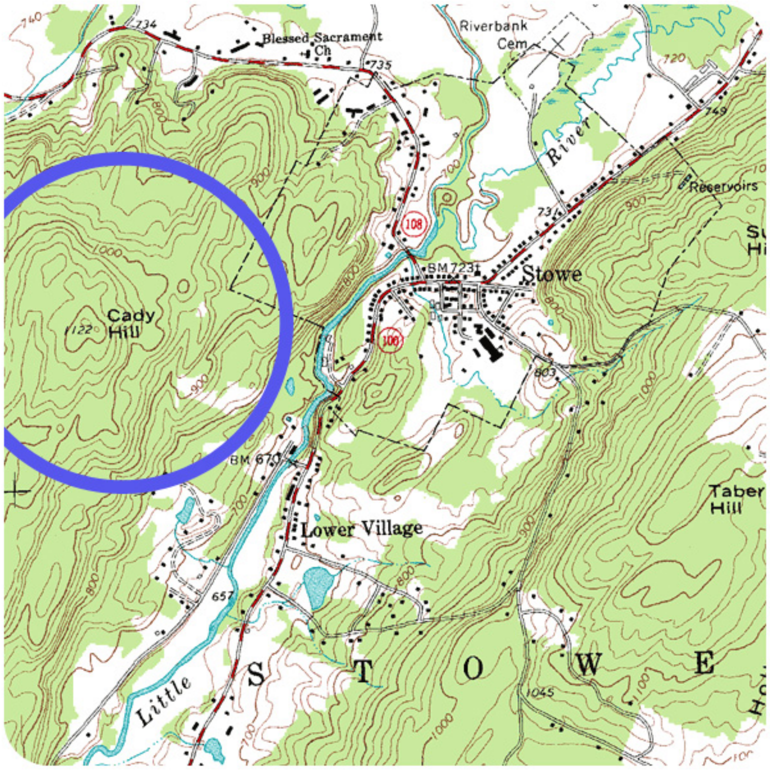


FIGURE 2.29
Portion of a USGS topographic map of Stowe, VT. Cady Hill (elevation 1122 ft) is shown by concentric circles in the lower left portion of the map. Another hill (elevation ~ 960 ft) is on the upper right portion of the map.

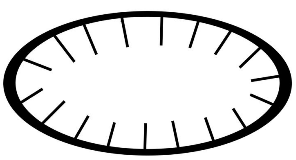


FIGURE 2.30
On a contour map, a circle with inward hatches indicates a depression.

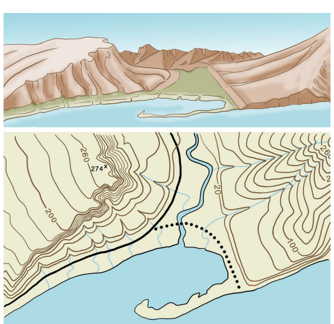


FIGURE 2.31
Illustrations of three-dimensional ground configurations (top) and corresponding topographic map (bottom). Note that the V-shaped markings on the topographic maps correspond to drainage channels. Also, the closely-spaced contour lines denote the rapid rising cliff face on the left side.

Information from Topographic Maps

As we mentioned above, topographic maps show the shape of the land. You can determine a lot of information about the landscape using a topographic map. These maps are invaluable for Earth scientists.

How Do Earth Scientists Use Topographic Maps?

Earth scientists use topographic maps for many things:

- Describing and locating surface features, especially geologic features.
- Determining the slope of the Earth's surface.
- Determining the direction of flow for surface water, groundwater, and mudslides.

Hikers, campers, and even soldiers use topographic maps to locate their positions in the field. Civil engineers use topographic maps to determine where roads, tunnels, and bridges should go. Land use planners and architects use topographic maps when planning development projects, such as housing projects, shopping malls, and roads.

Bathymetric Maps

Oceanographers use a type of topographic map that shows water depths (**Figure** 2.33). On this map, the contour lines represent depth below the surface. Therefore, high numbers are deeper depths and low numbers are shallow depths. These maps are made from depth soundings or sonar data. They help oceanographers understand the shape of bottoms of lakes, bays, and the ocean. This information also helps boaters navigate safely.

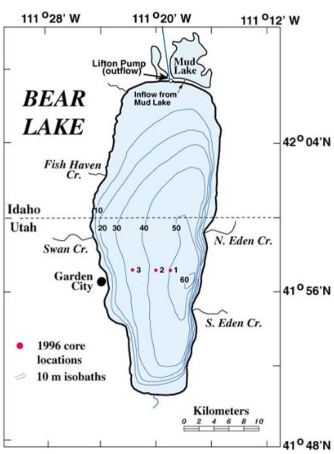


FIGURE 2.32

Bathymetric map of Bear Lake, Utah.

Geologic Maps

A geologic map shows the different rocks that are exposed at the surface of a region. Rock units are shown in a color identified in a key. On the geologic map of the Grand Canyon, for example, different rock types are shown in different colors. Some people call the Grand Canyon "layer cake geology" because most of the rock units are in layers. Rock units show up on both sides of a stream valley.

A geologic map looks very complicated in a region where rock layers have been folded, like the patterns in marble cake. Faults are seen on this geologic map cutting across rock layers. When rock layers are tilted, you will see stripes of each layer on the map. There are symbols on a geologic map that tell you which direction the rock layers slant, and often there is a cut away diagram, called a cross section, that shows what the rock layers look like below the surface. A large-scale geologic map will just show geologic provinces. They do not show the detail of individual rock layers.

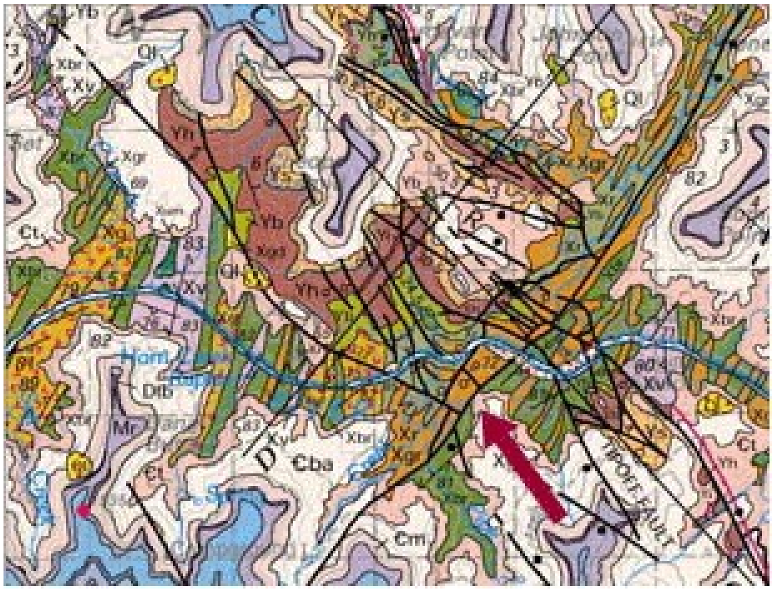


FIGURE 2.33

A portion of the geologic map of the Grand Canyon, Arizona.

Lesson Summary

- Topographic maps are flat maps that show the three-dimensional surface features of an area. Topographic maps help users see the how the land changes in elevation.
- Contour lines on a topographic map connect points of equal elevation above sea level.
- Contour lines run next to each other. Each contour line is separated by a constant difference in elevation, usually noted on the map.
- Topographic maps have a horizontal scale to indicate horizontal distances.
- People use topographic maps to locate interesting landforms, to find their way through an area, and to determine the direction water flows in an area.
- Oceanographers use bathymetric maps to show the features of the bottom of a body of water.
- Geologic maps display rock units and geologic features. A small scale map displays individual rock units while a large scale map shows geologic provinces.

Lesson Review Questions

Recall

1. Describe what the following features would look like on a topographic map.

- a stream channel
- a hilltop
- a valley
- a cliff

2. How do you find a stream valley on a topographic map? How can you tell if the stream has water in it all year round? How can you determine which way the water is flowing?

3. If you were the captain of a very large boat, what type of map would you want to have to keep your boat traveling safely?

Apply Concepts

4. Draw a topographic map of a steep slow that slowly enters a valley. Draw a topographic map of a steep cliff that is almost perpendicular to a valley.

5. On a topographic map, six contour lines span a horizontal distance of 0.5 inches. The horizontal scale is 1 inch equals 2000 ft. How far apart are the first and sixth lines?

Think Critically

6. On a topographic map, five contour lines are very close together in one area. What is the shape of these lines if the feature is a hill? What is the shape of these lines if the feature is a cliff?

7. On a topographic map, a river is shown crossing from Point A in the northwest to Point B in the southeast. Point A is on a contour line of 1800 ft and Point B is on a contour line of 2400 ft. In which direction does the river flow?

8. On the geologic map of the Grand Canyon, a rock unit called the Kaibab Limestone takes up the entire surface of the region. Down some steep topographic lines is a very thin rock unit called the Toroweap Formation and just in from that is another thin unit, the Coconino sandstone. Describe how these three rock units sit relative to each other.

Points to Consider

- Imagine that you are a civil engineer. How could you use a topographic map to build a road, bridge, or tunnel through an area like the one shown in **Figure** 2.29? Would you want your road to go up and down or remain as flat as possible? What areas would need a bridge in order to cross them easily? Can you find a place where a tunnel would be helpful?
- If you wanted to participate in orienteering, would it be better to have a topographic map or a regular road map? How would a topographic map help you?

2.4 Using Satellites and Computers

Lesson Objectives

- Describe various types of satellite images and the information that each provides.
- Explain how a Global Positioning System (GPS) works.
- Explain how computers can be used to make maps.

Vocabulary

- Geographic Information System (GIS)
- geostationary orbit
- polar orbit

Introduction

If you look at the surface of the Earth from your yard or street, you can only see a short distance. If you climb a tree or go to the top floor of your apartment building, you can see further. If you flew over your neighborhood in a plane, you could see still further. Finally, if you orbited the Earth, you would be able to see a very large portion of the planet. This is why scientists use satellites to get a good view of Earth. To see things on a large scale, you need to get the highest view.

What Satellites Can Do

To understand what satellites can do, let's look at an example. One of the deadliest hurricanes in United States history hit Galveston, Texas in 1900. The storm was first spotted at sea on Monday, August 27th, 1900. It was a tropical storm when it hit Cuba on September 3rd. By September 8th, it had intensified to a hurricane over the Gulf of Mexico. It came ashore at Galveston (**Figure** 2.34). Because there was not advanced warning, more than 8000 people lost their lives.

Today, we have satellites with many different types of instruments that orbit the Earth. With these satellites, satellites can see hurricanes form at sea. They can follow hurricanes as they move from far out in the oceans to shore. Weather forecasters can warn people who live along the coasts. These advanced warning give people time to prepare for the storm. They can find a safe place or even evacuate the area, which helps save lives.

FIGURE 2.34
Left: Track of hurricane that hit Galveston, Texas on Sept. 8, 1900. Right: Galveston in the aftermath.

Satellite Orbits

Satellites orbit high above the Earth in several ways. Different orbits are important for viewing different things about the planet.

Geostationary Orbit

A satellite in a **geostationary orbit** flies above the planet at a distance of 36,000 km. It takes 24 hours to complete one orbit. The satellite and the Earth both complete one rotation in 24 hours. This means that the satellite stays over the same spot. Weather satellites use this type of orbit to observe changing weather conditions over a region. Communications satellites, like satellite TV, use this type of orbit to keep communications going full time.

Polar Orbit

Another useful orbit is the **polar orbit** (**Figure** 2.35). The satellite orbits at a distance of several hundred kilometers. It makes one complete orbit around the Earth from the North Pole to the South Pole about every 90 minutes. In this same amount of time, the Earth rotates only slightly underneath the satellite. So in less than a day, the satellite can see the entire surface of the Earth. Some weather satellites use a polar orbit to see how the weather is changing globally. Also, some satellites that observe the land and oceans use a polar orbit.

Scientific Satellites

The National Aeronautics and Space Administration (NASA) has launched a fleet of satellites to study the Earth (**Figure** 2.36). The satellites are operated by several government agencies, including NASA, the National Oceano-

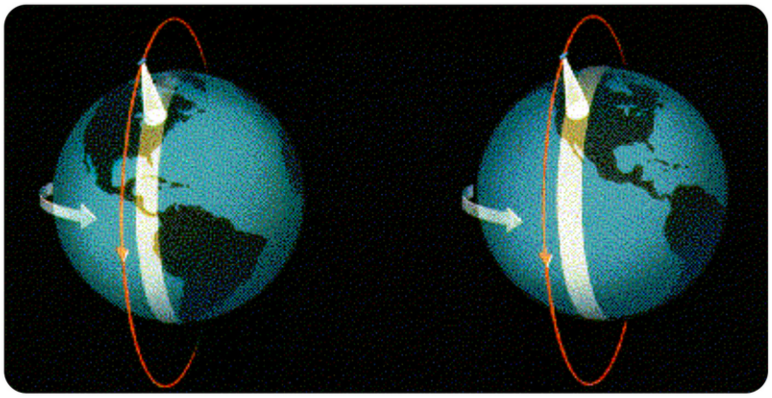


FIGURE 2.35
Satellite in a polar orbit.

graphic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS). By using different types of scientific instruments, satellites make many kinds of measurements of the Earth.

FIGURE 2.36
NASA's fleet of satellites to study the Earth.

- Some satellites measure the temperatures of the land and oceans.
- Some record amounts of gases in the atmosphere, such as water vapor and carbon dioxide.
- Some measure their height above the oceans very precisely. From this information, they can measure sea level.
- Some measure the ability of the surface to reflect various colors of light. This information tells us about plant life.

Some examples of the images from these types of satellites are shown in **Figure** 2.37.

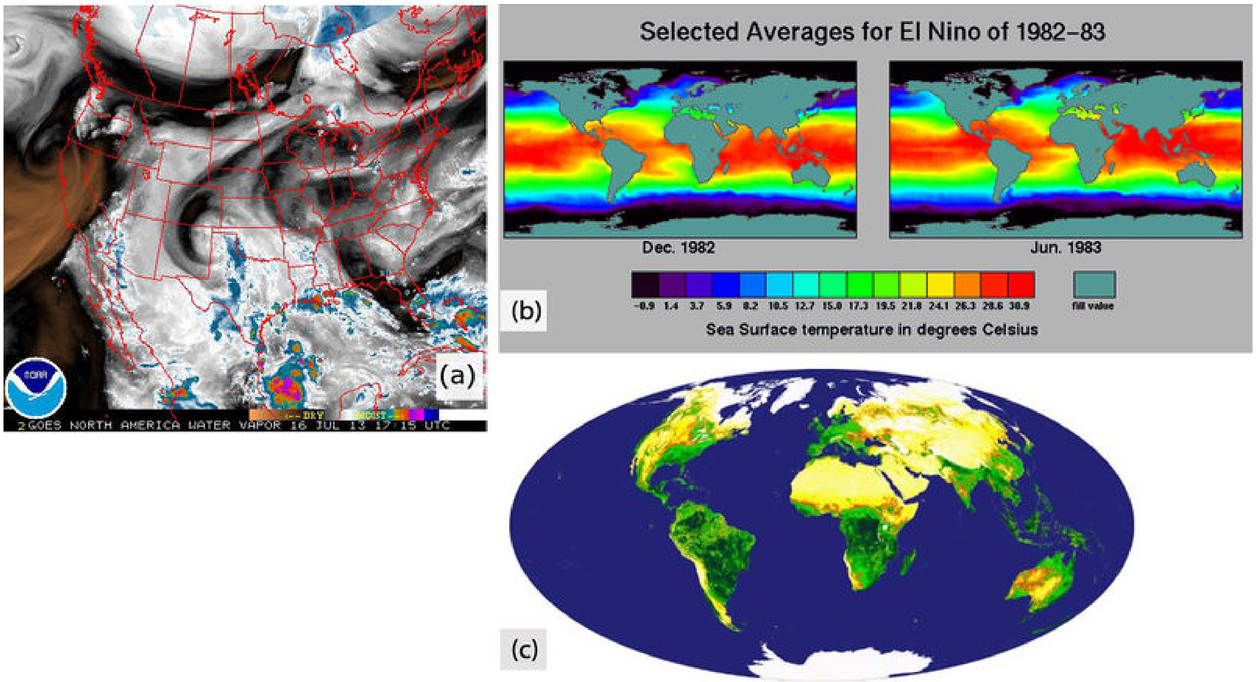


FIGURE 2.37
Various satellite images: (a) water vapor in atmosphere, (b) ocean surface temperatures, (c) global vegetation.

Global Positioning System

In order to locate your position on a map, you must know your latitude and your longitude. But you need several instruments to measure latitude and longitude. What if you could do the same thing with only one instrument? Satellites can also help you locate your position on the Earth's surface.

By 1993, the United States military had launched 24 satellites to help soldiers locate their positions on battlefields. This system of satellites was called the Global Positioning System (GPS). Later, the United States government allowed the public to use this system. Here's how it works.

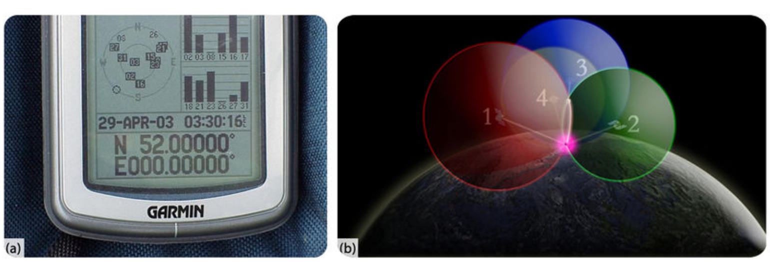


FIGURE 2.38
(a) You need a GPS receiver to use the GPS system. (b) It takes signals from 4 GPS satellites to find your location precisely on the surface

You must have a GPS receiver to use the system (**Figure** 2.38). You can buy many types of these in stores. The

GPS receiver detects radio signals from nearby GPS satellites. There are precise clocks on each satellite and in the receiver. The receiver measures the time for radio signals from satellite to reach it. The receiver uses the time and the speed of radio signals to calculate the distance between the receiver and the satellite. The receiver does this with at least four different satellites to locate its position on the Earth's surface (**Figure** 2.38). GPS receivers are now being built into many items, such as cell phones and cars.

Computer-Generated Maps

Prior to the late 20th and early 21st centuries, mapmakers sent people out in the field to determine the boundaries and locations for various features for maps. State or county borders were used to mark geological features. Today, people in the field use GPS receivers to mark the locations of features. Map-makers also use various satellite images and computers to draw maps. Computers are able to break apart the fine details of a satellite image, store the pieces of information, and put them back together to make a map. In some instances, computers can make 3-D images of the map and even animate them. For example, scientists used computers and satellite images from Mars to create a 3-D image of Mars' ice cap (**Figure** 2.39). The image makes you feel as if you are looking at the ice cap from the surface of Mars.

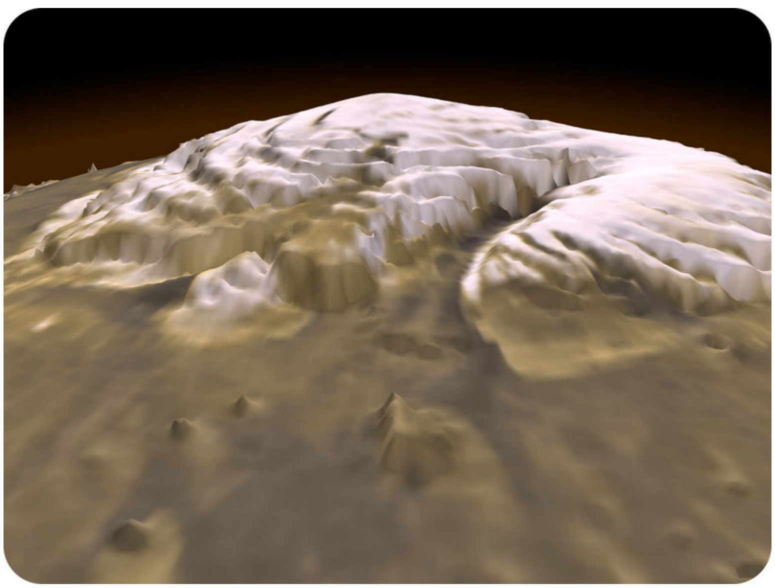


FIGURE 2.39
This three-dimensional image of Mars' north pole was made from satellite images and computers.

When you link any type of information to a location, you can put together incredibly useful maps and images. The information could be numbers of people living in an area, types of plants or soil, locations of groundwater or levels of rainfall. As long as you can link the information to a position with a GPS receiver, you can store it in a computer for later processing and map-making. This type of mapping is called a **Geographic Information System (GIS)**. Geologists can use GIS to make maps of natural resources. City leaders might link these resources to where people live and help plan the growth of cities or communities. Other types of data can be linked by GIS. For example, **Figure** 2.40 shows a map of the counties where farmers made insurance claims for crop damage in 2008.

Computers have improved how maps are made. They have also increased the amount of information that can be displayed. During the 21st century, computers will be used more and more in mapping.

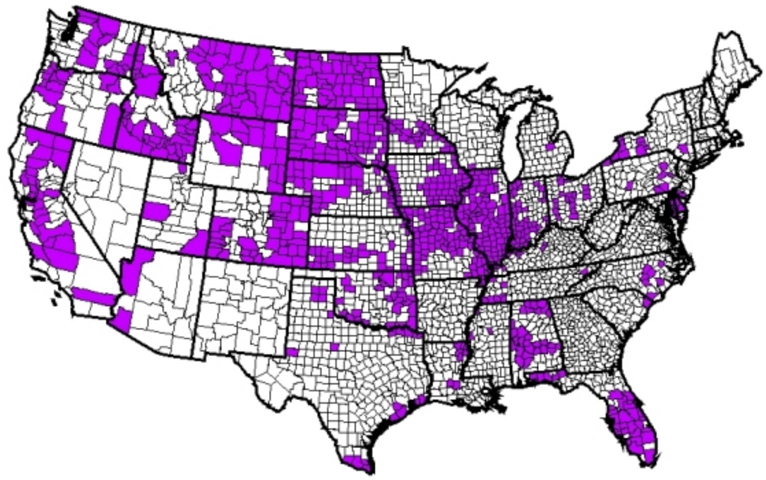


FIGURE 2.40
Map of insurance filings for crop damage in 2008.

Lesson Summary

- Satellites give a larger view of the Earth's surface from high above. They carry instruments that make many types of measurements for Earth scientists.
- Satellites can enter different types of Earth orbits to gather different types of information.
- A group of specialized satellites called Global Positioning Satellites help people to pinpoint their location.
- Location information, satellite views, and other information can be linked together in Geographical Information Systems (GIS).

Lesson Review Questions

Recall

1. What is the use of each of these types of satellites?

- weather satellite
- communications satellite
- global positioning satellite
- climate satellite

2. What is Geographical Information System, or GIS, used for?

Apply Concepts

3. Explain the difference between geostationary orbits and polar orbits.

4. What if you had a GPS that could track only one satellite? Two satellites? How many satellites do you need for a good estimate of your location? Why that number?

Thinking Critically

5. What would have happened if there had been satellites during the time of the 1900 Galveston earthquake?

6. What would have happened if there had been no satellites when hurricane Katrina struck the Gulf of Mexico coast in 2005?

Points to Consider

- How is tracking a hurricane different from trying to predict where a tornado will strike?
- People have GPS units in their cars. What skills are they no longer using if they use a GPS?
- What do images of objects in space do for our view of humans and of the universe?

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CHAPTER 3 MS Earth's Minerals

Chapter Outline

Scientists have discovered more than 4,000 minerals in Earth's crust. Some minerals are found in very large amounts. Most minerals are found in small amounts. Some are very rare. Some are common. Many minerals are useful. Modern society depends on minerals and rocks that are mined. Mining is difficult work, but is necessary for us to have the goods we use.

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3.1 Minerals

Lesson Objectives

- Describe the properties that all minerals share.
- Describe some different crystal structures of minerals.
- Identify the groups in which minerals are classified.

Vocabulary

- atom
- chemical compound
- crystal
- compound
- electron
- element
- ion
- matter
- mineral
- molecule
- neutron
- nucleus
- proton
- silicate

Introduction

You use objects that are made from minerals every day, even if you do not realize it. You are actually eating a mineral when you eat food that contains salt. You are drinking from a mineral when you drink from a glass. You might wear silver jewelry. The shiny metal silver, the white grains of salt, and the clear glass may not seem to have much in common, but they are all made from minerals (**Figure** 3.1). Silver is a mineral. Table salt is the mineral halite. Glass is produced from the mineral quartz.

Just looking at that list you see that minerals are very different from each other. If minerals are so different, what do all minerals have in common?

What is Matter?

To understand minerals, we must first understand matter. **Matter** is the substance that physical objects are made of.

FIGURE 3.1
Silver is used to make sterling silver jewelry. Table salt is the mineral halite. Glass is produced from the mineral quartz.

Atoms and Elements

The basic unit of matter is an **atom**. At the center of an atom is its **nucleus**. **Protons** are positively charged particles in the nucleus. Also in the nucleus are **neutrons** with no electrical charge. Orbiting the nucleus are tiny electrons. **Electrons** are negatively charged. An atom with the same number of protons and electrons is electrically neutral. If the atom has more or less electrons to protons it is called an **ion**. An ion will have positive charge if it has more protons than electrons. It will have negative charge if it has more electrons than protons.

An atom is the smallest unit of a chemical **element**. That is, an atom has all the properties of that element. All atoms of the same element have the same number of protons.

Molecules and Compounds

A **molecule** is the smallest unit of a **chemical compound**. A compound is a substance made of two or more elements. The elements in a chemical compound are always present in a certain ratio.

Water is probably one of the simplest compounds that you know. A water molecule is made of two hydrogen atoms and one oxygen atom (**Figure** 3.2). All water molecules have the same ratio: two hydrogen atoms to one oxygen atom.

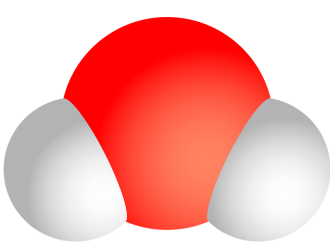

FIGURE 3.2
A water molecule has two hydrogen atoms (shown in gray) bonded to one oxygen molecule (shown in red).

What are Minerals?

A **mineral** is a solid material that forms by a natural process. A mineral can be made of an element or a compound. It has a specific chemical composition that is different from other minerals. One mineral's physical properties differ from others'. These properties include crystal structure, hardness, density and color. Each is made of different elements. Each has different physical properties. For example, silver is a soft, shiny metal. Salt is a white, cube-shaped crystal. Diamond is an extremely hard, translucent crystal.

Natural Processes

Minerals are made by natural processes. The processes that make minerals happen in or on the Earth. For example, when hot lava cools, mineral crystals form. Minerals also precipitate from water. Some minerals grow when rocks are exposed to high pressures and temperatures.

Could something like a mineral be made by a process that was not natural? People make gemstones in a laboratory. Synthetic diamond is a common one. But that stone is not a mineral. It was not formed by a natural process.

Inorganic Substances

A mineral is an inorganic substance. It was not made by living organisms. Organic substances contain carbon. Some organic substances are proteins, carbohydrates, and oils. Everything else is inorganic. In a few cases, living organisms make inorganic materials. The calcium carbonate shells made by marine animals are inorganic.

Definite Composition

All minerals have a definite chemical makeup. A few minerals are made of only one kind of element. Silver is a mineral made only of silver atoms. Diamond and graphite are both made only of the element carbon.

Minerals that are not pure elements are made of chemical compounds. For example, the mineral quartz is made of the compound silicon dioxide, or SiO_2. This compound has one atom of the element silicon for every two atoms of the element oxygen.

Each mineral has its own unique chemical formula. For example, the mineral hematite has two iron atoms for every three oxygen atoms. The mineral magnetite has three iron atoms for every four oxygen atoms. Many minerals have very complex chemical formulas that include several elements. However, even in more complicated compounds, the elements occur in definite ratios.

Solid Crystals

Minerals must be solid. For example, ice and water have the same chemical composition. Ice is a solid, so it is a mineral. Water is a liquid, so it is not a mineral.

Some solids are not crystals. Glass, or the rock obsidian, are solid but not crystals. In a **crystal**, the atoms are arranged in a pattern. This pattern is regular and it repeats. **Figure** 3.3 shows how the atoms are arranged in halite (table salt). Halite contains atoms of sodium and chlorine in a pattern. Notice that the pattern goes in all three dimensions.

The pattern of atoms in all halite is the same. Think about all of the grains of salt that are in a salt shaker. The atoms are arranged in the same way in every piece of salt.

Sometimes two different minerals have the same chemical composition. But they are different minerals because they have different crystal structures. Diamonds are beautiful gemstones because they are very pretty and very hard.

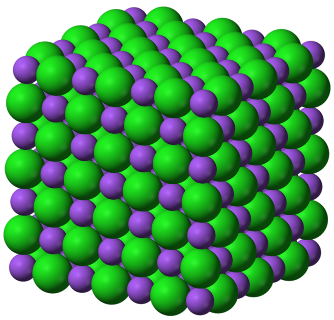

FIGURE 3.3
Sodium ions (purple balls) bond with chloride ions (green balls) to form halite crystals.

Graphite is the "lead" in pencils. It's not hard at all! Amazingly, both are made just of carbon. Compare the diamond with the pencil lead in **Figure** 3.4. Why are they so different? The carbon atoms in graphite bond to form layers. The bonds between each layer are weak. The carbon sheets can just slip past each other. The carbon atoms in diamonds bond together in all three directions. This strong network makes diamonds very hard.

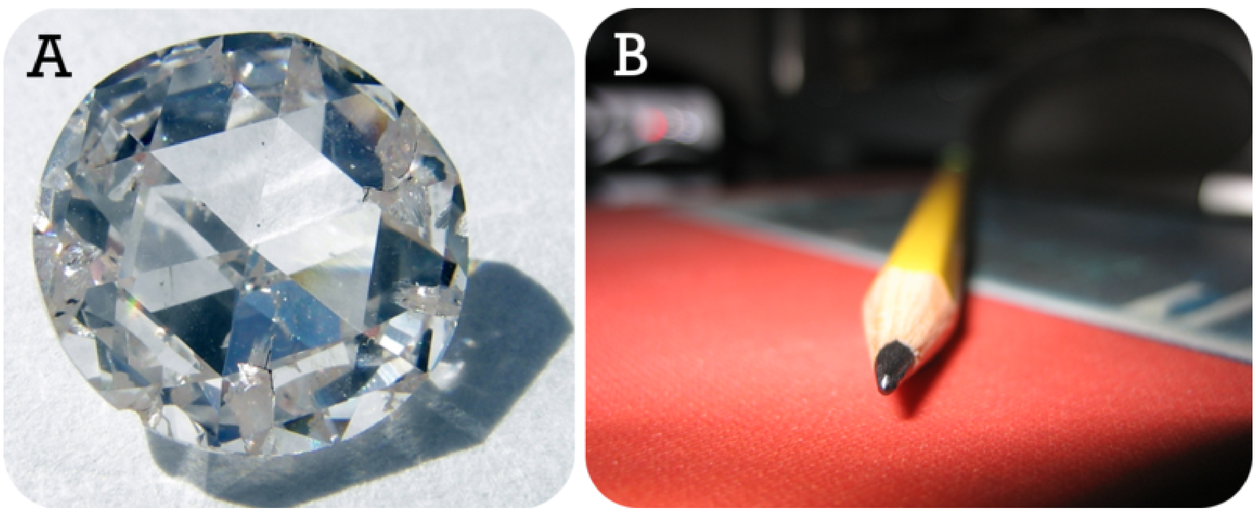

FIGURE 3.4
Diamonds (A) and graphite (B) are both made of only carbon, but they're not much alike.

Physical Properties

The patterns of atoms that make a mineral affect its physical properties. A mineral's crystal shape is determined by the way the atoms are arranged. For example, you can see how atoms are arranged in halite in **Figure** 3.3. You can see how salt crystals look under a microscope in **Figure** 3.5. Salt crystals are all cubes whether they're small or large.

Other physical properties help scientists identify different minerals. They include:

- Color: the color of the mineral.
- Streak: the color of the mineral's powder.

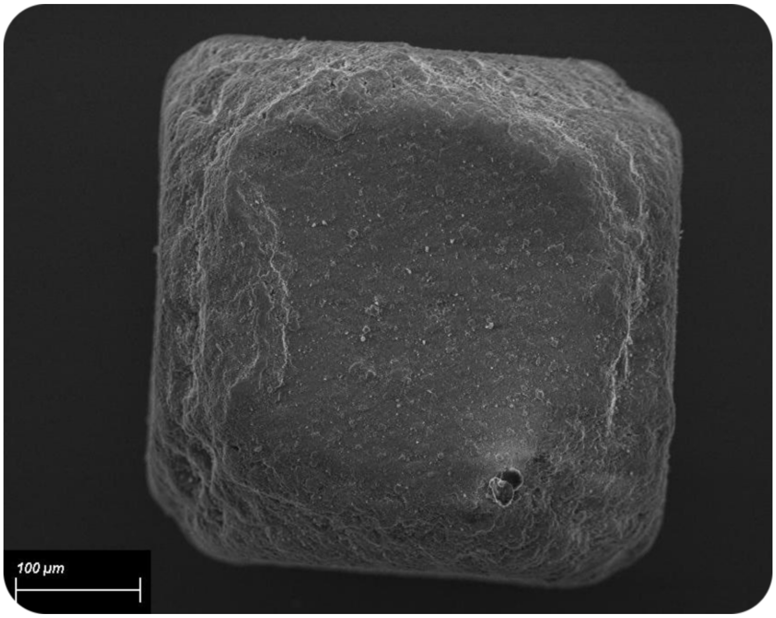

FIGURE 3.5
Under a microscope, salt crystals are cubes.

- Luster: the way light reflects off the mineral's surface.
- Specific gravity: how heavy the mineral is relative to the same volume of water.
- Cleavage: the mineral's tendency to break along flat surfaces.
- Fracture: the pattern in which a mineral breaks.
- Hardness: what minerals it can scratch and what minerals can scratch it.

Groups of Minerals

Imagine you are in charge of organizing more than 100 minerals for a museum exhibit. People can learn a lot more if they see the minerals together in groups. How would you group the minerals together in your exhibit?

Mineralogists are scientists who study minerals. They divide minerals into groups based on chemical composition. Even though there are over 4,000 minerals, most minerals fit into one of eight mineral groups. Minerals with similar crystal structures are grouped together.

Silicate Minerals

About 1,000 silicate minerals are known. This makes silicates the largest mineral group. Silicate minerals make up over 90 percent of Earth's crust!

Silicates contain silicon atoms and oxygen atoms. One silicon atom is bonded to four oxygen atoms. These atoms form a pyramid (**Figure** 3.6). The silicate pyramid is the building block of silicate minerals. Most silicates contain other elements. These elements include calcium, iron, and magnesium.

Silicate minerals are divided into six smaller groups. In each group, the silicate pyramids join together differently. The pyramids can stand alone. They can form into connected circles called rings. Some pyramids link into single and double chains. Others form large, flat sheets. Some join in three dimensions.

Feldspar and quartz are the two most common silicates. In beryl, the silicate pyramids join together as rings. Biotite is mica. It can be broken apart into thin, flexible sheets. Compare the beryl and the biotite shown in **Figure** 3.7.

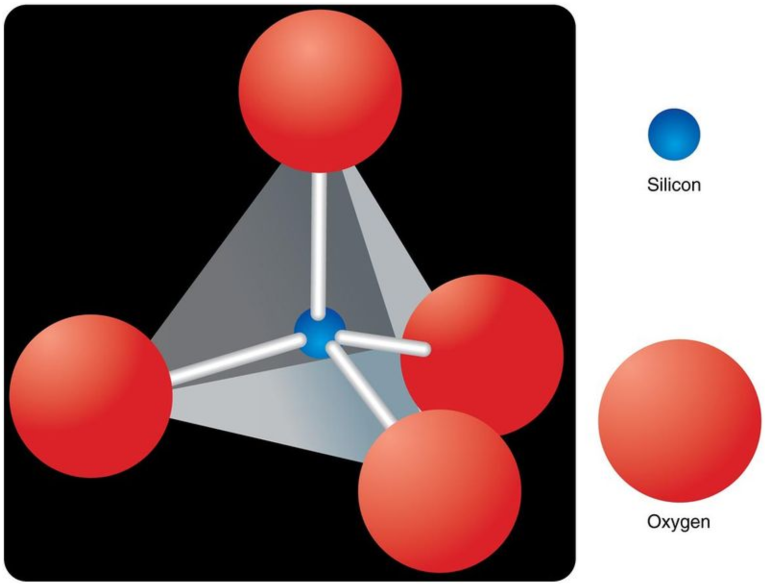

FIGURE 3.6
One silicon atom bonds to four oxygen atoms to form a pyramid

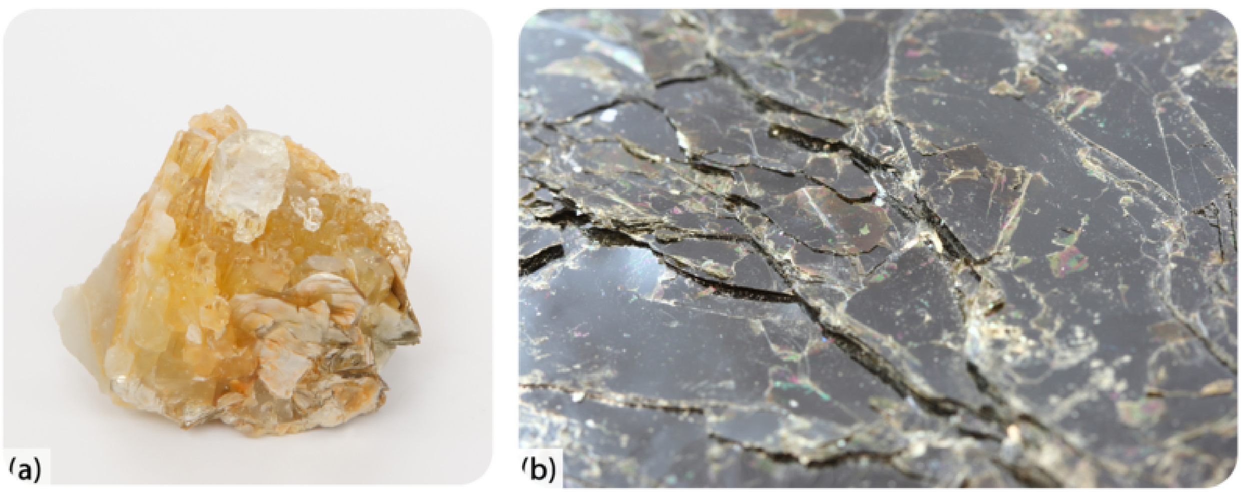

FIGURE 3.7
Beryl (a) and biotite (b) are both silicate minerals.

Native Elements

Native elements contain only atoms of one type of element. They are not combined with other elements. There are very few examples of these types of minerals. Some native elements are rare and valuable. Gold, silver, sulfur, and diamond are examples.

Carbonates

What do you guess **carbonate** minerals contain? If you guessed carbon, you would be right! All carbonates contain one carbon atom bonded to three oxygen atoms. Carbonates may include other elements. A few are calcium, iron, and copper.

Carbonate minerals are often found where seas once covered the land. Some carbonate minerals are very common. Calcite contains calcium, carbon, and oxygen. Have you ever been in a limestone cave or seen a marble tile? Calcite is in both limestone and marble. Azurite and malachite are also carbonate minerals, but they contain copper instead of calcium. They are not as common as calcite. They are used in jewelry. You can see in **Figure** 3.8 that they are very colorful.

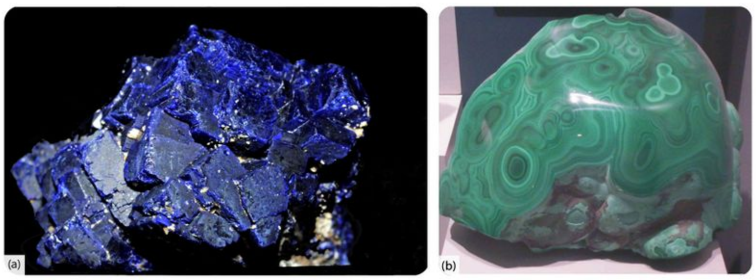

FIGURE 3.8
The deep blue mineral is azurite and the green is malachite. Both of these carbonate minerals are used for jewelry.

Halides

Halide minerals are salts. They form when salt water evaporates. This mineral class includes more than just table salt. Halide minerals may contain the elements fluorine, chlorine, bromine, or iodine. Some will combine with metal elements. Common table salt is a halide mineral that contains the elements chlorine and sodium. Fluorite is a type of halide that contains fluorine and calcium. Fluorite can be found in many colors. If you shine an ultraviolet light on fluorite, it will glow!

Oxides

Earth's crust contains a lot of oxygen. The oxygen combines with many other elements to create oxide minerals. Oxides contain one or two metal elements combined with oxygen. Oxides are different from silicates because they do not contain silicon. Many important metals are found as oxides. For example, hematite and magnetite are both oxides that contain iron. Hematite (Fe_2O_3) has a ratio of two iron atoms to three oxygen atoms. Magnetite (Fe_3O_4) has a ratio of three iron atoms to four oxygen atoms. Notice that the word "magnetite" contains the word "magnet". Magnetite is a magnetic mineral.

Phosphates

Phosphate minerals have a structure similar to silicates. In silicates, an atom of silicon is bonded to oxygen. In phosphates, an atom of phosphorus, arsenic, or vanadium is bonded to oxygen. There are many types of phosphate mineral, but still phosphate minerals are rare. The composition of phosphates is complex. For example, turquoise contains copper, aluminum, and phosphorus. The stone is rare and is used to make jewelry.

Sulfates

Sulfate minerals contain sulfur atoms bonded to oxygen atoms. Like halides, they can form in places where salt water evaporates. Many minerals belong in the sulfate group, but there are only a few common sulfate minerals. Gypsum is a common sulfate mineral that contains calcium, sulfate, and water. Gypsum is found in various forms. For example, it can be pink and look like it has flower petals. However, it can also grow into very large white crystals. Gypsum crystals that are 11 meters long have been found. That is about as long as a school bus! Gypsum also forms at the Mammoth Hot Springs in Yellowstone National Park, shown in **Figure** 3.9.

FIGURE 3.9
Gypsum is the white mineral that is common around hot springs. This is Mammoth Hot Springs in Yellowstone National Park.

Sulfides

Sulfides contain metal elements combined with sulfur. Sulfides are different from sulfates. They do not contain oxygen. Pyrite is a common sulfide mineral. It contains iron combined with sulfur. Pyrite is also known as "fool's gold." Gold miners have mistaken pyrite for gold because pyrite has a greenish gold color.

Lesson Summary

- A mineral is a naturally occurring inorganic solid. It has a definite composition and crystal structure.
- The atoms in minerals are arranged in regular, repeating patterns.
- These patterns are responsible for a mineral's physical properties.
- Minerals are divided into groups. The groups are based on their chemical composition.
- Silicates are the most common minerals.

Lesson Review Questions

Recall

1. What is matter?

2. What are atoms and what are they made of?

3. What is a molecule? What substances do molecules make?

4. Go through the eight mineral groups. List the elements that are contained by all minerals in each group.

Apply Concepts

5. Quartz is made of one silicon atom and two oxygen atoms. If you find a mineral and find that it is made of one silicon atom and one oxygen atom is it quartz?

6. Why is water ice considered a mineral?

7. A shady looking character offers you a valuable mineral made of carbon. You know that diamonds are made of carbon so you give him $100 for one. Have you gotten yourself a good deal? Why or why not?

Think Critically

8. Why are diamonds "a girls best friend?" What other uses might diamonds have?

9. Coal is made of ancient plant parts that were squeezed together and heated. Is coal a mineral? Explain.

Points to Consider

- What is one way you could tell the difference between two different minerals?
- Why would someone want to make minerals when they are found in nature?
- Why are minerals so colorful? Can color be used to identify minerals?

3.2 Identification of Minerals

Lesson Objectives

- Explain how minerals are identified.
- Describe how color, luster, and streak are used to identify minerals.
- Summarize specific gravity.
- Explain how the hardness of a mineral is measured.
- Describe the properties of cleavage and fracture.
- Identify additional properties that can be used to identify some minerals.

Vocabulary

- cleavage
- density
- fracture
- hardness
- luster
- streak

Introduction

How could you describe your shirt when you are talking to your best friend on the phone? You might describe the color, the way the fabric feels, and the length of the sleeves. These are all physical properties of your shirt. If you did a good job describing your shirt, your friend would recognize the shirt when you wear it. Minerals also have physical properties that are used to identify them.

How are Minerals Identified?

Imagine you were given a mineral sample similar to the one shown in **Figure** 3.10. How would you try to identify your mineral? You can observe some properties by looking at the mineral. For example, you can see that its color is beige. The mineral has a rose-like structure. But you can't see all mineral properties. You need to do simple tests to determine some properties. One common one is how hard the mineral is. You can use a mineral's properties to identify it. The mineral's physical properties are determined by its chemical composition and crystal structure.

FIGURE 3.10
You can use properties of a mineral to identify it. The color and rose-like structure of this mineral mean that it is gypsum.

Color, Streak, and Luster

Diamonds have many valuable properties. Diamonds are extremely hard and are used for industrial purposes. The most valuable diamonds are large, well-shaped and sparkly. Turquoise is another mineral that is used in jewelry because of its striking greenish-blue color. Many minerals have interesting appearances. Specific terms are used to describe the appearance of minerals.

Color

Color is probably the easiest property to observe. Unfortunately, you can rarely identify a mineral only by its color. Sometimes, different minerals are the same color. For example, you might find a mineral that is a gold color, and so think it is gold. But it might actually be pyrite, or "fool's gold," which is made of iron and sulfide. It contains no gold atoms.

A certain mineral may form in different colors. **Figure** 3.11 shows four samples of quartz, including one that is colorless and one that is purple. The purple color comes from a tiny amount of iron. The iron in quartz is a chemical impurity. Iron is not normally found in quartz. Many minerals are colored by chemical impurities. Other factors can also affect a mineral's color. Weathering changes the surface of a mineral. Because color alone is unreliable, geologists rarely identify a mineral just on its color. To identify most minerals, they use several properties.

Streak

Streak is the color of the powder of a mineral. To do a streak test, you scrape the mineral across an unglazed porcelain plate. The plate is harder than many minerals, causing the minerals to leave a streak of powder on the plate. The color of the streak often differs from the color of the larger mineral sample, as **Figure** 3.12 shows.

Streak is more reliable than color to identify minerals. The color of a mineral may vary. Streak does not vary. Also, different minerals may be the same color, but they may have a different color streak. For example, samples of hematite and galena can both be dark gray. They can be told apart because hematite has a red streak and galena has a gray streak.

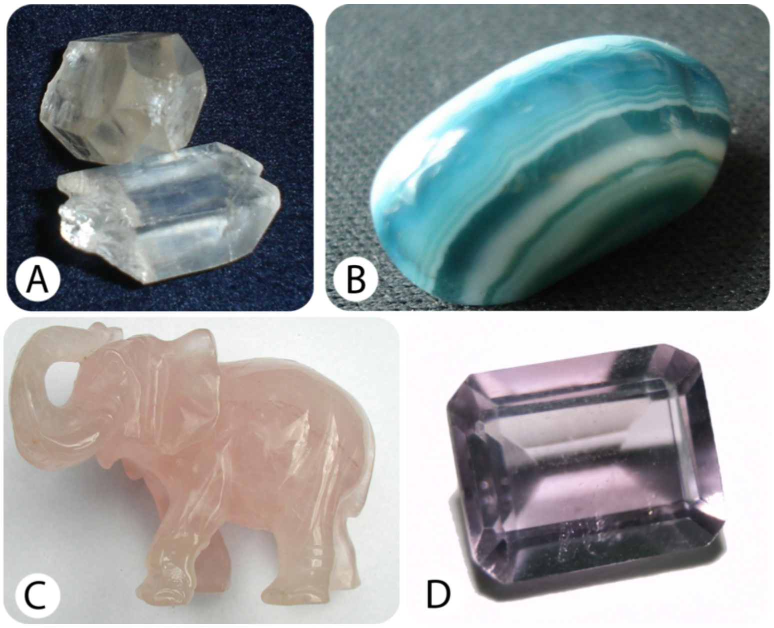

FIGURE 3.11
Quartz comes in many different colors including: (A) transparent quartz, (B) blue agate, (C) rose quartz, and (D) purple amethyst.

FIGURE 3.12
Rub a mineral across an unglazed porcelain plate to see its streak. The hematite shown here has a red streak.

Luster

Luster describes the way light reflects off of the surface of the mineral. You might describe diamonds as sparkly or pyrite as shiny. But mineralogists have special terms to describe luster. They first divide minerals into metallic and non-metallic luster. Minerals that are opaque and shiny, like pyrite, are said to have a "metallic" luster. Minerals with a "non-metallic" luster do not look like metals. There are many types of non-metallic luster. Six are described in **Table** 3.1.

TABLE 3.1: Minerals with Non-Metallic Luster

Non-Metallic Luster	Appearance
Adamantine	Sparkly
Earthy	Dull, clay-like
Pearly	Pearl-like
Resinous	Like resins, such as tree sap
Silky	Soft-looking with long fibers
Vitreous	Glassy

Can you match the minerals in **Figure** 3.13 with the correct luster from **Table** 3.1 without looking at the caption?

Density

You are going to visit a friend. You fill one backpack with books so you can study later. You stuff your pillow into another backpack that is the same size. Which backpack will be easier to carry? Even though the backpacks are the same size, the bag that contains your books is going to be much heavier. It has a greater density than the backpack with your pillow.

Density describes how much matter is in a certain amount of space. Substances that have more matter packed into a given space have higher densities. The water in a drinking glass has the same density as the water in a bathtub or swimming pool. All substances have characteristic densities, which does not depend on how much of a substance you have.

Mass is a measure of the amount of matter in an object. The amount of space an object takes up is described by its volume. The density of an object depends on its mass and its volume. Density can be calculated using the following equation:

$$\text{Density} = \text{Mass}/\text{Volume}$$

Samples that are the same size, but have different densities, will have different masses. Gold has a density of about 19 g/cm^3. Pyrite has a density of only about 5 g/cm^3. Quartz is even less dense than pyrite, and has a density of 2.7 g/cm^3. If you picked up a piece of pyrite and a piece of quartz that were the same size, the pyrite would seem almost twice as heavy as the quartz.

Hardness

Hardness is a mineral's ability to resist being scratched. Minerals that are not easily scratched are hard. You test the hardness of a mineral by scratching its surface with a mineral of a known hardness. Mineralogists use the Mohs Hardness Scale, shown in **Table** 3.2, as a reference for mineral hardness. The scale lists common minerals in order of their relative hardness. You can use the minerals in the scale to test the hardness of an unknown mineral.

Mohs Hardness Scale

As you can see, diamond is a 10 on the Mohs Hardness Scale. Diamond is the hardest mineral; no other mineral can scratch a diamond. Quartz is a 7. It can be scratched by topaz, corundum, and diamond. Quartz will scratch minerals

FIGURE 3.13

(A) Diamonds have an adamantine luster. These minerals are transparent and highly reflective. (B) Kaolinite is a clay with a dull or earthy luster. (C) Opal's luster is greasy. (D) Chalcopyrite, like its cousin pyrite, has metallic luster. (E) Stilbite (orange) has a resinous luster. (F) The white ulexite has silky luster. (G) Sphalerite has a submetallic luster. (H) This Mayan artifact is carved from jade. Jade is a mineral with a waxy luster.

that have a lower number on the scale. Fluorite is one. Suppose you had a piece of pure gold. You find that calcite scratches the gold. Gypsum does not. Gypsum has a hardness of 2 and calcite is a 3. That means the hardness of gold is between gypsum and calcite. So the hardness of gold is about 2.5 on the scale. A hardness of 2.5 means that gold is a relatively soft mineral. It is only about as hard as your fingernail.

TABLE 3.2: Mohs Scale

Hardness	Mineral
1	Talc

TABLE 3.2: (continued)

Hardness	Mineral
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Cleavage and Fracture

Different types of minerals break apart in their own way. Remember that all minerals are crystals. This means that the atoms in a mineral are arranged in a repeating pattern. This pattern determines how a mineral will break. When you break a mineral, you break chemical bonds. Because of the way the atoms are arranged, some bonds are weaker than other bonds. A mineral is more likely to break where the bonds between the atoms are weaker.

Cleavage

Cleavage is the tendency of a mineral to break along certain planes. When a mineral breaks along a plane it makes a smooth surface. Minerals with different crystal structures will break or cleave in different ways, as in **Figure** 3.14. Halite tends to form cubes with smooth surfaces. Mica tends to form sheets. Fluorite can form octahedrons.

FIGURE 3.14
Minerals with different crystal structures have a tendency to break along certain planes.

Minerals can form various shapes. Polygons are shown in **Figure** 3.15. The shapes form as the minerals are broken along their cleavage planes. Cleavage planes determine how the crystals can be cut to make smooth surfaces. People who cut gemstones follow cleavage planes. Diamonds and emeralds can be cut to make beautiful gemstones.

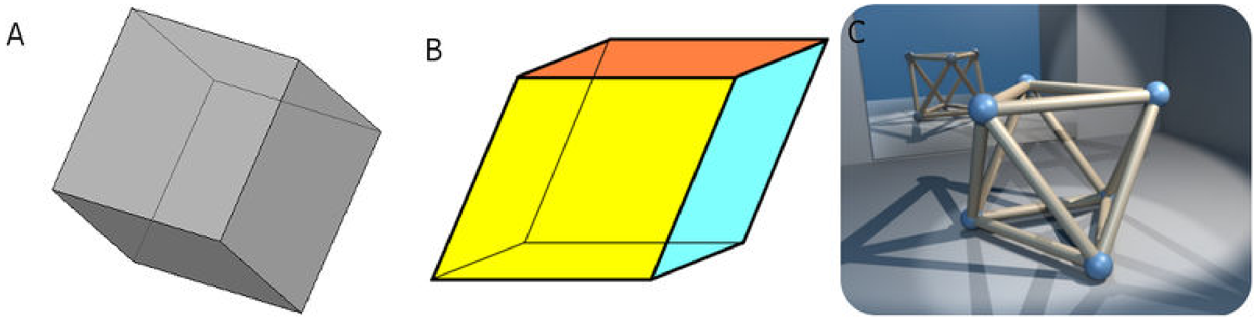

FIGURE 3.15
Cubes have six sides that are all the same size square. All of the angles in a cube are equal to 90°. Rhombohedra also have six sides, but the sides are diamond-shaped. Octahedra have eight sides that are all shaped like triangles.

Fracture

Fracture describes how a mineral breaks without any pattern. A fracture is uneven. The surface is not smooth and flat. You can learn about a mineral from the way it fractures. If a mineral splinters like wood, it may be fibrous. Some minerals, such as quartz, fracture to form smooth, curved surfaces. A mineral that broke forming a smooth, curved surface is shown in **Figure** 3.16.

Other Identifying Characteristics

Minerals have other properties that can be used for identification. For example, a mineral's shape may indicate its crystal structure. Sometimes crystals are too small to see. Then a mineralogist may use a special instrument to find the crystal structure.

Some minerals have unique properties. These can be used to the minerals. Some of these properties are listed in **Table** 3.3. An example of a mineral that has each property is also listed.

TABLE 3.3: Special Mineral Properties

Property	Description	Example of Mineral
Fluorescence	Mineral glows under ultraviolet light	Fluorite
Magnetism	Mineral is attracted to a magnet	Magnetite
Radioactivity	Mineral gives off radiation that can be measured with Geiger counter	Uraninite
Reactivity	Bubbles form when mineral is exposed to a weak acid	Calcite
Smell	Some minerals have a distinctive smell	Sulfur (smells like rotten eggs)

FIGURE 3.16
This mineral formed a smooth, curved surface when it fractured.

Lesson Summary

- You can identify a mineral by its appearance and other properties.
- The color and luster describe the appearance of a mineral, and streak describes the color of the powdered mineral.
- Each mineral has a characteristic density.
- Mohs Hardness Scale is used to compare the hardness of minerals.
- The way a mineral cleaves or fractures depends on the crystal structure of the mineral.
- Some minerals have special properties that can be used to help identify the mineral.

Lesson Review Questions

Recall

1. What is cleavage? What is fracture? If you are looking at a mineral face, how can you tell them apart?

2. What is color? When would you use color to identify a mineral?

3. What is streak? Why would you use streak instead of color to identify a mineral?

Apply Concepts

4. What type of luster do gemstones mostly have? Why do you think this type of luster is popular for jewelry?

5. If a mineral has a unique property that only that type of mineral has is it good for identifying that mineral? Is there any time that it might not be?

Think Critically

6. You are trying to identify a mineral sample. Apatite scratches the surface of the mineral. Which mineral would you use next to text the mineral's hardness—fluorite or feldspar? Explain your reasoning.

7. You have two mineral samples that are about the size of a golf ball. Mineral A has a density of 5 g/cm^3. Mineral B is twice as dense as Mineral A. What is the density of Mineral B?

Points to Consider

- Some minerals are colored because they contain chemical impurities. How did the impurities get into the mineral?
- What two properties of a mineral sample would you have to measure to calculate its density?

3.3 Formation of Minerals

Lesson Objectives

- Describe how melted rock produces minerals.
- Explain how minerals form from solutions.

Vocabulary

- lava
- magma
- rocks

Introduction

Minerals are all around you. They are used to make your house, your computer, even the buttons on your jeans. But where do minerals come from? There are many types of minerals, and they do not all form in the same way. Some minerals form when salt water on Earth's surface evaporates. Others form from water mixtures that are seeping through rocks far below your feet. Still others form when molten rock cools.

Formation from Magma and Lava

You are on vacation at the beach. You take your flip-flops off so you can go swimming. The sand is so hot it hurts your feet. You have to run to the water. Now imagine if it were hot enough for the sand to melt.

Some places inside Earth are so hot that rock melts. Melted rock inside the Earth is called magma. **Magma** can be hotter than 1,000°C. When magma erupts onto Earth's surface, it is known as **lava**, as **Figure** 3.17 shows. Minerals form when magma and lava cool.

Formation from Solutions

Most water on Earth, like the water in the oceans, contains elements. The elements are mixed evenly through the water. Water plus other substances makes a solution. The particles are so small that they will not come out when you filter the water. But the elements in water can form solid mineral deposits.

FIGURE 3.17
Lava is melted rock that erupts onto Earth's surface.

Minerals from Salt Water

Fresh water contains a small amount of dissolved elements. Salt water contains a lot more dissolved elements. Water can only hold a certain amount of dissolved substances. When the water evaporates, it leaves behind a solid layer of minerals, as **Figure** 3.18 shows. At this time, the particles come together to form minerals. These solids sink to the bottom. The amount of mineral formed is the same as the amount dissolved in the water. Seawater is salty enough for minerals to precipitate as solids. Some lakes, such as Mono Lake in California, or Utah's Great Salt Lake, can also precipitate salts.

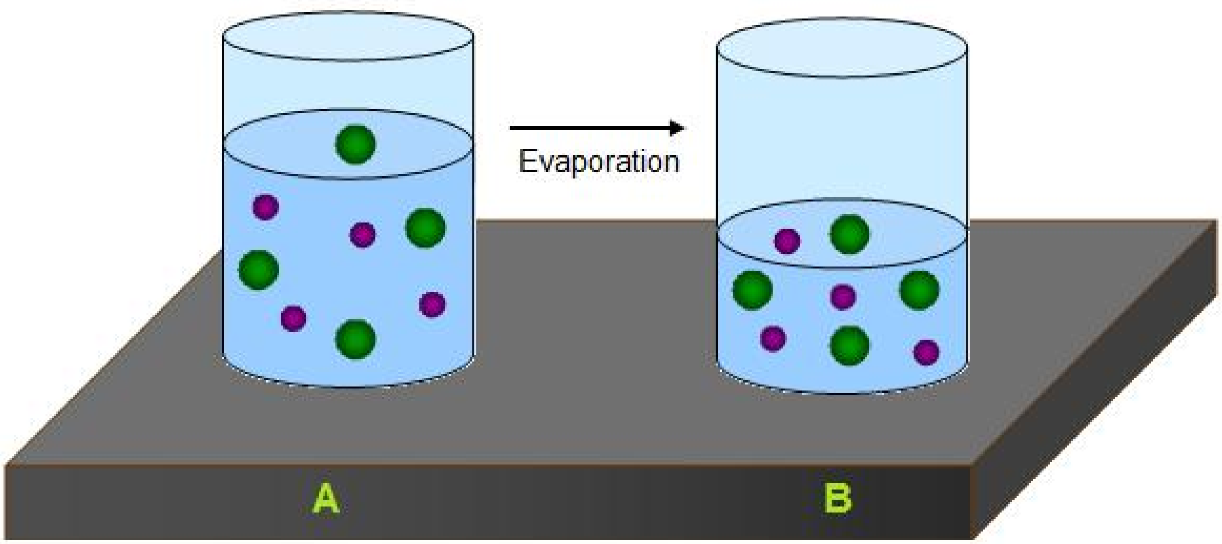

FIGURE 3.18
When the water in glass A evaporates, the dissolved mineral particles are left behind.

Salt easily precipitates out of water, as does calcite, as **Figure** 3.19 shows. The limestone towers in the figure are made mostly of the mineral calcite. The calcite was deposited in the salty and alkaline water of Mono Lake, in California. Calcium-rich spring water enters the bottom of the lake. The water bubbles up into the alkaline lake. The calcite "tufa" towers form. When the lake level drops, the tufa towers are revealed.

FIGURE 3.19
Tufa towers are found in interesting formations at Mono Lake, California.

Minerals from Hot Underground Water

Underground water can be heated by magma. The hot water moves through cracks below Earth's surface. Hot water can hold more dissolved particles than cold water. The hot, salty solution has chemical reactions with the rocks around it. The water picks up more dissolved particles. As it flows through open spaces in rocks, the water deposits solid minerals. When a mineral fills cracks in rocks, the deposits are called "veins." **Figure** 3.20 shows a white quartz vein. When the minerals are deposited in open spaces, large crystals grow. These rocks are called geodes. **Figure** 3.20 shows a "geode" that was formed when amethyst crystals grew in an open space in a rock.

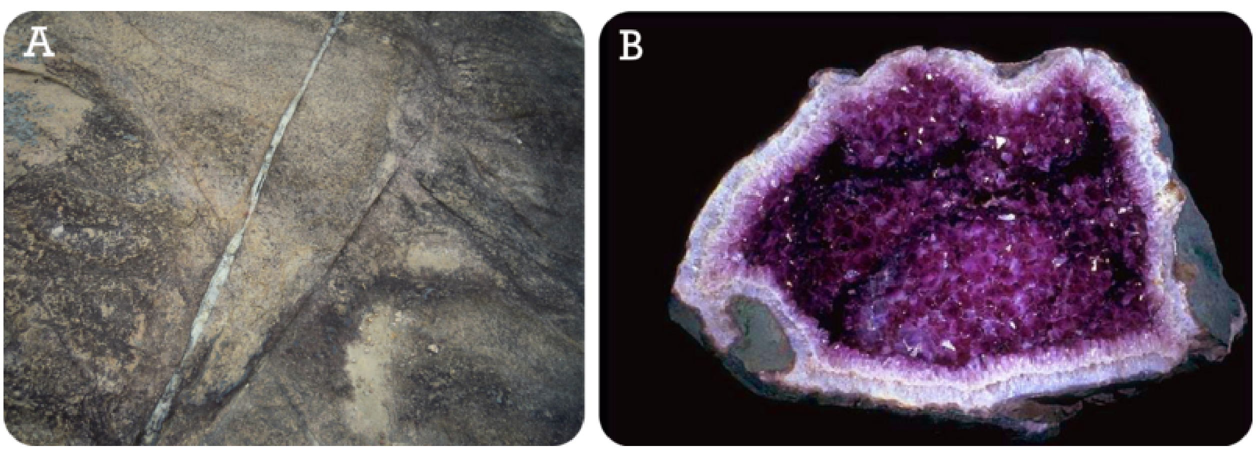

FIGURE 3.20
(A) A quartz vein formed in this rock. (B) Geodes form when minerals evaporate out in open spaces inside a rock.

Lesson Summary

- Mineral crystals that form when magma cools are usually larger than crystals that form when lava cools.
- Minerals are deposited from salty water solutions on Earth's surface and underground.

Lesson Review Questions

Recall

1. How does magma differ from lava?

2. What happens to elements in salt water when the water evaporates?

Apply Concepts

3. Describe how minerals can form out of salt water. What are all the steps in the process?

Think Critically

4. You are handed a rock with large and form beautiful crystals. Another rock is made of the same mineral type but the crystals are small and not well formed. How is the way the two sets of that mineral formed different?

Points to Consider

- When most minerals form, they combine with other minerals to form rocks. How can these minerals be used?
- The same mineral can be formed by different processes. How can the way a mineral forms affect how the mineral is used?

3.4 Mining and Using Minerals

Lesson Objectives

- Explain how minerals are mined.
- Describe how metals are made from mineral ores.
- Summarize the ways in which gemstones are used.
- Identify some useful minerals.

Vocabulary

- gemstone
- ore

Introduction

When you use a roll of aluminum foil or some baby powder, you probably don't think about how the products were made. We use minerals in many everyday items.

Minerals have to be removed from the ground and made into the products. All the metals we use start out as an ore. Mining the ore is just the first step. Next, the ore must be separated from the rest of the rock that is mined. Then, the minerals need to be separated out of the ore.

Ore Deposits

A mineral deposit that contains enough minerals to be mined for profit is called an **ore**. Ores are rocks that contain concentrations of valuable minerals. The bauxite shown in the **Figure** 3.21 is a rock that contains minerals that are used to make aluminum.

Finding and Mining Minerals

Ores have high concentrations of valuable minerals. Certain places on Earth are more likely to have certain ores. Geologists search for the places that might have ore deposits. Some of the valuable deposits may be hidden underground. To find an ore deposit, geologists will go to a likely spot. They then test the physical and chemical properties of soil and rocks. Ore deposits contain valuable minerals. They may also contain other chemical elements that indicate an ore deposit is nearby.

FIGURE 3.21
Aluminum is made from the minerals in rocks known as bauxite.

After a mineral deposit is found, geologists determine how big it is. They outline the deposit and the surrounding geology on a map. The miners calculate the amount of valuable minerals they think they will get from the deposit. The minerals will only be mined if it is profitable. If it is profitable, they must then decide on the way it should be mined. The two main methods of mining are surface mining and underground mining. Placers are a type of surface deposit.

Surface Mining

Surface mining is used to obtain mineral ores that are near the surface. Blasting breaks up the soil and rocks that contain the ore. Enormous trucks haul the broken rocks to locations where the ores can be removed. Surface mining includes open-pit mining, quarrying, and strip mining.

As the name suggests, open-pit mining creates a big pit from which the ore is mined. **Figure** 3.22 shows an open-pit diamond mine in Russia. The size of the pit grows as long as the miners can make a profit. Strip mines are similar to open-pit mines, but the ore is removed in large strips. A quarry is a type of open-pit mine that produces rocks and minerals that are used to make buildings and roads.

Placer Mining

Placer minerals collect in stream gravels. They can be found in modern rivers or ancient riverbeds. California was nicknamed the Golden State. This can be traced back to the discovery of placer gold in 1848. The amount of placer gold brought in miners from around the world. The gold formed in rocks in the Sierra Nevada Mountains. The rocks also contained other valuable minerals. The gold weathered out of the hard rock. It washed downstream and then settled in gravel deposits along the river. Currently, California has active gold and silver mines. California also has mines for non-metal minerals. For example, sand and gravel are mined for construction.

FIGURE 3.22
This diamond mine is more than 500 m deep.

Underground Mining

If an ore is deep below Earth's surface it may be too expensive to remove all the rock above it. These deposits are taken by underground mining. Underground mines can be very deep. The deepest gold mine in South Africa is more than 3,700 m deep (that is more than 2 miles)! There are various methods of underground mining. Underground mining is more expensive than surface mining. Tunnels must be blasted into the rock so that miners and equipment can get to the ore. Underground mining is dangerous work. Fresh air and lights must be brought in to the tunnels for the miners. The miners breathe in lots of particles and dust while they are underground. The ore is drilled, blasted, or cut away from the surrounding rock and taken out of the tunnels. Sometimes there are explosions as ore is being drilled or blasted. This can lead to a mine collapse. Miners may be hurt or killed in a mining accident.

Making Metals from Minerals

Most minerals are a combination of metal and other elements. The rocks that are taken from a mine are full of valuable minerals plus rock that isn't valuable. This is called waste rock. The valuable minerals must be separated from the waste rock. One way to do this is with a chemical reaction. Chemicals are added to the ores at very high temperatures.

For example, getting aluminum from waste rock uses a lot of energy. This is because temperatures greater than 900^{o}C are needed to separate out the aluminum. It also takes a huge amount of electricity. If you recycle just 40 aluminum cans, you will save the energy in one gallon of gasoline. We use over 80 billion cans each year. If all of these cans were recycled, we would save the energy in 2 billion gallons of gasoline!

Uses of Ore Minerals

We rely on metals, such as aluminum, copper, iron, and gold. Look around the room. How many objects have metal parts? Metals are used in the tiny parts inside your computer, in the wires of anything that uses electricity, and to make the structure of a large building, such as the one shown in the **Figure** 3.23.

FIGURE 3.23
The dome of the capital building in Hartford, Connecticut is coated with gold leaf.

Gemstones and Their Uses

Some minerals are valuable simply because they are beautiful. Jade has been used for thousands of years in China. Native Americans have been decorating items with turquoise since ancient times. Minerals like jade, turquoise, diamonds, and emeralds are gemstones. A **gemstone** is a material that is cut and polished to use in jewelry. Many gemstones, such as those shown in **Figure** 3.24, are minerals.

FIGURE 3.24
Gemstones come in many colors.

Gemstones are beautiful, rare, and do not break or scratch easily. Generally, rarer gems are more valuable. If a gem is popular, unusually large or very well cut, it will be more valuable.

Most gemstones are not used exactly as they are found in nature. Usually, gems are cut and polished. **Figure** 3.25 shows an uncut piece of ruby and a ruby that has been cut and polished. The way a mineral splits along a surface allows it to be cut to produce smooth surfaces. Notice that the cut and polished ruby sparkles more. Gems sparkle because light bounces back when it hits them. These gems are cut so that the most amount of light possible bounces back. Other gemstones, such as turquoise, are opaque, which means light does not pass through them. These gems are not cut in the same way.

FIGURE 3.25
Ruby is cut and polished to make the gemstone sparkle. Left: Ruby Crystal. Right: Cut Ruby.

Gemstones also have other uses. Most diamonds are actually not used as gemstones. Diamonds are used to cut and polish other materials, such as glass and metals, because they are so hard. The mineral corundum, which makes the gems ruby and sapphire, is used in products like sandpaper. Synthetic rubies and sapphires are also used in lasers.

Other Useful Minerals

Metals and gemstones are often shiny, so they catch your eye. Many minerals that we use everyday are not so noticeable. For example, the buildings on your block could not have been built without minerals. The walls in your home might use the mineral gypsum for the sheetrock. The glass in your windows is made from sand, which is mostly the mineral quartz. Talc was once commonly used to make baby powder. The mineral halite is mined for rock salt. Diamond is commonly used in drill bits and saw blades to improve their cutting ability. Copper is used in electrical wiring, and the ore bauxite is the source for the aluminum in your soda can.

Mining and the Environment

Mining provides people with many resources they need, but mining can be hazardous to people and the environment. Miners should restore the mined region to its natural state. It is also important to use mineral resources wisely. Most ores are non-renewable resources.

Land Reclamation

After the mining is finished, the land is greatly disturbed. The area around the mine needs to be restored to its natural state. This process of restoring the area is called "reclamation." Native plants are planted. Pit mines may be refilled or reshaped so that they can become natural areas again. The mining company may be allowed to fill the pit with water to create a lake. The pits may be turned into landfills. Underground mines may be sealed off or left open as homes for bats.

Mine Pollution

Mining can cause pollution. Chemicals released from mining can contaminate nearby water sources. **Figure** 3.26 shows water that is contaminated from a nearby mine. The United States government has mining standards to protect water quality.

FIGURE 3.26
Scientists test water that has been contaminated by a mine.

Lesson Summary

- Geologists look for mineral deposits that will be profitable to mine.
- Ores that are close to the surface are mined by surface mining methods. Ores that are deep in Earth are mined using underground methods.
- Metals ores must be melted to make metals.
- Many gems are cut and polished to increase their beauty.
- Minerals are used in a variety of ways.

Lesson Review Questions

Recall

1. What are placers? How do placer deposits form?

2. What makes an ore deposit valuable?

Apply Concepts

3. Why would a mining company choose to do a surface mine? Why would it choose to do an underground mine?

4. Once the ore rocks are taken to a refinery, what happens to get the ore out?

Thinking Critically

5. What are some disadvantages of underground mining?
6. What is the bottom line when it comes to deciding how what and how to mine?
7. How is land reclaimed after mining? Is it ever fully recovered?
8. How might the history of the Golden State been different if placers had not been found in its rivers?

Points to Consider

- Are all mineral deposits ores?
- An open-pit diamond mine may one day be turned into an underground mine. Why would this happen?
- Diamonds are not necessarily the rarest gem. Why do people value diamonds more than most other gems?

3.5 References

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CHAPTER 4 MS Rocks

Chapter Outline

Have you ever heard the phrase "rock solid?" Something is rock solid if it does not and cannot change. It will not fail or go wrong. A rock-solid plan is a sure bet. A rock-solid idea is sure to be doable. Devil's Tower in Wyoming looks rock solid. It looks like it would not change or move. Even in a million years it would look just like it does now.

In this chapter you will find out that rocks do change. Rocks can change from one type to another. Rocks can alter to have different characteristics but still be the same type. Most changes in rocks take place over long periods of time. More rarely the changes take only a short time. This rock formation's days are numbered... and a diamond is not forever.

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4.1 Types of Rocks

Lesson Objectives

- Define rock and describe what rocks are made of.
- Know the three main groups of rocks.
- Explain how each of these three rock types are formed.
- Describe the rock cycle.

Vocabulary

- deposited
- sediments

Introduction

There are three major rock types. Rock of any of these three rock types can become rock of one of the other rock types. Rock can also change to a different rock of the same type. Rocks give good clues as to what was happening in a region during the time that rock formed.

The Rock Cycle

All rocks on Earth change, but these changes usually happen very slowly. Some changes happen below Earth's surface. Some changes happen above ground. These changes are all part of the rock cycle. The rock cycle describes each of the main types of rocks, how they form and how they change. **Figure** 4.1 shows how the three main rock types are related to each other. The arrows within the circle show how one type of rock may change to rock of another type. For example, igneous rock may break down into small pieces of sediment and become sedimentary rock. Igneous rock may be buried within the Earth and become metamorphic rock. Igneous rock may also change back to molten material and re-cool into a new igneous rock.

Rocks are made of minerals. The minerals may be so tiny that you can only see them with a microscope. The minerals may be really large. A rock may be made of only one type of mineral. More often rocks are made of a mixture of different minerals. Rocks are named for the combinations of minerals they are made of and the ways those minerals came together. Remember that different minerals form under different environmental conditions. So the minerals in a rock contain clues about the conditions in which the rock formed (**Figure** 4.2).

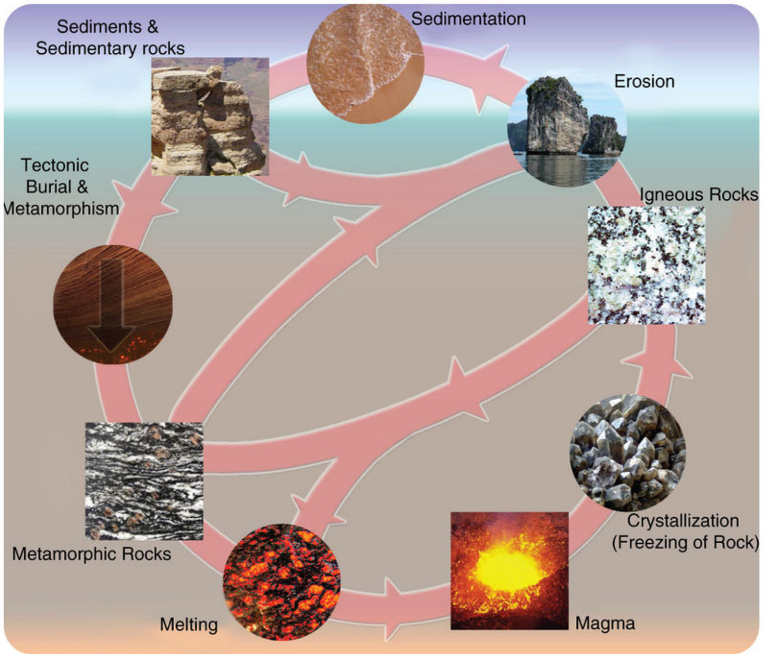


FIGURE 4.1
The rock cycle.

FIGURE 4.2
Rocks contain many clues about the conditions in which they formed. The minerals contained within the rocks also contain geological information.

Three Main Categories of Rocks

Geologists group rocks based on how they were formed. The three main kinds of rocks are:

1. Igneous rocks form when magma cools below Earth's surface or lava cools at the surface (**Figure** 4.3).

2. Sedimentary rocks form when sediments are compacted and cemented together (**Figure** 4.4). These sediments may be gravel, sand, silt or clay. Sedimentary rocks often have pieces of other rocks in them. Some sedimentary rocks form the solid minerals left behind after a liquid evaporates.

3. Metamorphic rocks form when an existing rock is changed by heat or pressure. The minerals in the rock change but do not melt (**Figure** 4.5). The rock experiences these changes within the Earth.

FIGURE 4.3
Lava is molten rock. This lava will harden into an igneous rock.

FIGURE 4.4
This sandstone is an example of a sedimentary rock. It formed when many small pieces of sand were cemented together to form a rock.

Rocks can be changed from one type to another, and the rock cycle describes how this happens.

Processes of the Rock Cycle

Any type of rock can change and become a new type of rock. Magma can cool and crystallize. Existing rocks can be weathered and eroded to form sediments. Rock can change by heat or pressure deep in Earth's crust. There are three main processes that can change rock:

- Cooling and forming crystals. Deep within the Earth, temperatures can get hot enough to melt rock. This molten material is called magma. As it cools, crystals grow, forming an igneous rock. The crystals will grow larger if the magma cools slowly, as it does if it remains deep within the Earth. If the magma cools quickly, the crystals will be very small.
- Weathering and erosion. Water, wind, ice, and even plants and animals all act to wear down rocks. Over time

FIGURE 4.5
This mica schist is a metamorphic rock. It was changed from a sedimentary rock like shale.

they can break larger rocks into smaller pieces called sediments. Moving water, wind, and glaciers then carry these pieces from one place to another. The sediments are eventually dropped, or **deposited**, somewhere. The sediments may then be compacted and cemented together. This forms a sedimentary rock. This whole process can take hundreds or thousands of years.

- Metamorphism. This long word means "to change form." A rock undergoes metamorphism if it is exposed to extreme heat and pressure within the crust. With metamorphism, the rock does not melt all the way. The rock changes due to heat and pressure. A metamorphic rock may have a new mineral composition and/or texture.

An interactive rock cycle diagram can be found here: http://www.classzone.com/books/earth_science/terc/content/investigations/es0602/es0602page02.cfm?chapter_no=investigation

The rock cycle really has no beginning or end. It just continues. The processes involved in the rock cycle take place over hundreds, thousands, or even millions of years. Even though for us rocks are solid and unchanging, they slowly change all the time.

Lesson Summary

- There are three main types of rocks: igneous, sedimentary, and metamorphic.
- Melting and later cooling, erosion and sedimentation, and metamorphism transform one type of rock into another type of rock or change sediments into rock.
- The rock cycle describes the transformations of one type of rock to another.

Lesson Review Questions

Recall

1. What is the difference between magma and lava?

2. What are igneous rocks? How do igneous rocks form?
3. What are metamorphic rocks? How do metamorphic rocks form?
4. What are sedimentary rocks? How do sedimentary rocks form?

Apply Concepts

5. How do minerals combine to form an igneous rock?
6. How do minerals combine to form a metamorphic rock?
7. How do minerals combine to form a sedimentary rock?

Think Critically

8. What clues do the minerals in an igneous rock give about how the rock formed? A metamorphic rock? A sedimentary rock?
9. Describe how an igneous rock can change to a metamorphic rock.
10. If Earth's interior was cool, how would this change the types of rocks formed on Earth?

Points to Consider

- What processes on Earth are involved in forming rocks?
- What rocks are important to modern humans and for what purposes?

4.2 Igneous Rocks

Lesson Objectives

- Describe how igneous rocks are formed.
- Describe the properties of some common types of igneous rocks.
- Relate some common uses of igneous rocks.

Vocabulary

- extrusive
- intrusive

Introduction

Most of the Earth is made of igneous rock. The entire mantle is igneous rock, as are some areas of the crust. One of the most common igneous rocks is granite (**Figure** 4.6). Many mountain ranges are made of granite. People use granite for countertops, buildings, monuments and statues. Pumice is also an igneous rock. Perhaps you have used a pumice stone to smooth your skin. Pumice stones are put into giant washing machines with new jeans and tumbled around. The result is stone-washed jeans!

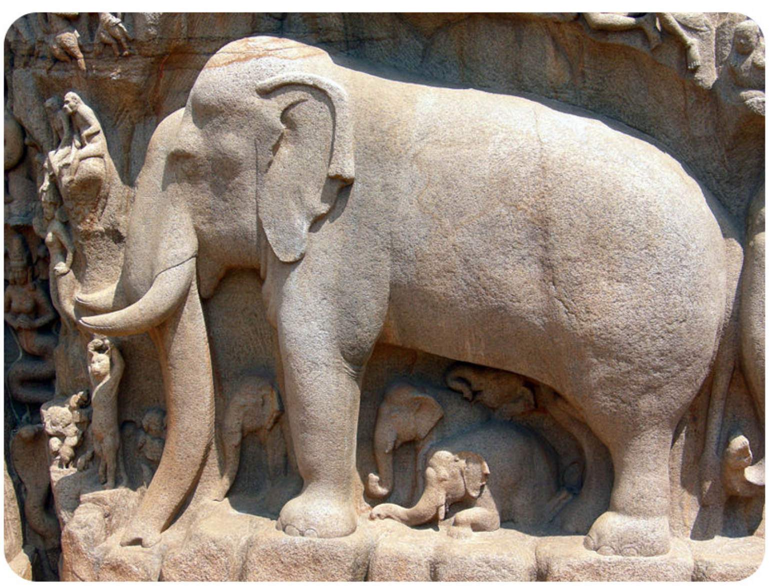


FIGURE 4.6
This life-size elephant is carved from granite.

Forming Crystals

Igneous rocks form when magma cools and forms crystals. These rocks can form at Earth's surface or deep underground. **Figure** 4.7 shows a landscape in California's Sierra Nevada that consists entirely of granite.

FIGURE 4.7
The Sierra Nevada of California are composed mainly of granite. These rocks are beautifully exposed in the Yosemite Valley.

Intrusive igneous rocks cool and form into crystals beneath the surface. Deep in the Earth, magma cools slowly. Slow cooling gives large crystals a chance to form. Intrusive igneous rocks have relatively large crystals that are easy to see. Granite is the most common intrusive igneous rock. **Figure** 4.8 shows four types of intrusive rocks.

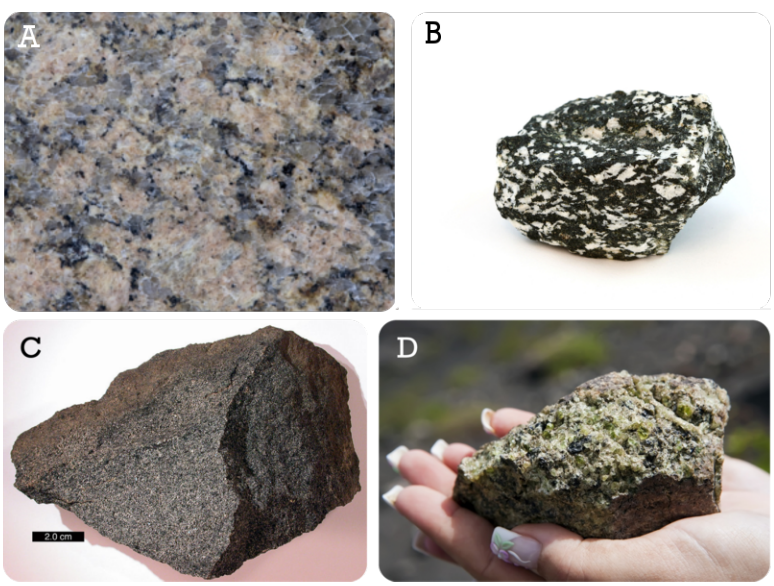


FIGURE 4.8
(A) This granite has more plagioclase feldspar than many granites. (B) Diorite has more dark-colored minerals than granite. (C) Gabbro. (D) Peridotite is an intrusive igneous rock with olivine and other mafic minerals.

Extrusive igneous rocks form above the surface. The lava cools quickly as it pours out onto the surface (**Figure** 4.9). Extrusive igneous rocks cool much more rapidly than intrusive rocks. They have smaller crystals, since the rapid cooling time does not allow time for large crystals to form. Some extrusive igneous rocks cool so rapidly that crystals do not develop at all. These form a glass, such as obsidian. Others, such as pumice, contain holes where gas bubbles were trapped in the lava. The holes make pumice so light that it actually floats in water. The most common extrusive igneous rock is basalt. It is the rock that makes up the ocean floor. **Figure** 4.10 shows four types of extrusive igneous rocks.

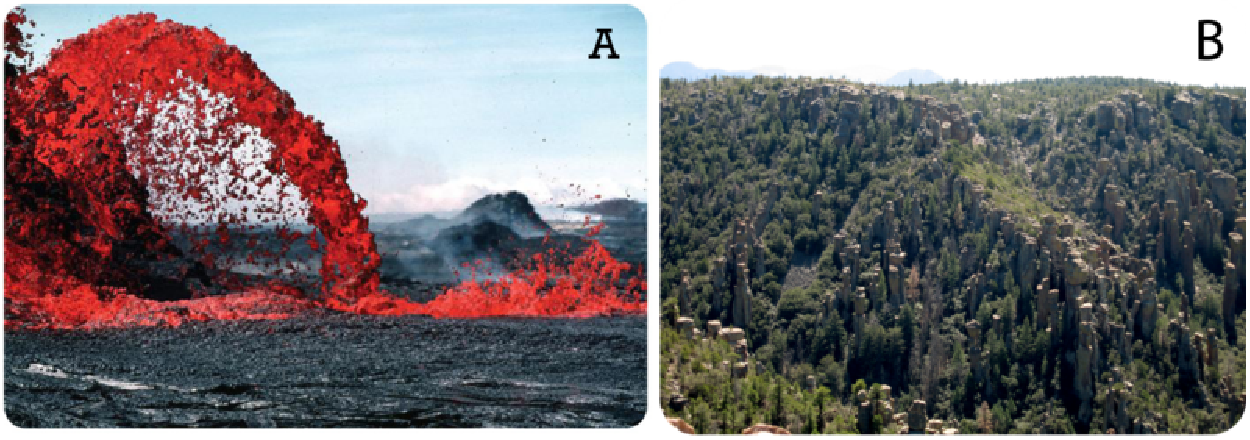


FIGURE 4.9
(A) Lava cools to form extrusive igneous rock. The rocks here are basalts. (B) The strange rock formations of Chiricahua National Monument in Arizona are formed of the extrusive igneous rock rhyolite.

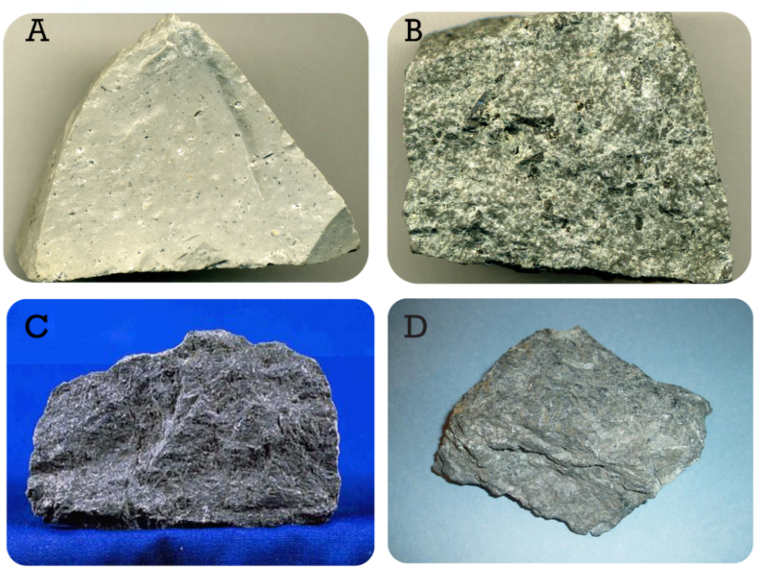


FIGURE 4.10
(A) This rhyolite is light colored. Few minerals are visible to the naked eye. (B) Andesite is darker than rhyolite. (C) Since basalt crystals are too small to see, the rock looks dark all over. (D) Komatiite is a very rare ultramafic rock. This rock is derived from the mantle.

Composition

Igneous rocks are grouped by the size of their crystals and the minerals they contain. The minerals in igneous rocks are grouped into families. Some contain mostly lighter colored minerals, some have a combination of light and dark minerals, and some have mostly darker minerals. The combination of minerals is determined by the composition of the magma. Magmas that produce lighter colored minerals are higher in silica. These create rocks such as granite and rhyolite. Darker colored minerals are found in rocks such as gabbro and basalt.

There are actually more than 700 different types of igneous rocks. Diorite is extremely hard and is commonly used for art. It was used extensively by ancient civilizations for vases and other decorative art work (**Figure** 4.11).

FIGURE 4.11
This sarcophagus is housed at the Vatican Museum. The rock is the igneous extrusive rock porphyry. Porphyry has large crystals because the magma began to cool slowly, then erupted.

Lesson Summary

- Igneous rocks form either when they cool very slowly deep within the Earth or when magma cools rapidly at the Earth's surface.
- Composition of the magma will determine the minerals that will crystallize forming different types of igneous rocks.

Lesson Review Questions

Recall

1. What is the difference between an intrusive and an extrusive igneous rock?

2. List three common uses of igneous rocks.

Apply Concepts

3. Why do extrusive igneous rocks usually have smaller crystals than intrusive igneous rocks?

4. How are igneous rocks classified?

Think Critically

5. Occasionally, igneous rocks will contain both large crystals and tiny mineral crystals. Propose a way that both these sizes of crystals might have formed in the rock.

6. Why is the ocean floor more likely to have extrusive rocks than intrusive rocks?

Points to Consider

- Do you think igneous rocks could form where you live?
- Would all igneous rocks with the same composition have the same name? Explain why they might not.
- Could an igneous rock cool at two different rates? What would the crystals in such a rock look like?

4.3 Sedimentary Rocks

Lesson Objectives

- Describe how sedimentary rocks are formed.
- Describe the properties of some common sedimentary rocks.
- Relate some common uses of sedimentary rocks.

Vocabulary

- cemented
- compacted
- fossils

Introduction

FIGURE 4.12
Layers of sand turned to rock are seen in the Navajo sandstone. The geologic feature is a slot canyon called Antelope Canyon.

Did you know that the White House, the official home and workplace of the President of the United States of America, is made out of the same material as the rock faces in **Figure** 4.12? This material is a sedimentary rock called sandstone. Sandstone is very porous. Water can easily move through it. So the sandstone of the White House could have been water damaged. But during construction workers covered the sandstone in a mixture of salt, rice, and glue. This mixture protects the sandstone and is what gives the White House its distinct white color.

Sediments

Most sedimentary rocks form from sediments. Sediments are small pieces of other rocks, like pebbles, sand, silt, and clay. Sedimentary rocks may include fossils. **Fossils** are materials left behind by once-living organisms. Fossils can be pieces of the organism, like bones. They can also be traces of the organism, like footprints.

Most often, sediments settle out of water (**Figure** 4.13). For example, rivers carry lots of sediment. Where the water slows, it dumps these sediments along its banks, into lakes and the ocean. When sediments settle out of water, they form horizontal layers. A layer of sediment is deposited. Then the next layer is deposited on top of that layer. So each layer in a sedimentary rock is younger than the layer under it. It is older than the layer over it.

FIGURE 4.13
Cobbles, pebbles, and sands are the sediments that are seen on this beach.

Sediments are deposited in many different types of environments. Beaches and deserts collect large deposits of sand. Sediments also continuously wind up at the bottom of the ocean and in lakes, ponds, rivers, marshes, and swamps. Avalanches produce large piles of sediment. The environment where the sediments are deposited determines the type of sedimentary rock that can form.

Sedimentary Rock Formation

Sedimentary rocks form in two ways. Particles may be cemented together. Chemicals may precipitate.

Clastic Rocks

Over time, deposited sediments may harden into rock. First, the sediments are **compacted**. That is, they are squeezed together by the weight of sediments on top of them. Next, the sediments are **cemented** together. Minerals fill in the spaces between the loose sediment particles. These cementing minerals come from the water that moves through the sediments. These types of sedimentary rocks are called "clastic rocks." Clastic rocks are rock fragments that are compacted and cemented together.

Clastic sedimentary rocks are grouped by the size of the sediment they contain. Conglomerate and breccia are made of individual stones that have been cemented together. In conglomerate, the stones are rounded. In breccia, the stones are angular. Sandstone is made of sand-sized particles. Siltstone is made of smaller particles. Silt is smaller than sand but larger than clay. Shale has the smallest grain size. Shale is made mostly of clay-sized particles and hardened mud.

Chemical Sedimentary Rocks

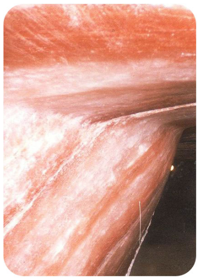
Chemical sedimentary rocks form when crystals precipitate out from a liquid. The mineral halite, also called rock salt, forms this way. You can make halite! Leave a shallow dish of salt water out in the Sun. As the water evaporates, salt crystals form in the dish. There are other chemical sedimentary rocks, like gypsum.

Table 4.1 shows some common types of sedimentary rocks and the types of sediments that make them up.

TABLE 4.1: Common Sedimentary Rocks

Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Limestone	Bioclastic
	Coal	Organic

TABLE 4.1: (continued)

Picture	Rock Name	Type of Sedimentary Rock
	Rock Salt	Chemical precipitate

Lesson Summary

- Most sedimentary rocks form from sediments. These sediments are deposited, forming layers.
- The youngest layers are found on top, with older layers below.
- Sediments must be compacted and cemented to make sedimentary rock.
- Chemical sedimentary rocks are made of precipitated minerals.

Lesson Review Questions

Recall

1. What are three things that sedimentary rocks may be made of?

2. Describe the two processes necessary for sediments to harden into rock.

Apply Concepts

3. If you see a sedimentary rock outcrop and red layers of sand are on top of pale yellow layers of sand, what do you know for sure about the ages of the two layers?

Think Critically

4. What type of sedimentary rock is coal?

5. Why do you think sandstone allows water to move through it easily?

Points to Consider

- If you were interested in learning about Earth's history, which type of rocks would give you the most information?

- Could a younger layer of sedimentary rock ever be found under an older layer? How do you think this could happen?
- Could a sedimentary rock form only by compaction from intense pressure?

4.4 Metamorphic Rocks

Lesson Objectives

- Describe how metamorphic rocks are formed.
- Describe the properties of some common metamorphic rocks.
- Relate some common uses of metamorphic rocks.

Vocabulary

- contact metamorphism
- foliation
- regional metamorphism
- stable

Introduction

Metamorphism changes rocks by heat and pressure. These agents create an entirely new type of rock. Metamorphism changes rocks physically and/or chemically.

Metamorphism

Metamorphic rocks start off as some kind of rock. The starting rock can be igneous, sedimentary or even another metamorphic rock. Heat and/or pressure then change the rock's physical or chemical makeup.

During metamorphism a rock may change chemically. Ions move and new minerals form. The new minerals are more stable in the new environment. Extreme pressure may lead to physical changes like **foliation**. Foliation forms as the rocks are squeezed. If pressure is exerted from one direction, the rock forms layers. This is foliation. If pressure is exerted from all directions, the rock usually does not show foliation.

There are two main types of metamorphism:

1. **Contact metamorphism** results when magma contacts a rock, changing it by extreme heat (**Figure** 4.14).

2. **Regional metamorphism** occurs over a wide area. Great masses of rock are exposed to pressure from rock and sediment layers on top of it. The rock may also be compressed by other geological processes.

Metamorphism does not cause a rock to melt completely. It only causes the minerals to change by heat or pressure.

Hornfels is a rock with alternating bands of dark and light crystals. Hornfels is a good example of how minerals rearrange themselves during metamorphism (**Figure** 4.14). The minerals in hornfels separate by density. The result

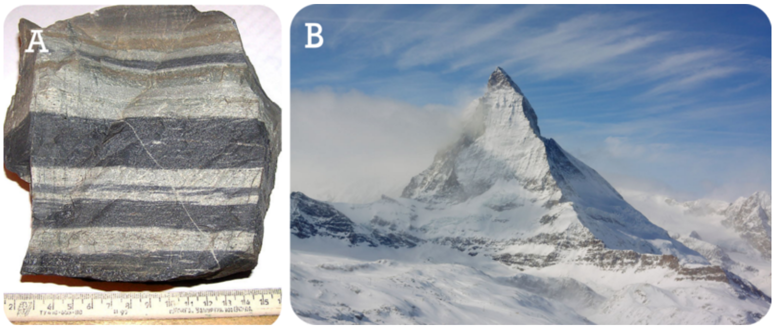


FIGURE 4.14
(A) Hornfels is a rock that is created by contact metamorphism. (B) Hornfels is so hard that it can create peaks like the Matterhorn.

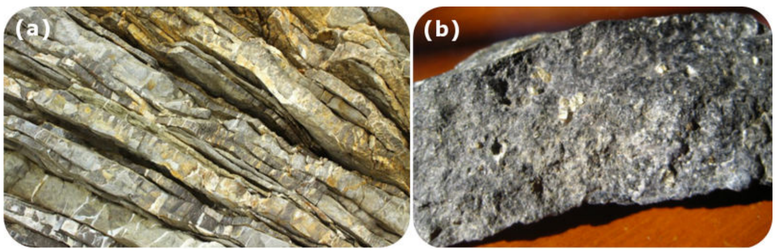


FIGURE 4.15
(A) Regional metamorphic rocks often display layering called foliation. (B) Regional metamorphism with high pressures and low temperatures can result in blue schist.

is that the rock becomes banded. Gneiss forms by regional metamorphism from extremely high temperature and pressure.

Uses of Metamorphic Rocks

Quartzite and marble are the most commonly used metamorphic rocks. They are frequently chosen for building materials and artwork. Marble is used for statues and decorative items like vases (**Figure** 4.16). Quartzite is very hard and is often crushed and used in building railroad tracks. Schist and slate are sometimes used as building and landscape materials.

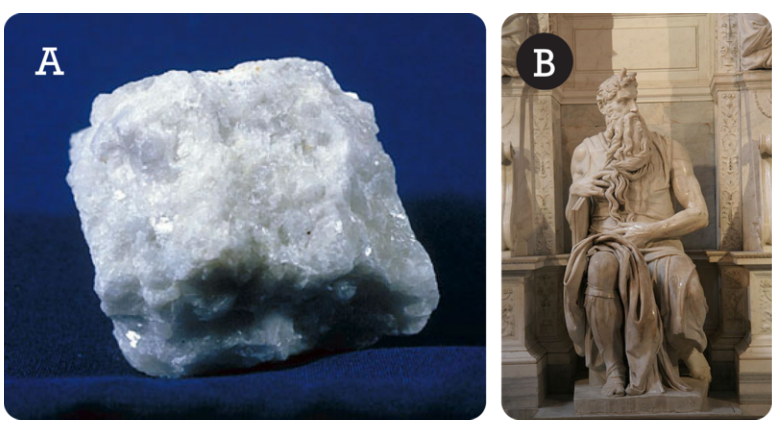


FIGURE 4.16
(A) Marble is a beautiful rock that is commonly used for buildings. (B) Many of the great statues of the Renaissance were carved from marble. Michelangelo created this Moses between 1513 and 1515.

Lesson Summary

- Metamorphic rocks form when heat and pressure transform an existing rock into a new rock.
- Contact metamorphism occurs when hot magma transforms rock that it contacts.
- Regional metamorphism transforms large areas of existing rocks under the tremendous heat and pressure created by tectonic forces.

Lesson Review Questions

Recall

1. Why do the minerals in a rock sometimes rearrange themselves when exposed to heat or pressure?
2. List and describe the two main types of metamorphism.

Apply Concepts

3. How does layering form in metamorphic rocks?
4. What clues in metamorphic rocks tell you how they were formed?

Think Critically

5. Suppose a phyllite sample was exposed to even more heat and pressure. What metamorphic rock would form?

Points to Consider

- What type of plate boundary would produce the most intense metamorphism of rock?
- Do you think new minerals could form when an existing rock is metamorphosed?

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CHAPTER 5 MS Earth's Energy

Chapter Outline

In these light blue pipes flows energy. Energy, or the ability to do work, is necessary for everything from plants performing photosynthesis to you chewing your lunch. It can come from many sources, including the Sun, wind, flowing water, and fossil fuels, and in many forms. While energy cannot be created or destroyed, however, there is a fast-approaching limit on how quickly humans can keep using up energy sources like oil and coal. In this chapter, you will learn about how energy comes to be stored in those forms and about energy alternatives that are sustainable for the future.

5.1 Earth's Energy

Lesson Objectives

- Compare ways in which energy is changed from one form to another.
- Discuss what happens when we burn a fuel.
- Describe the difference between renewable and non-renewable resources.
- Classify different energy resources as renewable or non-renewable.

Vocabulary

- chemical energy
- energy
- fuel
- kinetic energy
- Law of Conservation of Energy
- potential energy

Introduction

Did you know that everything you do takes energy? Even while you are sitting still, your body is using energy to breathe and to keep your blood circulating. Energy controls all of the different processes in your body. But it's not just the human body that needs energy. Everything that moves or changes in any way, from plants to animals to machines, needs energy. Have you ever wondered where all of this energy comes from?

The Sources of Earth's Energy

Almost all energy comes from the Sun. Plants make food energy from sunlight. Fossil fuels are made of the remains of plants and animals that stored the Sun's energy millions of years ago.

The Sun heats some areas more than others, which causes wind. The Sun's energy also drives the water cycle, which moves water over the surface of the Earth. Both wind and water power can be used as renewable resources.

Earth's internal heat does not depend on the Sun for energy. This heat comes from remnant heat when the planet formed. It also comes from the decay of radioactive elements. Radioactivity is an important source of energy.

The Need for Energy

Energy provides the ability to move or change matter from one state to another (for example, from solid to liquid). Every living thing needs energy to live and grow. Your body gets its energy from food, but that is only a small part of the energy you use every day. Cooking your food takes energy, and so does keeping it cold in the refrigerator or the freezer. The same is true for heating or cooling your home. Whether you are turning on a light in the kitchen or riding in a car to school, you are using energy. Billions of people all around the world use energy, so there is a huge demand for resources to provide all of this energy. Why do we need so much energy? The main reason is that almost everything that happens on Earth involves energy.

Conservation of Energy

Energy changes form when something happens. But the total amount of energy always stays the same. The **Law of Conservation of Energy** says that energy cannot be created or destroyed. Scientists observed that energy could change from one form to another. They also observed that the overall amount of energy did not change.

Energy Changes

Here is an example of how energy changes form: kicking a soccer ball. Your body gets energy from food. Where does the food get its energy? If you're eating a plant, then the energy comes directly from the Sun. If you're eating an animal, then the energy comes from a plant that got its energy from the Sun.

Your body breaks down the food. It converts the food to chemical energy and stores it. When you are about to kick the ball, the energy must be changed again. **Potential energy** has the potential to do work. When your leg is poised to kick the ball but is not yet moving, your leg has potential energy. A ball at the top of a hill has the potential energy of location.

Kinetic energy is the energy of anything in motion. Your muscles move your leg, your foot kicks the ball, and the ball gains kinetic energy (**Figure** 5.1). The kinetic energy was converted from potential energy that was in your leg before the kick. The action of kicking the ball is energy changing forms. The same is true for anything that involves change.

Energy, Fuel, and Heat

Energy is the ability to do work. Fuel stores energy and can be released to do work. Heat is given off when fuel is burned.

Energy

What makes energy available whenever you need it? If you unplug a lamp, the light goes off. The lamp does not have a supply of energy to keep itself lit. The lamp uses electricity that comes through the outlet as its source of energy. The electricity comes from a power plant. The power plant has a source of energy to produce this electricity.

Fuel

The energy to make the electricity comes from fuel. Fuel stores the energy and releases it when it is needed. **Fuel** is any material that can release energy in a chemical change. The food you eat acts as a fuel for your body. Gasoline

FIGURE 5.1
Kicking a soccer ball takes energy from your food and gives it to the soccer ball.

and diesel fuel are fuels that provide the energy for most cars, trucks, and buses. But there are many different kinds of fuel.

For fuel to be useful, its energy must be released in a way that can be controlled.

Heat

When fuel is burned, most of the energy is released as heat. Some of this heat can be used to do work. Heat cooks food or warms your house. Sometimes the heat is just waste heat. It still heats the environment, though.

Heat from a fire can boil a pot of water. If you put an egg in the pot, you can eat a hard boiled egg in 15 minutes (cool it down first!). The energy to cook the egg was stored in the wood. The wood got that energy from the Sun when it was part of a tree. The Sun generated the energy by nuclear fusion. You started the fire with a match. The head of the match stores energy as chemical energy. That energy lights the wood on fire. The fire burns as long as there is energy in the wood. Once the wood has burned up, there is no energy left in it. The fire goes out.

Types of Energy Resources

Energy resources can be put into two categories —renewable or non-renewable. Nonrenewable resources are used faster than they can be replaced. Renewable resources can be replaced as quickly as they are used. Renewable resources may also be so abundant that running out is impossible.

The difference between non-renewable and renewable resources is like the difference between ordinary batteries and rechargeable ones. If a flashlight when ordinary batteries goes dead, the batteries need to be replaced. But if the flashlight has rechargeable batteries, the batteries can be placed in a charger. The charger transfers energy from an outlet into the batteries. Once recharged, the batteries can be put back into the flashlight. Rechargeable batteries can be used again and again (**Figure** 5.2). In this way, the energy in the rechargeable batteries is renewable.

FIGURE 5.2
Rechargeable batteries are renewable because they can be refilled with energy. Is the energy they are refilled with always renewable?

Types of Nonrenewable Resources

Fossil fuels include coal, oil, and natural gas. Fossil fuels are the greatest energy source for modern society. Millions of years ago, plants used energy from the Sun to form carbon compounds. These compounds were later transformed into coal, oil, or natural gas. Fossil fuels take millions of years to form. For this reason, they are non-renewable. We will use most fossil fuels up in a matter of decades. Burning fossil fuels releases large amounts of pollution. The most important of these may be the greenhouse gas carbon dioxide.

Types of Renewable Resources

Renewable energy resources include solar, water, wind, biomass, and geothermal power. These resources are usually replaced at the same rate that we use them. Scientists know that the Sun will continue to shine for billions of years. So we can use the solar energy without it ever running out. Water flows from high places to lower ones. Wind blows from areas of high pressure to areas of low pressure. We can use the flow of wind and water to generate power. We can count on wind and water to continue to flow! Burning wood is an example of biomass energy. Changing grains into biofuels is biomass energy. Biomass is renewable because we can plant new trees or crops to replace the ones we use. Geothermal energy uses water that was heated by hot rocks. There are always more hot rocks available to heat more water.

Even renewable resources can be used unsustainably. We can cut down too many trees without replanting. We might need grains for food rather than biofuels. Some renewable resources are too expensive to be widely used. As the technology improves and more people use renewable energy, the prices will come down. The cost of renewable resources will go down relative to fossil fuels as we use fossil fuels up. In the long run renewable resources will need to make up a large amount of what we use.

Important Things to Consider About Energy Resources

Before we put effort into increasing the use of an energy source, we should consider two things. Is there a practical way to turn the resource into useful form of energy? For example, it is not practical if we don't get much more energy from burning a fuel than we put into making it.

What happens when we turn the resource into energy? What happens when we use that resource? Mining the resource may cause a lot of health problems or environmental damage. Using the resource may create a large amount of pollution. In this case, that fuel may also not be the best choice for an energy resource.

KQED: Climate Watch: Unlocking the Grid

Today we rely on electricity more than ever, but the resources that currently supply our power are finite. The race is on to harness more renewable resources, but getting all that clean energy from production sites to homes and businesses is proving to be a major challenge. Learn more by watching the resource below: http://www.kqed.org/quest/television/climate-watch-unlocking-the-grid

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Lesson Summary

- According to the Law of Conservation of Energy, energy is neither created nor destroyed.
- Renewable resources can be replaced at the rate they are being used.
- Nonrenewable resources are available in limited amounts or are being used faster than they can be replaced.

Lesson Review Questions

Recall

1. Define energy, fuel and heat. How are they interrelated?

Apply Concepts

2. Think of getting on a roller coaster. What time of energy is used as use walk onto the coaster? What type of energy does the coaster use as it climbs up the hill? As it sits at the top? As it flies down?

Think Critically

3. Where does most energy come from? Where else does energy come from?

4. What substances burn? If a substance doesn't burn, why not? Could it burn? For example, how could you get orange juice to burn?

5. Is it worth developing non-renewable resources? Should we just develop renewable resources?

Points to Consider

- How long do fossil fuels take to form?
- Are all fossil fuels non-renewable resources?
- Do all fossil fuels affect the environment equally?

5.2 Nonrenewable Energy Resources

Lesson Objectives

- Describe how fossil fuels are formed.
- Describe different fossil fuels, and understand why they are non-renewable resources.
- Explain how fossil fuels are turned into useful forms of energy.
- Understand that when we burn a fossil fuel, most of its energy is released as heat.
- Describe how the use of fossil fuels affects the environment.

Vocabulary

- hydrocarbons

Introduction

Have you ever seen dinosaur fossils at a museum? The same processes that formed dinosaur fossils created fossil fuels. Fossil fuels are now our most important energy resources. Most of the energy we use for industry comes from them. Most energy to heat and cool homes and to get us around does, too. Fossil fuels provide high-quality energy. But the use of fossil fuels has consequences. Burning fossil fuel releases pollutants, including greenhouse gases. Also, we are using up these resources much faster than they can be replaced.

Formation of Fossil Fuels

Fossil fuels are made from plants and animals that lived hundreds of millions of years ago. The plants and animals died. Their remains settled onto the ground and at the bottom of the sea. Layer upon layer of organic material was laid down. Eventually, the layers were buried very deeply. They experienced intense heat and pressure. Over millions of years, the organic material turned into fossil fuels.

Fossil fuels are compounds of carbon and hydrogen, called **hydrocarbons**. Hydrocarbons can be solid, liquid, or gas. The solid form is coal. The liquid form is petroleum, or crude oil. The gaseous form is natural gas.

Coal

Coal is a solid hydrocarbon. Coal is useful as a fuel, especially for generating electricity.

How Coal Forms

Coal forms from dead plants that settled at the bottom of swamps millions of years ago. Water and mud in the swamp kept oxygen away from the plant material. Sand and clay settled on top of the decaying plants. The weight of this material squeezed out the water and some other substances. Over time, the organic material became a carbon-rich rock. This rock is coal.

What Coal Is

Coal is a black or brownish-black rock that burns easily (**Figure** 5.3). Most coal is sedimentary rock. The hardest type of coal, anthracite, is a metamorphic rock. That is because it is exposed to higher temperature and pressure as it forms. Coal is mostly carbon, but some other elements can be found in coal, including sulfur.

FIGURE 5.3

Coal is a solid hydrocarbon formed from decaying plant material over millions of years.

Mining Coal

Around the world, coal is the largest source of energy for electricity. The United States is rich in coal. Pennsylvania and the region to the west of the Appalachian Mountains are some of the most coal-rich areas of the United States.

Coal has to be mined to get it out of the ground. Coal mining affects the environment and human health. Coal mining can take place underground or at the surface. Each method has some advantages and disadvantages.

- Surface mining exposes minerals that were underground to air and water at the surface. These minerals contain the chemical element sulfur. Sulfur mixes with air and water to make sulfuric acid. This acid is a highly corrosive chemical. Sulfuric acid gets into nearby streams and can kill fish, plants, and animals. Surface mining is safer for the miners.
- Coal mining underground is dangerous for the coal miners. Miners are sometimes killed if there is an explosion or a mine collapse. Miners breathe in coal dust and can get terrible lung diseases after a number of years in the mines.

Using Coal

To prepare coal for use, the coal is first crushed into powder and burned in a furnace. Like other fuels, coal releases most of its energy as heat when it burns. The heat from the burning coal is used to boil water. This makes steam. The steam spins turbines, which creates electricity.

Oil

Oil is a thick, dark brown or black liquid. It is found in rock layers of the Earth's crust. Oil is currently the most commonly used source of energy in the world.

How Oil Forms

The way oil forms is similar in many ways to coal. Tiny organisms like plankton and algae die and settle to the bottom of the sea. Sediments settle over the organic material. Oxygen is kept away by the sediments. When the material is buried deep enough, it is exposed to high heat and pressure. Over millions of years, the organic material transforms into liquid oil.

Mining Oil

The United States produces only about one-quarter as much oil as it uses. The main oil producing regions in the U.S. are the Gulf of Mexico, Texas, Alaska, and California.

Geologists look for oil in folded layers of rock called anticlines. Oil moves through permeable rock and is trapped by the impermeable cap rock.

FIGURE 5.4
This oil refinery processes crude oil into usable energy sources, such as gasoline.

Types of Oil

Oil comes out of the ground as crude oil. Crude oil is a mixture of many different hydrocarbons. Oil is separated into different compounds at an oil refinery (**Figure** 5.4). This is done by heating the oil. Each hydrocarbon compound in crude oil boils at a different temperature. We get gasoline, diesel, and heating oil, plus waxes, plastics, and fertilizers from crude oil.

These fuels are rich sources of energy. Since they are mostly liquids they can be easily transported. These fuels provide about 90% of the energy used for transportation around the world.

Gasoline

Gasoline is a concentrated resource. It contains a large amount of energy for its weight. This is important because the more something weighs, the more energy is needed to move it. If gasoline could only provide a little energy, a car would have to carry a lot of it to be able to travel very far. Or the car would need to be filled up frequently. So a highly concentrated energy resource is a practical fuel to power cars and other forms of transportation.

Let's consider how gasoline powers a car. As gasoline burns, it releases most of its energy as heat. It also releases carbon dioxide gas and water vapor. The heat makes the gases expand. This forces the pistons inside the engine to move. The engine makes enough power to move the car.

Using Oil

Using gasoline to power automobiles affects the environment. The exhaust fumes from burning gasoline cause air pollution. These pollutants include smog and ground-level ozone. Air pollution is a big problem for cities where large numbers of people drive every day. Burning gasoline also produces carbon dioxide. This is a greenhouse gas and is a cause of global warming. Similar pollutants come from other forms of oil.

Natural Gas

Natural gas is mostly methane.

How Natural Gas Forms

Natural gas is often found along with coal or oil in underground deposits. This is because natural gas forms with these other fossil fuels. One difference between natural gas and oil is that natural gas forms at higher temperatures.

Natural Gas Use

The largest natural gas reserves in the United States are located in the Rocky Mountain states, Texas, and the Gulf of Mexico region. California also has natural gas, mostly in the northern Sacramento Valley and the Sacramento Delta.

Natural gas must be processed before it can be used as a fuel. Poisonous chemicals and water must be removed.

Natural gas is delivered to homes, where it is used for cooking and heating. Natural gas is also a major energy source for powering turbines to make electricity. Natural gas releases most of its energy as heat when it burns. The power plant is able to use this heat, either in the form of hot gases or steam, to spin turbines. The spinning turbines turn generators, and the generators create electricity.

Consequences of Natural Gas Use

Processing natural gas has harmful effects on the environment, just like oil. Natural gas burns cleaner than other fossil fuels. As a result, it causes less air pollution. It also produces less carbon dioxide than the other fossil fuels. Still, natural gas does emit pollutants.

Problems with Fossil Fuels

Fossil fuels present many problems. These fuels are non-renewable resources, so our supplies of them will eventually run out. Safety can be a problem, too. Since these fuels burn so easily, a natural gas leak in a building or an underground pipe can lead to a deadly explosion.

Using fossil fuels affects the environment in a variety of ways. There are impacts to the environment when we extract these resources. Burning these fuels causes air pollution. These fuels release carbon dioxide, which is a major factor in global warming (**Figure** 5.5).

FIGURE 5.5
Burning fossil fuels releases pollutants into the air.

Many of the problems with fossil fuels are worse for coal than for oil or natural gas. Burning coal releases more carbon dioxide than either oil or natural gas. Yet coal is the most common fossil fuel, so we continue to burn large amounts of it. That makes coal the biggest contributor to global warming.

Another problem with coal is that most coal contains sulfur. As it burns, the sulfur goes into the air as sulfur dioxide. Sulfur dioxide is the main cause of acid rain. Acid rain can be deadly to plants, animals, and whole ecosystems. Burning coal also puts a large number of small solid particulates into the air. These particles are dangerous to people, especially those who have asthma. People with asthma may end up in the hospital on days when particulate pollution is high.

Nuclear Energy

Nuclear energy is produced by splitting the nucleus of an atom. This releases a huge amount of energy.

How Nuclear Power Plants Work

Nuclear power plants use uranium that has been concentrated in fuel rods (**Figure** 5.6). The uranium atoms are split apart when they are hit by other extremely tiny particles. These particles must be controlled or they would cause a dangerous explosion.

Nuclear power plants use the energy they produce to heat water. The water turns into steam, which causes a turbine to spin. This in turn produces electricity.

Nuclear Power and a Resource

Many countries around the world use nuclear energy as a source of electricity. For example, France gets about 80% of its electricity from nuclear energy. In the United States, a little less than 20% of electricity comes from nuclear energy.

FIGURE 5.6
Nuclear power plants like this one provide France with almost 80% of its electricity.

Nuclear energy does not pollute. If there are no accidents, a nuclear power plant releases nothing but steam into the air. But nuclear energy does create other environmental problems. Splitting atoms creates dangerous radioactive waste. These wastes can remain dangerous for hundreds of thousands of years. Scientists and engineers are still looking for ways to keep this waste safely away from people.

KQED: Nuclear Energy Use

Nuclear power is a controversial subject in California and most other places. Nuclear power has no pollutants including carbon emissions, but power plants are not always safe and the long-term disposal of wastes is a problem that has not yet been solved. The future of nuclear power is murky. Find out more at: http://science.kqed.org/quest/audio/new-nuclear/

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Lesson Summary

- Coal, oil and natural gas are all fossil fuels formed from the remains of once living organisms.
- Coal is our largest source of energy for producing electricity.
- Mining and using coal produce many environmental impacts, including carbon dioxide emissions and acid rain.
- Oil and natural gas are important sources of energy for many types of vehicles and uses in our homes and industry.
- Fossil fuels are non-renewable sources of energy that produce environmental damage.

- Nuclear energy is produced by splitting atoms. It also produces radioactive wastes that are very dangerous for many years.

Lesson Review Questions

Recall

1. How does coal form? How are the formation of oil and natural gas different from coal?
2. Waxes can be made from the processing of which fossil fuel?

Apply Concepts

3. What environmental problems are caused by surface coal mining?
4. What health problems are caused by underground coal mining?

Think Critically

5. Anthracite is the hardest type of coal because it is metamorphic. Anthracite causes less pollution when it burns. Why do you think that is?
6. What properties would a fuel have to have for it to be a good replacement for gasoline? Explain.

Points to Consider

- How are renewable sources of energy different from non-renewable sources of energy?
- Are all renewable energy sources equally practical?
- Are all renewable energy sources equally good for the environment?

5.3 Renewable Energy Resources

Lesson Objectives

- Describe different renewable resources, and explain why they are renewable.
- Describe how the Sun is the source of most of Earth's energy.
- Describe how energy is carried from one place to another as heat and by moving objects.
- Understand how conduction, convection, and radiation transfer energy as heat when renewable energy sources are used.
- Understand that some renewable energy sources cost less than others and some cause less pollution than others.
- Explain how renewable energy resources are turned into useful forms of energy.
- Describe how the use of different renewable energy resources affects the environment.
- Describe how a nuclear power plant produces energy.

Vocabulary

- conduction
- convection
- radiation

Introduction

What if we could have all of the energy we needed and never run out of it? What if we could use this energy without polluting the air and water? In the future, renewable sources of energy may be able to provide all of the energy we need. Some of these resources can give us "clean" energy that causes little or no pollution.

There are plenty of clean energy options available for us to use. The largest amount of energy to reach Earth's surface is from the Sun. Earth receives 174 petawatts (1.74 x 1017 W) of energy from the Sun each year. Another 23 terawatts (2.3 x 1013 W) of energy flows outward from the Earth's interior. By contrast, the total world power consumption is around 16 terawatts (1.6 x 1013W) per year. So solar or geothermal energy alone could provide all of the energy people need if it could be harnessed.

Solar Energy

Energy from the Sun

The Sun is Earth's main source of energy. The Sun gives us both light and heat. The Sun changes hydrogen into helium through nuclear fusion. This releases huge amounts of energy. The energy travels to the Earth mostly

FIGURE 5.7
Solar energy is clean and renewable. Solar panels are needed to collect the sunlight for use.

as visible light. The energy is carried through the empty space by **radiation**. We can use sunlight as an energy resource, called solar energy (**Figure** 5.7).

Solar Energy as a Resource

Solar energy has been used on a small scale for hundreds of years. Today we are using solar energy for more of our power demands. Solar power plants are being built in many locations around the world. In the United States, the southwestern deserts are well suited for solar plants.

Solar Power Plants

Sunlight is turned into electricity at a solar power plant. These power plants use a large group of mirrors to focus sunlight on one place. This place is called a receiver (**Figure** 5.8). At the receiver, a liquid such as oil or water is heated to a high temperature. The liquid transfers its heat by **conduction**. In conduction, energy moves between two objects that are in contact. The higher temperature object transfers heat to the lower temperature object. For example, when you heat a pot of water on a stove top, energy moves from the pot to its metal handle by conduction. At a solar power plant, the energy conducted by the heated liquid is used to make electricity.

Solar Energy Use

Solar energy is used to heat homes and water, and to make electricity. Scientists and engineers have many ways to get energy from the Sun (**Figure** 5.9). One is by using solar cells. Solar cells are devices that turn sunlight directly into electricity. Lots of solar cells make up an individual solar panel. You may have seen solar panels on roof tops. The Sun's heat can also be trapped in your home by using south facing windows and good insulation.

Consequences of Solar Energy Use

Solar energy has many benefits. It does not produce any pollution. There is plenty of it available, much more than we could possibly use.

FIGURE 5.8
A solar power tower is used to concentrate the solar energy collected by many solar panels.

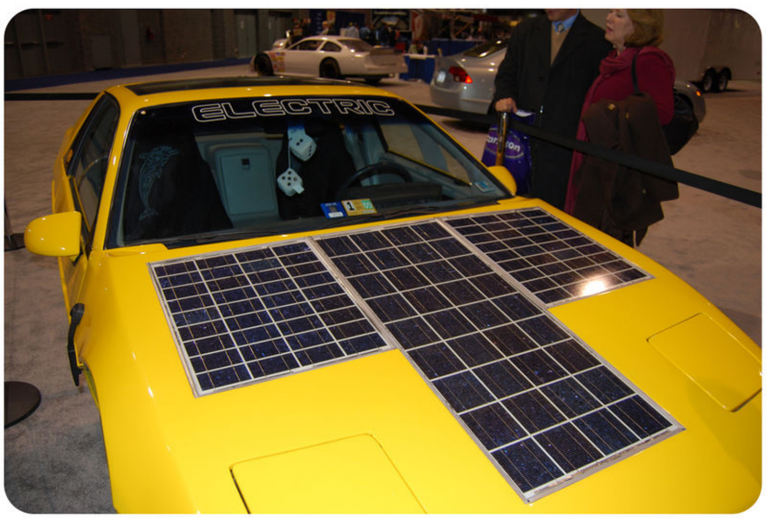


FIGURE 5.9
Solar panels on top of a car could power the car. This technology is a long way from being practical.

But solar energy has problems. The Sun doesn't shine at night. A special battery is needed to store extra energy during the day for use at night. The technology for most uses of solar energy is still expensive. Until solar technology becomes more affordable, most people will prefer to get their energy from other sources.

Water Power

Moving water has energy (**Figure** 5.10). That energy is used to make electricity. Hydroelectric power harnesses the energy of water moving down a stream. Hydropower is the most widely used form of renewable energy in the world. This abundant energy source provides almost one fifth of the world's electricity. The energy of waves and tides can also be used to produce water power. At this time, wave and tidal power are rare.

FIGURE 5.10
Glen Canyon Dam harnesses the power of flowing water to generate electricity.

Hydropower Plants

To harness water power, a stream must be dammed. Narrow valleys are the best for dams. While sitting in the reservoir behind the dam, the water has potential energy. Water is allowed to flow downhill into a large turbine. While flowing downhill, the water has kinetic energy. Kinetic energy makes the turbine spin. The turbine is connected to a generator, which makes electricity.

Hydropower as a Resource

Many of the suitable streams in the United States have been developed for hydroelectric power. Many streams worldwide also have hydroelectric plants. Hydropower is a major source of California's electricity. It accounts for about 14.5 percent of the total. Most of California's nearly 400 hydroelectric power plants are located in the Sierra Nevada mountains.

Benefits and Problems of Hydropower

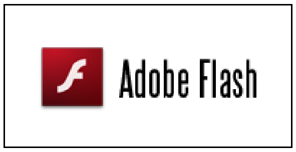
Water power does not burn a fuel. So it causes less pollution than many other kinds of energy. Water power is also a renewable resource. Water keeps flowing downhill. Although we use some of the energy from this movement, we are not using up the water.

Water power does have problems. A large dam stops a stream's flow, which floods the land upstream. A beautiful location may be lost. People may be displaced. The dams and turbines also change the downstream environment. Fish and other living things may not be able to survive. Dams slow the release of silt. Downstream deltas retreat and beaches may be starved of sand. Seaside cities may become exposed to storms and rising sea levels.

Tidal power stations may need to close off a narrow bay or estuary. Wave power plants must withstand coastal storms and the corrosion of seawater.

KQED: Harnessing Power from the Sea

Although not yet widely used, many believe tidal power has more potential than wind or solar power for meeting alternative energy needs. Quest radio looks at plans for harnessing power from the sea by San Francisco and along the northern California coast. Learn more at: http://science.kqed.org/quest/audio/harnessing-power-from-the-sea/



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Wind Power

FIGURE 5.11

Winds are funneled through passes in mountain ranges. Altamont Pass in California is the site of many wind turbines.

The energy from the Sun creates wind (**Figure** 5.11). Wind energy moves by **convection**. The Sun heats some locations more than others. Warm air rises, so other air rushes in to fill the hole left by the rising air. This horizontal movement of air is called wind.

Wind as a Resource

Wind power uses moving air as a source of energy. Some types of wind power have been around for a long time. People have used windmills to grind grain and pump water for hundreds of years. Sailing ships have depended on wind for millennia. Wind is now used to generate electricity. Moving air can make a turbine spin, just like moving water can. Moving air has kinetic energy. When wind hits the blades of the turbine, the kinetic energy makes the blades move. The turbine spins and creates electricity.

Wind Power Advantages and Disadvantages

Wind power has many advantages. It is clean: it does not release pollutants or carbon dioxide. It is plentiful almost everywhere. The technology to harness wind energy is being developed rapidly.

Wind power also has problems. Wind does not blow all of the time, so wind energy must be stored for later use. Alternatively, another energy source needs to be available when the wind is not blowing. Wind turbines are expensive. They can wear out quickly. Finally, windmills are not welcomed by residents of some locations. They say that they are unattractive. Yet even with these problems, wind turbines are a competitive form of renewable energy.

Many states are currently using wind power. Wind turbines are set up in mountain passes. This is common in California, where cool Pacific Ocean air is sucked across the passes and into the warmer inland valleys.

Biomass

Biomass is another renewable source of energy. Biomass includes wood, grains, and other plant materials or waste materials. People can burn wood directly for energy in the form of heat. Biomass can also be processed to make biofuel. Biofuel is a fairly new type of energy that is becoming more popular. Biomass is useful because it can be made liquid. This means that they can be used in cars and trucks. Some car engines can be powered by pure vegetable oil or even recycled vegetable oil. Sometimes the exhaust from these cars smells like French fries!

By using biofuels, we can cut down on the amount of fossil fuel that we use. Because living plants take carbon dioxide out of the air, growing plants for biofuel can mean that we will put less of this gas into the air overall. This could help us do something about the problem of global warming.

Geothermal Energy

Geothermal energy comes the Earth's internal heat. Hot springs and geysers are produced by water that is heated by magma or hot rock below the surface.

At a geothermal power plant, engineers drill wells into the hot rocks. Hot water or steam may come up through the wells. Alternatively, water may be put down into the well to be heated. It then comes up. The hot water or steam makes a turbine spin. This makes electricity.

Geothermal Energy as a Resource

Because the hot water or steam can be used directly to make a turbine spin, geothermal energy can be used without processing. Geothermal energy is clean and safe. It is renewable. There will always be hot rocks and water can be pumped down into a well. There, the water can be heated again to make more steam.

Geothermal energy is an excellent resource in some parts of the world. Iceland is gets about one fourth of its electricity from geothermal sources. In the United States, California leads all states in producing geothermal energy. Geothermal energy in California is concentrated in the northern part of the state. The largest plant is in the Geysers Geothermal Resource Area. Geothermal energy is not economical everywhere. Many parts of the world do not have underground sources of heat that are close enough to the surface for building geothermal power plants.

KQED: Geothermal Heats Up

Where Earth's internal heat gets close to the surface, geothermal power is a clean source of energy. In California, The Geysers supplies energy for many nearby homes and businesses. Learn more at: http://science.kqed.org/quest/video/geothermal-heats-up/

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Lesson Summary

- Solar energy, water power, wind power, biomass energy, and geothermal energy are renewable energy sources.
- Solar energy can be used either by passively storing and holding the Sun's heat, converting it to electricity, or concentrating it.
- There are many ways to use the energy of moving water, including hydroelectric dams.
- Wind power uses the energy of moving air to turn turbines.
- Biomass energy uses renewable materials like wood or grains to produce energy.
- Geothermal energy uses heat from magma within the Earth to heat homes or produce steam that turns turbines.

Lesson Review Questions

Recall

1. Explain how convection works.

2. Explain how conduction works.

3. Explain how radiation works.

Apply Concepts

4. Electricity is made when some type of energy turns a turbine. Explain how this happens and give two examples.

5. Explain how mirrors are used in some solar energy plants.

Think Critically

6. What are the tradeoffs for renewable and non-renewable energy sources? Which way do you think society should go? Should we find every last bit of fossil fuels to use? Should we develop renewables more rapidly?

7. Mining is one of the hidden costs of resources, both renewable and non-renewable. How does mining figure in to the cost/benefit considerations of resources?

Points to Consider

- What areas do you think would be best for using solar energy?
- What causes the high temperatures deep inside the Earth that make geothermal energy possible?
- Do you think your town or city could use wind or water power?

5.4 References

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CHAPTER 6 MS Plate Tectonics

Chapter Outline

Earth is a restless planet. Heat in the Earth's interior causes giant plates of crust to move around on the surface. The crashing and smashing of these plates leads to nearly all of the geological activity we see. Plate collisions bring us volcanoes and earthquakes, mountain ranges, and many resources. Seafloor forms as plates move apart. Some of Earth's most beautiful landscapes come from plate tectonics. The Grand Tetons in Wyoming rose up as the Farallon Plate sunk beneath the North American Plate during the Laramide orogeny.

Miles Orchinik. CK-12 Foundation. CC BY-NC 3.0.

6.1 Inside Earth

Lesson Objectives

- Compare and describe each of Earth's layers.
- Compare some of the ways geologists learn about Earth's interior.
- Define oceanic and continental crust and the lithosphere.
- Describe how heat moves, particularly how convection takes place in the mantle.
- Compare the two parts of the core and describe why they are different from each other.

Vocabulary

- asthenosphere
- convection cell
- continental crust
- core
- crust
- lithosphere
- mantle
- meteorite
- oceanic crust
- plate tectonics
- seismic waves

Introduction

From outside to inside, Earth is divided into crust, mantle, and core. Each has a different chemical makeup. Earth can also be divided into layers with different properties. The two most important are lithosphere and asthenosphere.

How Do We Know About Earth's Interior?

If someone told you to figure out what is inside Earth, what would you do? How could you figure out what is inside our planet? How do scientists figure it out?

Seismic Waves

Geologists study earthquake waves to "see" Earth's interior. Waves of energy radiate out from an earthquake's focus. These are called **seismic waves** (**Figure** 6.1). Seismic waves change speed as they move through different materials. This causes them to bend. Some seismic waves do not travel through liquids or gases. Scientists use all of this information to understand what makes up the Earth's interior.

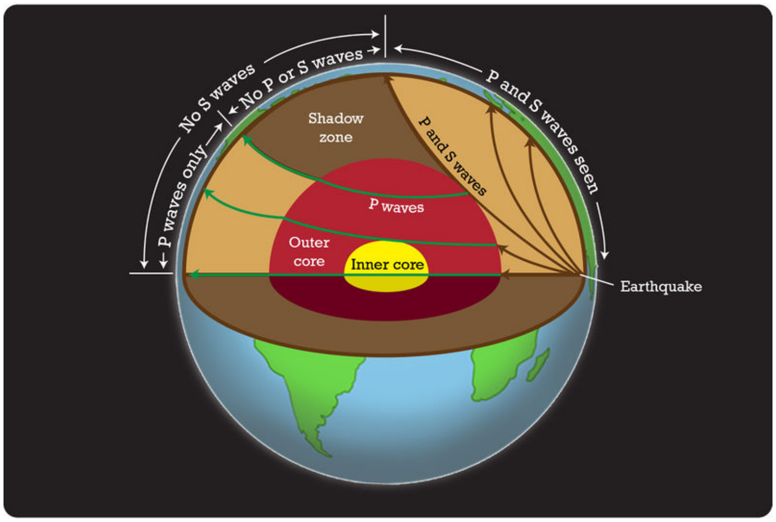

FIGURE 6.1
The properties of seismic waves allow scientists to understand the composition of Earth's interior.

Meteorites

Scientists study **meteorites** to learn about Earth's interior. Meteorites formed in the early solar system. These objects represent early solar system materials. Some meteorites are made of iron and nickel. They are thought to be very similar to Earth's core (**Figure** 6.2). An iron meteorite is the closest thing to a sample of the core that scientists can hold in their hands!

FIGURE 6.2
The Willamette Meteorite is a metallic meteorite that was found in Oregon.

Crust

Crust, mantle, and core differ from each other in chemical composition. It's understandable that scientists know the most about the crust, and less about deeper layers (**Figure** 6.3). Earth's **crust** is a thin, brittle outer shell. The crust is made of rock. This layer is thinner under the oceans and much thicker in mountain ranges.

Oceanic Crust

There are two kinds of crust. **Oceanic crust** is made of basalt lavas that flow onto the seafloor. It is relatively thin, between 5 to 12 kilometers thick (3 - 8 miles). The rocks of the oceanic crust are denser (3.0 g/cm^3) than the rocks that make up the continents. Thick layers of mud cover much of the ocean floor.

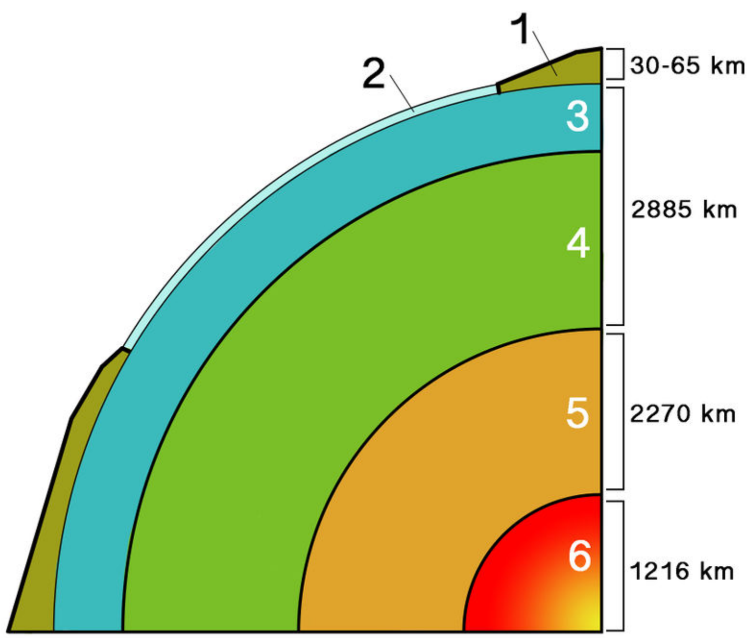

FIGURE 6.3
A cross-section of Earth showing the following layers: (1) continental crust, (2) oceanic crust, (3) upper mantle, (4) lower mantle, (5) outer core, (6) inner core.

Continental Crust

Continental crust is much thicker than oceanic crust. It is 35 kilometers (22 miles) thick on average, but it varies a lot. Continental crust is made up of many different rocks. All three major rock types —igneous, metamorphic, and sedimentary —are found in the crust. On average, continental crust is much less dense (2.7 g/cm3) than oceanic crust. Since it is less dense, it rises higher above the mantle than oceanic crust.

Mantle

Beneath the crust is the **mantle**. The mantle is made of hot, solid rock. Through the process of conduction, heat flows from warmer objects to cooler objects (**Figure** 6.4). The lower mantle is heated directly by conduction from the core.

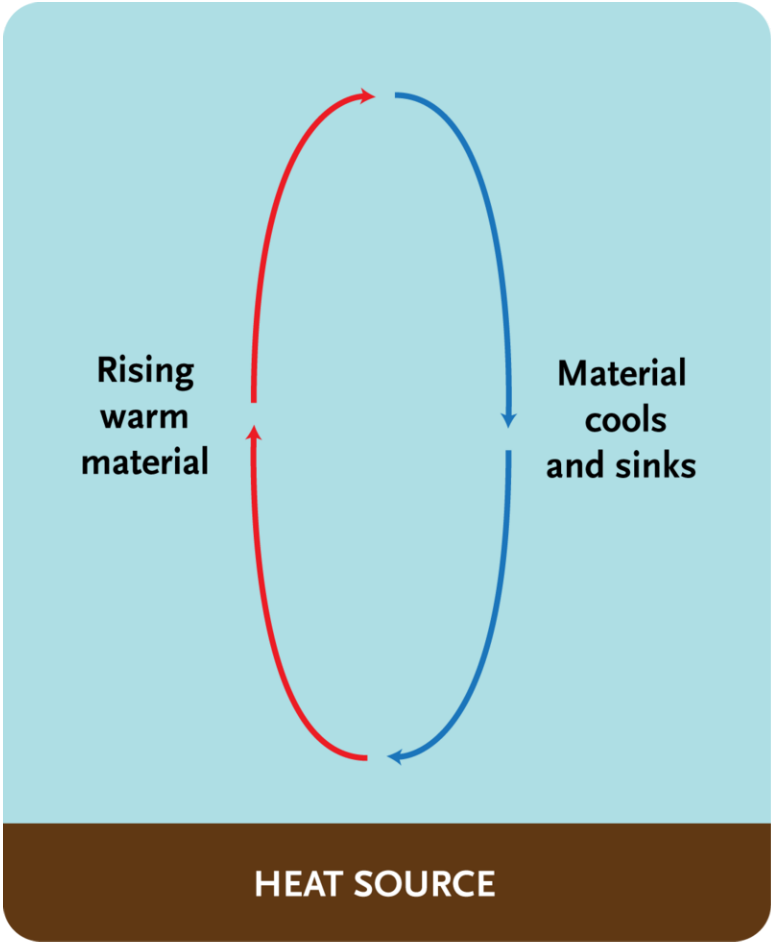

FIGURE 6.4
In the process of conduction, heat flows from warmer objects to cooler objects.

Hot lower mantle material rises upwards (**Figure** 6.5). As it rises, it cools. At the top of the mantle it moves horizontally. Over time it becomes cool and dense enough that it sinks. Back at the bottom of the mantle, it travels horizontally. Eventually the material gets to the location where warm mantle material is rising. The rising and sinking of warm and cooler material is convection. The motion described creates a convection cell.

Core

The dense, iron **core** forms the center of the Earth. Scientists know that the core is metal from studying metallic meteorites and the Earth's density. Seismic waves show that the outer core is liquid, while the inner core is solid. Movement within Earth's outer liquid iron core creates Earth's magnetic field. These convection currents form in the outer core because the base of the outer core is heated by the even hotter inner core.

Lithosphere and Asthenosphere

Lithosphere and asthenosphere are layers based on physical properties. The outermost layer is the **lithosphere**. The lithosphere is the crust and the uppermost mantle. In terms of physical properties, this layer is rigid, solid, and brittle. It is easily cracked or broken.

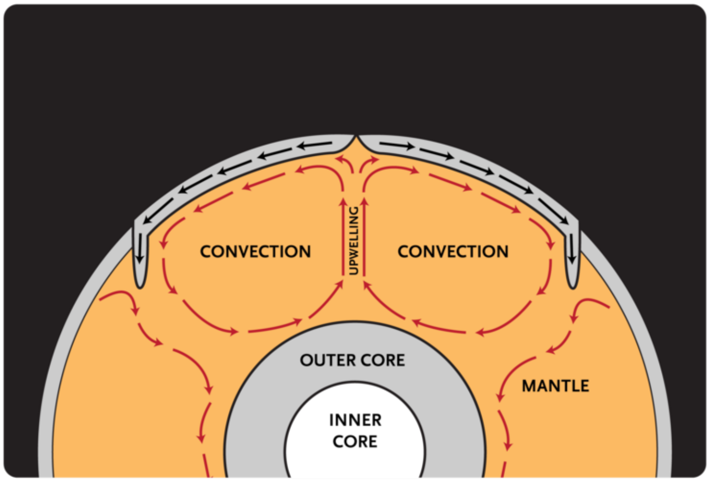

FIGURE 6.5
The rising and sinking of mantle material of different temperatures and densities creates a convection cell.

Below the lithosphere is the **asthenosphere**. The asthenosphere is also in the upper mantle. This layer is solid, but it can flow and bend. A solid that can flow is like silly putty.

Lesson Summary

- The Earth is made of three layers with different composition: the crust, mantle, and core.
- The lithosphere is made of the rigid, brittle, solid crust and uppermost mantle.
- Beneath the lithosphere, the asthenosphere is solid rock that can flow.
- The hot core warms the base of the mantle, which creates convection currents in the mantle.

Lesson Review Questions

Recall

1. List two ways that scientists learn about what makes up the Earth's interior.

2. What type of rock makes up the oceanic crust?

3. What types of rock make up the continental crust?

Apply Concepts

4. Describe the properties of the lithosphere and asthenosphere. What parts of the Earth do these layers include?

5. When you put your hand near a pan above a pan filled with boiling water, does your hand warm up because of convection or conduction? If you touch the pan, does your hand warm up because of convection or conduction?

Think Critically

6. List two reasons that scientists know that the outer core is liquid.

7. Suppose that Earth's interior contains a large amount of lead. Lead is very dense: 11.34 g/cm^3. Would the lead be more likely to be found in the crust, mantle, or core?

Points to Consider

- The oceanic crust is thinner and denser than continental crust. All crust sits atop the mantle. What might our planet be like if this were not true.
- If sediments fall onto the seafloor over time, what can sediment thickness tell scientists about the age of the seafloor in different regions?
- How might convection cells in the mantle affect the movement of plates of lithosphere on the planet's surface?

6.2 Continental Drift

Lesson Objectives

- Be able to explain the continental drift hypothesis.
- Describe the evidence Wegener used to support his continental drift idea.
- Describe how the north magnetic pole appeared to move, and how that is evidence for continental drift.

Vocabulary

- continental drift
- magnetic field

Introduction

To develop plate tectonics, first scientists had to accept that continents could move. Today they do. But it took a long time for scientists to accept that this could happen (**Figure** 6.6). This idea is called continental drift.

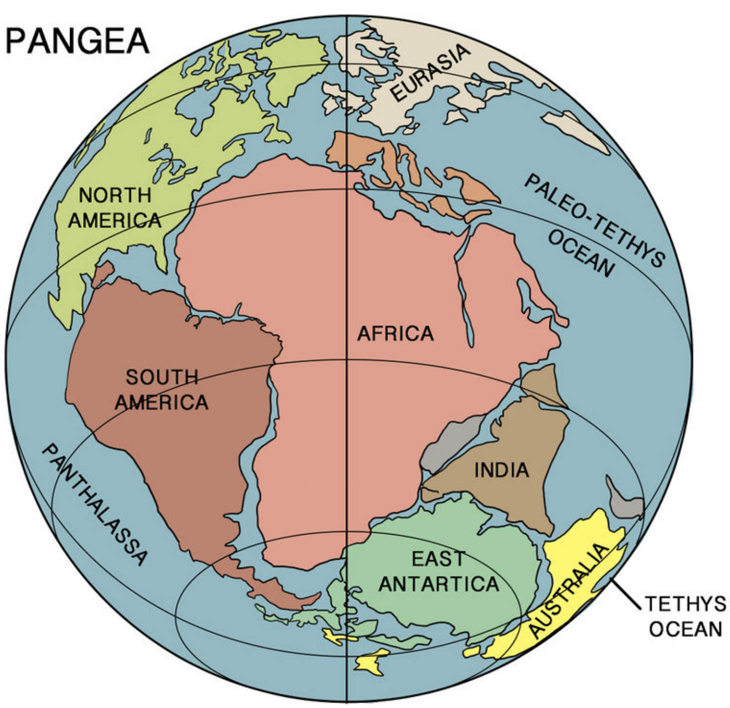

FIGURE 6.6
The supercontinent Pangaea contained all of the modern day continents.

The Continental Drift Idea

Alfred Wegener was an early 20th century German meteorologist. Wegener believed that the continents were once all joined together. He named the supercontinent Pangaea, meaning “all earth.“ Wegener suggested that Pangaea broke up long ago. Since then, the continents have been moving to their current positions. He called his hypothesis **continental drift**.

Evidence for Continental Drift

Wegener and his supporters collected a great deal of evidence for the continental drift hypothesis. Wegener found that this evidence was best explained if the continents had at one time been joined together.

Rocks and Geologic Structures

Wegener found rocks of the same type and age on both sides of the Atlantic Ocean. He thought that the rocks formed side by side. These rocks then drifted apart on separate continents.

Wegener also matched up mountain ranges across the Atlantic Ocean. The Appalachian Mountains were just like mountain ranges in eastern Greenland, Ireland, Great Britain, and Norway. Wegener concluded that they formed as a single mountain range. This mountain range broke apart as the continents split up. The mountain range separated as the continents drifted.

Fossil Plants and Animals

Wegener also found evidence for continental drift from fossils (**Figure** 6.7). The same type of plant and animal fossils are found on continents that are now widely separated. These organisms would not have been able to travel across the oceans.

Fossils of the seed fern Glossopteris are found across all of the southern continents. These seeds are too heavy to be carried across the ocean by wind. Mesosaurus fossils are found in South America and South Africa. Mesosaurus could swim, but only in fresh water. Cynognathus and Lystrosaurus were reptiles that lived on land. Both of these animals were unable to swim at all. Their fossils have been found across South America, Africa, India and Antarctica.

Wegener thought that all of these organisms lived side by side. The lands later moved apart so that the fossils are separated.

Glaciation

Wegener also looked at evidence from ancient glaciers. Glaciers are found in very cold climates near the poles. The evidence left by some ancient glaciers is very close to the equator. Wegener knew that this was impossible! However, if the continents had moved, the glaciers would have been centered close to the South Pole.

Climate

Coral reefs are found only in warm water. Coal swamps are also found in tropical and subtropical environments. Wegener discovered ancient coal seams and coral reef fossils in areas that are much too cold today. Wegener thought that the continents have moved since the time of Pangaea.

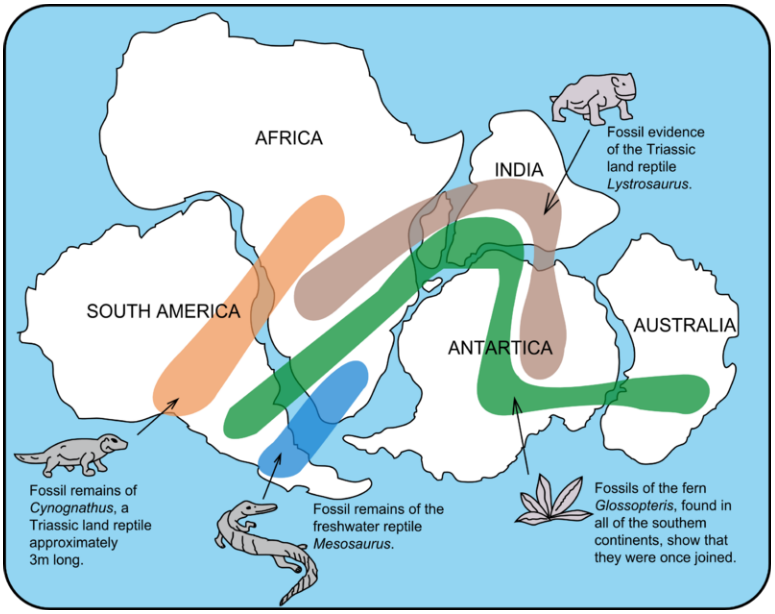

FIGURE 6.7
Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart. Wegener suggested that when the organisms were alive, the lands were joined and the organisms were living side-by-side.

Magnetic Evidence

Some important evidence for continental drift came after Wegener's death. This is the magnetic evidence. Earth's magnetic field surrounds the planet from pole to pole. If you have ever been hiking or camping, you may have used a compass to help you find your way. A compass points to the magnetic North Pole. The compass needle aligns with Earth's **magnetic field** (**Figure** 6.8).

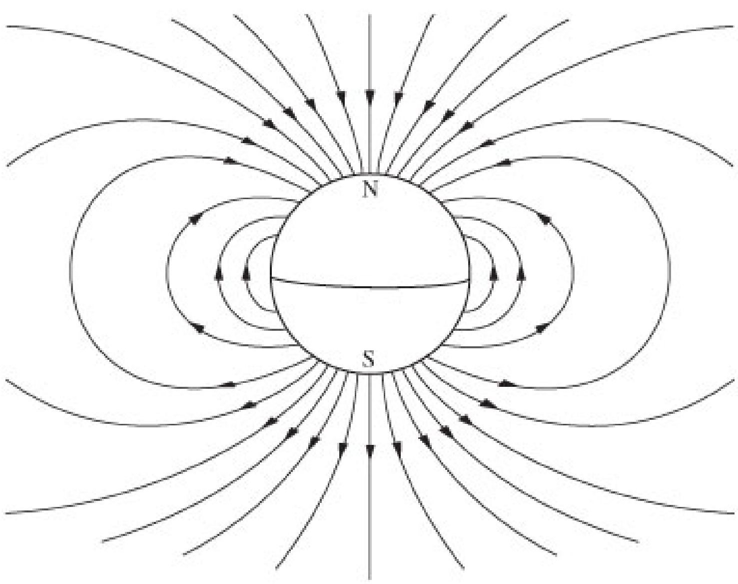

FIGURE 6.8
Earth's magnetic field is like a magnet with its north pole near the geographic north pole and the south pole near the geographic south pole.

Some rocks contain little compasses too! As lava cools, tiny iron-rich crystals line up with Earth's magnetic field.

Anywhere lavas have cooled, these magnetite crystals point to the magnetic poles. The little magnets point to where the north pole was when the lava cooled. Scientists can use this to figure out where the continents were at that time. This evidence clearly shows that the continents have moved.

During Wegener's life, scientists did not know how the continents could move. Wegener's idea was nearly forgotten. But as more evidence mounted, new ideas came about.

Lesson Summary

- Alfred Wegener gathered evidence that the continents had moved around on Earth's surface.
- The evidence for continental drift included the fit of the continents; the distribution of ancient fossils, rocks, and mountain ranges; and the locations of ancient climate zones.
- Although the evidence was extremely strong, scientists did not yet know how continents could move, so most rejected the idea.

Lesson Review Questions

Recall

1. How do the continents resemble puzzle pieces?

2. List the evidence Wegener had for continental drift.

Apply Concepts

3. What other regions fit together besides South America and Africa?

Think Critically

4. Make a case before a scientific jury to convince them that continental drift is real. Line up all your evidence. Does the lack of a mechanism for continents to move destroy your case?

5. What ideas can you come up with for what could drive continental motions?

Points to Consider

- Why is continental drift referred to as a hypothesis and not a theory?
- Why is Wegener's continental drift idea accepted today?
- Explain how each of these phenomena can be used as evidence for continental drift:
- The fit of the continents
- The distribution of fossils
- The distribution of similar rock types
- Rocks from ancient climate zones

6.3 Seafloor Spreading

Lesson Objectives

- List the main features of the seafloor: mid-ocean ridges, deep sea trenches, and abyssal plains.
- Describe what seafloor magnetism tells scientists about the seafloor.
- Describe the process of seafloor spreading.

Vocabulary

- echo sounder
- seafloor spreading
- trenches

Introduction

Ocean research during World War II gave scientists the tools to find out how the continents move. The evidence all pointed to seafloor spreading.

Seafloor Bathymetry

Before World War II, people thought the seafloor was completely flat and featureless. There was no reason to think otherwise.

Echo Sounders

But during the war, battleships and submarines carried echo sounders. Their goal was to locate enemy submarines (**Figure** 6.9). **Echo sounders** produce sound waves that travel outward in all directions. The sound waves bounce off the nearest object, and then return to the ship. Scientists know the speed of sound in seawater. They then can calculate the distance to the object that the sound wave hit. Most of these sound waves did not hit submarines. They instead were used to map the ocean floor.

Features of the Seafloor

Scientists were surprised to find huge mountains and deep trenches when they mapped the seafloor. The mid-ocean ridges form majestic mountain ranges through the deep oceans (**Figure** 6.10).

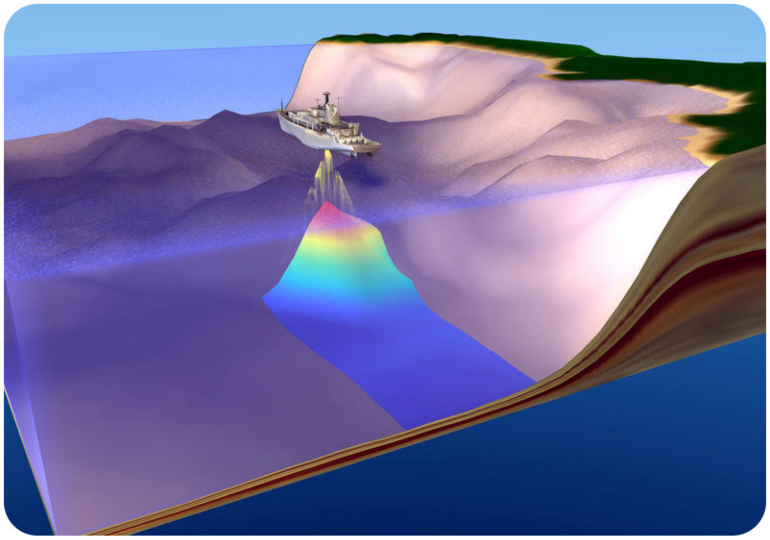

FIGURE 6.9
A ship sends out sound waves to create a picture of the seafloor below it. The echo sounder pictured has many beams and as a result it creates a three dimensional map of the seafloor beneath the ship. Early echo sounders had only a single beam and created a line of depth measurements.

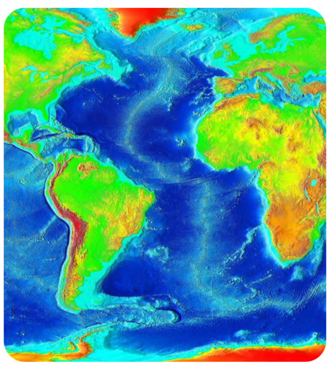

FIGURE 6.10
A modern map of the eastern Pacific and Atlantic Oceans. Darker blue indicates deeper seas. A mid-ocean ridge can be seen running through the center of the Atlantic Ocean. Deep sea trenches are found along the west coast of Central and South America and in the mid-Atlantic, east of the southern tip of South America. Isolated mountains and flat, featureless regions can also be spotted.

Deep sea trenches are found near chains of active volcanoes. These volcanoes can be at the edges of continents or in the oceans. **Trenches** are the deepest places on Earth. The deepest trench is the Mariana Trench in the southwestern Pacific Ocean. This trench plunges about 11 kilometers (35,840 feet) beneath sea level. The ocean floor does have lots of flat areas. These abyssal plains are like the scientists had predicted.

Seafloor Magnetism

Warships also carried magnetometers. They were also used to search for submarines. The magnetometers also revealed a lot about the magnetic properties of the seafloor.

Polar Reversals

Indeed, scientists discovered something astonishing. Many times in Earth's history, the magnetic poles have switched positions. North becomes south and south becomes north! When the north and south poles are aligned as they are now, geologists say it is normal polarity. When they are in the opposite position, they say that it is reversed polarity.

Magnetic Stripes

Scientists were also surprised to discover a pattern of stripes of normal and reversed polarity. These stripes surround the mid-ocean ridges. There is one long stripe with normal magnetism at the top of the ridge. Next to that stripe are two long stripes with reversed magnetism. One is on either side of the normal stripe. Next come two normal stripes and then two reversed stripes, and so on across the ocean floor. The magnetic stripes end abruptly at the edges of continents. Sometimes the stripes end at a deep sea trench (**Figure** 6.11).

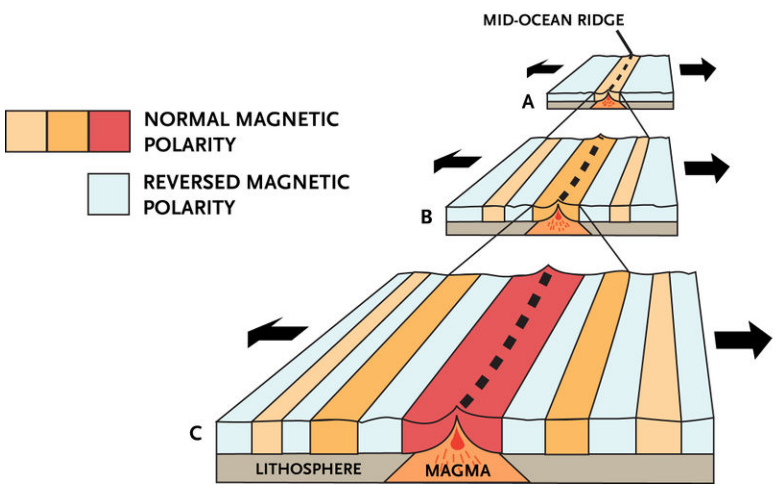

FIGURE 6.11
Scientists found that magnetic polarity in the seafloor was normal at mid-ocean ridges but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

Seafloor Ages

The scientists used geologic dating techniques on seafloor rocks. They found that the youngest rocks on the seafloor were at the mid-ocean ridges. The rocks get older with distance from the ridge crest. The scientists were surprised to find that the oldest seafloor is less than 180 million years old. This may seem old, but the oldest continental crust is around 4 billion years old.

Scientists also discovered that the mid-ocean ridge crest is nearly sediment free. The crust is also very thin there. With distance from the ridge crest, the sediments and crust get thicker. This also supports the idea that the youngest rocks are on the ridge axis and that the rocks get older with distance away from the ridge (**Figure** 6.12). Something causes the seafloor to be created at the ridge crest. The seafloor is also destroyed in a relatively short time.

The Seafloor Spreading Hypothesis

The **seafloor spreading** hypothesis brought all of these observations together in the early 1960s. Hot mantle material rises up at mid-ocean ridges. The hot magma erupts as lava. The lava cools to form new seafloor. Later, more lava erupts at the ridge. The new lava pushes the seafloor that is at the ridge horizontally away from ridge axis. The seafloor moves!

In some places, the oceanic crust comes up to a continent. The moving crust pushes that continent away from the ridge axis as well. If the moving oceanic crust reaches a deep sea trench, the crust sinks into the mantle. The creation and destruction of oceanic crust is the reason that continents move. Seafloor spreading is the mechanism that Wegener was looking for!

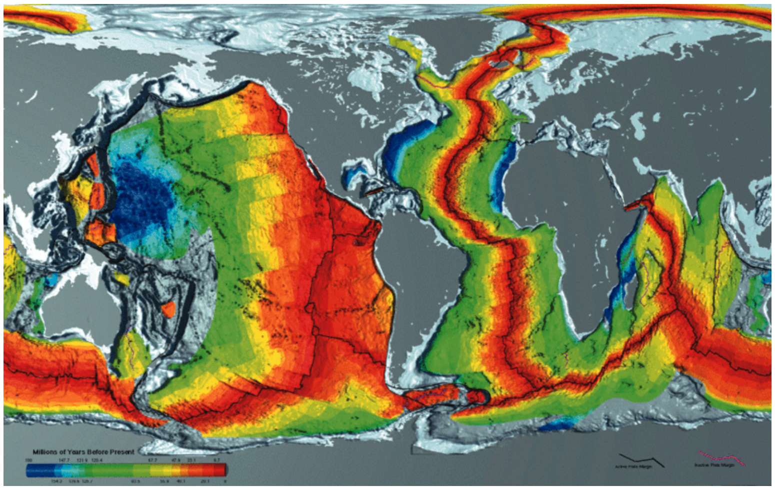

FIGURE 6.12
Seafloor is youngest near the mid-ocean ridges and gets progressively older with distance from the ridge. Orange areas show the youngest seafloor. The oldest seafloor is near the edges of continents or deep sea trenches.

Lesson Summary

- Using technologies developed during World War II, scientists were able to gather data that allowed them to recognize that seafloor spreading is the mechanism for Wegener's drifting continents.
- Maps of the ocean floor showed high mountain ranges and deep trenches.
- Changes in Earth's magnetic field give clues as to how seafloor forms and the importance of mid-ocean ridges in the creation of oceanic crust.
- Seafloor spreading processes create new oceanic crust at mid-ocean ridges and destroy older crust at deep sea trenches.

Lesson Review Questions

Recall

1. Describe a mid-ocean ridge. What geological processes are happening there?

2. Describe deep sea trenches and abyssal plains and their relative ages.

Apply Concepts

3. Using what you've learned about echo sounders, how do bats and dolphins use sound waves to create pictures of their worlds?

Think Critically

4. Why is the oceanic crust so young? Why is the continental crust so old?

5. Describe how continents move across the ocean basins.

6. Where would plate tectonics theory be if World War II hasn't happened?

Points to Consider

- How were the technologies that were developed during World War II used by scientists for the development of the seafloor spreading hypothesis?
- In what two ways did magnetic data lead scientists to understand more about plate tectonics?
- How does seafloor spreading provide a mechanism for continental drift?
- Describe the features of the North Pacific Ocean basin described in terms of seafloor spreading.

6.4 Theory of Plate Tectonics

Lesson Objectives

- Describe what a plate is and how scientists can recognize its edges.
- Explain how the plates move by convection in the mantle.
- Describe the three types of plate boundaries and the features of each type of boundary.
- Describe how plate tectonics processes lead to changes in Earth's surface features.

Vocabulary

- continental rifting
- convergent plate boundary
- divergent plate boundary
- intraplate activity
- island arc
- plate
- plate boundary
- subduction
- subduction zone
- transform fault
- transform plate boundary

Introduction

The theory of plate tectonics explains most of the features of Earth's surface. Plate tectonics helps us to understand where and why mountains form. Using the theory, we know where new ocean floor will be created and where it will be destroyed. We know why earthquakes and volcanic eruptions happen where they do. We even can search for mineral resources using information about past plate motions. Plate tectonics is the key that unlocks many of the mysteries of our amazing planet.

Earth's Tectonic Plates

The Cold War helped scientists to learn more about our planet. They set up seismograph networks during the 1950s and early 1960s. The purpose was to see if other nations were testing atomic bombs. Of course, at the same time, the seismographs were recording earthquakes.

Earthquake Locations

The scientists realized that the earthquakes were most common in certain areas. In the oceans, they were found along mid-ocean ridges and deep sea trenches. Earthquakes and volcanoes were common all around the Pacific Ocean. They named this region the Pacific Ring of Fire (**Figure** 6.13). Earthquakes are also common in the world's highest mountains, the Himalaya Mountains of Asia. The Mediterranean Sea also has many earthquakes.

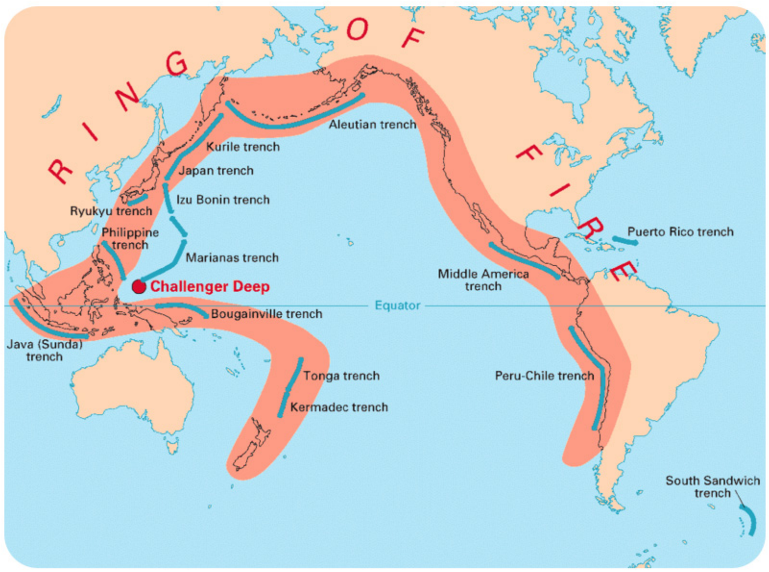

FIGURE 6.13
The Ring of Fire that circles the Pacific Ocean is where the most earthquakes and volcanic eruptions take place.

Earthquakes and Plate Boundaries

Earthquakes are used to identify plate boundaries (**Figure** 6.14). When earthquake locations are put on a map, they outline the **plates**. The movements of the plates are called plate tectonics.

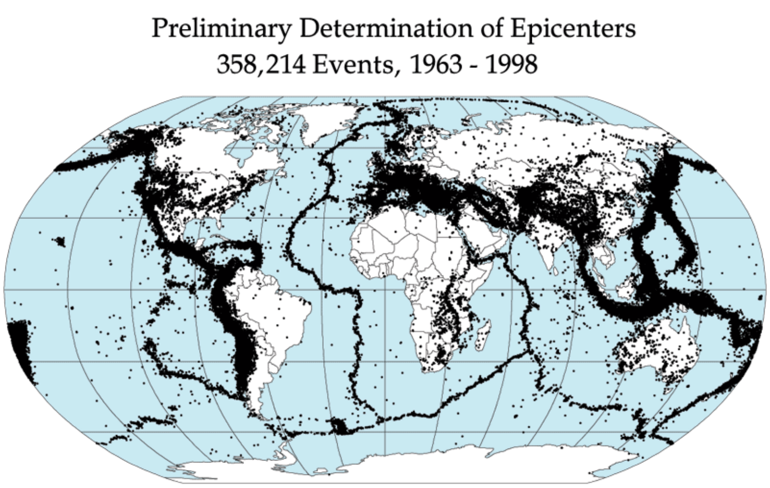

FIGURE 6.14
A map of earthquake epicenters shows that earthquakes are found primarily in lines that run up the edges of some continents, through the centers of some oceans, and in patches in some land areas.

The lithosphere is divided into a dozen major and several minor plates. Each plate is named for the continent or ocean basin it contains. Some plates are made of all oceanic lithosphere. A few are all continental lithosphere. But most plates are made of a combination of both.

Scientists have determined the direction that each plate is moving (**Figure** 6.15). Plates move around the Earth's surface at a rate of a few centimeters a year. This is about the same rate fingernails grow.

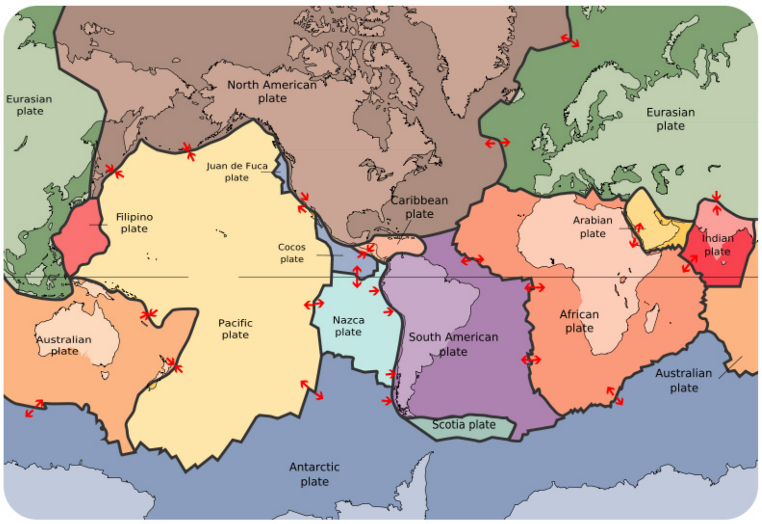

FIGURE 6.15
Earth's plates are shown in different colors. Arrows show the direction the plate is moving.

How Plates Move

Convection within the Earth's mantle causes the plates to move. Mantle material is heated above the core. The hot mantle rises up towards the surface (**Figure** 6.16). As the mantle rises it cools. At the surface the material moves horizontally away from a mid-ocean ridge crest. The material continues to cool. It sinks back down into the mantle at a deep sea trench. The material sinks back down to the core. It moves horizontally again, completing a convection cell.

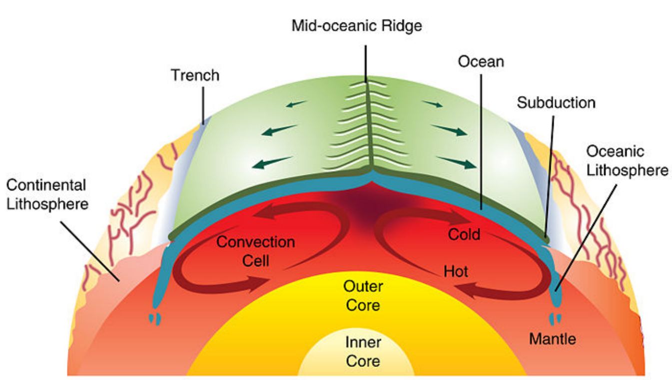

FIGURE 6.16
Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

Plate Boundaries

Plate boundaries are where two plates meet. Most geologic activity takes place at plate boundaries. This activity includes volcanoes, earthquakes, and mountain building. The activity occurs as plates interact. How can plates interact? Plates can move away from each other. They can move toward each other. Finally, they can slide past each other.

These are the three types of plate boundaries:

- **Divergent plate boundaries**: the two plates move away from each other.
- **Convergent plate boundaries**: the two plates move towards each other.
- **Transform plate boundaries**: the two plates slip past each other.

The features that form at a plate boundary are determined by the direction of plate motion and by the type of crust at the boundary.

Divergent Plate Boundaries

Plates move apart at divergent plate boundaries. This can occur in the oceans or on land.

Mid-ocean Ridges

Plates move apart at mid-ocean ridges. Lava rises upward, erupts, and cools. Later, more lava erupts and pushes the original seafloor outward. This is seafloor spreading. Seafloor spreading forms new oceanic crust. The rising magma causes earthquakes. Most mid-ocean ridges are located deep below the sea. The island of Iceland sits right on the Mid-Atlantic ridge (**Figure** 6.17).

FIGURE 6.17
The rift valley in Iceland that is part of the Mid-Atlantic Ridge is seen in this photo.

Continental Rifting

A divergent plate boundary can also occur within a continent. This is called **continental rifting** (**Figure** 6.18). Magma rises beneath the continent. The crust thins, breaks, and then splits apart. This first produces a rift valley. The East African Rift is a rift valley. Eastern Africa is splitting away from the African continent. Eventually, as the continental crust breaks apart, oceanic crust will form. This is how the Atlantic Ocean formed when Pangaea broke up.

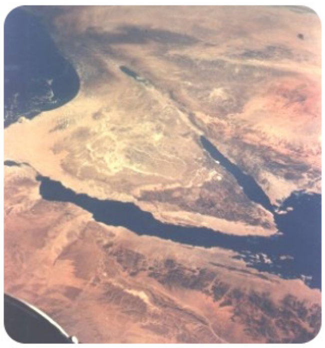

FIGURE 6.18
The Arabian, Indian, and African plates are rifting apart, forming the Great Rift Valley in Africa. The Dead Sea fills the rift with seawater.

Convergent Plate Boundaries

A convergent plate boundary forms where two plates collide. That collision can happen between a continent and oceanic crust, between two oceanic plates, or between two continents. Oceanic crust is always destroyed in these collisions.

Ocean-Continent Convergence

Oceanic crust may collide with a continent. The oceanic plate is denser, so it undergoes **subduction**. This means that the oceanic plate sinks beneath the continent. This occurs at an ocean trench (**Figure** 6.19). **Subduction zones** are where subduction takes place.

As you would expect, where plates collide there are lots of intense earthquakes and volcanic eruptions. The subducting oceanic plate melts as it reenters the mantle. The magma rises and erupts. This creates a volcanic mountain range near the coast of the continent. This range is called a **volcanic arc**. The Andes Mountains, along the western edge of South America, are a volcanic arc (**Figure** 6.20).

Ocean-Ocean Convergence

Two oceanic plates may collide. In this case, the older plate is denser. This plate subducts beneath the younger plate. As the subducting plate is pushed deeper into the mantle, it melts. The magma this creates rises and erupts. This forms a line of volcanoes, known as an **island arc** (**Figure** 6.21). Japan, Indonesia, the Philippine Islands, and the Aleutian Islands of Alaska are examples of island arcs (**Figure** 6.22).

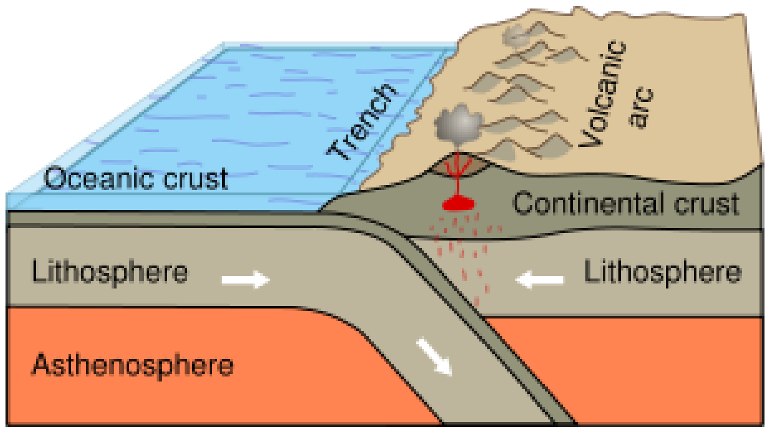

FIGURE 6.19
Subduction of an oceanic plate beneath a continental plate forms a line of volcanoes known as a continental arc and causes earthquakes.

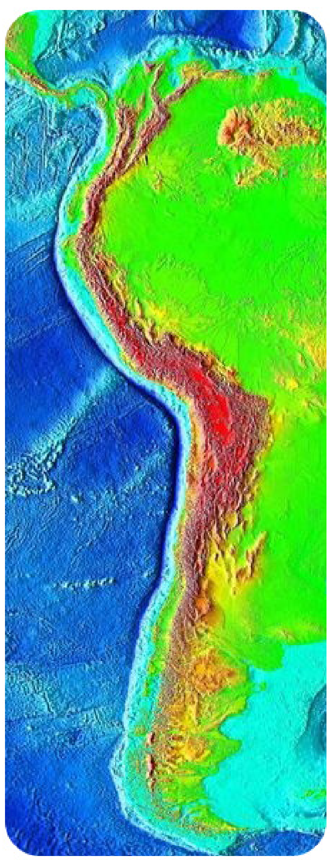

FIGURE 6.20
A relief map of South America shows the trench west of the continent. The Andes Mountains line the western edge of South America.

Continent-Continent Convergence

Continental lithosphere is low in density and very thick. Continental lithosphere cannot subduct. So when two continental plates collide, they just smash together, just like if you put your hands on two sides of a sheet of paper and bring your hands together. The material has nowhere to go but up (**Figure** 6.23)! Earthquakes and metamorphic rocks result from the tremendous forces of the collision. But the crust is too thick for magma to get through, so there are no volcanoes.

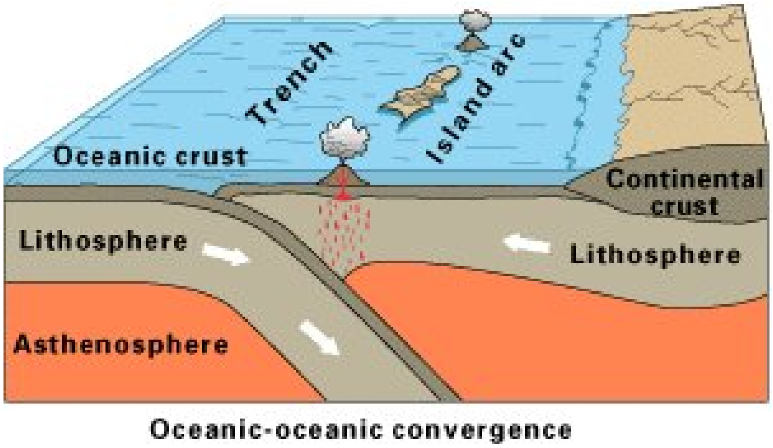

FIGURE 6.21
A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.

FIGURE 6.22
The Aleutian Islands that border southern Alaska are an island arc. In this winter image from space, the volcanoes are covered with snow.

Mountain Building

Continent-continent convergence creates some of the world's largest mountains ranges. The Himalayas (**Figure** 6.24) are the world's tallest mountains. They are forming as two continents collide. The Appalachian Mountains are the remnants of a larger mountain range. This range formed from continent-continent collisions in the time of Pangaea.

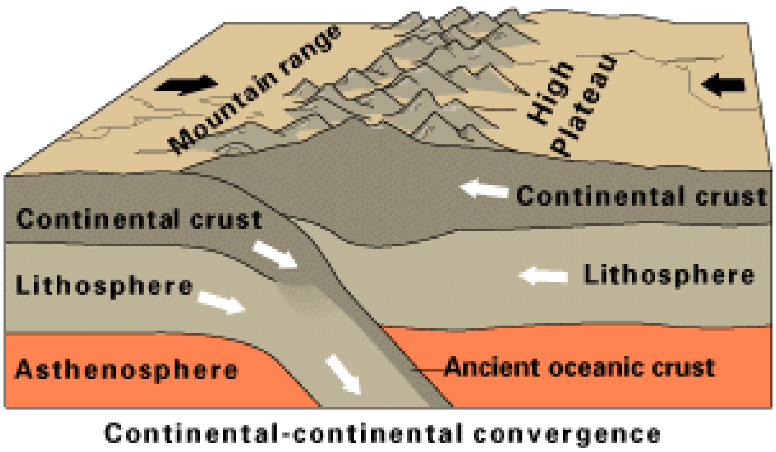

FIGURE 6.23
When two plates of continental crust collide, the material pushes upward, forming a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

FIGURE 6.24
The Karakoram Range is part of the Himalaya Mountains. K2, pictured here, is the second highest mountain the world at over 28,000 feet. The number and height of mountains is impressive.

Transform Plate Boundaries

Two plates may slide past each other in opposite directions. This is called a transform plate boundary. These plate boundaries experience massive earthquakes. The world's best known transform fault is the San Andreas Fault in California (**Figure** 6.25). At this fault, the Pacific and North American plates grind past each other. Transform plate boundaries are most common as offsets along mid-ocean ridges.

Transform plate boundaries are different from the other two types. At divergent plate boundaries, new oceanic crust is formed. At convergent boundaries, old oceanic crust is destroyed. But at transform plate boundaries, crust is not created or destroyed.

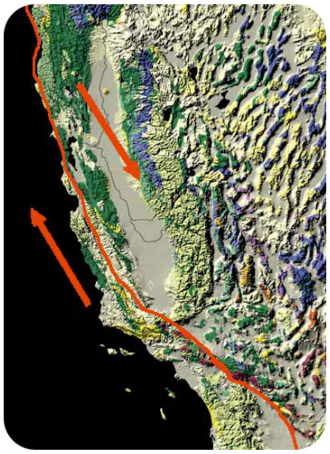

FIGURE 6.25
The red line is the San Andreas Fault. On the left is the Pacific Plate, which is moving northeast. On the right is the North American Plate, which is moving southwest. The movement of the plates is relative to each other.

Earth's Changing Surface

Knowing where plate boundaries are helps explain the locations of landforms and types of geologic activity. The activity can be current or old.

Active Plate Margins

Western North America has volcanoes and earthquakes. Mountains line the region. California, with its volcanoes and earthquakes, is an important part of the Pacific Ring of Fire. This is the boundary between the North American and Pacific Plates.

Passive Plate Margins

Mountain ranges also line the eastern edge of North America. But there are no active volcanoes or earthquakes. Where did those mountains come from? These mountains formed at a convergent plate boundary when Pangaea came together. About 200 million years ago these mountains were similar to the Himalayas today (**Figure** 6.26)! There were also earthquakes.

The Supercontinent Cycle

Scientists think that Pangaea was not the first supercontinent. There were others before it. The continents are now moving together. This is because of subduction around the Pacific Ocean. Eventually, the Pacific will disappear and a new supercontinent will form. This won't be for hundreds of millions of years. The creation and breakup of a supercontinent takes place about every 500 million years.

Intraplate Activity

Most geological activity takes place at plate boundaries. But some activity does not. Much of this **intraplate activity** is found at hot spots. Hotspot volcanoes form as plumes of hot magma rise from deep in the mantle.

FIGURE 6.26
The White Mountains in New Hampshire are part of the Appalachian province. The mountains are only around 6,000 feet high.

Hotspots in the Oceans

A chain of volcanoes forms as an oceanic plate moves over a hot spot. This is how it happens. A volcano forms over the hotspot. Since the plate is moving, the volcano moves off of the hotspot. When the hotspot erupts again, a new volcano forms over it. This volcano is in line with the first. Over time, there is a line of volcanoes. The youngest is directly above the hot spot. The oldest is the furthest away (**Figure** 6.27).

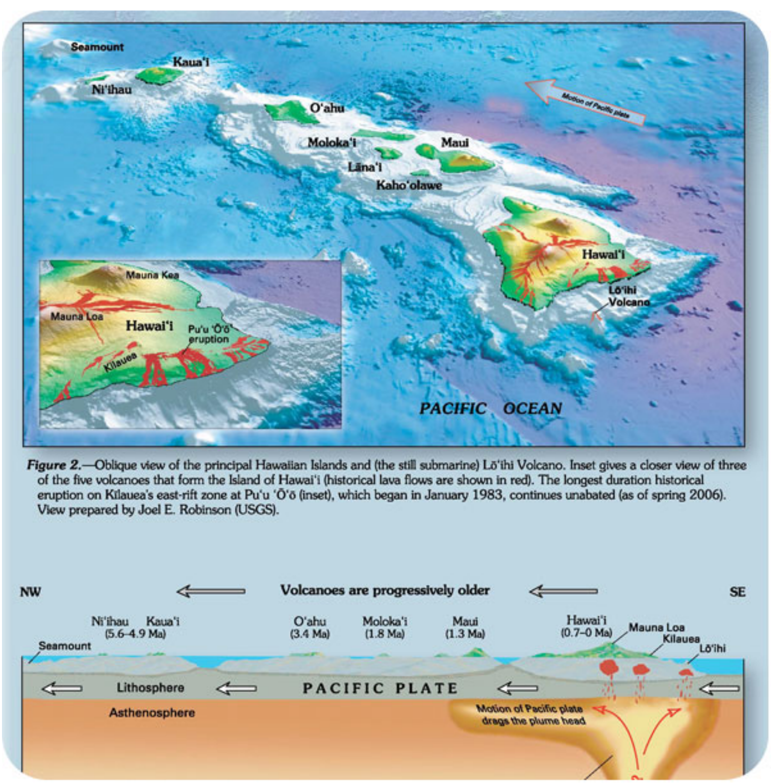

FIGURE 6.27
This view of the Hawaiian islands shows the youngest islands in the southeast and the oldest in the northwest. Kilauea volcano, which makes up the southeastern side of the Big Island of Hawaii, is located above the Hawaiian hotspot.

The Hawaii-Emperor chain of volcanoes formed over the Hawaiian Hotspot. The Hawaiian Islands formed most recently. Kilauea volcano is currently erupting. It is over the hotspot. The Emperor Seamounts are so old they no longer reach above sea level. The oldest of the Emperor Seamounts is about to subduct into the Aleutian trench off of Alaska. Geologists use hotspot chains to tell the direction and the speed a plate is moving.

Hotspots Beneath Continents

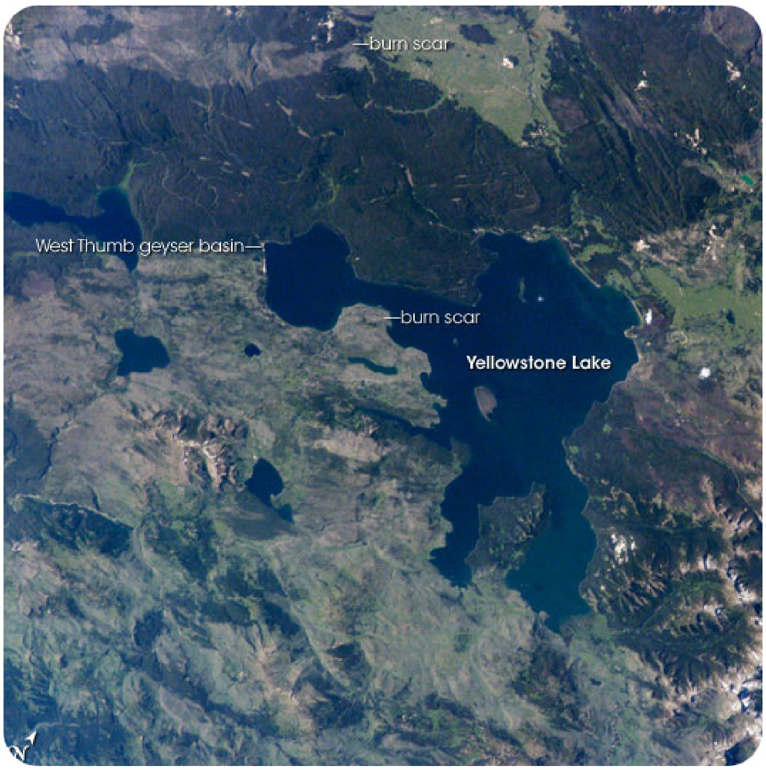

FIGURE 6.28
Yellowstone Lake lies at the center of a giant caldera. This hole in the ground was created by enormous eruptions at the Yellowstone hotspot. The hotspot lies beneath Yellowstone National Park.

Hot spots are also found under the continental crust. Since it is more difficult for magma to make it through the thick crust, they are much less common. One exception is the Yellowstone hotspot (**Figure** 6.28). This hotspot is very active. In the past, the hotspot produced enormous volcanic eruptions. Now its activity is best seen in the region's famous geysers.

Lesson Summary

- Convection in the mantle drives the movement of the plates of lithosphere over the Earth's surface. New oceanic crust forms at the ridge and pushes the older seafloor away from the ridge horizontally.
- Plates interact at three different types of plate boundaries: divergent, convergent and transform fault boundaries, where most of the Earth's geologic activity takes place.
- These processes acting over long periods of time are responsible for the geographic features we see.

Lesson Review Questions

Recall

1. Name the three types of plate boundaries? Which has volcanoes? Which has earthquakes? Which has mountain building?

Apply Concepts

2. Describe convection. How does this work to create plate boundaries?

Think Critically

3. Make some generalizations about which types of plate boundaries have volcanoes and which have earthquakes. Could you look at a plate boundary and determine what geological activity there would be?

4. Why is continental crust thicker than oceanic crust? Why is oceanic crust relatively thin?

Points to Consider

- On the map in **Figure** 6.15, the arrows show the directions that the plates are going. The Atlantic has a mid-ocean ridge, where seafloor spreading is taking place. The Pacific Ocean has many deep sea trenches, where subduction is taking place. What is the future of the Atlantic plate? What is the future of the Pacific plate?
- Using your hands and words, explain to someone how plate tectonics works. Be sure you describe how continents drift and how seafloor spreading provides a mechanism for continental movement.
- Now that you know about plate tectonics, where do you think would be a safe place to live if you wanted to avoid volcanic eruptions and earthquakes?

6.5 References

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CHAPTER 7 MS Earthquakes

Chapter Outline

After the 1906 San Francisco earthquake, much of the city was destroyed. Besides the loss of buildings to ground shaking, a massive fire after the quake burned down much of what was left. The experiences people gain from earthquakes like these allow engineers and city planners to create safer buildings. Earthquakes will always happen. The damage that is done to property and lives can be changed.

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7.1 Stress in Earth's Crust

Lesson Objectives

- List the different types of stresses that change rock.
- Compare the different types of folds and the conditions under which they form.
- Compare fractures and faults and define how they are related to earthquakes.
- Compare how mountains form and at what types of plate boundaries.

Vocabulary

- anticline
- basin
- compression
- confining stress
- deform
- dip-slip fault
- dome
- fault zone
- fold
- footwall
- fracture
- hanging wall
- joint
- monocline
- normal fault
- reverse fault
- shear
- slip
- stress
- strike-slip fault
- syncline
- tension
- thrust fault

Introduction

When plates collide, move apart, and slide past each other, lots of things happen. Nearly all earthquakes, volcanic eruptions, and mountain building happens at plate boundaries.

When plates are pushed or pulled, the rock is subjected to stress. Stress can cause a rock to change shape or to break. When a rock bends without breaking, it folds. When the rock breaks, it fractures. Mountain building and earthquakes are some of the responses rocks have to stress.

Causes and Types of Stress

Stress is the force applied to a rock. There are four types of stresses:

- **Confining stress** happens as weight of all the overlying rock pushes down on a deeply buried rock. The rock is being pushed in from all sides, which compresses it. The rock will not deform because there is no place for it to move.
- **Compression** stress squeezes rocks together. Compression causes rocks to fold or fracture (**Figure** 7.1). When two cars collide, compression causes them to crumple. Compression is the most common stress at convergent plate boundaries.

FIGURE 7.1
Stress caused these rocks to fracture.

- **Tension** stress pulls rocks apart. Tension causes rocks to lengthen or break apart. Tension is the major type of stress found at divergent plate boundaries.
- **Shear** stress happens when forces slide past each other in opposite directions (**Figure** 7.2). This is the most common stress found at transform plate boundaries.

The amount of stress on a rock may be greater than the rock's strength. In that case, the rock will change and **deform** (**Figure** 7.3). Deep within the Earth, the pressure is very great. A rock behaves like a stretched rubber band. When the stress stops, the rock goes back to its original shape. If more stress is applied to the rock, it bends and flows. It does not return to its original shape. Near the surface, if the stress continues, the rock will **fracture** and break.

Geologic Structures

Sedimentary rocks are formed in horizontal layers. This is magnificently displayed around the southwestern United States. The arid climate allows rock layers to be well exposed (**Figure** 7.4). The lowest layers are the oldest and the higher layers are younger.

Folds, joints and faults are caused by stresses. **Figure** 7.5 shows joints in a granite hillside.

If a sedimentary rock is tilted or folded, we know that stresses have changed the rock (**Figure** 7.6).

FIGURE 7.2
This rock has undergone shearing. The pencil is pointing to a line. Stresses forced rock on either side of that line to go in opposite directions.

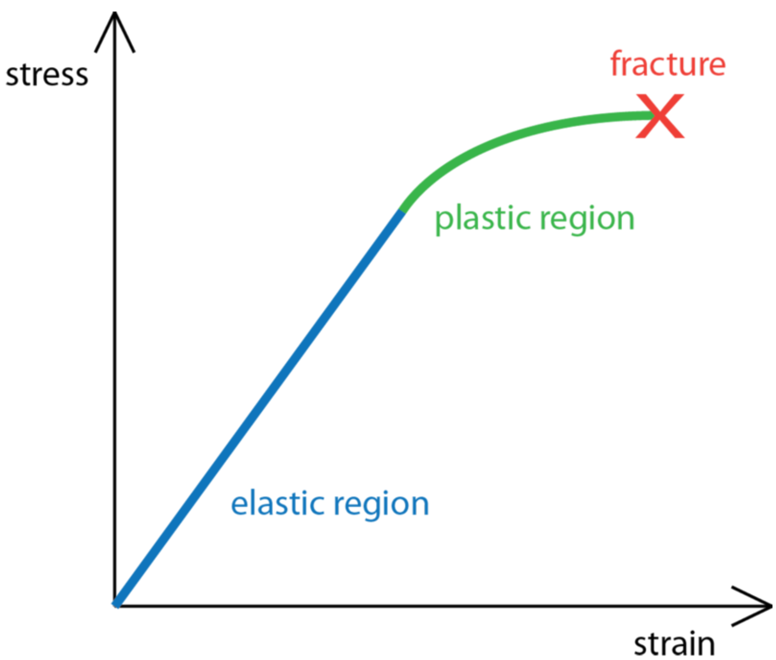

FIGURE 7.3
With increasing stress, the rock deforms and may eventually fracture.

Folds

Deep within the Earth, as plates collide, rocks crumple into **folds**. You can model these folds by placing your hands on opposite edges of a piece of cloth and pushing your hands together. In sedimentary rocks, you can easily trace the folding of the layers. In the **Figure** 7.6, the rock layers are no longer horizontal. They tilt downhill from right to left in a monocline. Once rocks are folded, they do not return to their original shape.

There are three types of folds: monoclines, anticlines, and synclines. A **monocline** is a simple "one step" bend in the rock layers (**Figure** 7.7). In a monocline, the oldest rocks are still at the bottom and the youngest are at the top.

An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** 7.8). The oldest

FIGURE 7.4
Layers of different types of rocks are exposed in this photo from Grand Staircase-Escalante National Monument. White layers of limestone are hard and form cliffs. Red layers of shale are flakier and form slopes.

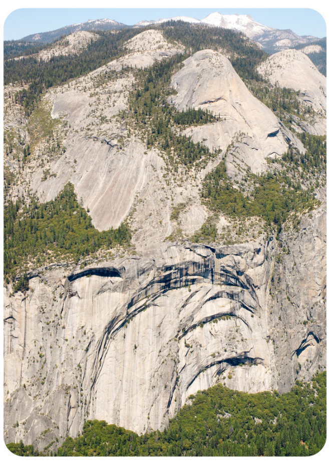

FIGURE 7.5
Joints in this granite created a zone of weakness. The rock below the joints fell, leaving scars in this hillside.

rocks are found at the center of an anticline. The youngest rocks are draped over them at the top of the structure. When upward folding rocks form a circular structure, that structure is called a **dome**. If the top of the dome is eroded off, the oldest rocks are exposed at the center.

A **syncline** is a fold that bends downward (**Figure** 7.9). In a syncline, the youngest rocks are at the center. The oldest rocks are at the outside edges. When rocks bend downward in a circular structure, it is called a **basin**. If the rocks are eroded, the youngest rocks are at the center. Basins can be enormous, like the Michigan Basin.

Faults

With enough stress, a rock will fracture, or break. The fracture is called a **joint** if the rock breaks but doesn't move, as shown in **Figure** 7.10.

If the rocks on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** 7.11). Faults can occur alone or in clusters, creating a **fault zone**. Earthquakes happen when rocks break and move suddenly. The energy released causes an earthquake.

Slip is the distance rocks move along a fault, as one block of rock moves past the other. The angle of a fault is called

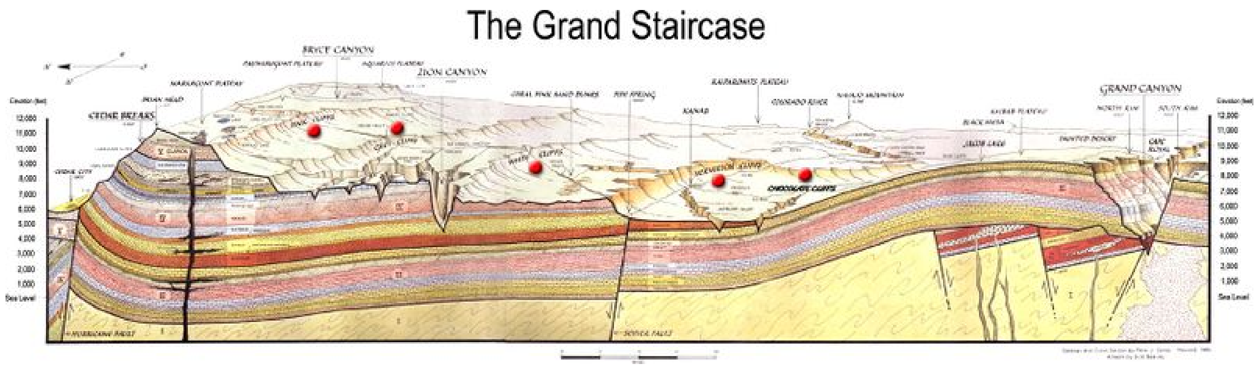

FIGURE 7.6
This is a geologic cross section of the Grand Staircase in Utah. A small fold, called an syncline, is revealed at the left of the diagram.

FIGURE 7.7
The rock layers in the center right are tilted in one direction, forming a monocline.

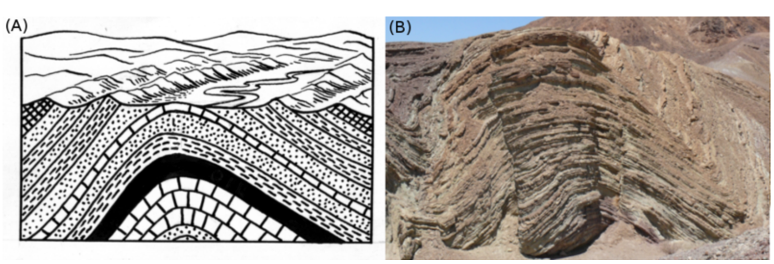

FIGURE 7.8
An anticline is a convex upward fold, as shown in (A). An anticline is well displayed in (B), which was taken at Calico Ghost Town, California.

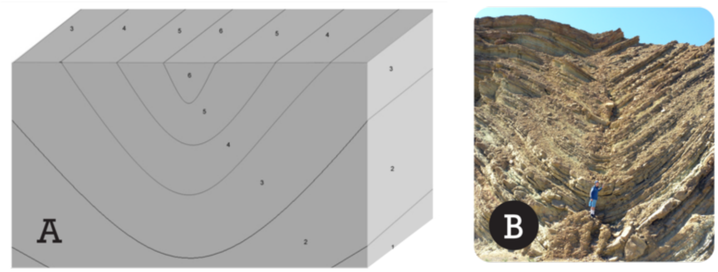

FIGURE 7.9
(A) A syncline is a concave downward fold. (B) This syncline is seen at Calico Ghost Town near Barstow, California.

FIGURE 7.10
Joints in boulders in the Arizona desert. The rock on either side of the joints has not moved.

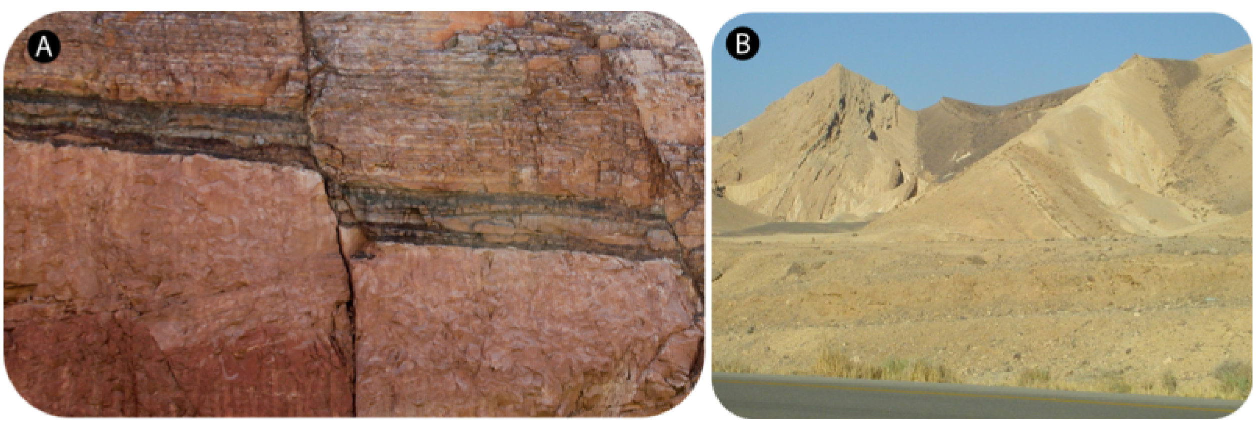

FIGURE 7.11
(A) This image shows a small fault. The black rock layer is not a line because a fault has broken it. Rock on each side of the fault has moved. (B) A large fault runs between the lighter colored rock on the left and the darker colored rock on the right. There has been so much movement along the fault that the darker rock doesn't resemble anything around it.

the fault's "dip." If the fault dips at an angle, the fault is a **dip-slip fault**.

Imagine you are standing on a road looking at the fault. The **hanging wall** is the rock that overlies the fault, while the **footwall** is beneath the fault. If you are walking along a fault, the hanging wall is above you and the footwall is where your feet would be. Miners often extract mineral resources along faults. They used to hang their lanterns above their heads. That is why these layers were called the hanging wall.

In **normal faults**, the hanging wall drops down relative to the footwall. Normal faults are caused by tension that pulls the crust apart, causing the hanging wall to slide down. Normal faults can build huge mountain ranges in regions experiencing tension (**Figure** 7.12).

FIGURE 7.12
The Teton Range in Wyoming rose up along a normal fault.

When compression squeezes the crust into a smaller space, the hanging wall pushes up relative to the footwall. This creates a **reverse fault**. A **thrust fault** is a type of reverse fault where the angle is nearly horizontal. Rocks can slip many miles along thrust faults (**Figure** 7.13).

Strike-Slip

A **strike-slip fault** is a dip-slip fault where the dip of the fault plane is vertical. Strike-slip faults result from shear stresses. If you stand with one foot on each side of a strike-slip fault, one side will be moving toward you while the other side moves away from you. If your right foot moves toward you, the fault is known as a right-lateral strike-slip fault. If your left foot moves toward you, the fault is a left-lateral strike-slip fault (**Figure** 7.14).

San Andreas Fault

The San Andreas Fault in California is a right-lateral strike-slip fault (**Figure** 7.15). It is also a transform fault because the San Andreas is a plate boundary. As you can see, California will not fall into the ocean someday. The land west of the San Andreas Fault is moving northeastward, while the North American plate moves southwest. Someday, millions of years from now, Los Angeles will be a suburb of San Francisco!

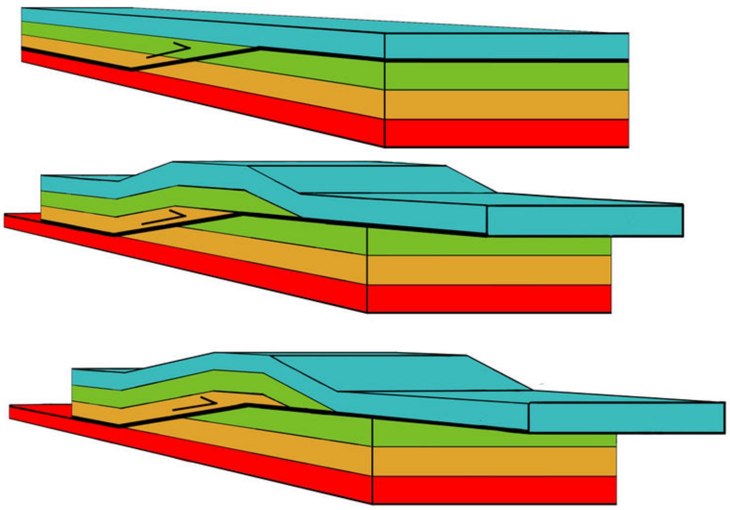

FIGURE 7.13
In this thrust fault, the rock on the left is thrust over the rock on the right.

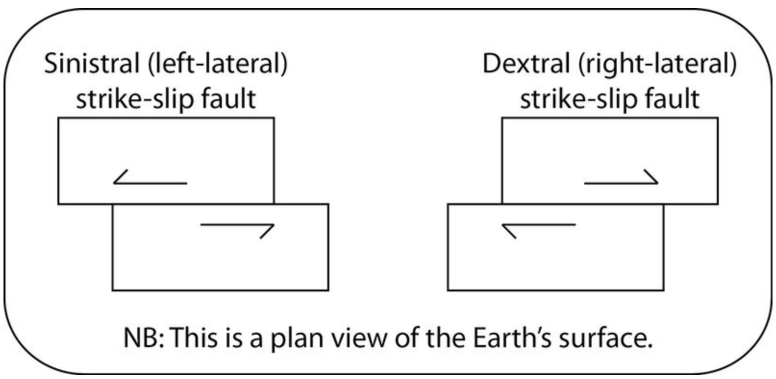

FIGURE 7.14
Diagram of strike-slip faults.

FIGURE 7.15
The San Andreas Fault is visible from the air in some locations. This transform fault separates the Pacific plate on the west and the North American plate on the east.

Stress and Mountain Building

Many processes create mountains. Most mountains form along plate boundaries. A few mountains may form in the middle of a plate. For example, huge volcanoes are mountains formed at hotspots within the Pacific Plate.

Continent-Continent Convergence

Most of the world's largest mountains form as plates collide at convergent plate boundaries. Continents are too buoyant to get pushed down into the mantle. So when the plates smash together, the crust crumples upwards. This creates mountains. Folding and faulting in these collision zones makes the crust thicker.

The world's highest mountain range, the Himalayas, is growing as India collides with Eurasia. About 80 million years ago, India was separated from Eurasia by an ocean (**Figure** 7.16). As the plates collided, pieces of the old seafloor were forced over the Asian continent. This old seafloor is now found high in the Himalayas (**Figure** 7.17).

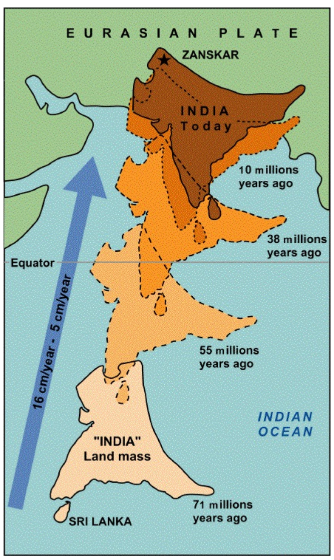

FIGURE 7.16
As India rams into Eurasia, the Himalaya Mountains rise.

Oceanic Plate Subduction

Volcanic mountain ranges form when oceanic crust is pushed down into the mantle at convergent plate boundaries. The Andes Mountains are a chain of coastal volcanic mountains. They are forming as the Nazca plate subducts beneath the South American plate (**Figure** 7.18).

Rifting

Mid-ocean ridges form at divergent plate boundaries. As the ocean floor separates an enormous line of volcanoes is created.

When continental crust is pulled apart, it breaks into blocks. These blocks of crust are separated by normal faults. The blocks slide up or down. The result is alternating mountain ranges and valleys. This topography is known as basin-and-range (**Figure** 7.19). The area near Death Valley, California is the center of a classic basin-and-range province (**Figure** 7.20).

FIGURE 7.17
The Himalayas.

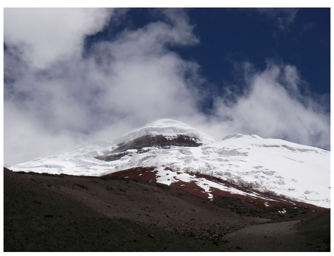

FIGURE 7.18
Cotopaxi is in the Andes Mountains of Ecuador. The 19,300 foot tall mountain is the highest active volcano in the world.

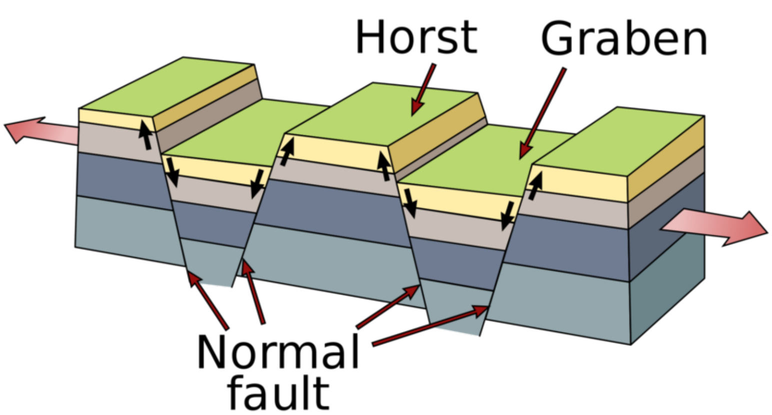

FIGURE 7.19
This diagram shows how a basin-and-range forms.

Lesson Summary

- Stress is the force applied to a rock, which can cause the rock to change. The three main types of stress go along with the three types of plate boundaries. Compression is common at convergent boundaries, tension at divergent boundaries, and shear at transform boundaries.
- Rocks can bend and fold. Rocks can also fracture and break. Movement along a fracture produces a fault. The two main types of faults are dip-slip and strike-slip.

FIGURE 7.20
This photograph was taken from a basin with a range in the distance near Death Valley, California.

- In dip-slip faults, the angle of the fault plane is at an angle. In strike-slip faults, the fault plane is vertical.
- The world's largest mountains grow at convergent plate boundaries, primarily by thrust faulting and folding.

Lesson Review Questions

Recall

1. What causes confining stress? What type of deformation is caused by confining stress?

2. What causes compression stress? What type of deformation is caused by compression stress?

3. What causes tension stress? What type of deformation is caused by tension stress?

4. What causes shear stress? What type of deformation is caused by shear stress?

Apply Concepts

5. What happens when a rock deforms plastically? For how long does this happen? What factors should be considered when answering that last question?

6. Why is California know for having so many large earthquakes?

7. Imagine that you find a sequence of rock layers with the older rocks at the top and the younger rocks at the bottom. How could this have happened?

Think Critically

8. Identify all of the structures that you can find in the image below.

9. In the image above, where are the oldest rocks in each structure? Where are the youngest rocks?

Points to Consider

- Think about stresses in the ocean basins. Where in the ocean basins are plates pulling apart? Where do plates come together?
- Earthquakes are primarily the result of plate tectonic motions. What type of stress would cause earthquakes at each of the three types of plate boundaries?
- Which type of plate boundary do you think has the most dangerous earthquakes? How do earthquakes cause the greatest damage?

7.2 Nature of Earthquakes

Lesson Objectives

- Be able to identify an earthquake focus and its epicenter.
- Identify earthquake zones and what makes some regions prone to earthquakes.
- Compare the characteristics of the different types of seismic waves.
- Describe how tsunamis are caused by earthquakes, particularly using the 2004 Boxing Day Tsunami as an example.

Vocabulary

- amplitude
- body waves
- crest
- earthquake
- elastic rebound theory
- epicenter
- focus
- Love waves
- primary waves (P-waves)
- Rayleigh waves
- secondary waves (S-waves)
- surface waves
- trough
- tsunami
- wavelength

Introduction

An **earthquake** is sudden ground movement. This movement is caused by the sudden release of the energy stored in rocks. An earthquake happens when so much stress builds up in the rocks that the rocks break. An earthquake's energy is transmitted by seismic waves. Each year, there are more than 150,000 earthquakes strong enough to be felt by people. An amazing 900,000 are recorded by seismometers.

Causes of Earthquakes

Almost all earthquakes occur at plate boundaries. All types of plate boundaries have earthquakes. Convection within the Earth causes the plates to move. As the plates move, stresses build. When the stresses build too much, the rocks break. The break releases the energy that was stored in the rocks. The sudden release of energy creates an earthquake. During an earthquake the rocks usually move several centimeters or rarely as much as a few meters. **Elastic rebound theory** describes how earthquakes occur (**Figure** 7.21).

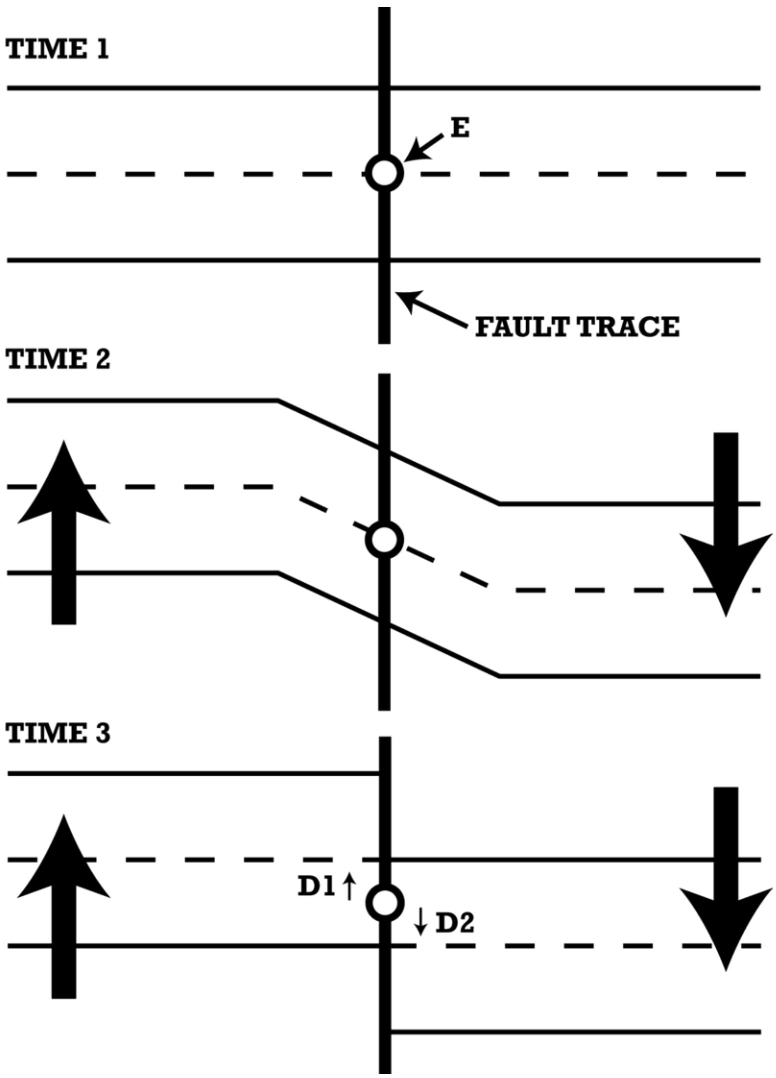

FIGURE 7.21

Elastic rebound theory. Stresses build on both sides of a fault. The rocks deform plastically as seen in Time 2. When the stresses become too great, the rocks return to their original shape. To do this, the rocks move, as seen in Time 3. This movement releases energy, creating an earthquake.

Earthquake Focus and Epicenter

Where an earthquake takes place is described by its focus and epicenter.

Focus

The point where the rock ruptures is the earthquake's **focus**. The focus is below the Earth's surface. A shallow earthquake has a focus less than 70 kilometers (45 miles). An intermediate-focus earthquake has a focus between 70 and 300 kilometers (45 to 200 miles). A deep-focus earthquake is greater than 300 kilometers (200 miles). About 75% of earthquakes have a focus in the top 10 to 15 kilometers (6 to 9 miles) of the crust. Shallow earthquakes cause the most damage. This is because the focus is near the Earth's surface, where people live.

Epicenter

The area just above the focus, on the land surface, is the earthquake's **epicenter** (**Figure** 7.22). The towns or cities near the epicenter will be strongly affected by the earthquake.

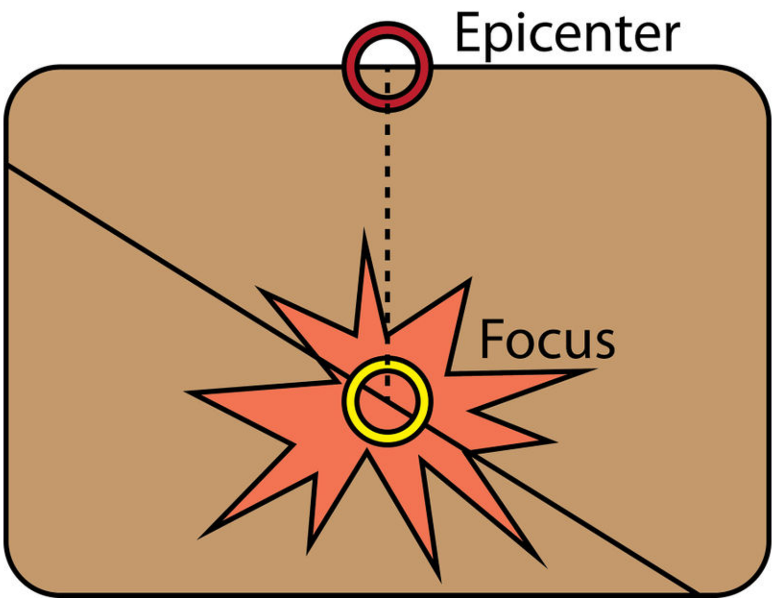

FIGURE 7.22
The focus of an earthquake is in the ground where the ground breaks. The epicenter is the point at the surface just above the focus.

Earthquake Zones

Nearly 95% of all earthquakes take place along one of the three types of plate boundaries. As you learned in the *Plate Tectonics* chapter, scientists use the location of earthquakes to draw plate boundaries.

The region around the Pacific Ocean is called the Pacific Ring of Fire. This is due to the volcanoes that line the region. The area also has the most earthquakes. About 80% of all earthquakes strike this area. The Pacific Ring of Fire is caused by the convergent and transform plate boundaries that line the Pacific Ocean basin.

About 15% of all earthquakes take place in the Mediterranean-Asiatic belt. The convergent plate boundaries in the region are shrinking the Mediterranean Sea. The convergence is also causing the Himalayas to grow. The remaining 5% of earthquakes are scattered around the other plate boundaries. A few earthquakes take place in the middle of a plate, away from plate boundaries.

Transform Plate Boundaries

Transform plate boundaries produce enormous and deadly earthquakes. These quakes at transform faults have shallow focus. This is because the plates slide past each other without moving up or down. The largest earthquake on the San Andreas Fault occurred in 1906 in San Francisco. Other significant earthquakes in California include the 1989 Loma Prieta earthquake near Santa Cruz (**Figure** 7.23) and the 1994 Northridge earthquake near Los Angeles.

There are many other faults spreading off the San Andreas, which produce around 10,000 earthquakes a year (**Figure** 7.24). While most of those earthquakes cannot even be felt by people nearby, occasionally one is very strong.

FIGURE 7.23
Three people died in this mall in Santa Cruz during the 1989 Loma Prieta earthquake.

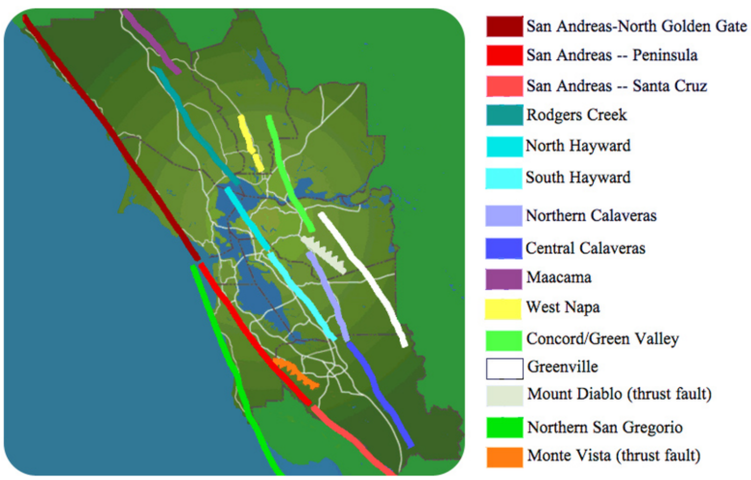

FIGURE 7.24
The San Andreas Fault runs through the San Francisco Bay Area. Other related faults cross the region. Lines indicate strike slip faults. Lines with hatches are thrust faults.

Subduction Zones

Convergent plate boundaries also produce strong, deadly earthquakes. Earthquakes mark the motions of colliding plates and the locations where plates plunge into the mantle. These earthquakes can be shallow, intermediate or deep focus.

The Philippine plate and the Pacific plate subduct beneath Japan, creating as many as 1,500 earthquakes every year. In March 2011, the 9.0 magnitude Tōhoku earthquake struck off of northeastern Japan. Damage from the quake was severe. More severe was the damage from the tsunami generated by the quake (**Figure** 7.25). In all, 25,000 people were known dead or missing.

The Cascades Volcanoes line the Pacific Northwest of the United States. Here, the Juan de Fuca plate subducts beneath the North American plate. The Cascades volcanoes are active and include Mount Saint Helens. Major earthquakes occur here approximately every 300 to 600 years. The last was in 1700. Its magnitude was between 8.7 and 9.2. It has now been more than 300 years since that earthquake. The next massive earthquake could strike the Pacific Northwest at any time.

FIGURE 7.25
The damage in Minato, Japan after a 9.0 magnitude earthquake and the massive tsunami it generated struck in March, 2011.

Continent-Continent Collisions

The collision of two continents also creates massive earthquakes. Many earthquakes happen in the region in and around the Himalayan Mountains. The 2001 Gujarat, India earthquake is responsible for about 20,000 deaths, with many more people injured or made homeless.

Divergent Plate Boundaries

Earthquakes also occur at divergent plate boundaries. At mid-ocean ridges, these earthquakes tend to be small and shallow focus because the plates are thin, young, and hot. Earthquakes in the oceans are usually far from land, so they have little effect on peoples' lives. On land, where continents are rifting apart, earthquakes are larger and stronger.

Intraplate Earthquakes

About 5% of earthquakes take place within a plate, away from plate boundaries. These intraplate earthquakes are caused by stresses within a plate. The plate moves over a spherical surface, creating zones of weakness. Intraplate earthquakes happen along these zones of weakness.

A large intraplate earthquake occurred in 1812. A magnitude 7.5 earthquake struck near New Madrid, Missouri. This is a region not usually known for earthquakes. Because very few people lived here at the time, only 20 people died. The New Madrid Seismic Zone continues to be active (**Figure** 7.26). Many more people live here today.

Seismic Waves

Seismic waves are the energy from earthquakes. Seismic waves move outward in all directions away from their source. Each type of seismic wave travels at different speeds in different materials. All seismic waves travel through rock, but not all travel through liquid or gas. Geologists study seismic waves to learn about earthquakes and the Earth's interior.

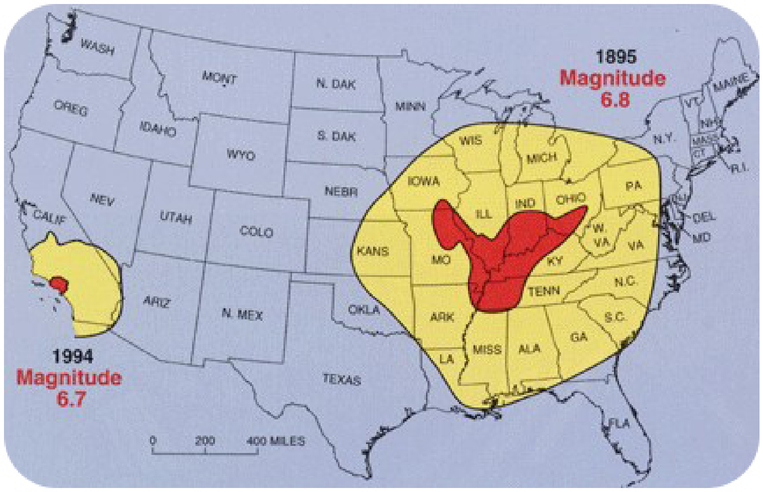

FIGURE 7.26
The range of damage in the 1895 New Madrid earthquake and the 1994 Los Angeles earthquake. New Madrid activity affected a much larger area.

Wave Structure

Seismic waves are just one type of wave. Sound and light also travel in waves. Every wave has a high point called a **crest** and a low point called a **trough**. The height of a wave from the center line to its crest is its **amplitude**. The horizontal distance between waves from crest to crest (or trough to trough) is its **wavelength** (**Figure** 7.27).

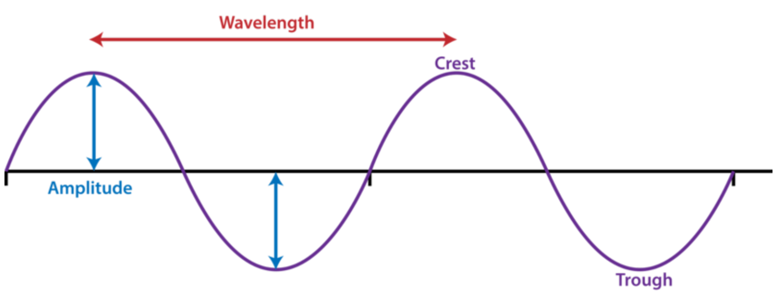

FIGURE 7.27
The energy from earthquakes travels in waves, such as the one shown in this diagram.

Types of Seismic Waves

There are two major types of seismic waves. **Body waves** travel through the Earth's interior. **Surface waves** travel along the ground surface. In an earthquake, body waves are responsible for sharp jolts. Surface waves are responsible for rolling motions that do most of the damage in an earthquake.

Body Waves

Primary waves (P-waves) and **secondary waves (S-waves)** are the two types of body waves (**Figure** 7.28). Body waves move at different speeds through different materials.

P-waves are faster. They travel at about 6 to 7 kilometers (about 4 miles) per second. Primary waves are so named because they are the first waves to reach a seismometer. P-waves squeeze and release rocks as they travel. The material returns to its original size and shape after the P-wave goes by. For this reason, P-waves are not the most damaging earthquake waves. P-waves travel through solids, liquids and gases.

S-waves are slower than P-waves. They are the second waves to reach a seismometer. S-waves move up and down. They change the rock's shape as they travel. S-waves are about half as fast as P-waves, at about 3.5 km (2 miles) per second. S-waves can only move through solids. This is because liquids and gases don't resist changing shape.

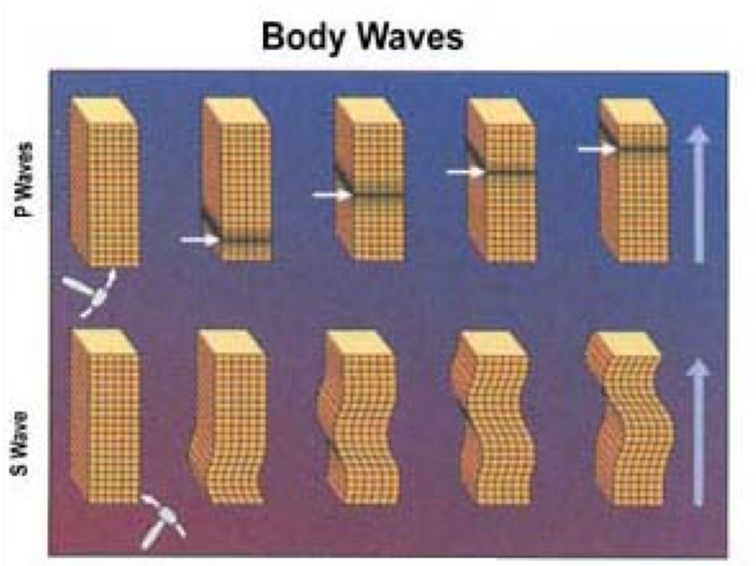

FIGURE 7.28
P-waves and S-waves are the two types of body waves.

Surface Waves

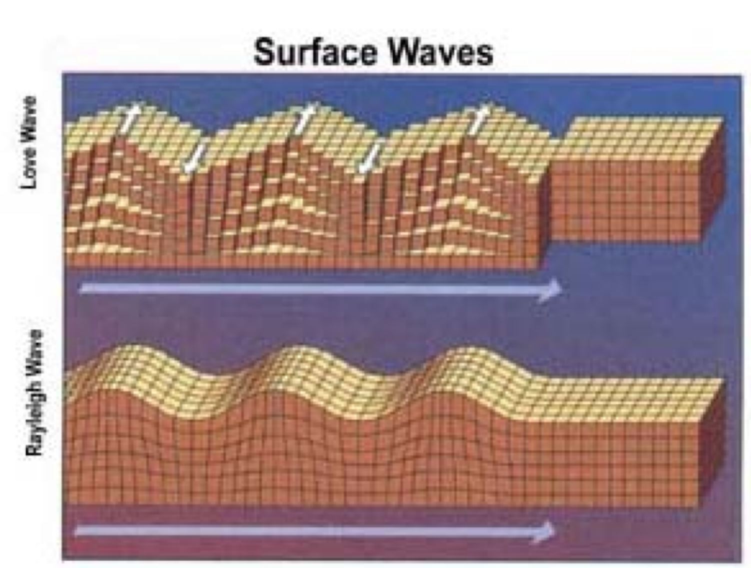

FIGURE 7.29
Love waves and Rayleigh waves are the two types of surface waves.

Surface waves travel along the ground outward from an earthquake's epicenter. Surface waves are the slowest of all seismic waves. They travel at 2.5 km (1.5 miles) per second. There are two types of surface waves. **Love waves** move side-to-side, much like a snake. **Rayleigh waves** produce a rolling motion as they move up and backwards (**Figure** 7.29). Surface waves cause objects to fall and rise, while they are also swaying back and forth. These motions cause damage to rigid structures during an earthquake.

Tsunami

Earthquakes can cause **tsunami**. These deadly ocean waves may result from any shock to ocean water. A shock could be a meteorite impact, landslide, or a nuclear explosion.

An underwater earthquake creates a tsunami this way: The movement of the crust displaces water. The displacement forms a set of waves. The waves travel at jet speed through the ocean. Since the waves have low amplitudes and long wavelengths, they are unnoticed in deep water. As the waves reach shore they compress. They are also pushed upward by the shore. For these reasons, tsunami can grow to enormous wave heights. Tsunami waves can cause tremendous destruction and loss of life. Fortunately, few undersea earthquakes generate tsunami.

The Boxing Day Tsunami, 2004

The Boxing Day Tsunami struck on December 26, 2004. This tsunami was by far the deadliest of all time (**Figure** 7.30). The tsunami was caused by the second largest earthquake ever recorded. The Indian Ocean Earthquake registered magnitude 9.1. The quake struck near Sumatra, Indonesia, where the Indian plate is subducting beneath the Burma plate. It released about 550 million times the energy of the atomic bomb dropped on Hiroshima.

FIGURE 7.30
This dramatic image shows the Boxing Day Tsunami of 2004 coming ashore.

Several tsunami waves were created. The tsunami struck eight countries around the Indian Ocean (**Figure** 7.31).

About 230,000 people died. More than 1.2 million people lost their homes. Many more lost their way of making a living. Fishermen lost their boats, and businesspeople lost their restaurants and shops. Many marine animals washed onshore, including dolphins, turtles, and sharks.

Tilly Smith, Hero

Like other waves, a tsunami wave has a crest and a trough. When the wave hits the beach, the crest or the trough may come ashore first. When the trough comes in first, water is sucked out to sea. The seafloor just offshore from

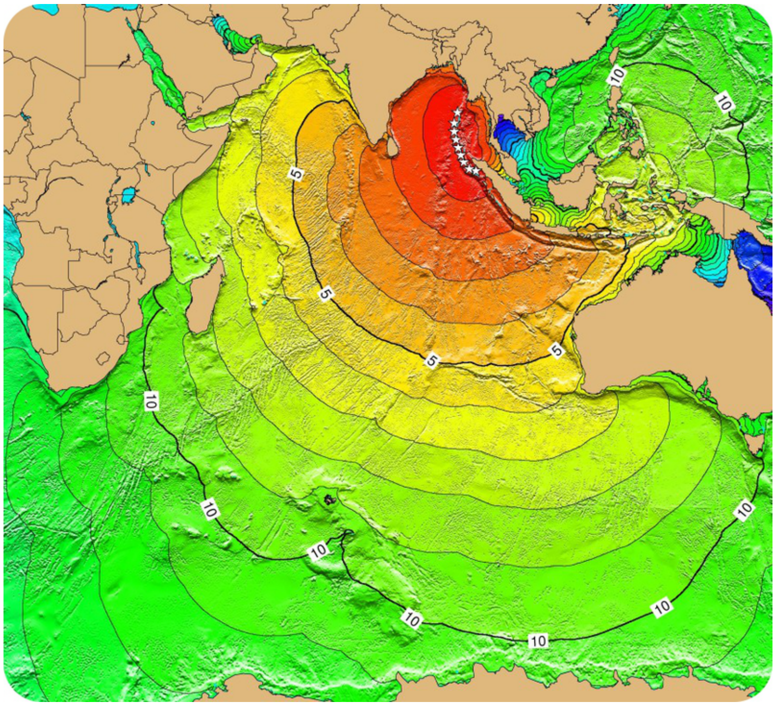

FIGURE 7.31
Travel time map for the Boxing Day Tsunami (in hours). Countries near red, orange, and yellow areas were affected the most.

the beach is exposed. Curious people often walk out onto the beach to see the unusual sight. They drown when the wave crest hits.

One amazing story from the Indian Ocean tsunami is that of Tilly Smith. Tilly was a 10-year-old British girl who was visiting Maikhao Beach in Thailand with her parents. Tilly had learned about tsunami in school two weeks before the earthquake. She knew that the receding water and the frothy bubbles at the sea surface meant a tsunami was coming. Tilly told her parents, who told other tourists and the staff at their hotel. The beach was evacuated and no one on Maikhao Beach died. Tilly is credited with saving nearly 100 people!

Tsunami Warning Systems

Most of the Indian Ocean tragedy could have been avoided if a warning system had been in place(**Figure** 7.32). As of June 2006, the Indian Ocean now has a warning system. Since tsunami are much more common in the Pacific, communities around the Pacific have had a tsunami warning system since 1948.

Warning systems aren't always helpful. People in communities very close to the earthquake do not have enough time to move inland or uphill. Farther away from the quake, evacuation of low-lying areas saves lives.

Lesson Summary

- During an earthquake, the ground shakes as stored up energy is released from rocks.
- Nearly all earthquakes occur at plate boundaries, and all types of plate boundaries have earthquakes.
- The Pacific Ocean basin and the Mediterranean-Asiatic belt are the two geographic regions most likely to experience quakes.
- Body waves travel through the Earth and arrive at seismograms before surface waves.
- The surface seismic waves do the most damage because they only travel along the surface of the ground.

FIGURE 7.32
This sign is part of the tsunami warning system used in communities around the Pacific Ocean since 1948.

- Tsunami are deadly ocean waves that can be caused by undersea earthquakes.

Lesson Review Questions

Recall

1. What is an earthquake's focus? What is its epicenter?

2. Other than a transform fault boundary, what type of plate boundary produces large earthquakes and where are these earthquakes likely to occur?

3. What are the two types of body waves? What are the characteristics of each?

4. What materials can P-waves travel through and how fast are they? Describe a P-wave's motion.

5. What materials can S-waves travel through and how fast are they? Describe an S-wave's motion.

6. How are surface waves different from body waves? In general, which type of wave is more damaging in an earthquake?

Apply Concepts

7. Where do most earthquakes take place? Why?

8. What causes an earthquake?

9. An earthquake just took place at Kilauea in Hawaii (an intraplate volcano). What caused it?

10. What happens when two continents collide? Draw a diagram of the fault.

11. What did Tilly Smith notice on the beach in Thailand that prompted the evacuation of the beach before the enormous tsunami hit in 2004? How were these signs evidence of a tsunami?

Think Critically

12. Try to picture in your mind the Pacific plate moving. It is being created at the East Pacific Rise. It is being destroyed at subduction zones in most locations. Now picture where the earthquakes are taking place.

13. Do the largest earthquakes cause the most deaths and the most damage to property?

14. What type of plate motion formed the Cascades Mountains of the Pacific Northwest? What is likely to occur in the future? Include earthquakes and tsunami.

Points to Consider

- The last time there was a large earthquake on the Hayward Fault in the San Francisco Bay area of California was in 1868. Use elastic rebound theory to describe what may be happening along the Hayward Fault today and what will likely happen in the future.
- Why is California so prone to earthquakes?
- How could coastal California be damaged by a tsunami? Where would the earthquake occur? How could such a tsunami be predicted?

7.3 Measuring and Predicting Earthquakes

Lesson Objectives

- Describe how seismologists can use seismic waves to learn about earthquakes and the Earth's interior.
- Describe how to find an earthquake's epicenter.
- Describe the different earthquake magnitude scales and what the numbers for moment magnitude mean.
- Describe how earthquakes are predicted and why the field of earthquake prediction has had little success.

Vocabulary

- Mercalli Intensity Scale
- moment magnitude scale
- Richter magnitude scale
- seismogram
- seismograph
- seismometer

Introduction

Seismograms record earthquake strength. Scientists can use them to determine the distance to an earthquake. Using at least three seismograms, they can locate the earthquake's epicenter. Scientists measure earthquake intensity in several ways. So far no one has found a way to predict earthquakes.

Measuring Seismic Waves

Seismic waves are measured on a seismograph. Seismographs contain a lot of information, and not just about earthquakes.

Seismographs

A **seismograph** is a machine that records seismic waves. In the past, seismographs produced a **seismogram**. A seismogram is a paper record of the seismic waves the seismograph received. Seismographs have a weighted pen suspended from a stationary frame. A drum of paper is attached to the ground. As the ground shakes in an earthquake, the pen remains stationary but the drum moves beneath it. This creates the squiggly lines that make up a seismogram (**Figure** 7.33).

Modern seismographs record ground motions using electronic motion detectors. The data are recorded digitally on a computer.

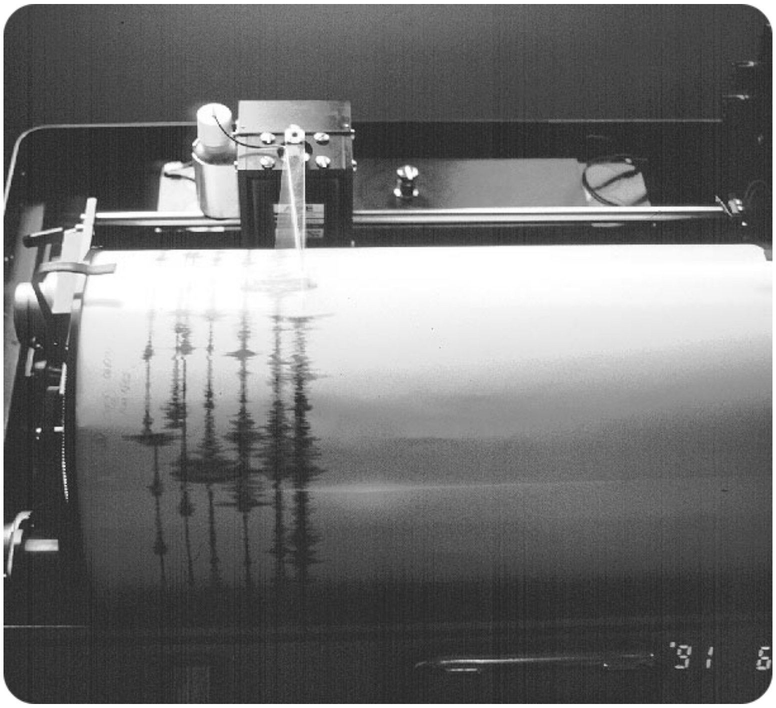

FIGURE 7.33
This seismograph records seismic waves.

What We Learn from Seismograms

Seismograms contain a lot of information about an earthquake: its strength, length and distance. Wave height used to determine the magnitude of the earthquake. The seismogram shows the different arrival times of the seismic waves (**Figure** 7.34). The first waves are P-waves since they are the fastest. S-waves come in next and are usually larger than P-waves. The surface waves arrive just after the S-waves. If the earthquake has a shallow focus, the surface waves are the largest ones recorded.

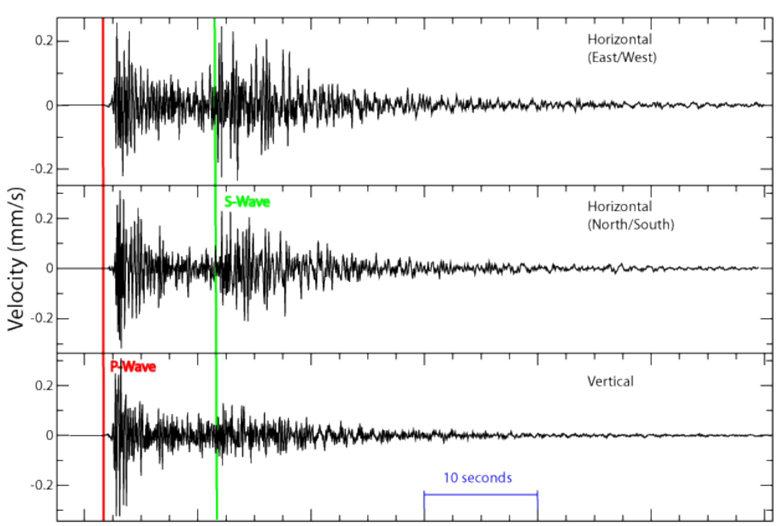

FIGURE 7.34
These seismograms show the arrival of P-waves and S-waves.

A seismogram may record P-waves and surface waves, but not S-waves. This means that it was located more than halfway around the Earth from the earthquake. The reason is that Earth's outer core is liquid. S-waves cannot travel through liquid. So the liquid outer core creates an S-wave shadow zone on the opposite side of the Earth from the quake.

Finding the Epicenter

One seismogram indicates the distance to the epicenter. This is determined by the P-and S-wave arrival times. If a quake is near the seismograph, the S-waves arrive shortly after the P-waves. If a quake is far from the seismograph, the P-waves arrive long before the S-waves. The longer the time is between the P-and S-wave arrivals, the further away the earthquake was from the seismograph. First, seismologists calculate the arrival time difference. Then they know the distance to the epicenter from that seismograph.

Next, the seismologists try to determine the location of the earthquake epicenter. To do this they need the distances to the epicenter from at least three seismographs. Let's say that they know that an earthquake's epicenter is 50 kilometers from Kansas City. They draw a circle with a 50 km radius around that seismic station. They do this twice more around two different seismic stations. The three circles intersect at a single point. This is the earthquake's epicenter (**Figure** 7.35).

FIGURE 7.35
Seismographs in Portland, Los Angeles, and Salt Lake City are used to find an earthquake epicenter.

Earthquake Intensity

The ways seismologists measure an earthquake have changed over the decades. Initially, they could only measure what people felt and saw, the intensity. Now they can measure the energy released during the quake, the magnitude.

Earthquake Intensity

Early in the 20th century, earthquakes were described in terms of what people felt and the damage that was done to buildings. The **Mercalli Intensity Scale** describes earthquake intensity.

There are many problems with the Mercalli scale. The damage from an earthquake is affected by many things. Different people experience an earthquake differently. Using this scale, comparisons between earthquakes were difficult to make. A new scale was needed.

The Richter Magnitude Scale

Charles Richter developed the **Richter magnitude scale** in 1935. The Richter scale measures the magnitude of an earthquake's largest jolt of energy. This is determined by using the height of the waves recorded on a seismograph.

Richter scale magnitudes jump from one level to the next. The height of the largest wave increases 10 times with each level. So the height of the largest seismic wave of a magnitude 5 quake is 10 times that of a magnitude 4 quake. A magnitude 5 is 100 times that of a magnitude 3 quake. With each level, thirty times more energy is released. A difference of two levels on the Richter scale equals 900 times more released energy.

The Richter scale has limitations. A single sharp jolt measures higher on the Richter scale than a very long intense earthquake. Yet this is misleading because the longer quake releases more energy. Earthquakes that release more energy are likely to do more damage. As a result, another scale was needed.

The Moment Magnitude Scale

The **moment magnitude scale** is the favored method of measuring earthquake magnitudes. It measures the total energy released by an earthquake. Moment magnitude is calculated by two things. One is the length of the fault break. The other is the distance the ground moves along the fault.

Earthquake Magnitudes

Each year, more than 900,000 earthquakes are recorded. 150,000 of them are strong enough to be felt by people. About 18 each year are major, with a Richter magnitude of 7.0 to 7.9. Usually there is one earthquake with a magnitude of 8 to 8.9 each year.

Earthquakes with a magnitude in the 9 range are rare. The United States Geological Survey lists five such earthquakes on the moment magnitude scale since 1900 (see **Figure** 7.36). All but one, the Great Indian Ocean Earthquake of 2004, occurred somewhere around the Pacific Ring of Fire.

Earthquake Prediction

Scientists are not able to predict earthquakes. Since nearly all earthquakes take place at plate boundaries, scientists can predict where an earthquake will occur (**Figure** 7.37). This information helps communities to prepare for an earthquake. For example, they can require that structures are built to be earthquake safe.

Predicting when an earthquake will occur is much more difficult. Scientists can look at how often earthquakes have struck in the past. This does not allow an accurate prediction for the future. Small tremors, called foreshocks, often happen a short time before a major quake. The ground may also tilt as stress builds up in the rocks. Water levels in wells also change as groundwater moves through rock fractures. These do not usually allow accurate predictions.

Folklore tells of animals behaving strangely just before an earthquake. Most people tell stories of these behaviors after the earthquake. Chinese scientists actively study the behavior of animals before earthquakes to see if there is a connection. So far nothing concrete has come of these studies.

Once an earthquake has started, many actions must take place. Seismometers can detect P-waves a few seconds before more damaging S-waves and surface waves arrive. Although a few seconds is not much, computers can shut down gas mains and electrical transmission lines. They can initiate protective measures in chemical plants, nuclear power plants, mass transit systems, airports, and roadways.

FIGURE 7.36
Earthquake and tsunami damage in Japan, 2011. The Tōhoku earthquake had a magnitude of 9.0.

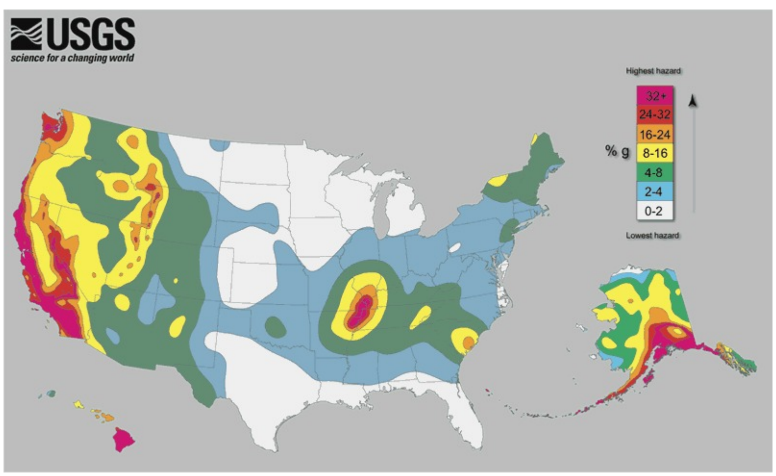

FIGURE 7.37
This map shows earthquake probability regions in the United States.

Lesson Summary

- Seismologists use seismograms to determine how strong an earthquake is, how far away it is, and how long it lasts.
- Epicenters can be calculated using the difference in the arrival times of P-and S-waves from three seismograms.
- The intensity of an earthquake can be determined in many ways. The Mercalli Scale identifies the damage done and what people feel, the Richter Scale measures the height of the largest seismic wave, and the moment

magnitude scale measures the total energy released by an earthquake.
- Despite some successes, seismologists cannot yet accurately predict earthquakes.

Lesson Review Questions

Recall

1. How does a seismograph work?

2. In what order do waves arrive at a seismograph?

3. What information is needed for seismologists to calculate the distance that a seismic station is from an earthquake's epicenter?

4. Describe how to locate an earthquake epicenter.

Apply Concepts

5. Draw a picture to show the S-wave shadow zone. How does this indicate a liquid outer core?

6. While the Mercalli scale is still used for measuring earthquake magnitude, why is it not the only scale used? Where does it fall short relative to the Richter and moment magnitude scales?

Think Critically

7. Like the Richter scale, the moment magnitude scale is logarithmic. The 2011 Tōhoku earthquake in Japan was 9.0 and did tremendous damage. A few months earlier, an 8.8 struck Chile and did much less damage. Why?

8. What are the characteristics of a good earthquake prediction? Why are these features needed?

Points to Consider

- If you live in an earthquake prone area, how do you feel about your home now that you've read this section? Since earthquakes are unlikely to be predicted, what can you do to minimize the risk to you and your family? If you do not live in an earthquake prone area, what would it take to get you to move to one? Also, what risks from natural disasters do you face where you live?
- What do you think is the most promising set of clues that scientists might someday be able to use to predict earthquakes?
- What good does information about possible earthquake locations do for communities in those earthquake-prone regions?

7.4 Staying Safe in Earthquakes

Lesson Objectives

- Describe different types of earthquake damage.
- Describe the features that make a structure more earthquake safe.
- Describe the ways that a person and a household can protect themselves in earthquake country.

Vocabulary

- liquefy

Introduction

Only hurricanes cause more damage than earthquakes. Only one source of earthquake damage is ground shaking. More damage may be done from the tsunami, fires, and landslides that can happen afterwards. Communities along faults can prepare for earthquakes. One way is to use earthquake-safe construction methods and to make older buildings stronger. If you live in earthquake country, it is important to secure heavy objects and put together an emergency kit.

Damage from Earthquakes

Earthquake magnitude affects how much damage is done in an earthquake. A larger earthquake damages more buildings and kills more people than a smaller earthquake. But that's not the only factor that determines earthquake damage. The location of an earthquake relative to a large city is important. More damage is done if the ground shakes for a long time.

The amount of damage also depends on the geology of the region. Strong, solid bedrock shakes less than soft or wet soils. Wet soils **liquefy** during an earthquake and become like quicksand. Soil on a hillside that is shaken loose can become a landslide.

Hazard maps help city planners choose the best locations for buildings (**Figure** 7.38). For example, when faced with two possible locations for a new hospital, planners must build on bedrock rather than silt and clay.

Mexico City, 1985

The 1985 Mexico City earthquake measured magnitude 8.1. The earthquake killed at least 9,000 people, injured 30,000 more, and left 100,000 people homeless. It destroyed 416 buildings, and seriously damaged 3,000 other buildings.

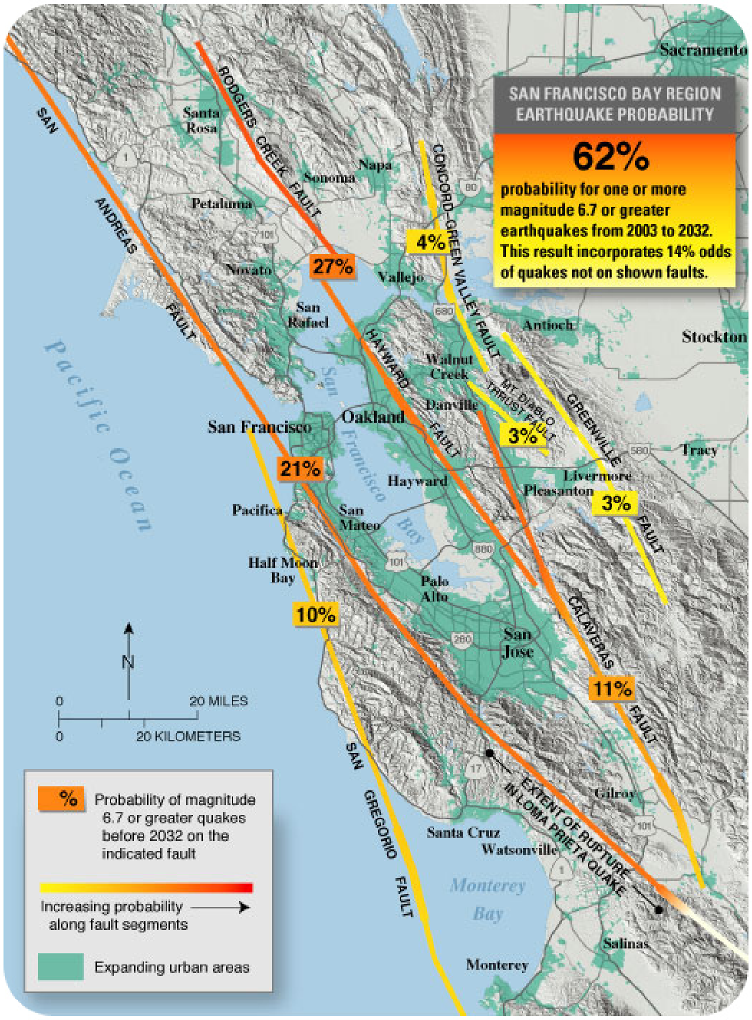

FIGURE 7.38
This hazard map predicts the likelihood of strong earthquakes in the area around San Francisco, California.

The intense destruction was due to the soft ground the city is built on. Silt and clay fill a basin made of solid rock. In an earthquake, seismic waves bounce back-and-forth off the sides and bottom of the rock basin. This amplifies the shaking. The wet clay converts to quicksand (**Figure** 7.39).

Many buildings were not anchored to bedrock. They settled into the muck. This caused enormous damage. Water, sewer, and electrical systems were destroyed, resulting in fires. Acapulco was much closer to the epicenter, but since the city is built on bedrock it suffered little damage.

Anchorage, Alaska, 1964

The amount of damage depends on the amount of development in the region. The 1964 Great Alaska Earthquake, near Anchorage, was the largest earthquake ever recorded in North America. The gigantic quake had a magnitude of 9.2. The earthquake lasted for several minutes and the ground slipped up to 11.5 meters (38 feet). An area of 100,000 square miles (250,000 square km) was affected. The ground liquefied, causing landslides (**Figure** 7.40). The earthquake occurred at a subduction zone, and large tsunami up to 70 meters (20 feet) high were created.

Despite the intensity of the earthquake, only 131 people died. Most deaths were due to the tsunami. Property damage was just over $300 million ($1.8 billion in 2007 U.S. dollars). The reason there was such a small amount of damage is that very few people lived in the area (Alaska had only been a state for five years!). A similar earthquake today

FIGURE 7.39
Mexico City suffers tremendously in earthquakes because it is built on an old lake bed. In 1985 many buildings collapsed.

FIGURE 7.40
A landslide in a neighborhood in Anchorage Alaska after the 1964 Great Alaska earthquake.

would affect many more people.

Earthquake-Safe Structures

Buildings must be specially built to withstand earthquakes. Skyscrapers and other large structures built on soft ground must be anchored to bedrock. Sometimes that bedrock is hundreds of meters below the ground surface!

Buildings

Building materials need to be both strong and flexible. Small structures, like houses, should bend and sway. Wood and steel bend. Brick, stone, and adobe are brittle and will break. Larger buildings must sway, but not so much that they touch nearby buildings. Counterweights and diagonal steel beams can hold down sway. Buildings need strong, flexible connections where the walls meet the foundation. Earthquake-safe buildings are well connected (**Figure** 7.41).

FIGURE 7.41
The Transamerica Pyramid in San Francisco is more stable in an earthquake or in high winds than a rectangular skyscraper.

Steel or wood can be added to older buildings to reinforce a building's structure and its connections (**Figure** 7.42). Elevated freeways and bridges can also be reinforced so that they do not collapse. Important structures must be designed to survive intact.

Avoiding Fire

One of the biggest problems caused by earthquakes is fire. Fires start because earthquakes rupture gas and electrical lines. Water mains may break. This makes it difficult to fight the fires. The shapes of pipes can make a big difference. Straight pipes will break in a quake. Zigzag pipes bend and flex when the ground shakes. In San Francisco, water and gas pipelines are separated by valves. Areas can be isolated if one segment breaks.

Making Choices

Strong, sturdy structures are expensive to build. Communities must decide how safe to make their buildings. They must weigh how great the hazard is, what different building strategies will cost, and how much risk they are willing to take.

FIGURE 7.42
Buildings can be retrofit to be made more earthquake safe.

Protecting Yourself in an Earthquake

If you live in an earthquake zone, there are many things you can do to protect yourself. You must protect your home. Your household must be ready to live independently for a few days. It may take emergency services that long to get to everyone.

Before an Earthquake:

- Make sure the floor, walls, roof, and foundation are all well attached to each other. Have an engineer evaluate your house for structural integrity.
- Bracket or brace brick chimneys to the roof.
- Be sure that heavy objects are not stored in high places. Move them to low places so that they do not fall.
- Secure water heaters all around and at the top and bottom.
- Bolt heavy furniture onto walls with bolts, screws, or strap hinges.
- Replace halogen and incandescent light bulbs with fluorescent bulbs to lessen fire risk.
- Check to see that gas lines are made of flexible material so they do not rupture. Any equipment that uses gas should be well secured.
- Everyone in the household should know how to shut off the gas line. A wrench should be placed nearby for

doing so.
- Prepare an earthquake kit with at least three days' supply of water and food. Include a radio and batteries.
- Place flashlights all over the house so there is always one available. Place one in the glove box of your car.
- Keep several fire extinguishers around the house to fight any small fires that break out.
- Be sure to have a first aid kit. Everyone in the household who is capable should know basic first aid and CPR.
- Plan in advance how you will evacuate your property and where you will go. Do not plan on driving, as roadways will likely be damaged.

During the Earthquake:

- If you are in a building, drop to the ground, get beneath a sturdy table or desk, cover your head, and hold on.
- Stay away from windows and mirrors since glass can break and fall on you. Stay away from large furniture that may fall on you.
- If the building is structurally unsound, get outside as fast as possible. Run into an open area away from buildings and power lines that may fall on you.
- If you are in a car, stay in the car and stay away from structures that might collapse like overpasses, bridges, or buildings.

After the Earthquake:

- Be aware that aftershocks are likely.
- Avoid dangerous areas, like hillsides, that may experience a landslide.
- Turn off water, gas lines, and power to your home.
- Use your phone only if there is an emergency. Many people with urgent needs will be trying to get through to emergency services.
- Be prepared to wait for help or instructions. Assist others as necessary.

Lesson Summary

- A person standing in an open field in an earthquake will almost certainly be safe. Nearly all earthquake danger is from buildings falling, roadways collapsing, or from the fires and tsunami that come after the shaking stops.
- Communities can prepare for earthquakes by requiring that buildings be earthquake safe and by educating citizens on how to prepare for an earthquake.
- Individuals and households can prepare in two ways: by protecting your home and by being ready to live independently for a few days.

Lesson Review Questions

Recall

1. What usually kills or injures people in an earthquake?

2. In two earthquakes of the same size, what could cause greater damage for one community?

Apply Concepts

3. What types of building design make a skyscraper earthquake safe?

4. If you live in earthquake country, what can you do to minimize your dangers?

Think Critically

5. Pretend that you live in an old home in an earthquake-prone region. No work has ever been done to prepare your home for an earthquake. What should you do to minimize the harm that will come to yourself and your home?

6. Will a building better withstand an earthquake if it is built absolutely solid, or if it is able to sway? Why?

Points to Consider

- Many people think that in a large earthquake California will fall into the ocean and that Arizona and Nevada will be beachfront property. Why is this not true?
- If you were the mayor of a small city in an earthquake-prone area, what would you like to know before choosing the building site of a new hospital?
- How are decisions made for determining how much money to spend preparing people and structures for earthquakes?

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40. Courtesy of the National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Good_Friday_Earthquake_at_Turnagain_Arm.jpg . Public Domain
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CHAPTER 8 MS Volcanoes

Chapter Outline

A fissure eruption on a volcano in Iceland. The lava flows downhill and turns snow into steam. Iceland is made of a set of volcanoes that are the result of a hotspot that lies on a mid-ocean ridge. The island is the only location where the mid-ocean ridge can be seen above sea level. Icelandic volcanoes have made the news lately since some have shut down air traffic in parts of Europe.

8.1 Volcanic Activity

Lesson Objectives

- Explain how volcanoes form.
- Describe places where volcanoes occur.
- Describe what volcanic hot spots are and where they occur.

Vocabulary

- fissure
- hot spot
- mantle plume

Introduction

Volcanoes are fantastic displays of the power of the Earth. What is a volcano? How and where are they formed? Why do some places have lots of volcanoes?

Where Volcanoes Are Found

Volcanoes rise where magma forms underground. Volcanoes are found at convergent plate boundaries and at hotspots. Volcanic activity is found at divergent plate boundaries. The map in **Figure** 8.1 shows where volcanoes are located.

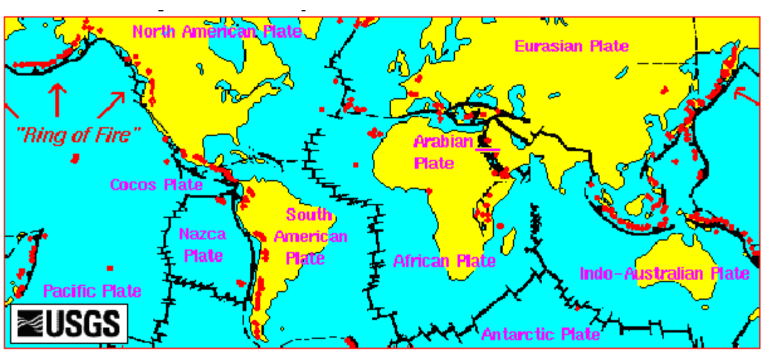

FIGURE 8.1
This map shows where volcanoes are located.

Divergent Plate Boundaries

There is a lot of volcanic activity at divergent plate boundaries in the oceans. As the plates pull away from each other, they create deep fissures. Molten lava erupts through these cracks. The East Pacific Rise is a divergent plate boundary in the Pacific Ocean (**Figure** 8.2). The Mid-Atlantic Ridge is a divergent plate boundary in the Atlantic Ocean.

Continents can also rift apart. When mantle gets close enough to the surface, volcanoes form. Eventually, a rift valley will create a new mid-ocean ridge.

Convergent Plate Boundaries

Lots of volcanoes form along subduction plate boundaries. The edges of the Pacific Plate are a long subduction boundary. Lines of volcanoes can form at subduction zones on oceanic or continental crust. Japan is an example of a volcanic arc on oceanic crust. The Cascade Range and Andes Mountains are volcanic arcs on continental crust.

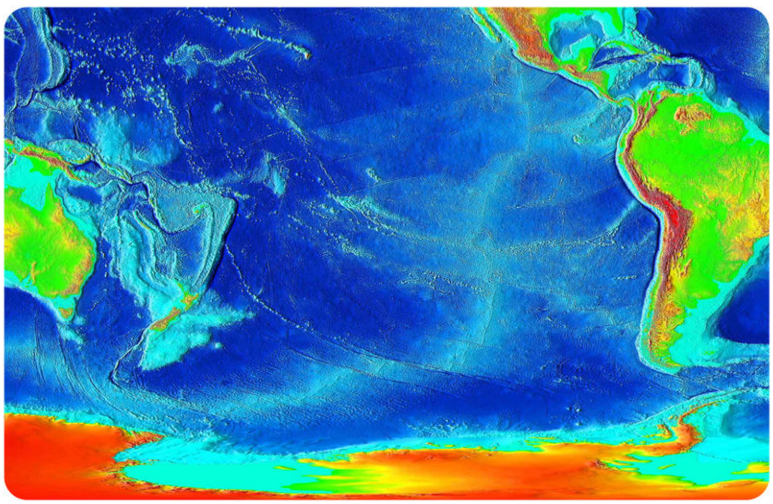

FIGURE 8.2
The Pacific Ocean basin is a good place to look for volcanoes. The light blue wavy line that goes up the right-center of the diagram is the East Pacific Rise. Trenches due to subduction are on the west and east sides of the plate. Hawaii trends southeast-northwest near the center-top of the image.

Volcanic Hot Spots

Some volcanoes form over active **hot spots**. Scientists count about 50 hot spots on the Earth. Hot spots may be in the middle of a tectonic plate. Hot spots lie directly above a column of hot rock called a **mantle plume**. Mantle plumes continuously bring magma up from the mantle towards the crust (**Figure** 8.3).

As the tectonic plates move above a hot spot, they form a chain of volcanoes. The islands of Hawaii formed over a hot spot in the middle of the Pacific plate. The Hawaii hot spot has been active for tens of millions of years. The volcanoes of the Hawaiian Islands formed at this hot spot. Older volcanoes that formed at the hot spot have eroded below sea level. These are called the Emperor Seamounts.

Loihi seamount is currently active beneath the water southeast of the Big Island of Hawaii. One day the volcano will rise above sea level and join the volcanoes of the island or create a new island (**Figure** 8.4).

Hot spots may also be active at plate boundaries. This is especially common at mid-ocean ridges. Iceland is formed by a hot spot along the Mid-Atlantic Ridge.

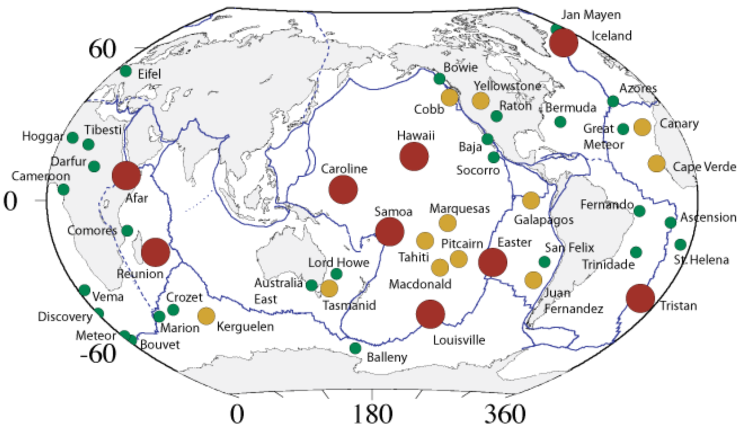

FIGURE 8.3

Mantle plumes are found all over the world, especially in the ocean basins. The size of the eruptions is different at different plumes.

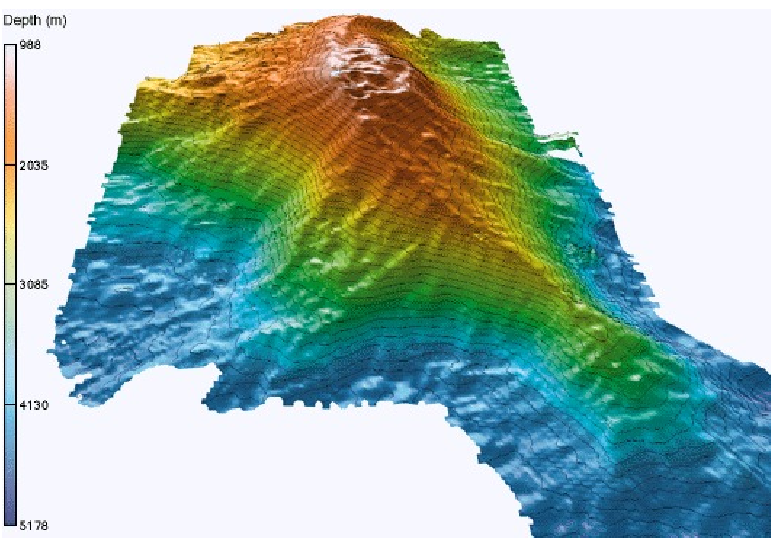

FIGURE 8.4

A bathymetric map of Loihi seamount. Loihi will be the next shield volcano in the Hawaiian-Emperor chain.

Hot spots are found within continents, but not as commonly as within oceans. The Yellowstone hot spot is a famous example of a continental hot spot.

Lesson Summary

- Volcanoes form when magma reaches the Earth's surface.
- Volcanoes occur most often along plate boundaries.
- Convergent plate boundaries, where oceanic crust is forced down into the mantle, form many of the volcanoes found on Earth.
- Divergent plate boundaries produce huge mountain ranges under water in every ocean basin.
- Volcanoes like those that make up the islands of Hawaii form over areas called hot spots.

Lesson Review Questions

Recall

1. What is a hot spot?
2. How is a hot spot related to a mantle plume?
3. Why do hot spot volcanoes form in lines?

Apply Concepts

4. What plate tectonic setting produces the most volcanoes?
5. What are the ages of hotspot volcanoes relative to each other?
6. What are the ages of volcanic arc volcanoes relative to each other?

Think Critically

7. Volcanoes have been found on Venus, Mars, and even Jupiter's moon Io. What do you think this indicates to planetary geologists?

Points to Consider

- When you look at the map of tectonic plates (**Figure** 8.1), what areas besides the Pacific Ring of Fire would you expect to have volcanic activity?
- Why do you think some volcanoes are no longer active and probably never will be again?
- Why do you think it's hard to study hot spots?

8.2 Volcanic Eruptions

Lesson Objectives

- Explain how volcanoes erupt.
- Describe and compare the types of volcanic eruptions.
- Distinguish between different types of lava and understand the difference between magma and lava.
- Describe a method for predicting volcanic eruptions.

Vocabulary

- active volcano
- dormant volcano
- eruption
- explosive eruption
- extinct volcano
- magma chamber
- pyroclast

Introduction

In 1980, Mount St. Helens, located between Portland, Oregon and Seattle, Washington, erupted explosively. The eruption killed 57 people, destroyed 250 homes, and swept away 47 bridges. The volcano blew off its top so that it lost over 400 meters (1,300 feet) of height. Mt. St. Helens is still active (**Figure** 8.5). Within the crater, a new lava dome formed. How did this eruption occur? Why aren't all volcanoes explosive, like Mt. St. Helens? Why did so many people die if we knew that it was going to erupt?

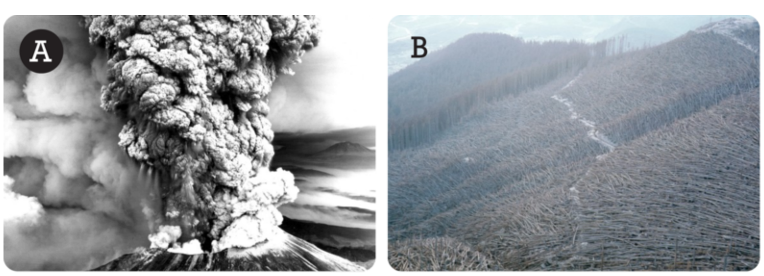

FIGURE 8.5

(A) Mount St. Helens eruption on May 18, 1980. Mt. Adams is in the background on the right. (B) The eruption of Mt. St. Helens blew down acres of trees like they were toothpicks.

How Volcanoes Erupt

All volcanoes share the same basic features. First, mantle rock melts. The molten rock collects in magma chambers that can be 160 kilometers (100 miles) beneath the surface. As the rock heats, it expands. The hot rock is less dense than the surrounding rock. The magma rises toward the surface through cracks in the crust. A volcanic **eruption** occurs when the magma reaches the surface. Lava can reach the surface gently or explosively.

Types of Eruptions

Eruptions can be explosive or non-explosive. Only rarely do gentle and explosive eruptions happen in the same volcano.

Explosive Eruptions

An **explosive eruption** produces huge clouds of volcanic ash. Chunks of the volcano fly high into the atmosphere. Explosive eruptions can be 10,000 times as powerful as an atomic bomb (**Figure** 8.6). Hot magma beneath the surface mixes with water. This forms gases. The gas pressure grows until it must be released. The volcano erupts in an enormous explosion.

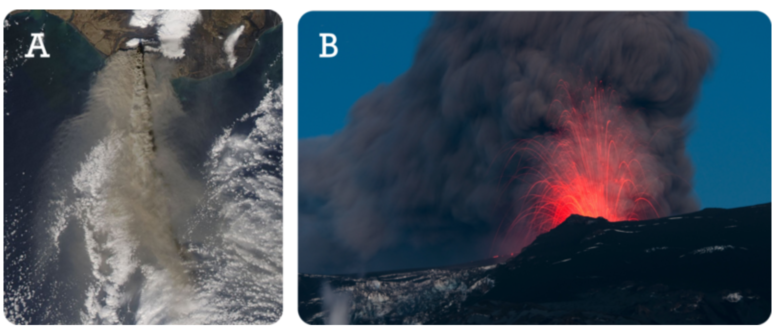

FIGURE 8.6
(A) Eyjafjallajökull volcano in Iceland spewed ash into the atmosphere in 2010. This was a fairly small eruption, but it disrupted air travel across Europe for six days. (B) The eruption seen from nearby.

Ash and particles shoot many kilometers into the sky. The material may form a mushroom cloud, just like a nuclear explosion. Hot fragments of rock, called **pyroclasts**, fly up into the air at very high speeds. The pyroclasts cool in the atmosphere. Some ash may stay in the atmosphere for years. The ash may block out sunlight. This changes weather patterns and affects the temperature of the Earth. For a year or two after a large eruption, sunsets may be especially beautiful worldwide.

Volcanic gases can form poisonous, invisible clouds. The poisonous gases may be toxic close to the eruption. The gases may cause environmental problems like acid rain and ozone destruction.

Mt St. Helens was not a very large eruption for the Cascades. Mt. Mazama blew itself apart in an eruption about 42 times more powerful than Mount St. Helens in 1980. Today all that remains of that huge stratovolcano is Crater Lake (**Figure** 8.18).

Non-explosive Eruptions

Some volcanic eruptions are non-explosive (**Figure** 8.7). This happens when there is little or no gas. The lava is thin, fluid and runny. It flows over the ground like a river. People generally have a lot of warning before a lava flow like this reaches them, so non-explosive eruptions are much less deadly. They may still be destructive to property, though. Even when we know that a lava flow is approaching, there are few ways of stopping it!

FIGURE 8.7
A lava flow in Iceland in 1984.

Magma and Lava

Great volcanic explosions and glowing red rivers of lava are fascinating. All igneous rock comes from magma or lava. Remember that magma is molten rock that is below Earth's surface. Lava is molten rock at Earth's surface.

Magma

Magma forms deep beneath the Earth's surface. Rock melts below the surface under tremendous pressure and high temperatures. Molten rock flows like taffy or hot wax. Most magmas are formed at temperatures between 600^oC and 1300^oC (**Figure** 8.8).

Magma collects in **magma chambers** beneath Earth's surface. Magma chambers are located where the heat and pressure are great enough to melt rock. These locations are at divergent or convergent plate boundaries or at hotpots.

The chemistry of a magma determines the type of igneous rock it forms. The chemistry also determines how the magma moves. Thicker magmas tend to stay below the surface or erupt explosively. When magma is fluid and runny, it often reaches the surface by flowing out in rivers of lava.

Lava

The way lava flows depends on what it is made of. Thick lava doesn't flow easily. It may block the vent of a volcano. If the lava traps a lot of gas, the pressure builds up. After the pressure becomes greater and greater, the volcano finally explodes. Ash and pyroclasts shoot up into the air. Pumice, with small holes in solid rock, shows where gas bubbles were when the rock was still molten.

Fluid lava flows down mountainsides. The rock that the flow becomes depends on which type of lava it is and where it cools. The three types of flows are a'a, pahoehoe, and pillow lava.

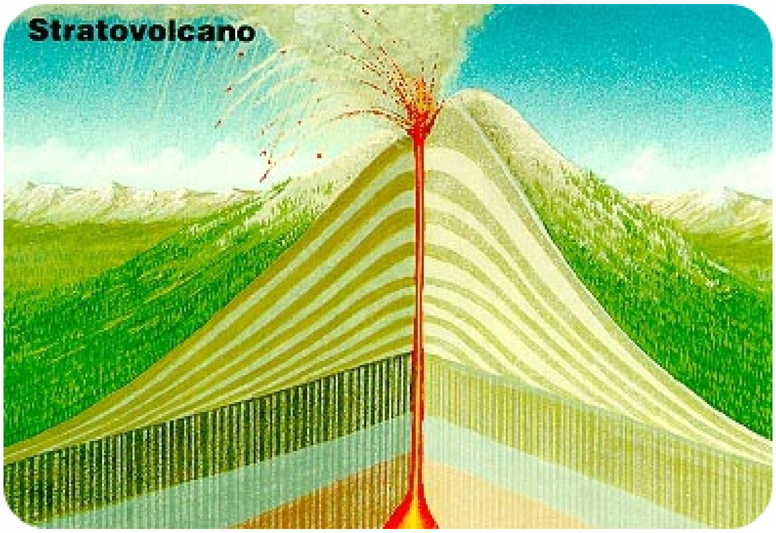

FIGURE 8.8
Magma beneath a volcano erupts onto the volcano's surface. Layer upon layer of lava creates a volcano.

A'a Lava

A'a lava is the thickest of the non-explosive lavas. A'a forms a thick and brittle crust, which is torn into rough, rubbly pieces. The solidified surface is angular, jagged and sharp. A'a can spread over large areas as the lava continues to flow underneath.

Pāhoehoe Lava

Pāhoehoe lava is thinner than a'a, and flows more readily. Its surface looks more wrinkly and smooth. Pāhoehoe lava flows in a series of lobes that form strange twisted shapes and natural rock sculptures (**Figure** 8.9). Pāhoehoe lava can form lava tubes. The outer layer of the lava flow cools and solidifies. The inner part of the flow remains fluid. The fluid lava flows through and leaves behind a tube (**Figure** 8.10).

FIGURE 8.9
Ropy pahoehoe flows are common on Kilauea Volcano in Hawaii.

FIGURE 8.10
A lava tube in a pahoehoe flow.

Pillow Lava

Pillow lava is created from lava that enters the water. The volcanic vent may be underwater. The lava may flow over land and enter the water (**Figure** 8.11). Once in the water, the lava cools very quickly. The lava forms round rocks that resemble pillows. Pillow lava is particularly common along mid-ocean ridges.

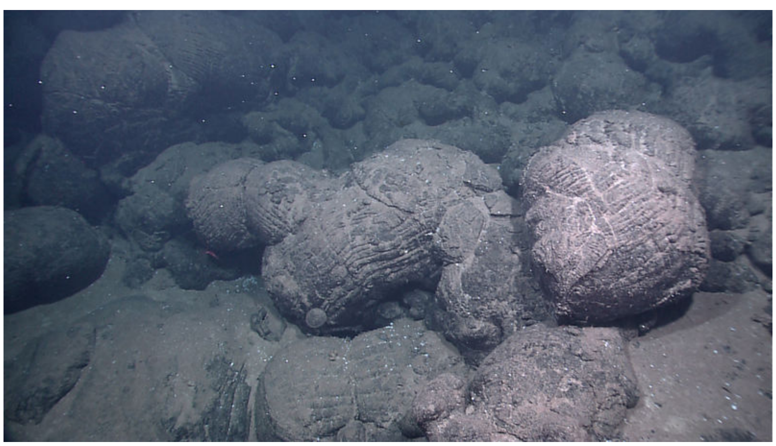

FIGURE 8.11
These underwater rocks in the Galapagos formed from pillow lava.

Predicting Volcanic Eruptions

Volcanic eruptions can be devastating, particularly to the people who live close to volcanoes. Volcanologists study volcanoes to be able to predict when a volcano will erupt. Many changes happen when a volcano is about to erupt.

History of Volcanic Activities

Scientists study a volcano's history to try to predict when it will next erupt. They want to know how long it has been since it last erupted. They also want to know the time span between its previous eruptions.

Volcanoes can be active, dormant, or extinct (**Figure** 8.12). An **active volcano** may be currently erupting. Alternatively, it may be showing signs that it will erupt in the near future. A **dormant volcano** no longer shows signs of activity. But it has erupted in recent history and will probably erupt again. An **extinct volcano** is one that has not erupted in recent history. Scientists think that it will probably not erupt again. Scientists watch both active and dormant volcanoes closely for signs that show they might erupt.

FIGURE 8.12

(A) Mount Etna in Italy is certainly an active volcano. (B) Mount Rainer in Washington State is currently dormant. The volcano could and probably will erupt again. (C) Shiprock in northern New Mexico is the remnant of a long-extinct volcano.

Earthquakes

Earthquakes may take place every day near a volcano. But before an eruption the number and size of earthquakes increases. This is the result of magma pushing upward into the magma chamber. This motion causes stresses on neighboring rock to build up. Eventually the ground shakes. A continuous string of earthquakes may indicate that a volcano is about to erupt. Scientists use seismographs to record the length and strength of each earthquake.

Slope Tilt

All that magma and gas pushing upwards can make the volcano's slope begin to swell. Ground swelling may change the shape of a volcano or cause rock falls and landslides. Most of the time, the ground tilting is not visible. Scientists detect it by using tiltmeters, which are instruments that measure the angle of the slope of a volcano.

Gases

Scientists measure the gases that escape from a volcano to predict eruptions. Gases like sulfur dioxide (SO_2), carbon dioxide (CO_2), hydrochloric acid (HCl), and water vapor can be measured at the site. Gases may also be measured from satellites. The amounts of gases and the ratios of gases are calculated to help predict eruptions.

Remote Monitoring

Satellites can be used to monitor more than just gases (**Figure** 8.13). Satellites can look for high temperature spots or areas where the volcano surface is changing. This allows scientists to detect changes accurately and safely.

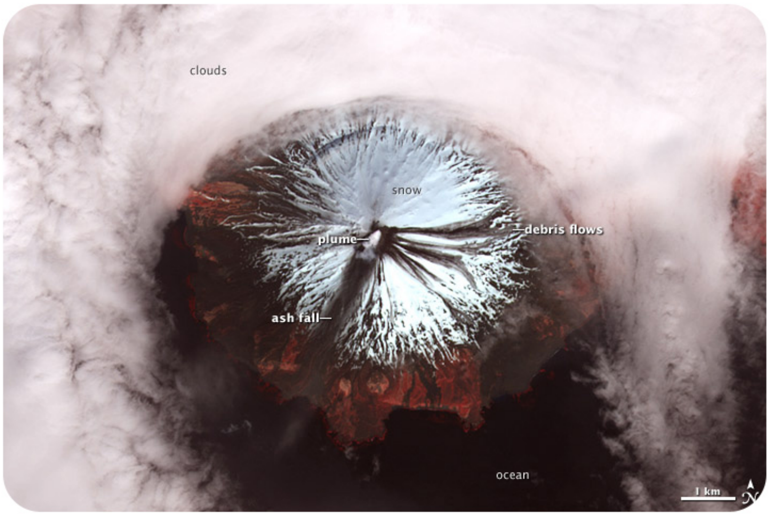

FIGURE 8.13
Mount Cleveland, in Alaska, is monitored by satellite.

Costs and Benefits of Predictions

No scientist or government agency wants to announce an eruption and then be wrong. There is a very real cost and disruption to society during a large-scale evacuation. If the scientists are wrong, people would be less likely to evacuate the next time scientists predicted an eruption. But if scientists predict an eruption that does take place it could save many lives.

Lesson Summary

- Volcanoes are produced when magma rises towards the Earth's surface because it is less dense than the surrounding rock.
- Volcanic eruptions can be non-explosive or explosive depending on the thickness of the magma.
- Explosive eruptions happen with thick magma and produce tremendous amounts of material ejected into the air.
- Non-explosive eruptions mostly produce various types of lava, such as a'a, pahoehoe and pillow lavas.
- Some signs that a volcano may soon erupt include an increase in earthquakes, surface bulging and released gases that can be monitored by scientists.

Lesson Review Questions

Recall

1. Describe what happens during an explosive volcanic eruption.

2. Describe what happens during a non-explosive volcanic eruption.
3. What are pyroclasts?

Apply Concepts

4. What is a magma chamber and what are its characteristics?
5. The boiling point of water is 100^{o}C. Why might water make an eruption more explosive?
6. Why is predicting volcanic eruptions so important?

Think Critically

7. What factors are considered in predicting volcanic eruptions?

Points to Consider

- What types of evidence would scientists use to determine whether an ancient volcanic eruption was explosive or non-explosive?
- Are all volcanoes shaped like tall mountains with a crater on the peak?
- What language do you think gives us the names a'a and pāhoehoe?
- What changes in the pattern of earthquakes might indicate a volcano is about to erupt?

8.3 Types of Volcanoes

Lesson Objectives

- Describe the basic shapes of volcanoes.
- Compare the features of volcanoes.
- Describe the stages in the formation of volcanoes.

Vocabulary

- caldera
- cinder cone
- composite volcano
- shield volcano
- strata
- supervolcano

Introduction

Some volcanoes are tall, cone-shaped mountains. They may be covered by snow or even glaciers. Some volcanoes are huge, gently sloping mountains. Many volcanoes are very small cones. Volcanic eruptions can come through cracks in the ground. Thin, fluid and runny lava forms gentle slopes. Thicker lavas build tall, steep volcanoes. Volcano types are discussed in this section.

Types of Volcanoes

A composite volcano forms the tall cone shape you usually think of when you think of a volcano. Shield volcanoes are huge, gently sloping volcanoes. Cinder cones are small, cone-shaped volcanoes.

Composite Volcanoes

Figure 8.14 shows Mt. Fuji, a classic example of a composite volcano. **Composite volcanoes** have broad bases and steep sides. These volcanoes usually have a large crater at the top. The crater was created during the volcano's last eruption.

Composite volcanoes are also called stratovolcanoes. This is because they are formed by alternating layers (strata) of magma and ash (**Figure** 8.15). The magma that creates composite volcanoes tends to be thick. The steep sides form because the lava cannot flow too far from the vent. The thick magma may also create explosive eruptions. Ash

FIGURE 8.14
Mt. Fuji is a well-known composite volcano.

and pyroclasts erupt into the air. Much of this material falls back down near the vent. This creates the steep sides of stratovolcanoes.

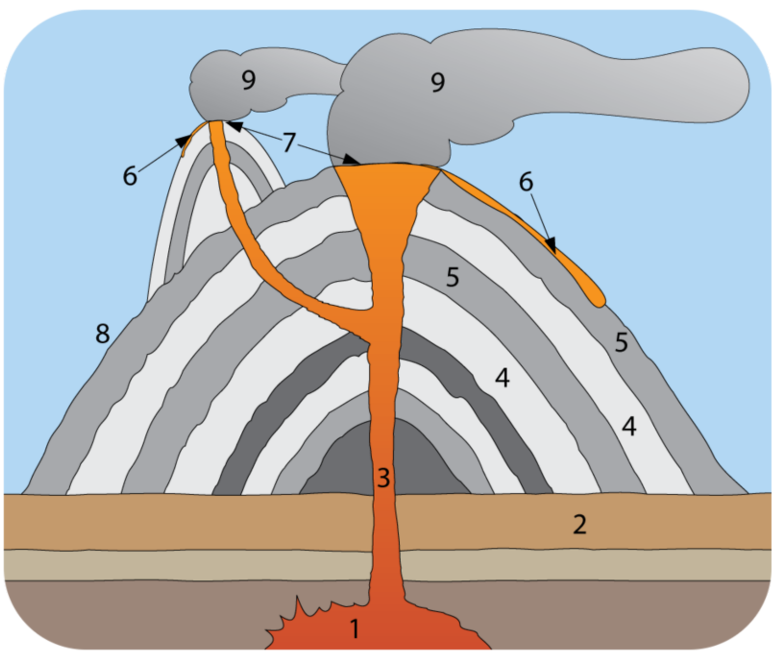

FIGURE 8.15
A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption.

Composite volcanoes are common along convergent plate boundaries. When a tectonic plate subducts, it melts. This creates the thick magma needed for these eruptions. The Pacific Ring of Fire is dotted by composite volcanoes.

Shield Volcanoes

Shield volcanoes look like a huge ancient warrior's shield laid down. **Figure** 8.16 shows the Kilaeua Volcano. A shield volcano has a very wide base. It is much flatter on the top than a composite volcano. The lava that creates shield volcanoes is reltively thin. The thin lava spreads out. This builds a large, flat volcano layer by layer. Shield

FIGURE 8.16
This portion of Kilauea, a shield volcano in Hawaii, erupted between 1969 and 1974.

volcanoes are very large. For example, the Mauna Loa Volcano has a diameter of more than 112 kilometers (70 miles). The volcano forms a significant part of the island of Hawaii. The top of nearby Mauna Kea Volcano is more than ten kilometers (6 miles) from its base on the seafloor.

Shield volcanoes often form along divergent plate boundaries. They also form at hot spots, like Hawaii. Shield volcano eruptions are non-explosive.

Cinder Cones

Cinder cones are the smallest and most common type of volcano. Cinder cones have steep sides like composite volcanoes. But they are much smaller, rarely reaching even 300 meters in height. Cinder cones usually have a crater at the summit. Cinder cones are composed of small fragments of rock, called cinders. The cinders are piled on top of one another. These volcanoes usually do not produce streams of lava. Cinder cones often form near larger volcanoes. Most composite and shield volcanoes have nearby cinder cones.

Cinder cones usually build up very rapidly. They only erupt for a short time. Many only produce one eruption. For this reason, cinder cones do not reach the sizes of stratovolcanoes or shield volcanoes (**Figure** 8.17).

Calderas

During a massive eruption all of the material may be ejected from a magma changer. Without support, the mountain above the empty chamber may collapse. This produces a huge **caldera**. Calderas are generally round, bowl-shaped formations like the picture in **Figure** 8.18.

Supervolcanoes

Supervolcanoes are the most dangerous type of volcano. During an eruption, enormous amounts of ash are thrown into the atmosphere. The ash encircles the globe. This blocks the Sun and lowers the temperature of the entire planet. The result is a volcanic winter.

FIGURE 8.17
A cinder cone volcano in Lassen National Park.

FIGURE 8.18
Crater Lake, Oregon is the remnant of Mount Mazama. After an enormous eruption the mountain collapsed, forming a caldera. Crater Lake should actually be named Caldera Lake. Wizard Island, within the lake, is a cinder cone.

A supervolcano eruption took place at Lake Toba in northern Sumatra about 75,000 years ago (**Figure** 8.19). This was the largest eruption in the past 25 million years. As much as 2,800 cubic kilometers of material was ejected into the atmosphere. The result was a 6- to 10-year volcanic winter. Some scientists think that only 10,000 humans survived worldwide. The numbers of other mammals also plummeted.

The most recent supervolcano eruption was in New Zealand. The eruption was less than 2000 years ago. For a supervolcano eruption it was small, about 100 cubic kilometers of material. A much larger super eruption in Colorado produced over 5,000 cubic kilometers of material. That eruption was 28 million years ago. It was 5000 times larger than the 1980 Mount St. Helens eruption.

The largest potentially active supervolcano in North America is Yellowstone. The caldera has had three super eruptions at 2.1 million, 1.3 million and 640,000 years ago. The floor of the Yellowstone caldera is slowly rising upwards. Another eruption is very likely but no one knows when.

The cause of supervolcano eruptions is being debated. Enormous magma chambers are filled with super hot magma. This enormous eruption leaves a huge hole. The ground collapses and creates a caldera.

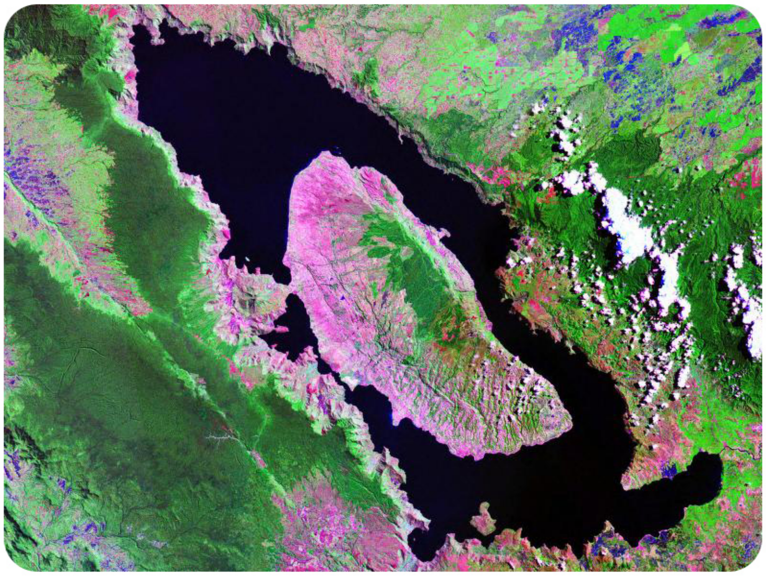

FIGURE 8.19
Lake Toba is now a caldera. It was the site of an enormous super eruption about 25 million years ago.

Lesson Summary

- Composite cones, shield volcanoes, cinder cones and supervolcanoes are some of the types of volcanoes formed.
- Composite cones are steep sided, cone shaped volcanoes that produce explosive eruptions.
- Shield volcanoes form very large, gently sloped volcanoes with a wide base.
- Cinder cones are the smallest volcanic landform. They are formed from accumulation of many small fragments of ejected material.
- A caldera forms when an explosive eruption leaves a large crater when the mountain blows apart.
- Supervolcanoes are tremendously devastating types of volcanoes that could destroy large areas when they erupt.

Lesson Review Questions

Recall

1. Describe a composite volcano and how it forms.

2. Describe a shield volcano and how it forms.

3. Describe a cinder cone and how it forms.

Apply Concepts

4. You have been told to visit an erupting volcano. Since you value your life, which type do you choose to visit and why?

5. How does the composition of magma affect the type of volcano that forms?

Think Critically

6. Scientists have only recently recognized the existence of supervolcanoes. Why were they the last type of volcano discovered?

7. The largest volcano in the solar system is not on Earth. What is needed for there to be an enormous volcano? What does this tell us about planets with enormous volcanoes?

Points to Consider

- Composite volcanoes usually have craters on the top. Why are the craters sometimes "U" or horseshoe-shaped?
- A shield volcano is relatively flat, and a composite volcano is relatively steep because of the type of magma that creates them. What type of lava might create a volcano that is steeper than a shield volcano but not as steep as a composite volcano?
- Some people believe there would be a worldwide catastrophe if a huge asteroid hits the Earth. How might an asteroid impact and a supervolcano eruption be similar?

8.4 Igneous Landforms and Geothermal Activity

Lesson Objectives

- List and describe landforms created by lava.
- Explain how magma creates different landforms.
- Describe the processes that create hot springs and geysers.

Vocabulary

- lava dome
- lava plateau
- intrusion
- hot spring
- geyser

Landforms from Lava

Extrusive igneous rocks cool at the surface. Volcanoes are one type of feature that forms from extrusive rocks. Several other interesting landforms are also extrusive features. Intrusive igneous rocks cool below the surface. These rocks do not always remain hidden. Rocks that formed in the crust are exposed when the rock and sediment that covers them is eroded away.

Lava Domes

When lava is thick, it flows slowly. If thick lava makes it to the surface, it cannot flow far from the vent. It often stays right in the middle of a crater at the top of a volcano. Here the lava creates a large, round **lava dome** (**Figure** 8.20).

Lava Plateaus

A **lava plateau** is made of a large amount of fluid lava. The lava flows over a large area and cools. This creates a large, flat surface of igneous rock. Lava plateaus may be huge. The Columbia Plateau covers over 161,000 square kilometers (63,000 square miles). It makes up parts of the states of Washington, Oregon, and Idaho.

Thin, fluid lava created the rock that makes up the entire ocean floor. This is from multiple eruptions from vents at the mid-ocean ridge. While not exactly a lava plateau, it's interesting to think about so much lava!

FIGURE 8.20
The Mono Craters in California are lava domes.

New Land

New land is created in volcanic eruptions. The Hawaiian Islands are shield volcanoes. These volcanoes formed from fluid lava (**Figure** 8.21). The island grows as lava is added on the coast. New land may also emerge from lava that erupts from beneath the water. This is one way that new land is created.

FIGURE 8.21
Lava erupts into the Pacific Ocean in Hawaii, creating new land.

Landforms from Magma

Magma that cools underground forms **intrusions** (**Figure** 8.22). Intrusions become land formations if they are exposed at the surface by erosion.

FIGURE 8.22
The granite intrusions that form the Sierra Nevada in California are well exposed.

Hot Springs and Geysers

Water works its way through porous rocks or soil. Sometimes this water is heated by nearby magma. If the water makes its way to the surface, it forms a hot spring or a geyser.

Hot Springs

When hot water gently rises to the surface, it creates a **hot spring**. A hot spring forms where a crack in the Earth allows water to reach the surface after being heated underground. Many hot springs are used by people as natural hot tubs. Some people believe that hot springs can cure illnesses. Hot springs are found all over the world, even in Antarctica!

Geysers

Geysers are also created by water that is heated beneath the Earth's surface. The water may become superheated by magma. It becomes trapped in a narrow passageway. The heat and pressure build as more water is added. When the pressure is too much, the superheated water bursts out onto the surface. This is a **geyser**.

There are only a few areas in the world where the conditions are right for the formation of geysers. Only about 1,000 geysers exist worldwide. About half of them are in the United States. The most famous geyser is Old Faithful at Yellowstone National Park (**Figure** 8.23). It is rare for a geyser to erupt so regularly, which is why Old Faithful is famous.

Lesson Summary

- Very thick lava that doesn't travel very far can produce lava domes at or near the Earth's surface or even within a volcano.

FIGURE 8.23
Old Faithful geyser in Yellowstone National Park erupts every 60 to 70 minutes, with a plume of hot water shooting up nearly 60 meters in the air.

- Lava plateaus and the entire ocean floor form from large lava flows that spread out over large areas.
- Many islands are formed from volcanoes.
- Magma can also cool and crystallize below the Earth's surface forming igneous intrusions.
- When magma heats groundwater, it can form hot springs and geysers.

Lesson Review Questions

Recall

1. What types of landforms form from intrusive igneous activity?

2. What types of landforms are created by lava?

Apply Concepts

3. How does new land form? Are the oceans being taken over by land? Why or why not?

Think Critically

4. Millions of people flock to Yellowstone National Park each year. Why are they drawn to the place? Would it be visited as much if the park were full of hot springs that were not geysers?

5. Do you think that Old Faithful will someday stop erupting? Why would it do that?

Points to Consider

- What might the Earth look like if there were no tectonic plates? Can you think of any planets or satellites (moons) that may not have tectonic plates? How is their surface different from that of the Earth?
- What kind of land formations have you seen that may have been created by volcanic activity? Did these rocks cool above or below the Earth's surface?

- Water is not the only material that can be ejected from geysers and hot springs. What other materials might be ejected from geysers and hot springs?

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Chapter 9 MS Weathering and Formation of Soil

Chapter Outline

Soil is a precious resource. It allows us to grow food and the materials we use to make everything from the shirt you have on to the medicine you took this morning. Soil is made up of small pieces of rock that have broken down over hundreds, if not thousands, of years. Soil is also partly made up of the remains of plants and animals, and is home to many organisms, from earthworms to ants. But soil can be damaged by unsustainable farming practices and clear-cut logging. In this chapter, you will learn how soil forms, what it contains, and how to protect it.

9.1 Weathering

Lesson Objectives

- Define mechanical and chemical weathering.
- Discuss agents of weathering.
- Give examples of each type of weathering.

Vocabulary

- abrasion
- chemical weathering
- erosion
- ice wedging
- mechanical weathering

Introduction

Weathering breaks rocks apart. Some types of weathering alter some minerals. **Erosion** moves the broken pieces.

What is Weathering?

Weathering changes solid rock into sediments. Sediments are different sizes of rock particles. Boulders are sediments; so is gravel. At the other end, silt and clay are also sediments. Weathering causes rocks at the Earth's surface to change form. The new minerals that form are stable at the Earth's surface.

It takes a long time for a rock or mountain to weather. But a road can do so much more quickly. If you live in a part of the world that has cold winters, you may only have to wait one year to see a new road start to weather (**Figure** 9.1).

Mechanical Weathering

Mechanical weathering breaks rock into smaller pieces. These smaller pieces are just like the bigger rock; they are just smaller! The rock has broken without changing its composition. The smaller pieces have the same minerals in the same proportions. You could use the expression "a chip off the old block" to describe mechanical weathering! The main agents of mechanical weathering are water, ice, and wind.

FIGURE 9.1
A hard winter has damaged this road.

Ice Wedging

Rocks can break apart into smaller pieces in many ways. **Ice wedging** is common where water goes above and below its freezing point (**Figure** 9.2). This can happen in winter in the mid-latitudes or in colder climates in summer. Ice wedging is common in mountainous regions.

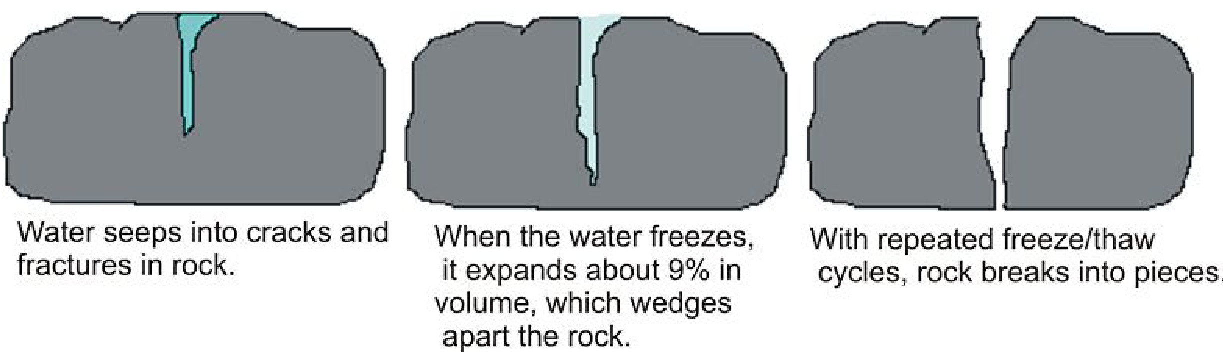

FIGURE 9.2
Diagram showing ice wedging.

This is how ice wedging works. When liquid water changes into solid ice, it increases in volume. You see this when you fill an ice cube tray with water and put it in the freezer. The ice cubes go to a higher level in the tray than the water. You also may have seen this if you put a can of soda into the freezer so that it cools down quickly. If you leave the can in the freezer too long, the liquid expands so much that it bends or pops the can. (For the record, water is very unusual. Most substances get smaller when they change from a liquid to a solid.)

Ice wedging happens because water expands as it goes from liquid to solid. When the temperature is warm, water works its way into cracks in rock. When the temperature cools below freezing, the water turns to ice and expands. The ice takes up more space. Over time, this wedges the rock apart. Ice wedging is very effective at weathering. You can find large piles of broken rock at the base of a slope. These rocks were broken up by ice wedging. Once loose, they tumbled down the slope.

Abrasion

Abrasion is another type of mechanical weathering. With abrasion, one rock bumps against another rock. Gravity causes abrasion as a rock tumbles down a slope. Moving water causes abrasion it moves rocks so that they bump against one another (**Figure** 9.3). Strong winds cause abrasion by blasting sand against rock surfaces. Finally, the ice in glaciers cause abrasion. Pieces of rock embedded in ice at the bottom of a glacier scrape against the rock below. If you have ever collected beach glass or pebbles from a stream, you have witnessed the work of abrasion.

FIGURE 9.3
Rocks on a beach are worn down by abrasion as passing waves cause them to strike each other.

Plants and Animals in Mechanical Weathering

Sometimes biological elements cause mechanical weathering. This can happen slowly. A plant's roots grow into a crack in rock. As the roots grow larger, they wedge open the crack. Burrowing animals can also cause weathering. By digging for food or creating a hole to live in the animal may break apart rock. Today, human beings do a lot of mechanical weathering whenever we dig or blast into rock. This is common when we build homes, roads, and subways, or quarry stone for construction or other uses.

Mechanical Weathering and Chemical Weathering

Mechanical weathering increases the rate of chemical weathering. As rock breaks into smaller pieces, the surface area of the pieces increases. With more surfaces exposed, there are more places for chemical weathering to occur. Let's say you wanted to make some hot chocolate on a cold day. It would be hard to get a big chunk of chocolate to dissolve in your milk or hot water. Maybe you could make hot chocolate from some smaller pieces like chocolate chips, but it is much easier to add a powder to your milk. This is because the smaller the pieces are, the more surface area they have. Smaller pieces dissolve more easily.

Chemical Weathering

Chemical weathering is different than mechanical weathering. The minerals in the rock change. The rock changes composition and becomes a different type of rock. Most minerals form at high pressure or high temperatures deep within Earth. But at Earth's surface, temperatures and pressures are much lower. Minerals that were stable deeper in the crust are not stable at the surface. That's why chemical weathering happens. Minerals that formed at higher temperature and pressure change into minerals that are stable at the surface. Chemical weathering is important. It starts the process of changing solid rock into soil. We need soil to grow food and create other materials we need. Chemical weathering works through chemical reactions that change the rock.

There are many agents of chemical weathering. Remember that water was a main agent of mechanical weathering. Well, water is also an agent of chemical weathering. That makes it a double agent! Carbon dioxide and oxygen are also agents of chemical weathering. Each of these is discussed below.

Water

Water is an amazing molecule. It has a very simple chemical formula, H_2O. It is made of just two hydrogen atoms bonded to one oxygen atom. Water is remarkable in terms of all the things it can do. Lots of things dissolve easily in water. Some types of rock can even completely dissolve in water! Other minerals change by adding water into their structure.

Carbon Dioxide

Carbon dioxide (CO_2) combines with water as raindrops fall through the air. This makes a weak acid, called carbonic acid. This happens so often that carbonic acid is a common, weak acid found in nature. This acid works to dissolve rock. It eats away at sculptures and monuments. While this is normal, more acids are made when we add pollutants to the air. Any time we burn any fossil fuel, it adds nitrous oxide to the air. When we burn coal rich in sulfur, it adds sulfur dioxide to the air. As nitrous oxide and sulfur dioxide react with water, they form nitric acid and sulfuric acid. These are the two main components of acid rain. Acid rain accelerates chemical weathering.

Oxygen

Oxygen strongly reacts with elements at the Earth's surface. You are probably most familiar with the rust that forms when iron reacts with oxygen (**Figure** 9.4). Many minerals are rich in iron. They break down as the iron changes into iron oxide. This makes the red color in soils.

Plants and animals also cause chemical weathering. As plant roots take in nutrients, elements are exchanged.

Weathering Happens at Different Rates

Each type of rock weathers in its own way. Certain types of rock are very resistant to weathering. Igneous rocks tend to weather slowly because they are hard. Water cannot easily penetrate them. Granite is a very stable igneous rock. Other types of rock are easily weathered because they dissolve easily in weak acids. Limestone is a sedimentary rock that dissolves easily. When softer rocks wear away, the more resistant rocks form ridges or hills.

Devil's Tower in Wyoming shows how different types of rock weather at different rates (**Figure** 9.5). The softer materials of the surrounding rocks were worn away. The resistant center of the volcano remains behind.

FIGURE 9.4
Iron ore oxidizes readily.

FIGURE 9.5
Devil's Tower shows differential weathering. Hard rock from inside a volcano makes up the tower.

Minerals also weather differently. Some minerals completely dissolve in water. As less resistant minerals dissolve away, a rock's surface becomes pitted and rough. When a less resistant mineral dissolves, more resistant mineral grains are released from the rock.

Lesson Summary

- Mechanical weathering breaks rocks into smaller pieces. Their composition does not change.
- Ice wedging and abrasion are two important processes of mechanical weathering.

- Chemical weathering breaks down rocks by forming new minerals. These minerals are stable at the Earth's surface.
- Water, carbon dioxide, and oxygen are important agents of chemical weathering.
- Different types of rocks weather at different rates. More resistant types of rocks will remain longer.

Lesson Review Questions

Recall

1. Name two types of mechanical weathering. Explain how each works to break apart rock.

2. What are three agents of chemical weathering? Give an example of each.

Apply Concepts

3. How do acids form in the atmosphere? What increases the acidity of rainfall?

4. What are the effects of acid rain?

Think Critically

5. Describe what you think weathering would be like in an arid region. What would weathering be like in a tropical region?

6. What type of surface weathers faster: a smooth surface or a jagged surface?

Points to Consider

- What types of surfaces other than rock are affected by weathering?
- What might the surface of the Earth look like if weathering did not occur?
- Do you think that you would be alive today if water did not dissolve elements?
- Would the same composition of rock weather the same way in three very different climates?

9.2 Soils

Lesson Objectives

- Discuss why soil is an important resource.
- Describe how soil forms from existing rocks.
- Describe the different textures and components of soil.
- Draw and describe a soil profile.
- Define the three climate-related soils: pedalfer, pedocal and laterite soil.

Vocabulary

- deciduous forest
- humus
- inorganic
- laterite
- loam
- organic
- pedalfer
- pedocal
- residual soil
- soil horizon
- soil profile
- subsoil
- topsoil
- transported soil

Introduction

Without weathering, we would not have any soil on Earth. People could not live on Earth without soil! Your life and the lives of most organisms depend on soil. Soil is only a very thin layer over solid rock. Yet, it is the place where reactions between solid rock, liquid water and air take place. We get wood, paper, cotton, medicines, and even pure water from soil. So soil is a very important resource. Our precious soil needs to be carefully managed and cared for. If we don't take care of the soil we have, we may not be able to use it in the future.

Characteristics and Importance of Soil

We can think about soil as a living resource. Soil is an ecosystem all by itself! Soil is a complex mixture of different materials. Some of them are **inorganic**. Inorganic materials are made from non-living substances like pebbles and sand. Soil also contains bits of **organic** materials from plants and animals. In general, about half of the soil is made of pieces of rock and minerals. The other half is organic materials. In the spaces of soil are millions of living organisms. These include earthworms, ants, bacteria, and fungi. In some soils, the organic portion is entirely missing. This is true of desert sand. At the other extreme, a soil may be completely organic. Peat, found in a bog or swamp, is totally organic soil. Organic materials are necessary for a soil to be fertile. The organic portion provides the nutrients needed for strong plant growth.

Soil Formation

Soil formation requires weathering. Where there is less weathering, soils are thinner. However, soluble minerals may be present. Where there is intense weathering, soils may be thick. Minerals and nutrients would have been washed out. Soil development takes a very long time. It may take hundreds or even thousands of years to form the fertile upper layer of soil. Soil scientists estimate that in the very best soil forming conditions, soil forms at a rate of about 1mm/year. In poor conditions, it may take thousands of years!

How well soil forms and what type of soil forms depends on many factors. These include climate, the original rock type, the slope, the amount of time, and biological activity.

Climate

Climate is the most important factor in soil formation. The climate of a region is the result of its temperature and rainfall. We can identify different climates by the plants that grow there (**Figure** 9.6).

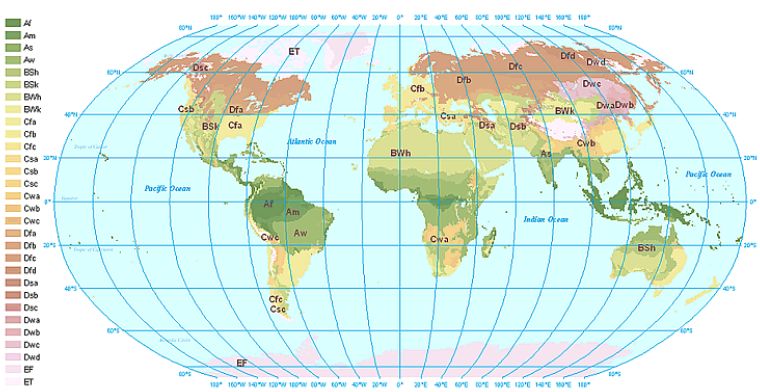

FIGURE 9.6

Climate is the most important factor in determining the type of soil that forms in a particular area.

Given enough time, a climate will produce a particular type of soil. The original rock type does not matter. The same rock type will form a different soil type in each different climate.

Rainfall

Rainfall in an area is important because it influences the rate of weathering. More rain means that more rainwater passes through the soil. The rainwater reacts chemically with the particles. The top layers of soil are in contact with the freshest water, so reactions are greatest there. High rainfall increases the amount of rock that experiences chemical reactions. High rainfall may also carry material away. This means that new surfaces are exposed. This increases the rate of weathering.

In tropical regions with high temperatures and lots of rain, thick soils form with no unstable minerals or nutrients. Conversely, dry regions produce thin soils, rich in unstable minerals.

Temperature

The temperature of a region is the other important part of climate. The rate of chemical reactions increases with higher temperatures. The rate doubles for every 10°C increase in temperature. Plants and bacteria grow and multiply faster in warmer areas.

Time

Soil formation increases with time. The longer the amount of time that soil remains in a particular area, the greater the degree of alteration. The warmer the temperatures, the more rainfall, and the greater the amount of time, the thicker the soils will become.

Parent Rock

The original rock is the source of the inorganic portion of the soil. Mechanical weathering breaks rock into smaller pieces. Chemical reactions change the rock's minerals. A **transported soil** forms from materials brought in from somewhere else. These soils form from sediments that were transported into the area and deposited. The rate of soil formation is faster for transported materials because they have already been weathered.

A soil is a **residual soil** when it forms in place. Only about one third of the soils in the United States form this way. The material comes from the underlying bedrock. Residual soils form over many years since it takes a long time for solid rock to become soil. First, cracks break up the bedrock. This may happen due to ice wedging. Weathering breaks up the rock even more. Then plants, such as lichens or grasses, become established. They cause further weathering. As more time passes and more layers of material weather, the soil develops.

Biological Activity

Biological activity produces the organic material in soil. **Humus** forms from the remains of plants and animals. It is an extremely important part of the soil. Humus coats the mineral grains. It binds them together into clumps that hold the soil together. This gives the soil its structure. Soils with high humus are better able to hold water. Soils rich with organic materials hold nutrients better and are more fertile. These soils are more easily farmed.

The color of soil indicates its fertility. Black or dark brown soils are rich in nitrogen and contain a high percentage of organic materials. Soils that are nitrogen poor and low in organic material might be gray, yellow, or red.

Soil Texture

The inorganic part of soil is made of different amounts of different size particles. This affects the characteristics of a soil. Water flows through soil more easily if the spaces between the particles are large enough and well connected. Sandy or silty soils are light soils because they drain water. Soils rich in clay are heavier. Clay particles allow only very small spaces between them, so clay-rich soils tend to hold water. Clay-rich soils are heavier and hold together more tightly. A soil that contains a mixture of grain sizes is called a **loam**.

Soil scientists measure the percentage of sand, silt, and clay in soil. They plot this information on a triangular diagram, with each type of particle at one corner (**Figure** 9.7).

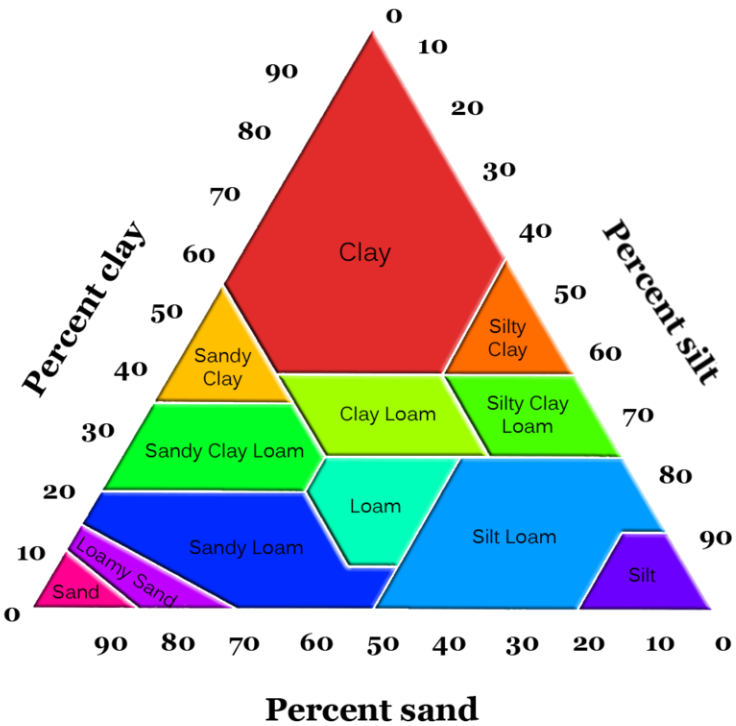

FIGURE 9.7
This diagram plots soil types by particle size.

The soil type is determined by where the soil falls on the diagram. At the top, the soil is clay rich. On the left corner, the soil is sandy. On the right corner, the soil is silty.

Soil Horizons and Profiles

Soil develops over time and forms soil horizons. **Soil horizons** are different layers of soil with depth. The most weathering occurs in the top layer. This layer is most exposed to weather! It is where fresh water comes into contact with the soil. Each layer lower is weathered just a little bit less than the layer above. As water moves down through the layers, it is able to do less work to change the soil.

If you dig a deep hole in the ground, you may see each of the different layers of soil. All together, the layers are a **soil profile**. Each horizon has its own set of characteristics (**Figure** 9.8). In the simplest soil profile, a soil has three horizons.

Topsoil

The first horizon is the "A" horizon. It is more commonly called the **topsoil**. The topsoil is usually the darkest layer of the soil. It is the layer with the most organic material. Humus forms from all the plant and animal debris that falls to or grows on the ground. The topsoil is also the region with the most biological activity. Many organisms live within this layer. Plant roots stretch down into this layer. The roots help to hold the topsoil in place.

Topsoil usually does not have very small particles like clay. Clay-sized particles are carried to lower layers as water seeps down into the ground. Many minerals dissolve in the fresh water that moves through the topsoil. These minerals are carried down to the lower layers of soil.

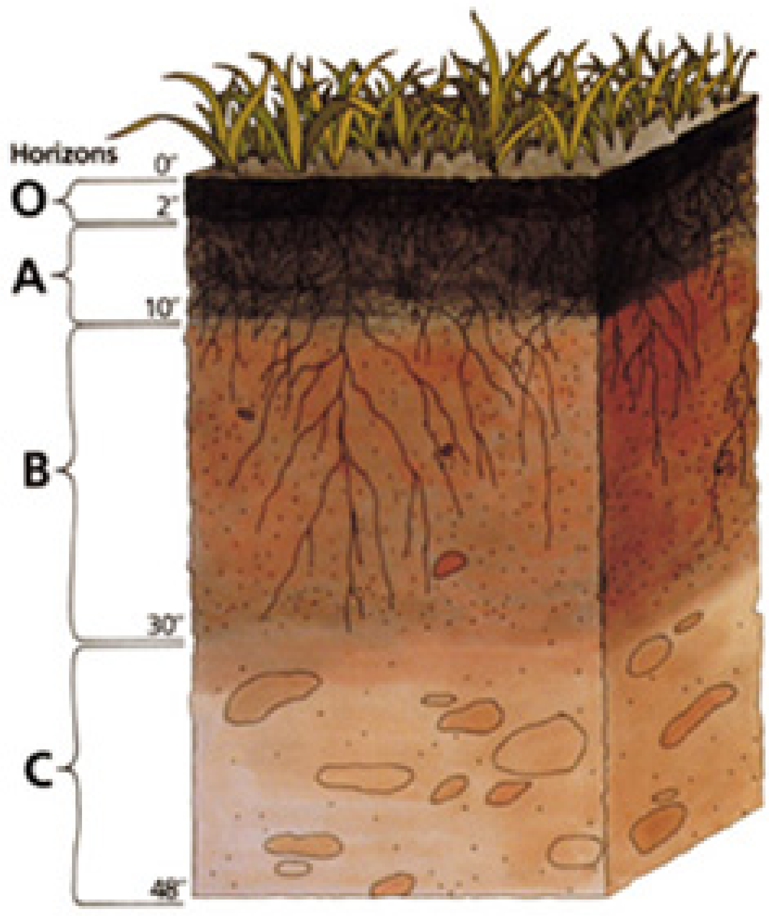

FIGURE 9.8
In this diagram, a cut through soil shows different soil layers.

Subsoil

Below the topsoil is the "B" horizon. This is also called the **subsoil**. Soluble minerals and clays accumulate in the subsoil. Because it has less organic material, this layer is lighter brown in color than topsoil. It also holds more water due to the presence of iron and clay. There is less organic material in this layer.

C-horizon

The next layer down is the "C" horizon. This layer is made of partially altered bedrock. There is evidence of weathering in this layer. Still, it is possible to identify the original rock type from which this soil formed (**Figure** 9.9).

Not all climate regions develop soils. Arid regions are poor at soil development. Not all regions develop the same soil horizons. Some areas develop as many as five or six distinct layers. Others develop only a few.

Types of Soils

For soil scientists, there are thousands of types of soil! Soil scientists put soils into very specific groups with certain characteristics. Each soil type has its own name. Let's consider a much simpler model, with just three types of soil.

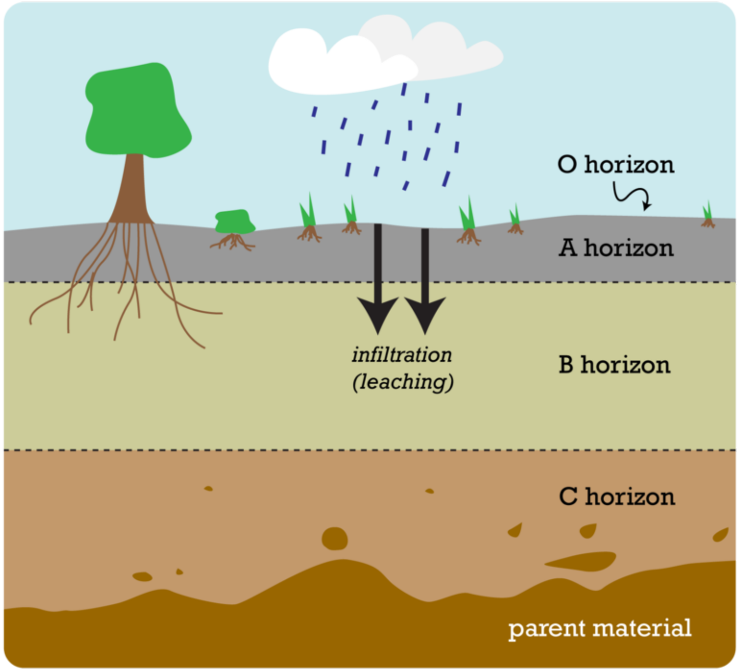

FIGURE 9.9
This image shows the various soil horizons.

These types are based on climate. Just remember that there are many more than just these three types.

Pedalfer

One important type of soil forms in a **deciduous forest**. In these forests, trees lose their leaves each winter. Deciduous trees need lots of rain — at least 65 cm of rainfall per year. Deciduous forests are common in the temperate, eastern United States. The type of soil found in a deciduous forest is a **pedalfer** (**Figure** 9.10). This type of soil is usually dark brown or black in color and very fertile.

FIGURE 9.10
Pedalfer soils support temperate forests, such as in the eastern United States.

Pedocal

Pedocal soil forms where grasses and brush are common (**Figure** 9.11). The climate is drier, with less than 65 cm of rain per year. With less rain, there is less chemical weathering. There is less organic material and the soils are slightly less fertile.

FIGURE 9.11
Grasslands grow on pedocal soils.

Laterite

A third important type of soil is **laterite**. Laterite forms in tropical areas. Temperatures are warm and rain falls every day (**Figure** 9.12). So much rain falls that chemical weathering is intense. All soluble minerals are washed from the soil. Plant nutrients get leached or carried away. There is practically no humus. Laterite soils are often red in color from the iron oxides. If laterites are exposed to the Sun, they bake as hard as a brick.

FIGURE 9.12
The Amazon Rainforest grows on laterite soils.

Soil Conservation

Soil is a renewable resource. But it is only renewable if we take care of it. Natural events can degrade soil. These events include droughts, floods, insect plagues, or diseases that damage soil ecosystems. Human activities can also degrade soil. There are many ways in which people neglect or abuse this important resource.

Harmful Practices

People remove a lot of vegetation. They log forests or prepare the land for farming or construction. Even just walking or riding your bike over the same place can kill the grass. But plants help to hold the soil in place (**Figure** 9.13). Without plants to protect it, soil may be carried away by wind or running water. In many areas, soil is eroding faster than it is forming. In these locations, soil is a non-renewable resource.

FIGURE 9.13
Material that is not held down can blow in the wind. Topsoil is lost this way.

Soils may also remain in place but become degraded. Soil is contaminated if too much salt accumulates. Soil can also be contaminated by pollutants.

Protecting Soil

There are many ways to protect soil. We can add organic material like manure or compost. This increases the soil's fertility. Increased fertility improves the soil's ability to hold water and nutrients. Inorganic fertilizers also increase fertility. These fertilizers are less expensive than natural fertilizers, but they do not provide the same long term benefits.

Careful farming helps to keep up soil quality each season. One way is to plant different crops each year. Another is to alternate the crops planted in each row of the field. These techniques preserve and replenish soil nutrients. Planting nutrient rich cover crops helps the soil. Planting trees as windbreaks, plowing along contours of a field, or building terraces into steeper slopes all help to hold soil in place (**Figure** 9.14). No-till or low-till farming disturbs the ground as little as possible during planting.

FIGURE 9.14
Trees form a windbreak at the edge of these fields.

Lesson Summary

- Soil is an important resource. Life on Earth could not exist as it does today without soil.
- The type of soil that forms depends mostly on climate but to a lesser extent on original parent rock material.
- Soil texture and composition plus the amount of organic material in a soil determine a soil's qualities and fertility.
- Given enough time, existing rock will produce layers within the soil, called a soil profile.
- Ultimately, the climate of a particular region will produce a unique type of soil for that climate.

Lesson Review Questions

Recall

1. What is the role of climate in soil formation?
2. What is the role of the parent rock in the creation of a soil?
3. Compare and contrast residual soils and transported soils.
4. Describe the characteristics of topsoil.

Apply Concepts

5. Describe two ways in which soil is a living resource.
6. Why do people add fertilizers to soil?
7. How does the C-horizon of a residual soil differ from the C-horizon of a transported soil?

Think Critically

8. Where would you choose to buy land for a farm if you wanted fertile soil and did not want to have to irrigate your crops?

Points to Consider

- Why is soil such an important resource?
- Do you think a mature soil would form faster from unaltered bedrock or from transported materials?
- If soil erosion is happening at a greater rate than new soil can form, what will eventually happen to the soil in that region?
- Do you think there are pollutants that could not easily be removed from soil?

9.3 References

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CHAPTER 10 MS Erosion and Deposition

Chapter Outline

This photo shows Horseshoe Bend on the Colorado River as it flows through the Grand Canyon. Notice the trees growing along the river's edge. They look tiny from the top of the canyon. They show how deep the canyon is.

The Colorado River carved this spectacular canyon down through layer upon layer of rock. How can water cut through rock? How did the horseshoe shape form? In this chapter, you'll find answers to questions like these. You'll learn how moving water and other natural forces shape Earth's surface, sometimes in spectacular ways.

10.1 Erosion and Deposition by Flowing Water

Lesson Objectives

- Explain how flowing water causes erosion and deposition.
- Describe how runoff, streams, and rivers change Earth's surface.
- Identify features caused by groundwater erosion and deposition.

Vocabulary

- alluvial fan
- cave
- delta
- deposition
- erosion
- floodplain
- levee
- meander
- oxbow lake
- saltation
- sinkhole
- suspension
- traction

Introduction

Erosion and deposition are responsible for many landforms. **Erosion** is the transport of sediments. Agents of erosion include flowing water, waves, wind, ice, or gravity. Eroded material is eventually dropped somewhere else. This is called **deposition**.

How Flowing Water Causes Erosion and Deposition

Flowing water is a very important agent of erosion. Flowing water can erode rocks and soil. Water dissolves minerals from rocks and carries the ions. This process happens really slowly. But over millions of years, flowing water dissolves massive amounts of rock.

Moving water also picks up and carries particles of soil and rock. The ability to erode is affected by the velocity, or speed, of the water. The size of the eroded particles depends on the velocity of the water. Eventually, the water deposits the materials. As water slows, larger particles are deposited. As the water slows even more, smaller particles are deposited. The graph in **Figure** 10.1 shows how water velocity and particle size influence erosion and deposition.

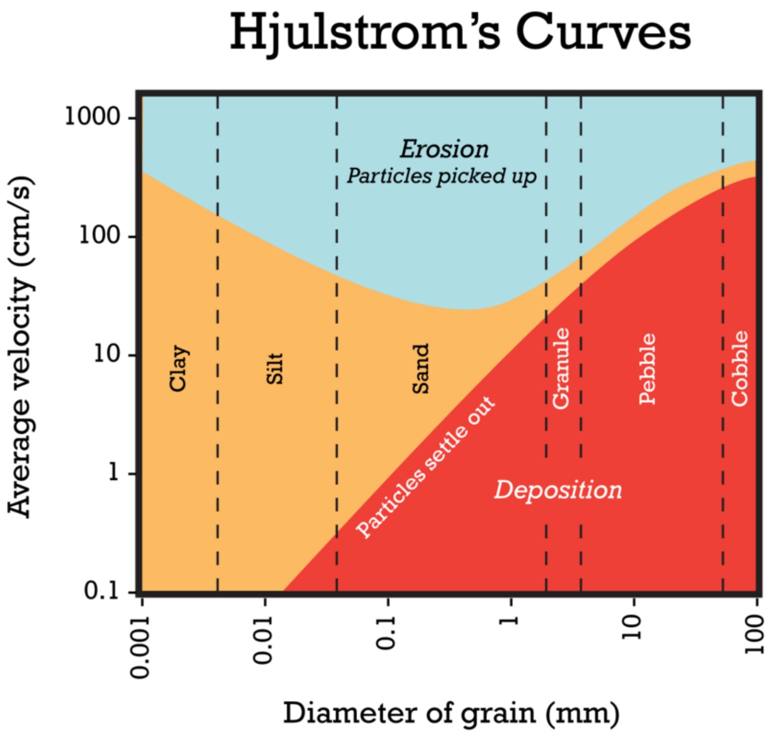

FIGURE 10.1
Flowing water erodes or deposits particles depending on how fast the water is moving and how big the particles are.

Water Speed and Erosion

Faster-moving water has more energy. Therefore, it can carry larger particles. It can carry more particles. What causes water to move faster? The slope of the land over which the water flows is one factor. The steeper the slope, the faster the water flows. Another factor is the amount of water that's in the stream. Streams with a lot of water flow faster than streams that are nearly dry.

Particle Size and Erosion

The size of particles determines how they are carried by flowing water. This is illustrated in **Figure** 10.2.

- Minerals that dissolve in water form salts. The salts are carried in solution. They are mixed thoroughly with the water.
- Small particles, such as clay and silt, are carried in **suspension**. They are mixed throughout the water. These particles are not dissolved in the water.
- Somewhat bigger particles, such as sand, are moved by **saltation**. The particles move in little jumps near the stream bottom. They are nudged along by water and other particles.
- The biggest particles, including gravel and pebbles, are moved by **traction**. In this process, the particles roll or drag along the bottom of the water.

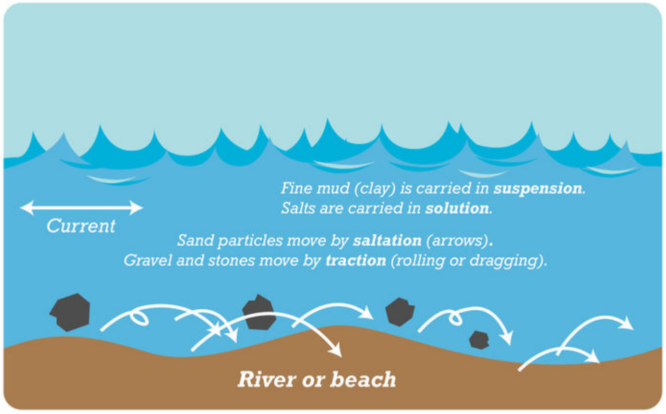

FIGURE 10.2
How Flowing Water Moves Particles. How particles are moved by flowing water depends on their size.

Deposition by Water

Flowing water slows down when it reaches flatter land or flows into a body of still water. What do you think happens then? The water starts dropping the particles it was carrying. As the water slows, it drops the largest particles first. The smallest particles settle out last.

Erosion and Deposition by Surface Water

Water that flows over Earth's surface includes runoff, streams, and rivers. All these types of flowing water can cause erosion and deposition.

Erosion by Runoff

When a lot of rain falls in a short period of time, much of the water is unable to soak into the ground. Instead, it runs over the land. Gravity causes the water to flow from higher to lower ground. As the runoff flows, it may pick up loose material on the surface, such as bits of soil and sand.

Runoff is likely to cause more erosion if the land is bare. Plants help hold the soil in place. The runoff water in **Figure** 10.3 is brown because it eroded soil from a bare, sloping field. Can you find evidence of erosion by runoff where you live? What should you look for?

Much of the material eroded by runoff is carried into bodies of water, such as streams, rivers, ponds, lakes, or oceans. Runoff is an important cause of erosion. That's because it occurs over so much of Earth's surface.

Erosion by Mountain Streams

Streams often start in mountains, where the land is very steep. You can see an example in **Figure** 10.4. A mountain stream flows very quickly because of the steep slope. This causes a lot of erosion and very little deposition. The rapidly falling water digs down into the stream bed and makes it deeper. It carves a narrow, V-shaped channel.

FIGURE 10.3
Erosion by Runoff. Runoff has eroded small channels through this bare field.

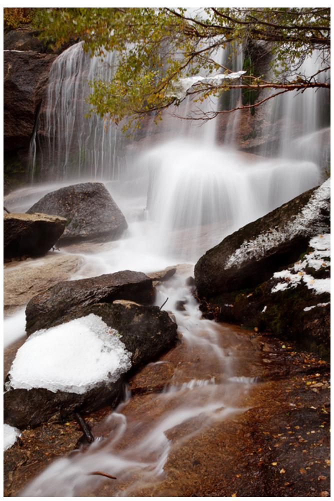

FIGURE 10.4
Mountain Stream. This mountain stream races down a steep slope.

How a Waterfall Forms

Mountain streams may erode waterfalls. As shown in **Figure** 10.5, a waterfall forms where a stream flows from an area of harder to softer rock. The water erodes the softer rock faster than the harder rock. This causes the stream bed to drop down, like a step, creating a waterfall. As erosion continues, the waterfall gradually moves upstream.

Erosion by Slow-Flowing Rivers

Rivers flowing over gentle slopes erode the sides of their channels more than the bottom. Large curves, called **meanders**, form because of erosion and deposition by the moving water. The curves are called meanders because they slowly "wander" over the land. You can see how this happens in **Figure** 10.6.

As meanders erode from side to side, they create a **floodplain**. This is a broad, flat area on both sides of a river. Eventually, a meander may become cut off from the rest of the river. This forms an **oxbow lake**, like the one in **Figure** 10.6.

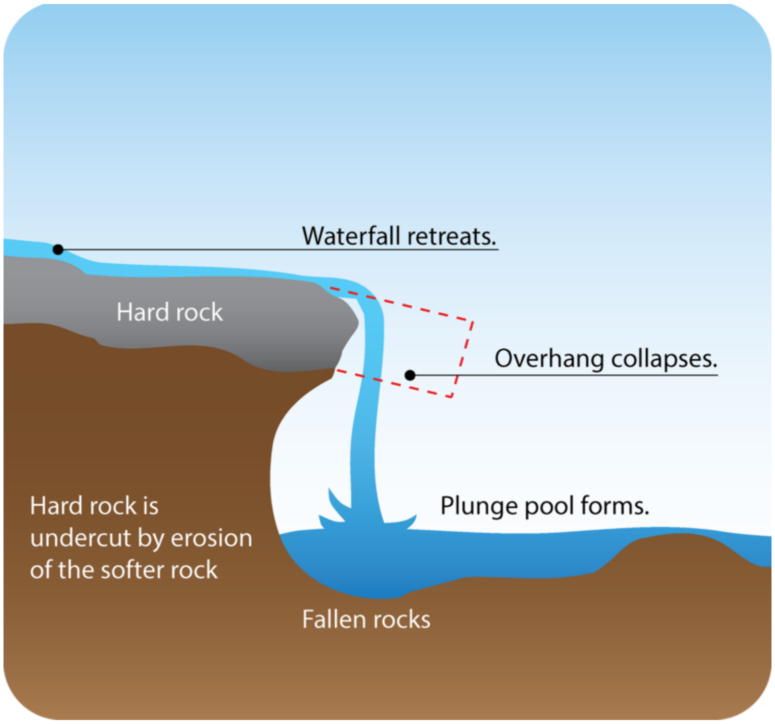

FIGURE 10.5
How a Waterfall Forms and Moves. Why does a waterfall keep moving upstream?

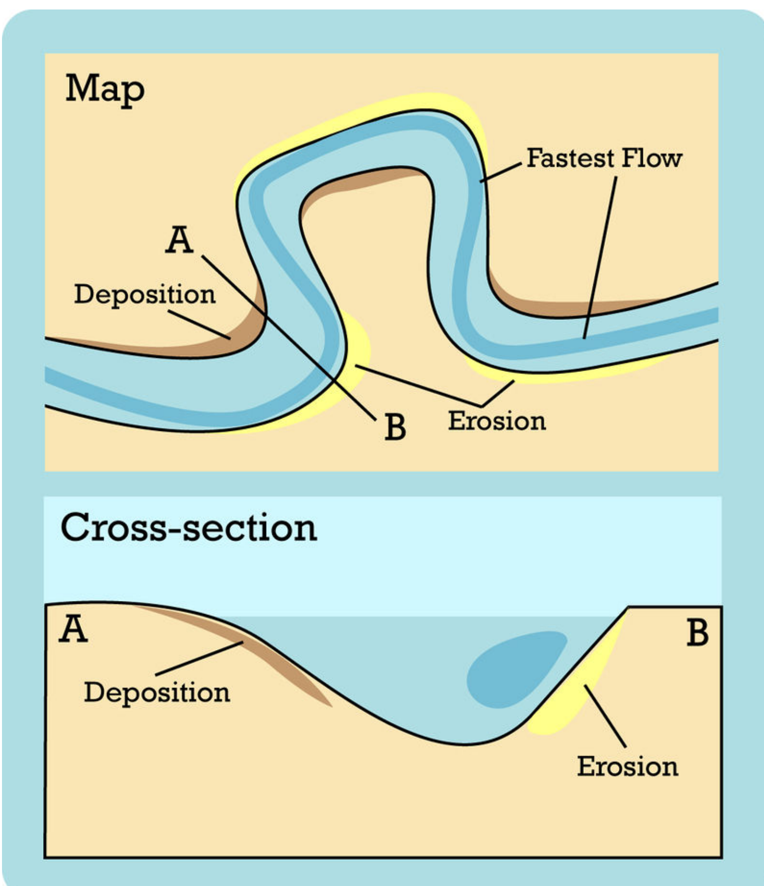

FIGURE 10.6
Meanders form because water erodes the outside of curves and deposits eroded material on the inside. Over time, the curves shift position.

Deposition by Streams and Rivers

When a stream or river slows down, it starts dropping its sediments. Larger sediments are dropped in steep areas, but smaller sediments can still be carried. Smaller sediments are dropped as the slope becomes less steep.

Alluvial Fans

In arid regions, a mountain stream may flow onto flatter land. The stream comes to a stop rapidly. The deposits form an **alluvial fan**, like the one in **Figure** 10.7.

FIGURE 10.7
An alluvial fan in Death Valley, California (left), Nile River Delta in Egypt (right).

Deltas

Deposition also occurs when a stream or river empties into a large body of still water. In this case, a **delta** forms. A delta is shaped like a triangle. It spreads out into the body of water. An example is shown in **Figure** 10.7.

Deposition by Flood Waters

A flood occurs when a river overflows it banks. This might happen because of heavy rains.

Floodplains

As the water spreads out over the land, it slows down and drops its sediment. If a river floods often, the floodplain develops a thick layer of rich soil because of all the deposits. That's why floodplains are usually good places for growing plants. For example, the Nile River in Egypt provides both water and thick sediments for raising crops in the middle of a sandy desert.

Natural Levees

A flooding river often forms natural levees along its banks. A **levee** is a raised strip of sediments deposited close to the water's edge. You can see how levees form in **Figure** 10.8. Levees occur because floodwaters deposit their biggest sediments first when they overflow the river's banks.

Erosion and Deposition by Groundwater

Some water soaks into the ground. It travels down through tiny holes in soil. It seeps through cracks in rock. The water moves slowly, pulled deeper and deeper by gravity. Underground water can also erode and deposit material.

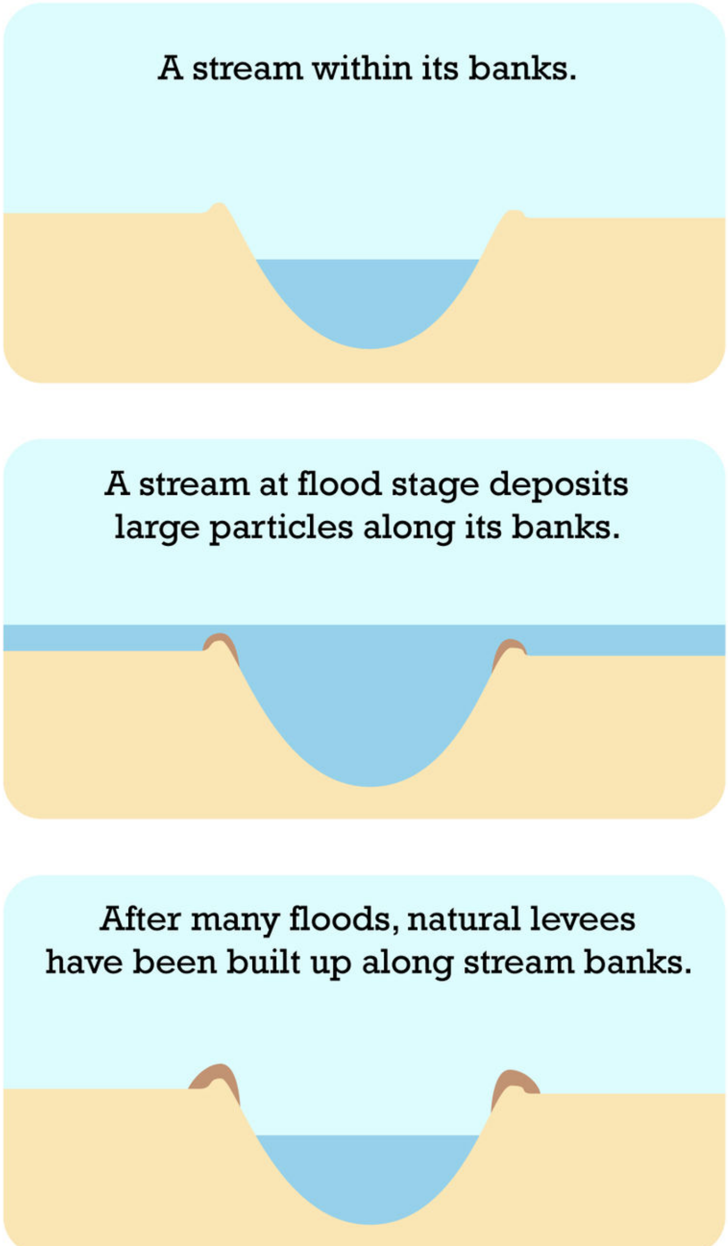

FIGURE 10.8
This diagram shows how a river builds natural levees along its banks.

Caves

As groundwater moves through rock, it dissolves minerals. Some rocks dissolve more easily than others. Over time, the water may dissolve large underground holes, or **caves**. Groundwater drips from the ceiling to the floor of a cave. This water is rich in dissolved minerals. When the minerals come out of solution, they are deposited. They build up on the ceiling of the cave to create formations called stalactites. A stalactite is a pointed, icicle-like mineral deposit that forms on the ceiling of a cave. They drip to the floor of the cave and harden to form stalagmites. A stalagmite is a more rounded mineral deposit that forms on the floor of a cave (**Figure** 10.9). Both types of formations grow in size as water keeps dripping and more minerals are deposited.

FIGURE 10.9
This cave has both stalactites and stalagmites.

Sinkholes

As erosion by groundwater continues, the ceiling of a cave may collapse. The rock and soil above it sink into the ground. This forms a **sinkhole** on the surface. You can see an example of a sinkhole in **Figure** 10.10. Some sinkholes are big enough to swallow vehicles and buildings.

FIGURE 10.10
A sinkhole.

Lesson Summary

- Water flowing over Earth's surface or underground causes erosion and deposition.
- Water flowing over a steeper slope moves faster and causes more erosion.
- How water transports particles depends on their size. When water slows down, it starts depositing sediment,

starting with the largest particles first.
- Runoff erodes the land after a heavy rain. It picks up sediment and carries most of it to bodies of water. Mountain streams erode narrow, V-shaped valleys and waterfalls.
- Erosion and deposition by slow-flowing rivers creates broad floodplains and meanders.
- Deposition by streams and rivers may form alluvial fans and deltas. Floodwaters may deposit natural levees.
- Erosion and deposition by groundwater can form caves and sinkholes. Stalactites and stalagmites are mineral deposits that build up in caves as water continues to drip.

Lesson Review Questions

Recall

1. Define erosion.
2. What is deposition?
3. When does flowing water deposit the sediment it is carrying?
4. What happens to the sediment eroded by runoff?
5. Describe how a waterfall forms?
6. What are meanders?

Apply Concepts

7. Make a table that relates particle size to the way particles are transported by flowing water.
8. Create a sketch that shows effects of groundwater erosion and deposition.

Think Critically

9. Explain why mountain streams erode V-shaped valleys.
10. What might be pros and cons of living on the floodplain of a river?

Points to Consider

Ocean waves are another form of moving water. They also cause erosion and deposition.

- How do waves erode shorelines?
- What landforms are deposited by waves?

10.2 Erosion and Deposition by Waves

Lesson Objectives

- Explain how waves cause erosion of shorelines.
- Describe features formed by wave deposition.
- Identify ways to protect shorelines from wave erosion.

Vocabulary

- barrier island
- breakwater
- groin
- longshore drift
- sandbar
- sea arch
- sea stack
- spit

Introduction

Have you ever stood on a sandy ocean beach and let the waves wash over your feet? If you have, then you probably felt the sand being washed out from under your feet by the outgoing waves. This is an example of wave erosion. What are waves? Why do they cause erosion? And what happens to the sand that waves wash away from the beach?

What Are Waves?

All waves are the way energy travels through matter. Ocean waves are energy traveling through water. They form when wind blows over the surface of the ocean. Wind energy is transferred to the sea surface. Then, the energy is carried through the water by the waves. **Figure** 10.11 shows ocean waves crashing against rocks on a shore. They pound away at the rocks and anything else they strike.

Three factors determine the size of ocean waves:

1. The speed of the wind.
2. The length of time the wind blows.
3. The distance the wind blows.

The faster, longer, and farther the wind blows, the bigger the waves are. Bigger waves have more energy.

FIGURE 10.11
Ocean waves transfer energy from the wind through the water. This gives waves the energy to erode the shore.

Wave Erosion

Runoff, streams, and rivers carry sediment to the oceans. The sediment in ocean water acts like sandpaper. Over time, they erode the shore. The bigger the waves are and the more sediment they carry, the more erosion they cause.

Landforms From Wave Erosion

Erosion by waves can create unique landforms (**Figure** 10.12).

- Wave-cut cliffs form when waves erode a rocky shoreline. They create a vertical wall of exposed rock layers.
- **Sea arches** form when waves erode both sides of a cliff. They create a hole in the cliff.
- **Sea stacks** form when waves erode the top of a sea arch. This leaves behind pillars of rock.

FIGURE 10.12
Over millions of years, wave erosion can create wave-cut cliffs (A), sea arches (B), or sea stacks (C).

Wave Deposition

Eventually, the sediment in ocean water is deposited. Deposition occurs where waves and other ocean motions slow. The smallest particles, such as silt and clay, are deposited away from shore. This is where water is calmer. Larger particles are deposited on the beach. This is where waves and other motions are strongest.

Beaches

In relatively quiet areas along a shore, waves may deposit sand. Sand forms a beach, like the one in **Figure** 10.13. Many beaches include bits of rock and shell. You can see a close-up photo of beach deposits in **Figure** 10.14.

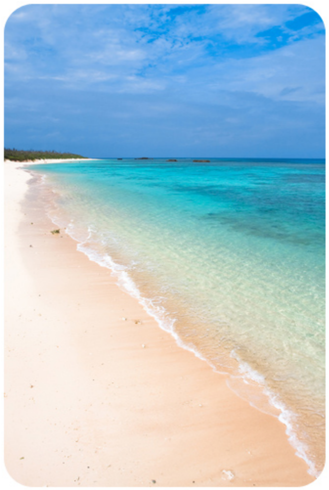

FIGURE 10.13
Sand deposited along a shoreline creates a beach.

FIGURE 10.14
Beach deposits usually consist of small pieces of rock and shell in addition to sand.

Longshore Drift

Most waves strike the shore at an angle. This causes **longshore drift**. Longshore drift moves sediment along the shore. Sediment is moved up the beach by an incoming wave. The wave approaches at an angle to the shore. Water then moves straight offshore. The sediment moves straight down the beach with it. The sediment is again picked up by a wave that is coming in at an angle. This motion is show in **Figure** 10.15 and at the link below.

http://oceanica.cofc.edu/an%20educator'sl%20guide%20to%20folly%20beach/guide/driftanimation.htm

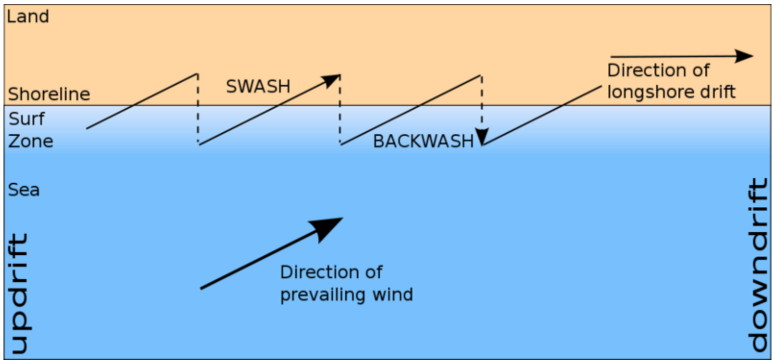

FIGURE 10.15
Longshore drift carries particles of sand and rock down a coastline.

Landforms Deposited by Waves

Deposits from longshore drift may form a spit. A **spit** is a ridge of sand that extends away from the shore. The end of the spit may hook around toward the quieter waters close to shore. You can see a spit in **Figure** 10.16.

FIGURE 10.16
Spit from Space. Farewell Spit in New Zealand is clearly visible from space. This photo was taken by an astronaut orbiting Earth.

Waves may also deposit sediments to form **sandbars** and **barrier islands**. You can see examples of these landforms in **Figure** 10.17.

Protecting Shorelines

Shores are attractive places to live and vacation. But development at the shore is at risk of damage from waves. Wave erosion threatens many homes and beaches on the ocean. This is especially true during storms, when waves may be much larger than normal.

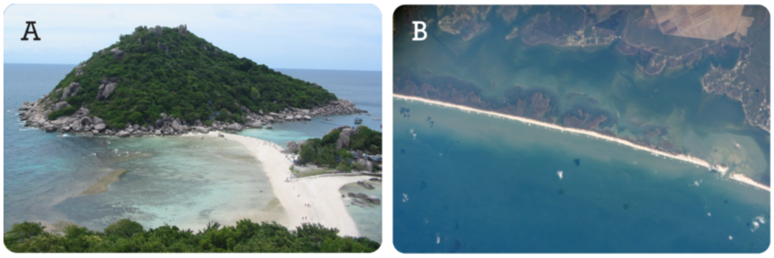

FIGURE 10.17

Wave-Deposited Landforms. These landforms were deposited by waves. (A) Sandbars connect the small islands on this beach on Thailand. (B) A barrier island is a long, narrow island. It forms when sand is deposited by waves parallel to a coast. It develops from a sandbar that has built up enough to break through the water's surface. A barrier island helps protect the coast from wave erosion.

Breakwaters

Barrier islands provide natural protection to shorelines. Storm waves strike the barrier island before they reach the shore. People also build artificial barriers, called **breakwaters**. Breakwaters also protect the shoreline from incoming waves. You can see an example of a breakwater in **Figure** 10.18. It runs parallel to the coast like a barrier island.

FIGURE 10.18

A breakwater is an artificial barrier island. How does it help protect the shoreline?

Groins

Longshore drift can erode the sediment from a beach. To keep this from happening, people may build a series of groins. A **groin** is wall of rocks or concrete that juts out into the ocean perpendicular to the shore. It stops waves from moving right along the beach. This stops the sand on the upcurrent side and reduces beach erosion. You can see how groins work in **Figure** 10.19.

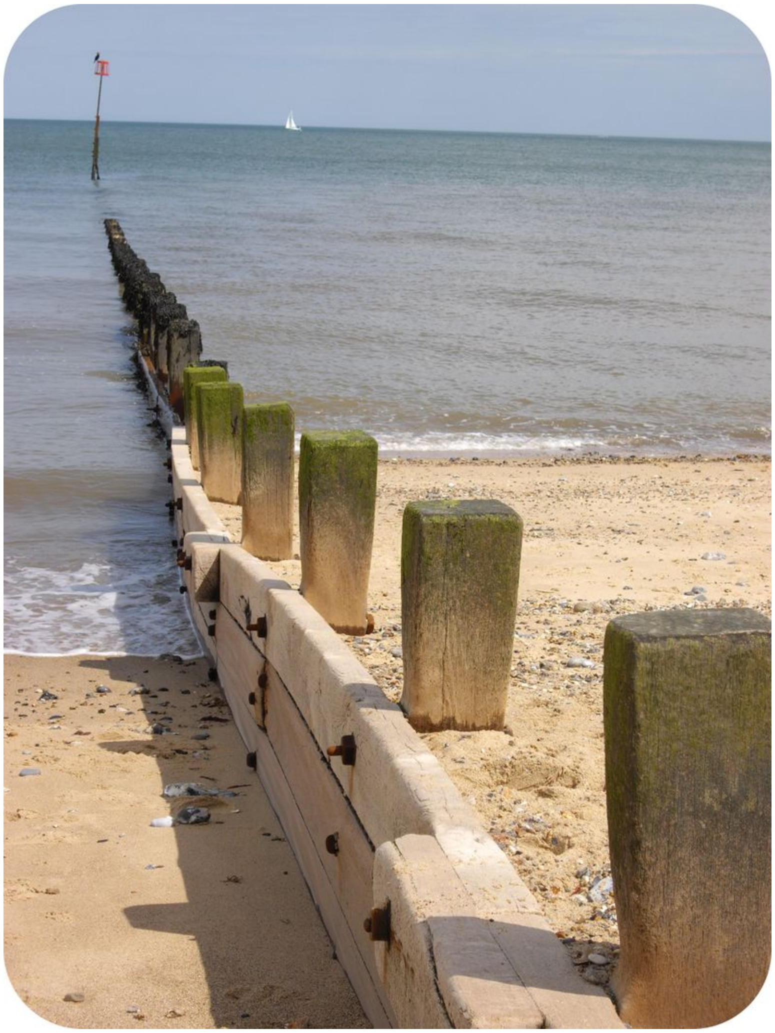

FIGURE 10.19
A groin is built perpendicular to the shoreline. Sand collects on the upcurrent side.

Lesson Summary

- Ocean waves are energy traveling through water. They are caused mainly by wind blowing over the water.
- Sediment in ocean water acts like sandpaper. Over time, it erodes the shore. It can create unique landforms, such as wave-cut cliffs, sea arches, and sea stacks.
- Deposits by waves include beaches. They may shift along the shoreline due to longshore drift. Other wave deposits are spits, sand bars, and barrier islands.
- Breakwaters are structures that protect the coast like barrier islands. Groins are structures that help prevent longshore drift from eroding a beach.

Lesson Review Questions

Recall

1. What are waves?

2. How do ocean waves cause erosion?
3. Identify three types of landforms created by wave erosion.
4. What is a spit? How does it form?

Apply Concepts

5. Create a diagram to illustrate the concept of longshore drift.

Think Critically

6. Why are the smallest particles on a beach usually sand?
7. Explain how a barrier island helps protect the coast from wave erosion.
8. Compare and contrast how breakwaters and groins protect shorelines.

Points to Consider

Moving air, like moving water, causes erosion. Moving air is called wind.

- How does wind cause erosion? Does the wind carry particles in the same ways that moving water does?
- What landforms are deposited by the wind?

10.3 Erosion and Deposition by Wind

Lesson Objectives

- Explain how wind causes erosion.
- Describe sediments deposited by wind.
- Identify ways to prevent wind erosion.

Vocabulary

- loess
- sand dune

Introduction

Wind is only air moving over Earth's surface, but it can cause a lot of erosion. Look at **Figure** 10.20. It will give you an idea of just how much erosion wind can cause. The dust storm in the photo occurred in Arizona. All that dust in the air was picked up and carried by the wind. The wind may carry the dust for hundreds of kilometers before depositing it.

FIGURE 10.20
Dust storm over Arizona desert. Have you ever experienced a dust storm like this one?

Wind Erosion

Dust storms like the one in **Figure** 10.20 are more common in dry climates. The soil is dried out and dusty. Plants may be few and far between. Dry, bare soil is more easily blown away by the wind than wetter soil or soil held in place by plant roots.

How the Wind Moves Particles

Like flowing water, wind picks up and transports particles. Wind carries particles of different sizes in the same ways that water carries them. You can see this in **Figure** 10.21.

- Tiny particles, such as clay and silt, move by suspension. They hang in the air, sometimes for days. They may be carried great distances and rise high above the ground.
- Larger particles, such as sand, move by saltation. The wind blows them in short hops. They stay close to the ground.
- Particles larger than sand move by traction. The wind rolls or pushes them over the surface. They stay on the ground.

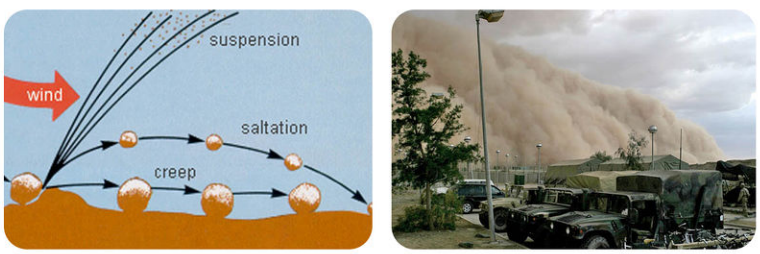

FIGURE 10.21
Wind transports particles in different ways depending on their size (left). A dust storm in the Middle East (right).

Abrasion

Did you ever see workers sandblasting a building to clean it? Sand is blown onto the surface to scour away dirt and debris. Wind-blown sand has the same effect. It scours and polishes rocks and other surfaces. Wind-blown sand may carve rocks into interesting shapes. You can see an example in **Figure** 10.22. This form of erosion is called abrasion. It occurs any time rough sediments are blown or dragged over surfaces. Can you think of other ways abrasion might occur?

Wind Deposition

Like water, when wind slows down it drops the sediment it's carrying. This often happens when the wind has to move over or around an obstacle. A rock or tree may cause wind to slow down. As the wind slows, it deposits the largest particles first. Different types of deposits form depending on the size of the particles deposited.

Deposition of Sand

When the wind deposits sand, it forms small hills of sand. These hills are called **sand dunes**. For sand dunes to form, there must be plenty of sand and wind. Sand dunes are found mainly in deserts and on beaches. You can see

FIGURE 10.22
Sand blown by fierce winds have carved this rock in to an interesting shape.

examples of sand dunes in **Figure** 10.23.

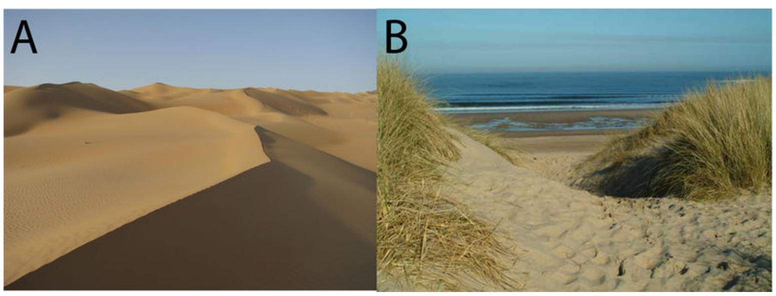

FIGURE 10.23
Sand dunes form where the wind deposits sand. (A) Desert sand dunes. (B) Sand dunes line many beaches like this one in Australia.

How Sand Dunes Form

What causes a sand dune to form? It starts with an obstacle, such as a rock. The obstacle causes the wind to slow down. The wind then drops some of its sand. As more sand is deposited, the dune gets bigger. The dune becomes the obstacle that slows the wind and causes it to drop its sand. The hill takes on the typical shape of a sand dune, shown in **Figure** 10.24.

FIGURE 10.24
A sand dune has a gentle slope on the side the wind blows from. The opposite side has a steep slope. This side is called the slip face.

Migration of Sand Dunes

Once a sand dune forms, it may slowly migrate over the land. The wind moves grains of sand up the gently sloping side of the dune. This is done by saltation. When the sand grains reach the top of the dune, they slip down the steeper side. The grains are pulled by gravity. The constant movement of sand up and over the dune causes the dune to move along the ground. It always moves in the same direction that the wind usually blows. Can you explain why?

Loess

When the wind drops fine particles of silt and clay, it forms deposits called **loess**. Loess deposits form vertical cliffs. Loess can become a thick, rich soil. That's why loess deposits are used for farming in many parts of the world. You can see an example of loess in **Figure** 10.25.

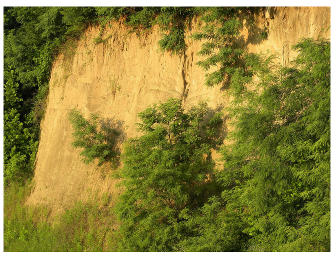

FIGURE 10.25
Loess cliffs in Mississippi.

Preventing Wind Erosion

It's very important to control wind erosion of soil. Good soil is a precious resource that takes a long time to form. Covering soil with plants is one way to reduce wind erosion. Plants and their roots help hold the soil in place. They also help the soil retain water so it is less likely to blow away.

Planting rows of trees around fields is another way to reduce wind erosion. The trees slow down the wind, so it doesn't cause as much erosion. Fences like the one in **Figure** 10.26 serve the same purpose. The fence in the figure is preventing erosion and migration of sand dunes on a beach.

Lesson Summary

- Dry, bare soil is more likely to be eroded by the wind than moist soil or soil covered with plants. How wind carries particles depends on their size. The sediment in wind causes erosion by abrasion.
- Sand dunes form when the wind deposits sand. Loess form when the wind deposits clay and silt.
- Wind erosion can be prevented by keeping the ground covered with plants. They help hold the soil in place. Rows of trees and fences can help by slowing the wind.

FIGURE 10.26

Protecting Sand Dunes from Wind Erosion. Many beaches uses fences like this one to reduce wind erosion of sand. If plants start growing on the dunes, they help hold the sand in place.

Lesson Review Questions

Recall

1. How does the wind carry particles of sand?
2. What is abrasion?
3. What are sand dunes? Where are they found?
4. Describe loess.
5. Identify two ways to reduce wind erosion.

Apply Concepts

6. Wind-blown snow forms drifts that are similar to sand dunes. Apply lesson concepts to infer how you could reduce snowdrifts in a driveway.

Think Critically

7. Compare and contrast how the wind transports clay, sand, and pebbles.
8. Explain why a sand dune migrates.

Points to Consider

Abrasion is the main way that wind causes erosion. The next lesson explains how glaciers cause erosion.

- How do you think glaciers cause erosion?
- Do you think glaciers might erode by abrasion, like the wind?

10.4 Erosion and Deposition by Glaciers

Lesson Objectives

- Describe how continental and valley glaciers form.
- Explain how glaciers cause erosion.
- Identify landforms deposited by glaciers.

Vocabulary

- continental glacier
- glacial till
- glacier
- moraine
- plucking
- valley glacier

Introduction

Glaciers are masses of flowing ice. Today, they cover only about 10 percent of Earth's surface. They are getting smaller and smaller as Earth's temperature rises. But just 12,000 years ago, glaciers dipped as far south as Chicago and New York City. Much of Europe was also covered with glaciers at that time.

Glaciers erode and leave behind telltale landforms. These landforms are like clues. They show the direction a glacier flowed and how far it advanced. Did glaciers leave clues where you live? Would you know what to look for?

How Glaciers Form

Glaciers form when more snow falls than melts each year. Over many years, layer upon layer of snow compacts and turns to ice. There are two different types of glaciers: continental glaciers and valley glaciers. Each type forms some unique features through erosion and deposition. An example of each type is pictured in **Figure** 10.27.

- A **continental glacier** is spread out over a huge area. It may cover most of a continent. Today, continental glaciers cover most of Greenland and Antarctica. In the past, they were much more extensive.
- A **valley glacier** is long and narrow. Valley glaciers form in mountains and flow downhill through mountain river valleys.

FIGURE 10.27
(A) The continent of Antarctica is covered with a continental glacier. (B) A valley glacier in the Canadian Rockies. (C) The surface of a valley glacier.

Erosion by Glaciers

Like flowing water, flowing ice erodes the land and deposits the material elsewhere. Glaciers cause erosion in two main ways: plucking and abrasion.

- **Plucking** is the process by which rocks and other sediments are picked up by a glacier. They freeze to the bottom of the glacier and are carried away by the flowing ice.
- Abrasion is the process in which a glacier scrapes underlying rock. The sediments and rocks frozen in the ice at the bottom and sides of a glacier act like sandpaper. They wear away rock. They may also leave scratches and grooves that show the direction the glacier moved.

Erosion by Valley Glaciers

Valley glaciers form several unique features through erosion. You can see some of them in **Figure** 10.28.

- As a valley glacier flows through a V-shaped river valley, it scrapes away the sides of the valley. It carves a U-shaped valley with nearly vertical walls. A line called the trimline shows the highest level the glacier reached.
- A cirque is a rounded hollow carved in the side of a mountain by a glacier. The highest cliff of a cirque is called the headwall.
- An arête is a jagged ridge that remains when cirques form on opposite sides of a mountain. A low spot in an arête is called a col.
- A horn is a sharp peak that is left behind when glacial cirques are on at least three sides of a mountain.

FIGURE 10.28

Features Eroded by Valley Glaciers. Erosion by valley glaciers forms the unique features shown here.

Deposition by Glaciers

Glaciers deposit their sediment when they melt. They drop and leave behind whatever was once frozen in their ice. It's usually a mixture of particles and rocks of all sizes, called **glacial till**. Water from the melting ice may form lakes or other water features. **Figure** 10.29 shows some of the landforms glaciers deposit when they melt.

- **Moraine** is sediment deposited by a glacier. A ground moraine is a thick layer of sediments left behind by a retreating glacier. An end moraine is a low ridge of sediments deposited at the end of the glacier. It marks the greatest distance the glacier advanced.
- A drumlin is a long, low hill of sediments deposited by a glacier. Drumlins often occur in groups called drumlin fields. The narrow end of each drumlin points in the direction the glacier was moving when it dropped the sediments.
- An esker is a winding ridge of sand deposited by a stream of meltwater. Such streams flow underneath a retreating glacier.
- A kettle lake occurs where a chunk of ice was left behind in the sediments of a retreating glacier. When the ice melted, it left a depression. The meltwater filled it to form a lake.

Lesson Summary

- Glaciers are masses of flowing ice. Continental glaciers are huge. They may spread out over much of a continent. Valley glaciers are long and narrow. They form in mountains and flow through mountain river valleys.

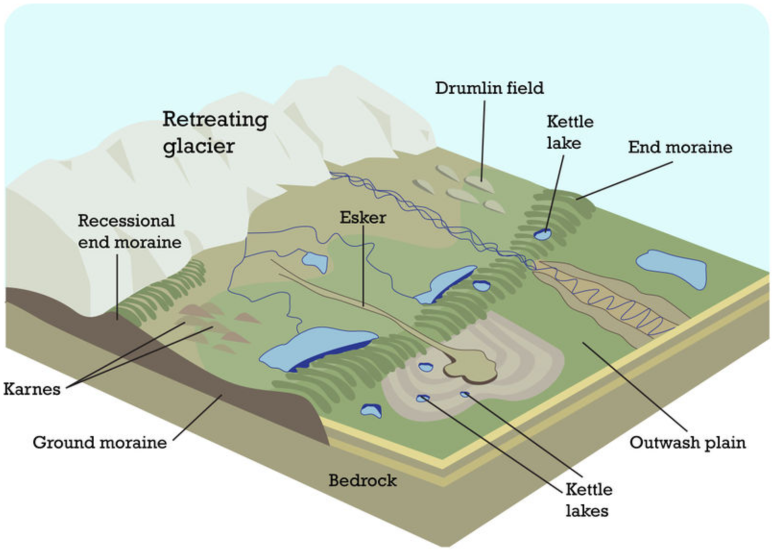

FIGURE 10.29
Take a look at the glacial deposits. How far did the glacier in the diagram advance before it started retreating?

- Glaciers cause erosion by plucking and abrasion. Valley glaciers form several unique features through erosion, including cirques, arêtes, and horns.
- Glaciers deposit their sediment when they melt. Landforms deposited by glaciers include drumlins, kettle lakes, and eskers.

Lesson Review Questions

Recall

1. What is a glacier?
2. Describe how glaciers form.
3. Identify the two main ways glaciers cause erosion.
4. Name and describe three unique features eroded by valley glaciers.
5. What is glacial till?

Apply Concepts

6. Create a lesson to teach younger students how a kettle lake forms. Outline your lesson.

Think Critically

7. Compare and contrast valley and continental glaciers and how they change Earth's surface.
8. Areas once covered by glaciers may have large boulders called erratics, like the one in the photo below. Infer why erratics typically consist of a different type of rock than the bedrock where they are found.

Points to Consider

So far in this chapter, you've read how moving water, air, and ice shape Earth's surface. Water and ice move because of gravity.

- Do you think gravity can erode and deposit sediment without the help of water or ice?
- How might gravity alone shape Earth's surface?

10.5 Erosion and Deposition by Gravity

Lesson Objectives

- Identify causes and effects of landslides and mudslides.
- Explain how slump and creep occur.

Vocabulary

- creep
- landslide
- mass movement
- mudslide
- slump

Introduction

Gravity is responsible for erosion by flowing water and glaciers. That's because gravity pulls water and ice downhill. These are ways gravity causes erosion indirectly. But gravity also causes erosion directly. Gravity can pull soil, mud, and rocks down cliffs and hillsides. This type of erosion and deposition is called **mass movement**. It may happen suddenly. Or it may occur very slowly, over many years.

Landslides and Mudslides

The most destructive types of mass movement are landslides and mudslides. Both occur suddenly.

Landslides

A **landslide** happens when a large amount of soil and rock suddenly falls down a slope because of gravity. You can see an example in **Figure** 10.30. A landslide can be very destructive. It may bury or carry away entire villages.

A landslide is more likely if the soil has become wet from heavy rains. The wet soil becomes slippery and heavy. Earthquakes often trigger landslides. The shaking ground causes soil and rocks to break loose and start sliding. If a landslide flows into a body of water, it may cause a huge wave called a tsunami.

FIGURE 10.30
This 2001 landslide in El Salvador (Central America) was started by an earthquake. Soil and rocks flowed down a hillside and swallowed up houses in the city below.

Mudslides

A **mudslide** is the sudden flow of mud down a slope because of gravity. Mudslides occur where the soil is mostly clay. Like landslides, mudslides usually occur when the soil is wet. Wet clay forms very slippery mud that slides easily. You can see an example of a mudslide in **Figure** 10.31.

FIGURE 10.31
Mudslide. A mudslide engulfs whatever is in its path.

Other Types of Mass Movement

Two other types of mass movement are slump and creep. Both may move a lot of soil and rock. However, they usually aren't as destructive as landslides and mudslides.

Slump

Slump is the sudden movement of large blocks of rock and soil down a slope. You can see how it happens in **Figure** 10.32. All the material moves together in big chunks. Slump may be caused by a layer of slippery, wet clay underneath the rock and soil on a hillside. Or it may occur when a river undercuts a slope. Slump leaves behind crescent-shaped scars on the hillside.

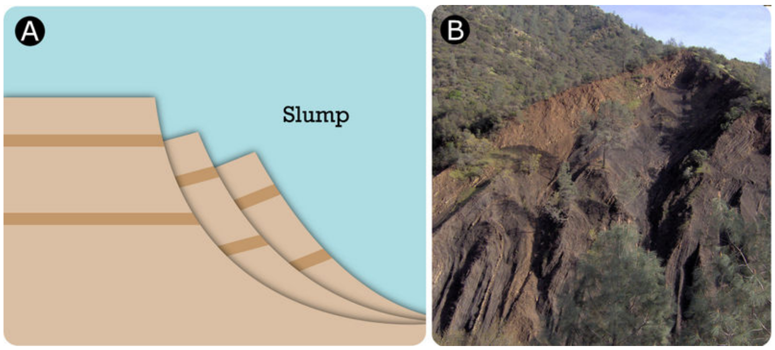

FIGURE 10.32
Slump takes place suddenly, like a landslide. How does slump differ from a landslide?

Creep

Creep is the very slow movement of rock and soil down a hillside. Creep occurs so slowly you can't see it happening. You can only see the effects of creep after years of movement. This is illustrated in **Figure** 10.33. The slowly moving ground causes trees, fence posts, and other structures on the surface to tilt downhill.

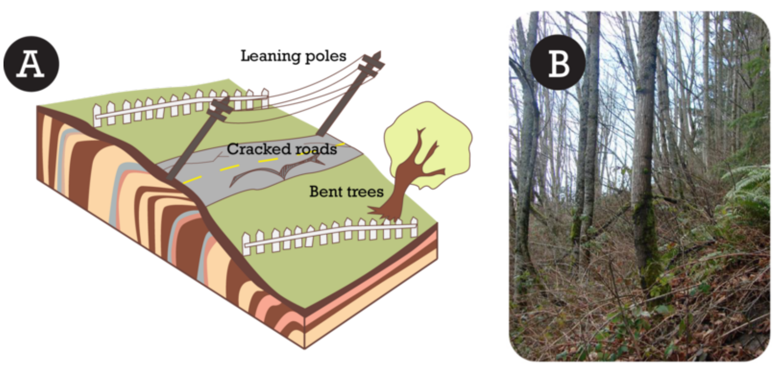

FIGURE 10.33
Creep is seen on a hillside. What evidence shows creep has occurred?

Creep usually takes place where the ground freezes and thaws frequently. Soil and rock particles are lifted up when the ground freezes. When the ground thaws, the particles settle down again. Each time they settle down, they move a tiny bit farther down the slope because of gravity.

Lesson Summary

- Gravity can pull soil, mud, and rocks down cliffs and hillsides. This is called mass movement. The most destructive types of mass movement are landslides and mudslides. They occur suddenly and without warming. They engulf everything in their path.

- Two other types of mass movement are slump and creep. They usually aren't as destructive as landslides and mudslides. Slump is the sudden movement of large blocks of rock and soil down a slope. Creep is the very slow movement of rock and soil down a slope. It causes trees, fence posts, and other structures to tilt downhill.

Lesson Review Questions

Recall

1. Define mass movement.
2. List four types of mass movement.
3. What is a landslide?
4. What factors increase the chances of landslides occurring?
5. What type of soil forms mudslides?

Apply Concepts

6. Assume you are riding in a car down a road or street. Suddenly, you see evidence of creep. Describe it.

Think Critically

7. Relate earthquakes to mass movement.
8. Compare and contrast slump and creep.

Points to Consider

Erosion and deposition are always changing Earth's surface.

- Do you think that the same forces that cause erosion today —moving water, wind, ice, and gravity —were also at work in the past?
- How might observations of erosion and deposition today help us understand Earth's history?

10.6 References

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CHAPTER 11 MS Evidence About Earth's Past

Chapter Outline

Do you recognize this animal from its skeleton? If you guessed it's *Tyrannosaurus rex*, you're right. Like other dinosaurs, *T. rex* went extinct about 65 million years ago. How do we know what this extinct animal looked like? The answer is right in front of you: from the fossils it left behind. This *T. rex* isn't a true fossil. It's just a copy on display in a museum. But many fossils of *T. rex* have been found.

Fossils not only show us what extinct animals looked like. They also provide evidence about past environments and geological processes. In this chapter, you'll find out how scientists use clues from fossils to understand Earth's history.

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11.1 Fossils

Lesson Objectives

- Explain what fossils are.
- Describe how fossils form.
- State what scientists can learn from fossils.

Vocabulary

- fossilization
- index fossil

Introduction

For thousands of years, people have discovered fossils. They have wondered about the creatures that left them. In ancient times, fossils inspired myths. Stories were told about monsters and other incredible creatures. For example, dinosaur fossils discovered in China two thousand years ago were thought to be dragon bones.

Do you know what fossils are? Do you know how they form? And do you know what they can tell us about the past?

What Are Fossils?

Fossils are preserved remains or traces of organisms that lived in the past. Most preserved remains are hard parts, such as teeth, bones, or shells. Examples of these kinds of fossils are pictured in **Figure** 11.1. Preserved traces can include footprints, burrows, or even wastes. Examples of trace fossils are also shown in **Figure** 11.1.

How Fossils Form

The process by which remains or traces of living things become fossils is called **fossilization**. Most fossils are preserved in sedimentary rocks.

Fossils in Sedimentary Rock

Most fossils form when a dead organism is buried in sediment. Layers of sediment slowly build up. The sediment is buried and turns into sedimentary rock. The remains inside the rock also turn to rock. The remains are replaced by minerals. The remains literally turn to stone. Fossilization is illustrated in **Figure** 11.2.

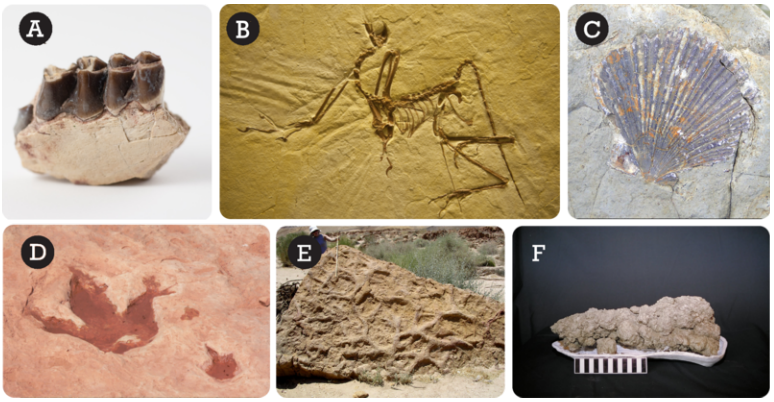


FIGURE 11.1
A variety of fossil types are pictured here. Preserved Remains: (A) teeth of a cow, (B) nearly complete dinosaur skeleton embedded in rock, (C) sea shell preserved in a rock. Preserved Traces: (D) dinosaur tracks in mud, (E) fossil animal burrow in rock, (F) fossil feces from a meat-eating dinosaur in Canada.

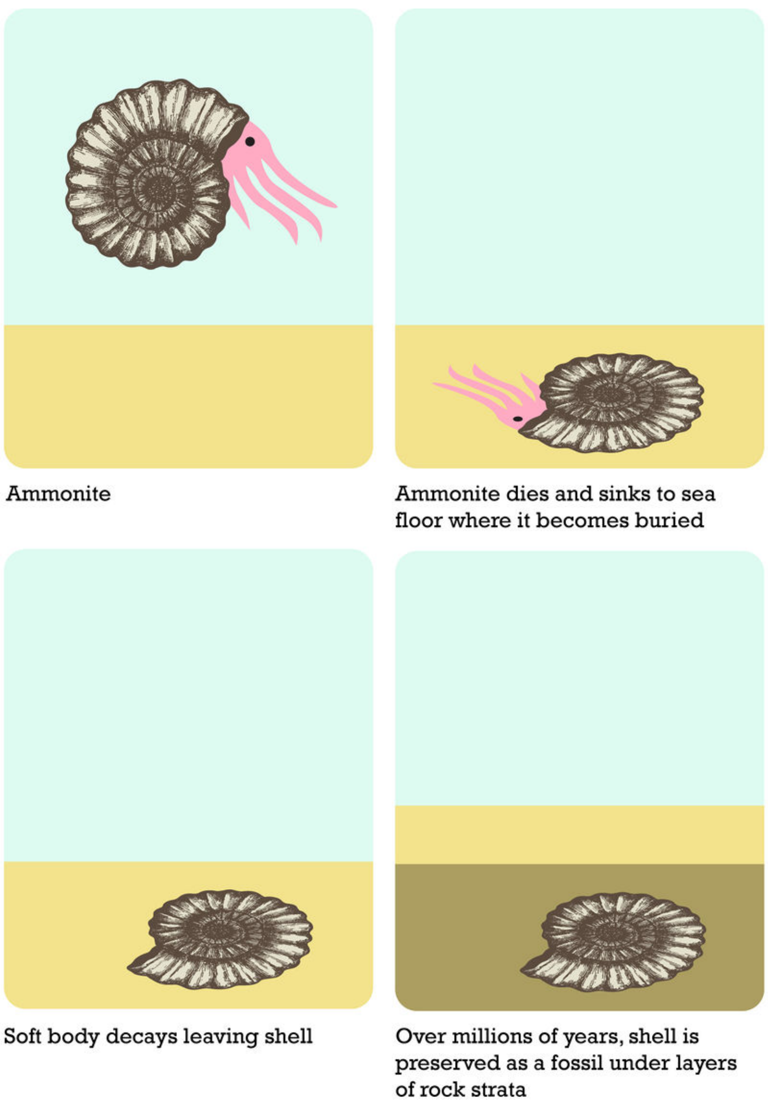


FIGURE 11.2
Fossilization. This flowchart shows how most fossils form.

Other Ways Fossils Form

Fossils may form in other ways. With complete preservation, the organism doesn't change much. As seen below, tree sap may cover an organism and then turn into amber. The original organism is preserved so that scientists might be able to study its DNA. Organisms can also be completely preserved in tar or ice. Molds and casts are another way organisms can be fossilized. A mold is an imprint of an organism left in rock. The organism's remains break down completely. Rock that fills in the mold resembles the original remains. The fossil that forms in the mold is called a cast. Molds and casts usually form in sedimentary rock. With compression, an organism's remains are put under great pressure inside rock layers. This leaves behind a dark stain in the rock.

You can read about them in **Figure** 11.3.

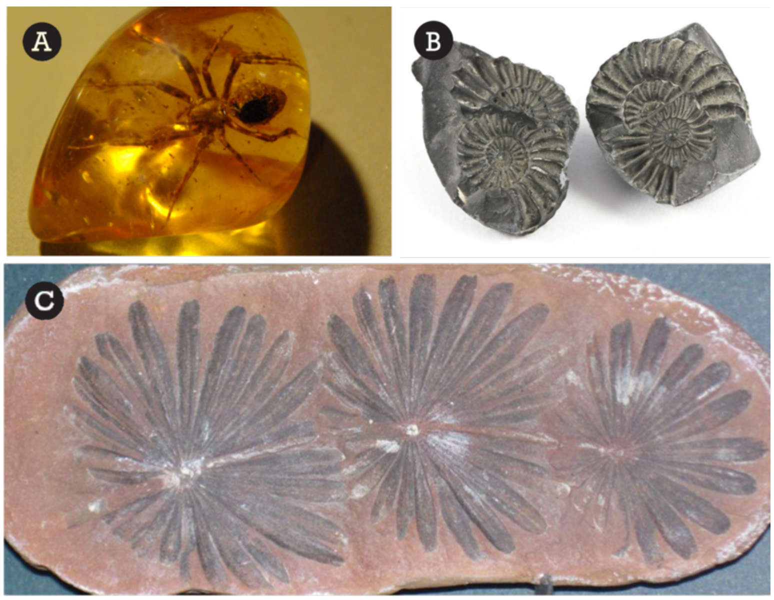


FIGURE 11.3
Ways Fossils Form. (A) Complete Preservation. This spider looks the same as it did the day it died millions of years ago! (B) Molds and Casts. A mold is a hole left in rock after an organism's remains break. A cast forms from the minerals that fill that hole and solidify. (C) Compression. A dark stain is left on a rock that was compressed. These ferns were fossilized by compression.

Why Fossilization is Rare

It's very unlikely that any given organism will become a fossil. The remains of many organisms are consumed. Remains also may be broken down by other living things or by the elements. Hard parts, such as bones, are much more likely to become fossils. But even they rarely last long enough to become fossils. Organisms without hard parts are the least likely to be fossilized. Fossils of soft organisms, from bacteria to jellyfish, are very rare.

Learning from Fossils

Of all the organisms that ever lived, only a tiny number became fossils. Still, scientists learn a lot from fossils. Fossils are our best clues about the history of life on Earth.

Fossil Clues

Fossils give clues about major geological events. Fossils can also give clues about past climates.

- Fossils of ocean animals are found at the top of Mt. Everest. Mt. Everest is the highest mountain on Earth. These fossils show that the area was once at the bottom of a sea. The seabed was later uplifted to form the Himalaya mountain range. An example is shown in the **Figure** 11.4.
- Fossils of plants are found in Antarctica. Currently, Antarctica is almost completely covered with ice. The fossil plants show that Antarctica once had a much warmer climate.

FIGURE 11.4
What can we learn from fossil clues like this fish fossil found in the Wyoming desert?

Index Fossils

Fossils are used to determine the ages of rock layers. **Index fossils** are the most useful for this. Index fossils are of organisms that lived over a wide area. They lived for a fairly short period of time. An index fossil allows a scientist to determine the age of the rock it is in.

Trilobite fossils, as shown in **Figure** 11.5, are common index fossils. Trilobites were widespread marine animals. They lived between 500 and 600 million years ago. Rock layers containing trilobite fossils must be that age. Different species of trilobite fossils can be used to narrow the age even more.

FIGURE 11.5
Trilobites are good index fossils. Why are trilobite fossils useful as index fossils?

Lesson Summary

- Fossils are preserved remains or traces of organisms that lived in the past. Most fossils form in sedimentary rock. Fossils can also be preserved in other ways. Fossilization is rare. It's very unlikely for any given organism to become a fossil.
- Fossils are the best form of evidence about the history of life on Earth. Fossils also give us clues about major geological events and past climates. Index fossils are useful for determining the ages of rock layers.

Lesson Review Questions

Recall

1. What are fossils?

2. Give examples of trace fossils.

3. Why are most preserved remains teeth, bones, or shells?

4. Describe how fossils form in sedimentary rock.

5. Why is fossilization rare?

Apply Concepts

6. Create an original diagram to explain the concept of index fossil. Your diagram should include sedimentary rock layers and fossils.

Think Critically

7. Compare and contrast the frog fossil in **Figure** 11.3 and the fossil dinosaur tracks in **Figure** 11.1. Infer what you might learn from each type of fossil.

8. Earth's climate became much cooler at different times in the past. Predict what fossil evidence you might find for this type of climate change.

Points to Consider

Fossils can help scientists estimate the ages of rocks. Some types of evidence show only that one rock is older or younger than another. Other types of evidence reveal a rock's actual age in years.

- What evidence might show that one rock is older or younger than another?
- What evidence might reveal how long ago rocks formed?

11.2 Relative Ages of Rocks

Lesson Objectives

- Explain how stratigraphy can be used to determine the relative ages of rocks.
- State how unconformities occur.
- Identify ways to match rock layers in different areas.
- Describe how Earth's history can be represented by the geologic time scale.

Vocabulary

- geologic time scale
- key bed
- law of superposition
- relative age
- stratigraphy
- unconformity

Introduction

The way things happen now is the same way things happened in the past. Earth processes have not changed over time. Mountains grow and mountains slowly wear away, just as they did billions of years ago. As the environment changes, living creatures adapt. They change over time. Some organisms may not be able to adapt. They become **extinct**, meaning that they die out completely.

Historical geologists study the Earth's past. They use clues from rocks and fossils to figure out the order of events. They think about how long it took for those events to happen.

Laws of Stratigraphy

The study of rock strata is called **stratigraphy**. The laws of stratigraphy can help scientists understand Earth's past. The laws of stratigraphy are usually credited to a geologist from Denmark named Nicolas Steno. He lived in the 1600s. The laws are illustrated in **Figure** 11.6. Refer to the figure as you read about the laws below.

Law of Superposition

Superposition refers to the position of rock layers and their relative ages. **Relative age** means age in comparison with other rocks, either younger or older. The relative ages of rocks are important for understanding Earth's history.

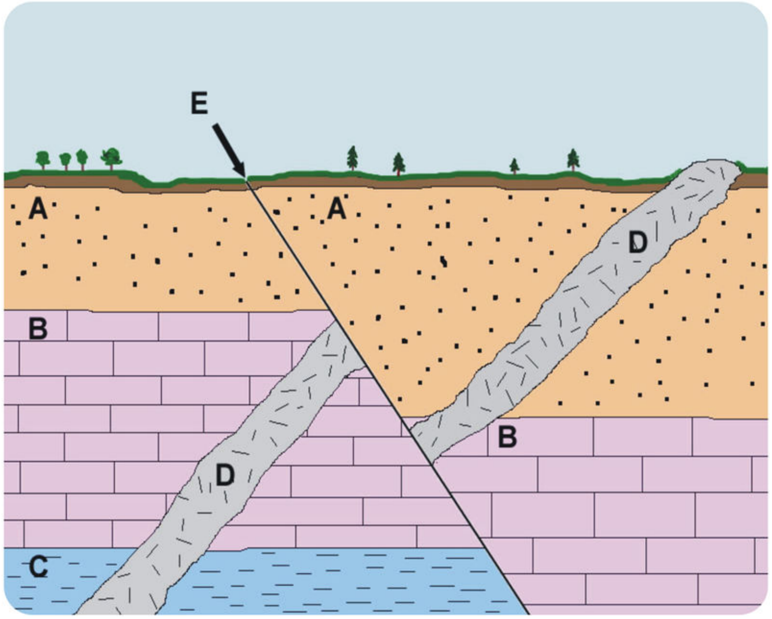


FIGURE 11.6
Laws of Stratigraphy. This diagram illustrates the laws of stratigraphy. A = Law of Superposition, B = Law of Lateral Continuity, C = Law of Original Horizontality, D = Law of Cross-Cutting Relationships

New rock layers are always deposited on top of existing rock layers. Therefore, deeper layers must be older than layers closer to the surface. This is the **law of superposition**. You can see an example in **Figure** 11.7.

FIGURE 11.7
Superposition. The rock layers at the bottom of this cliff are much older than those at the top. What force eroded the rocks and exposed the layers?

Law of Lateral Continuity

Rock layers extend laterally, or out to the sides. They may cover very broad areas, especially if they formed at the bottom of ancient seas. Erosion may have worn away some of the rock, but layers on either side of eroded areas will still "match up."

Look at the Grand Canyon in **Figure** 11.8. It's a good example of lateral continuity. You can clearly see the same rock layers on opposite sides of the canyon. The matching rock layers were deposited at the same time, so they are the same age.

FIGURE 11.8
Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

Law of Original Horizontality

Sediments were deposited in ancient seas in horizontal, or flat, layers. If sedimentary rock layers are tilted, they must have moved after they were deposited.

Law of Cross-Cutting Relationships

Rock layers may have another rock cutting across them, like the igneous rock in **Figure** 11.9. Which rock is older? To determine this, we use the law of cross-cutting relationships. The cut rock layers are older than the rock that cuts across them.

Unconformities

Geologists can learn a lot about Earth's history by studying sedimentary rock layers. But in some places, there's a gap in time when no rock layers are present. A gap in the sequence of rock layers is called an **unconformity**.

Look at the rock layers in **Figure** 11.10. They show a feature called Hutton's unconformity. The unconformity was discovered by James Hutton in the 1700s. Hutton saw that the lower rock layers are very old. The upper layers are much younger. There are no layers in between the ancient and recent layers. Hutton thought that the intermediate rock layers eroded away before the more recent rock layers were deposited.

Hutton's discovery was a very important event in geology! Hutton determined that the rocks were deposited over time. Some were eroded away. Hutton knew that deposition and erosion are very slow. He realized that for both to occur would take an extremely long time. This made him realize that Earth must be much older than people thought. This was a really big discovery! It meant there was enough time for life to evolve gradually.

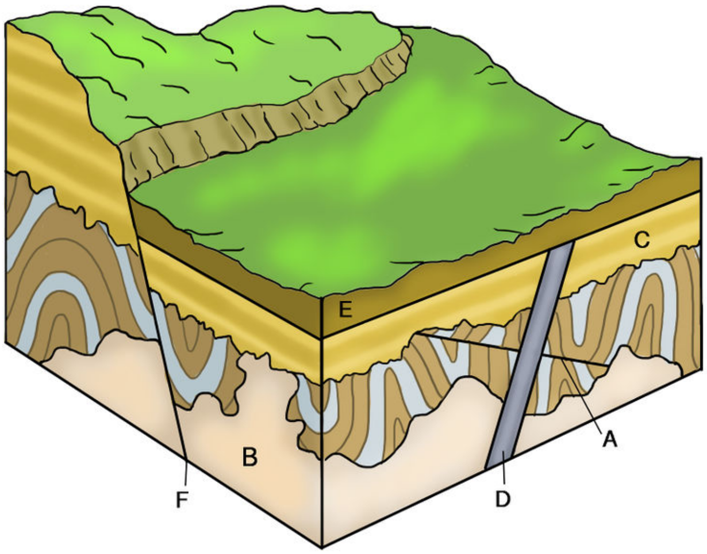


FIGURE 11.9
Cross-cutting relationships in rock layers. Rock D is a dike that cuts across all the other rocks. Is it older or younger than the other rocks?

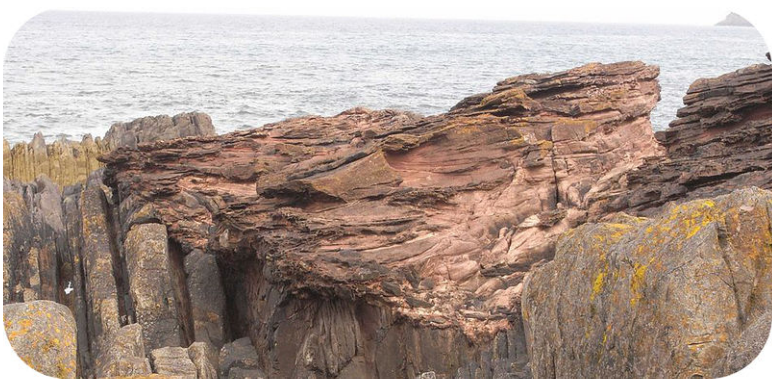


FIGURE 11.10
Hutton's unconformity, in Scotland.

Matching Rock Layers

When rock layers are in the same place, it's easy to give them relative ages. But what if rock layers are far apart? What if they are on different continents? What evidence is used to match rock layers in different places?

Widespread Rock Layers

Some rock layers extend over a very wide area. They may be found on more than one continent or in more than one country. For example, the famous White Cliffs of Dover are on the coast of southeastern England. These distinctive rocks are matched by similar white cliffs in France, Belgium, Holland, Germany, and Denmark (see **Figure** 11.11). It is important that this chalk layer goes across the English Channel. The rock is so soft that the Channel Tunnel connecting England and France was carved into it!

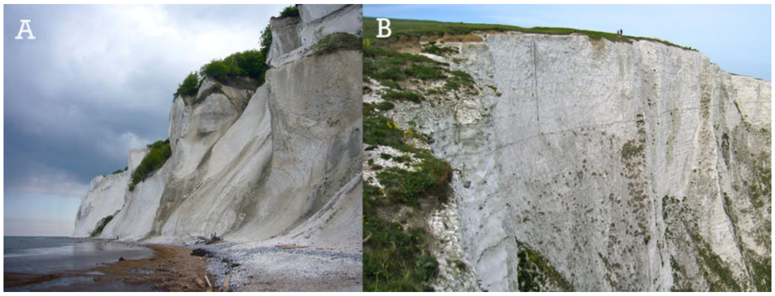


FIGURE 11.11
Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

Key Beds

Like index fossils, key beds are used to match rock layers. A **key bed** is a thin layer of rock. The rock must be unique and widespread. For example, a key bed from around the time that the dinosaurs went extinct is very important. A thin layer of clay was deposited over much of Earth's surface. The clay has large amount of the element iridium. Iridium is rare on Earth but common in asteroids. This unusual clay layer has been used to match rock up layers all over the world. It also led to the hypothesis that a giant asteroid struck Earth and caused the dinosaurs to go extinct.

Using Index Fossils

Index fossils are commonly used to match rock layers in different places. You can see how this works in **Figure** 11.12. If two rock layers have the same index fossils, then they're probably about the same age.

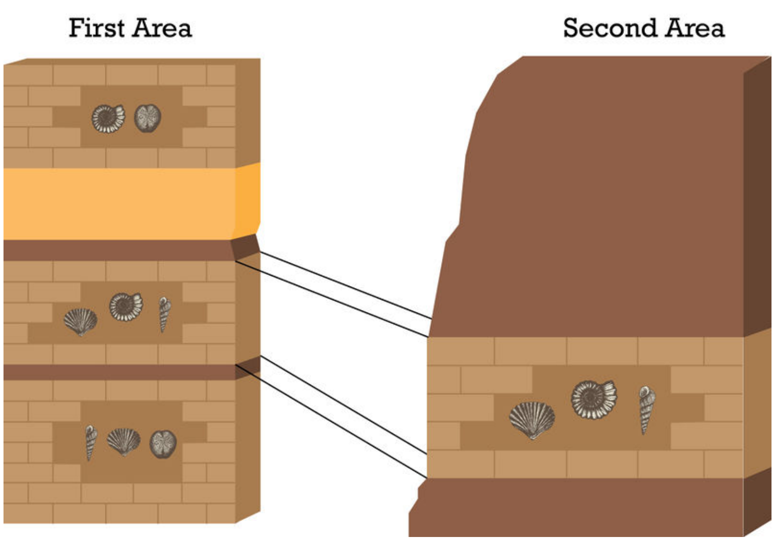


FIGURE 11.12
Using Index Fossils to Match Rock Layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

The Geologic Time Scale

Earth formed 4.5 billion years ago. Geologists divide this time span into smaller periods. Many of the divisions mark major events in life history.

Dividing Geologic Time

Divisions in Earth history are recorded on the **geologic time scale**. For example, the Cretaceous ended when the dinosaurs went extinct. European geologists were the first to put together the geologic time scale. So, many of the names of the time periods are from places in Europe. The Jurassic Period is named for the Jura Mountains in France and Switzerland, for example.

Putting Events in Order

To create the geologic time scale, geologists correlated rock layers. Steno's laws were used to determine the relative ages of rocks. Older rocks are at the bottom and younger rocks are at the top. The early geologic time scale could only show the order of events. The discovery of radioactivity in the late 1800s changed that. Scientists could determine the exact age of some rocks in years. They assigned dates to the time scale divisions. For example, the Jurassic began about 200 million years ago. It lasted for about 55 million years.

Divisions of the Geologic Time Scale

The largest blocks of time on the geologic time scale are called "eons." Eons are split into "eras." Each era is divided into "periods." Periods may be further divided into "epochs." Geologists may just use "early" or "late." An example is "late Jurassic," or "early Cretaceous." **Figure** 11.13 shows you what the geologic time scale looks like.

EON	ERA	PERIOD	MILLIONS OF YEARS AGO
Phanerozoic	Cenozoic	Quaternary	1.6
		Tertiary	66
	Mesozoic	Cretaceous	138
		Jurassic	205
		Triassic	240
	Paleozoic	Permian	290
		Pennsylvanian	330
		Mississippian	360
		Devonian	410
		Silurian	435
		Ordovician	500
		Cambrian	570
Proterozoic	Late Proterozoic Middle Proterozoic Early Proterozoic		2500
Archean	Late Archean Middle Archean Early Archean		3800?
Pre-Archean			

FIGURE 11.13
The Geologic Time Scale.

Life and the Geologic Time Scale

The geologic time scale may include illustrations of how life on Earth has changed. Major events on Earth may also be shown. These include the formation of the major mountains or the extinction of the dinosaurs. **Figure** 11.14 is a different kind of the geologic time scale. It shows how Earth's environment and life forms have changed.

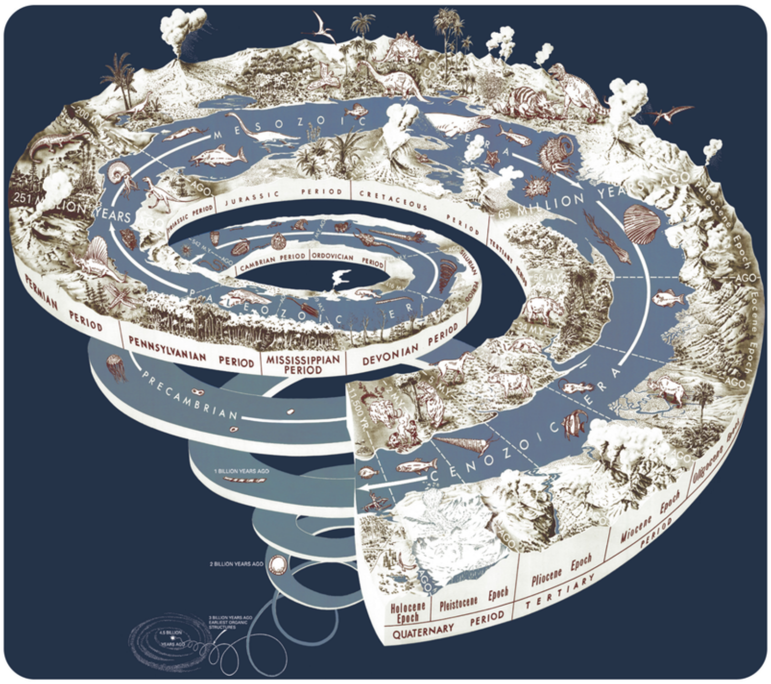


FIGURE 11.14

The evolution of life is shown on this spiral.

Your Place in Geologic Time

We now live in the Phanerozoic Eon, the Cenozoic Era, the Quaternary Period, and the Holocene Epoch. "Phanerozoic" means visible life. During this eon, rocks contain visible fossils. Before the Phanerozoic, life was microscopic. The Cenozoic Era means new life. It encompasses the most recent forms of life on Earth. The Cenozoic is sometimes called the Age of Mammals. Before the Cenozoic came the Mesozoic and Paleozoic. The Mesozoic means middle life. This is the age of reptiles, when dinosaurs ruled the planet. The Paleozoic is old life. Organisms like invertebrates and fish were the most common lifeforms.

Lesson Summary

- The study of rock layers is called stratigraphy. Laws of stratigraphy help scientists determine the relative ages of rocks. The main law is the law of superposition. This law states that deeper rock layers are older than layers closer to the surface.
- An unconformity is a gap in rock layers. They occur where older rock layers eroded away completely before new rock layers were deposited.
- Other clues help determine the relative ages of rocks in different places. They include key beds and index fossils.
- Scientists use the geologic time scale to illustrate the order in which events on Earth have happened.

- The geologic time scale was developed after scientists observed changes in the fossils going from oldest to youngest sedimentary rocks. They used relative dating to divide Earth's past in several chunks of time when similar organisms were on Earth.
- The geologic time scale is divided into eons, eras, periods, and epochs.

Lesson Review Questions

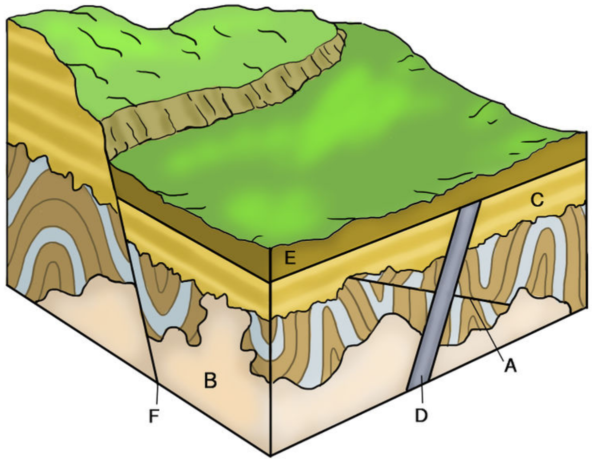
Recall

1. Define stratigraphy.
2. What is the relative age of a rock?
3. State the law of superposition.
4. What are unconformities?
5. How do key beds help date rock layers?

Apply Concepts

6. Apply laws of stratigraphy to explain the rock formation below.

7. Which rock in the illustration below formed first, the igneous rock (A) or the sedimentary rock (B)? Apply lesson concepts to support your answer.



8. Why did early geologic time scales not include the number of years ago that events happened?

Think Critically

9. Use the law of lateral continuity to explain why the same rock layers are found on opposite sides of the Grand Canyon.

10. Dinosaurs went extinct about 66 million years ago. Which period of geologic time was the last in which dinosaurs lived?

11. Why are sedimentary rocks more useful than metamorphic or igneous rocks in establishing the relative ages of rock?

Points to Consider

In this lesson, you read how scientists determine the relative ages of sedimentary rock layers. The law of superposition determines which rock layers are younger or older than others.

- What about the actual ages of rocks? Is there a way to estimate their ages in years?
- And what about other kinds of rocks? For example, is there a way to estimate the ages of igneous rocks?

11.3 Absolute Ages of Rocks

Lesson Objectives

- Describe radioactive decay.
- Explain radiometric dating.

Vocabulary

- absolute age
- carbon-14 dating
- half-life
- isotope
- radioactive decay
- radiometric dating

Introduction

The age of a rock in years is its **absolute age**. Absolute ages are much different from relative ages. The way of determining them is different, too. Absolute ages are determined by radiometric methods, such as carbon-14 dating. These methods depend on radioactive decay.

Radioactive Decay

Radioactive decay is the breakdown of unstable elements into stable elements. To understand this process, recall that the atoms of all elements contain the particles protons, neutrons, and electrons.

Isotopes

An element is defined by the number of protons it contains. All atoms of a given element contain the same number of protons. The number of neutrons in an element may vary. Atoms of an element with different numbers of neutrons are called **isotopes**.

Consider carbon as an example. Two isotopes of carbon are shown in **Figure** 11.15. Compare their protons and neutrons. Both contain 6 protons. But carbon-12 has 6 neutrons and carbon-14 has 8 neutrons.

Almost all carbon atoms are carbon-12. This is a stable isotope of carbon. Only a tiny percentage of carbon atoms are carbon-14. Carbon-14 is unstable. **Figure** 11.16 shows carbon dioxide, which forms in the atmosphere from

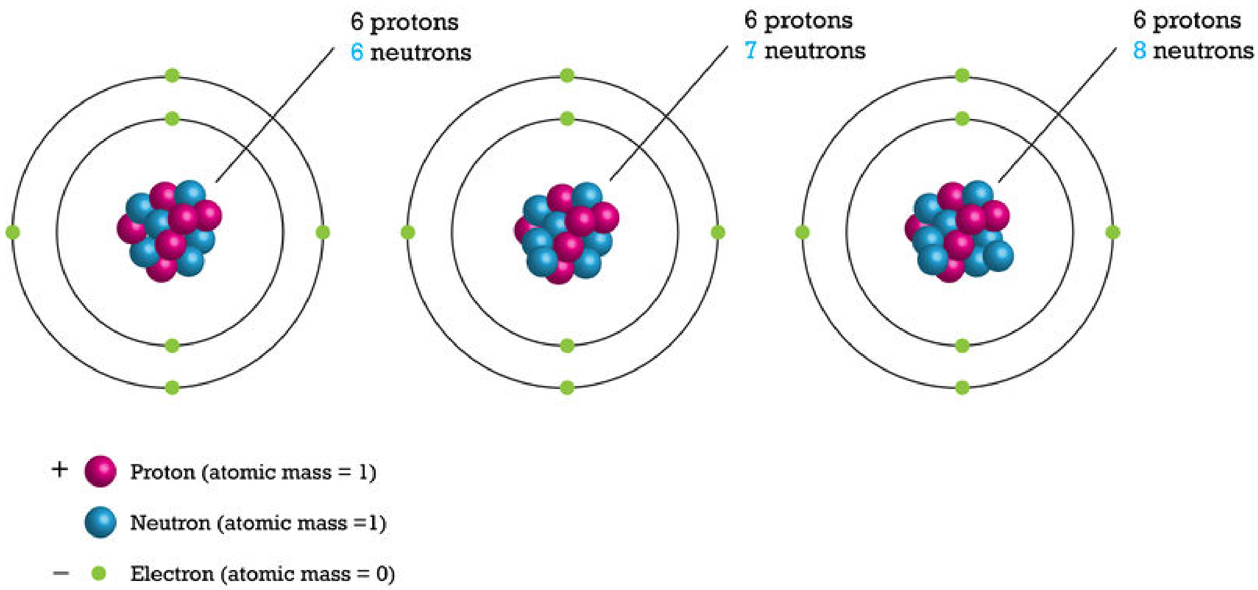


FIGURE 11.15
Isotopes are named for their number of protons plus neutrons. If a carbon atom had 7 neutrons, what would it be named?

carbon-14 and oxygen. Neutrons in cosmic rays strike nitrogen atoms in the atmosphere. The nitrogen forms carbon-14. Carbon in the atmosphere combines with oxygen to form carbon dioxide. Plants take in carbon dioxide during photosynthesis. In this way, carbon-14 enters food chains.

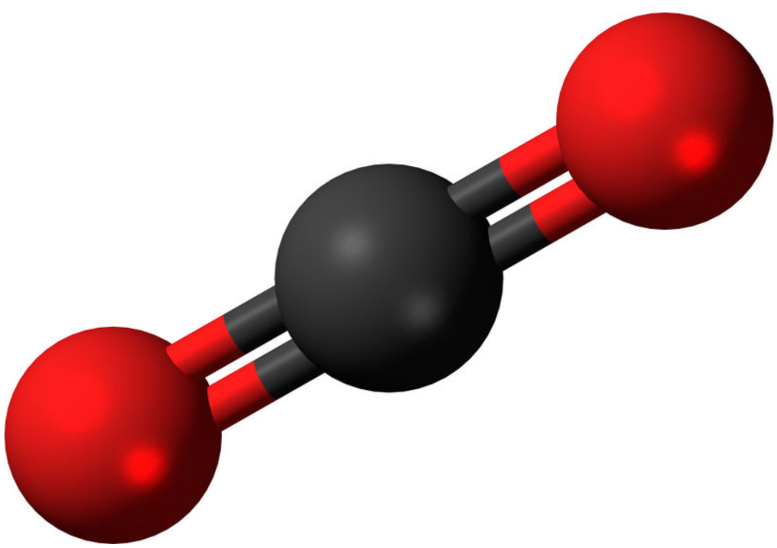


FIGURE 11.16
Carbon-14 forms in the atmosphere. It combines with oxygen and forms carbon dioxide. How does carbon-14 end up in fossils?

Decay of Unstable Isotopes

Like other unstable isotopes, carbon-14 breaks down, or decays. For carbon-14 decay, each carbon-14 atom loses an alpha particle. It changes to a stable atom of nitrogen-14. This is illustrated in **Figure** 11.17.

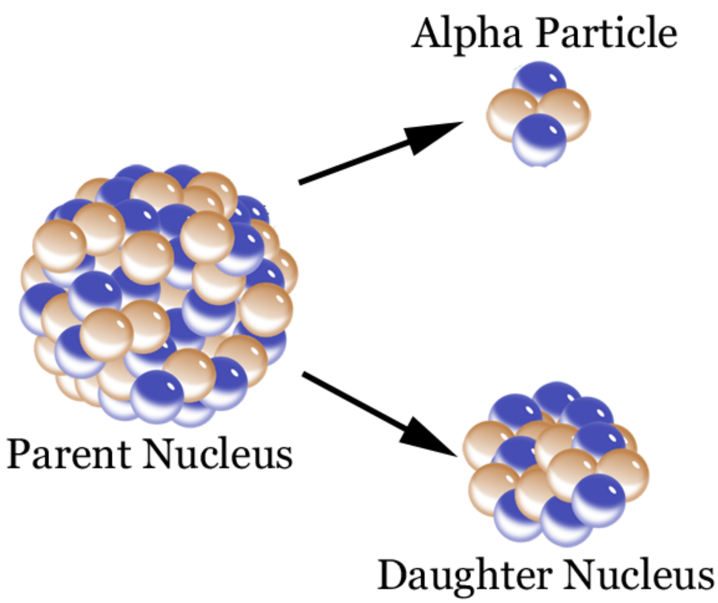


FIGURE 11.17
Unstable isotopes, such as carbon-14, decay by losing atomic particles. They form different, stable elements when they decay. In this case, the daughter is nitrogen-14.

The decay of an unstable isotope to a stable element occurs at a constant rate. This rate is different for each isotope pair. The decay rate is measured in a unit called the half-life. The **half-life** is the time it takes for half of a given amount of an isotope to decay. For example, the half-life of carbon-14 is 5730 years. Imagine that you start out with 100 grams of carbon-14. In 5730 years, half of it decays. This leaves 50 grams of carbon-14. Over the next 5730 years, half of the remaining amount will decay. Now there are 25 grams of carbon-14. How many grams will there be in another 5730 years? **Figure** 11.18 graphs the rate of decay of carbon-14.

Radiometric Dating

The rate of decay of unstable isotopes can be used to estimate the absolute ages of fossils and rocks. This type of dating is called **radiometric dating**.

Carbon-14 Dating

The best-known method of radiometric dating is **carbon-14 dating**. A living thing takes in carbon-14 (along with stable carbon-12). As the carbon-14 decays, it is replaced with more carbon-14. After the organism dies, it stops taking in carbon. That includes carbon-14. The carbon-14 that is in its body continues to decay. So the organism contains less and less carbon-14 as time goes on. We can estimate the amount of carbon-14 that has decayed by measuring the amount of carbon-14 to carbon-12. We know how fast carbon-14 decays. With this information, we can tell how long ago the organism died.

Carbon-14 has a relatively short half-life. It decays quickly compared to some other unstable isotopes. So carbon-14 dating is useful for specimens younger than 50,000 years old. That's a blink of an eye in geologic time. But

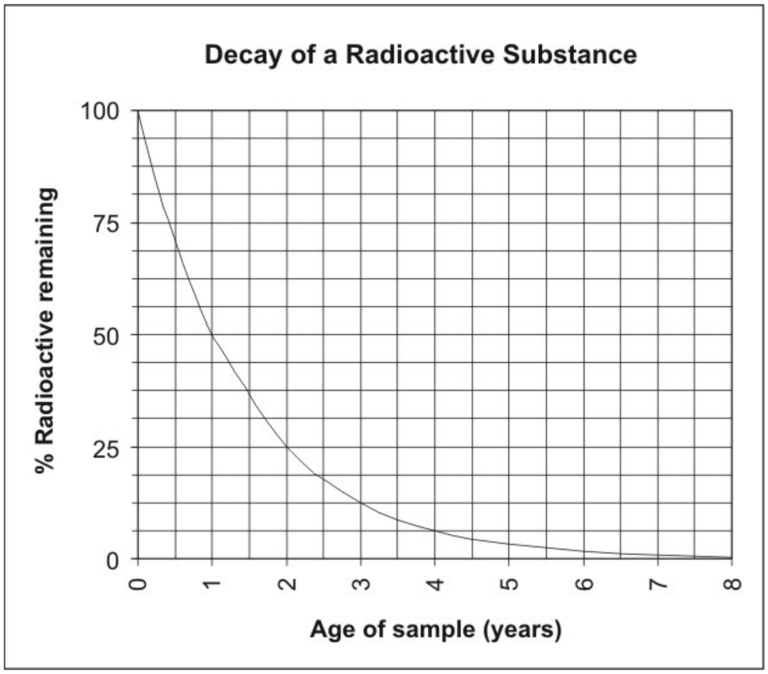


FIGURE 11.18
The rate of decay of carbon-14 is stable over time.

radiocarbon dating is very useful for more recent events. One important use of radiocarbon is early human sites. Carbon-14 dating is also limited to the remains of once-living things. To date rocks, scientists use other radioactive isotopes.

Other Radioactive Isotopes

The isotopes in **Table** 11.1 are used to date igneous rocks. These isotopes have much longer half-lives than carbon-14. Because they decay more slowly, they can be used to date much older specimens. Which of these isotopes could be used to date a rock that formed half a million years ago?

TABLE 11.1: Isotope Rock Dating

Unstable Isotope	Decays to	At a Half-Life of (years)	Dates Rocks Aged (years old)
Potassium-40	Argon-40	1.3 billion	100 thousand – 1 billion
Uranium-235	Lead-207	700 million	1 million – 4.5 billion
Uranium-238	Lead-206	4.5 billion	1 million – 4.5 billion

Lesson Summary

- The age of a rock in years is its absolute age. The main evidence for absolute age comes from radiometric dating methods, such as carbon-14 dating. These methods depend on radioactive decay.
- Radioactive decay is the breakdown of unstable isotopes into stable elements. For example, carbon-14 is an unstable isotope of carbon that decays to the stable element nitrogen-14. The rate of decay of an isotope is measured in half-lives. A half-life is the time it takes for half a given amount of an isotope to decay.
- Radiometric dating uses the rate of decay of unstable isotopes to estimate the absolute ages of fossils and rocks. Carbon-14 can be used to date recent organic remains. Other isotopes can be used to date igneous rocks that are much older.

Think Critically

7. Explain how carbon-14 dating works.
8. Compare and contrast carbon-14 dating and potassium-40 dating.

Points to Consider

Scientists estimate the ages of rock layers in order to better understand Earth's history and the history of life.

- What do you already know about Earth's history? For example, do you know how Earth formed?
- How old is Earth? When did the planet first form? And when did life first appear?

11.4 References

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CHAPTER 12 MS Earth's History

Chapter Outline

Bubbling mud in Yellowstone National Park may resemble what the early Earth looked like. Of course, no one was there to see it so no one knows for sure.

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12.1 The Origin of Earth

Lesson Objectives

- Describe how the solar system formed more than 4 billion years ago.
- Explain how Earth's atmosphere has changed over time.
- Explain the conditions that allowed the first forms of life to develop on Earth.

Vocabulary

- atmosphere
- nuclear fusion
- water vapor

Introduction

Imagine a giant camera in space. That camera has recorded pictures of Earth over the last 4.6 billion years. How do you think Earth looked at different times? How do you think it changed?

Formation the Solar System

Our solar system began about 5 billion years ago. The Sun, planets and other solar system objects all formed at about the same time.

The Solar Nebula

The Sun and planets formed from a giant cloud of gas and dust. This was the solar nebula. The cloud contracted and began to spin. As it contracted, its temperature and pressure increased. The cloud spun faster, and formed into a disk. Scientists think the solar system at that time looked like these disk-shaped objects in the Orion Nebula (**Figure** 12.1). New stars are forming in the Orion Nebula today.

Solar System Bodies Form

Temperatures and pressures at the center of the cloud were extreme. It was so hot that **nuclear fusion** reactions began. In these reactions hydrogen fuses to make helium. Extreme amounts of energy are released. Our Sun became a star! Material in the disk surrounding the Sun collided. Small particles collided and became rocks. Rocks collided and became boulders. Eventually planets formed from the material (**Figure** 12.2). Dwarf plants, comets, and asteroids formed too (**Figure** 12.3).

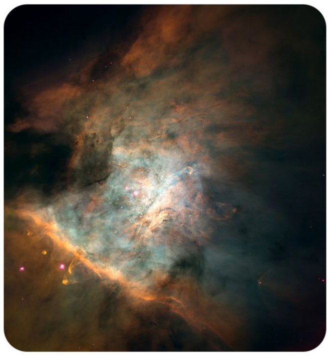


FIGURE 12.1
The Orion Nebula is the birthplace of new stars.

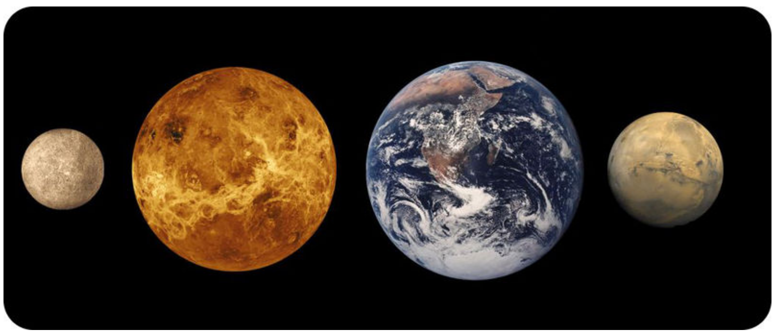


FIGURE 12.2
The Inner Planets.

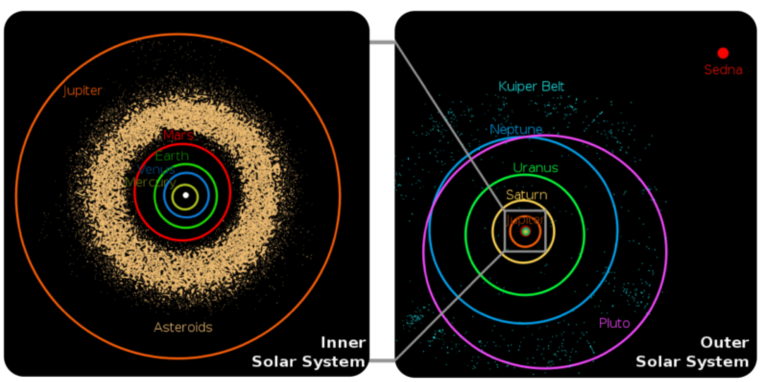


FIGURE 12.3
The Kuiper Belt, a ring of icy debris in our solar system just beyond Neptune, contains many solar system bodies.

Formation Earth and Moon

Material at a similar distances from the Sun collided together to form each of the planets. Earth grew from material in its part of space. Moon's origin was completely different from Earth's.

Earth Forms

Earth formed like the other planets. Different materials in its region of space collided. Eventually the material made a planet. All of the collisions caused Earth to heat up. Rock and metal melted. The molten material separated into layers. Gravity pulled the denser material into the center. The lighter elements rose to the surface (**Figure** 12.4). Because the material separated, Earth's core is made mostly of iron. Earth's crust is made mostly of lighter materials. In between the crust and the core is Earth's mantle, made of solid rock.

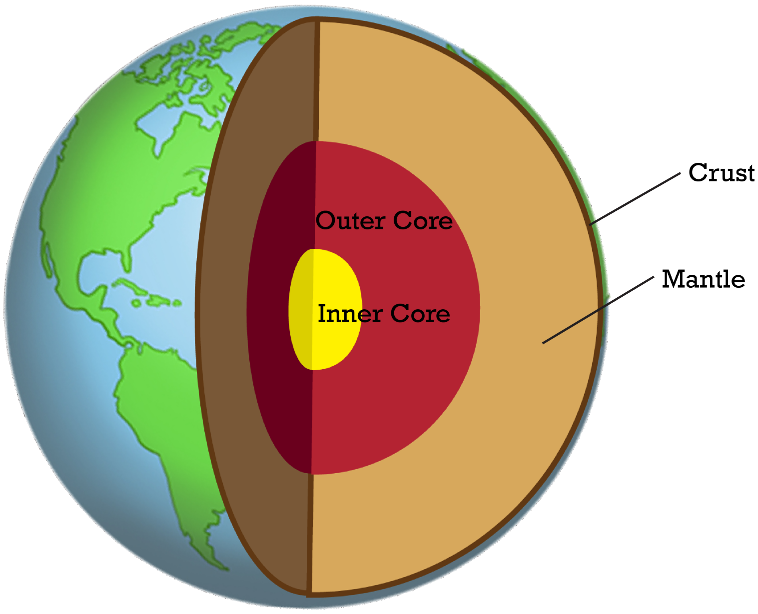


FIGURE 12.4
Earth's layers.

Moon Forms

This model for how the Moon formed is the best fit of all of the data scientists have about the Moon.

In the early solar system there was a lot of space debris. Asteroids flew around, sometimes striking the planets. An asteroid the size of Mars smashed into Earth. The huge amount of energy from the impact melted most of Earth. The asteroid melted too. Material from both Earth and the asteroid was thrown out into orbit. Over time, this material smashed together to form our Moon. The lunar surface is about 4.5 billion years old. This means that the collision happened about 70 million years after Earth formed.

Formation of the Atmosphere and Oceans

An **atmosphere** is the gases that surround a planet. The early Earth had no atmosphere. Conditions were so hot that gases were not stable.

Earth's First Atmosphere

Earth's first atmosphere was different from the current one. The gases came from two sources. Volcanoes spewed gases into the air. Comets carried in ices from outer space. These ices warmed and became gases. Nitrogen, carbon dioxide, hydrogen, and **water vapor**, or water in gas form, were in the first atmosphere (**Figure** 12.5). Take a look at the list of gases. What's missing? The early atmosphere had almost no oxygen.

FIGURE 12.5
Gases from Earth's interior came through volcanoes and into the atmosphere.

The Early Oceans

Earth's atmosphere slowly cooled. Once it was cooler, water vapor could condense. It changed back to its liquid form. Liquid water could fall to Earth's surface as rain.

Over millions of years water collected to form the oceans. Water began to cycle on Earth as water evaporated from the oceans and returned again as rainfall.

Lesson Summary

- Our solar system began about 5 billion years ago as a nebula contracted, forming our Sun and the planets.
- Early Earth was a hostile world. The planet was continually bombarded by asteroids. Volcanoes erupted continually, spewing lava and gases into the air.
- Early on the planet was too hot for liquid water or an atmosphere. Eventually both formed.

Lesson Review Questions

Recall

1. What was the solar nebula? Why was it important in the early solar system?

2. Describe how Earth formed?

Apply Concepts

3. Why was nuclear fusion important in the early solar system?

4. Why was the early atmosphere different from the atmosphere we have today?

Think Critically

5. Describe how the different layers of the Earth vary by density.

6. List three ways the Earth is different today from when it was first formed.

7. Suppose that the Earth had been much cooler when it first formed. How would the Earth's interior be different than it is today?

Points to Consider

- How did life on Earth originate?
- What were early landmasses like?
- What happened when large amounts of oxygen entered the atmosphere?

12.2 Early Earth

Lesson Objectives

- Describe the supercontinents that have existed in Earth history.
- Discuss how life began and what early life was like.
- Trace the evolution of life from the first cells to multi-cellular organisms.

Vocabulary

- DNA (deoxyribonucleic acid)
- eukaryote
- nucleic acid
- prokaryote
- RNA (ribonucleic acid)
- supercontinent

Introduction

Earth has changed many times over billions of years. Huge mountains have formed, been destroyed, and been replaced with new mountains. Continents have moved, split apart and collided with each other. Ocean basins have opened up. Life on Earth evolved slowly for billions of years.

Early Continents

The earliest crust was probably basalt. It may have resembled the current seafloor. This crust formed before there were any oceans. More than 4 billion years ago, continental crust appeared. The first continents were very small compared with those today.

Continents Grow

Continents grow when **microcontinents**, or small continents, collide with each other or with a larger continent. Oceanic island arcs also collide with continents to make them grow.

Supercontinents

There are times in Earth history when all of the continents came together to form a **supercontinent**. Supercontinents come together and then break apart. Pangaea was the last supercontinent on Earth, but it was not the first. The supercontinent before Pangaea is called Rodinia. Rodinia contained about 75% of the continental landmass that is present today. The supercontinent came together about 1.1 billion years ago. Rodinia was not the first supercontinent either. Scientists think that three supercontinents came before Rodina, making five so far in Earth history.

Early Plate Tectonics

Since the early Earth was very hot, mantle convection was very rapid. Plate tectonics likely moved very quickly. The early Earth was a very active place with abundant volcanic eruptions and earthquakes. The remnants of these early rocks are now seen in the ancient cores of the continents.

Ancient Life

For the first 4 billion years of Earth history there is only a little evidence of life. Organisms were tiny and soft and did not fossilize well. But scientists use a variety of ways to figure out what this early life was like.

Life Begins

Life probably began in the oceans. No one knows exactly how or when. Life may have originated more than once. If life began before the Moon formed, that impact would have wiped it out and it would have had to originate again. Eventually conditions on Earth became less violent. The planet could support life.

The first organisms were made of only one cell (**Figure** 12.6). The earliest cells were **prokaryotes**. Prokaryotic cells are surrounded by a cell membrane, but they do not have a nucleus. The cells got their nutrients directly from the water. The cells needed to use these nutrients to live and grow.

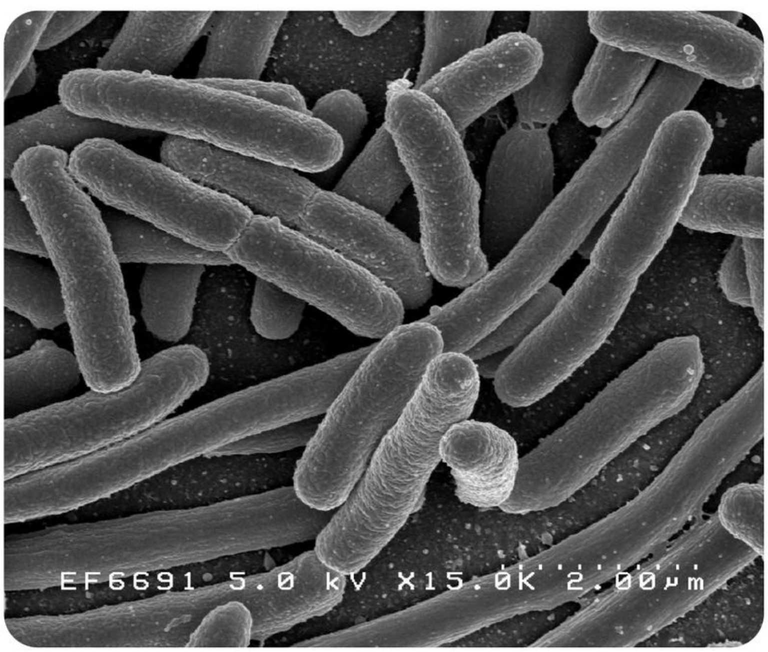


FIGURE 12.6
E. coli (Escherichia coli) is a primitive prokaryote that may resemble the earliest cells.

The cells also needed to be able to make copies of themselves. To do this they stored genetic information in **nucleic acids**. The two nucleic acids are **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid). Nucleic acids pass genetic instructions to the next generation.

Oxygen Enters the Atmosphere

Early cells took nutrients from the water. Eventually the nutrients would have become less abundant.

Around 3 billion years ago, photosynthesis began. Organisms could make their own food from sunlight and inorganic molecules. From these ingredients they made chemical energy that they used. Oxygen is a waste product of photosynthesis. That first oxygen combined with iron to create iron oxide. Later on, the oxygen entered the atmosphere.

Some of the oxygen in the atmosphere became ozone. The ozone layer formed to protect Earth from harmful ultraviolet radiation. This made the environment able to support more complex life forms.

Early Organisms

The first organisms to photosynthesize were cyanobacteria. These organisms may have been around as far back as 3.5 billion years and are still alive today (**Figure** 12.7). Now they are called blue-green algae. They are common in lakes and seas and account for 20% to 30% of photosynthesis today.

FIGURE 12.7
These rocks in Glacier National Park, Montana may contain some of the oldest fossil microbes on Earth.

Life Gets More Complex

Eukaryotes evolved about 2 billion years ago. Unlike prokaryotes, **eukaryotes** have a cell nucleus. They have more structures and are better organized. Organelles within a eukaryote can perform certain functions. Some supply energy; some break down wastes. Eukaryotes were better able to live and so became the dominant life form.

Multi-Cellular Life Originates

For life to become even more complex, multicellular organisms needed to evolve. Prokaryotes and eukaryotes can be multicellular.

Toward the end of the Precambrian, the Ediacara Fauna evolved (**Figure** 12.8). These are the fossils discovered by Walcott in the introduction to the next section. The Ediacara was extremely diverse. They appeared after Earth defrosted from a worldwide glaciation. The Ediacara fauna seem to have died out. Other multicellular organisms appeared in the Phanerozoic.

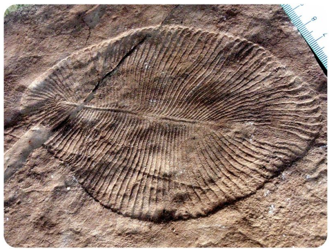


FIGURE 12.8
This fossil is from the Ediacara Fauna. Nothing alive today seems to have evolved from the Ediacara organisms.

Lesson Summary

- The first continents were small but they grew over time. Supercontinents have formed at least five times in Earth history.
- Earth was so hot that mantle convection was very rapid. Plates moved quickly.
- The first organisms were prokaryotes. Eukaryotes came on the scene about 2 billion years ago.
- After photosynthesis developed, the atmosphere slowly became more oxygen-rich. Cyanobacteria were dominant. Eventually the atmosphere accumulated free oxygen.

Lesson Review Questions

Recall

1. Why is the ozone layer important for Earth's life forms?
2. Describe the role of cyanobacteria in changing Earth's early atmosphere.

Apply Concepts

3. Explain two reasons why having an oxygen-rich atmosphere is important for life on Earth.

Think Critically

4. Describe a world without free oxygen in the atmosphere.
5. Why did life take so long to evolve seemingly small changes, like from prokaryote to eukaryote?
6. Is it possible that the planet could still be home only to prokaryotic cells?

Points to Consider

- Early life was very simple by comparison with the biodiversity we see today. How did so much diversity come to be?
- How do organisms change through time (how do they evolve)?
- Are humans the pinnacle of evolution?

12.3 History of Earth's Life Forms

Lesson Objectives

- Describe how adaptations develop.
- Explain how the fossil record shows us that species evolve over time.
- Describe the general development of Earth's life forms over the last 540 million years.

Vocabulary

- adaptation
- evolution
- paleontologist
- tropical
- variation

Introduction

In the summer of 1909, an American paleontologist named Charles Doolittle Walcott (**Figure** 12.9) was searching for fossils. His location was the Rocky Mountains of British Columbia, Canada. Riding on horseback, he noticed a fossil on the ground. He dug around and found even more fossils. These were some of the most bizarre organisms anyone had ever seen! One of the organisms had a soft body like a worm, five eyes, and a long nose like a vacuum cleaner hose. Nothing of the kind is alive today.

FIGURE 12.9

Charles Doolittle Walcott, an American paleontologist, discovered the fossils of numerous bizarre organisms.

These organisms lived during the Cambrian Period. The Cambrian marked the beginning of the Phanerozoic Eon. This time began about 540 million years ago. Many new and complex life forms began appearing on Earth. We still live in the Phanerozoic Eon. But life on Earth is very different today than it was 540 million years ago.

Biological Diversity

There are over 1 million species of plants and animals living on Earth today. Scientists think that there are millions more that have not yet been discovered.

Ways to Live in the Environment

Each organism has the ability to survive in a specific environment. Dry desert environments are difficult to live in. Desert plants have special stems and leaves to conserve water. Animals have other ways to live in the desert. The Namib Desert receives only 1.5 inches of rainfall each year. The Namib Desert beetle lives there. How do the beetles get enough water to survive? Early morning fog deposits water droplets. The droplets collect on a beetle's wings and back. The beetle tilts its rear end up. When the droplet is heavy enough, it slides forward. It lands in the beetle's mouth. There are many other environments that need unique approaches for survival (**Figure** 12.10).

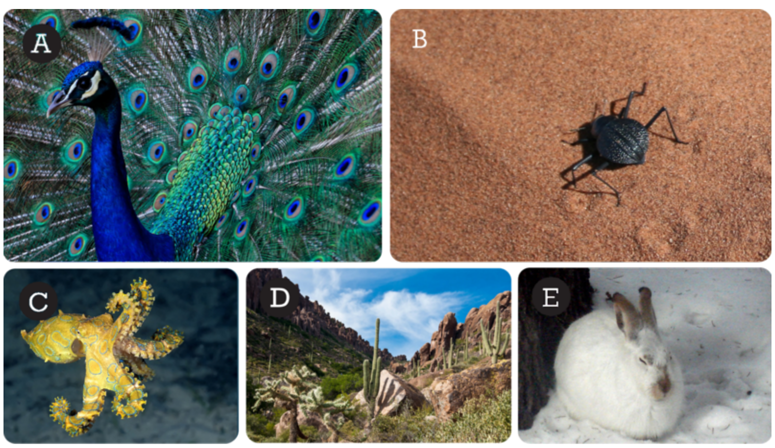


FIGURE 12.10

(A) Peacocks have tremendous feather displays to attract mates. (B) The Namib Desert Beetle has bumps on its back for collecting water. (C) Octopuses use their eight arms to hold on to the ground, hold on to prey and to escape predators. (D) Saguaro cacti are adapted for conserving water in the desert. (E) A mountain hare is well camouflaged in snow in winter.

Getting Food and Being Food (Or Not)

Organisms must be able to get food and avoid being food. Hummingbirds have long, thin beaks that help them drink nectar from flowers. Some flowers are tubular to fit hummingbird beaks. The battle between needing food and being food plays out in the drama between lions and zebras. When a herd of zebras senses a lion, the animals run away. The zebras' dark stripes confuse the lions. It becomes hard for them to focus on just one zebra. The zebras may get away. But lions are swift and agile. A lion may be able to get a zebra, maybe one that's old or sick.

Variation and Adaptation

Every organism is different from every other organism. Every organism's genes are different, too.

Variations

There are **variations** in the traits of a population. For example, there are lots of variations in the color of human hair. Hair can be blonde, brown, black, or even red. Hair color is a trait determined by genes.

Mutations

At some point, the variation probably came from a mutation. A **mutation** is a random change in an organism's genes. Mutations are natural. Some are harmful, but many are neutral. If the trait from the mutation is beneficial, that organism may have a better chance to survive. An organism that survives is likely to have offspring. If it does, it may pass the mutation on to its offspring. The offspring may be more likely to survive.

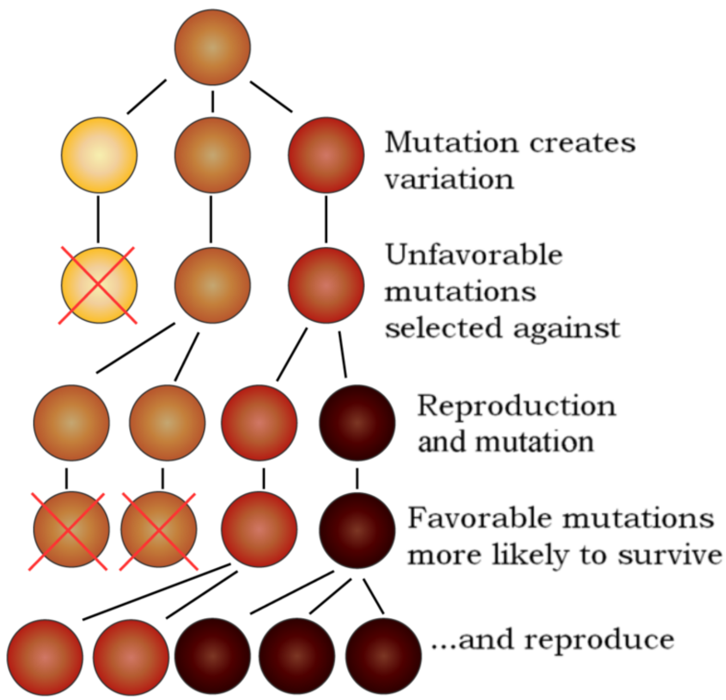


FIGURE 12.11
Genetic mutation is central to the creation of biological diversity.

Adaptations

Some of the characteristics an organism has may help it survive. These characteristics are called **adaptations**. Some adaptations are better than others.

Adaptations develop this way. Think about a population of oak trees. Imagine that a fungus has arrived from Asia to North America. Most of the North American are killed by the fungus. But a few oak trees have a mutation that allows them to survive the fungus. Those oak trees are better adapted to the new environment than the others. Those trees have a better chance of surviving. They will probably reproduce. The trees may pass on the favorable mutation to their offspring. The other trees will die. Eventually, the population of oak trees will change. Most of the trees will have the trait to survive the fungus. This is an adaptation. Over time, traits that help an organism survive become more common. Traits that hinder survival eventually disappear.

Biological Evolution

Adaptations in a species add up. If the environment is stable, the species won't change. But if the environment is changing, the species will need to adapt. Many adaptations may be necessary. In time, the species may change a lot. The descendants will be very different from their ancestors. They may even become a new species. This process is called **evolution**. Evolution happens as a species changes over time.

Organisms alive today evolved from earlier life forms. We can learn about this from fossils. For example, horse fossils from 60 million years ago are very different from modern horses. Ancient horses were much smaller than they are today (**Figure** 12.12). The horses' teeth and hooves have also changed. The horses evolved because of changes in their environment.

Studying the Fossil Record

Most of the organisms that once lived on Earth are now extinct. Earth's environment has changed many times. Many organisms could not adapt to the changes. They died out. The organisms that did survive passed traits on to their offspring. The changes added up, eventually producing the species we see today.

We study fossils to see the organisms that lived at certain times. We can see how those organisms changed with time. We can see how they evolved.

Phanerozoic Eon

The Phanerozoic Eon is divided into three eras —the Paleozoic, the Mesozoic, and the Cenozoic (**Table** 12.1). They span from about 540 million years ago to the present. We live now in the Cenozoic Era.

Earth's climate changed numerous times during the Phanerozoic Eon. Just before the beginning of the Phanerozoic Eon, much of the Earth was covered with glaciers. As the Phanerozoic Eon began, the climate became a warm and humid **tropical** climate. During the Phanerozoic, Earth's climate has gone through at least 4 major cycles between times of cold glaciers and times of warm tropical seas. Some organisms survived environmental changes in the climate; others became extinct when the climate changed beyond their capacity to cope with it.

The Cambrian Explosion

The warm, humid climate of the early Cambrian allowed life to expand and diversify. This brought the Cambrian Explosion. Life exploded both in diversity and in quantity!

By the beginning of the Paleozoic, organisms had developed shells. Shells could hold their soft tissues together. They could protect the organisms from predators and from drying out. Some organisms evolved external skeletons, called exoskeletons. Organisms with hard parts also make good fossils. Fossils from the Cambrian are much more abundant than fossils from the Precambrian.

There was much more diversity, so complex ecosystems could develop (**Figure** 12.14). All of this was in the seas.

Paleozoic Era

Paleozoic life was most diverse in the oceans. Paleozoic seas were full of worms, snails, clams, trilobites, sponges, and brachiopods. Organisms with shells were common.

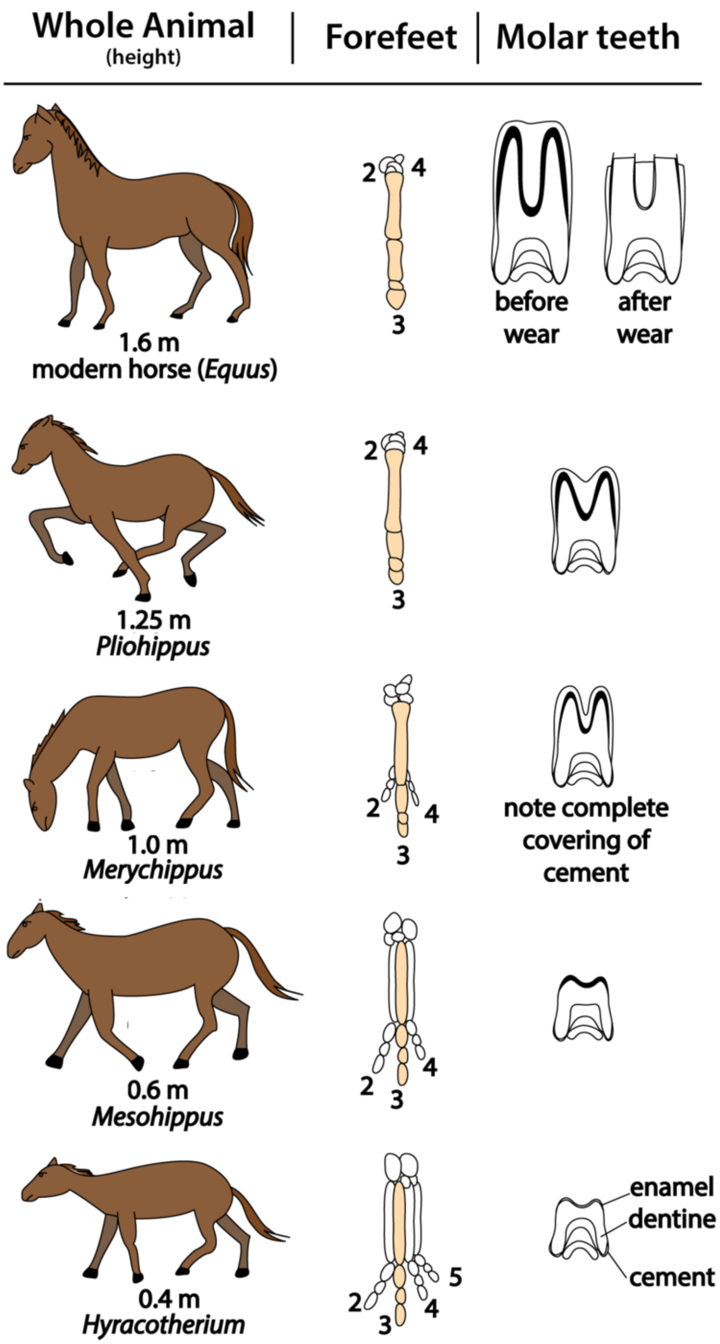


FIGURE 12.12
Ancient horses were quite different from present-day horses.

The first fish were simple, armored, jawless fish. Fish have internal skeletons. Some, like sharks, skates, and rays, have skeletons of cartilage. More advanced fish have skeletons of bones. Fish evolved jaws and many other adaptations for ocean life. **Figure** 12.13 shows some of the diversity of Earth's oceans.

Moving onto Land

An organism that lives in water is supported by the water. It does not need strong support structures. It also does not need to be protected against drying out. This is not true of land. Moving from the seas to land required many adaptations.

FIGURE 12.13
Mudskippers are fish that are able to walk short distances.

Algae had covered moist land areas for millions of years. By about 450 million years ago, plants began to appear on land. Once there were land plants, animals had a source of food and shelter. To move to land, animals needed strong skeletons. They needed protection from drying out. They needed to be able to breathe air. Eventually they had skeletons, lungs and the other the adaptations they needed moved onto the land.

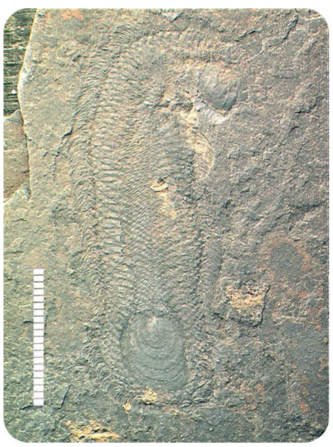


FIGURE 12.14
Halkieria, or scale worms, are an example of a fossil life from the Cambrian.

One group of fish evolved into amphibians. Insects and spiders were already land dwellers by the time amphibians appeared.

The Mesozoic Era

The Mesozoic Era is the age of reptiles. Mostly we think of it as the age of dinosaurs. Earth was populated by an enormous diversity of reptiles. Some were small and some were tremendously large. Some were peaceful plant eaters. Some were extremely frightening meat eaters. Some dinosaurs developed protection, such as horns, spikes, tail clubs, and shielding plates. These adaptations were defense against active predators.

Most dinosaurs lived on land. Still, pterosaurs flew the skies. Plesiosaurs and ichthyosaurs swam in the oceans (**Figure** 12.15). Feathered dinosaurs gave rise to birds.

FIGURE 12.15
Plesiosaurs were swimming dinosaurs.

The Cenozoic Era

The Cenozoic Era is the age of mammals. The Cenozoic began with the extinction of every land creature larger than a dog. The most famous victims were the dinosaurs.

Mammals have the ability to regulate body temperature. This is an advantage, as Earth's climate went through sudden and dramatic changes. Mastodons, saber tooth tigers, hoofed mammals, whales, primates and eventually humans all lived during the Cenozoic Era (**Figure** 12.16).

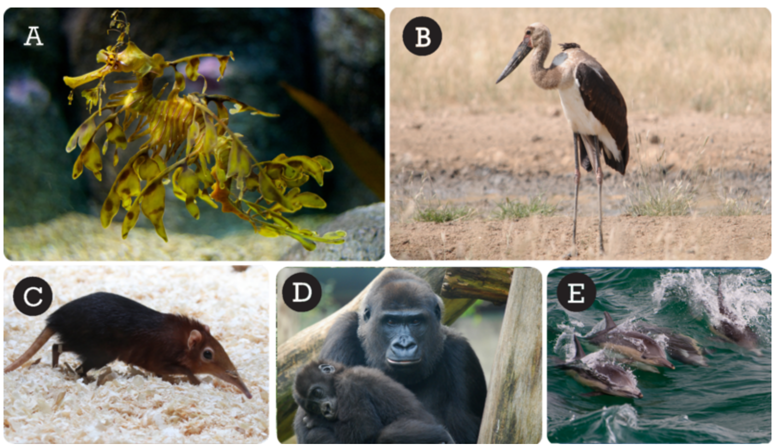


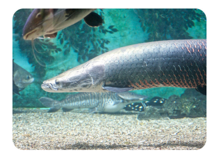
FIGURE 12.16
(A) A sea dragon is a type of fish. (B) African maribou. (C) Elephant shrew. (D) A mountain gorilla mother holding her baby. (E) A dolphin pod.

Table 12.1 shows some of the life forms that developed during the Phanerozoic Eon. Life gradually became more diverse and new species appeared. Most modern organisms evolved from species that are now extinct.

TABLE 12.1: Development of Life During the Phanerozoic Eon

Era	Millions of Years Ago	Major Forms of Life
Cenozoic	0.2 (200,000 years ago)	First humans
	35	First grasses; grasslands begin to dominate the land
Mesozoic	130	First plants with flowers
	150	First birds on Earth
	200	First mammals on Earth

TABLE 12.1: (continued)

Era	Millions of Years Ago	Major Forms of Life
	251	Age of dinosaurs begins 
Paleozoic	300	First reptiles on Earth
	360	First amphibians on Earth
	400	First insects on Earth
	475	First plants and fungi begin growing on land
	500	First fish on Earth 

Mass Extinctions

The eras of the Phanerozoic Eon are separated by mass extinctions. During these events, large numbers of organisms became extinct very rapidly. There have been several extinctions in the Phanerozoic but two stand out more than the others.

Permian Extinction

Between the Paleozoic Era and the Mesozoic Era was the largest mass extinction known. At the end of the Permian, nearly 95% of all marine species died off. In addition, 70% of land species became extinct. No one knows the cause of this extinction. Some scientists blame an asteroid impact. Other scientists think it was a gigantic volcanic eruption.

Cretaceous Extinction

The most famous mass extinction was 65 million years ago. Between the Mesozoic Era and the Cenozoic Era, about 50% of all animal species died off. This mass extinction is when the dinosaurs became extinct. Most scientists think that the extinction was caused by a giant meteorite that struck Earth. The impact heated the atmosphere until it became as hot as a kitchen oven. Animals roasted. Dust flew into the atmosphere and blocked sunlight for a year or more. This caused a deep freeze and ended photosynthesis. Sulfur from the impact mixed with water in the atmosphere. The result was acid rain. The rain dissolved the shells of the tiny marine plankton that form the base of the food chain. With little food being produced, animals starved.

Lesson Summary

- Adaptations are favorable traits that organisms inherit. Adaptations develop from variations within a population and help organisms to survive in their given environment.
- Changes in populations accumulate over time. This is called evolution.
- The fossil record shows us that present day life forms evolved from earlier different life forms. It shows us that the first organisms on Earth were simple bacteria that dominated the Earth for several billion years.
- Beginning about 540 million years ago, more complex organisms developed on Earth. During the Phanerozoic Eon all of the plant and animal types we know today have evolved.
- Many types of organisms that once lived are now extinct. Earth's overall environment, especially the climate, has changed many times. As organisms adapt to changing environmental conditions, new species appear and many become extinct.

Lesson Review Questions

Recall

1. Describe what is meant by adaptation.

Apply Concepts

2. Explain why unfavorable traits do not usually get passed to offspring.

3. List the order in which the major types of animals appeared on Earth.

Think Critically

4. The first animals on Earth had soft bodies. Gradually many animal species evolved that had hard outer parts called exoskeletons covering their bodies. How might an exoskeleton be a favorable adaptation?

5. How might climate have affected the ability of plants to grow over large areas during a given time?

6. One cause of mass extinctions is meteorite or comet impacts. What might be some additional causes of mass extinctions?

Points to Consider

- The processes of evolution are fundamental to much of biology. Why do people have such a hard time understanding them?
- A lot of organisms are dying out now due to changes in climate and effects of human activities. How does what's happening now resemble a mass extinction?
- The amount of biodiversity on Earth is staggering. Why are there so many different types of organisms?

For **Table** 12.1, from top to bottom:

- Mariana Ruiz Villarreal (Wikimedia:LadyofHats). http://commons.wikimedia.org/wiki/File:Abrictosaurus_-dinosaur.png . Public Domain.

12.4 References

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CHAPTER 13 MS Earth's Fresh Water

Chapter Outline

If you think of freshwater on Earth's surface, lakes and rivers might come to mind. But most of Earth's freshwater is frozen. Much of it occurs in glaciers, like the one pictured here. This massive sheet of ice is Portage Glacier in Alaska. It contains a huge amount of frozen water.

Where else is frozen water found on Earth? Besides solid ice, in what other states does Earth's freshwater exist? And how does water change from one state to another? This chapter answers these and many other questions about Earth's freshwater.

13.1 Water on Earth

Lesson Objectives

- Describe water and where it occurs on Earth.
- Give an overview of the water cycle.

Vocabulary

- condensation
- evaporation
- freshwater
- infiltration
- precipitation
- runoff
- transpiration
- water
- water cycle

Introduction

Water is all around you —in pipes, in puddles, even in people. Water covers more than 70 percent of Earth's surface. That's a good thing, because all life on Earth depends on water. In fact, without water, life as we know it could not exist. Water is a very special substance. Do you know why?

What Is Water?

Water is a simple chemical compound. Each molecule of water contains two hydrogen atoms (H_2) and one oxygen atom (O). That's why the chemical formula for water is H_2O.

If water is so simple, why is it special? Water is one of the few substances that exists on Earth in all three states of matter. Water occurs as a gas, a liquid and a solid. You drink liquid water and use it to shower. You breathe gaseous water vapor in the air. You may go ice skating on a pond covered with solid water —ice —in the winter.

Where Is Earth's Freshwater?

Earth is often called the "water planet." **Figure** 13.1 shows why. If astronauts see Earth from space, this is how it looks. Notice how blue the planet appears. That's because oceans cover much of Earth's surface. Water is also found in the clouds that rise above the planet.

FIGURE 13.1
Take a look at this image. Do you think that Earth deserves the name "water planet"?

Most of Earth's water is salt water in the oceans. As **Figure** 13.2 shows, only 3 percent of Earth's water is fresh. **Freshwater** is water that contains little or no dissolved salt. Most freshwater is frozen in ice caps and glaciers. Glaciers cover the peaks of some tall mountains. For example, the Cascades Mountains in North America and the Alps Mountains in Europe are capped with ice. Ice caps cover vast areas of Antarctica and Greenland. Chunks of ice frequently break off ice caps. They form icebergs that float in the oceans.

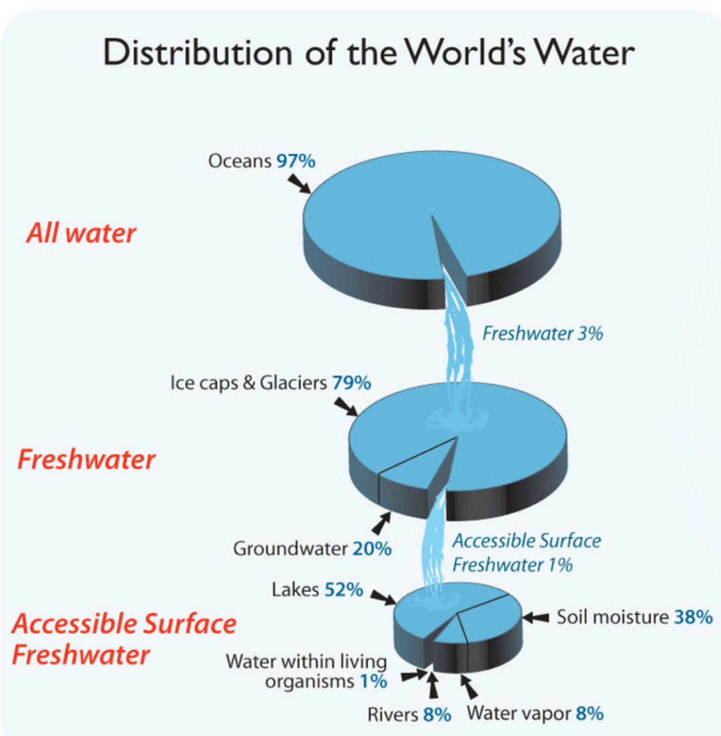


FIGURE 13.2
What percentage of Earth's surface freshwater is water vapor in the air?

Only a tiny fraction of Earth's freshwater is in the liquid state. Most liquid freshwater is under the ground in layers of rock. Of freshwater on the surface, the majority occurs in lakes and soil. What percentage of freshwater on the surface is found in living things?

The Water Cycle

Did you ever wonder where the water in your glass came from or where it's been? The next time you take a drink of water, think about this. Each water molecule has probably been around for billions of years. That's because Earth's water is constantly recycled.

How Water Is Recycled

Water is recycled through the water cycle. The **water cycle** is the movement of water through the oceans, atmosphere, land, and living things. The water cycle is powered by energy from the Sun. **Figure** 13.3 diagrams the water cycle.

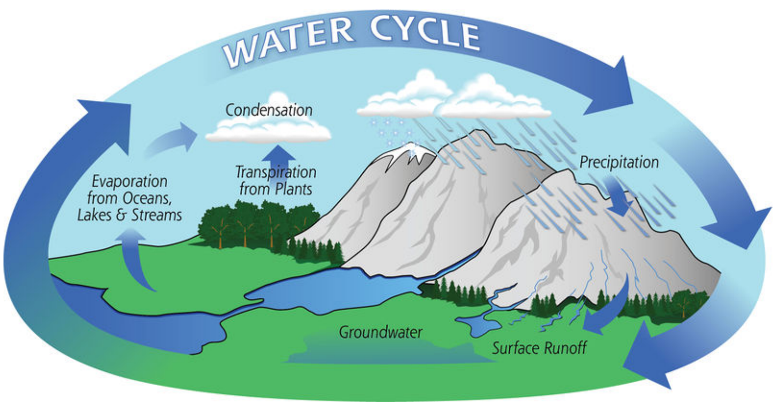


FIGURE 13.3
The water cycle has no beginning or end. Water just keeps moving along.

Processes in the Water Cycle

Water keeps changing state as it goes through the water cycle. This means that it can be a solid, liquid, or gas. How does water change state? How does it keep moving through the cycle? As **Figure** 13.3 shows, several processes are involved.

- **Evaporation** changes liquid water to water vapor. Energy from the Sun causes water to evaporate. Most evaporation is from the oceans because they cover so much area. The water vapor rises into the atmosphere.
- **Transpiration** is like evaporation because it changes liquid water to water vapor. In transpiration, plants release water vapor through their leaves. This water vapor rises into the atmosphere.
- **Condensation** changes water vapor to liquid water. As air rises higher into the atmosphere, it cools. Cool air can hold less water vapor than warm air. So some of the water vapor condenses into water droplets. Water droplets may form clouds.
- **Precipitation** is water that falls from clouds to Earth's surface. Water droplets in clouds fall to Earth when they become too large to stay aloft. The water falls as rain if the air is warm. If the air is cold, the water may freeze and fall as snow, sleet, or hail. Most precipitation falls into the oceans. Some falls on land.

- **Runoff** is precipitation that flows over the surface of the land. This water may travel to a river, lake, or ocean. Runoff may pick up fertilizer and other pollutants and deliver them to the water body where it ends up. In this way, runoff may pollute bodies of water.
- **Infiltration** is the process by which water soaks into the ground. Some of the water may seep deep underground. Some may stay in the soil, where plants can absorb it with their roots.

In all these ways, water keeps cycling. The water cycle repeats over and over again. Who knows? Maybe a water molecule that you drink today once quenched the thirst of a dinosaur.

Lesson Summary

- Water is a simple chemical compound. It exists on Earth in all three states of matter: liquid, gas, and solid. As a gas, water is called water vapor. As a solid, water is called ice.
- Oceans of salt water cover much of Earth's surface. Freshwater is water that contains little or no salt. Most of Earth's freshwater is frozen in ice caps and glaciers.
- Earth's water is constantly recycled through the water cycle. Water keeps changing state as it goes through the cycle. The water cycle includes processes such as evaporation, condensation, and precipitation.

Lesson Review Questions

Recall

1. What is freshwater?

2. Where is most of Earth's freshwater found?

3. What process changes water from a liquid to a gas? From a gas to a liquid?

4. Define infiltration and runoff.

Apply Concepts

5. Describe the substance known as water.

6. Why does most precipitation fall into the oceans?

Think Critically

7. Apply lesson concepts to explain how a forest fire might affect the water cycle.

8. Explain why this statement is true: "The water you drink today may once have quenched the thirst of a dinosaur."

9. How does the Sun drive the water cycle? What would happen to the water cycle if the Sun decreased its intensity by half?

Points to Consider

As water moves through the water cycle, it spends some time on Earth's surface as freshwater.

- Where is freshwater found on Earth's surface?
- How do people use freshwater on Earth's surface?

13.2 Surface Water

Lesson Objectives

- Identify features of streams and rivers.
- Describe ponds and lakes and how they form.
- Explain why wetlands are important.
- State how floods occur.

Vocabulary

- flood
- lake
- pond
- river
- stream
- wetland

Introduction

Only a very small percentage of Earth's water is fresh, liquid water on the surface. But that tiny fraction of water is vital. It is needed by humans, plants, and many other living things. Liquid freshwater flows over Earth's surface in streams and rivers. It also forms ponds, lakes, and wetlands. People use freshwater for drinking, washing, and industry. They also use it for fun. How do you use freshwater for fun?

Streams and Rivers

Look at the pictures of flowing water in **Figure** 13.4. A waterfall tumbles down a mountainside. A brook babbles through a forest. A river slowly meanders through a broad valley. What do all these forms of flowing water have in common? They are all streams.

What Are Streams and Rivers?

A **stream** is a body of freshwater that flows downhill in a channel. The channel of a stream has a bottom, or bed, and sides called banks. Any size body of flowing water can be called a stream. Usually, though, a large stream is called a **river**.

FIGURE 13.4
All these forms of flowing water are streams.

Features of Streams and Rivers

All streams and rivers have several features in common. These features are shown in (**Figure** 13.5). The place where a stream or river starts is its source. The source might be a spring, where water flows out of the ground. Or the source might be water from melting snow on a mountain top. A single stream may have multiple sources. A stream or river probably ends when it flows into a body of water, such as a lake or an ocean. A stream ends at its mouth. As the water flows into the body of water, it slows down and drops the sediment it was carrying. The sediment may build up to form a delta.

Several other features of streams and rivers are also shown in **Figure** 13.5.

- Small streams often flow into bigger streams or rivers. The small streams are called tributaries. A river and all its tributaries make up a river system.
- At certain times of year, a stream or river may overflow its banks. The area of land that is flooded is called the floodplain. The floodplain may be very wide where the river flows over a nearly flat surface.
- A river flowing over a floodplain may wear away broad curves. These curves are called meanders.

River Basins and Divides

All of the land drained by a river system is called its basin, or watershed. One river system's basin is separated from another river system's basin by a divide. The divide is created by the highest points between the two river basins. Precipitation that falls within a river basin always flows toward that river. Precipitation that falls on the other side of the divide flows toward a different river.

Figure 13.6 shows the major river basins in the U.S. You can watch an animation of water flowing through a river basin at this link: http://trashfree.org/btw/graphics/watershed_anim.gif

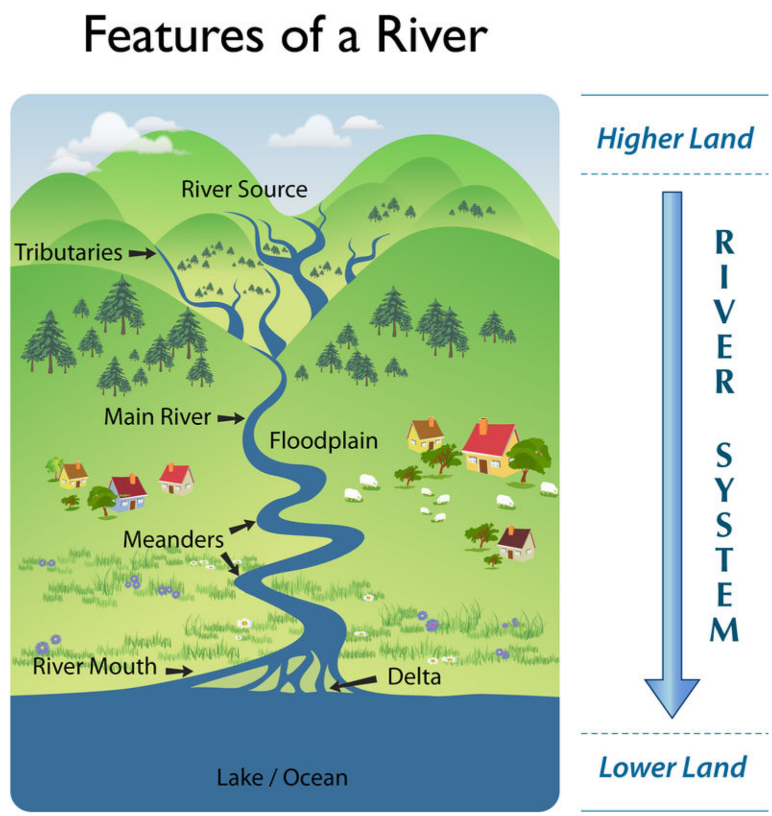


FIGURE 13.5
Water in a stream flows along the ground from higher to lower elevation. What force causes the water to keep flowing?

FIGURE 13.6
River basins in the U.S.

Ponds and Lakes

After a heavy rain, you may find puddles of water standing in low spots. The same principle explains why water collects in ponds and lakes. Water travels downhill, so a depression in the ground fills with standing water. A **pond** is a small body of standing water. A **lake** is a large body of standing water. Most lakes have freshwater, but a few are salty. The Great Salt Lake in Utah is an example of a saltwater lake.

The water in a large lake may be so deep that sunlight cannot penetrate all the way to the bottom. Without sunlight, water plants and algae cannot live on the bottom of the lake. That's because plants need sunlight for photosynthesis.

The largest lakes in the world are the Great Lakes. They lie between the U.S. and Canada, as shown in **Figure** 13.7. How great are they? They hold 22 percent of all the world's fresh surface water!

FIGURE 13.7
The Great Lakes of North America get their name from their great size.

Water in Ponds and Lakes

Ponds and lakes may get their water from several sources. Some falls directly into them as precipitation. Some enters as runoff and some from streams and rivers. Water leaves ponds and lakes through evaporation and also as outflow.

How Lakes Form

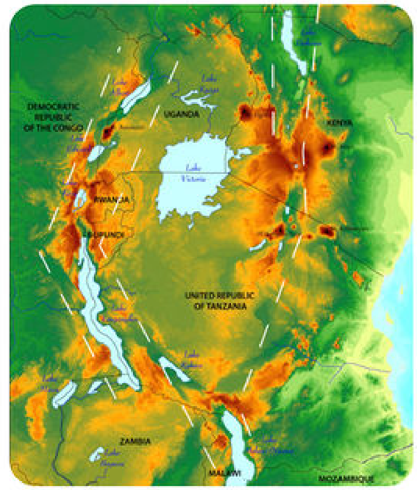
The depression that allows water to collect to form a lake may come about in a variety of ways. The Great Lakes, for example, are glacial lakes. A glacial lake forms when a glacier scrapes a large hole in the ground. When the glacier melts, the water fills the hole and forms a lake. Over time, water enters the lake from the sources mentioned above as well.

Other lakes are crater lakes or rift lakes, which are pictured in **Figure** 13.8. Crater lakes form when volcanic eruptions create craters that fill with water. Rift lakes form when movements of tectonic plates create low places that fill with water.

Wetlands

Some of Earth's freshwater is found in wetlands. A **wetland** is an area that is covered with water, or at least has very soggy soil, during all or part of the year. Certain species of plants thrive in wetlands, and they are rich ecosystems. Freshwater wetlands are usually found at the edges of steams, rivers, ponds, or lakes. Wetlands can also be found at the edges of seas.

This Russian lake formed in the crater created by a volcano.



The dotted white lines on this map mark the rift between tectonic plates in East Africa. Fault movements created depressions that filled with water. This formed many rift lakes, from Lake Malawi in the south to Lake Turkana in the north.

FIGURE 13.8

Craters and rifts become lakes when they fill with water. Where does the water come from?

Types of Freshwater Wetlands

Not all wetlands are alike, as you can see from **Figure** 13.9. Wetlands vary in how wet they are and how much of the year they are soaked. Wetlands also vary in the kinds of plants that live in them. This depends mostly on the climate where the wetland is found. Types of wetlands include marshes, swamps, and bogs.

- A marsh is a wetland that is usually under water. It has grassy plants, such as cattails.
- A swamp is a wetland that may or may not be covered with water but is always soggy. It has shrubs or trees.
- A bog is a wetland that has soggy soil. It is generally covered with mosses.

Importance of Wetlands

People used to think that wetlands were useless. Many wetlands were filled in with rocks and soil to create lands that were then developed with roads, golf courses, and buildings. Now we know that wetlands are very important. Laws have been passed to help protect them. Why are wetlands so important?

- Wetlands have great biodiversity. They provide homes or breeding sites to a huge variety of species. Because so much wetland area has been lost, many of these species are endangered.
- Wetlands purify water. They filter sediments and toxins from runoff before it enters rivers, lakes, and oceans.
- Wetlands slow rushing water. During hurricanes and other extreme weather, wetlands reduce the risk of floods.

Although the rate has slowed, wetlands are still being destroyed today.

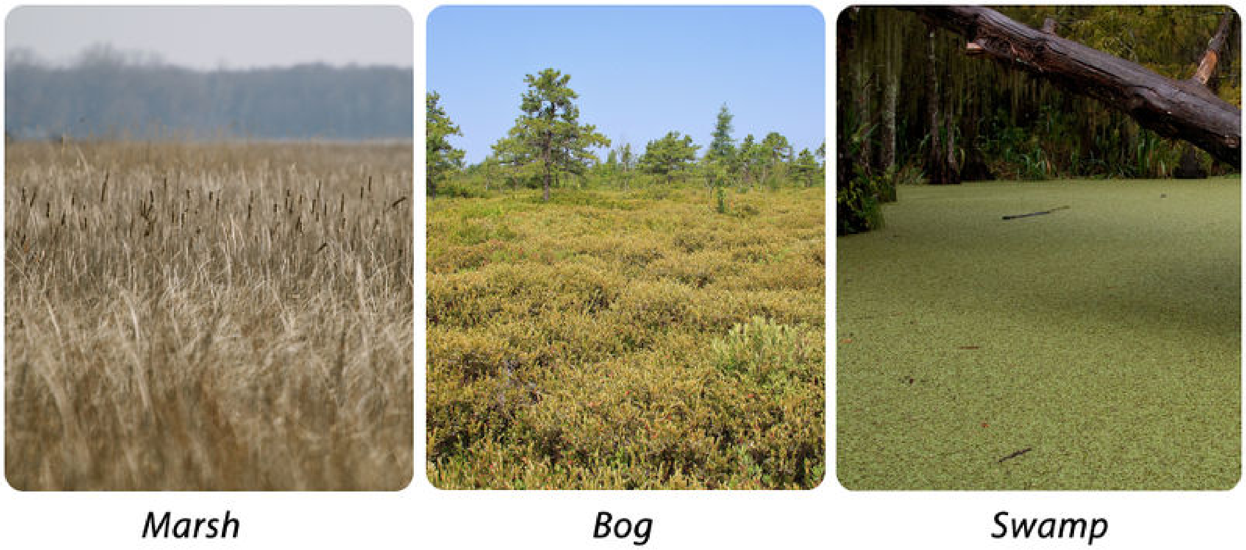


FIGURE 13.9
These are just three of many types of wetlands.

Floods

A **flood** occurs when so much water enters a stream or river that it overflows its banks. Flood waters from a river are shown in **Figure** 13.10. Like this flood, many floods are caused by very heavy rains. Floods may also occur when deep snow melts quickly in the spring.

FIGURE 13.10
A river in Indiana floods after very heavy rains. Some areas received almost a foot of rain in less than 24 hours!

Floods are a natural part of the water cycle, but they can cause a lot of damage. Farms and homes may be lost, and people may die. In 1939, millions of people died in a flood in China. Although freshwater is needed to grow crops and just to live, too much freshwater in the same place at once can be deadly.

Lesson Summary

- A stream is a body of water that flows downhill in a channel. A large stream is usually called a river.
- Standing freshwater forms ponds and lakes. Lakes are generally bigger than ponds. Lakes may form in several different ways.
- A wetland is an area that is wet for all or part of the year. Wetlands are home to certain types of plants.
- Wetlands are very important. They have great biodiversity. They purify water. They slow down rushing water and help prevent floods.
- Floods occur when so much water enters a stream or river that it overflows its banks. Floods may be caused by heavy rains or melting snow. They can cause a lot of damage and loss of life.

Lesson Review Questions

Recall

1. What are the source and mouth of a river?

2. Define tributary and river system.

3. How may water enter a pond or lake?

4. What is a wetland?

5. List three reasons why wetlands should be protected.

Apply Concepts

6. For each stream pictured in **Figure** 13.4, explain where it might be located on the map in **Figure** 13.5.

Think Critically

7. The Nile River in Egypt empties into the Mediterranean Sea. At the mouth of the river, there is a very large delta. Explain how the delta formed.

8. Compare and contrast glacial, crater, and rift lakes.

Points to Consider

- In the desert, water runs in channels after a storm. The channels are dry otherwise. Is this a stream?
- It may seem hard to believe, but most of Earth's freshwater is under our feet. It is stored below the surface of the ground.
  - How do you think water gets under the ground?
  - What happens to water after it goes under the ground? Is it trapped there forever?

13.3 Groundwater

Lesson Objectives

- Explain how water enters an aquifer.
- Explain how water leaves an aquifer.
- Define aquifer, and give an example.
- Define springs and geysers.
- State the purpose of wells and how they work.

Vocabulary

- aquifer
- groundwater
- spring
- water table
- well

Introduction

Rivers and lakes hold a lot of Earth's liquid freshwater. However, far more is hidden from sight. Where is it? It is stored under the ground. In fact, 20 times more of Earth's liquid freshwater is found below the surface than on the surface.

Groundwater

Freshwater below Earth's surface is called **groundwater**. The water infiltrates, or seeps down into, the ground from the surface. How does this happen? And where does the water go?

Porous and Impermeable Rock

Water infiltrates the ground because soil and rock are porous. Between the grains are pores, or tiny holes. Since water can move through this rock it is permeable. Eventually, the water reaches a layer of rock that is not porous and so is impermeable. Water stops moving downward when it reaches this layer of rock.

Look at the diagram in **Figure** 13.11. It shows two layers of porous rock. The top layer is not saturated; it is not full of water. The next layer is saturated. The water in this layer has nowhere else to go. It cannot seep any deeper into the ground because the rock below it is impermeable.

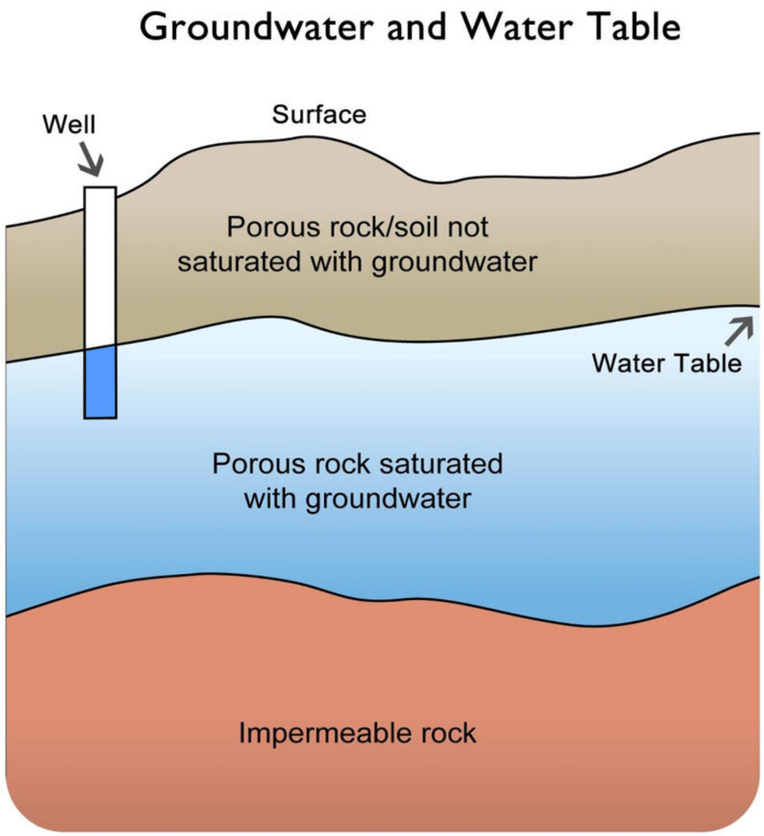


FIGURE 13.11
Water seeps into the ground through permeable material and stops when it reaches an impermeable rock. Predict the purpose of the well in the diagram.

The Water Table

The top of the saturated rock layer in **Figure** 13.11 is called the **water table**. The water table isn't like a real table. It doesn't remain firmly in one place. Instead, it rises or falls, depending on how much water seeps down from the surface. The water table is higher when there is a lot of rain and lower when the weather is dry.

Aquifer

An underground layer of rock that is saturated with groundwater is called an **aquifer**. A diagram of an aquifer is shown in **Figure** 13.12. Aquifers are generally found in porous rock, such as sandstone. Water infiltrates the aquifer from the surface. The water that enters the aquifer is called recharge.

Human Use of Aquifers

Most land areas have aquifers beneath them. Many aquifers are used by people for freshwater. The closer to the surface an aquifer is, the easier it is to get the water. However, an aquifer close to the surface is also more likely to become polluted. Pollutants can seep down through porous rock in recharge water.

An aquifer that is used by people may not be recharged as quickly as its water is removed. The water table may lower and the aquifer may even run dry. If this happens, the ground above the aquifer may sink. This is likely to damage any homes or other structures built above the aquifer.

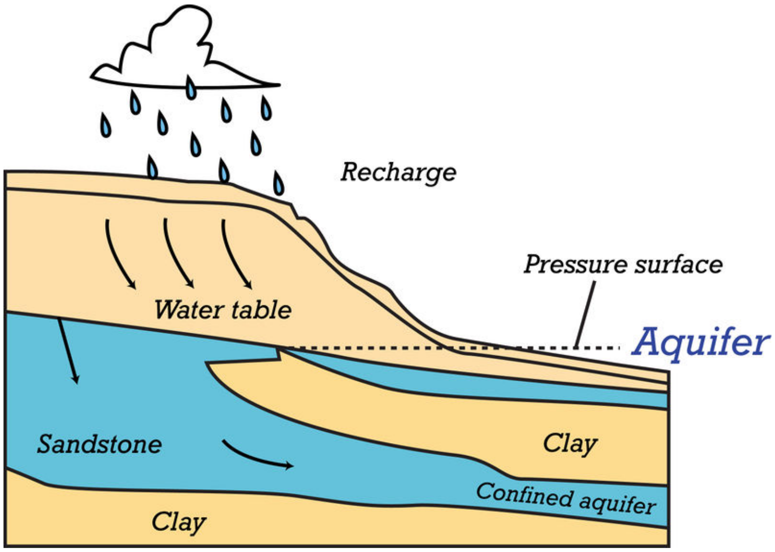


FIGURE 13.12
An aquifer is a layer of saturated porous rock. It lies below the water table. An impermeable layer, such as clay, is below the aquifer.

The Ogallala Aquifer

One of the biggest aquifers in the world is the Ogallala aquifer. As you can see from **Figure** 13.13, this aquifer lies beneath parts of eight U.S. states. It covers a total area of 451,000 square kilometers (174,000 square miles). In some places, it is less than a meter deep. In other places, it is hundreds of meters deep.

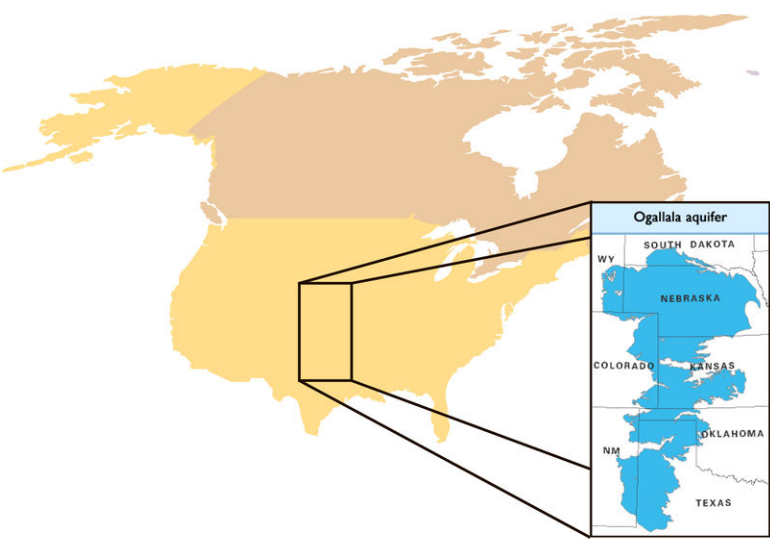


FIGURE 13.13
In this map, the area over the Ogallala aquifer is shaded in blue.

The Ogallala aquifer is an important source of freshwater in the American Midwest. This is a major farming area, and much of the water is used to irrigate crops. The water in this aquifer is being used up ten times faster than it is recharged. If this continues, what might happen to the Ogallala aquifer?

Springs and Geysers

The top of an aquifer may be high enough in some places to meet the surface of the ground. This often happens on a slope. The water flows out of the ground and creates a **spring**. A spring may be just a tiny trickle, or it may be a big gush of water. One of the largest springs in the world is Big Spring in Missouri, seen in **Figure** 13.14.

FIGURE 13.14
Big Spring is named for its large size. It releases more than 12,000 liters of water per second!

Water flowing out of the ground at a spring may flow downhill and enter a stream. That's what happens to the water that flows out of Big Spring in Missouri. If the water from a spring can't flow downhill, it may spread out to form a pond or lake instead. Lake George in New York State, which is pictured in **Figure** 13.15, is a spring-fed lake. The lake basin was carved by a glacier.

FIGURE 13.15
Lake George gets its water from a number of springs.

Mineral Springs and Hot Springs

Some springs have water that contains minerals. Groundwater dissolves minerals out of the rock as it seeps through the pores. The water in some springs is hot because it is heated by hot magma. Many hot springs are also mineral springs. That's because hot water can dissolve more minerals than cold water. Grand Prismatic Spring, shown in **Figure** 13.16, is a hot mineral spring. Dissolved minerals give its water a bright blue color. The edge of the spring is covered with thick orange mats of bacteria. The bacteria use the minerals in the hot water to make food.

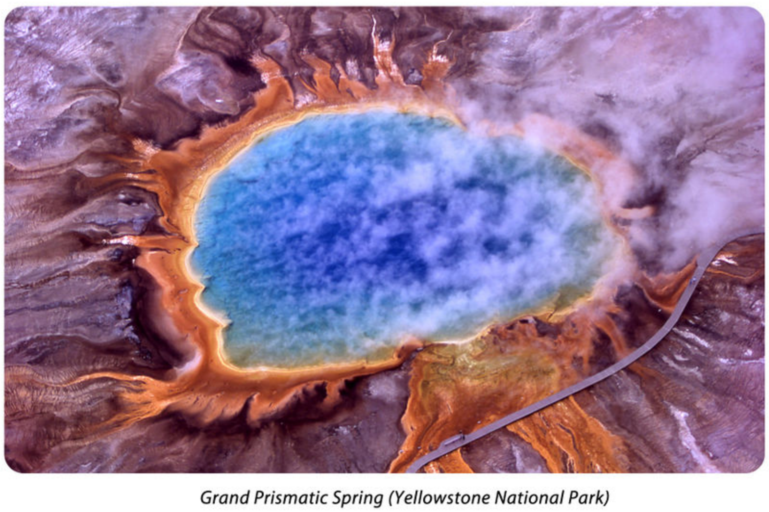


FIGURE 13.16
Grand Prismatic Spring in the Yellowstone National Park is the largest hot spring in the U.S. How can you tell from the photo that the water in this spring is hot?

Geysers

Heated groundwater may become trapped in spaces within rocks. Pressure builds up as more water seeps into the spaces. When the pressure becomes great enough, the water bursts out of the ground at a crack or weak spot. This is called a **geyser**. When the water erupts from the ground, the pressure is released. Then more water collects and the pressure builds up again. This leads to another eruption.

Old Faithful is the best-known geyser in the world. You can see a picture of it in **Figure** 13.17. The geyser erupts faithfully every 90 minutes, day after day. During each eruption, it may release as much as 30,000 liters of water!

FIGURE 13.17
Old Faithful in Yellowstone National Park is a geyser named for its regular cycle of eruptions.

Wells

Most groundwater does not flow out of an aquifer as a spring or geyser. So to use the water that's stored in an aquifer people must go after it. How? They dig a well. A **well** is a hole that is dug or drilled through the ground down to an aquifer. This is illustrated in **Figure** 13.18.

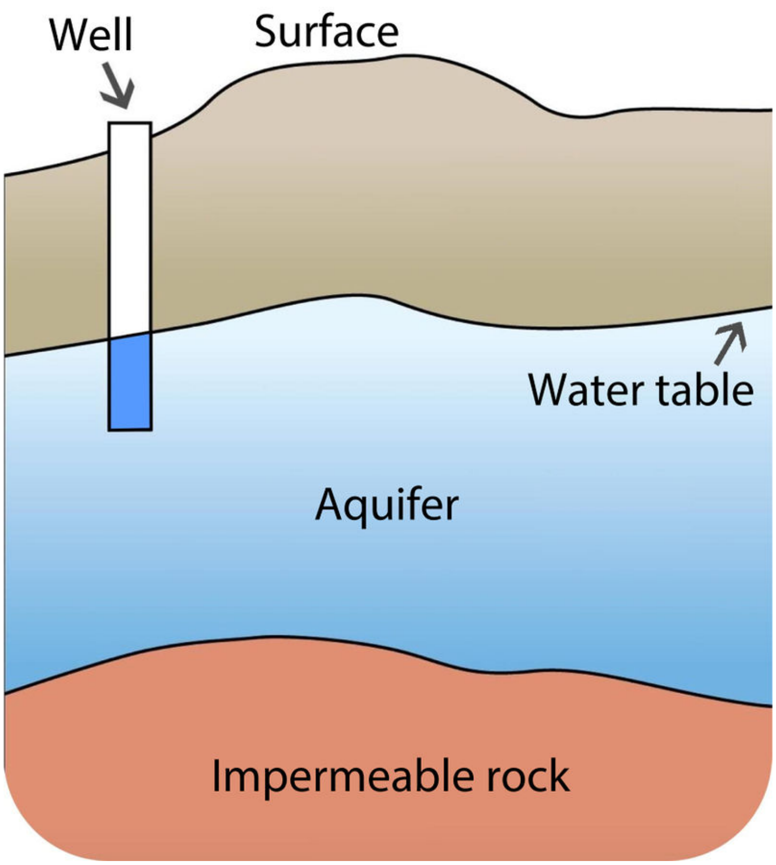


FIGURE 13.18
A well runs from the surface to a point below the water table. Why must a well go lower than the water table?

People have depended on water from wells for thousands of years. To bring water to the surface takes energy because the force of gravity must be overcome. Today, many wells use electricity to pump water to the surface. However, in some places, water is still brought to the surface the old-fashioned way — with human labor. The well pictured in **Figure** 13.19 is an example of this type of well. A hand-cranked pulley is used to lift the bucket of water to the surface.

Lesson Summary

- Groundwater is freshwater below Earth's surface. It seeps down from the surface through pores in soil and rock. It keeps seeping downward until it reaches a layer of impermeable rock.
- An aquifer is an underground layer of rock that is saturated with groundwater. One of the biggest aquifers in the world is the Ogallala aquifer in the American Midwest.

FIGURE 13.19
This old water well uses human muscle power to bring water to the surface.

- Water that flows out of the ground where an aquifer meets the surface is called a spring. Spring water may contain dissolved minerals. It may also be heated by magma in the crust. Heated groundwater that erupts from the ground under pressure is called a geyser.
- Many people get their freshwater from an aquifer. They obtain the water through a well. A well is a hole that is dug or drilled through the ground down to an aquifer.

Lesson Review Questions

Recall

1. Define groundwater.
2. Describe how water enters the ground.
3. What is the water table? What might cause it to rise or fall?
4. Define aquifer. Where does an aquifer get its water?
5. What is the purpose of a well?

Apply Concepts

6. Assume you live in a town that gets its water from an aquifer. The aquifer lies beneath the town. Apply lesson concepts to predict what may happen if water is pumped out of the aquifer faster than it is recharged. Then, write a letter to the editor of the town's newspaper. State what you think may happen. Argue for the need to use water wisely.

Think Critically

7. Compare and contrast springs and geysers.

8. LaShawna and her family went to Yellowstone National Park. They saw a spring called Green Dragon Spring. Steam was rising off the water. When LaShawna saw the steam, she said that the water must contain a lot of minerals. Do you agree with LaShawna's statement? Why or why not?

Points to Consider

Freshwater is needed by many living things on Earth. However, most of Earth's water is not fresh. Instead, it is salt water in the oceans.

- What do you know about Earth's oceans? For example, how deep are they? And why is their water salty?
- Ocean water moves in waves, tides, and currents. Do you know what causes these ocean water movements?

13.4 References

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Chapter 14 MS Earth's Oceans

Chapter Outline

There's no doubting the power of the ocean when you look at this photo. The surfer is riding a huge wave to shore. Not all ocean waves are this big. But all the world's oceans have waves. Waves are just one way that ocean water moves. Other ways include tides and currents.

Ocean water doesn't move like a stream. It doesn't flow downhill. So why does the water move? What causes waves and other ocean motions? In this chapter, you'll find out.

14.1 Introduction to the Oceans

Lesson Objectives

- Describe how the oceans formed.
- State how the oceans influence Earth.
- Describe the makeup of ocean water.
- Identify ocean zones.

Vocabulary

- aphotic zone
- benthic zone
- intertidal zone
- neritic zone
- oceanic zone
- photic zone

Introduction

Much of Earth's surface is covered with oceans. That's why Earth is called the "water planet." Without all that water, Earth would be a very different place. The oceans affect Earth's atmosphere and influence its climate. An incredible diversity of living things inhabit the ocean as well. You might think that oceans have always covered Earth's surface, but you would be wrong!

How the Oceans Formed

When Earth formed 4.6 billion years ago, it would not have been called the "water planet." There were no oceans then. In fact, there was no liquid water at all. Early Earth was too hot for liquid water to exist. Earth's early years were spent as molten rock and metal.

Water on Early Earth

Over time, Earth cooled. The surface hardened to become solid rock. Volcanic eruptions, like the one in **Figure** 14.1, brought lava and gases to the surface. One of the gases was water vapor. More water vapor came from asteroids and comets that crashed into Earth. As Earth cooled still more, the water vapor condensed to make Earth's first liquid water. At last, the oceans could start to form.

FIGURE 14.1
Volcanoes were one source of water vapor on ancient Earth. What were other sources?

Ancient Oceans

Earth's crust consists of many tectonic plates that move over time. Due to plate tectonics, the continents changed their shapes and positions during Earth history. As the continents changed, so did the oceans. About 250 million years ago, there was one huge land mass known as Pangaea. There was also one huge ocean called Panthalassa. You can see it in **Figure** 14.2.

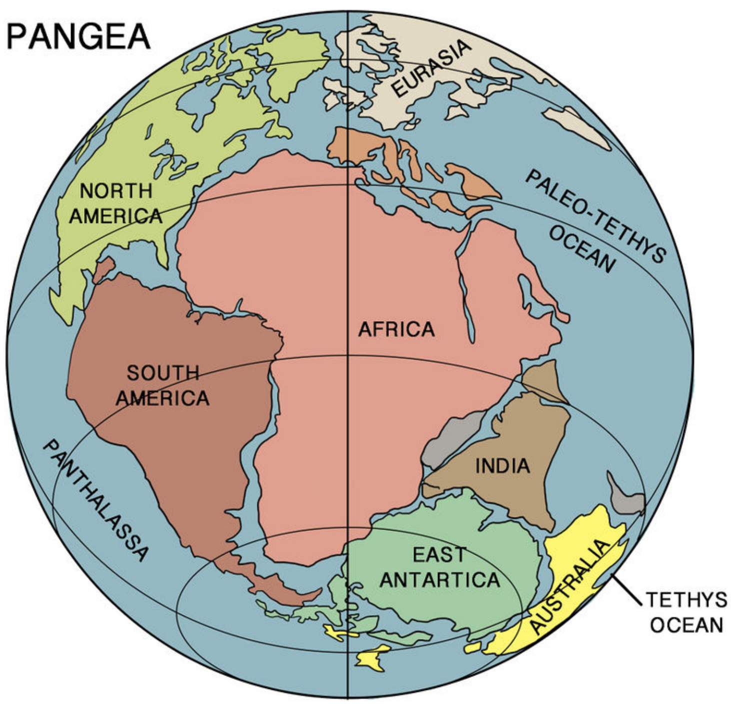

FIGURE 14.2
At the time shown, there was one vast ocean and two smaller ones. How many oceans are there today?

By 180 million years ago, Pangaea began to break up. The continents started to drift apart. They slowly moved to where they are today. The movement of the continents caused Panthalassa to break into smaller oceans. These oceans are now known as the Pacific, Atlantic, Indian, and Arctic Oceans. The waters of all the oceans are connected.

That's why some people refer to the oceans together as the "World Ocean."

The Oceans' Influence

Oceans cover more than 70 percent of Earth's surface and hold 97 percent of its surface water. It's no surprise that the oceans have a big influence on the planet. The oceans affect the atmosphere, climate, and living things.

Oceans and the Atmosphere

Oceans are the major source of water vapor in the atmosphere. Sunlight heats water near the sea surface, as shown in **Figure** 14.3. As the water warms, some of it evaporates. The water vapor rises into the air, where it may form clouds and precipitation. Precipitation provides the freshwater needed by plants and other living things.

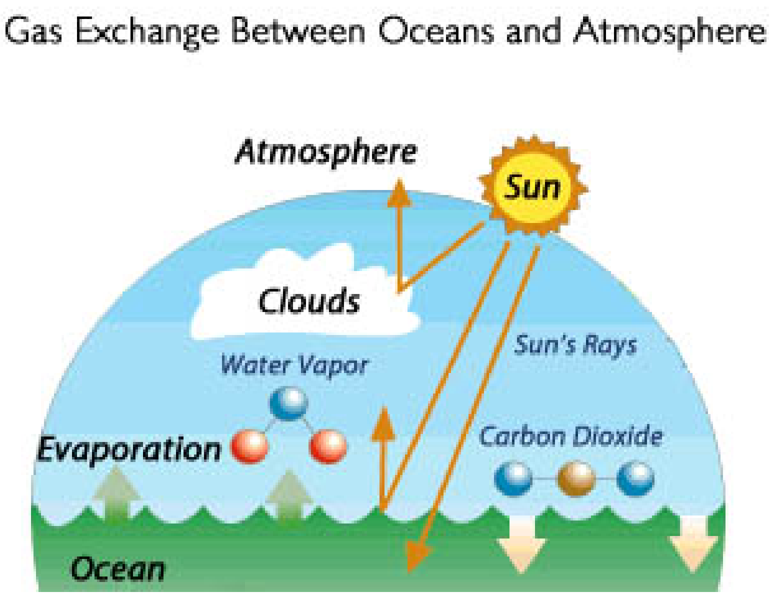

FIGURE 14.3
The oceans and atmosphere exchange gases. Why does water vapor enter the atmosphere from the water?

Ocean water also absorbs gases from the atmosphere. The most important are oxygen and carbon dioxide. Oxygen is needed by living things in the oceans. Much of the carbon dioxide sinks to the bottom of the seas. Carbon dioxide is a major cause of global warming. By absorbing carbon dioxide, the oceans help control global warming.

Oceans and Climate

Coastal areas have a milder climate than inland areas. They are warmer in the winter and cooler in the summer. That's because land near an ocean is influenced by the temperature of the oceans. The temperature of ocean water is moderate and stable. Why? There are two major reasons:

1. Water is much slower to warm up and cool down than land. As a result, oceans never get as hot or as cold as land.
2. Water flows through all the world's oceans. Warm water from the equator mixes with cold water from the poles. The mixing of warm and cold water makes the water temperature moderate.

Even inland temperatures are milder because of oceans. Without oceans, there would be much bigger temperature swings all over Earth. Temperatures might plunge hundreds of degrees below freezing in the winter. In the summer, lakes and seas might boil! Life as we know it could not exist on Earth without the oceans.

Oceans and Living Things

The oceans provide a home to many living things. In fact, a greater number of organisms lives in the oceans than on land. Coral reefs, like the one in **Figure** 14.4, have more diversity of life forms than almost anywhere else on Earth.

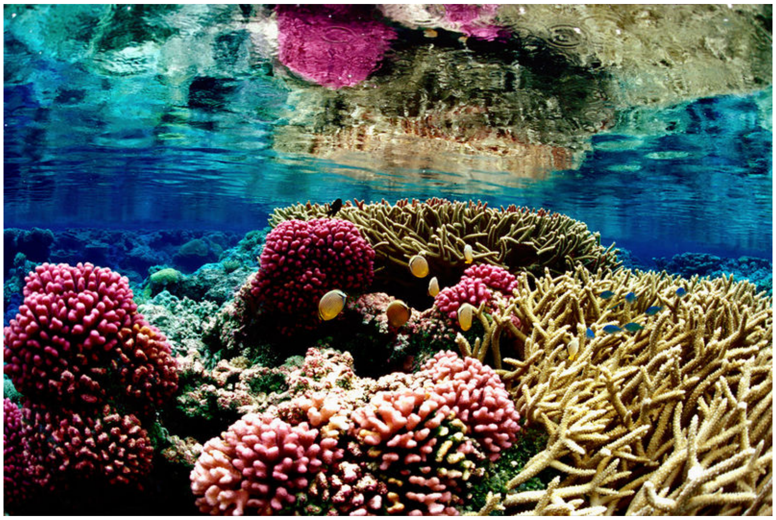

FIGURE 14.4
Coral reefs teem with life.

Makeup of Ocean Water

You know that ocean water is salty. But do you know why? How salty is it?

Why Is Ocean Water Salty?

Ocean water is salty because water dissolves minerals out of rocks. This happens whenever water flows over or through rocks. Much of this water and its minerals flow in rivers that end up in the oceans. Minerals dissolved in water form salts. When the water evaporates, it leaves the salts behind. As a result, ocean water is much saltier than other water on Earth.

How Salty Is Ocean Water?

Have you ever gone swimming in the ocean? If you have, then you probably tasted the salts in the water. By mass, salts make up about 3.5 percent of ocean water. **Figure** 14.5 shows the most common minerals in ocean water. The main components are sodium and chloride. Together they form the salt known as sodium chloride. You may know the compound as table salt or the mineral halite.

The amount of salts in ocean water varies from place to place. For example, near the mouth of a river, ocean water may be less salty. That's because river water contains less salt than ocean water. Where the ocean is warm, the water may be more salty. Can you explain why? (Hint: More water evaporates when the water is warm.)

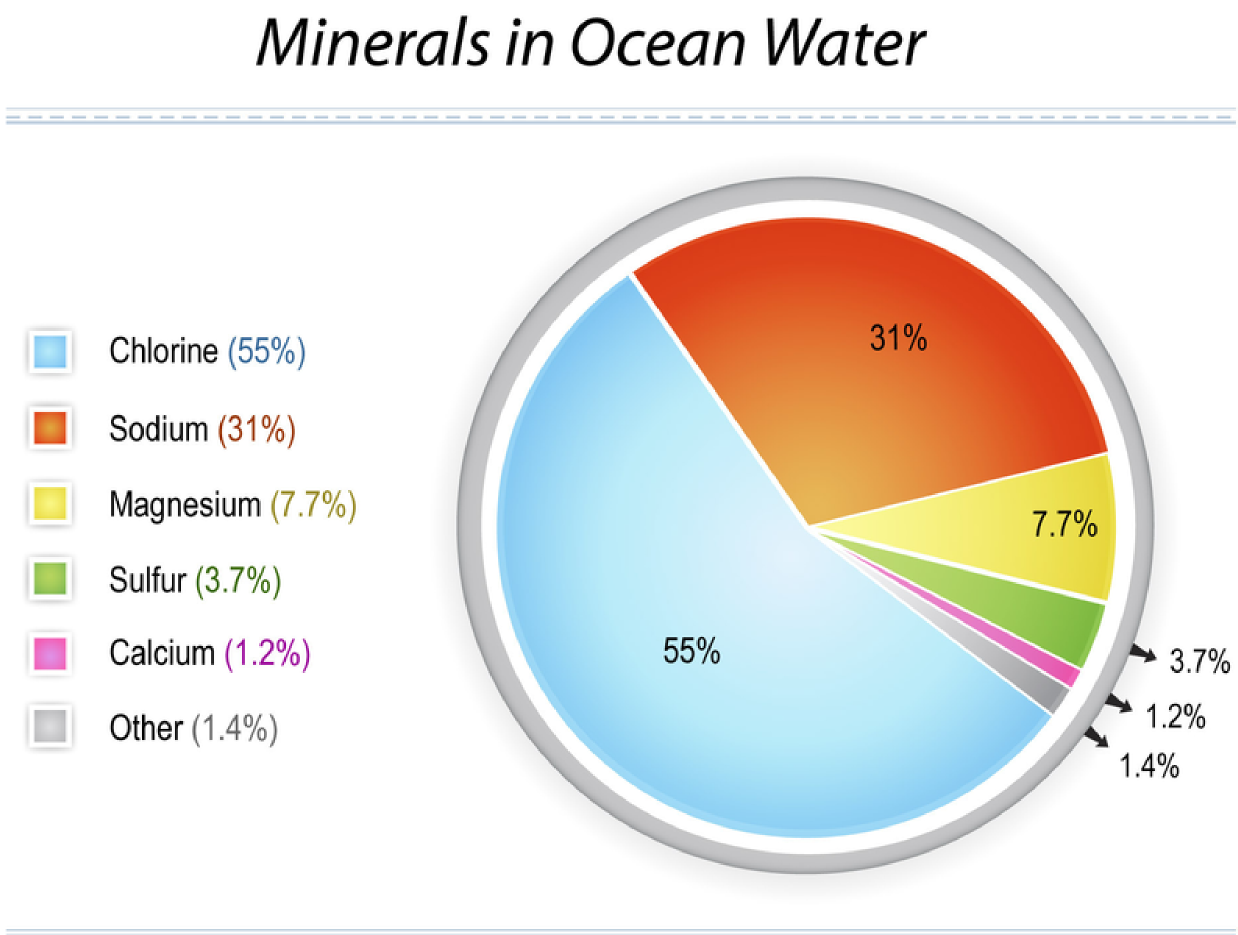

FIGURE 14.5
What percentage of the salts in ocean water is sodium chloride?

Ocean Zones

In addition to the amount of salts, other conditions in ocean water vary from place to place. One is the amount of nutrients in the water. Another is the amount of sunlight that reaches the water. These conditions depend mainly on two factors: distance from shore and depth of water. Oceans are divided into zones based on these two factors. The ocean floor makes up another zone. **Figure** 14.6 shows all the ocean zones.

Zones Based on Distance from Shore

There are three main ocean zones based on distance from shore. They are the **intertidal zone**, **neritic zone**, and **oceanic zone**. Distance from shore influences how many nutrients are in the water. Why? Most nutrients are washed into ocean water from land. Therefore, water closer to shore tends to have more nutrients. Living things need nutrients. So distance from shore also influences how many organisms live in the water.

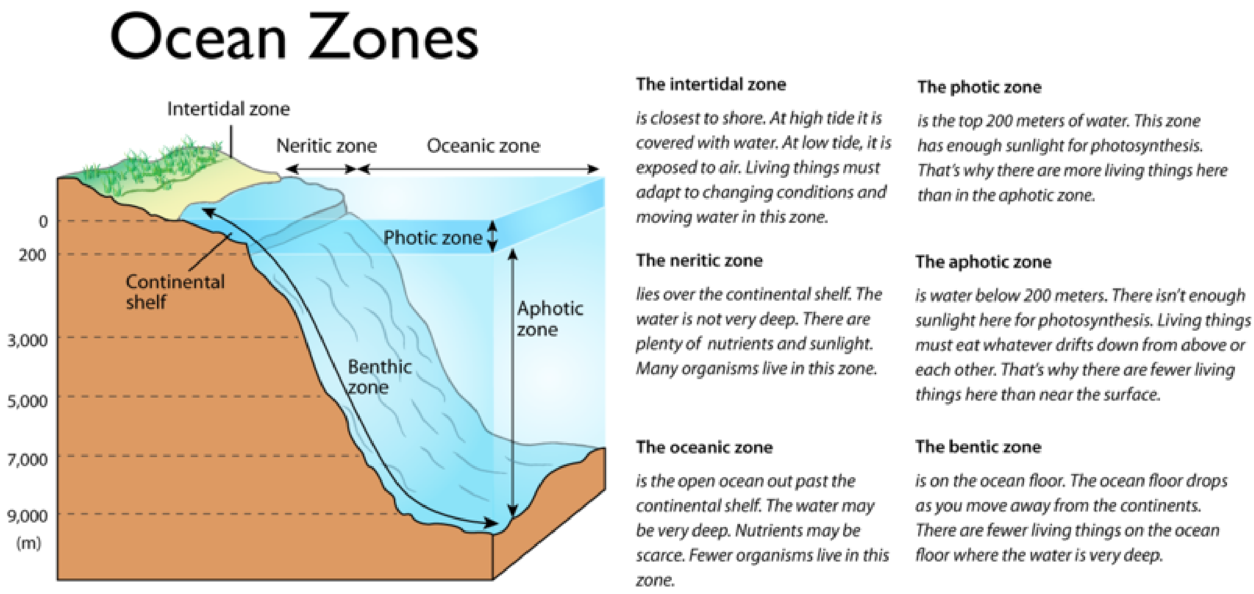

FIGURE 14.6
Distance from shore and depth of water define ocean zones. Which zone is on the ocean floor?

Zones Based on Depth of Water

Two main zones based on depth of water are the photic zone and aphotic zone. The **photic zone** is the top 200 meters of water. The **aphotic zone** is water deeper than 200 meters. The deeper you go, the darker the water gets. That's because sunlight cannot penetrate very far under water. Sunlight is needed for photosynthesis. So the depth of water determines whether photosynthesis is possible. There is enough sunlight for photosynthesis only in the photic zone.

Water also gets colder as you go deeper. The weight of the water pressing down from above increases as well. At great depths, life becomes very difficult. The pressure is so great that only specially adapted creatures can live there.

Lesson Summary

- Early Earth was too hot for liquid water to exist. Eventually Earth cooled. Water vapor from volcanoes and objects in space condensed. Oceans finally formed. The oceans changed size and shape as continents drifted.
- Oceans have a big influence on Earth. They exchange gases with the atmosphere. They prevent very hot and very cold temperatures. They are home to many living things.
- Dissolved mineral salts wash into the ocean. As ocean water evaporates, it leaves the salts behind. This makes the water saltier. Ocean water is about 3.5 percent salts. The main salt is sodium chloride.
- The ocean is divided into many zones. Some are based on distance from shore. Some are based on depth of water. The ocean floor is another zone.

Lesson Review Questions

Recall

1. State why there was no liquid water on ancient Earth.
2. Describe how the oceans influence Earth's atmosphere.
3. What is the makeup of ocean water?
4. Describe how ocean water changes as you go deeper in the water.
5. What is the benthic zone?
6. Define the intertidal zone.

Apply Concepts

7. Look at the map (**Figure** 14.7) of Washington State. Washington is on the Pacific coast. Find Raymond and Pullman on the map. Apply lesson concepts to predict how their temperatures compare. Explain your predictions.

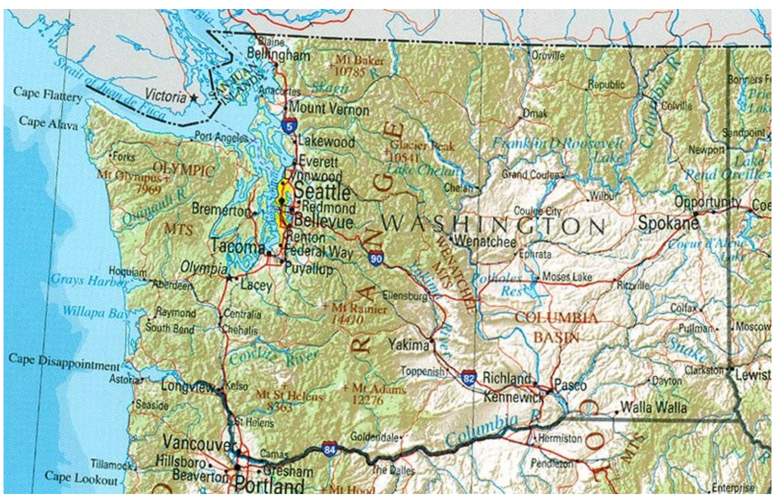

FIGURE 14.7
Map of Washington State.

8. Describe the causes of high and low tides on Earth.

Think Critically

9. Compare and contrast the photic and aphotic zones.

10. Imagine that you are going down to the bottom of the ocean in a tiny submarine. What might you see as you go down? Where will it be light? Where will you see the most life forms?

11. Relate ocean zones to nutrients and sunlight in ocean water.

Points to Consider

Most nutrients enter ocean water from the land. However, they may be carried far from shore by currents.

- Many large ocean currents have names. Can you name any ocean currents?
- Currents are like rivers flowing through the ocean. Rivers always flow downhill because of gravity. What do you think causes ocean currents to flow?

14.2 Ocean Movements

Lesson Objectives

- Describe how waves move through water.
- Explain what causes tides.
- Give an overview of surface currents.
- Identify the cause of deep currents.
- Describe upwelling.

Vocabulary

- convection current
- Coriolis effect
- deep current
- density
- neap tide
- spring tide
- surface current
- tide
- upwelling
- wave

Introduction

If you've ever visited an ocean shore, then you know that ocean water is always moving. Waves ripple through the water, as shown in **Figure** 14.8. The water slowly rises and falls because of tides. You may see signs warning of currents that flow close to shore. What causes all these ocean motions? Different types of motions have different causes.

Waves

Most ocean waves are caused by winds. A **wave** is the transfer of energy through matter. A wave that travels across miles of ocean is traveling energy, not water. Ocean waves transfer energy from wind through water. The energy of a wave may travel for thousands of miles. The water itself moves very little. **Figure** 14.9 shows how water molecules move when a wave goes by.

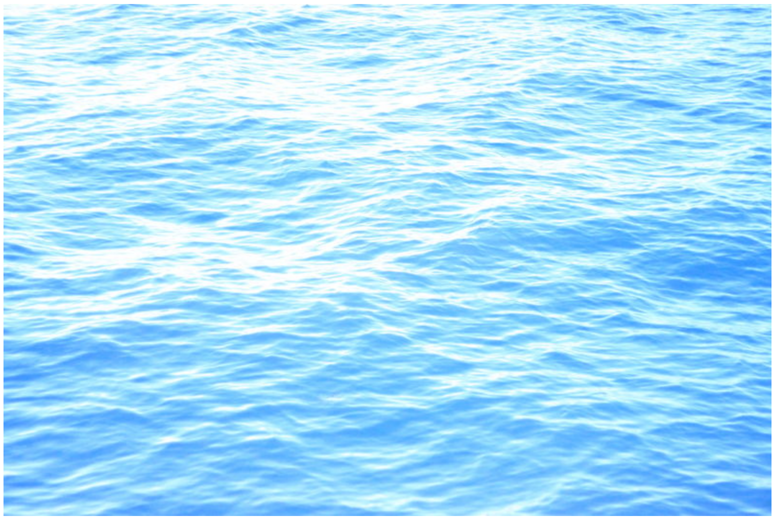

FIGURE 14.8
Waves cause the rippled surface of the ocean.

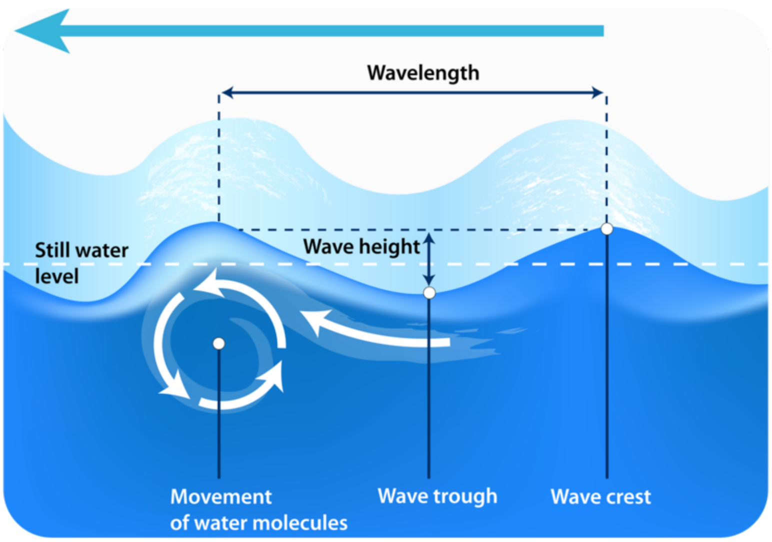

FIGURE 14.9
A wave travels through the water. How would you describe the movement of water molecules as a wave passes through?

The Size of Waves

Figure 14.9 also shows how the size of waves is measured. The highest point of a wave is the crest. The lowest point is the trough. The vertical distance between a crest and a trough is the height of the wave. Wave height is also called amplitude. The horizontal distance between two crests is the wavelength. Both amplitude and wavelength are measures of wave size.

The size of an ocean wave depends on how fast, over how great a distance, and how long the wind blows. The greater each of these factors is, the bigger a wave will be. Some of the biggest waves occur with hurricanes. A hurricane is a storm that forms over the ocean. Its winds may blow more than 150 miles per hour! The winds also travel over long distances and may last for many days.

Breaking Waves

Figure 14.10 shows what happens to waves near shore. As waves move into shallow water, they start to touch the bottom. The base of the waves drag and slow. Soon the waves slow down and pile up. They get steeper and unstable as the top moves faster than the base. When they reach the shore, the waves topple over and break.

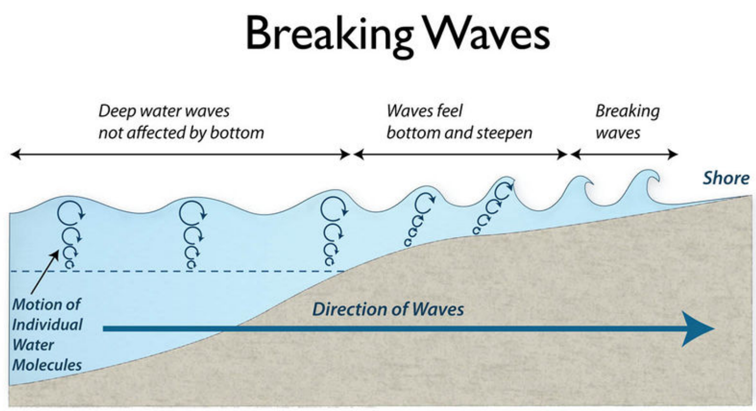

FIGURE 14.10
Waves break when they reach the shore.

Tsunamis

Not all waves are caused by winds. A shock to the ocean can also send waves through water. A tsunami is a wave or set of waves that is usually caused by an earthquake. As we have seen in recent years, the waves can be enormous and extremely destructive. Usually tsunami waves travel through the ocean unnoticed. But when they reach the shore they become enormous. Tsunami waves can flood entire regions. They destroy property and cause many deaths. **Figure** 14.11 shows the damage caused by a tsunami in the Indian Ocean in 2004.

FIGURE 14.11
A 2004 tsunami caused damage like this all along the coast of the Indian Ocean. Many lives were lost.

Tides

Tides are daily changes in the level of ocean water. They occur all around the globe. High tides occur when the water reaches its highest level in a day. Low tides occur when the water reaches its lowest level in a day. Tides keep cycling from high to low and back again. In most places the water level rises and falls twice a day. So there are two high tides and two low tides approximately every 24 hours.

In **Figure** 14.12, you can see the difference between high and low tides. This is called the tidal range.

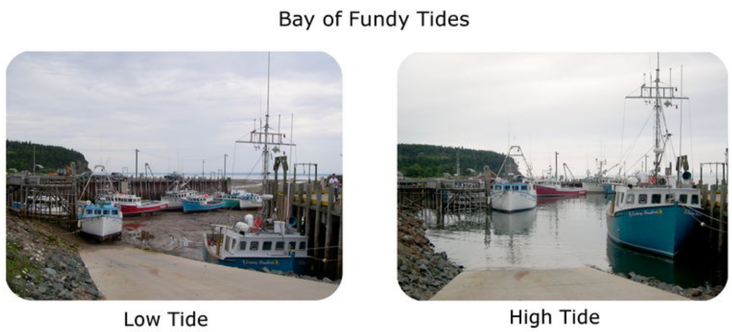

FIGURE 14.12
Where is the intertidal zone in this picture?

Why Tides Occur

Figure 14.13 shows why tides occur. The main cause of tides is the pull of the Moon's gravity on Earth. The pull is greatest on whatever is closest to the Moon. Although the gravity pulls the land, only the water can move. As a result:

- Water on the side of Earth facing the Moon is pulled hardest by the Moon's gravity. This causes a bulge of water on that side of Earth. That bulge is a high tide.
- Earth itself is pulled harder by the Moon's gravity than is the ocean on the side of Earth opposite the Moon. As a result, there is bulge of water on the opposite side of Earth. This creates another high tide.
- With water bulging on two sides of Earth, there's less water left in between. This creates low tides on the other two sides of the planet.

Spring Tides and Neap Tides

The Sun's gravity also pulls on Earth and its oceans. Even though the Sun is much larger than the Moon, the pull of the Sun's gravity is much less because the Sun is much farther away. The Sun's gravity strengthens or weakens the Moon's influence on tides.

Figure 14.14 shows the position of the Moon relative to the Sun at different times during the month. The positions of the Moon and Sun relative to each other determines how the Sun affects tides. This creates spring tides or neap tides.

- **Spring tides** occur during the new moon and full moon. The Sun and Moon are in a straight line either on the same side of Earth or on opposite sides. Their gravitational pull combines to cause very high and very low tides. Spring tides have the greatest tidal range.

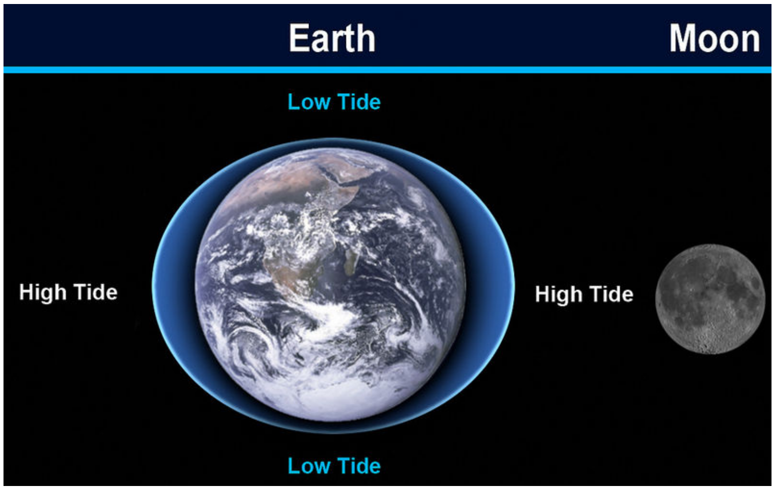

FIGURE 14.13
High and low tides are due mainly to the pull of the Moon's gravity.

- **Neap tides** occur during the first and third quarters of the Moon. The Moon and Sun are at right angles to each other. Their gravity pulls on the oceans in different directions so the highs and lows are not as great. Neap tides have the smallest tidal range.

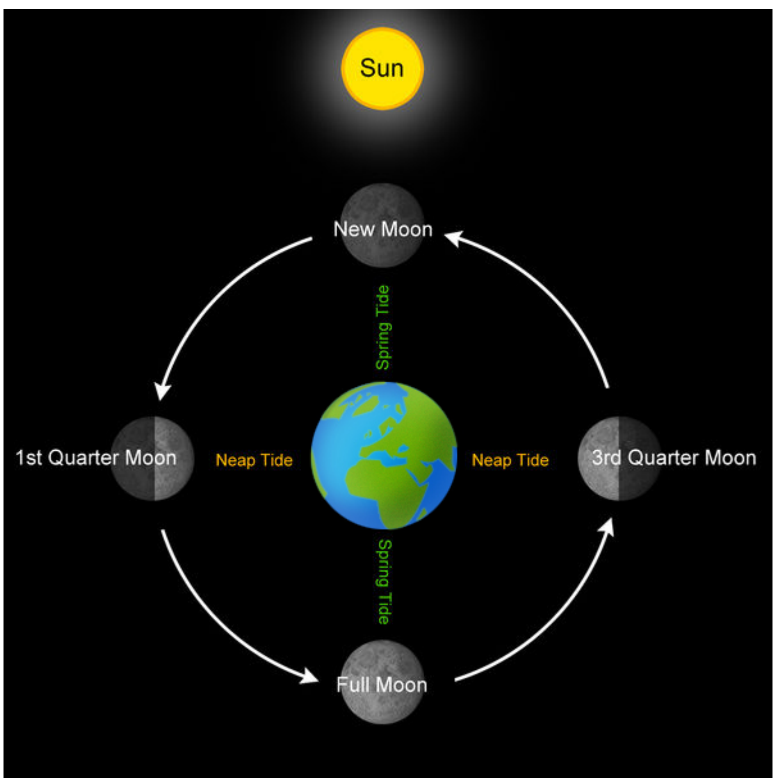

FIGURE 14.14
The Sun and Moon both affect Earth's tides.

This animation shows the effect of the Moon and Sun on the tides: http://www.onr.navy.mil/focus/ocean/motion/tides1.htm .

Surface Currents

Another way ocean water moves is in currents. A current is a stream of moving water that flows through the ocean. **Surface currents** are caused mainly by winds, but not the winds that blow and change each day. Surface currents are caused by the major wind belts that blow in the same direction all the time.

The major surface currents are shown in **Figure** 14.15. They flow in a clockwise direction in the Northern Hemisphere. In the Southern Hemisphere, they flow in the opposite direction.

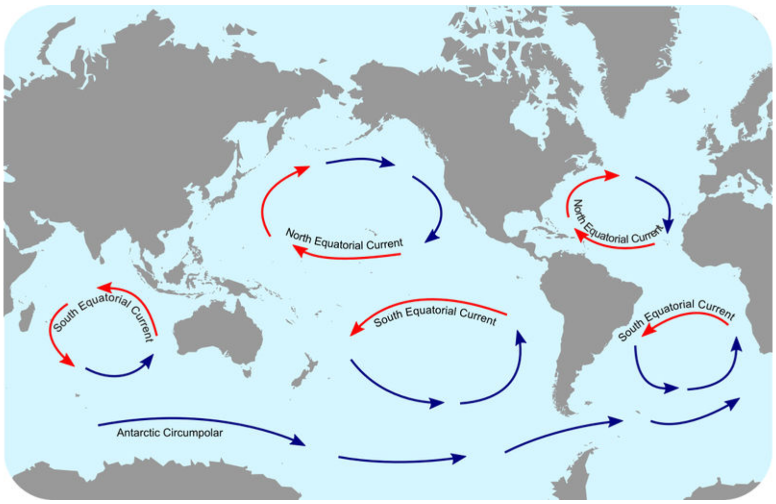

FIGURE 14.15
Earth's surface currents flow in the patterns shown here.

Coriolis Effect

Winds and surface currents tend to move from the hot equator north or south toward the much cooler poles. That's because of differences in the temperature of air masses over Earth's surface. But Earth is spinning on its axis underneath the wind and water as they move. The Earth rotates from west to east. As a result, winds and currents actually end up moving toward the northeast or southeast. This effect of Earth's rotation on the direction of winds and currents is called the **Coriolis effect**.

Surface Currents and Climate

Large ocean currents can have a big impact on the climate of nearby coasts. The Gulf Stream, for example, carries warm water from near the equator up the eastern coast of North America. Look at the map in **Figure** 14.16. It shows how the Gulf Stream warms both the water and land along the coast.

Deep Currents

Currents also flow deep below the surface of the ocean. **Deep currents** are caused by differences in density at the top and bottom. **Density** is defined as the amount of mass per unit of volume. More dense water takes up less space than less dense water. It has the same mass but less volume. Water that is more dense sinks. Less dense water rises. What can make water more dense?

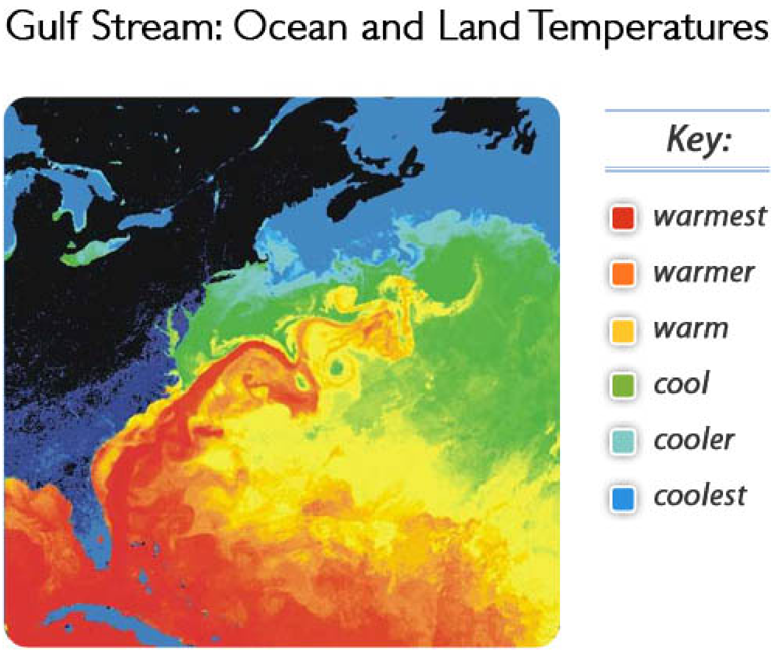

FIGURE 14.16
In this satellite photo, different colors indicate the temperatures of water and land. The warm Gulf Stream can be seen snaking up eastern North America.

Water becomes more dense when it is colder and when it has more salt. In the North Atlantic Ocean, cold winds chill the water at the surface. Sea ice grows in this cold water, but ice is created from fresh water. The salt is left behind in the seawater. This cold, salty water is very dense, so it sinks to the bottom of the North Atlantic. Downwelling can take place in other places where surface water becomes very dense (see **Figure** 14.17).

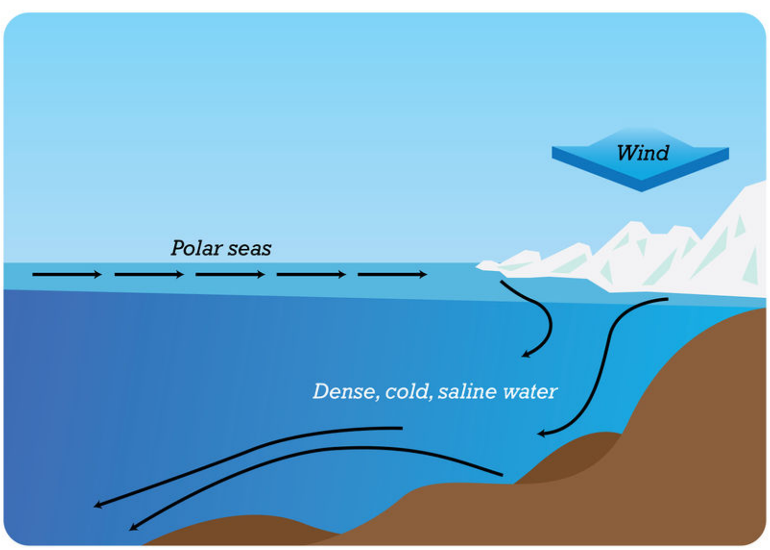

FIGURE 14.17
Deep currents flow because of differences in density of ocean water.

When water sinks it pushes deep water along at the bottom of the ocean. This water circulates through all of the ocean basins in deep currents.

Upwelling

Sometimes deep ocean water rises to the surface. This is called **upwelling**. **Figure** 14.18 shows why it happens. Strong winds blow surface water away from shore. This allows deeper water to flow to the surface and take its place.

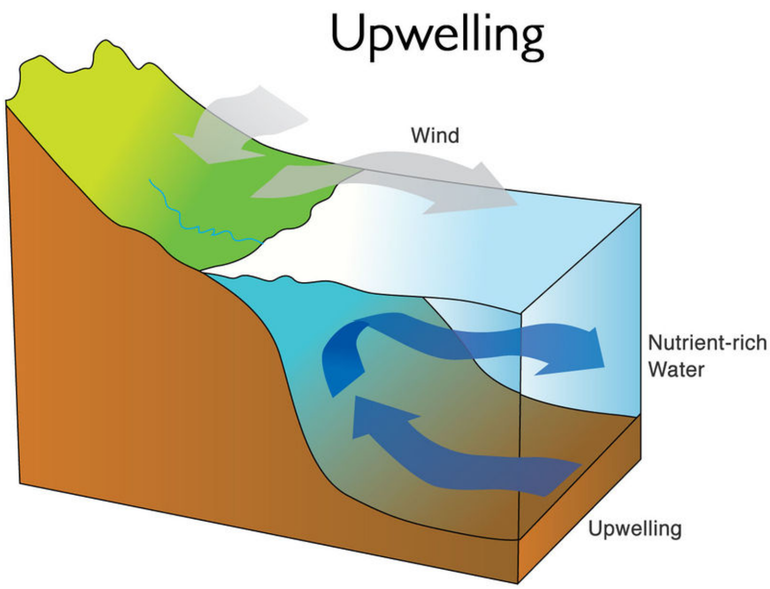

FIGURE 14.18

An upwelling occurs when deep ocean water rises to the surface.

When water comes up from the deep, it brings a lot of nutrients with it. Why is deep water so full of nutrients? Over time, dead organisms and other organic matter settle to the bottom water and collect. The nutrient-rich water that comes to the surface by upwelling supports many living things.

Lesson Summary

- Most ocean waves are caused by winds. The size of a wave depends on how fast, how far, and how long the wind blows. Tsunamis are waves caused by earthquakes.
- Tides are daily changes in the level of ocean water. They are caused mainly by the pull of the Moon's gravity on Earth and its oceans. The Sun's gravity also influences tides.
- Surface currents are like streams flowing through the surface of the ocean. They are caused mainly by winds. Earth's rotation influences their direction. This is called the Coriolis effect. Surface currents may affect the climate of nearby coasts.
- Deep currents are convection currents that occur far below the surface. They are caused by differences in the density of ocean water.
- Upwelling occurs when deep ocean water rises to the surface. The water brings nutrients with it. These nutrients support many organisms.

Lesson Review Questions

Recall

1. Identify two causes of ocean waves.
2. What factors determine how big a wave is?
3. What is the Coriolis effect?
4. Define density. How is the density of water related to its temperature?
5. Describe upwelling. State why it occurs.

Apply Concepts

6. The crest of an ocean wave is 3 meters above the still water level. The trough is 3 meters below the still water level. The horizontal distance between the crest and trough is 8 meters. Draw a diagram of this wave. Label the crest, trough, and distances. Then calculate the wave's amplitude and wavelength.

7. Assume that a spring tide occurs on September 1. Predict when the next neap tide will occur. When will the next spring tide occur? Explain your answers.

Think Critically

8. Explain why waves break on the shore.

9. If the tidal cycle was actually 12 hours then high tides would occur at the same time every day. In reality, high tides occur about every 12 hours and 25 minutes. Can you think of why this would be the case?

10. Are deep currents the same as surface currents except that they are near the ocean bottom?

Points to Consider

Upwelling brings nutrients to the surface from the ocean floor. Nutrients are important resources for ocean life. However, they aren't the only resources on the ocean floor.

- What other resources do you think might be found on the ocean floor?
- It's hard to get resources from the ocean floor. Can you explain why?

14.3 The Ocean Floor

Lesson Objectives

- Describe how scientists study the ocean floor.
- Identify major features of the ocean floor.
- List resources found on the ocean floor.

Vocabulary

- abyssal plain
- continental shelf
- continental slope
- mid-ocean ridge
- oceanic trench
- seamount
- sonar

Introduction

Vast, unknown spaces still exist for humans to explore. Of course, outer space is still mostly unknown. But some of the most interesting and hardest to reach places are much closer to home. They are on the ocean floor.

Only a tiny fraction of the ocean floor has ever been studied. Why? Humans can't travel deep below the water's surface without special vehicles. The pressure of the water is too great. Total darkness and extreme cold make it even more difficult. That's why people have worked for decades to invent technology for studying the ocean floor.

Studying the Ocean Floor

Scientists study the ocean floor in various ways. Scientists —or their devices —may actually travel to the ocean floor. Or they may study the ocean floor from the surface. One way is with a tool called **sonar**.

Using Sonar

Did you ever shout and hear an echo? If you did, that's because the sound waves bounced off a hard surface and back to you. The same principle explains how sonar works. A ship on the surface sends sound waves down to the ocean floor. The sound waves bounce off the ocean floor and return to the surface, like an echo. **Figure** 14.19 show how this happens.

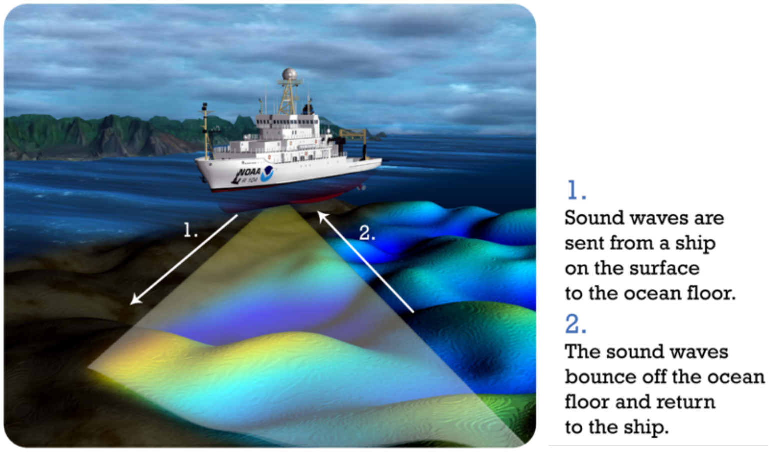

FIGURE 14.19
Sound waves travel through ocean water, but they bounce off the ocean floor. They move through ocean water at a known speed. Can you use these facts to explain how sonar works?

Sonar can be used to measure how deep the ocean is. A device records the time it takes sound waves to travel from the surface to the ocean floor and back again. Sound waves travel through water at a known speed. Once scientists know the travel time of the wave, they can calculate the distance to the ocean floor. They can then combine all of these distances to make a map of the ocean floor. **Figure** 14.20 shows an example of this type of map.

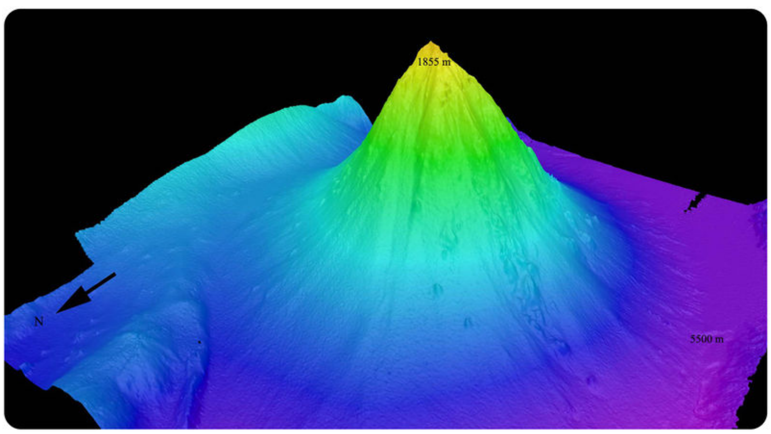

FIGURE 14.20
A map of a 10,000 foot-high undersea volcano in Indonesia made by multibeam solar.

Traveling to the Ocean Floor

Only a specially designed vehicle can venture beneath the sea surface. But only very special vehicles can reach the ocean floor. Three are described here and pictured in **Figure** 14.21:

- In 1960, scientists used the submersible Trieste to travel into the Mariana Trench. They succeeded, but the trip was very risky. Making humans safe at such depths costs a lot of money. People have not traveled to this depth again. In 2012, the film director, James Cameron, dove to the bottom of the Mariana Trench by himself in a submersible that he had built for the purpose.
- The vehicle named Alvin was developed soon after Trieste. The submersible has made over 4,000 dives deep into the ocean. People can stay underwater for up to 9 hours. Alvin has been essential for developing a scientific understanding the world's oceans.

- Today, remote-control vehicles, called remotely operated vehicles (ROVs) go to the deepest ocean floor. They don't have any people on board. However, they carry devices that record many measurements. They also collect sediments and take photos.

FIGURE 14.21
Vehicles for Underwater Exploration. These special vehicles have been used to study the ocean floor.

Features on the Ocean Floor

Scientists have learned a lot about the ocean floor. For example, they know that Earth's tallest mountains and deepest canyons are on the ocean floor. The major features on the ocean floor are described below. They are also shown in **Figure** 14.22.

- The **continental shelf** is the ocean floor nearest the edges of continents. It has a a gentle slope. The water over the continental shelf is shallow.
- The **continental slope** lies between the continental shelf and the abyssal plain. It has a steep slope with a sharp drop to the deep ocean floor.
- The **abyssal plain** forms much of the floor under the open ocean. It lies from 3 to 6 kilometers (1.9 to 3.7 miles) below the surface. Much of it is flat.
- An **oceanic trench** is a deep canyon on the ocean floor. Trenches occur where one tectonic plate subducts under another. The deepest trench is the Mariana Trench in the Pacific Ocean. It plunges more than 11 kilometers (almost 7 miles) below sea level.
- A **seamount** is a volcanic mountain on the ocean floor. Seamounts that rise above the water surface are known as islands. There are many seamounts dotting the seafloor.
- The **mid-ocean ridge** is a mountain range that runs through all the world's oceans. It is almost 64,000 kilometers (40,000 miles) long! It forms where tectonic plates pull apart. Magma erupts through the ocean floor to make new seafloor. The magma hardens to create the ridge.

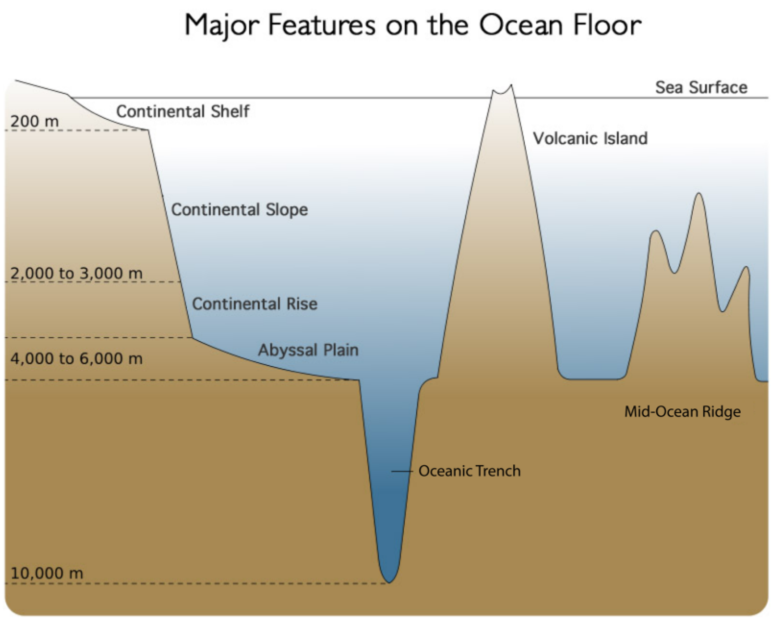

FIGURE 14.22
The features of the ocean floor. This diagram has a lot of vertical exaggeration.

Resources from the Ocean Floor

The ocean floor is rich in resources. The resources include both living and nonliving things.

Living Resources

The ocean floor is home to many species of living things. Some from shallow water are used by people for food. Clams and some fish are among the many foods we get from the ocean floor. Some living things on the ocean floor are sources of human medicines. For example, certain bacteria on the ocean floor produce chemicals that fight cancer.

Nonliving Resources

Oil and natural gas lie below some regions of the seafloor. Large drills on floating oil rigs must be used to reach them. This is risky for workers on the rigs. It is also risky for the ocean and its living things. An oil rig explosion caused a massive oil leak in the Gulf of Mexico in 2010. Oil poured into the water for several months. The oil caused great harm to habitats and living things, both in the water and on the coast. The oil spill also hurt the economy of Gulf Coast states. The effects of the oil spill are still being tallied.

There are many minerals on the ocean floor. Some settle down from the water above. Some are released in hot water through vents, or cracks, in the seafloor. The minerals in hot water settle out and form metallic chimneys, as in **Figure** 14.23. These metals could be mined, but they are very deep in the sea and very far from land. This means that mining them would be too expensive and not worth the effort.

Some types of minerals form balls called nodules. Nodules may be tiny or as big as basketballs. They contain manganese, iron, copper, and other useful minerals. As many as 500 billion tons of nodules lie on the ocean floor! However, mining them would be very costly and could be harmful to the ocean environment.

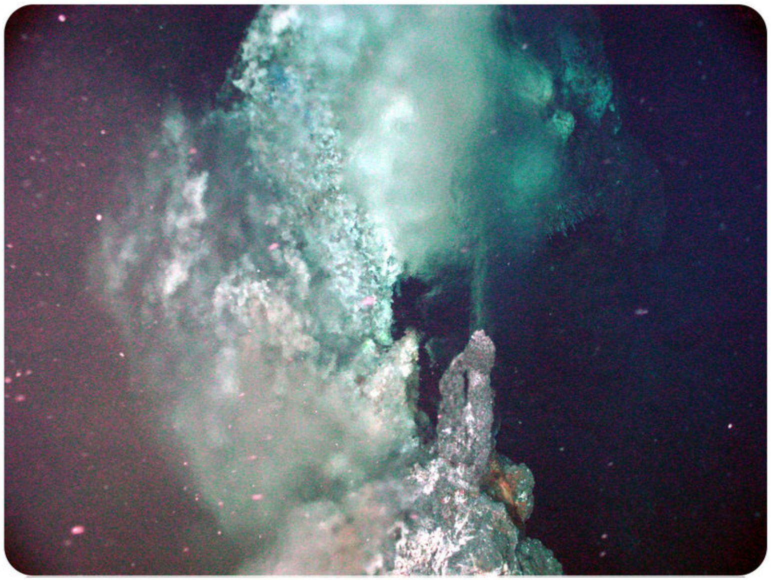

FIGURE 14.23
Metals from the ocean crust are brought by hot water onto the seafloor to create chimneys, as shown in this photo.

Lesson Summary

- Studying the ocean floor is difficult because the environment is so hostile. The seafloor can be studied indirectly with tools such as sonar. It can be studied directly using special vehicles. Some vehicles carry scientists and their devices to the ocean floor. Other vehicles are operated remotely.
- Features of the ocean floor include the continental shelf and slope, abyssal plain, trenches, seamounts, and the mid-ocean ridge.
- The ocean floor is rich in resources. Living things on the ocean floor are used for food or medicines. Nonliving resources include oil, gas, and minerals.

Lesson Review Questions

Recall

1. Why is it difficult to study the deep ocean floor?
2. What is sonar? How can it be used to study the seafloor?
3. What are the continental slope and continental shelf?
4. Gives examples of living resources from the ocean floor.
5. Identify nonliving resources on or below the ocean floor.

Apply Concepts

6. Create a diagram to show how sonar is used to find the distance from the surface to the ocean floor.

Think Critically

7. Relate features of the ocean floor to plate tectonics.

Points to Consider

Many organisms live on the ocean floor. Others live elsewhere in the ocean.

- Where else do organisms live in the ocean?
- How might organisms that live on the ocean floor differ from those that live in other parts of the ocean?

14.4 Ocean Life

Lesson Objectives

- Identify three major groups of marine life.
- Describe marine food chains.

Vocabulary

- benthos
- marine organism
- nekton
- phytoplankton
- plankton
- zooplankton

Introduction

Living things in the oceans are called **marine organisms**. They range from tiny bacteria to the largest known animal, the blue whale. All are adapted for life in salt water. Most are adapted for extreme pressures.

Living Things in the Ocean

When you think of life in the ocean, do you think of fish? Actually, fish are not the most common life forms in the ocean. Plankton are the most common. Plankton make up one of three major groups of marine life. The other two groups are nekton and benthos. **Figure** 14.24 shows the three groups.

Plankton

Plankton are living things that float in the water. Most plankton are too small to see with the unaided eye. Some examples are shown in **Figure** 14.25. Plankton are unable to move on their own. Ocean motions carry them along.

There are two main types of plankton:

1. **Phytoplankton** are "plant-like" plankton. They make food by photosynthesis. They live in the photic zone. Most are algae.
2. **Zooplankton** are "animal-like" plankton. They feed on phytoplankton. They include tiny animals and fish larvae.

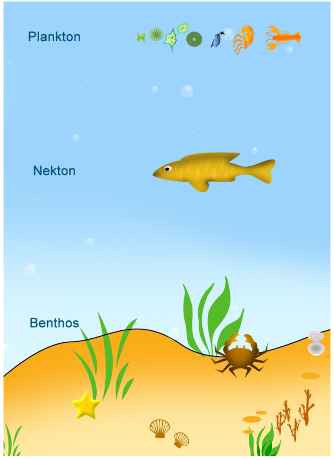

FIGURE 14.24
Living things in the oceans are placed in these three groups.

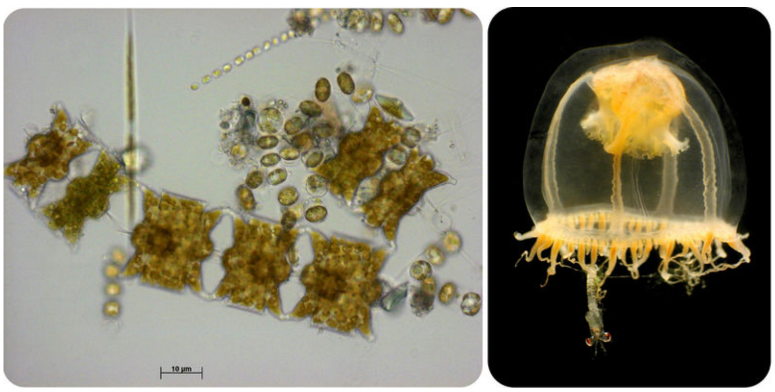

FIGURE 14.25
The phytoplankton (left) and zooplankton (right) shown here have been magnified. Otherwise, they would be too small for you to see.

Nekton

Nekton are living things that swim through the water. They may live at any depth, in the photic or aphotic zone. Most nekton are fish, although some are mammals. Fish have fins and streamlined bodies to help them swim. Fish also have gills to take oxygen from the water. **Figure** 14.26 shows examples of nekton.

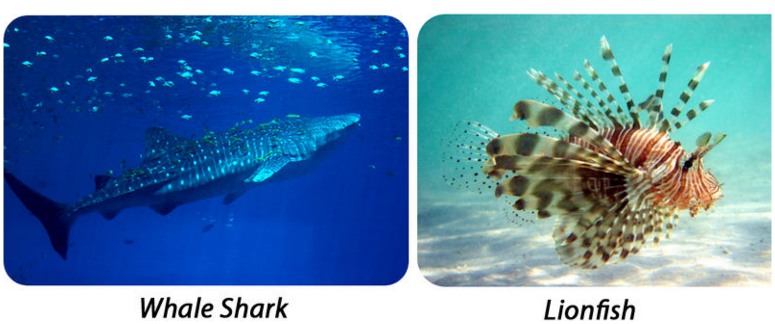

FIGURE 14.26
Nekton swim through ocean water.

Benthos

Benthos are living things on the ocean floor. Many benthic organisms attach themselves to rocks and stay in one place. This protects them from crashing waves and other water movements. Some benthic organisms burrow into sediments for food or protection. Benthic animals may crawl over the ocean floor. Examples of benthos include clams and worms. **Figure** 14.27 shows two other examples.

FIGURE 14.27
These animals live on the ocean floor.

Some benthos live near vents on the deep ocean floor. Tubeworms are an example (see **Figure** 14.28). Scalding hot water pours out of the vents. The hot water contains chemicals that some specialized bacteria can use to make food. Tubeworms let the bacteria live inside them. The bacteria get protection and the tubeworms get some of the food.

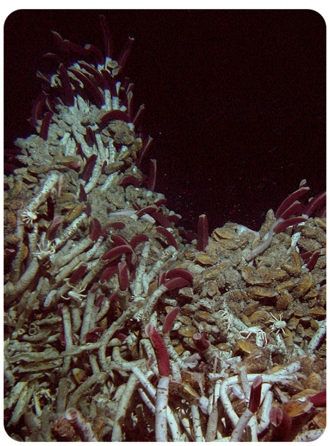

FIGURE 14.28
Tubeworms live near hot water vents on the deep ocean floor.

Marine Food Chains

Figure 14.29 shows a marine food chain. Phytoplankton form the base of the food chain. Phytoplankton are the most important primary producers in the ocean. They use sunlight and nutrients to make food by photosynthesis. Small zooplankton consume phytoplankton. Larger organisms eat the small zooplankton. Larger predators eat these consumers. In an unusual relationship, some enormous whales depend on plankton for their food. They filter tremendous amounts of these tiny creatures out of the water.

The bacteria that make food from chemicals are also primary producers. These organisms do not do photosynthesis since there is no light at the vents. They do something called chemosynthesis. They break down chemicals to make food.

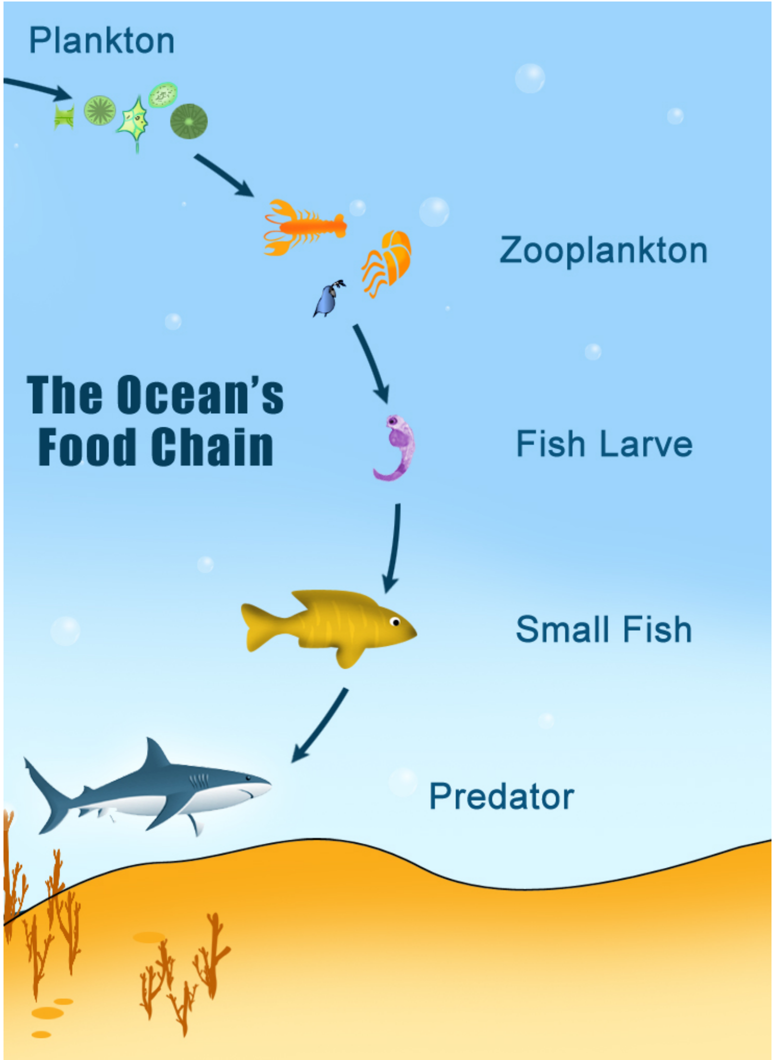

FIGURE 14.29
Many marine food chains look like this example.

When marine organisms die, decomposers break them down. This returns their nutrients to the water. The nutrients can be used again to make food. Decomposers in the oceans include bacteria and worms. Many live on the ocean floor. Do you know why?

Lesson Summary

- Three main groups of ocean life are plankton, nekton, and benthos. Plankton float in the water. Nekton swim through the water. Benthos live on the ocean floor.
- Phytoplankton are the primary producers in the ocean. They form the base of most marine food chains.

Lesson Review Questions

Recall

1. Define marine organism.
2. What are phytoplankton and zooplankton?
3. Why do phytoplankton live in the photic zone?
4. Define nekton.
5. Where do benthos live?

Apply Concepts

6. Create a marine food chain that includes the following living things: jellyfish, worm, shark, algae.

Think Critically

7. Compare and contrast plankton, nekton, and benthos.
8. Explain the importance of phytoplankton to other forms of ocean life.

Points to Consider

This chapter describes how the oceans influence Earth's atmosphere.

- What else do you know about the atmosphere? For example, what gases does it contain?
- The ocean is divided into zones. Do you think the atmosphere is divided into zones as well?

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CHAPTER 15 MS Earth's Atmosphere

Chapter Outline

Did you ever see such an awesome sight? This picture may not look real, but it's an actual photo of the night sky. Unless you live far north or south of the equator, you probably never saw the sky look like this. What causes the fantastic lights? The answer is Earth's atmosphere.

Lights like these may be among the most spectacular effects of Earth's atmosphere. But they certainly aren't the most important for life on Earth. Without the atmosphere, Earth would be nothing but a bare rock orbiting the Sun. It would be more like the Moon than the green planet we know. To learn more about the amazing air around us, keep reading. This chapter is all about Earth's atmosphere.

15.1 The Atmosphere

Lesson Objectives

- Explain why Earth's atmosphere is important.
- Describe the composition of the atmosphere.
- List properties of the atmosphere.

Vocabulary

- air pressure
- altitude
- sound

Introduction

Why is Earth the only planet in the solar system known to have life? The main reason is Earth's atmosphere. The atmosphere is a mixture of gases that surrounds the planet. We also call it air. The gases in the air include nitrogen, oxygen, and carbon dioxide. Along with water vapor, air allows life to survive. Without it, Earth would be a harsh, barren world.

Why the Atmosphere Is Important

We are lucky to have an atmosphere on Earth. The atmosphere supports life, and is also needed for the water cycle and weather. The gases of the atmosphere even allow us to hear.

The Atmosphere and Living Things

Most of the atmosphere is nitrogen, but it doesn't do much. Carbon dioxide and oxygen are the gases in the atmosphere that are needed for life.

- Plants need carbon dioxide for photosynthesis. They use sunlight to change carbon dioxide and water into food. The process releases oxygen. Without photosynthesis, there would be very little oxygen in the air.
- Other living things depend on plants for food. These organisms need the oxygen plants release to get energy out of the food. Even plants need oxygen for this purpose.

The Atmosphere and the Sun's Rays

The atmosphere protects living things from the Sun's most harmful rays. Gases reflect or absorb the strongest rays of sunlight. **Figure** 15.1 models this role of the atmosphere.

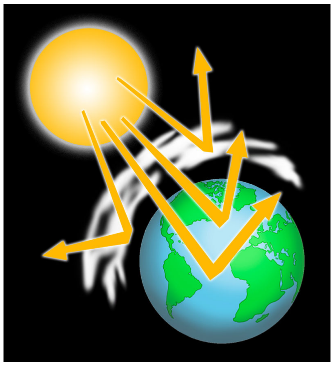

FIGURE 15.1
The atmosphere shields Earth from harmful solar rays.

The Atmosphere and Earth's Temperature

Gases in the atmosphere surround Earth like a blanket. They keep the temperature in a range that can support life. The gases keep out some of the Sun's scorching heat during the day. At night, they hold the heat close to the surface, so it doesn't radiate out into space.

The Atmosphere and Earth's Water

Figure 15.2 shows the role of the atmosphere in the water cycle. Water vapor rises from Earth's surface into the atmosphere. As it rises, it cools. The water vapor may then condense into water droplets and form clouds. If enough water droplets collect in clouds they may fall as rain. This how freshwater gets from the atmosphere back to Earth's surface.

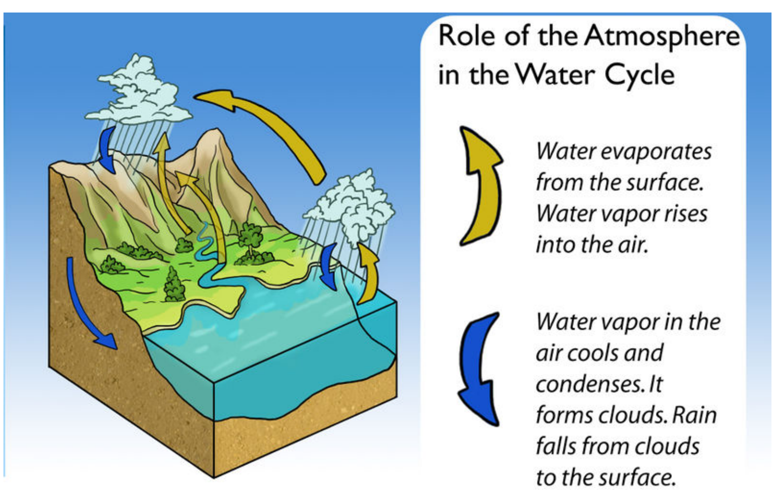

FIGURE 15.2
The atmosphere is a big part of the water cycle. What do you think would happen to Earth's water without it?

The Atmosphere and Weather

Without the atmosphere, there would be no clouds or rain. In fact, there would be no weather at all. Most weather occurs because the atmosphere heats up more in some places than others.

The Atmosphere and Weathering

Weather makes life interesting. Weather also causes weathering. Weathering is the slow wearing down of rocks on Earth's surface. Wind-blown sand scours rocks like sandpaper. Glaciers of ice scrape across rock surfaces like a file. Even gentle rain may seep into rocks and slowly dissolve them. If the water freezes, it expands. This eventually causes the rocks to crack. Without the atmosphere, none of this weathering would happen.

The Atmosphere and Sound

Sound is a form of energy that travels in waves. Sound waves can't travel through empty space, but they can travel through gases. Gases in the air allow us to hear most of the sounds in our world. Because of air, you can hear birds singing, horns tooting, and friends laughing. Without the atmosphere, the world would be a silent, eerie place.

Composition of Air

Air is easy to forget about. We usually can't see it, taste it, or smell it. We can only feel it when it moves. But air is actually made of molecules of many different gases. It also contains tiny particles of solid matter.

Gases in Air

Figure 15.3 shows the main gases in air. Nitrogen and oxygen make up 99 percent of air. Argon and carbon dioxide make up much of the rest. These percentages are the same just about everywhere in the atmosphere.

Air also includes water vapor. The amount of water vapor varies from place to place. That's why water vapor isn't included in **Figure** 15.3. It can make up as much as 4 percent of the air. Ozone is a molecule made of three oxygen atoms. Ozone collects in a layer in the stratosphere.

Particles in the Air

Air includes many tiny particles. The particles may consist of dust, soil, salt, smoke, or ash. Some particles pollute the air and may make it unhealthy to breathe. But having particles in the air is very important. Tiny particles are needed for water vapor to condense on. Without particles, water vapor could not condense. Then clouds could not form and Earth would have no rain.

Properties of Air

We usually can't sense the air around us unless it is moving. But air has the same basic properties as other matter. For example, air has mass, volume and, of course, density.

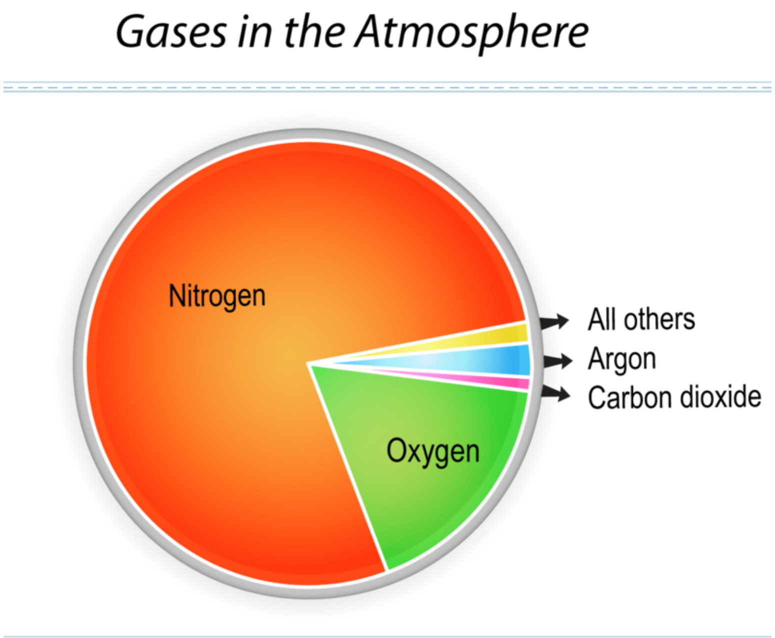

FIGURE 15.3
This graph identifies the most common gases in air.

Density of Air

Density is mass per unit volume. Density is a measure of how closely molecules are packed together. The closer together they are, the greater the density. Since air is a gas, the molecules can pack tightly or spread out.

The density of air varies from place to place. Air density depends on several factors. One is temperature. Like other materials, warm air is less dense than cool air. Since warmer molecules have more energy, they are more active. The molecules bounce off each other and spread apart. Another factor that affects the density of air is altitude.

Altitude and Density

Altitude is height above sea level. The density of air decreases with height. There are two reasons. At higher altitudes, there is less air pushing down from above. Also, gravity is weaker farther from Earth's center. So at higher altitudes, air molecules can spread out more. Air density decreases. You can see this in **Figure** 15.4.

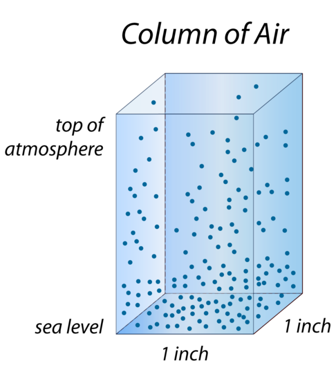

FIGURE 15.4
This drawing represents a column of air. The column rises from sea level to the top of the atmosphere. Where does air have the greatest density?

Air Pressure

Because air is a gas, its molecules have a lot of energy. Air molecules move a lot and bump into things. For this reason, they exert pressure. **Air pressure** is defined as the weight of the air pressing against a given area.

At sea level, the atmosphere presses down with a force of about 1 kilogram per square centimeter (14.76 pounds per square inch). If you are standing at sea level, you have more than a ton of air pressing against you. Why doesn't the pressure crush you? Air presses in all directions at once. Other molecules of air are pushing back.

Altitude and Air Pressure

Like density, the pressure of the air decreases with altitude. There is less air pressing down from above the higher up you go. Look at the bottle in **Figure** 15.5. It was drained by a hiker at the top of a mountain. Then the hiker screwed the cap on the bottle and carried it down to sea level. At the lower altitude, air pressure crushed it. Can you explain why?

FIGURE 15.5
At sea level, pressure was greater outside than inside the bottle. The greater outside pressure crushed the bottle.

Lesson Summary

- Gases in the atmosphere are needed by living things. They protect life from the Sun's harmful rays. They also keep temperatures in a range that can support life. Gases in air play a major part in the water cycle, weather, and weathering. They are also needed to transmit most sounds.
- Nitrogen and oxygen make up about 99 percent of the air. Argon and carbon dioxide make up much of the rest. The air also contains water vapor. The amount of water vapor varies from place to place.
- Air has mass and volume. It also has density and exerts pressure. Both the density and pressure of air decrease with altitude.

Lesson Review Questions

Recall

1. State how living things interact with the atmosphere.

2. How does the atmosphere keep Earth warm at night?
3. What role does the atmosphere play in the water cycle?
4. Why does weathering on Earth's surface depend on the atmosphere?
5. Describe the composition of air.

Apply Concepts

6. Create a graph that shows how air pressure changes with altitude. Use the data in **Table** 15.1 as a guide.

TABLE 15.1: Data for Problem 6

Air Pressure (atm)	Altitude (m)	Altitude (ft)
1	0	0
3/4	2,750	7,902
1/2	5,486	18,000
1/3	8,376	27,480
1/10	16,132	52,926
1/100	30,901	101,381
1/1,000	48,467	159,013
1/10,000	69,464	227,899
1/100,000	86,282	283,076

Think Critically

7. Explain how and why the density of air changes with altitude.

8. Review **Figure** 15.5 and its caption. What would the bottle look like if the hiker hadn't screwed on the cap before returning to sea level? Explain your answer.

Points to Consider

In this lesson, you read that air density and pressure change with altitude. The temperature of the air also changes with altitude. Air temperature measures the heat energy of air molecules.

- What heats the atmosphere? Where does air gets its energy?
- What causes the atmosphere to lose energy and become cooler?

15.2 Energy in the Atmosphere

Lesson Objectives

- Define energy.
- Describe solar energy.
- State how heat moves through the atmosphere.
- Describe how solar energy varies across Earth's surface.
- Explain the greenhouse effect.

Vocabulary

- electromagnetic spectrum
- energy
- greenhouse effect
- greenhouse gas
- infrared light
- photon
- ultraviolet (UV) light
- visible light

Introduction

Picture yourself sitting by the campfire in **Figure** 15.6. You and your friends are using the fire to heat soup in a pot. As the Sun goes down, the air gets chilly. You move closer to the fire. Heat from the fire warms you. Light from the fire allows you to see your friends.

What Is Energy?

What explains all of these events? The answer can be summed up in one word: energy. **Energy** is defined as the ability to do work. Doing anything takes energy. A campfire obviously has energy. You can feel its heat and see its light.

Forms of Energy

Heat and light are forms of energy. Other forms are chemical and electrical energy. Energy can't be created or destroyed. It can change form. For example, a piece of wood has chemical energy stored in its molecules. When the wood burns, the chemical energy changes to heat and light energy.

FIGURE 15.6
These campers can feel and see the energy of their campfire.

Movement of Energy

Energy can move from one place to another. It can travel through space or matter. That's why you can feel the heat of a campfire and see its light. These forms of energy travel from the campfire to you.

Energy from the Sun

Almost all energy on Earth comes from the Sun. The Sun's energy heats the planet and the air around it. Sunlight also powers photosynthesis and life on Earth.

Photons of Energy

The Sun gives off energy in tiny packets called **photons**. Photons travel in waves. **Figure** 15.7 models a wave of light. Notice the wavelength in the figure. Waves with shorter wavelengths have more energy.

Electromagnetic Spectrum

Energy from the Sun has a wide range of wavelengths. The total range of energy is called the **electromagnetic spectrum**. You can see it in **Figure** 15.8.

Visible light is the only light that humans can see. Different wavelengths of visible light appear as different colors. Radio waves have the longest wavelengths. They also have the least amount of energy. **Infrared light** has wavelengths too long for humans to see, but we can feel them as heat. The atmosphere absorbs the infrared light. **Ultraviolet (UV) light** is in wavelengths too short for humans to see. The most energetic UV light is harmful to life. The atmosphere absorbs most of this UV light from the Sun. Gamma rays have the highest energy and they are the most damaging rays. Fortunately, gamma rays don't penetrate Earth's atmosphere.

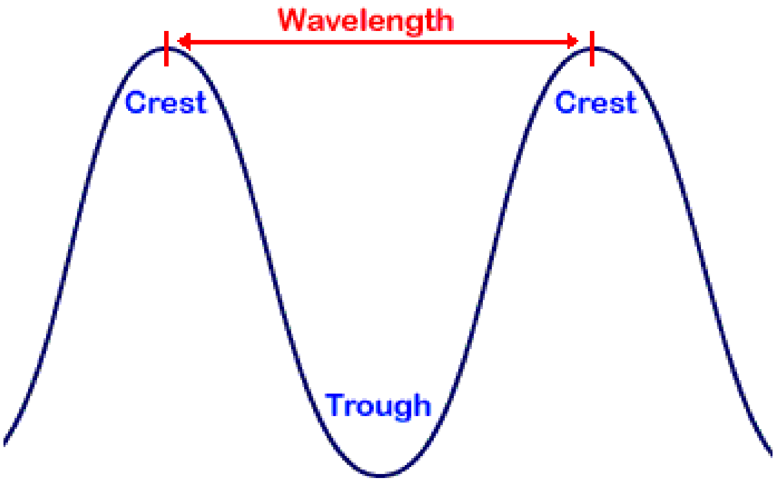

FIGURE 15.7
This curve models a wave. Based on this figure, how would you define wavelength?

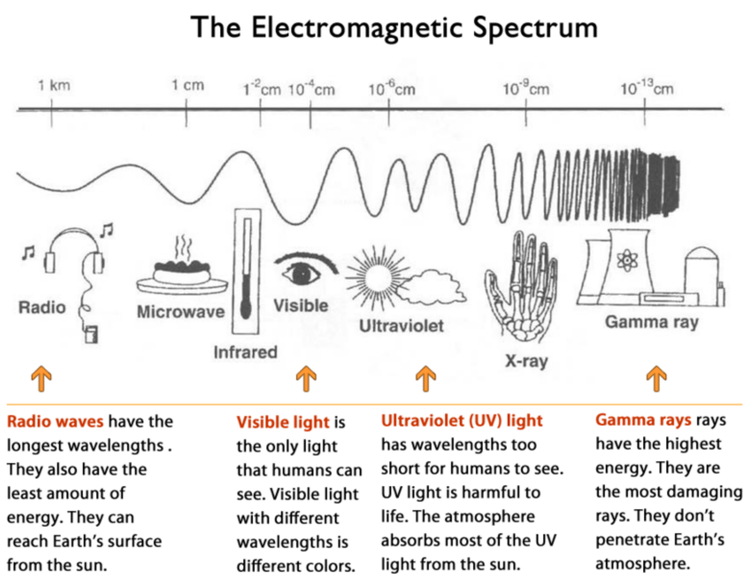

FIGURE 15.8
Compare the wavelengths of radio waves and gamma rays. Which type of wave has more energy?

How Energy Moves Through the Atmosphere

Energy travels through space or material. Heat energy is transferred in three ways: radiation, conduction, and convection.

Radiation

Radiation is the transfer of energy by waves. Energy can travel as waves through air or empty space. The Sun's energy travels through space by radiation. After sunlight heats the planet's surface, some heat radiates back into the atmosphere.

Conduction

In conduction, heat is transferred from molecule to molecule by contact. Warmer molecules vibrate faster than cooler ones. They bump into the cooler molecules. When they do they transfer some of their energy. Conduction happens mainly in the lower atmosphere. Can you explain why?

Convection

Convection is the transfer of heat by a current. Convection happens in a liquid or a gas. Air near the ground is warmed by heat radiating from Earth's surface. The warm air is less dense, so it rises. As it rises, it cools. The cool air is dense, so it sinks to the surface. This creates a convection current, like the one in **Figure** 15.9. Convection is the most important way that heat travels in the atmosphere.

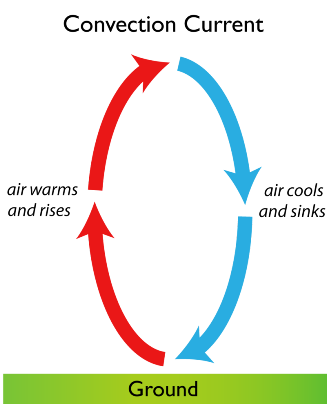

FIGURE 15.9
Convection currents are the main way that heat moves through the atmosphere. Why does warm air rise?

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight. You can see this in **Figure** 15.10. The Sun's rays strike Earth's surface most directly at the equator. This focuses the rays on a small area. Near the poles, the Sun's rays strike the surface at a slant. This spreads the rays over a wide area. The more focused the rays are, the more energy an area receives and the warmer it is.

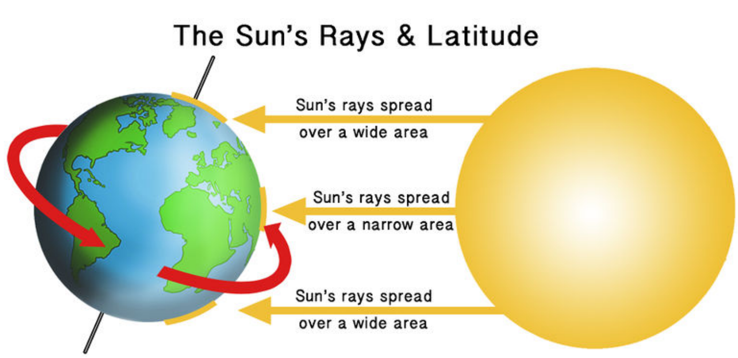

FIGURE 15.10
The lowest latitudes get the most energy from the Sun. The highest latitudes get the least.

How do the differences in energy striking different latitudes affect Earth? The planet is much warmer at the equator than at the poles. In the atmosphere, the differences in heat energy cause winds and weather. On the surface, the differences cause ocean currents. Can you explain how?

The Greenhouse Effect

When sunlight heats Earth's surface, some of the heat radiates back into the atmosphere. Some of this heat is absorbed by gases in the atmosphere. This is the **greenhouse effect**, and it helps to keep Earth warm. The greenhouse effect allows Earth to have temperatures that can support life.

Gases that absorb heat in the atmosphere are called **greenhouse gases**. They include carbon dioxide and water vapor. Human actions have increased the levels of greenhouse gases in the atmosphere. This is shown in **Figure** 15.11. The added gases have caused a greater greenhouse effect. How do you think this affects Earth's temperature?

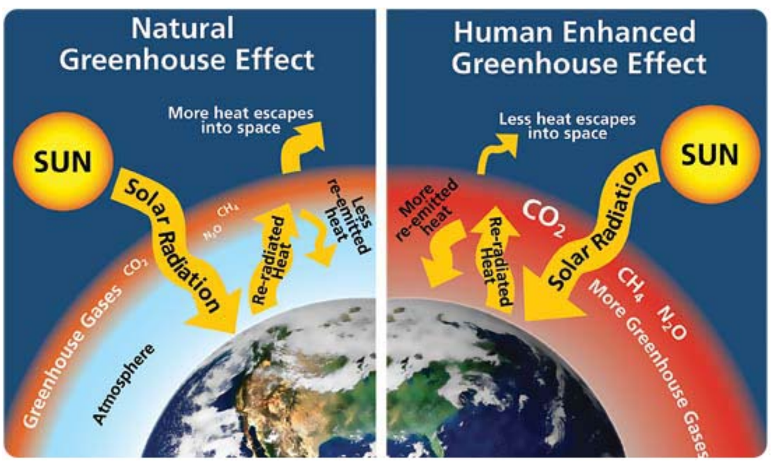

FIGURE 15.11
Human actions have increased the natural greenhouse effect.

Lesson Summary

- Energy is the ability to do work. Heat and light are forms of energy. Energy can change form. It can also move from place to place.
- Earth gets its energy from the Sun. The Sun gives off photons of energy that travel in waves. All the wavelengths of the Sun's energy make up the electromagnetic (EM) spectrum.
- Energy moves in three ways. By radiation, it travels in waves across space. By conduction, it moves between molecules that are in contact. By convection, it moves in a current through a liquid or gas.
- Energy from the Sun is more focused at the equator than the poles. Differences in energy by latitude cause winds and weather.
- Greenhouse gases in the atmosphere absorb heat. This is called the greenhouse effect and it makes the planet warmer. Human actions have increased the greenhouse effect.

Lesson Review Questions

Recall

1. Define energy. List three forms of energy.
2. Describe the electromagnetic spectrum.
3. How is wavelength related to the energy of light?
4. What is the greenhouse effect?
5. List two greenhouse gases.

Apply Concepts

6. Look at **Figure** 15.6. Apply lesson concepts to explain three ways that heat from the campfire can travel.

Think Critically

7. Why is Earth colder at the poles than the equator?
8. Explain how human actions have increased the greenhouse effect.

Points to Consider

Energy from the Sun heats the air in Earth's atmosphere. You might predict that air temperature would increase steadily with altitude. After all, the higher you go, the closer you are to the Sun. But it's not that simple.

- Besides the Sun, what might heat up the atmosphere?
- How do you think air temperature might change with altitude?

15.3 Layers of the Atmosphere

Lesson Objectives

- Describe how the temperature of the atmosphere changes with altitude.
- Outline the properties of the troposphere.
- Explain the role of the ozone layer in the stratosphere.
- Describe conditions in the mesosphere.
- Explain how the Sun affects the thermosphere.
- Identify the exosphere.

Vocabulary

- exosphere
- mesosphere
- ozone
- stratosphere
- temperature inversion
- thermosphere
- troposphere

Introduction

Earth's atmosphere is divided into five major layers. The layers are based on temperature.

Temperature of the Atmosphere

Air temperature changes as altitude increases. In some layers of the atmosphere, the temperature decreases. In other layers, it increases. You can see this in **Figure** 15.12. Refer to this figure as you read about the layers below.

Troposphere

The **troposphere** is the lowest layer of the atmosphere. In it, temperature decreases with altitude. The troposphere gets some of its heat directly from the Sun. Most, however, comes from Earth's surface. The surface is heated by the Sun and some of that heat radiates back into the air. This makes the temperature higher near the surface than at higher altitudes.

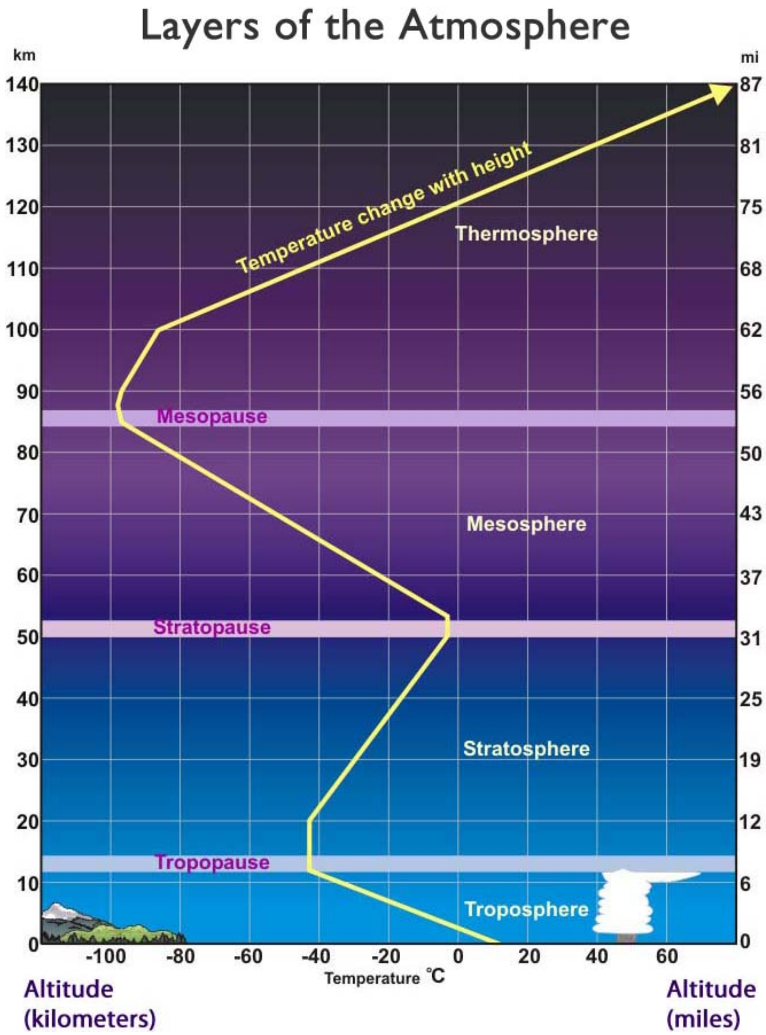

FIGURE 15.12
How does air temperature change in the layer closest to Earth?

Properties of the Troposphere

Look at the troposphere in **Figure** 15.12. This is the shortest layer of the atmosphere. It rises to only about 12 kilometers (7 miles) above the surface. Even so, this layer holds 75 percent of all the gas molecules in the atmosphere. That's because the air is densest in this layer.

Mixing of Air

Air in the troposphere is warmer closer to Earth's surface. Warm air is less dense than cool air, so it rises higher in the troposphere. This starts a convection cell. Convection mixes the air in the troposphere. Rising air is also a main cause of weather. All of Earth's weather takes place in the troposphere.

Temperature Inversion

Sometimes air doesn't mix in the troposphere. This happens when air is cooler close to the ground than it is above. The cool air is dense, so it stays near the ground. This is called a **temperature inversion**. An inversion can trap air pollution near the surface. Temperature inversions are more common in the winter. Can you explain why?

FIGURE 15.13
Temperature Inversion and Air Pollution. How does a temperature inversion affect air quality?

Tropopause

At the top of the troposphere is a thin layer of air called the tropopause. You can see it in **Figure** 15.12. This layer acts as a barrier. It prevents cool air in the troposphere from mixing with warm air in the stratosphere.

Stratosphere

The **stratosphere** is the layer above the troposphere. The layer rises to about 50 kilometers (31 miles) above the surface.

Temperature in the Stratosphere

Air temperature in the stratosphere layer increases with altitude. Why? The stratosphere gets most of its heat from the Sun. Therefore, it's warmer closer to the Sun. The air at the bottom of the stratosphere is cold. The cold air is dense, so it doesn't rise. As a result, there is little mixing of air in this layer.

The Ozone Layer

The stratosphere contains a layer of ozone gas. **Ozone** consists of three oxygen atoms (O_3). The ozone layer absorbs high-energy UV radiation. As you can see in **Figure** 15.14, UV radiation splits the ozone molecule. The split creates an oxygen molecule (O_2) and an oxygen atom (O). This split releases heat that warms the stratosphere. By absorbing UV radiation, ozone also protects Earth's surface. UV radiation would harm living things without the ozone layer.

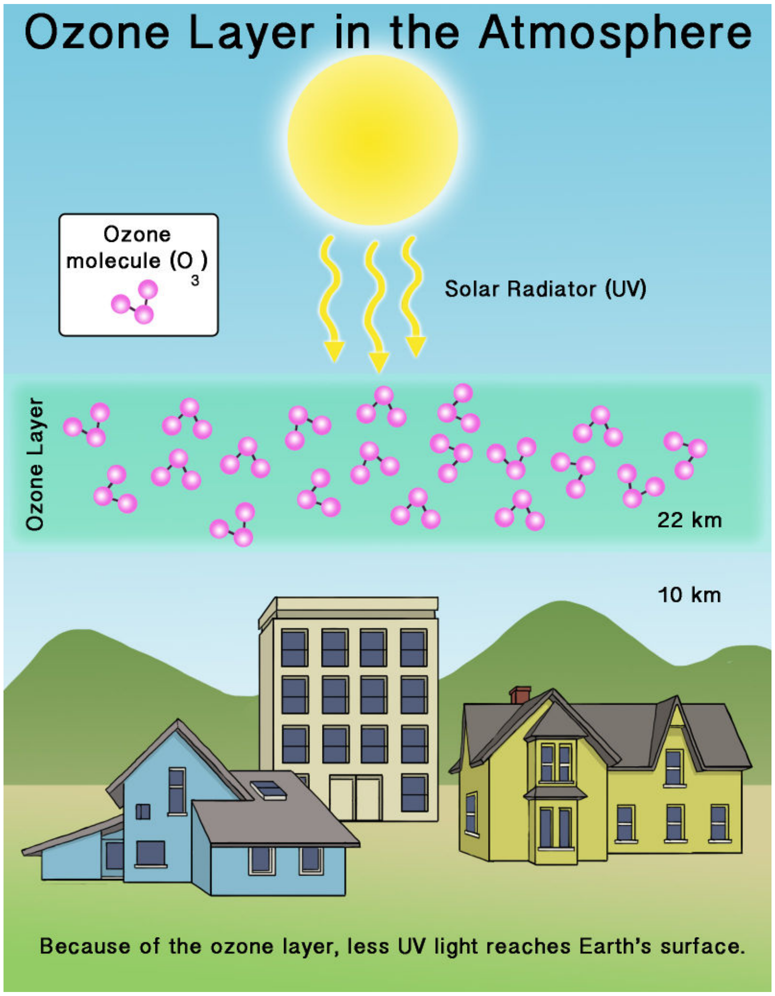

FIGURE 15.14
How does the ozone layer protect Earth's surface from UV light?

Stratopause

At the top of the stratosphere is a thin layer called the stratopause. It acts as a boundary between the stratosphere and the mesosphere.

Mesosphere

The **mesosphere** is the layer above the stratosphere. It rises to about 85 kilometers (53 miles) above the surface. Temperature decreases with altitude in this layer.

Temperature in the Mesosphere

There are very few gas molecules in the mesosphere. This means that there is little matter to absorb the Sun's rays and heat the air. Most of the heat that enters the mesosphere comes from the stratosphere below. That's why the mesosphere is warmest at the bottom.

Meteors in the Mesosphere

Did you ever see a meteor shower, like the one in **Figure** 15.15? Meteors burn as they fall through the mesosphere. The space rocks experience friction with the gas molecules. The friction makes the meteors get very hot. Many meteors burn up completely in the mesosphere.

FIGURE 15.15
Friction with gas molecules causes meteors to burn up in the mesosphere.

Mesopause

At the top of the mesosphere is the mesopause. Temperatures here are colder than anywhere else in the atmosphere. They are as low as -100° C (-212° F)! Nowhere on Earth's surface is that cold.

Thermosphere

The **thermosphere** is the layer above the mesosphere. It rises to 600 kilometers (372 miles) above the surface. The International Space Station orbits Earth in this layer as in **Figure** 15.16.

Temperature in the Thermosphere

Temperature increases with altitude in the thermosphere. Surprisingly, it may be higher than 1000° C (1800° F) near the top of this layer! The Sun's energy there is very strong. The molecules absorb the Sun's energy and are heated up. But there are so very few gas molecules, that the air still feels very cold. Molecules in the thermosphere gain or lose electrons. They then become charged particles called ions.

Northern and Southern Lights

Have you ever seen a brilliant light show in the night sky? Sometimes the ions in the thermosphere glow at night. Storms on the Sun energize the ions and make them light up. In the Northern Hemisphere, the lights are called the northern lights, or aurora borealis. In the Southern Hemisphere, they are called southern lights, or aurora australis.

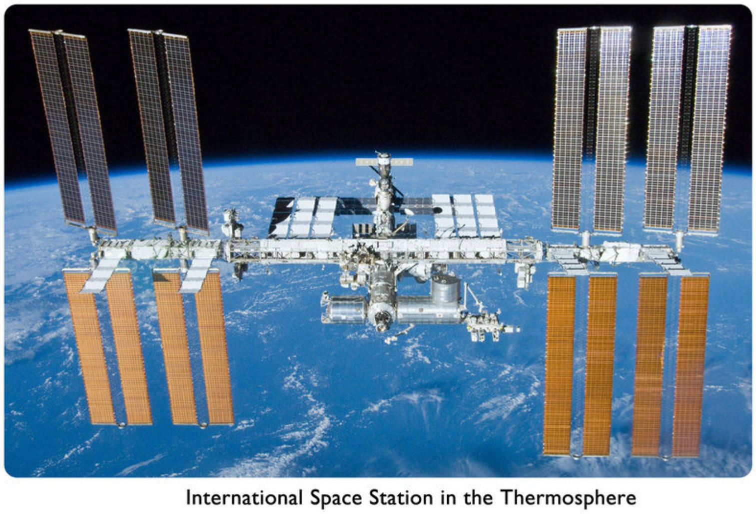

FIGURE 15.16
The International Space Station orbits in the thermosphere.

FIGURE 15.17
Glowing ions in the thermosphere light up the night sky.

Exosphere

The **exosphere** is the layer above the thermosphere. This is the top of the atmosphere. The exosphere has no real upper limit; it just gradually merges with outer space. Gas molecules are very far apart in this layer, but they are really hot. Earth's gravity is so weak in the exosphere that gas molecules sometimes just float off into space.

Lesson Summary

- Earth's atmosphere is divided into five major layers. The layers are based on temperature.
- The troposphere is the lowest layer. Temperature decreases with altitude in this layer. All weather takes place here.

- The stratosphere is the layer above the troposphere. Temperature increases with altitude in this layer. The ozone layer occurs here.
- The mesosphere is the layer above the stratosphere. Temperature decreases with altitude in this layer. Meteors burn up here.
- The thermosphere is the layer above the mesosphere. Temperature increases with altitude in this layer. The northern and southern lights occur here.
- The exosphere is the highest layer. Air molecules are very far apart. They may escape Earth's gravity and float into space.

Lesson Review Questions

Recall

1. How does temperature change in the troposphere?

2. What is a temperature inversion?

3. Why is the ozone layer in the stratosphere important to life on Earth?

4. Where does the mesosphere get its heat?

Apply Concepts

5. Think of a creative way you could model the layers of the atmosphere. Describe your model. How does it show temperature differences between the layers?

Think Critically

6. How is a temperature inversion like the temperatures of the stratosphere and troposphere?

7. Explain why air mixes in the troposphere but not in the stratosphere.

8. Why is there a hole in the ozone layer? What do you think the consequences of that hole are?

Points to Consider

Energy from the Sun is responsible for winds that blow in the troposphere.

- What is wind?
- How does energy cause winds to blow?

15.4 Air Movement

Lesson Objectives

- Explain why air moves.
- Identify causes of local winds.
- Describe global winds and jet streams.

Vocabulary

- global wind
- jet stream
- land breeze
- local wind
- monsoon
- sea breeze
- wind

Introduction

Whether it's a gentle breeze or strong wind, you are most aware of air when it moves. You can feel its molecules press against you. You can also see the effects of air movement. **Figure** 15.18 shows some examples.

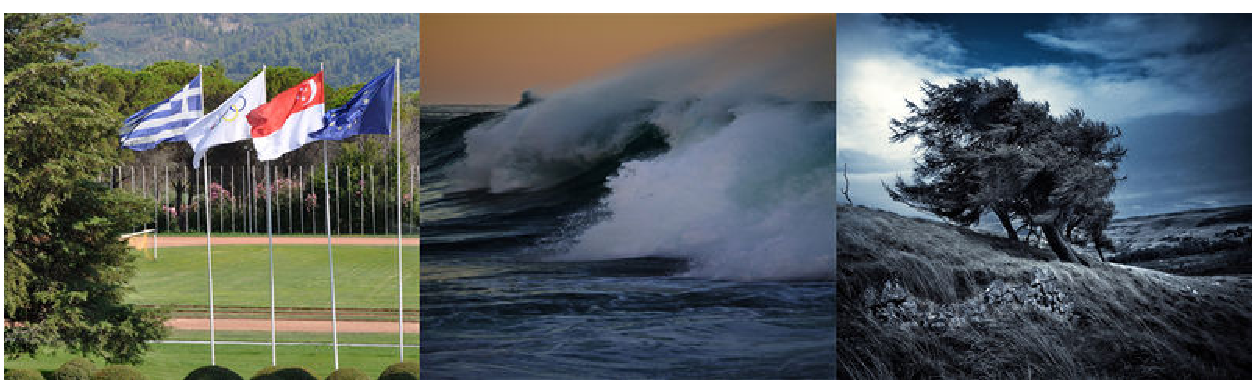

FIGURE 15.18
How can you tell the wind is blowing in these photos?

Why Air Moves

Air movement takes place in the troposphere. This is the lowest layer of the atmosphere. Air moves because of differences in heating. These differences create convection currents and winds. **Figure** 15.19 shows how this happens.

- Air in the troposphere is warmer near the ground. The warm air rises because it is light. The light, rising air creates an area of low air pressure at the surface.
- The rising air cools as it reaches the top of the troposphere. The air gets denser, so it sinks to the surface. The sinking, heavy air creates an area of high air pressure near the ground.
- Air always flows from an area of higher pressure to an area of lower pressure. Air flowing over Earth's surface is called **wind**. The greater the difference in pressure, the stronger the wind blows.

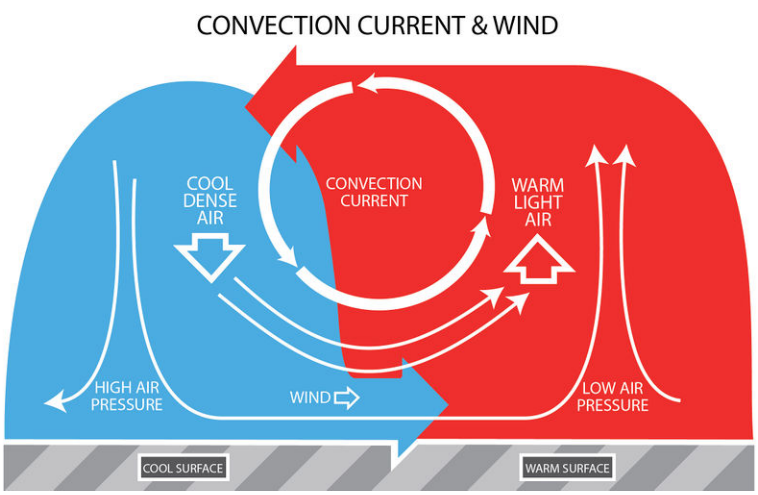

FIGURE 15.19
Differences in air temperature cause convection currents and wind.

Local Winds

Local winds are winds that blow over a limited area. They are influenced by local geography. Nearness to an ocean, lake or mountain range can affect local winds. Some examples are found below.

Land and Sea Breezes

Ocean water is slower to warm up and cool down than land. So the sea surface is cooler than the land in the daytime. It is also cooler than the land in the summer. The opposite is also true. The water stays warmer than the land during the night and the winter. These differences in heating cause local winds known as land and sea breezes. Land and sea breezes are illustrated in **Figure** 15.20.

- A **sea breeze** blows from sea to land during the day or in summer. That's when air over the land is warmer than air over the water. The warm air rises. Cool air from over the water flows in to take its place.
- A **land breeze** blows from land to sea during the night or in winter. That's when air over the water is warmer than air over the land. The warm air rises. Cool air from the land flows out to take its place.

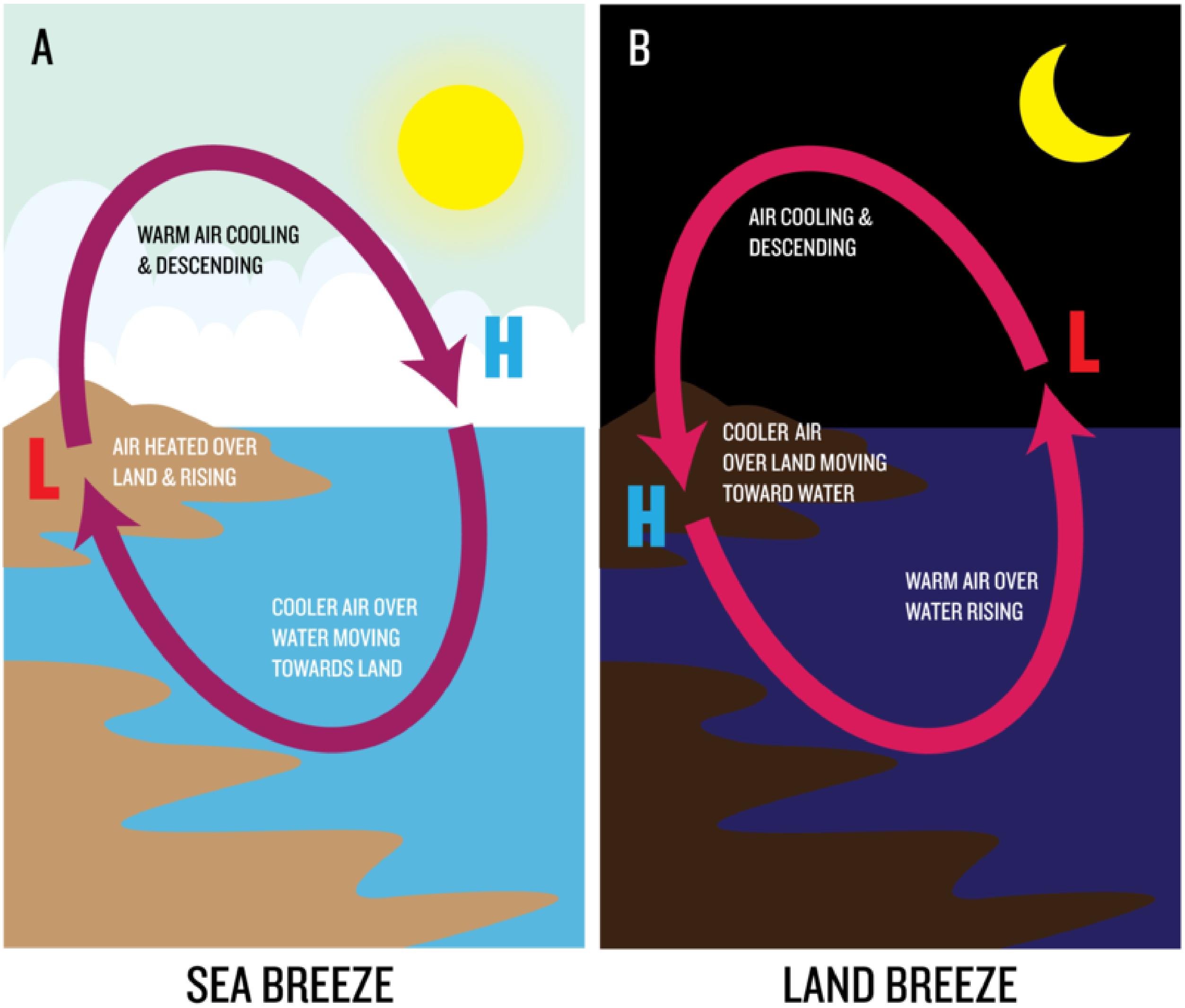

FIGURE 15.20
Land and sea breezes blow because of daily differences in heating.

Monsoons

Monsoons are like land and sea breezes, but on a larger scale. They occur because of seasonal changes in the temperature of land and water. In the winter, they blow from land to water. In the summer, they blow from water to land. In regions that experience monsoons, the seawater offshore is extremely warm. The hot air absorbs a lot of the moisture and carries it over the land. Summer monsoons bring heavy rains on land. Monsoons occur in several places around the globe. The most important monsoon in the world is in southern Asia, as shown in **Figure** 15.21. These monsoons are important because they carry water to the many people who live there.

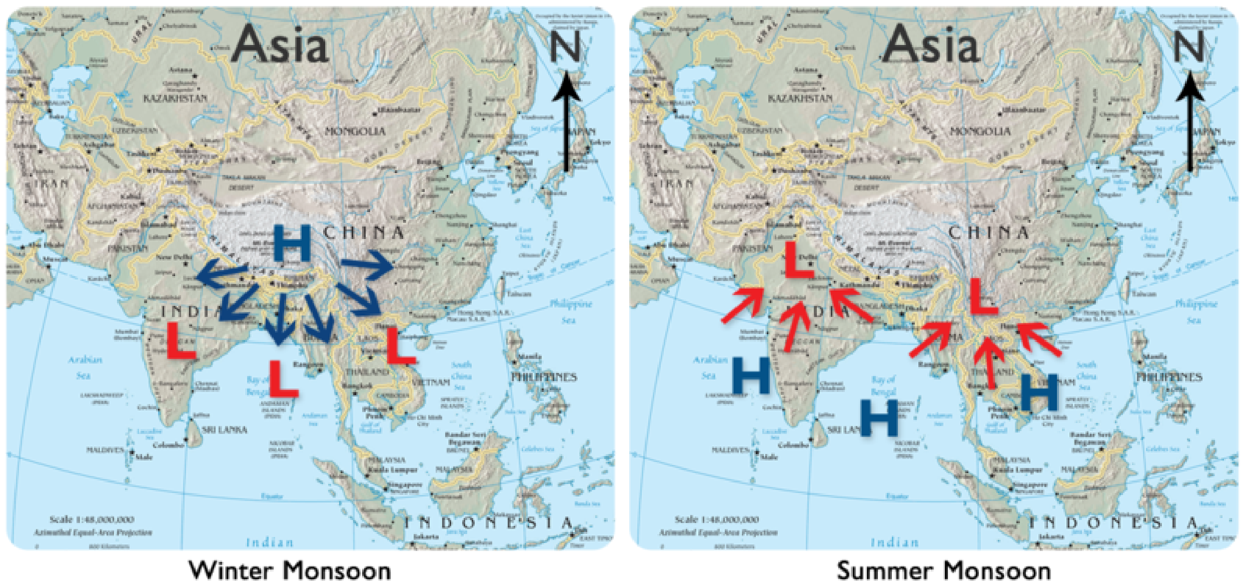

FIGURE 15.21
Monsoons blow over southern Asia.

Global Winds

Global winds are winds that occur in belts that go all around the planet. You can see them in **Figure** 15.22. Like local winds, global winds are caused by unequal heating of the atmosphere.

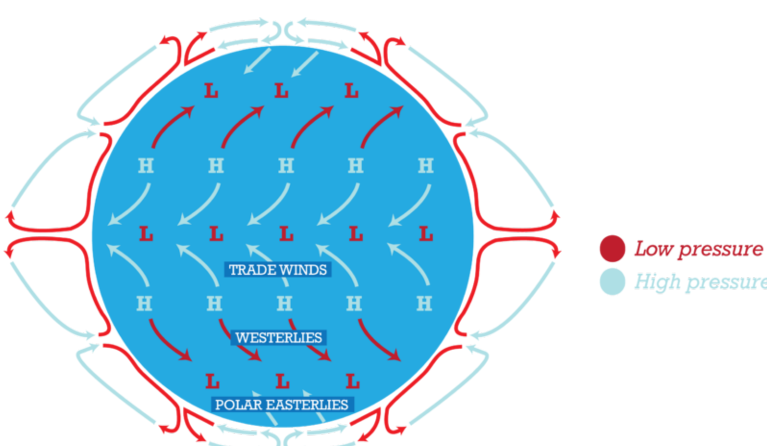

FIGURE 15.22
Global winds occur in belts around the globe.

Heating and Global Winds

Earth is hottest at the equator and gets cooler toward the poles. The differences in heating create huge convection currents in the troposphere. At the equator, for example, warm air rises up to the tropopause. It can't rise any higher, so it flows north or south.

By the time the moving air reaches 30° N or S latitude, it has cooled. The cool air sinks to the surface. Then it flows over the surface back to the equator. Other global winds occur in much the same way. There are three enormous convection cells north of the equator and three south of the equator.

Global Winds and the Coriolis Effect

Earth is spinning as air moves over its surface. This causes the Coriolis effect. Winds blow on a diagonal over the surface, instead of due north or south. From which direction do the northern trade winds blow?

Without Coriolis Effect the global winds would blow north to south or south to north. But Coriolis makes them blow northeast to southwest or the reverse in the Northern Hemisphere. The winds blow northwest to southeast or the reverse in the southern hemisphere.

The wind belts have names. The Trade Winds are nearest the equator. The next belt is the westerlies. Finally are the polar easterlies. The names are the same in both hemispheres.

Jet Streams

Jet streams are fast-moving air currents high in the troposphere. They are also the result of unequal heating of the atmosphere. Jet streams circle the planet, mainly from west to east. The strongest jet streams are the polar jets. The northern polar jet is shown in **Figure** 15.23.

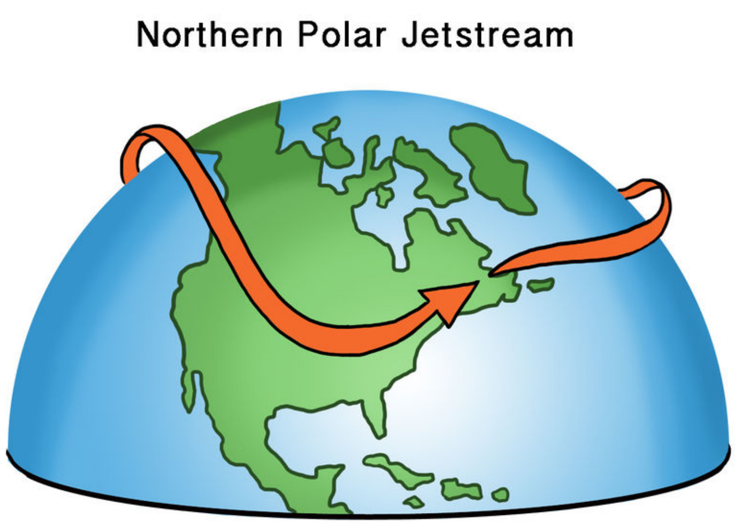

FIGURE 15.23

This jet stream helps planes fly quickly from west to east over North America. How do you think it affects planes that fly from east to west?

Lesson Summary

- Air movement takes place in the troposphere. Air moves because of differences in heating. The differences create convection currents and winds.
- Local winds are winds that blow over a limited area. They are influenced by local geography, such as nearness to an ocean. They include land and sea breezes as well as monsoons.
- Global winds occur in belts around the globe. They are caused by unequal heating of Earth's surface. The Coriolis effect causes global winds to blow on a diagonal over the surface. Unequal heating also causes jet streams high in the troposphere.

Lesson Review Questions

Recall

1. Define wind.

2. What are local winds?

3. Describe monsoons.

4. Why are summer monsoons likely to bring heavy rains?

5. How does the Coriolis effect influence global winds?

Apply Concepts

6. In **Figure** 15.22, find the global winds called prevailing westerlies. They blow over most the U.S. Apply lesson concepts to explain the direction these winds blow.

Think Critically

7. Explain how differences in heating cause wind.

8. Compare and contrast land and sea breezes with monsoons.

9. If changes in the atmosphere caused the Indian Ocean to cool down, how would the people of southern Asia be affected? What might be the result?

Points to Consider

Temperature differences in the atmosphere cause winds. They also cause other weather conditions, such as clouds and rain.

- How do temperature differences cause clouds to form?
- How do they affect precipitation?

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CHAPTER 16 MS Weather

Chapter Outline

This startling sight is a tornado. It may be only a few hundred meters in diameter, but it's a very powerful storm. Its circular winds can reach hundreds of kilometers per hour! The winds can turn cars into missiles and flatten entire towns.

Tornadoes are an extreme form of something that happens in the air around you all the time. They are a form of weather. Luckily, weather doesn't consist only of extremes like tornadoes. In fact, most of the time, you probably don't even notice the weather. Just what is weather? And what causes it? In this chapter, you'll find out.

16.1 Weather and Water in the Atmosphere

Lesson Objectives

- Explain what causes weather.
- Describe humidity and its role in weather.
- Explain how clouds are classified.
- Identify types of precipitation and how they form.

Vocabulary

- cirrus cloud
- cumulus cloud
- dew point
- fog
- freezing rain
- hail
- heat index
- humidity
- relative humidity
- sleet
- stratus cloud
- weather

Introduction

If someone in a distant place were to ask what your weather is like today, what would you say? How would you describe the weather right now where you are? Is it warm or cold? Sunny or cloudy? Calm or windy? Clear or rainy? What features of weather are important to mention?

What Is Weather?

What do temperature, clouds, winds, and rain have in common? They are all part of weather. **Weather** refers to the conditions of the atmosphere at a given time and place.

What Causes Weather?

Weather occurs because of unequal heating of the atmosphere. The source of heat is the Sun. The general principles behind weather can be stated simply:

- The Sun heats Earth's surface more in some places than others.
- Where it is warm, heat from the Sun warms the air close to the surface. If there is water at the surface, it may cause some of the water to evaporate.
- Warm air is less dense, so it rises. When this happens, more dense air flows in to take its place. The flowing surface air is wind.
- The rising air cools as it goes higher in the atmosphere. If it is moist, the water vapor may condense. Clouds may form, and precipitation may fall.

Weather and the Water Cycle

The water cycle plays an important role in weather. When liquid water evaporates, it causes humidity. When water vapor condenses, it forms clouds and precipitation. Humidity, clouds, and precipitation are all important weather factors.

Humidity

Humidity is the amount of water vapor in the air. High humidity increases the chances of clouds and precipitation.

Relative Humidity

Humidity usually refers to **relative humidity**. This is the percent of water vapor in the air relative to the total amount the air can hold. How much water vapor can the air hold? That depends on temperature. Warm air can hold more water vapor than cool air. You can see this in **Figure** 16.1.

Humidity and Heat

People often say, "it's not the heat but the humidity." Humidity can make a hot day feel even hotter. When sweat evaporates, it cools your body. But sweat can't evaporate when the air already contains as much water vapor as it can hold. The **heat index** is a measure of what the temperature feels like because of the humidity. You can see the heat index in **Figure** 16.2.

Dew Point

You've probably noticed dew on the grass on a summer morning. Why does dew form? Remember that the land heats up and cools down fairly readily. So when night comes, the land cools. Air that was warm and humid in the daytime also cools over night. As the air cools, it can hold less water vapor. Some of the water vapor condenses on the cool surfaces, such as blades of grass. The temperature at which water vapor condenses is called the **dew point**. If this temperature is below freezing, ice crystals of frost form instead of dew. As you can see in **Figure** 16.1, the dew point occurs at 100 percent relative humidity. Can you explain why?

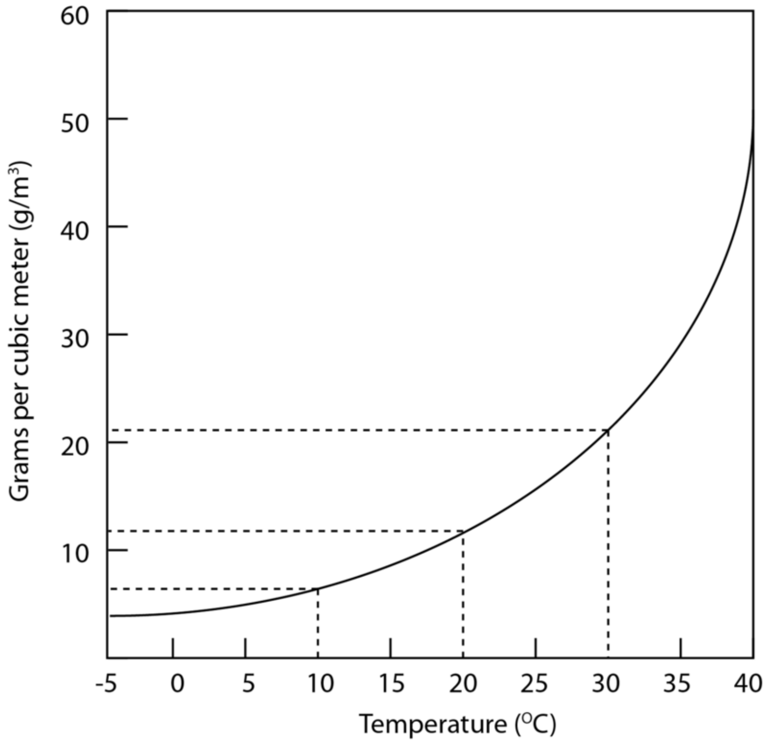


FIGURE 16.1
How much water vapor can the air hold when its temperature is 40 ° C?

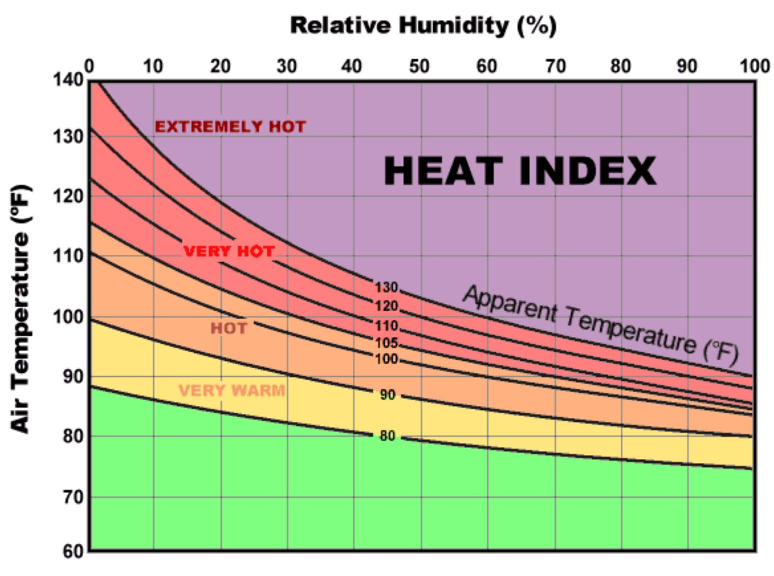


FIGURE 16.2
How hot does it feel when the air temperature is 90 °F? It depends on the humidity.

Clouds

Clouds form when air in the atmosphere reaches the dew point. Clouds may form anywhere in the troposphere. Clouds that form on the ground are called **fog**.

How Clouds Form

Clouds form when water vapor condenses around particles in the air. The particles are specks of matter, such as dust or smoke. Billions of these tiny water droplets come together to make up a cloud. If the air is very cold, ice crystals form instead of liquid water.

Classification of Clouds

Clouds are classified on the basis of where and how they form. Three main types of clouds are cirrus, stratus, and cumulus. **Figure** 16.3 shows these and other types of clouds.

- **Cirrus clouds** form high in the troposphere. Because it is so cold they are made of ice crystals. They are thin and wispy. Cirrus clouds don't usually produce precipitation, but they may be a sign that wet weather is coming.
- **Stratus clouds** occur low in the troposphere. They form in layers that spread horizontally and may cover the entire sky like a thick blanket. Stratus clouds that produce precipitation are called nimbostratus. The prefix *nimbo-* means "rain."
- **Cumulus clouds** are white and puffy. Convection currents make them grow upward and they may grow very tall. When they produce rain, they are called cumulonimbus.

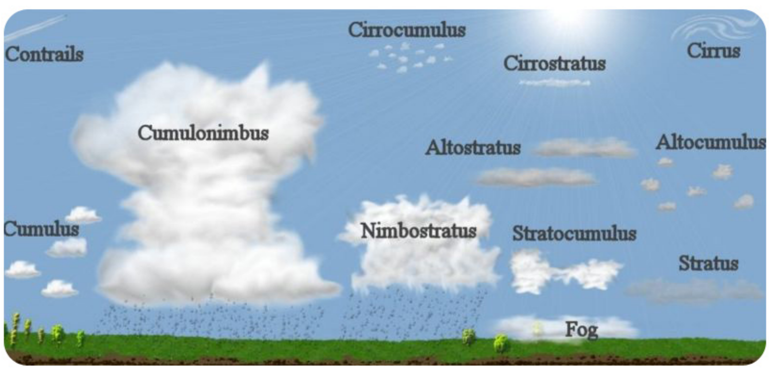


FIGURE 16.3

Find the cirrus, cirrostratus, and cirrocumulus clouds in the figure. What do they have in common? They all form high in the troposphere. Clouds that form in the mid troposphere have the prefix "alto-", as in altocumulus. Where do stratocumulus clouds form?

Clouds and Temperature

Clouds can affect the temperature on Earth's surface. During the day, thick clouds block some of the Sun's rays. This keeps the surface from heating up as much as it would on a clear day. At night, thick clouds prevent heat from radiating out into space. This keeps the surface warmer than it would be on a clear night.

Precipitation

Clouds are needed for precipitation. This may fall as liquid water, or it may fall as frozen water, such as snow.

Why Precipitation Falls

Millions of water molecules in a cloud must condense to make a single raindrop or snowflake. The drop or flake falls when it becomes too heavy for updrafts to keep it aloft. As a drop or flake falls, it may collect more water and get larger.

Types of Precipitation

Why does it snow instead of rain? Air temperature determines which type of precipitation falls. Rain falls if the air temperature is above freezing (0° C or 32° F). Frozen precipitation falls if the air or ground is below freezing. Frozen precipitation may fall as snow, sleet, or freezing rain. You can see how the different types form in **Figure** 16.4.

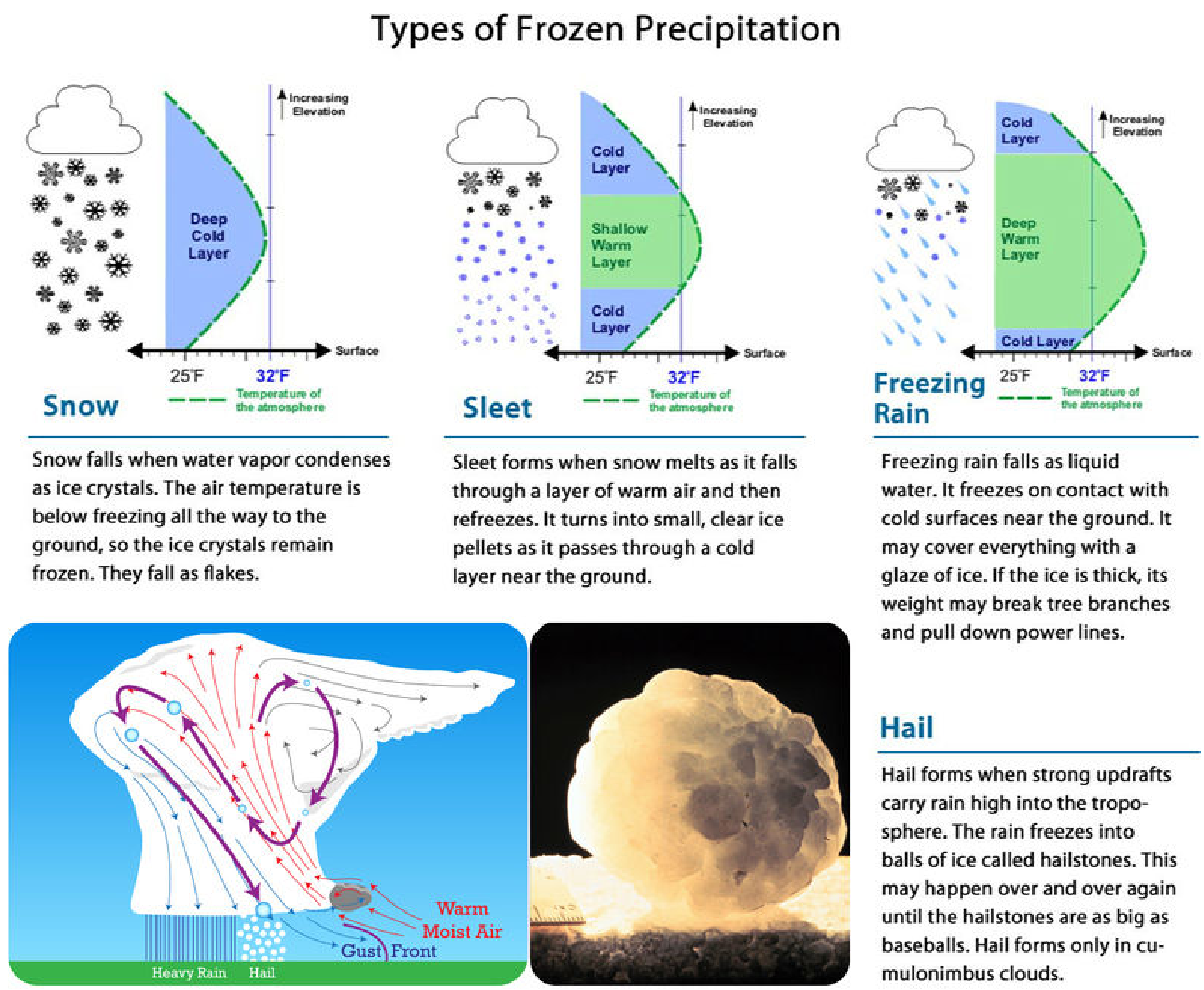


FIGURE 16.4

Frozen precipitation may fall as snow, sleet, or freezing rain.

Snow falls when water vapor condenses as ice crystals. The air temperature is below freezing all the way to the ground, so the ice crystals remain frozen. They fall as flakes. **Sleet** forms when snow melts as it falls through a layer of warm air and then refreezes. It turns into small, clear ice pellets as it passes through a cold layer near the ground. **Freezing rain** falls as liquid water. It freezes on contact with cold surfaces near the ground. It may cover everything with a glaze of ice. If the ice is thick, its weight may break tree branches and pull down power lines. **Hail** is another type of frozen precipitation. Hail forms in thunderstorms when strong updrafts carry rain high into the troposphere. The rain freezes into balls of ice called hailstones. This may happen over and over again until the hailstones are as big as baseballs. Hail forms only in cumulonimbus clouds.

Lesson Summary

- Weather refers to conditions of the atmosphere at a given time and place. It occurs because of unequal heating of the atmosphere. Humidity, clouds, and precipitation are important weather factors.
- Humidity is the amount of water vapor in the air. Relative humidity is the percent of water vapor in the air relative to the total amount the air can hold. The total amount depends on temperature.
- Clouds form when water vapor condenses in the air around specs of matter. Clouds are classified on the basis of where and how they form. Types of clouds include cirrus, stratus, and cumulus clouds.
- Precipitation is water that falls from clouds. It may fall as liquid or frozen water. Types of frozen precipitation include snow, sleet, freezing rain, and hail.

Lesson Review Questions

Recall

1. What is weather?

2. List three weather factors.

3. What is humidity?

4. How do clouds form?

5. Identify sleet, freezing rain, and hail.

Apply Concepts

6. Classify the clouds pictured in **Figure** 16.5.

Think Critically

7. Explain how dew point is related to air temperature and relative humidity.

8. You are lying in your sleeping bag on a cold morning. Your sleeping bag is wet with water. You know it didn't rain last night. What happened?

9. Infer why hail forms only in cumulonimbus clouds.

Points to Consider

A clear sky can quickly become covered with clouds. The clouds may bring a change in the weather.

- Why does a clear day turn cloudy?

FIGURE 16.5

- What causes weather to change?

16.2 Changing Weather

Lesson Objectives

- Describe air masses and how they move.
- Identify types of fronts and the weather they bring.
- Define cyclone and anticyclone.

Vocabulary

- air mass
- anticyclone
- cold front
- cyclone
- front
- occluded front
- stationary front
- warm front

Introduction

Did you ever hear this riddle?

Question: Why did the woman go outdoors with her purse open?

Answer: Because she expected some change in the weather!

Weather is always changing. One day might be cold and cloudy. The next day might be warm and sunny. Even on the same day, the weather can change a lot. A beautiful morning might be followed by a stormy afternoon. Why does weather change? The main reason is moving air masses.

Air Masses

An **air mass** is a large body of air that has about the same conditions throughout. For example, an air mass might have cold dry air. Another air mass might have warm moist air. The conditions in an air mass depend on where the air mass formed.

Formation of Air Masses

Most air masses form over polar or tropical regions. They may form over continents or oceans. Air masses are moist if they form over oceans. They are dry if they form over continents. Air masses that form over oceans are called maritime air masses. Those that form over continents are called continental air masses. **Figure** 16.6 shows air masses that form over or near North America.

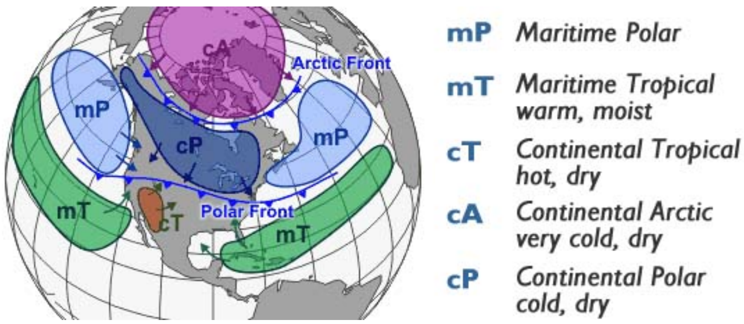


FIGURE 16.6
North American air masses.

An air mass takes on the conditions of the area where it forms. For example, a continental polar air mass has cold dry air. A maritime polar air mass has cold moist air. Which air masses have warm moist air? Where do they form?

Movement of Air Masses

When a new air mass goes over a region it brings its characteristics to the region. This may change the area's temperature and humidity. Moving air masses cause the weather to change when they contact different conditions. For example, a warm air mass moving over cold ground may cause an inversion.

Why do air masses move? Winds and jet streams push them along. Cold air masses tend to move toward the equator. Warm air masses tend to move toward the poles. Coriolis effect causes them to move on a diagonal. Many air masses move toward the northeast over the U.S. This is the same direction that global winds blow.

Fronts

When cold air masses move south from the poles, they run into warm air masses moving north from the tropics. The boundary between two air masses is called a **front**. Air masses usually don't mix at a front. The differences in temperature and pressure cause clouds and precipitation. Types of fronts include cold, warm, occluded, and stationary fronts.

Cold Fronts

A **cold front** occurs when a cold air mass runs into a warm air mass. This is shown in **Figure** 16.7. The cold air mass moves faster than the warm air mass and lifts the warm air mass out of its way. As the warm air rises, its water vapor condenses. Clouds form, and precipitation falls. If the warm air is very humid, precipitation can be heavy. Temperature and pressure differences between the two air masses cause winds. Winds may be very strong along a cold front.

As the fast-moving cold air mass keeps advancing, so does the cold front. Cold fronts often bring sudden changes in the weather. There may be a thin line of storms right at the front that moves as it moves. In the spring and summer,

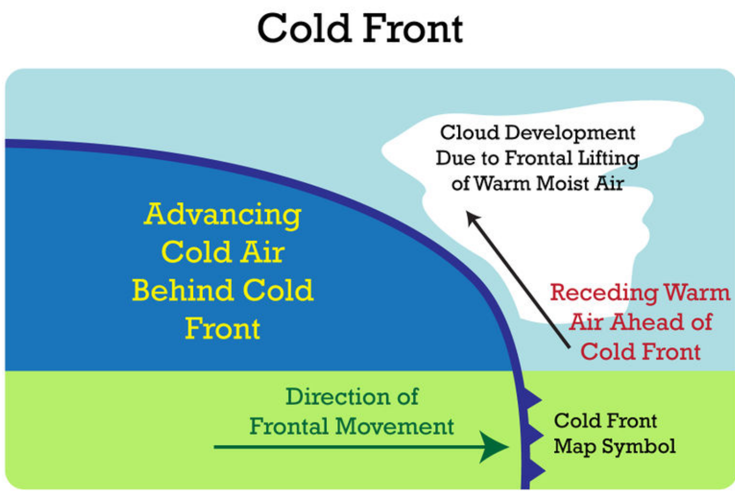


FIGURE 16.7
Cold fronts often bring stormy weather.

these storms may be thunderstorms and tornadoes. In the late fall and winter, snow storms may occur. After a cold front passes, the cold air mass behind it brings cooler temperatures. The air is likely to be less humid as well. Can you explain why?

Warm Fronts

When a warm air mass runs into a cold air mass it creates a **warm front**. This is shown in **Figure** 16.8. The warm air mass is moving faster than the cold air mass, so it flows up over the cold air mass. As the warm air rises, it cools, resulting in clouds and sometimes light precipitation. Warm fronts move slowly and cover a wide area. After a warm front passes, the warm air mass behind it brings warmer temperatures. The warm air is also likely to be more humid.

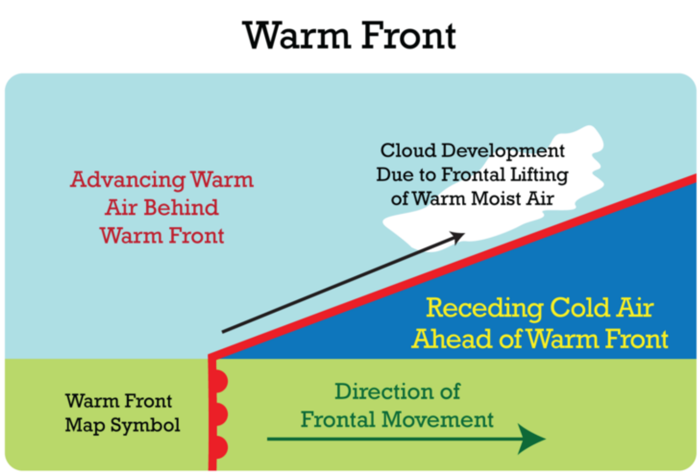


FIGURE 16.8
Warm fronts generally bring cloudy weather.

Occluded Fronts

With an **occluded front**, a warm air mass becomes trapped between two cold air masses. The warm air is lifted up above the cold air as in **Figure** 16.9. Cloudy weather and precipitation along the front are typical.

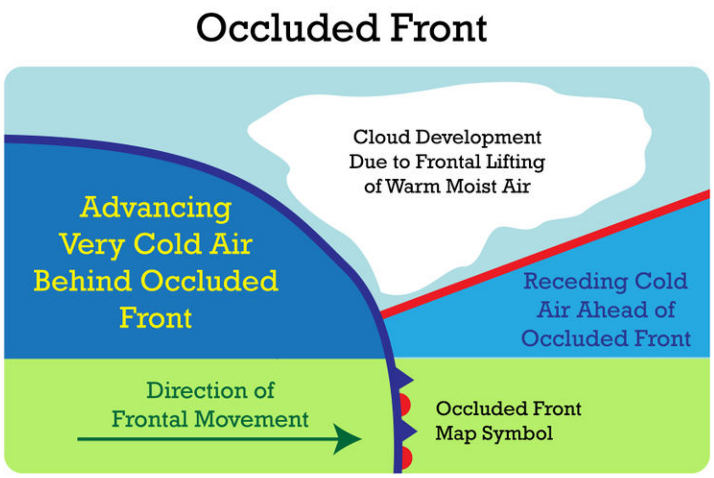


FIGURE 16.9
How does an occluded front differ from a warm or cold front?

Stationary Fronts

Sometimes two air masses stop moving when they meet. These stalled air masses create a **stationary front**. Such a front may bring clouds and precipitation to the same area for many days.

Cyclones and Anticyclones

Cold air is dense, so it sinks. This creates a center of high pressure. Warm air is less dense so it rises. This creates a center of low pressure. Air always flows from higher to lower pressure. As the air flows, Earth's surface rotates below it causing Coriolis effect. So while the wind blows into the low pressure, it revolves in a circular pattern. This wind pattern forms a cyclone. The same happens while the wind blows out of a high pressure. This forms an anticyclone. Both are shown in **Figure** 16.10.

- A **cyclone** is a system of winds that rotates around a center of low pressure. Cyclones bring cloudy, wet weather.
- An **anticyclone** is a system of winds that rotates around a center of high pressure. Anticyclones bring fair, dry weather.

Lesson Summary

- An air mass is a large body of air that has about the same conditions throughout. Air masses take on the conditions of the area where they form. Winds and air currents cause air masses to move. Moving air masses cause changes in the weather.

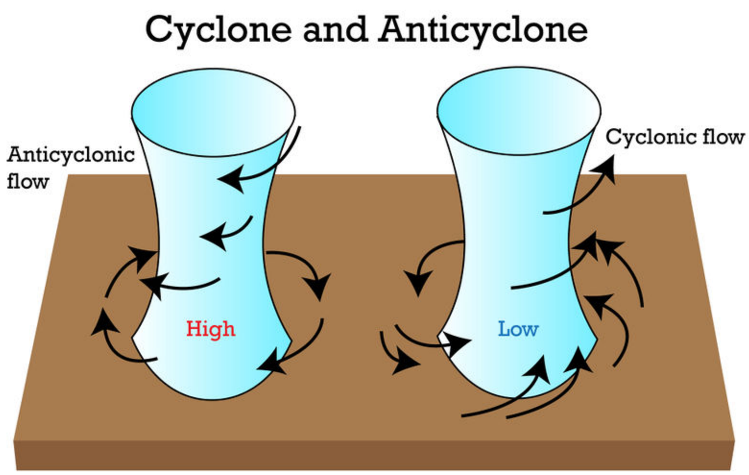


FIGURE 16.10
In the Northern Hemisphere, cyclones rotate counterclockwise and anticyclones rotate clockwise. This is the reverse in the Southern Hemisphere.

- A front forms at the boundary between two air masses. Types of fronts include cold, warm, occluded, and stationary fronts. Clouds, precipitation, and storms commonly occur along fronts.
- A cyclone is a system of winds that rotates around a center of low air pressure. An anticyclone is a system of winds that rotates around a center of high air pressure.

Lesson Review Questions

Recall

1. What is an air mass?
2. Describe continental polar and maritime tropical air masses.
3. What causes air masses to move?
4. What is a front?
5. Define cyclone and anticyclone.

Apply Concepts

6. Create an original diagram to represent an occluded front. It should include weather conditions along the front.

Think Critically

7. Compare and contrast warm and cold fronts.
8. The weather report states that your town is under a stationary front. You look out the window and see rain. Predict what the weather will be like tomorrow. Explain your prediction.

Points to Consider

Remember the tornado on the first page of this chapter? Tornadoes usually occur along cold fronts.

- Tornadoes are one type of storm. What are some other types of storms?
- Tornadoes usually form during severe thunderstorms or hurricanes. Do you know why?

16.3 Storms

Lesson Objectives

- Define storm.
- Explain why thunderstorms occur.
- Describe tornadoes.
- Explain how hurricanes form.
- Identify two types of winter storms.

Vocabulary

- blizzard
- hurricane
- lake-effect snow
- lightning
- storm
- storm surge
- thunder
- thunderstorm
- tornado
- windchill

Introduction

In 2005, Hurricane Katrina caused a huge flood in the city of New Orleans. **Figure** 16.11 shows what the city looked like after the hurricane. Mile after mile of homes and businesses were covered with flood water. Billions of dollars of damage were done. More than 2,000 people died. Hurricanes are extremely strong storms and Katrina was stronger than most. What are storms? What causes them? And what gives a storm its strength? Read on to find out.

What Are Storms?

A **storm** is an episode of severe weather caused by a major disturbance in the atmosphere. Storms can vary a lot in the time they last and in how severe they are. A storm may last for less than an hour or for more than a week. It may affect just a few square kilometers or thousands. Some storms are harmless and some are disastrous. The size and strength of a storm depends on the amount of energy in the atmosphere. Greater differences in temperature and air pressure produce stronger storms. Types of storms include thunderstorms, tornadoes, hurricanes, and winter storms such as blizzards.

FIGURE 16.11
A coast guard officer looks for survivors of Hurricane Katrina.

Thunderstorms

Thunderstorms are are known for their heavy rains and lightning. In strong thunderstorms, hail and high winds are also likely. Thunderstorms are very common. Worldwide, there are about 14 million of them each year! In the U.S., they are most common —and strongest —in the Midwest.

What Causes Thunderstorms?

Thunderstorms occur when the air is very warm and humid. The warm air rises rapidly to create strong updrafts. When the rising air cools, its water vapor condenses. The updrafts create tall cumulonimbus clouds called thunderheads. You can see one in **Figure** 16.12.

FIGURE 16.12
A thunderhead is a cumulonimbus cloud.

Lightning and Thunder

During a thunderstorm, some parts of a thunderhead become negatively charged. Other parts become positively charged. The difference in charge creates lightning. **Lightning** is a huge release of electricity. Lightning can jump between oppositely charged parts of the same cloud, between one cloud and another, or between a cloud and the ground. You can see lightning in **Figure** 16.13. Lightning blasts the air with energy. The air heats and expands so quickly that it explodes. This creates the loud sound of **thunder**.

Do you know why you always hear the boom of thunder after you see the flash of lightning? It's because light travels faster than sound. If you count the seconds between seeing lightning and hearing thunder, you can estimate how far away the lightning was. A lapse of 5 seconds is equal to about a mile.

FIGURE 16.13
Lightning flashes across an Arizona sunset.

Tornadoes

Severe thunderstorms have a lot of energy and strong winds. This allows them to produce tornadoes. A **tornado** is a funnel-shaped cloud of whirling high winds. You can see a tornado in **Figure** 16.14. The funnel moves along the ground, destroying everything in its path. As it moves it loses energy. Before this happens it may have gone up to 25 kilometers (16 miles). Fortunately, tornadoes are narrow. They may be only 150 meters (500 feet) wide.

Classifying Tornadoes

The winds of a tornado can reach very high speeds. The faster the winds blow, the greater the damage they cause. Wind speed and damage are used to classify tornadoes. **Table** 16.1 shows how.

TABLE 16.1: Fujita Scale (F Scale) of Tornado Intensity

F Scale	(km/hr)	(mph)	Damage
F0	64-116	40-72	Light - tree branches fall and chimneys may collapse
F1	117-180	73-112	Moderate - mobile homes, autos pushed aside

TABLE 16.1: (continued)

F Scale	(km/hr)	(mph)	Damage
F2	181-253	113-157	Considerable - roofs torn off houses, large trees uprooted
F3	254-332	158-206	Severe - houses torn apart, trees uprooted, cars lifted
F4	333-419	207-260	Devastating - houses leveled, cars thrown
F5	420-512	261-318	Incredible - structures fly, cars become missiles
F6	>512	>318	Maximum tornado wind speed

FIGURE 16.14
Tornadoes are small but mighty storms.

Tornado Alley

Look at the map in **Figure** 16.15. It shows where the greatest number of tornadoes occur in the U.S. Tornadoes can happen almost anywhere in the U.S. but only this area is called "tornado alley." Why do so many tornadoes occur here? This is where warm air masses from the south run into cold air masses from the north.

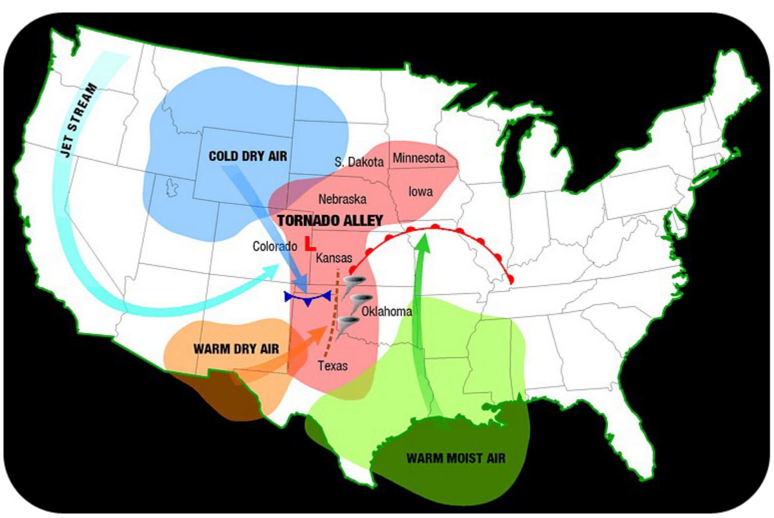


FIGURE 16.15
Tornadoes are most common in the central part of the U.S.

Hurricanes

Tornadoes may also come from hurricanes. A **hurricane** is an enormous storm with high winds and heavy rains. Hurricanes may be hundreds of kilometers wide. They may travel for thousands of kilometers. The storm's wind speeds may be greater than 251 kilometers (156 miles) per hour. Hurricanes develop from tropical cyclones.

Hurricanes form over warm very ocean water. This water gives them their energy. As long as a hurricane stays over the warm ocean, it keeps growing stronger. However, if it goes ashore or moves over cooler water, it is cut off from the hot water energy. The storm then loses strength and slowly fades away.

The Eye of a Hurricane

At the center of a hurricane is a small area where the air is calm and clear. This is the eye of the hurricane. The eye forms at the low-pressure center of the hurricane. You can see the eye of a hurricane in **Figure** 16.16.

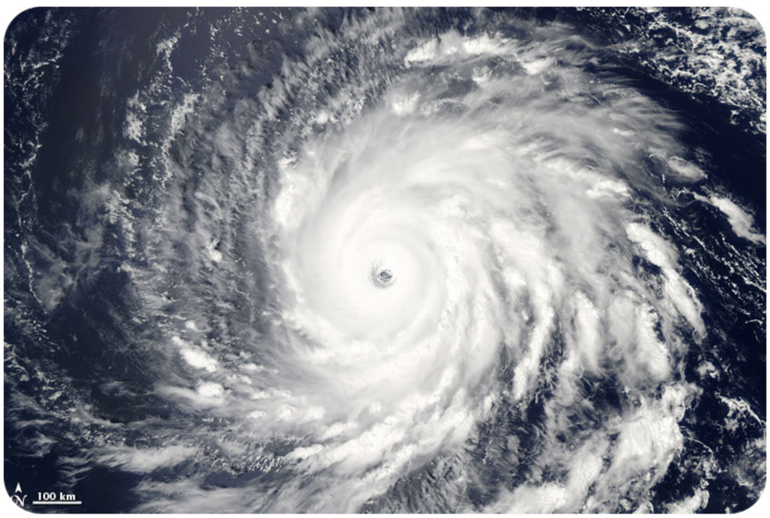


FIGURE 16.16
The eye of this hurricane is easy to see from space.

Classifying Hurricanes

Like tornadoes, hurricanes are classified on the basis of wind speed and damage. **Table** 16.2 shows how.

TABLE 16.2: Saffir - Simpson Hurricane Scale

Category	Kph	Mph	Damage
1 (weak)	119-153	74-95	Above normal; no real damage to structures
2 (moderate)	154-177	96-110	Some roofing, door, and window damage, considerable damage to vegetation, mobile homes, and piers
3 (strong)	178-209	111-130	Some buildings damaged; mobile homes destroyed

TABLE 16.2: (continued)

Category	Kph	Mph	Damage
4 (very strong)	210-251	131-156	Complete roof failure on small residences; major erosion of beach areas; major damage to lower floors of structures near shore
5 (devastating)	>251	>156	Complete roof failure on many residences and industrial buildings; some complete building failures

Storm Surge

Some of the damage from a hurricane is caused by storm surge. **Storm surge** is very high water located in the low pressure eye of the hurricane. The very low pressure of the eye allows the water level to rise above normal sea level. Storm surge can cause flooding when it reaches land. You can see this in **Figure** 16.17. High winds do a great deal of damage in hurricanes. High winds can also create very big waves. If the large waves are atop a storm surge, the high water can flood the shore. If the storm happens to occur at high tide, the water will rise even higher.

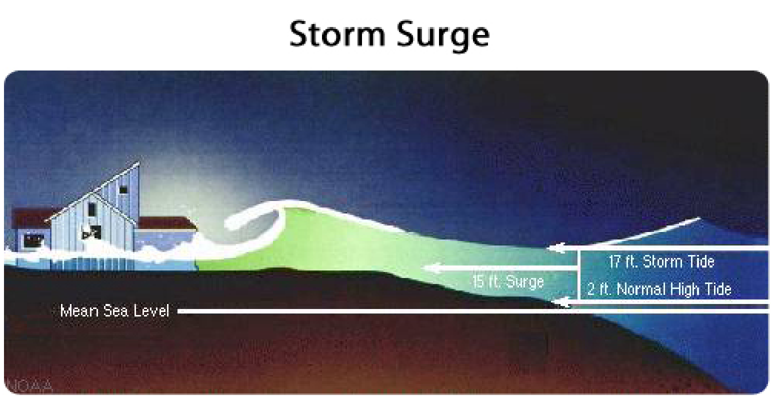


FIGURE 16.17
Storm surge can cause serious flooding.

Winter Storms

Like hurricanes, winter storms develop from cyclones. But in the case of winter storms, the cyclones form at higher latitudes. In North America, cyclones often form when the jet stream dips south in the winter. This lets dry polar air pour south. At the same time, warm moist air from the Gulf of Mexico flows north. When the two air masses meet, the differences in temperature and pressure cause strong winds and heavy precipitation. Two types of winter storms that occur in the U.S. are blizzards and lake-effect snow storms.

Blizzards

A **blizzard** is a snow storm that has high winds. To be called a blizzard, a storm must have winds greater than 56 kilometers (35 miles) per hour and visibility of $\frac{1}{4}$ mile or less because of wind-blown snow. You can see a blizzard in **Figure** 16.18.

FIGURE 16.18
Blizzard in Washington, D.C. Blizzards are unusual in Washington, D.C many parts of the United States. Do they ever occur where you live?

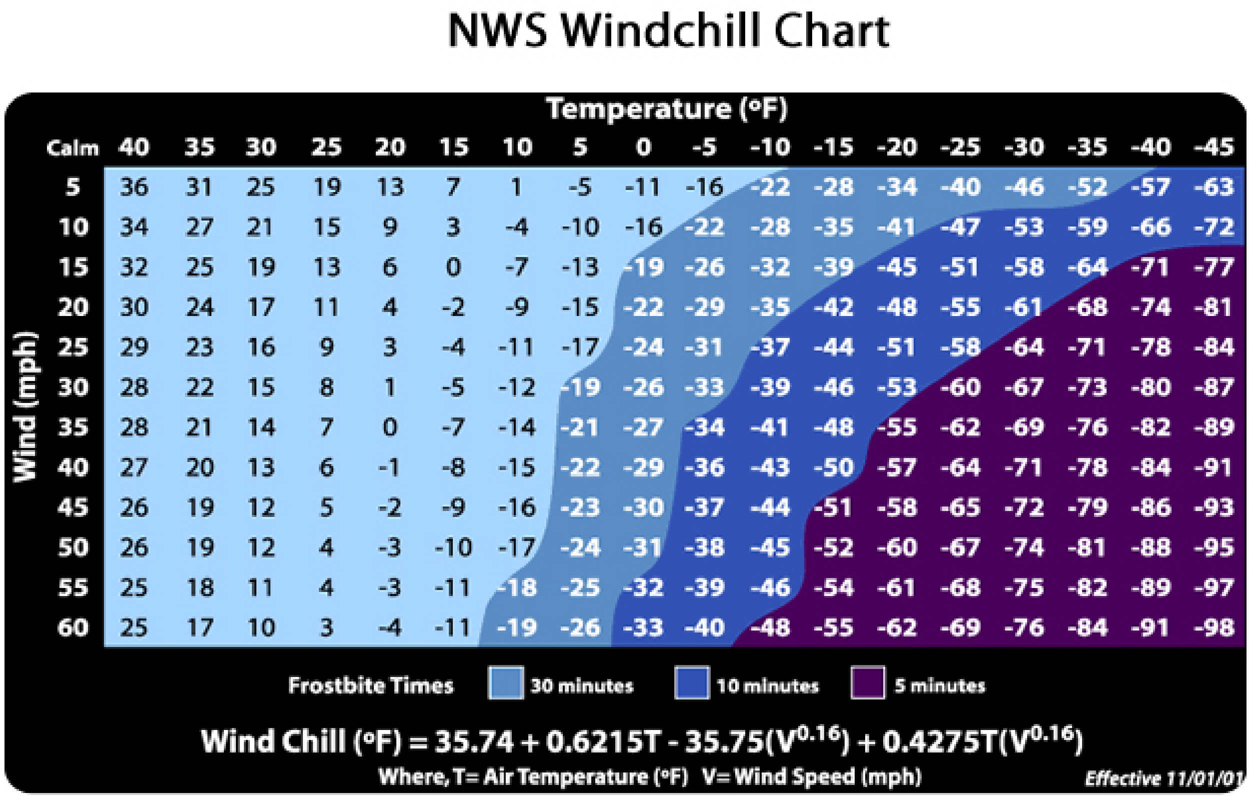
Blizzards are dangerous storms. The wind may blow the snow into deep drifts. Along with the poor visibility, the snow drifts make driving risky. The wind also makes cold temperatures more dangerous. The greater the wind speed, the higher the windchill. **Windchill** is what the temperature feels like when the wind is taken into account. It depends on air temperature and wind speed, as you can see in **Figure** 16.19. Higher windchill will cause a person to suffer frostbite and other harmful effects of cold sooner than if the wind isn't blowing.

Lake-Effect Snow

Some places receive very heavy snowfall just about every winter. If they are near a lake, they may be getting **lake-effect snow**. **Figure** 16.20 shows how lake-effect snow occurs. Winter winds pick up moisture as they pass over the relatively warm waters of a large lake. When the winds reach the cold land on the other side, the air cools. Since there was so much moisture in the air it can drop a lot of snow. More than 254 centimeters (100 inches) of snow may fall in a single lake-effect storm!

Lesson Summary

- A storm is an episode of severe weather. It is caused by a major disturbance in the atmosphere. Types of storms include thunderstorms, tornadoes, and hurricanes.
- A thunderstorm is a storm with heavy rains and lightning. It may also have hail and high winds. Thunderstorms are very common. They occur when the air is very warm and humid.
- A tornado is a storm with a funnel-shaped cloud. It has very strong, whirling winds. Tornadoes are small but powerful. They occur with thunderstorms and hurricanes.
- A hurricane is a large storm with high winds and heavy rains. Hurricanes develop from tropical cyclones. They form over warm ocean water. Much of the damage from hurricanes may be caused by storm surge.
- Winter storms develop from cyclones at higher latitudes. They include blizzards and lake-effect snow storms.



NWS Windchill Chart

Wind (mph) \ Temperature (°F): Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes; 10 minutes; 5 minutes

Wind Chill (°F) $= 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$

Where, T = Air Temperature (°F) V = Wind Speed (mph)

Effective 11/01/01

FIGURE 16.19

Windchill temperatures may be very low in blizzards because of the high wind speeds. How long does it take for frostbite to occur when the air temperature is 0 °F and the wind speed is 55 miles per hour?

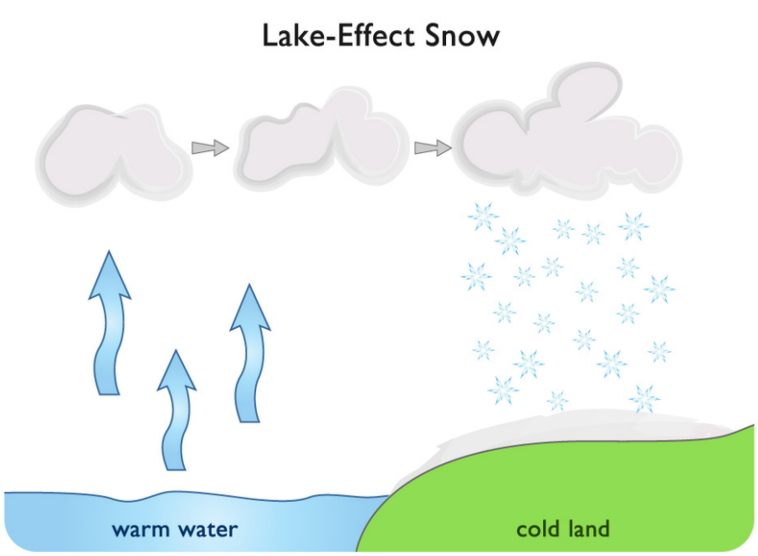


FIGURE 16.20

Lake-effect snow falls on the east side of lakes in North America. These snows are heaviest on the east sides of the Great Lakes.

Lesson Review Questions

Recall

1. Define storm. List three types of storms.
2. Why do thunderstorms occur?
3. What is lightning? What causes it?
4. Where is tornado alley? Why do so many tornadoes occur there?
5. Where do hurricanes form? Where do they get their energy?

Apply Concepts

6. **Figure** 16.21 shows damage caused by a tornado. Explain how you could use the photo to classify the tornado.

FIGURE 16.21

7. Describe in words what this graph shows (see **Figure** 16.22). Explain the pattern in the graph. (Hint: How do hurricanes form?)

Think Critically

8. Predict which part of the U.S. is most likely to have blizzards. Explain your prediction.
9. Explain why lake-effect snow storms occur on the east side of lakes in the U.S.

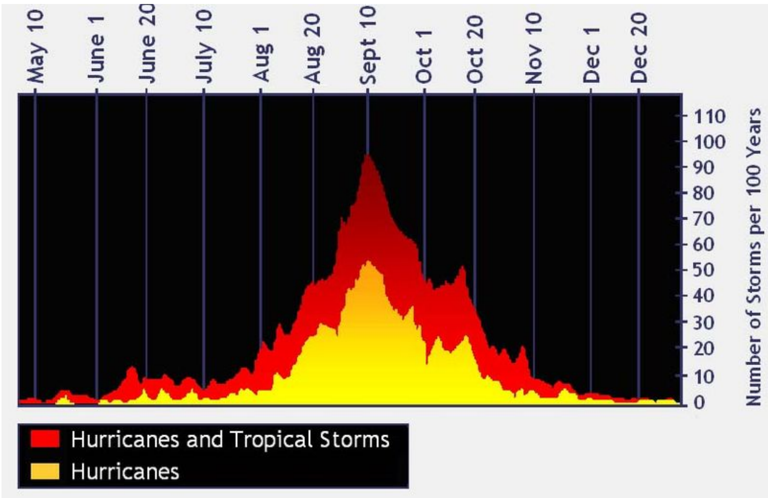


FIGURE 16.22

Points to Consider

Storms can be very dangerous. But with advance warning, people can take steps to stay safe. For example, if a hurricane is predicted, they can leave the coast and move inland.

- How can storms be predicted?
- What data are needed? How are the data collected?

16.4 Weather Forecasting

Lesson Objectives

- State how meteorologists predict the weather.
- Outline how technology and computers are used to forecast the weather.
- Describe what weather maps show.

Vocabulary

- anemometer
- barometer
- hygrometer
- meteorologist
- rain gauge
- snow gauge
- thermometer
- weather balloon
- weather map
- weather satellite
- weather station
- wind vane

Introduction

Did you ever have a picnic ruined by a surprise rainstorm? People often complain when the weather forecast is wrong. But in fact, weather forecasts today are much more accurate than they were just 20 years ago. Scientists who study and forecast the weather are called **meteorologists**. How do they predict the weather?

Predicting the Weather

Weather is very difficult to predict. That's because it's very complex and many factors are involved. Slight changes in even one factor can cause a big change in the weather. Still, certain "rules of thumb" generally apply. These "rules" help meteorologists forecast the weather. For example, low pressure is likely to bring stormy weather. So if a center of low pressure is moving your way, you can expect a storm.

Technology and Computers

Predicting the weather requires a lot of weather data. Technology is used to gather the data and computers are used to analyze the data. Using this information gives meteorologists the best chance of predicting the weather.

Weather Instruments

Weather instruments measure weather conditions. One of the most important conditions is air pressure, which is measured with a **barometer**. **Figure** 16.23 shows how a barometer works. There are also a number of other commonly used weather instruments (see **Figure** 16.24):

- A **thermometer** measures temperature.
- An **anemometer** measures wind speed.
- A **rain gauge** measures the amount of rain.
- A **hygrometer** measures humidity.
- A **wind vane** shows wind direction.
- A **snow gauge** measures the amount of snow.

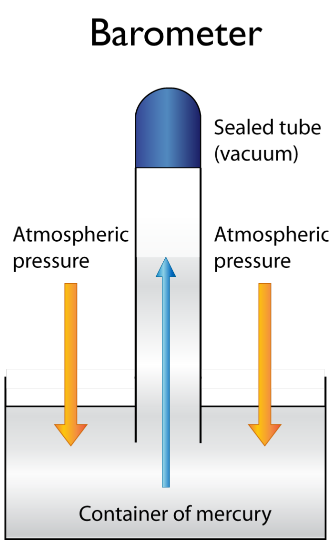


FIGURE 16.23
The greater the air pressure outside the tube, the higher the mercury rises inside the tube. Mercury can rise in the tube because there's no air pressing down on it.

Collecting Data

Weather instruments collect data from all over the world at thousands of weather stations. Many are on land but some float in the oceans on buoys. You can see what a weather station looks like in **Figure** 16.25. There's probably at least one weather station near you.

Other weather devices are needed to collect weather data in the atmosphere. They include weather balloons, satellites, and radar. You can read about them in **Figure** 16.25.

Weather stations contain many instruments for measuring weather conditions. The **weather balloon** in **Figure** 16.25 will rise into the atmosphere until it bursts. As it rises, it will gather weather data and send it to the surface.

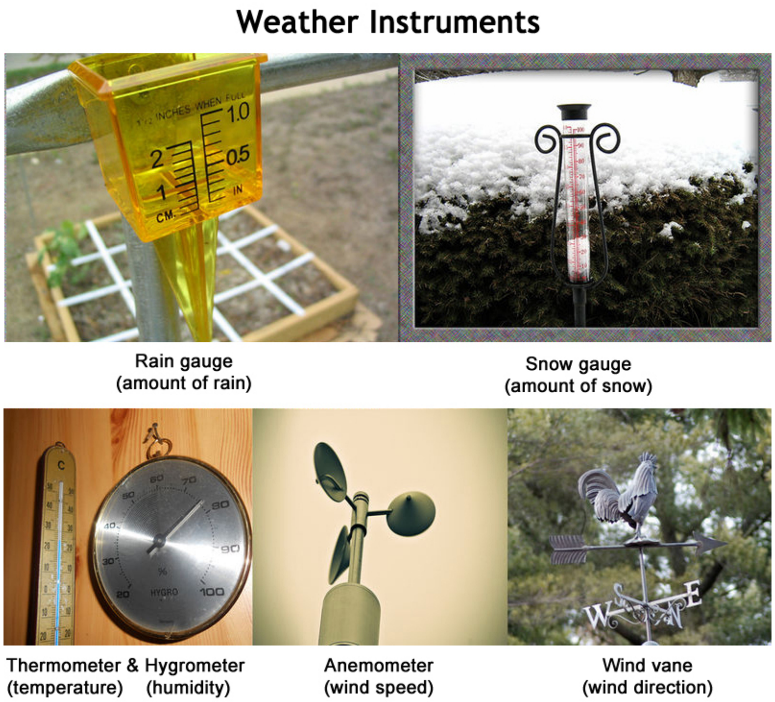


FIGURE 16.24
Some of the most commonly used weather instruments. (a) Thermometer: temperature, (b) Anemometer: wind speed, (c) Rain gauge: amount of rain, (d) Hygrometer: humidity, (e) Wind vane: wind direction, (f) Snow gauge: amount of snow.

FIGURE 16.25
Weather stations collect data on land and sea. Weather balloons, satellites, and radar collect data in the atmosphere.

Many **weather satellites** orbit Earth. They constantly collect and transmit weather data from high above the surface. A radar device sends out radio waves in all directions. The waves bounce off water in the atmosphere and then return to the sender. The radar data shows where precipitation is falling. It's raining in the orange-shaded area shown above.

Using Computers

What do meteorologists do with all that weather data? They use it in weather models. The models analyze the data and predict the weather. The models require computers. That's because so many measurements and calculations are involved.

Weather Maps

You may have seen weather maps like the one in **Figure** 16.26. A **weather map** shows weather conditions for a certain area. The map may show the actual weather on a given day or it may show the predicted weather for some time in the future. Some weather maps show many weather conditions. Others show a single condition.

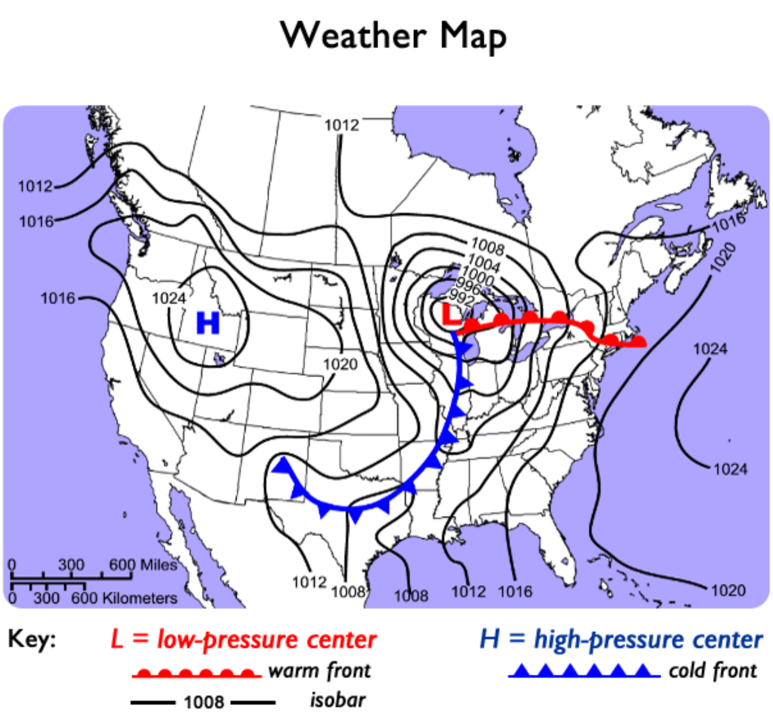


FIGURE 16.26
This weather map shows air pressure contours. Which state has the lowest air pressure shown on the map?

Air Pressure Maps

The weather map in **Figure** 16.26 shows air pressure. The lines on the map connect places that have the same air pressure. Air pressure is measured in a unit called the millibar. Isobars are the lines that connect the points with the same air pressure. The map also shows low- and high-pressure centers and fronts. Find the cold front on the map. This cold front is likely to move toward the northeast over the next couple of days. How could you use this information to predict what the weather will be on the East Coast?

Other Weather Maps

Instead of air pressure, weather maps may show other weather conditions. For example, a temperature map might show the high and low temperatures of major cities. The map may have isotherms, lines that connect places with the same temperature.

Lesson Summary

- Weather is very complex. This makes it hard to predict. Certain "rules" can help. For example, low pressure brings stormy weather.
- Weather instruments measure weather factors. Weather stations collect data on Earth's surface. Weather balloons, satellites, and radar collect data in the atmosphere. Computer models analyze the data and help predict the weather.
- A weather map shows the weather for a certain area. It can show actual or predicted weather. It may show a single weather condition or more than one.

Lesson Review Questions

Recall

1. Why is weather difficult to predict?
2. List three weather instruments, and state what they measure.
3. What is the role of weather balloons and weather satellites?
4. What does a weather map show?
5. Define isobars and isotherms.

Apply Concepts

6. What concepts explain how a barometer works?
7. In the weather map in **Figure** 16.26, where is the weather most likely to be clear and dry? How do you know?

Think Critically

8. Explain how radar could be used to track an approaching thunderstorm.

Points to Consider

In this chapter you learned about weather. Weather is sometimes confused with climate. The two are related but not the same.

- What is climate?
- How does climate differ from weather?

16.5 References

1. Jodi So. CK-12 Foundation . CC BY-NC 3.0
2. Courtesy of NOAA. http://oceanservice.noaa.gov/education/yos/resource/JetStream/global/hi.htm . Public Domain
3. Christopher M. Klaus. http://commons.wikimedia.org/wiki/File:Cloud_types.jpg . Public Domain
4. Top 3 images courtesy of NOAA; bottom left image by CK-12 Foundation - Christopher Auyeung; bottom right courtesy of National Severe Storms Laboratory. Top 3 images: http://www.srh.noaa.gov/jetstream//synoptic/precip.htm; Bottom right image: http://commons.wikimedia.org/wiki/File:Granizo.jpg . CC BY-NC 3.0 (top 3 images and bottom right images released in public domain)
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Weather Balloon: http://commons.wikimedia.org/wiki/File:Ballon_radiosonde_f.jpg; Weather Satellite: http://commons.wikimedia.org/wiki/File:GOES_8_Spac0255.jpg; Weather Radar: http://commons.wikimedia.org/wiki/File:Sturmfront_auf_Doppler-Radar-Schirm.jpg . Public Domain

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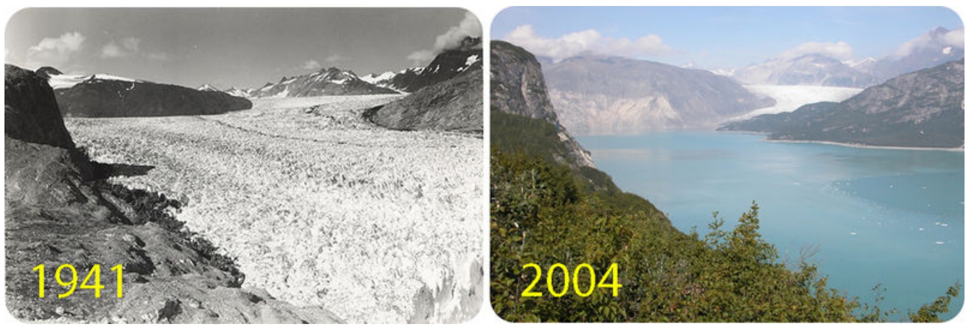
CHAPTER 17 MS Climate

Chapter Outline



These photos were taken in the same place, 63 years apart. What a difference a few decades can make! The earlier photo shows the massive Riggs Glacier in Alaska. The later photo shows what has happened to it. Why did so much of the glacier melt? The answer is climate change.

What is climate? Why does it change? The answer to the first question is easy. The answer to the second question is harder. You'll learn answers to both questions when you read this chapter.

1941 *photo: William Osgood Field, NSIDC. nsidc.org/cgi–bin/gpd_deliver_jpg.pl?muir*1941081301*. Free use if cited.*2004 *photo: Bruce F. Molnia, USGS. nsidc.or*

17.1 Climate and Its Causes

Lesson Objectives

- Define climate.
- State how climate is related to latitude.
- Explain how oceans influence climate.
- Describe how mountains affect climate.

Vocabulary

- climate
- rain shadow

Introduction

One winter day in Chicago, the temperature hit 20° C (68° F). This would be normal for Miami in the winter, but in Chicago, it felt like a heat wave. The scene in **Figure** 17.1 is more typical for Chicago in the winter. The "heat wave" on that winter day is an example of weather. The typical temperature for that day is part of Chicago's climate.

FIGURE 17.1
Cold and snow are typical for Chicago in the winter.

What Is Climate?

Climate is the average weather of a place over many years. It includes average temperatures. It also includes average precipitation. The timing of precipitation is part of climate as well. What determines the climate of a place? Latitude is the main factor. A nearby ocean or mountain range can also play a role.

Latitude and Climate

Latitude is the distance north or south of the equator. It's measured in degrees, from 0° to 90°. Several climate factors vary with latitude.

Latitude and Temperature

Temperature changes with latitude. You can see how in **Figure** 17.2

- At the equator, the Sun's rays are most direct. Temperatures are highest.
- At higher latitudes, the Sun's rays are less direct. The farther an area is from the equator, the lower is its temperature.
- At the poles, the Sun's rays are least direct. Much of the area is covered with ice and snow, which reflect a lot of sunlight. Temperatures are lowest here.

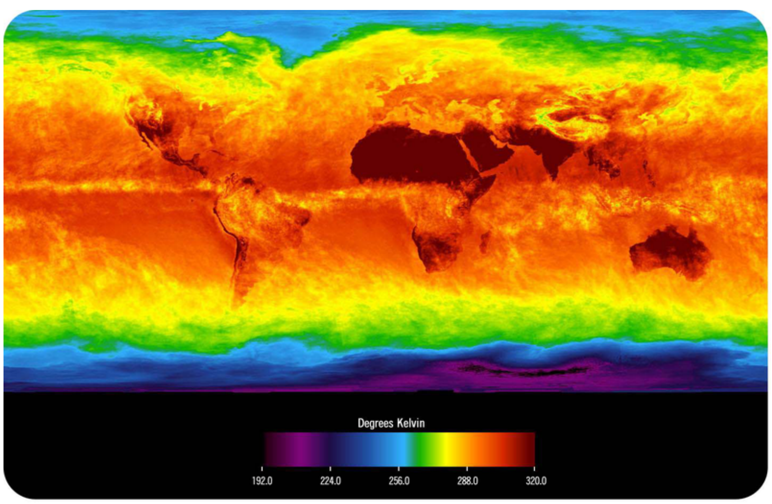


FIGURE 17.2
Find the cool spot in Asia at 30° north latitude. Why is it cool for its latitude? (Hint: What else might influence temperature?)

Latitude and Precipitation

Global air currents affect precipitation. How they affect it varies with latitude. You can see why in **Figure** 17.3.

Latitude and Prevailing Winds

Global air currents cause global winds. **Figure** 17.4 shows the direction that these winds blow. Global winds are the prevailing, or usual, winds at a given latitude. The winds move air masses, which causes weather.

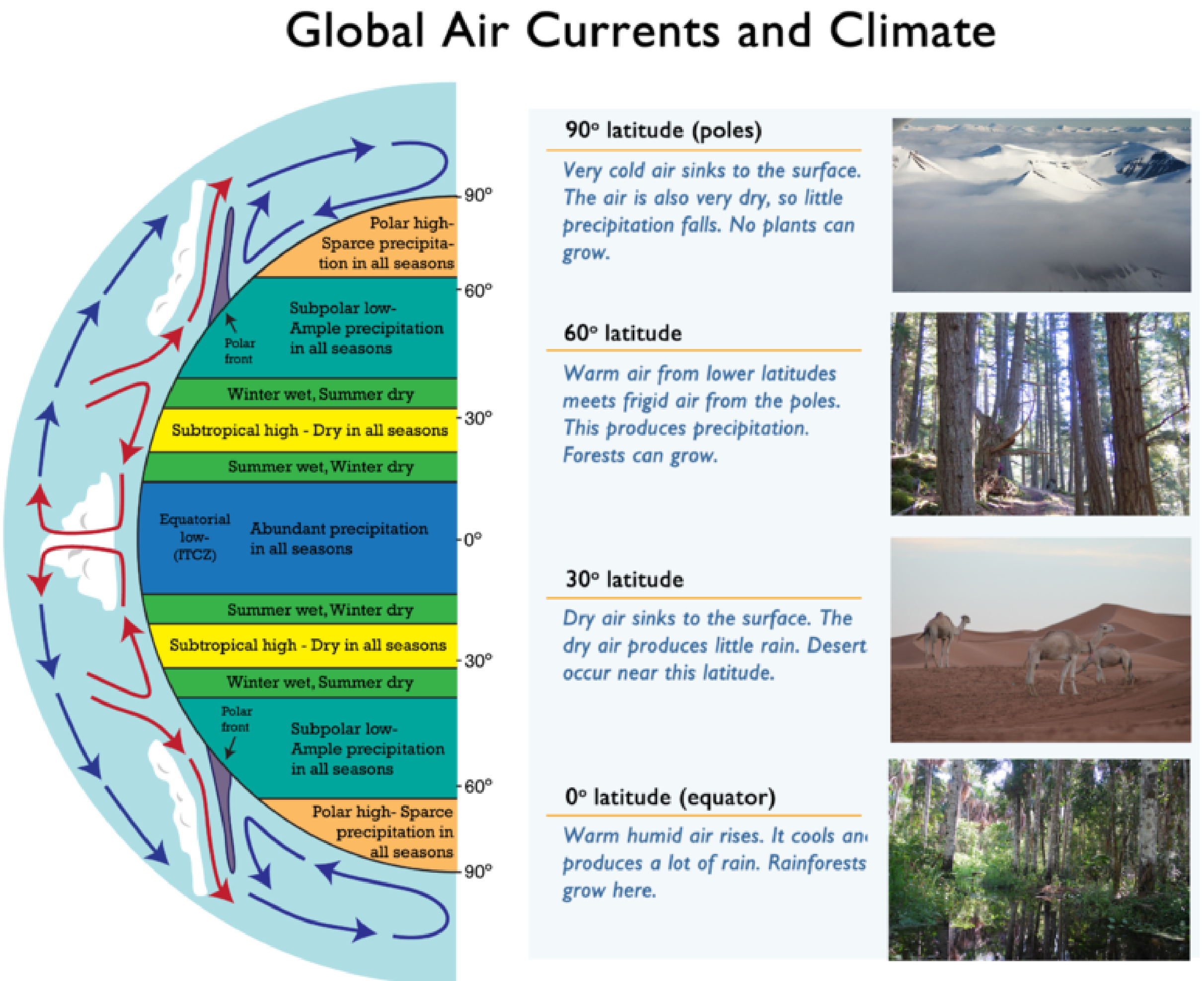


FIGURE 17.3
Global air currents are shown on the left. You can see how they affect climate on the right.

The direction of prevailing winds determines which type of air mass usually moves over an area. For example, a west wind might bring warm moist air from over an ocean. An east wind might bring cold dry air from over a mountain range. Which wind prevails has a big effect on the climate. What if the prevailing winds are westerlies? What would the climate be like?

Oceans and Climate

When a place is near an ocean, the water can have a big effect on the climate.

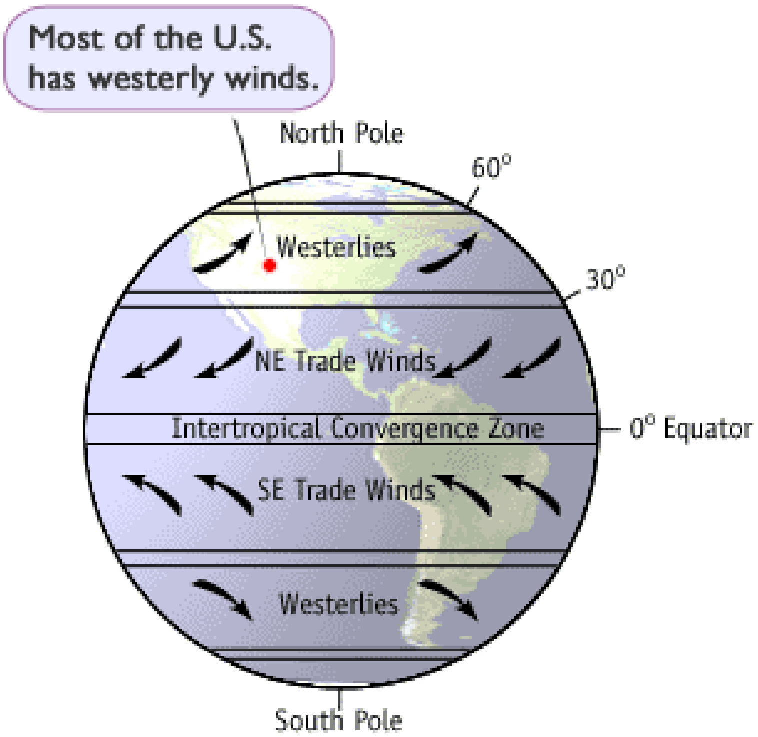


FIGURE 17.4
The usual direction of the wind where you live depends on your latitude. This determines where you are in the global wind belts.

Coastal and Inland Climates

Even places at the same latitude may have different climates if one is on a coast and one is inland.

- On the coast, the climate is influenced by warm moist air from the ocean. A coastal climate is usually mild. Summers aren't too hot, and winters aren't too cold. Precipitation can be high due to the moisture in the air.
- Farther inland, the climate is influenced by cold or hot air from the land. This air may be dry because it comes from over land. An inland climate is usually more extreme. Winters may be very cold, and summers may be very hot. Precipitation can be low.

Ocean Currents and Climate

Ocean currents carry warm or cold water throughout the world's oceans. They help to even out the temperatures in the oceans. This also affects the temperature of the atmosphere and the climate around the world. Currents that are near shore have a direct impact on climate. They may make the climate much colder or warmer. You can see examples of this in **Figure** 17.5.

Mountains and Climate

Did you ever hike or drive up a mountain? Did you notice that it was cooler near the top? Climate is not just different on a mountain. Just having a mountain range nearby can affect the climate.

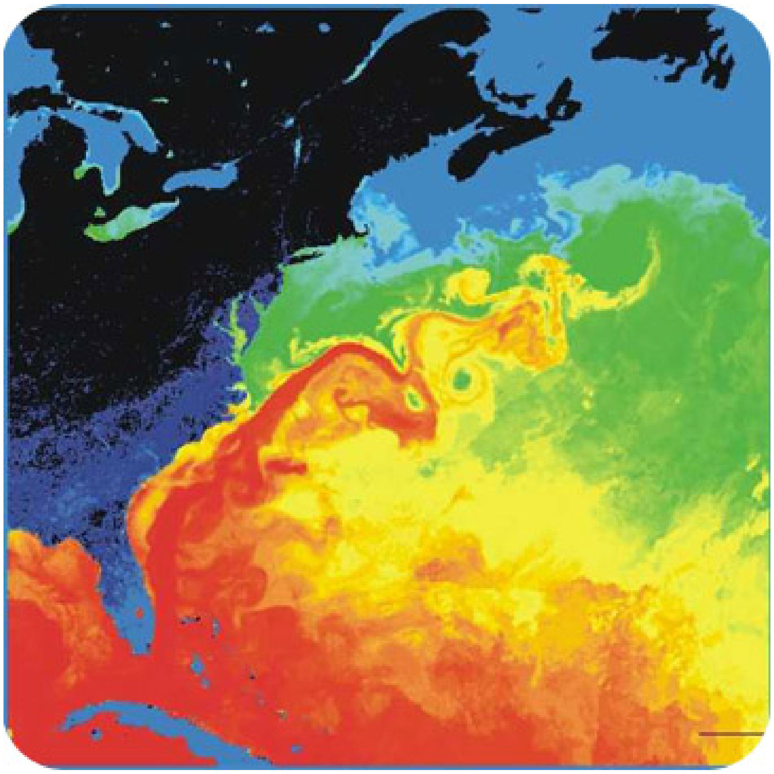


FIGURE 17.5
The Gulf Stream moves warm equatorial water up the western Pacific and into northern Europe, where it raises temperatures in the British Isles.

Altitude and Temperature

Air temperature falls at higher altitudes. You can see this in **Figure** 17.6. Why does this happen? Since air is less dense at higher altitudes, its molecules are spread farther apart than they are at sea level. These molecules have fewer collisions, so they produce less heat.

Look at the mountain in **Figure** 17.7. The peak of Mount Kilimanjaro, Tanzania (Africa, 3° south latitude) is 6 kilometers (4 miles) above sea level. At 3°S it's very close to the equator. At the bottom of the mountain, the temperature is high year round. How can you tell that it's much cooler at the top?

Mountains and Precipitation

Mountains can also affect precipitation. Mountains and mountain ranges can cast a **rain shadow**. As winds rise up a mountain range the air cools and precipitation falls. On the other side of the range the air is dry and it sinks. So there is very little precipitation on the far (leeward) side of a mountain range. **Figure** 17.8 shows how this happens.

Lesson Summary

- Climate is the average weather of a place over many years. It varies with latitude. It may also be influenced by nearby oceans or mountains.
- Temperature falls from the equator to the poles. Global air currents create wet and dry zones at different latitudes. They also create global winds.
- Oceans influence the climate of coasts. A coastal climate is mild. It may also get plenty of rain. An inland climate has greater temperature extremes. It can also be dry.

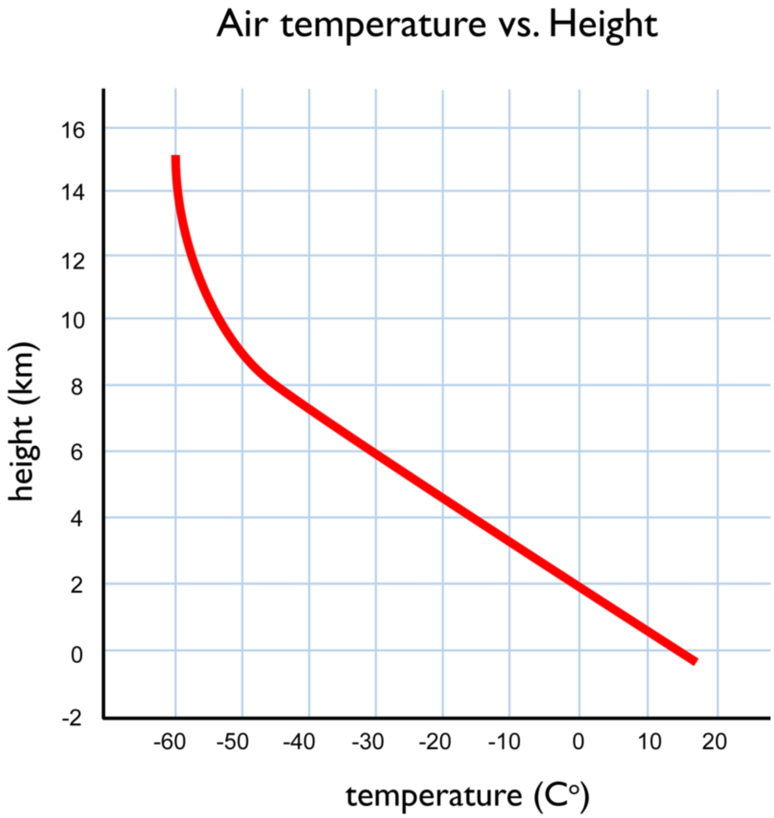


FIGURE 17.6
Air temperature drops as you go higher.

FIGURE 17.7
Mount Kilimanjaro has very different climates at the top and bottom.

- The air is cooler as you go higher up a mountain. Mountain ranges can also cast rain shadows.

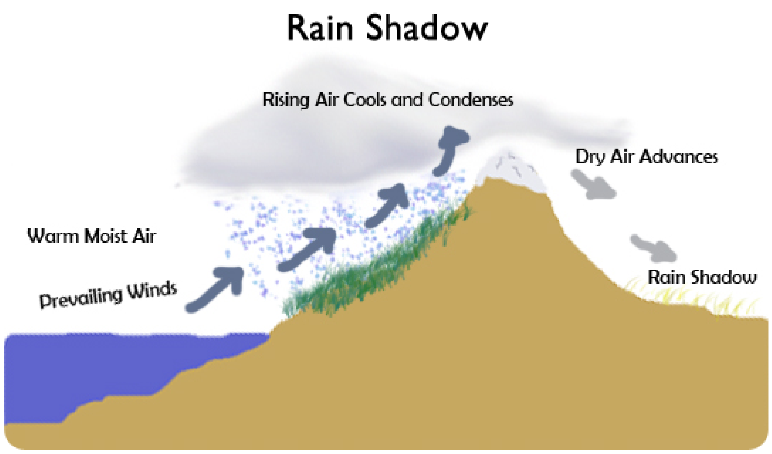


FIGURE 17.8
What role do prevailing winds play in a rain shadow?

Lesson Review Questions

Recall

1. What is climate?
2. Describe how temperature changes with latitude.
3. Why are many deserts found near 30° latitude?
4. How does altitude influence temperature?
5. What is a rain shadow?

Apply Concepts

6. An ocean current flows from north to south off the western coast of a continent. The current flows close to land at 50° N latitude. Predict how the current affects the climate of the coast at that latitude. Explain your prediction.

Think Critically

7. Explain how prevailing winds influence climate.
8. Compare and contrast coastal and inland climates.

Points to Consider

In this lesson, you read how latitude, oceans, and mountains affect climate.

- Do you think you could predict the climate of a place, based on its location?
- Do you think that similar locations around the globe might have the same climate?

17.2 World Climates

Lesson Objectives

- Identify world climates and where they are found.
- Define microclimate, and give an example.

Vocabulary

- alpine tundra
- biome
- continental climate
- desert
- humid continental climate
- humid subtropical climate
- marine west coast climate
- Mediterranean climate
- microclimate
- polar climate
- polar tundra
- steppe
- subarctic climate
- temperate climate
- tropical climate
- tropical rainforest

Introduction

The same latitudes should have the same types of climate all around the globe, but many other factors play a role in climate. Oceans and mountain ranges also influence climate in the same ways worldwide. You can see this in **Figure** 17.9. The major climate types are determined by a lot of factors, including latitude. You can see where the climate types are on the map and then read about them below.

Major Climate Types

Major climate types are based on temperature and precipitation. These two factors determine what types of plants can grow in an area. Animals and other living things depend on plants. So each climate is associated with certain types of living things. A major type of climate and its living things make up a **biome**. As you read about the major climate types below, find them on the map in **Figure** 17.9.

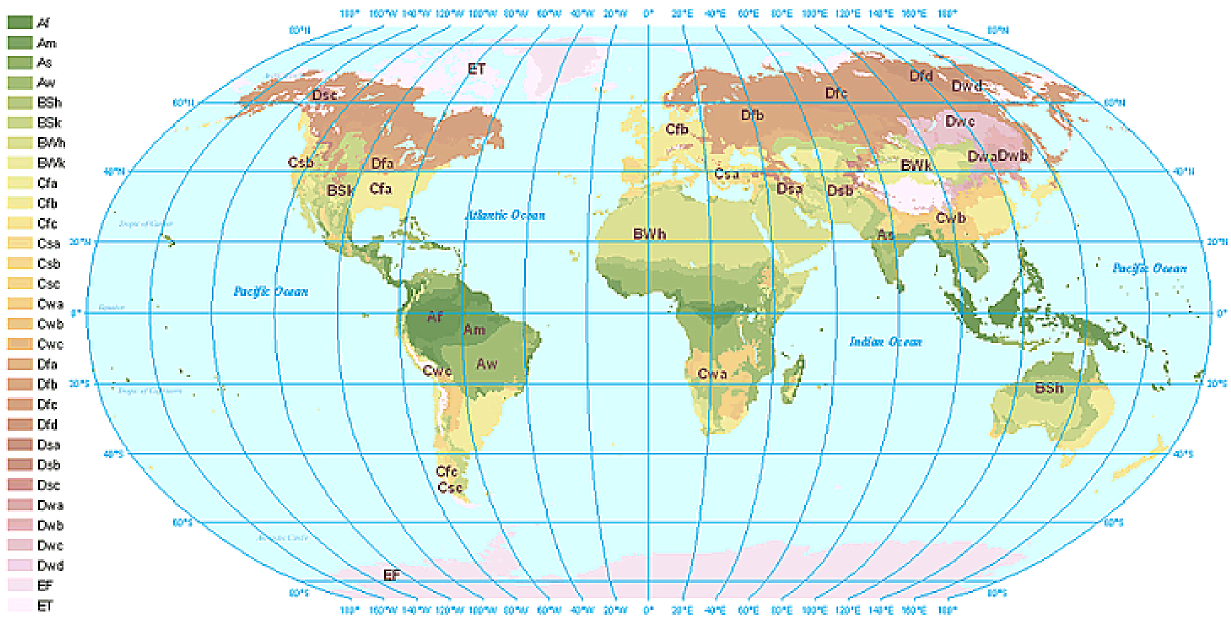


FIGURE 17.9

Find where you live on the map. What type of climate do you have?

Tropical Climates

Tropical climates are found around the equator. As you'd expect, these climates have warm temperatures year round. Tropical climates may be very wet or wet and dry.

- Tropical wet climates occur at or very near the equator. They have high rainfall year round. **Tropical rainforests** grow in this type of climate.
- Tropical wet and dry climates occur between 5° and 20° latitude and receive less rainfall. Most of the rain falls in a single season. The rest of the year is dry. Few trees can withstand the long dry season, so the main plants are grasses (see **Figure** 17.10).

Dry Climates

Dry climates receive very little rainfall. They also have high rates of evaporation. This makes them even drier.

- The driest climates are **deserts**. Most occur between about 15° and 30° latitude. This is where dry air sinks to the surface in the global circulation cells. Deserts receive less than 25 centimeters (10 inches) of rain per year. They may be covered with sand dunes or be home to sparse but hardy plants (see **Figure** 17.11). With few clouds, deserts have hot days and cool nights.
- Other dry climates get a little more precipitation. They are called **steppes**. These regions have short grasses and low bushes (see **Figure** 17.11). Steppes occur at higher latitudes than deserts. They are dry because they are in continental interiors or rain shadows.

FIGURE 17.10
Africa is famous for its grasslands and their wildlife.

FIGURE 17.11
Dry climates may be deserts or steppes. Sonoran Desert in Arizona (22° north latitude), Utah Steppe (40° north latitude).

Temperate Climates

Temperate climates have moderate temperatures. These climates vary in how much rain they get and when the rain falls. You can see different types of temperate climates in **Figure** 17.12.

- **Mediterranean climates** are found on the western coasts of continents. The latitudes are between 30° and 45°. The coast of California has a Mediterranean climate. Temperatures are mild and rainfall is moderate. Most of the rain falls in the winter, and summers are dry. To make it through the dry summers, short woody plants are common.
- **Marine west coast climates** are also found on the western coasts of continents. They occur between 45° and 60° latitude. The coast of Washington State has this type of climate. Temperatures are mild and there's plenty

of rainfall all year round. Dense fir forests grow in this climate.

- **Humid subtropical climates** are found on the eastern sides of continents between about 20° and 40° latitude. The southeastern U.S. has this type of climate. Summers are hot and humid, but winters are chilly. There is moderate rainfall throughout the year. Pine and oak forests grow in this climate.

FIGURE 17.12
How do these climates differ from each other?

Continental Climates

Continental climates are found in inland areas. They are too far from oceans to experience the effects of ocean water. Continental climates are common between 40° and 70° north latitude. There are no continental climates in the Southern Hemisphere. Can you guess why? The southern continents at this latitude are too narrow. All of their inland areas are close enough to a coast to be affected by the ocean!

- **Humid continental climates** are found between 40° and 60° north latitude. The northeastern U.S. has this type of climate. Summers are warm to hot, and winters are cold. Precipitation is moderate, and it falls year round. Deciduous trees grow in this climate. They lose their leaves in the fall and grow new ones in the spring.
- **Subarctic climates** are found between 60° and 70° north latitude. Much of Canada and Alaska have this type of climate. Summers are cool and short. Winters are very cold and long. Little precipitation falls, and most of it falls during the summer. Conifer forests grow in this climate (see **Figure** 17.13).

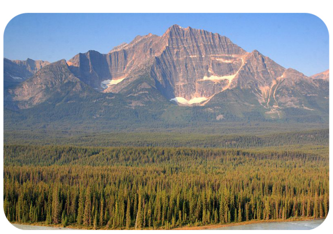


FIGURE 17.13
Conifer forests are typical of the subarctic.

Polar Climates

Polar climates are found near the North and South Poles. They also occur on high mountains at lower latitudes. The summers are very cool, and the winters are frigid. Precipitation is very low because it's so cold. You can see examples of polar climates in **Figure** 17.14.

- **Polar tundra** climates occur near the poles. Tundra climates have permafrost. Permafrost is layer of ground below the surface that is always frozen, even in the summer. Only small plants, such as mosses, can grow in this climate.
- **Alpine tundra** climates occur at high altitudes at any latitude. They are also called highland climates. These regions are very cold because they are so far above sea level. The alpine tundra climate is very similar to the polar tundra climate.
- Ice caps are areas covered with thick ice year round. Ice caps are found only in Greenland and Antarctica. Temperatures and precipitation are both very low. What little snow falls usually stays on the ground. It doesn't melt because it's too cold.

FIGURE 17.14

Polar climates include polar and alpine tundra. Polar Tundra in Northern Alaska (70 ° N latitude), Alpine Tundra in the Colorado Rockies (40 ° N latitude).

Microclimates

A place might have a different climate than the major climate type around it. This is called a **microclimate**. Look at **Figure** 17.15. The south-facing side of the hill gets more direct sunlight than the north side of a hill. This gives the south side a warmer microclimate. A microclimate can be due to a place being deeper. Since cold air sinks, a depression in the land can be a lot colder than the land around it.

Lesson Summary

- Climate types are based on temperature and precipitation. A major climate type and its living things make up a biome. Climate types include tropical, temperate, continental, and polar climates.
- A microclimate is a local climate that differs from the major climate type around it. For example, the south-facing side of a hill may have a warmer microclimate.

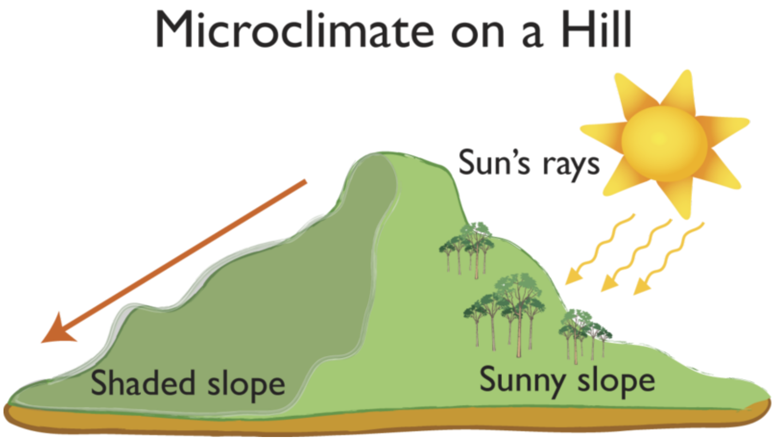


FIGURE 17.15
Hills and other features can create microclimates.

Lesson Review Questions

Recall

1. Define biome.
2. Identify two types of tropical climates.
3. How do steppes differ from deserts?
4. Where are Mediterranean climates found?
5. Describe a marine west coast climate.
6. What is permafrost?
7. What is a microclimate? Give an example.

Apply Concepts

8. Identify the type of climate in the green-shaded areas in the **Figure** 17.16. Describe this type of climate.

FIGURE 17.16

Think Critically

9. Some tropical climates have rainforests. Others have grasslands. What explains the difference?

10. Compare and contrast two types of continental climates.

Points to Consider

Earth's overall climate is getting warmer.

- Why is Earth's climate changing?
- How is climate change affecting living things?

17.3 Climate Change

Lesson Objectives

- Outline how Earth's climate has changed over time.
- Identify causes and effects of climate change.
- Describe El Niño and La Niña.

Vocabulary

- El Niño
- global warming
- ice age
- La Niña

Introduction

The weather changes all the time. It can change in a matter of minutes. Changes in climate occur more slowly, and the changes tend to be small. But even small changes in climate can make a big difference for Earth and its living things.

How Earth's Climate Has Changed

Earth's climate has changed many times through Earth's history. It's been both hotter and colder than it is today.

The Big Picture

Over much of Earth's past, the climate was warmer than it is today. Picture in your mind dinosaurs roaming the land. They're probably doing it in a pretty warm climate! But ice ages also occurred many times in the past. An **ice age** is a period when temperatures are cooler than normal. This causes glaciers to spread to lower latitudes. Scientists think that ice ages occurred at least six times over the last billion years alone. How do scientists learn about Earth's past climates?

Pleistocene Ice Age

The last major ice age took place in the Pleistocene. This epoch lasted from 2 million to 14,000 years ago. Earth's temperature was only 5° C (9° F) cooler than it is today. But glaciers covered much of the Northern Hemisphere. In

Figure 17.17, you can see how far south they went. Clearly, a small change in temperature can have a big impact on the planet. Humans lived during this ice age.

FIGURE 17.17
Pleistocene glaciers covered an enormous land area. Chicago is just one city that couldn't have existed during the Pleistocene.

Earth's Recent Temperature

Since the Pleistocene, Earth's temperature has risen. **Figure** 17.18 shows how it changed over just the last 1500 years. There were minor ups and downs. But each time, the anomaly (the difference from average temperature) was less than 1° C (1.8° F).

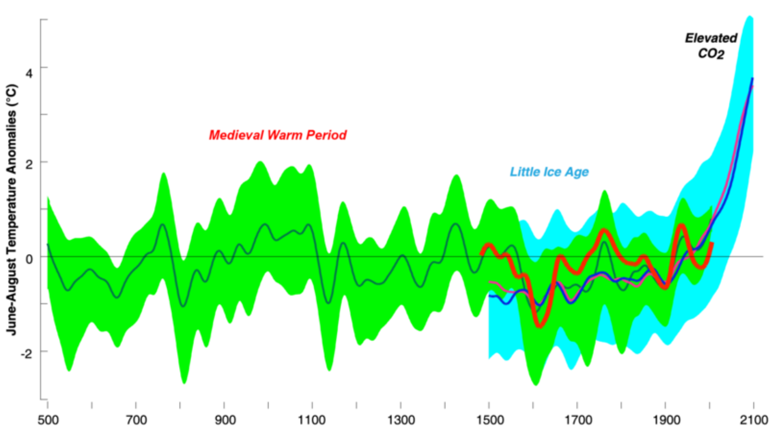


FIGURE 17.18
Earth's temperature. Different sets of data all show an increase in temperature since about 1880 (the Industrial Revolution).

Since the mid 1800s, Earth has warmed up quickly. Look at **Figure** 17.19. The 14 hottest years on record have all occurred since 1900. Eight of them have occurred since 1998! This is what is usually meant by **global warming**.

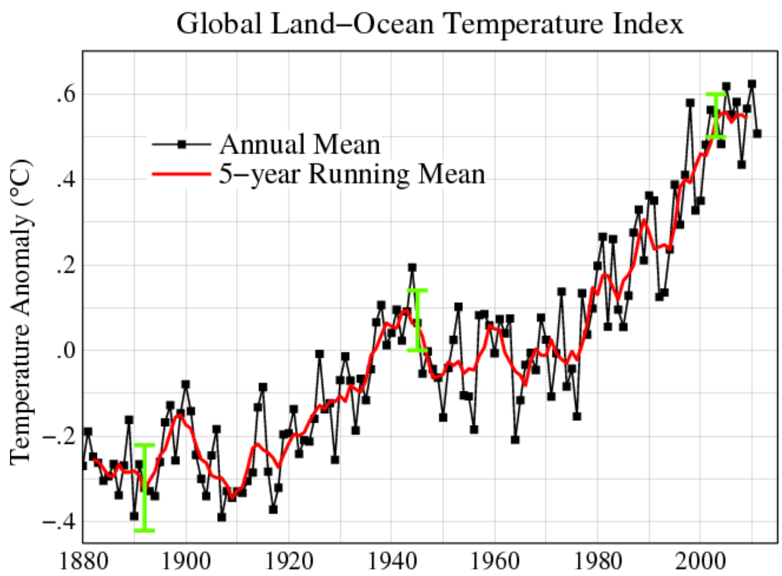


FIGURE 17.19
Earth's temperature (1850–2007). Earth has really heated up over the last 150 years. Do you know why?

Explaining Long-Term Climate Change

Natural processes caused earlier climate changes. Human beings are the main cause of recent global warming.

Causes of Climate Change in Earth History

Several natural processes may affect Earth's temperature. They range from sunspots to Earth's wobble.

- Sunspots are storms on the Sun. When the number of sunspots is high, the Sun gives off more energy than usual. Still, there is little evidence for climate changing along with the sunspot cycle.
- Plate movements cause continents to drift closer to the poles or the equator. Ocean currents also shift when continents drift. All these changes can affect Earth's temperature.
- Plate movements trigger volcanoes. A huge eruption could spew so much gas and ash into the air that little sunlight would reach the surface for months or years. This could lower Earth's temperature.
- A large asteroid hitting Earth would throw a lot of dust into the air. This could block sunlight and cool the planet.
- Earth goes through regular changes in its position relative to the Sun. Its orbit changes slightly. Earth also wobbles on its axis of rotation. The planet also changes the tilt on its axis. These changes can affect Earth's temperature.

Causes of Global Warming

Recent global warming is due mainly to human actions. Burning fossil fuels adds carbon dioxide to the atmosphere. Carbon dioxide is a greenhouse gas. It's one of several that human activities add to the atmosphere. An increase in greenhouse gases leads to greater greenhouse effect. The result is increased global warming. **Figure** 17.20 shows the increase in carbon dioxide since 1960.

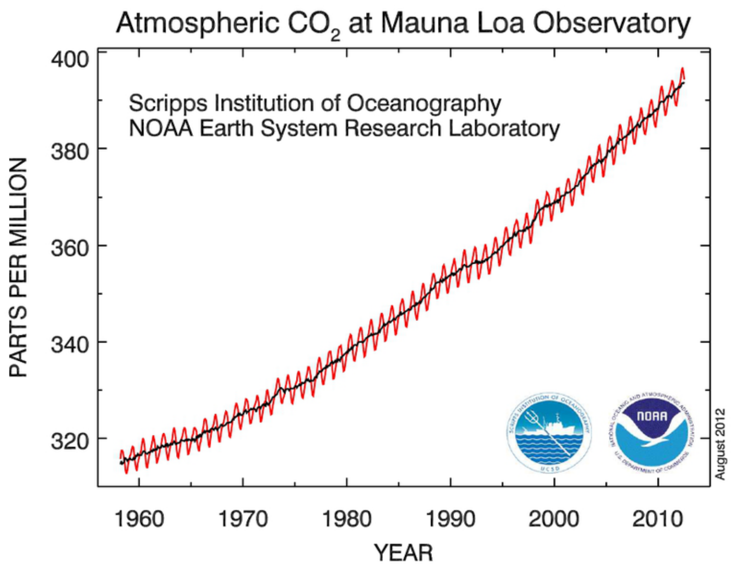


FIGURE 17.20
How much more carbon dioxide was in the air in 2005 than in 1960?

Effects of Global Warming

As Earth has gotten warmer, sea ice has melted. This has raised the level of water in the oceans. **Figure** 17.21 shows how much sea level has risen since 1880.

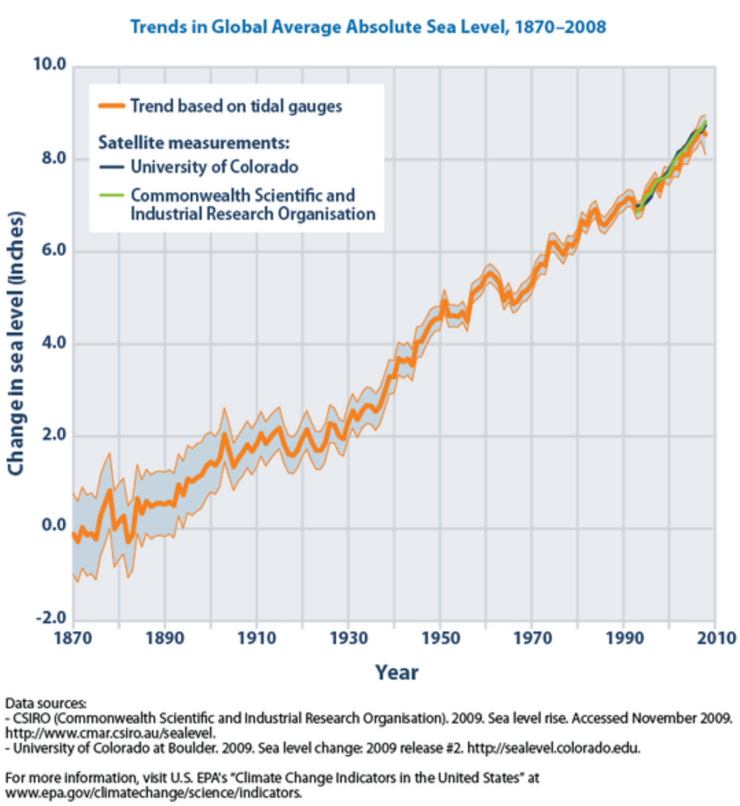


FIGURE 17.21
How much did sea level rise between 1880 and 2000?

Other effects of global warming include more extreme weather. Earth now has more severe storms, floods, heat waves, and droughts than it did just a few decades ago. Many living things cannot adjust to the changing climate. For example, coral reefs are dying out in all the world's oceans.

How Will Climate Change in the Future?

Earth's temperature will keep rising unless greenhouse gases are curbed. The temperature in 2100 may be as much as 5° C (9° F) higher than it was in 2000. Since the glacial periods of the Pleistocene, average temperature has risen about 4° C. That's just 4° C from abundant ice to the moderate climate we have today. How might a 5° C increase in temperature affect Earth in the future?

Warming will affect the entire globe by the end of this century. The map in **Figure** 17.22 shows the average temperature in the 2050s. This is compared with the average temperature in 1971 to 2000. In what place is the temperature increase the greatest? Where in the United States is the temperature increase the highest?

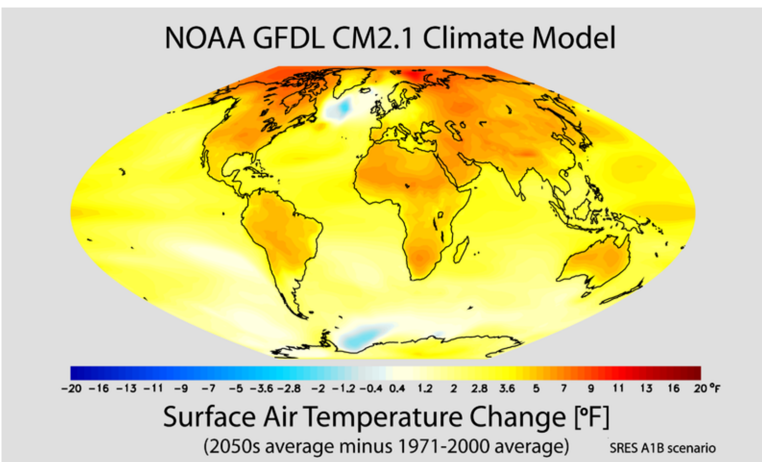


FIGURE 17.22

The Arctic will experience the greatest temperature changes.

As temperature rises, more sea ice will melt. **Figure** 17.23 shows how much less sea ice there may be in 2050 if temperatures keep going up. This would cause sea level to rise even higher. Some coastal cities could be under water. Millions of people would have to move inland. How might other living things be affected?

Short-Term Climate Change

You've probably heard of El Niño and La Niña. These terms refer to certain short-term changes in climate. The changes are natural and occur in cycles. To understand the changes, you first need to know what happens in normal years. This is shown in **Figure** 17.24.

El Niño

During an **El Niño**, the western Pacific Ocean is warmer than usual. This causes the trade winds to change direction. The winds blow from west to east instead of east to west. This is shown in **Figure** 17.25. The warm water travels east across the equator, too. Warm water piles up along the western coast of South America. This prevents upwelling. Why do you think this is true?

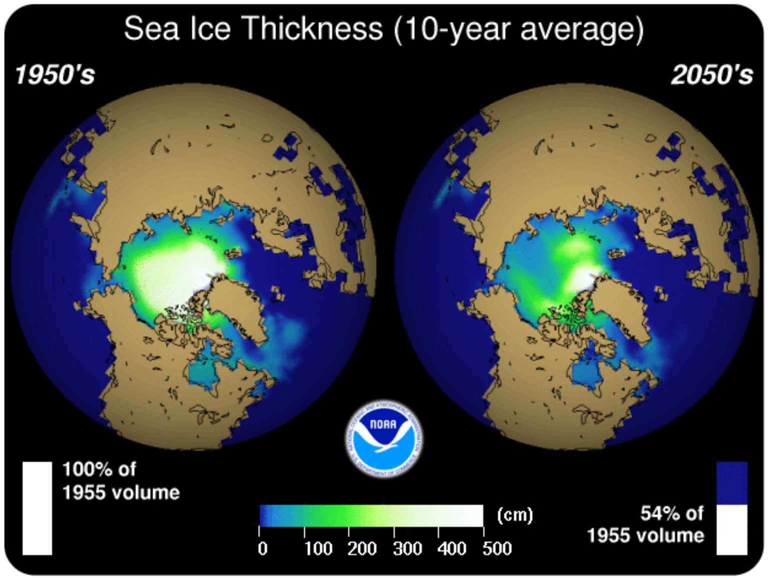


FIGURE 17.23
In the 2050s, there may be only half as much sea ice as there was in the 1950s.

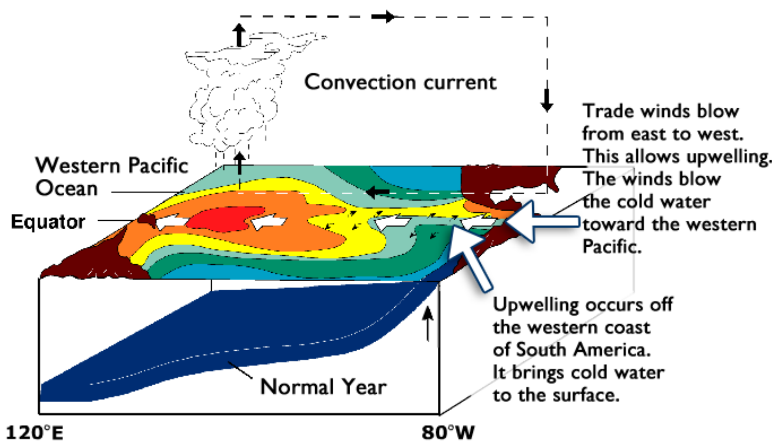


FIGURE 17.24
This diagram represents the Pacific Ocean in a normal year. North and South America are the brown shapes on the right.

These changes in water temperature, winds, and currents affect climates worldwide. The changes usually last a year or two. Some places get more rain than normal. Other places get less. In many locations, the weather is more severe.

La Niña

La Niña generally follows El Niño. It occurs when the Pacific Ocean is cooler than normal. **Figure** 17.26 shows what happens. The trade winds are like they are in a normal year. They blow from east to west. But in a La Niña the winds are stronger than usual. More cool water builds up in the western Pacific. These changes can also affect climates worldwide.

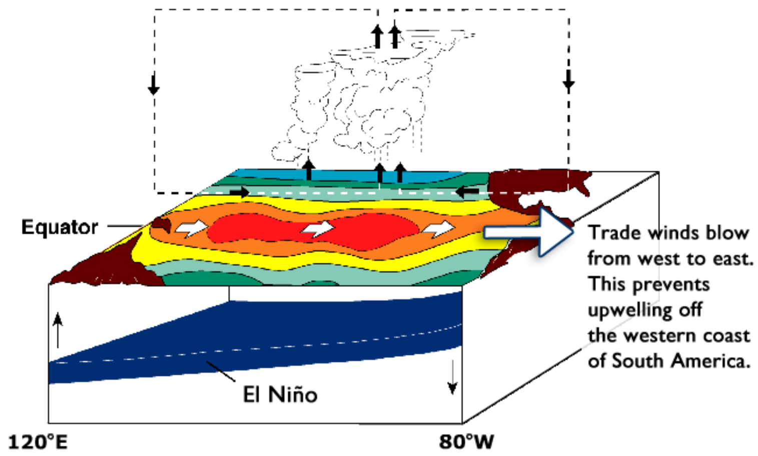


FIGURE 17.25
How do you think El Niño affects climate on the western coast of South America?

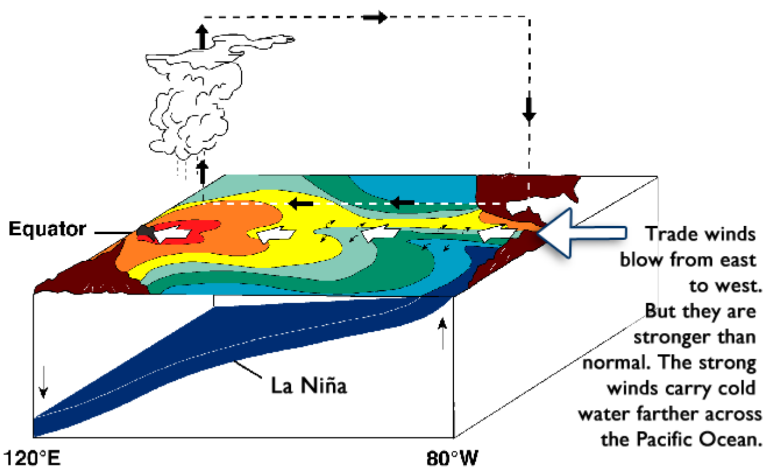


FIGURE 17.26
How do you think La Niña affects climate on the western coast of South America?

Global Warming and Short-Term Climate Change

Some scientists think that global warming is affecting the cycle of El Niño and La Niña. These short-term changes seem to be cycling faster now than in the past. They are also more extreme.

Lesson Summary

- Earth's climate has changed many times. Long warm periods were broken up by ice ages. Over the past 150 years, climate has warmed quickly.
- Climate change in Earth history was due to natural processes. Recent global warming is due mainly to human actions. The burning of fossil fuels releases greenhouse gases into the air. This creates greater greenhouse effect and global warming.
- El Niño and La Niña are short-term climate changes. They occur in cycles and influence weather all over the planet. They may be affected by global warming since El Niño is triggered by warmer ocean temperatures.

Lesson Review Questions

Recall

1. What is an ice age?
2. Describe the Pleistocene ice age.
3. Outline recent changes in Earth's temperature.
4. What does global warming usually refer to?
5. Identify three natural causes of climate change.
6. List two effects of global warming.

Apply Concepts

7. Create a public service announcement about global warming. Explain how global warming is related to human actions and what people can do to reduce it. (Hint: How can people produce less carbon dioxide?)

Think Critically

8. Compare and contrast El Niño and La Niña.
9. Nearly all scientists are united in saying that human activities are causing much of the warming we see. Why do you think politicians are reluctant to believe them? Why is the public reluctant to believe them?

Points to Consider

A place's climate determines what kinds of plants and animals can live there.

- Would you expect similar plants and animals to be found in the same type of climate all over the world?
- Besides climate, what factors might influence which plants and animals are found in a place?

17.4 References

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CHAPTER 18 MS Ecosystems and Human Populations

Chapter Outline

A sea of people throngs the street of La Plaine Saint-Denis, France. How many people do you see? Are there too many to count? This photo shows just a tiny fraction of the billions of people who live on Earth today. Our vast numbers show that we are a very successful species. But our numbers are also a problem. We are harming the environment. We are affecting ecosystems all over the planet.

How did the human population become so large? How are we affecting Earth's ecosystems? In this chapter, you'll find out.

18.1 Ecosystems

Lesson Objectives

- Define ecosystem, and give examples.
- Identify abiotic factors in ecosystems.
- Describe biotic factors in ecosystems.
- Explain how energy flows through ecosystems.
- Outline how matter moves through ecosystems.

Vocabulary

- abiotic factor
- biotic factor
- carnivore
- community
- consumer
- decomposer
- ecosystem
- food chain
- food web
- grazer
- habitat
- herbivore
- niche
- nutrients
- omnivore
- population
- predator
- prey
- producer
- scavenger
- species

Introduction

You open your front door and step outside. It doesn't matter where you live, you are in your ecosystem. All around you are living and nonliving things. You're surrounded by air. You feel warm sunlight on your face. There's soil under your feet. You see plants and hear a bird singing. Your own body is covered with billions of bacteria. All of these things are part of your ecosystem.

What Is an Ecosystem?

An **ecosystem** is a group of living things and their environment. The word ecosystem is short for "ecological system." Like any system, an ecosystem is a group of parts that work together. You can see examples of ecosystems in **Figure** 18.1. The forest pictured is a big ecosystem. Besides trees, what living things do you think are part of the forest ecosystem? The dead tree stump in the same forest is a small ecosystem. It includes plants, mosses, and fungi. It also includes insects and worms.

FIGURE 18.1
An ecosystem can be big or small. A small ecosystem can be part of a larger ecosystem.

Abiotic Factors

Abiotic factors are the nonliving parts of ecosystems. They include air, sunlight, soil, water, and minerals. These are all things that are needed for life. They determine which living things — and how many of them — an ecosystem can support. **Figure** 18.2 shows an ecosystem and its abiotic factors.

Biotic Factors

Biotic factors are the living parts of ecosystems. They are the species of living things that reside together.

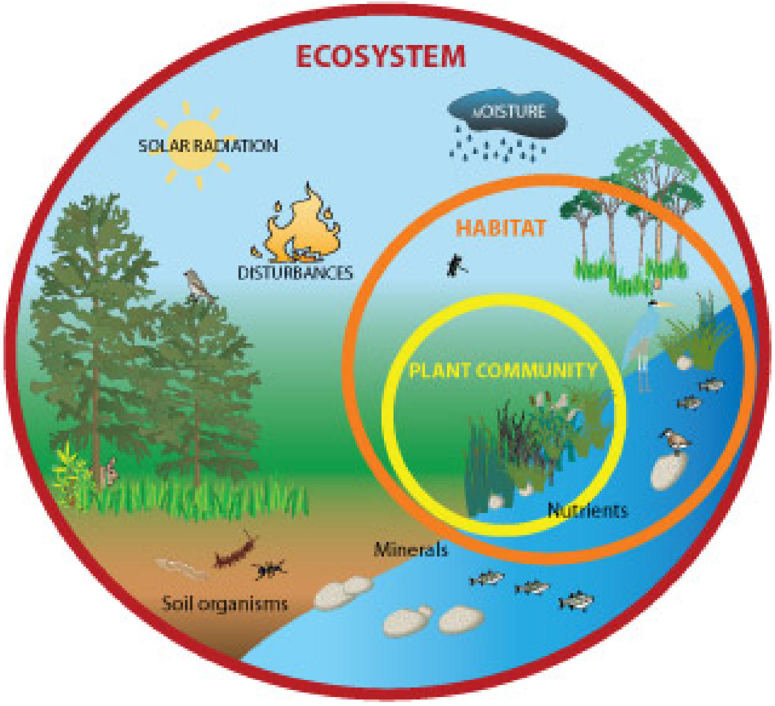

FIGURE 18.2
Which abiotic factors do you see here?

Species, Niche, and Habitat

A **species** is a unique type of organism. Members of a species can interbreed and produce offspring that can breed (they are fertile). Organisms that are not in the same species cannot do this. Examples of species include humans, lions, and redwood trees. Can you name other examples?

Each species has a particular way of making a living. This is called its **niche**. You can see the niche of a lion in **Figure** 18.3. A lion makes its living by hunting and eating other animals. Each species also has a certain place where it is best suited to live. This is called its **habitat**. The lion's habitat is a grassland. Why is a lion better off in a grassland than in a forest?

How a Lion "Makes a Living"

FIGURE 18.3
A lion hunts a water buffalo. What is the water buffalo's niche?

Living Together

All the members of a species that live in the same area form a **population**. Many different species live together in an ecosystem. All their populations make up a **community**. What populations live together in the grassland in **Figure** 18.3?

Roles in Ecosystems

All ecosystems have living things that play the same basic roles. Some organisms must be producers. Others must be consumers. Decomposers are also important.

Producers

Producers are living things that use energy to make food. Producers make food for themselves and other living things. There are two types of producers:

- By far the most common producers use the energy in sunlight to make food. This is called photosynthesis. Producers that photosynthesize include plants and algae. These organisms must live where there is plenty of sunlight. Which living things are producers in **Figure** 18.3?
- Other producers use the energy in chemicals to make food. This is called chemosynthesis. Only a very few producers are of this type, and all of them are microbes. These producers live deep under the ocean where there is no sunlight. You can see an example in **Figure** 18.4.

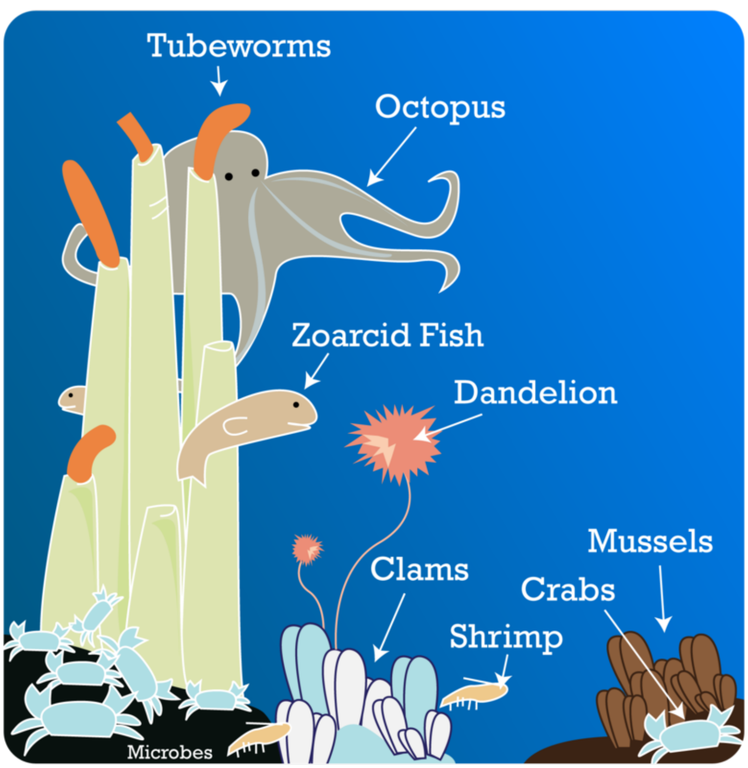

FIGURE 18.4
Microbes use chemicals to make food. The chemicals pour out of a crack on the ocean floor at a mid-ocean ridge. What consumers live in this ecosystem?

Consumers

Consumers can't make their own food. Consumers must eat producers or other consumers. **Figure** 18.5 lists the three main types of consumers. Which type are you?

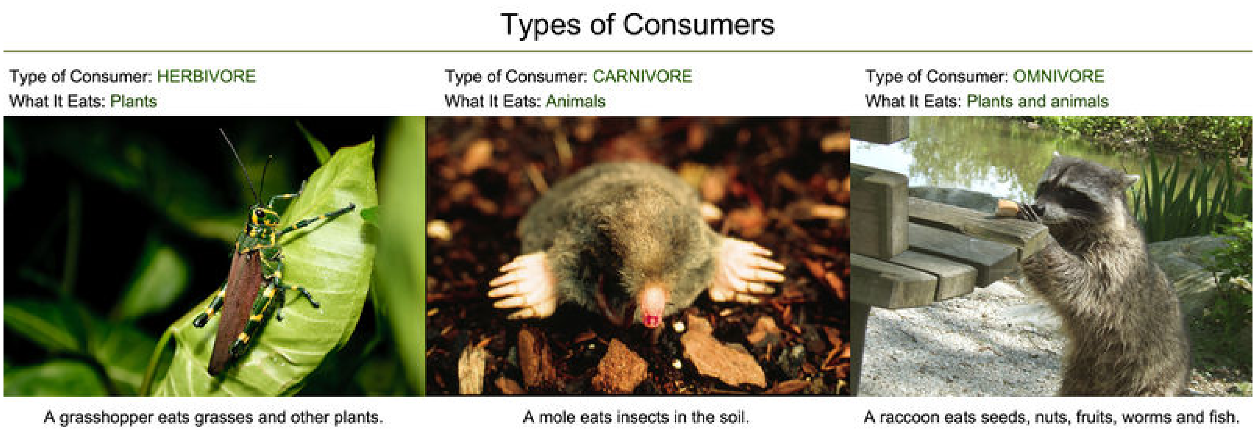

FIGURE 18.5

Examples of the main types of consumers. Can you name other consumers of each type?

Consumers get their food in different ways **Figure** 18.6. **Grazers** feed on living organisms without killing them. A rabbit nibbles on leaves and a mosquito sucks a drop of blood. **Predators**, like lions, capture and kill animals for food. The animals they eat are called **prey**. Even some plants are consumers. Pitcher plants trap insects in their sticky fluid in their "pitchers." The insects are their prey. **Scavengers** eat animals that are already dead. This hyena is eating the remains of a lion's prey. **Decomposers** break down dead organisms and the wastes of living things. This dung beetle is rolling a ball of dung (animal waste) back to its nest. The beetle will use the dung to feed its young. The mushrooms pictured are growing on a dead log. They will slowly break it down. This releases its nutrients to the soil.

How Energy Flows Through Ecosystems

All living things need energy. They need it to power the processes of life. For example, it takes energy to grow. It also takes energy to produce offspring. In fact, it takes energy just to stay alive. Remember that energy can't be created or destroyed. It can only change form. Energy changes form as it moves through ecosystems.

The Flow of Energy

Most ecosystems get their energy from the Sun. Only producers can use sunlight to make usable energy. Producers convert the sunlight into chemical energy or food. Consumers get some of that energy when they eat producers. They also pass some of the energy on to other consumers when they are eaten. In this way, energy flows from one living thing to another.

FIGURE 18.6
Ways consumers get food. Do you know how earthworms get food?

Food Chains

A **food chain** is a simple diagram that shows one way energy flows through an ecosystem. You can see an example of a food chain in **Figure** 18.7. Producers form the base of all food chains. The consumers that eat producers are called primary consumers. The consumers that eat primary consumers are secondary consumers. This chain can continue to multiple levels.

At each level of a food chain, a lot of energy is lost. Only about 10 percent of the energy passes to the next level. Where does that energy go? Some energy is given off as heat. Some energy goes into animal wastes. Energy also goes into growing things that another consumer can't eat, like fur. It's because so much energy is lost that most food chains have just a few levels. There's not enough energy left for higher levels.

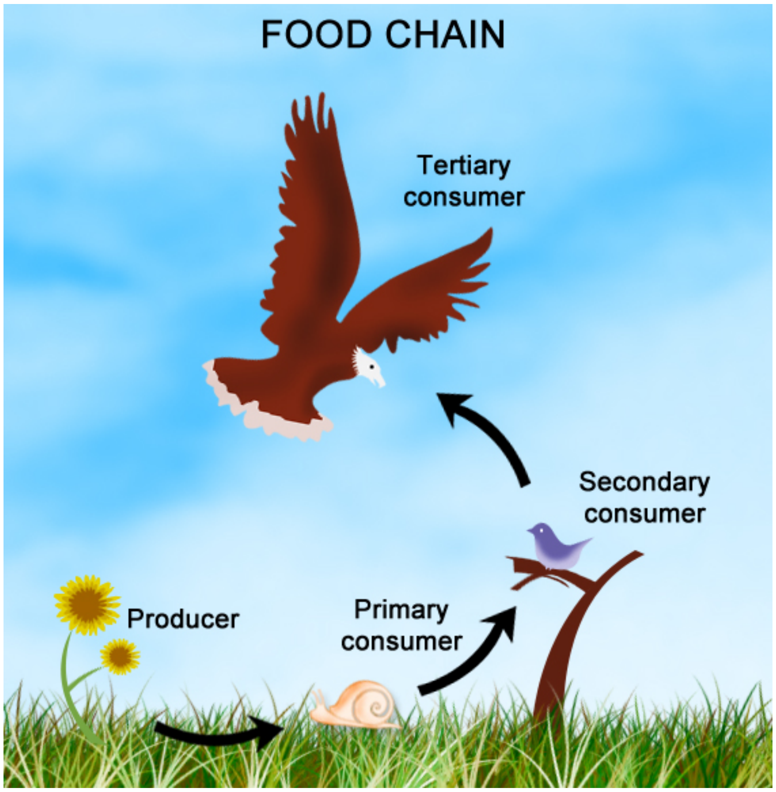

FIGURE 18.7
What do the arrows stand for in a food chain?

Food Webs

Food chains are too simple to represent the real world. They don't show all the ways that energy flows through an ecosystem. A more complex diagram is called a **food web**. You can see an example in **Figure** 18.8. A food web consists of many overlapping food chains. Can you identify the food chains in the figure? How many food chains include the mouse?

How Matter Moves Through Ecosystems

Living things need nonliving matter as well as energy. What do you think matter is used for? One thing is to build bodies. They also need it to carry out the processes of life. Any nonliving matter that living things need is called a **nutrient**. Carbon and nitrogen are examples of nutrients. Unlike energy, matter is recycled in ecosystems. You can see how in **Figure** 18.9.

- Decomposers release nutrients when they break down dead organisms.
- The nutrients are taken up by plants through their roots.
- The nutrients pass to primary consumers when they eat the plants.
- The nutrients pass to higher level consumers when they eat lower level consumers.
- When living things die, the cycle repeats.

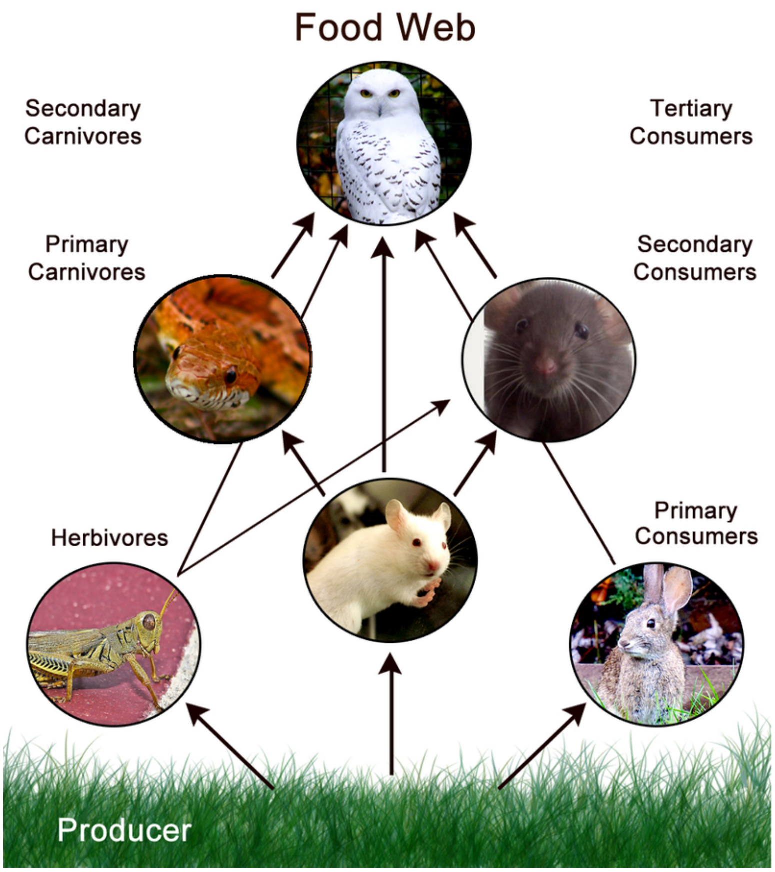

FIGURE 18.8

The owl in this food web consumes at two different levels. What are they?

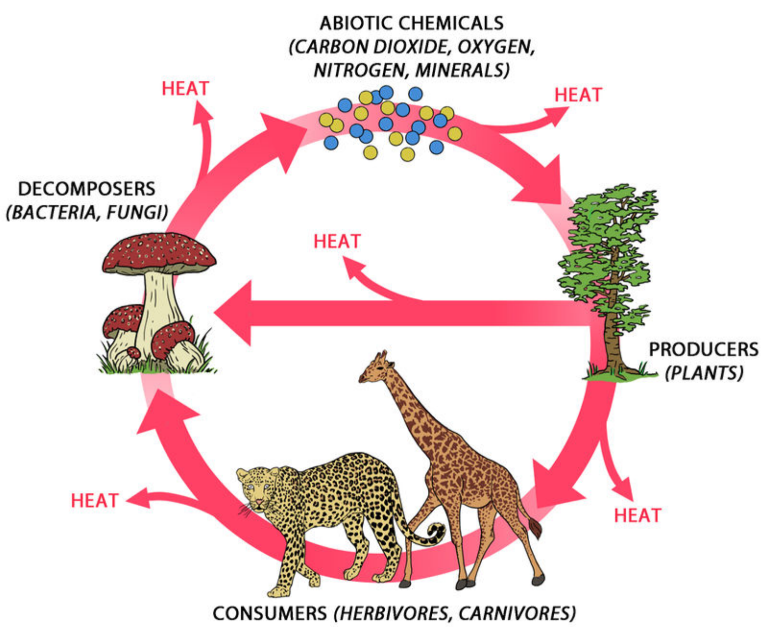

FIGURE 18.9

This diagram shows two cycles. One is the cycle of energy, the other is the cycle of matter. Compare the two cycles. Do you see how the Sun keeps adding energy? That's because energy is lost at each step of the cycle. Matter doesn't have to be added. Can you explain why?

Lesson Summary

- An ecosystem is a group of living things and their environment. It is made up of both living and nonliving things.
- Abiotic factors are the nonliving parts of ecosystems. They include air, soil, and other things organisms need. They determine which organisms — and how many of them — can live in an ecosystem.
- Biotic factors are the living parts of ecosystems. They include species of living things.
- All ecosystems have organisms that play the same roles. They all have producers and consumers.
- All living things need energy. Most ecosystems get energy from the Sun. Producers use the energy to make food. They pass some of the energy to consumers. Food chains and food webs show how energy flows through ecosystems.
- Living things also need matter. Unlike energy, matter is recycled in ecosystems.

Lesson Review Questions

Recall

1. Define ecosystem. Give two examples.

2. List four abiotic factors in ecosystems.

3. Identify three types of consumers, based on what they eat.

4. Give an example of each of these types of organisms: predator, scavenger, and decomposer.

5. What is a nutrient?

Apply Concepts

6. Look at the plants in **Figure** 18.2. Describe their habitat and niche.

7. Draw a food chain that consists of the following organisms: fox, grass, mountain lion, and rabbit. Label each living thing with its role in the food chain. Show how energy enters the food chain.

Think Critically

8. Explain how these concepts are related: species, population, and community.

9. Compare and contrast the two types of producers.

Points to Consider

In this lesson, you read that matter is recycled in ecosystems. You already know how water is recycled. Its cycle includes living things, the air, and the oceans. In the next lesson, you'll read about the cycles of two important nutrients, starting with carbon.

- Can you predict how carbon cycles?
- Do you think carbon cycles between living and nonliving things?

18.2 Cycles of Matter

Lesson Objectives

- Explain why carbon is important to life.
- Outline the carbon cycle.
- Give an overview of the nitrogen cycle.

Vocabulary

- carbon cycle
- dead zone
- nitrogen cycle

Introduction

Did you know that carbon is the basis of life on Earth? Living things consist mainly of carbon. Carbon compounds also control life processes. Your own body is mostly carbon. But do you know what carbon is?

The Element Carbon

Carbon is an element. By itself, it's a black solid. You can see a lump of carbon in **Figure** 18.10. Carbon is incredibly important because of what it makes when it combines with many other elements. Carbon can form a wide variety of substances. For example, in the air, carbon combines with oxygen to form the gas carbon dioxide.

FIGURE 18.10
This piece of carbon looks like a lump of coal. Coal is mostly carbon.

In living things, carbon combines with several other elements. For example, it may combine with nitrogen and hydrogen. Then it forms compounds such as sugars and proteins. How do living things get the carbon they need? Carbon moves through ecosystems in the carbon cycle.

The Carbon Cycle

In the **carbon cycle**, carbon moves through living and nonliving things. Carbon actually moves through two cycles that overlap. One cycle is mainly biotic; the other cycle is mainly abiotic. Both cycles are shown in **Figure** 18.11.

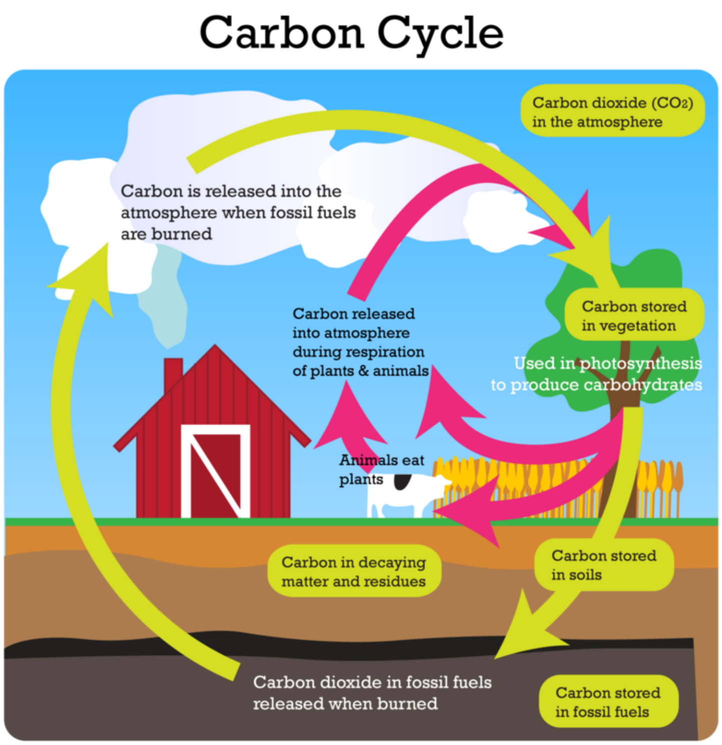

FIGURE 18.11
Carbon changes form as it moves through its cycle. Follow carbon through the diagram as you read about the cycle below.

How Carbon Cycles Through Living Things

Producers such as plants or algae use carbon dioxide in the air to make food. The organisms combine carbon dioxide with water to make sugar. They store the sugar as starch. Both sugar and starch are carbohydrates. Consumers get carbon when they eat producers or other consumers.

Carbon doesn't stop there. Living things get energy from food in a process called respiration. This releases carbon dioxide back into the atmosphere. The cycle then repeats.

How Carbon Cycles Through Nonliving Things

Carbon from decaying organisms enters the ground. Some carbon is stored in the soil. Some carbon may be stored underground for millions of years. This will form fossil fuels. When volcanoes erupt, carbon from the mantle is released as carbon dioxide into the air. Producers take in the carbon dioxide to make food. Then the cycle repeats.

The oceans also play an important role in the carbon cycle. Ocean water absorbs carbon dioxide from the air. In fact, the oceans contain 50 times more carbon than the atmosphere. Much of the carbon sinks to the bottom of the oceans, where it may stay for hundreds of years.

Human Actions and the Carbon Cycle

Human actions are influencing the carbon cycle. Burning of fossil fuels releases the carbon dioxide that was stored in ancient plants. Carbon dioxide is a greenhouse gas and is a cause of global warming.

Forests are also being destroyed. Trees may be cut down for their wood, or they may be burned to clear the land for farming. Burning wood releases more carbon dioxide into the atmosphere. You can see how a tropical rainforest was cleared for farming in **Figure** 18.12. With forests shrinking, there are fewer trees to remove carbon dioxide from the air. This makes the greenhouse effect even worse.

FIGURE 18.12
Large parts of this Amazon rainforest have been cleared to grow crops. How does this affect the carbon cycle?

The Nitrogen Cycle

Living things also need nitrogen. Nitrogen is a key element in proteins. Like carbon, nitrogen cycles through ecosystems. You can see the **nitrogen cycle** in **Figure** 18.13.

Fixing Nitrogen

Air is about 78 percent nitrogen. Decomposers release nitrogen into the air from dead organisms and their wastes. However, producers such as plants can't use these forms of nitrogen. Nitrogen must combine with other elements before producers can use it. This is done by certain bacteria in the soil. It's called "fixing" nitrogen.

Human Actions and the Nitrogen Cycle

Nitrogen is one of the most important nutrients needed by plants. That's why most plant fertilizers contain nitrogen. Adding fertilizer to soil allows more plants to grow. As a result, a given amount of land can produce more food. So far, so good. But what happens next?

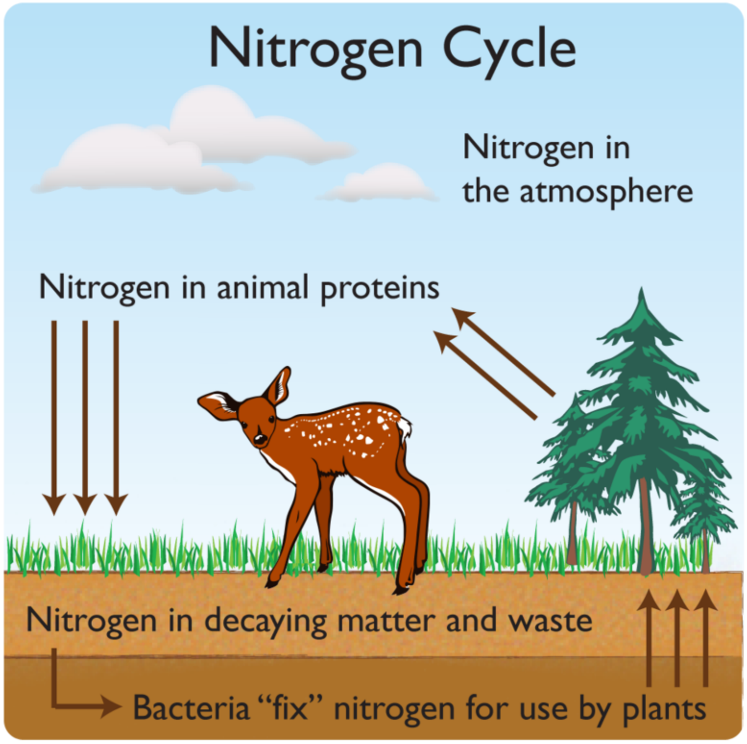

FIGURE 18.13
The nitrogen cycle includes air, soil, and living things.

Rain dissolves fertilizer in the soil. Runoff carries it away. The fertilizer ends up in bodies of water, from ponds to oceans. The nitrogen is a fertilizer in the water bodies. Since there is a lot of nitrogen it causes algae to grow out of control. **Figure** 18.14 shows a pond covered with algae. Algae may use up so much oxygen in the water that nothing else can grow. Soon, even the algae die out. Decomposers break down the dead tissue and use up all the oxygen in the water. This creates a dead zone. A **dead zone** is an area in a body of water where nothing grows because there is too little oxygen. There is a large dead zone in the Gulf of Mexico. You can see it **Figure** 18.14.

Lesson Summary

- Carbon is an element. Carbon is the basis of all life on Earth. Since carbon can combine with many other elements it forms a variety of different substances.
- Carbon moves through ecosystems in two cycles that overlap. In the biotic cycle, it moves between living things and the air. In the abiotic cycle, it moves between the air, ground, and oceans. By burning fossil fuels, humans have increased the amount of carbon dioxide in the air.
- Living things also need nitrogen. It cycles between the air, soil, and living things. By using fertilizers, humans have increased the amount of nitrogen in bodies of water.

Lesson Review Questions

Recall

1. Describe carbon.

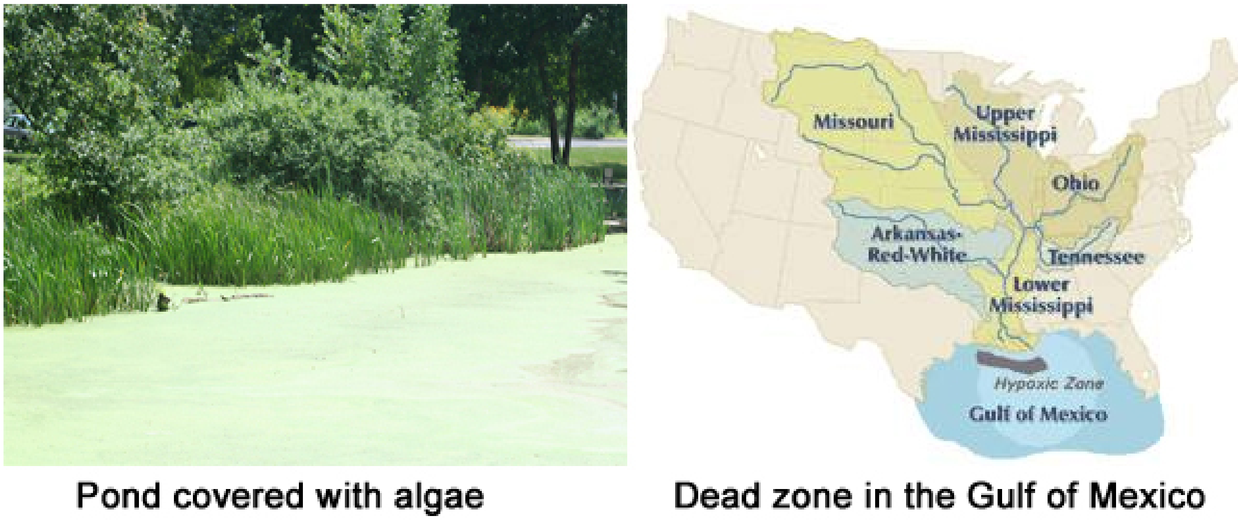

FIGURE 18.14

Effects of Too Much Nitrogen. The pond on the left is covered with algae because of fertilizer in the water. The red-shaded area in the map on the right is a dead zone in the Gulf of Mexico. It's called the hypoxic ("low oxygen") zone in the figure. The U.S. states outlined on the map have rivers that drain into the Gulf of Mexico. The rivers carry fertilizer from these areas into the Gulf. Pond Covered with Algae; Dead Zone in the Gulf of Mexico.

2. State why carbon is important to life.
3. Describe the biotic carbon cycle.
4. Outline the abiotic carbon cycle.
5. Describe how human actions have affected the carbon cycle.

Apply Concepts

6. How could you model the nitrogen cycle? Think of a creative way and describe it.

7. Look at the colorful organisms in **Figure** 18.15. Explain how they are involved in both biotic and abiotic carbon cycles.

Think Critically

8. Dead zones occur in many places around the world. They usually occur where rivers flow into oceans. Explain why.

Points to Consider

In this lesson, you read how human actions influence the carbon and nitrogen cycles. Human actions influence many natural processes. The influence may be great. One reason is that there are so many people on the planet.

FIGURE 18.15

- Do you know how many people live in the world today?
- Why has the human population grown so large?

18.3 The Human Population

Lesson Objectives

- Explain how populations grow.
- Describe how the human population has grown.
- State how the human population affects the environment.

Vocabulary

- carrying capacity
- demographic transition
- green revolution
- population growth rate (*r*)
- sustainable development

Introduction

Right now, there are almost 7 billion people in the world. As you read this sentence, at least three more people will be added. Think about that for second or so, and there's another three. You can actually watch the number of people increase, second by the second, at this link: http://www.intmath.com/Exponential-logarithmic-functions/world-population-live.php

Why is the human population growing so fast? Has it always grown this fast? What causes populations to grow? In this lesson, you'll find answers to all these questions.

How Populations Grow

A population usually grows when it has what it needs. If there's plenty of food and other resources, the population will get bigger. Look at **Table** 18.1. It shows how a population of bacteria grew. A single bacteria cell was added to a container of nutrients. Conditions were ideal. The bacteria divided every 30 minutes. After just 10 hours, there were more than a million bacteria! Assume the bacteria population keeps growing at this rate. How many bacteria will there be at 10.5 hours? Or at 12 hours?

TABLE 18.1: Growth of a Bacterial Population

Time (hours)	Number of Bacteria
0	1
0.5	2

TABLE 18.1: (continued)

Time (hours)	Number of Bacteria
1.0	4
1.5	8
2.0	16
2.5	32
3.0	64
3.5	128
4.0	256
4.5	512
5.0	1,024
5.5	2,048
6.0	4,096
6.5	8,192
7.0	16,384
7.5	32,768
8.0	65,536
8.5	131,072
9.0	262,144
9.5	524,288
10	1,048,576

Population Growth Rate

The **population growth rate** is how fast a population is growing. The letter r stands for the growth rate. The growth rate equals the number of new members added to the population in a year for each 100 members already in the population. The growth rate includes new members added to the population and old members removed from the population. Births add new members to the population. Deaths remove members from the population. The formula for population growth rate is:

$r = b - d$, where

b = birth rate (number of births in 1 year per 100 population members)
d = death rate (number of deaths in 1 year per 100 population members)

If the birth rate is greater than the death rate, r is positive. This means that the population is growing bigger. For example, if $b = 10$ and $d = 8$, $r = 2$. This means that the population is growing by 2 individuals per year for every 100 members of the population. This may not sound like much, but it's a fairly high rate of growth. A population growing at this rate would double in size in just 35 years!

If the birth rate is less than the death rate, r is negative. This means that the population is becoming smaller. What do you think might cause this to happen?

Carrying Capacity

A population can't keep growing bigger and bigger forever. Sooner or later, it will run out of things it needs. For a given species, there is a maximum population that can be supported by the environment. This maximum is called the **carrying capacity**. When a population gets close to the carrying capacity, it usually grows more slowly. You can see this in **Figure** 18.16. When the population reaches the carrying capacity, it stops growing.

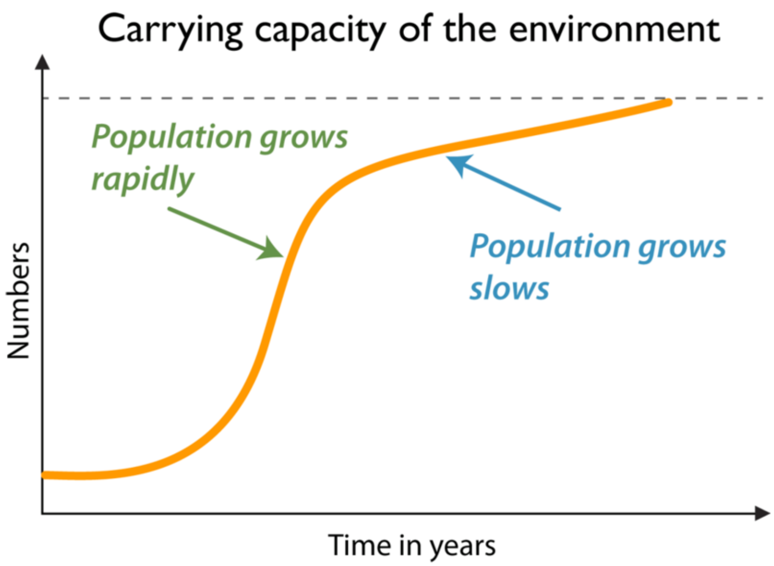

FIGURE 18.16
A population can't get much larger than the carrying capacity. What might happen if it did?

Human Population Growth

Figure 18.17 shows how the human population has grown. It grew very slowly for tens of thousands of years. Then, in the 1800s, something happened to change all that. The human population started to grow much faster.

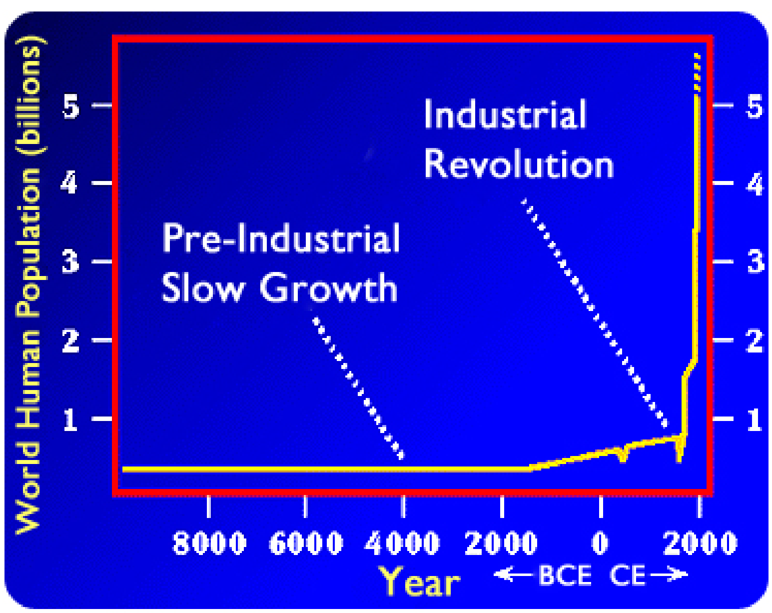

FIGURE 18.17
Growth of the human population. Until recently, the human population grew very slowly.

The Demographic Transition

The industrial revolution is what happened. The industrial revolution began in the late 1700s in Europe, North America, and a few other places. In these places, the human population grew faster. While there had always been a lot of births, the population grew because the death rate fell. It fell for several reasons:

1. New farm machines were invented. They increased the amount of food that could be produced. With more food, people were healthier and could live longer.
2. Steam engines and railroads were built. These machines could quickly carry food long distances. This made food shortages less likely.
3. Sanitation was improved. Sewers were dug to carry away human wastes (see **Figure** 18.18). This helped reduce the spread of disease.

FIGURE 18.18

Digging a London sewer (1840s). Before 1800, human wastes were thrown into the streets of cities such as London. In the early 1800s, sewers were dug to carry away the wastes.

With better food and less chance of disease, the death rate fell. More children lived long enough to reach adulthood and have children of their own. As the death rate fell, the birth rate stayed high for a while. This caused rapid population growth. However, the birth rate in these countries has since fallen to a rate close to that of the low death rate.

The result was slow population growth once again. These changes are called the **demographic transition**.

Recent Population Growth

More recently, the death rate has fallen because of the availability of more food and medical advances:

- A **green revolution** began in the mid 1900s. New methods and products increased how much food could be grown. For example, chemicals were developed that killed weeds without harming crops. Pesticides were developed that killed pests that destroyed crops.
- Vaccinations were developed that could prevent many diseases (see **Figure** 18.19). Antibiotics were discovered that could cure most infections caused by bacteria. Together, these two advances saved countless lives.

FIGURE 18.19
This child is getting a polio vaccine. He will never get sick with polio, which could save his live or keep him from becoming crippled.

Today in many countries, death rates have gone down but birth rates remain high. This means that the population is growing. **Figure** 18.20 shows the growth rates of human populations all over the world.

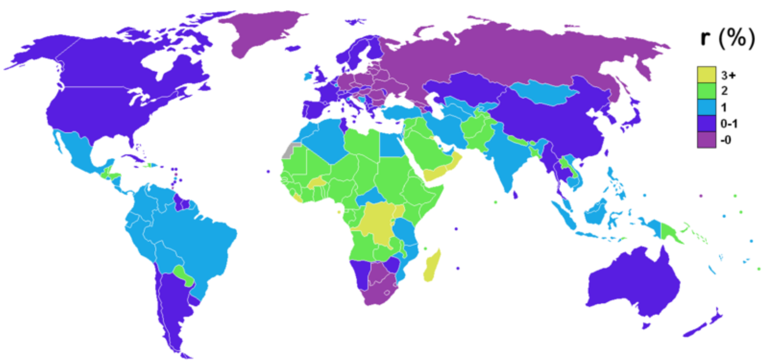

FIGURE 18.20
World population growth rates. Is the population growing faster in the wealthiest countries or the poorest countries?

Future Population Growth

The growth of the human population has started to slow down. You can see this in **Figure** 18.21. It may stop growing by the mid 2000s. Scientists think that the human population will peak at about 9 billion people. What will need to change for the population to stop growing then?

Human Population and the Environment

Are 9 billion people the human carrying capacity? It looks that way in **Figure** 18.21. But some people think there are too many of us already. That's because we are harming the environment.

- Supplying all those people with energy creates a lot of pollution. For example, huge oil spills have killed millions of living things.

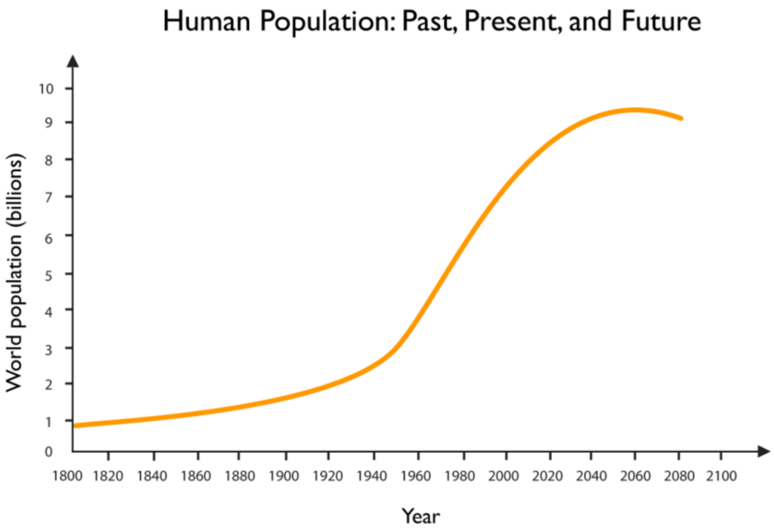

FIGURE 18.21
Compare this graph with the graph of the carrying capacity. What do you think is the carrying capacity of the human population?

- Burning fossil fuels pollutes the air. This also increases causes global warming.
- Fossil fuels and other resources are being used up. We may run out of oil by the mid 2000s. Many other resources will run out sooner or later.
- People are killing too many animals for food. For example, some of the best fishing grounds in the oceans have almost no fish left.
- People have destroyed many habitats. For example, they've drained millions of acres of wetlands. Wetlands have a great diversity of species. As wetlands shrink, species go extinct.
- People have allowed alien or invasive species - species originally from a different area - to invade new habitats. Often, the aliens have no natural enemies in their new home. They may drive native species extinct. **Figure** 18.22 gives an example.

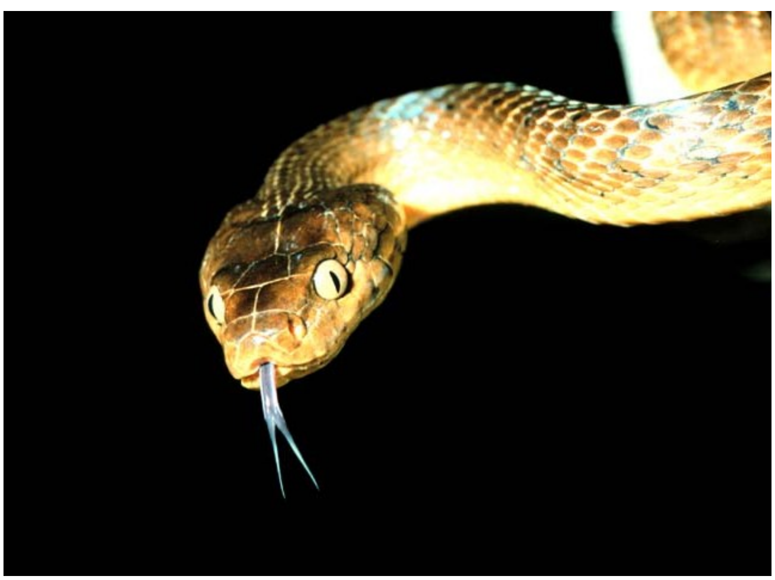

FIGURE 18.22
In the mid 1900s, Australian tree snakes invaded Guam and other islands in the Pacific. The snakes "stowed away" on boats and planes. Tree snakes had no natural enemies on the islands. Their populations exploded and they drove several island species extinct.

People themselves are also affected by the large size of the human population. A minority of people use most of the world's energy and other resources. Many other people lack resources. Many don't have enough to eat or live with the threat of hunger. Many also do not have safe, clean water. Some people live in crowded, run-down housing or something that is barely considered housing.

Sustainable Development

Is it possible for all the world's people to live well and still protect the planet? That's the aim of **sustainable development**. Its goals are to:

1. Distribute resources fairly.
2. Conserve resources so they won't run out.
3. Use resources in ways that won't harm ecosystems.

A smaller human population may be part of the solution. Better use of resources is another part. For example, when forests are logged, new trees should be planted. Everyone can help in the effort. What will you do?

Lesson Summary

- Populations usually grow bigger when they have what they need. How fast they grow depends on birth and death rates. They grow more slowly as they get close to the carrying capacity. This is the biggest population the environment can support.
- Human population growth was slow until the 1800s. Both birth and death rates were high. Then, the death rate started to fall. In industrial countries, the birth rate soon fell as well. However, in many other places, the birth rate is still high. As a result, the human population is growing rapidly. It may reach 9 billion by the mid 2000s.
- The human population is already harming the environment. Many people don't get enough resources. They may lack shelter, food, or clean water.
- Sustainable development is needed. This means using resources in such a way that they won't run out and the planet won't be harmed.

Lesson Review Questions

Recall

1. Define carrying capacity.

2. Describe how the human population grew up until the 1800s.

3. List two reasons the death rate fell in industrial countries in the 1800s.

4. What was the green revolution? When did happen? How did it affect the human population?

5. How is the human population harming the environment?

Apply Concepts

6. Compare the three populations in the **Table** 18.2. Which one is growing fastest? Explain your answer.

TABLE 18.2: Population Data for Question 6

Population	Birth Rate (per 100 people)	Death rate (per 100 people)
A	14	3
B	16	6
C	18	8

7. Draw a graph of population growth for North America. It should show how the rate of growth changed during the demographic transition.

Think Critically

8. Do you think the human population is already too big? Has it reached its carrying capacity? Why or why not?

9. What could you do to help sustainable development?

Points to Consider

In this chapter, you read how humans are harming the environment. For example, we are quickly using up many natural resources. Soil is one of our most precious natural resources. It takes a very long time to form. But it can be washed away in a single rainstorm.

- How do you think human actions are affecting the soil?
- What can people do to protect this important resource?

18.4 References

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6. Rabbit: Dan Perry; Mosquito: Courtesy of James Gathany, CDC; Pitcher plant: Tim Mansfield; Hyena: Demetrius John Kessy (Flickr:Diamond Glacier Adventures Ltd); Dung Beetle: Teddy Fotiou (Flickr:EpochCatcher); Mushrooms: Flickr:The_Gut. Rabbit: http://www.flickr.com/photos/golf_pictures/263989457/; Mosquito: http://commons.wikimedia.org/wiki/File:CDC-Gathany-Aedes-albopictus-1.jpg; Pitcher plants: http://www.flickr.com/photos/timbomb/406235908/; Hyena: http://www.flickr.com/photos/diamondglacieradventures/5613845130/; Dung Beetle: http://www.flickr.com/photos/epochcatcher/8227083897/; Mushrooms: http://www.flickr.com/photos/frogbelly/8084143639/ . Rabbit: CC BY 2.0; Mosquito: Public Domain; Pitcher plant: CC BY 2.0; Hyena: CC BY 2.0; Dung Beetle: CC BY 2.0; Mushrooms: CC BY 2.0
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CHAPTER 19 MS Human Actions and the Land

Chapter Outline

Thick clouds of dust rolled over the land. They blocked the Sun and turned day into night. The land was ruined, and the dust made people sick. Many died when dust filled their lungs. Thousands fled the area, never to return.

It sounds like fiction. Too bad it's not. This photo was taken in Texas in the 1930s. Scenes like this happened in many places, not only in Texas, but also in Oklahoma and other southern Plains states. The area became known as the Dust Bowl. What caused this calamity? Plowing had broken up the natural prairie sod and turned over the bare soil. Lack of rain left the bare soil dry as dust. High winds carried the soil away. A lot of the soil blew all the way to the East Coast and ended up in the Atlantic Ocean. Billions of tons of soil were lost, much of it in just a few days.

How did this happen? Why were people so careless with the soil? How could the Dust Bowl have been prevented? In this chapter, you'll find out.

Courtesy of NOAA George E. Marsh Album. www.photolib.noaa.gov/htmls/theb1365.htm. Public Domain.

19.1 Loss of Soil

Lesson Objectives

- Identify human actions that increase soil erosion.
- List ways to reduce soil loss.

Vocabulary

- contour cropping
- cover crop
- no-till planting
- strip cropping
- terracing
- windbreak

Introduction

It may "just" be dirt, but soil is one of our most important resources. We would starve without it. In fact, human beings — and most other land organisms — would never have evolved if it weren't for soil. That's because humans and other consumers rely on plants for food, and plants need soil. Soil anchors plant roots and provides them with water and nutrients.

People have always depended on soil. But for many generations, they took soil for granted. They didn't realize that their actions would cause so much soil erosion. The Dust Bowl dramatically showed people what being careless with soil could do.

Human Actions and Soil Erosion

Runoff carved channels in the soil in **Figure** 19.1. Running water causes most soil erosion, but wind can carry soil away too. What humans do to soil makes it more or less likely to be eroded by wind or water. Human actions that can increase soil erosion are described below.

Growing Crops

The photos in **Figure** 19.2 show how farming practices can increase soil erosion. Plant roots penetrate the soil and keep it from eroding. Plowing turns over bare soil and cuts through plant roots. Bare soil is exposed to wind and water. In the past, farmers always plowed fields before planting. Some farmers now use no-till farming, which does not disturb the soil as much.

FIGURE 19.1
Runoff carried away the bare soil in this field. Why do you think the soil bare to begin with?

The problem doesn't stop with plowing. Crops are usually planted in rows, with bare soil in between the rows. In places where crops grow only during part of the year, the land may be bare for a few months.

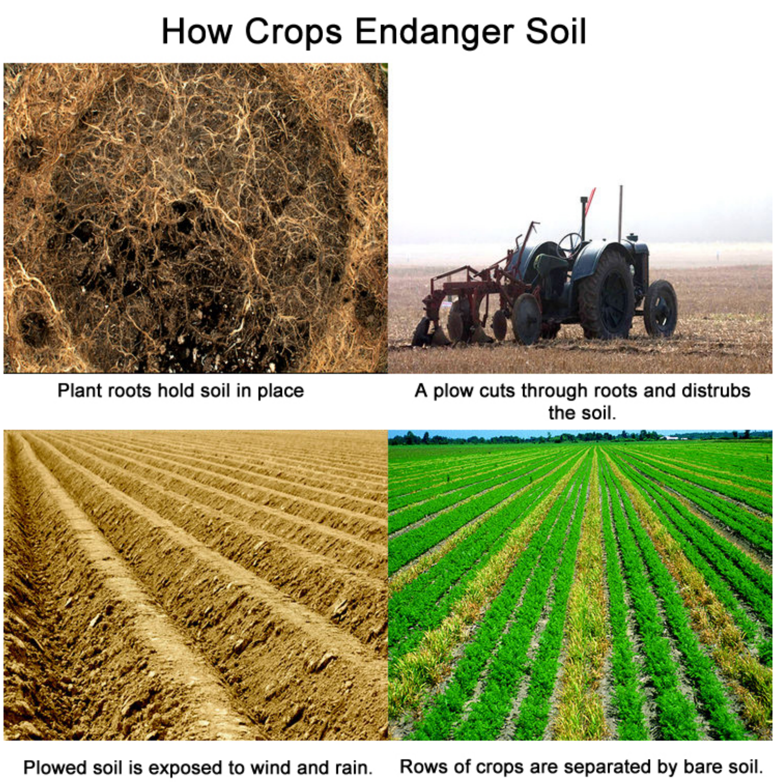

FIGURE 19.2
Farming leaves some soil exposed to erosion.

Grazing Animals

As you can see in **Figure** 19.3, some grazing animals, especially sheep and goats, eat grass right down to the roots. They may even pull the grass entirely out of the ground. Grazing animals can kill the grass or thin it out so much that it offers little protection to the soil. If animals are kept in the same place too long, the soil may become completely bare. The bare soil is easily eroded by wind and water.

FIGURE 19.3
Sheep and goats can damage plants and leave the soil bare.

Logging, Mining, and Construction

Other human actions that put soil at risk include logging, mining, and construction. You can see examples of each in **Figure** 19.4.

- When forests are cut down, the soil is suddenly exposed to wind and rain. Without trees, there is no leaf litter to cover the ground and protect the soil. When leaf litter decays, it adds humus and nutrients to the soil.
- Mining and construction strip soil off the ground and leave the land bare.
- Paved roads and parking lots prevent rainwater from soaking into the ground. This increases runoff and the potential for soil erosion.

Recreation

Even things that people do for fun can expose soil to erosion. For example, overuse of hiking trails can leave bare patches of soil. Off-road vehicles cause even more damage. You can see examples of this in **Figure** 19.5.

Preventing Soil Erosion

Soil is a renewable resource, but it can take thousands of years to form. That's why people need to do what they can to prevent soil erosion.

Farming Methods that Reduce Soil Erosion

The Dust Bowl taught people that soil could be lost by plowing and growing crops. This led to the development of new ways of farming that help protect the soil. Some of the methods are described in **Figure** 19.6.

FIGURE 19.4
Logging, mining, construction, and paving surfaces are some of the ways that soil erosion increases.

FIGURE 19.5
What's fun for people may be bad for soil. Off-road vehicles can destroy plants and leave the ground bare. This sets up the soil for erosion.

Other Ways to Reduce Soil Erosion

There are several other ways to help prevent soil loss. Some of them are shown in **Figure** 19.7.

- Prevent overgrazing. Frequently move animals from field to field. This gives the grass a chance to recover.
- Avoid logging steep hillsides. Cut only a few trees in any given place. Plant new trees to replace those that are cut down.
- Reclaim mine lands. Save the stripped topsoil and return it to the land. Once the soil is in place, plant trees and other plants to protect the bare soil.
- Use barriers to prevent runoff and soil erosion at construction sites. Plant grass to hold the soil in place.

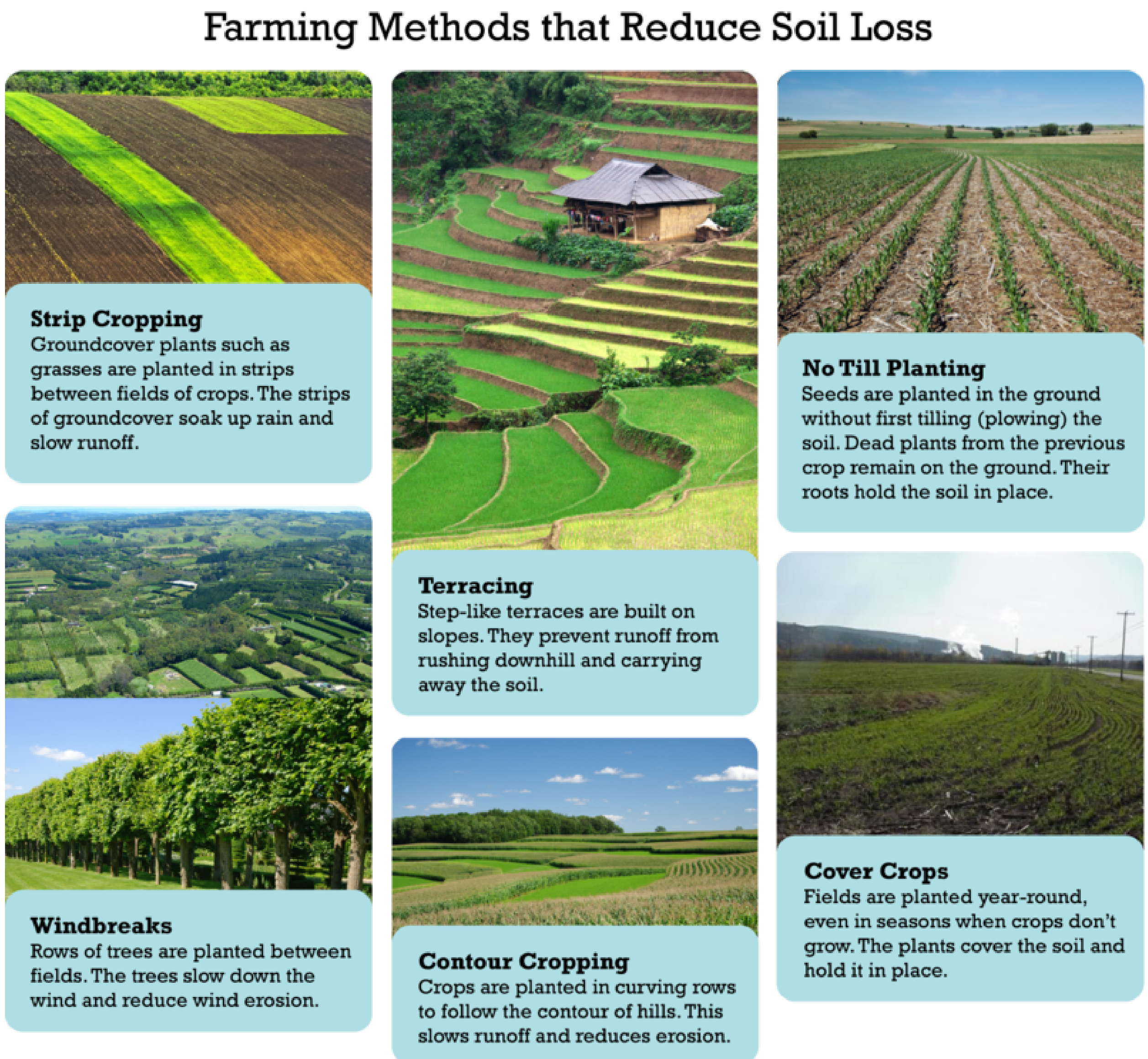

FIGURE 19.6
There are many farming methods that help prevent soil erosion.

- Develop paving materials that absorb water and reduce runoff.
- Restrict the use of off-road vehicles, especially in hilly areas.

Lesson Summary

- Many human actions make it easier for wind and water to carry away soil. They include plowing, logging, construction, and even some types of recreation.

FIGURE 19.7
Taking steps to control erosion can help save soil.

- Farming methods such as strip cropping and terracing help prevent soil erosion. Other ways to protect soil include replanting forests and reclaiming mine land.

Lesson Review Questions

Recall

1. How do plants help prevent soil loss?
2. How does logging endanger soil?
3. Describe the effects of construction on soil.
4. How do paved parking lots contribute to soil loss?
5. What is terracing? How does it reduce soil erosion?
6. What are cover crops, and why are they grown?

Apply Concepts

7. Off-road vehicles are popular in Pleasant Valley. Many people like to ride on a nearby grassy hillside. Write a letter to the editor of the Pleasant Valley Newspaper urging residents to protect the soil on the hillside. Your letter should explain why soil is important and why the soil on the hillside is at risk. Describe a better place to ride that is less likely to put soil at risk.

8. Look at **Figure** 19.8. Identify two farming methods that have been used to reduce soil loss. How do they help prevent erosion?

FIGURE 19.8

Think Critically

9. Explain why plowing before planting can lead to soil loss. What is the alternative? Why does it reduce soil loss?

Points to Consider

Increasing soil erosion isn't the only way that human actions can affect the land. Many human actions also pollute the land.

- What is pollution?
- What human actions might pollute the land?

19.2 Pollution of the Land

Lesson Objectives

- Describe the disaster of Love Canal and what it taught us.
- Identify hazardous waste.
- List ways to control hazardous waste.

Vocabulary

- hazardous waste
- pollution

Introduction

Disposing of industrial waste is one way that human actions pollute the land. This became clear more than 30 years ago in Love Canal, a neighborhood in Niagara Falls, New York. Love Canal may sound lovely, but it is not. Love Canal was and is a disaster. Love Canal been called one of the worst environmental disasters of all time.

The Story of Love Canal

Love Canal gained worldwide attention in the late 1970s when the press started covering its story. The story is outlined below and illustrated in **Figure** 19.9.

The Love Canal Disaster

The Love Canal disaster actually began back in the mid 1900s. The disaster continues even today.

- Starting in the early 1940s, a big chemical company put thousands of barrels of chemical waste into an old canal. Over the next 10 years, the company dumped almost 22,000 tons of chemicals into the ground!
- In the early 1950s, the company covered over the barrels in the canal with soil. Then they sold the land to the city for just a dollar. The city needed the land in order to build an elementary school. The company warned the city that toxic waste was buried there. But they thought the waste was safe. The school and hundreds of homes were also built over the old canal.
- As it turned out, the cheap price was no bargain. Chemicals started leaking from the barrels. Chemicals seeped into basements. Chemicals bubbled up to the surface of the ground. In some places, plants wouldn't even grow on the soil.

FIGURE 19.9
What can we learn from the story of Love Canal?

- People noticed bad smells. Many got sick, especially the children. Residents wanted to know if the old chemicals were the cause. But they had a hard time getting officials to listen. So they demonstrated and demanded answers.
- Finally, the soil was tested and was found to be contaminated with harmful chemicals. For example, it contained a lot of lead and mercury. Both can cause permanent damage to the human nervous system.
- The school was closed. More than 200 homes were evacuated. Much of the Love Canal neighborhood was bulldozed away. The area had a massive clean-up effort. The cleanup cost millions of dollars.
- More than three decades later, much of Love Canal is still too contaminated to be safe for people.

Learning from Love Canal

Love Canal opened people's eyes to toxic waste burial. They realized there must be other "Love Canals" all over the country. Thousands of contaminated sites were found. The Superfund Act was passed in 1980. The law required that money be set aside for cleanup of toxic waste sites, like the Elizabeth Copper Mine in Vermont (see the far-right image in **Figure** 19.9). The law also required safer disposal of hazardous waste in the future.

Pollution by Hazardous Waste

Love Canal highlighted the problem of pollution by hazardous waste. **Hazardous waste** is any waste that is dangerous to the health of people or the environment. It may be dangerous because it is toxic, corrosive, flammable, or explosive.

- Toxic waste is poisonous. Toxic waste may cause cancer or birth defects in people. It may also harm other living things.

- Corrosive waste is highly reactive with other substances. Corrosive waste may cause burns or destroy other materials that it touches.
- Flammable waste can burn easily. It may also give off harmful fumes when it burns.
- Explosive waste is likely to explode. The risk of explosion may be greater if the waste is mixed with other substances.

Table 19.1 shows some examples of hazardous waste. Look closely. Are any of these examples lurking around your home?

TABLE 19.1: It's not just chemical companies that produce hazardous waste. We all do.

Example	Description
	Cars contain toxic fluids such as brake fluid. The fluids may also be corrosive and flammable. This photo shows one way the fluids can end up in the ground.
	Cars use gas and oil. These materials are toxic and flammable. They pollute the land when they leak or spill.
	Batteries contain toxic and corrosive materials. People often toss them in the trash, but they should be disposed of properly.
	Electronics, such as old computers, contain toxic chemicals. They may be sent to landfills where the toxic materials end up in the ground.
	Medical waste can contain many hazards: Human body fluids may cause disease; old thermometers may contain toxic mercury; and pharmaceuticals may be toxic to people and other living things.

TABLE 19.1: (continued)

Example	Description
	Paints can be both toxic and flammable. Paints may spill on the ground or be thrown improperly in the trash.
	Chemicals are applied to farm fields and lawns. They include fertilizers, herbicides, and pesticides. Many of these chemicals are toxic to people and other animals.

Controlling Hazardous Waste

The greatest source of hazardous waste is industry. Agriculture is another major source. Even households produce a lot of hazardous waste.

Hazardous Waste from Industry and Agriculture

Thanks to the lessons of Love Canal, the U.S. now has laws requiring the safe disposal of hazardous waste. Companies must ensure that hazardous waste is not allowed to enter the environment in dangerous amounts. They must also protect their workers from hazardous materials. For example, they must provide employees with the proper safety gear and training (see **Figure** 19.10).

Household Hazardous Waste

Cleaning products, lawn chemicals, paints, batteries, motor oil —these are just some of the many hazardous materials that may be found in households. You might think that a household doesn't produce enough hazardous waste to worry about. But when you add up all the waste from all the households in a community, it's a different story. A city of just 50,000 people might produce more than 40 tons of hazardous waste each year! Clearly, how households deal with hazardous waste matters.

What can your family do? Reduce, reuse, recycle, or properly dispose of the wastes.

1. Reduce the amount of hazardous products you buy. For example, if you only need a quart of paint for a job, don't buy a gallon.
2. Use less hazardous products if you can. For example, clean windows with vinegar and water instead of toxic window cleaners.
3. Reuse products if it's safe to do so. For example, paint thinner that has been used to clean paint brushes can be strained and reused.

FIGURE 19.10
This agricultural worker is wearing the proper safety gear to handle a chemical pesticide.

4. Recycle whenever possible. For example, some service stations allow you to drop off used motor oil, car batteries, or tires for recycling.
5. Always properly dispose of hazardous waste. For example, let liquid waste evaporate before placing the container in the trash.

Proper disposal depends on the waste. Many hazardous products have disposal guidelines on the label. That's one reason why you should keep the products in their original containers. The labels also explain how to use the products safely. Follow the instructions to protect yourself and the environment. Most communities have centers for disposing of household hazardous waste (see **Figure** 19.11). Do you know how to dispose of hazardous waste in your community?

FIGURE 19.11
Avoid putting hazardous waste in the household trash. Instead, take it to a hazardous waste collection center.

Lesson Summary

- Love Canal was a major environmental disaster. A company dumped toxic chemical waste in the ground. It contaminated the soil and made people sick. Even after a massive cleanup effort, the ground is still toxic today.
- Love Canal highlighted the problem of pollution by hazardous waste. Pollution is the act of contaminating the environment with waste. Hazardous waste is any waste that is dangerous to the health of people or the environment. It may be toxic, corrosive, flammable, or explosive.
- Laws now require companies to dispose of hazardous wastes safely. Household hazardous waste can be reduced, reused, recycled, or disposed of at community collection centers.

Lesson Review Questions

Recall

1. Describe the Love Canal disaster.
2. What was learned from Love Canal?
3. Define pollution.
4. What is hazardous waste?
5. Some hazardous waste is toxic. What are other ways that hazardous waste can be harmful?
6. What is the greatest source of hazardous waste?
7. Identify three examples of hazardous waste. Include at least one example that is found in the home.

Apply Concepts

8. Create a public service announcement that explains how to control household hazardous waste.

Think Critically

9. Explain why it is important for households to control hazardous waste.

Points to Consider

Besides soil, humans depend on many other natural resources. These other natural resources also must be protected.

- What are some other natural resources?
- What can people do to protect them?

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CHAPTER 20 MS Human Actions and Earth's Resources

Chapter Outline

It was once a mountain. Now it's called the "richest hole in Earth." It produces almost 2 billion dollars worth of metals each year. What is it? It's the Kennecott Copper Mine in Utah. It's the world's biggest open-pit mine. In fact, it's the biggest hole humans have ever dug on Earth's surface. It's so big that it can be seen from space. It's 1.2 kilometers (0.75 miles) deep. If it were a stadium, it could seat more than 9 million people!

Metals such as those from the Kennecott Copper Mine are important natural resources. What other resources do we use? And how do we obtain them? Are metals and other resources in danger of being used up? In this chapter, you'll find out.

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20.1 Use and Conservation of Resources

Lesson Objectives

- Describe how people use natural resources.
- List ways to conserve natural resources.

Vocabulary

- conservation
- natural resource
- precycling

Introduction

A **natural resource** is anything in nature that humans need. Metals and fossil fuels are natural resources. But so are water, sunlight, soil, and wind. Even living things are natural resources.

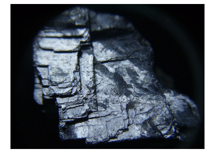
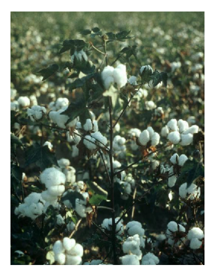
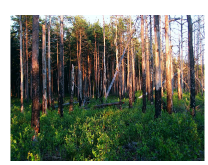
Using Natural Resources

We need natural resources for just about everything we do. We need them for food and clothing, for building materials and energy. We even need them to have fun. **Table** 20.1 gives examples of how we use natural resources. Can you think of other ways we use natural resources?

TABLE 20.1: Use of Natural Resources

Use	Resources	Example
Vehicles 	Rubber for tires from rubber trees Steel frames and other metal parts from minerals such as iron	iron ore 

TABLE 20.1: (continued)

Use	Resources	Example
Electronics 	Plastic cases from petroleum products Glass screens from minerals such as lead	lead ore 
Homes 	Nails from minerals such as iron Timber from trees	spruce timber 
Jewelry 	Gemstones such as diamonds Minerals such as silver	silver ore 
Food 	Sunlight, water, and soil Minerals such as phosphorus	corn seeds in soil 
Clothing 	Wool from sheep Cotton from cotton plants	cotton plants 
Recreation 	Water for boating and swimming Forests for hiking and camping	pine forest 

Some natural resources are renewable. Others are not. It depends in part on how we use them.

Renewable Resources

Renewable resources can be renewed as they are used. An example is timber, which comes from trees. New trees can be planted to replace those that are cut down. Sunlight is a renewable resource. It seems we will never run out of that!

Just because a resource is renewable, it doesn't mean we should use it carelessly. If we aren't careful, we can pollute resources. Then they may no longer be fit for use. Water is one example. If we pollute a water source it may not be usable for drinking, bathing or any other type of use. We can also overuse resources that should be renewable. In this case the resources may not be able to recover. For example, fish are renewable resources. That's because they can reproduce and make more fish. But water pollution and overfishing can cause them to die out if their population becomes too low. **Figure** 20.1 shows another example.

FIGURE 20.1
Forests should be renewable resources. The forest on the left is healthy and is used for recreation. The forest on the right was killed by acid rain.

Nonrenewable Resources

Some resources can't be renewed. At least, they can't be renewed fast enough to keep up with use. Fossil fuels are examples. It takes millions of years for them to form. We are using them up much more quickly. Elements that are used to produce nuclear power are other examples. They include uranium. This element is already rare. Sooner or later, it will run out.

Supplies of non-renewable resources are shrinking. This makes them harder to get. Oil is a good example. Oil reserves beneath land are running out. So oil companies have started to drill for oil far out in the ocean. This costs more money. It's also more dangerous. **Figure** 20.2 shows an oil rig that exploded in 2010. The explosion killed 11 people. Millions of barrels of oil spilled into the water. It took months to plug the leak.

Who Uses Natural Resources?

Rich nations use more natural resources than poor nations. In fact, the richest 20 percent of people use 85 percent of the world's resources. What about the poorest 20 percent of people? They use only 1 percent of the world's resources. You can see this unequal distribution of oil resources in **Figure** 20.3.

Imagine a world in which everybody had equal access to resources. Some people would have fewer resources than they do now. But many people would have more. In the real world, the difference between rich and poor just keeps growing.

FIGURE 20.2
This oil rig was pumping oil from below the ocean floor when it exploded.

More People, More Resources

Every 20 minutes, the human population adds 3,500 more people. More people need more resources. For example, we now use five times more fossil fuels than we did in 1970. The human population is expected to increase for at least 40 years. What will happen to resource use?

Conserving Natural Resources

How can we protect Earth's natural resources? One answer is **conservation**. This means saving resources. We need to save resources so some will be left for the future. We also need to protect resources from pollution and overuse.

When we conserve resources, we also cut down on the trash we produce. Americans throw out 340 million tons of trash each year. We throw out 2.5 million plastic bottles alone —every hour! Most of what we throw out ends up in landfills. You can see a landfill in **Figure** 20.4. In a landfill, all those plastic bottles take hundreds of years to break down. What are the problems caused by producing so much trash? Natural resources must be used to produce the materials. Land must be given over to dump the materials. If the materials are toxic, they may cause pollution.

The Three "R"s

You probably already know about the three "R"s. They stand for reduce, reuse, and recycle. The third "R" —recycle —has caught on in a big way. That's because it's easy. There are thousands of places to drop off items such as aluminum cans for recycling. Many cities allow you to just put your recycling in a special can and put it at the curb.

We haven't done as well with the first two "R"s —reducing and reusing. But they aren't always as easy as recycling. Recycling is better than making things from brand new materials. But it still takes some resources to turn recycled items into new ones. It takes no resources at all to reuse items or not buy them in the first place.

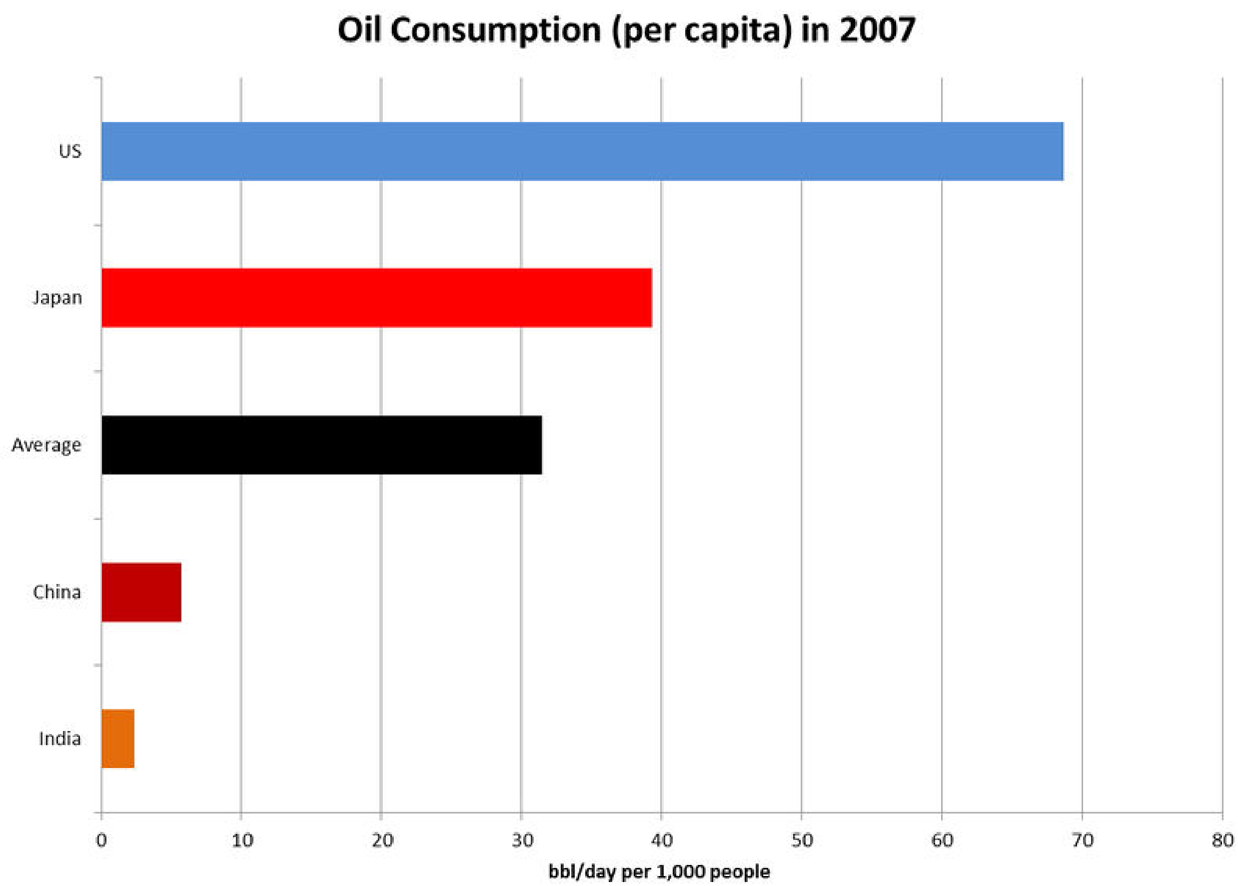


FIGURE 20.3
The U.S. uses more than its share of oil. What if everyone used resources this way? (Note: Per capita means "per person.")

Reducing Resource Use

Reducing resource use means just what it says —using fewer resources. There are lots of ways to reduce our use of resources.

- Buy durable goods. Choose items that are well made so they will last longer. You'll buy fewer items in the long run, so you'll save money as well as resources. That's a win-win!
- Repair rather than replace. Fix your bike rather than buying a new one. Sew on a button instead of buying a new shirt. You'll use fewer resources and save money.
- Buy only what you need. Don't buy a gallon of milk if you can only drink half of it before it spoils. Instead, buy a half gallon and drink all of it. You won't be wasting resources (or money!).
- Buy local. For example, buy local produce at a farmer's market, like the one in **Figure** 20.5. A lot of resources are saved by not shipping goods long distances. Products bought at farmer's markets use less packaging, too!

About a third of what we throw out is packaging. Try to buy items with the least amount of packaging. For example, buy bulk items instead of those that are individually wrapped. Also, try to select items with packaging that can be

FIGURE 20.4
Bulldozers crushes a mountain of trash.

FIGURE 20.5
Buying locally grown produce at a farmer's market saves resources.

reused or recycled. This is called **precycling**. Pop cans and plastic water bottles, for example, are fairly easy to recycle. Some types of packaging are harder to recycle. You can see examples in **Figure** 20.6. If it can't be reused or recycled, it's a waste of resources.

- Many plastics: The recycling symbol on the bottom of plastic containers shows the type of plastic they contain. Numbers 1 and 2 are easier to recycle than higher numbers.
- Mixed materials: Packaging that contains more than one material may be hard to recycle. This carton is made mostly of cardboard. But it has plastic around the opening.

Reusing Resources

Reusing resources means using items again instead of throwing them away. A reused item can be used in the same way by someone else. Or it can be used in a new way. For example, Shana has a pair of jeans she has outgrown. She might give them to her younger sister to wear. Or she might use them to make something different for herself, say, a denim shoulder bag. Some other ideas for reusing resources are shown in **Figure** 20.7.

Recycling Resources

Many things can be recycled. The materials in them can be reused in new products. For example, plastic water bottles can be recycled. The recycled material can be made into t-shirts! Old phone books can also be recycled

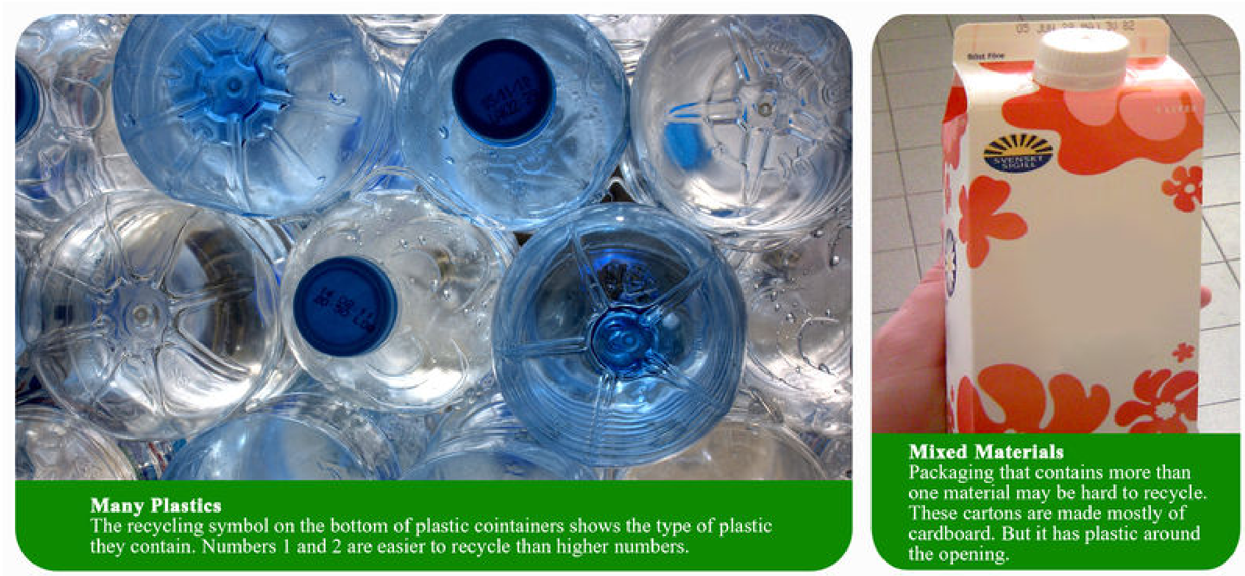


FIGURE 20.6

These types of packaging are hard to recycle. Could you reuse any of them?

and made into textbooks. When you shop for new products, look for those that are made of recycled materials (see **Figure** 20.8). Even food scraps and lawn waste can be recycled. They can be composted and turned into humus for the garden.

At most recycling centers, you can drop off metal cans, cardboard and paper products, glass containers, and plastic bottles. Recycling stations like the one in **Figure** 20.9 are common. Curbside recycling usually takes these items too. Do you know how to recycle in your community? Contact your local solid waste authority to find out. If you don't already recycle, start today. It's a big way you can help the planet!

Lesson Summary

- Natural resources are anything in nature that humans need. Some natural resources are renewable; some are non-renewable. Rich nations use far more natural resources than poor nations. As the human population grows, it will use more resources.
- Conservation means saving resources. To save natural resources, follow the three "R"s: reduce, reuse, and recycle.

Lesson Review Questions

Recall

1. Define natural resource.

FIGURE 20.7
Do you reuse products such as these? Can you think of other ways to reuse resources?

2. Name an item you use each day. What natural resources were used to make it?
3. Contrast resource use in wealthy and poor nations.
4. What is conservation?
5. What is precycling?

Apply Concepts

6. Create a mobile or bulletin board display that shows how to use the three Rs to conserve resources.

FIGURE 20.8
This label shows that the product was made from recycled materials.

FIGURE 20.9
Are there recycling stations like this one where you live?

Think Critically

7. Compare and contrast renewable and non-renewable resources. Give an example of each.
8. Why do we need to use renewable resources carefully?

Points to Consider

Like other resources, we use energy resources in many ways. Energy resources also need to be conserved.

- What are some of the ways we use energy?
- How can we conserve energy?

20.2 Use and Conservation of Energy

Lesson Objectives

- Describe how people use energy.
- List ways to conserve energy.

Vocabulary

Introduction

Everything we do uses energy. From taking a breath to blasting off in a rocket, everything takes energy. And all that energy must come from somewhere!

Using Energy

Think about your typical day. How do you use energy? Do you take a shower when you first get out of bed? What about taking a shower uses energy? It takes energy to heat the water and to pump the water to your home. Do you eat a hot breakfast? Energy is used to cook your food. Do you ride a bus or have someone drive you to school? Motor vehicles need energy from fossil fuels to run.

Energy Use in the U.S.

Figure 20.10 shows the major ways energy is used in the U.S. A lot of energy is used in homes. In fact, more energy is used in homes than in stores and businesses. Even more energy is used for transportation. A lot of fuel is necessary to move people and goods around the country. Industry uses the most energy. Industrial uses account for one-third of all the energy used in the U.S.

Energy Resources

Figure 20.11 shows the energy resources used in the U.S. The U.S. depends mainly on fossil fuels. Petroleum is used more than any other resource. Renewable energy resources, such as solar and wind energy, could provide all the energy we need, but they are not yet widely used in the U.S.

Using Energy to Get Energy

We must use energy to get energy resources. This is true of non-renewable and renewable energy. Getting fossil fuels so that they can be used takes many steps. All of these steps use energy.

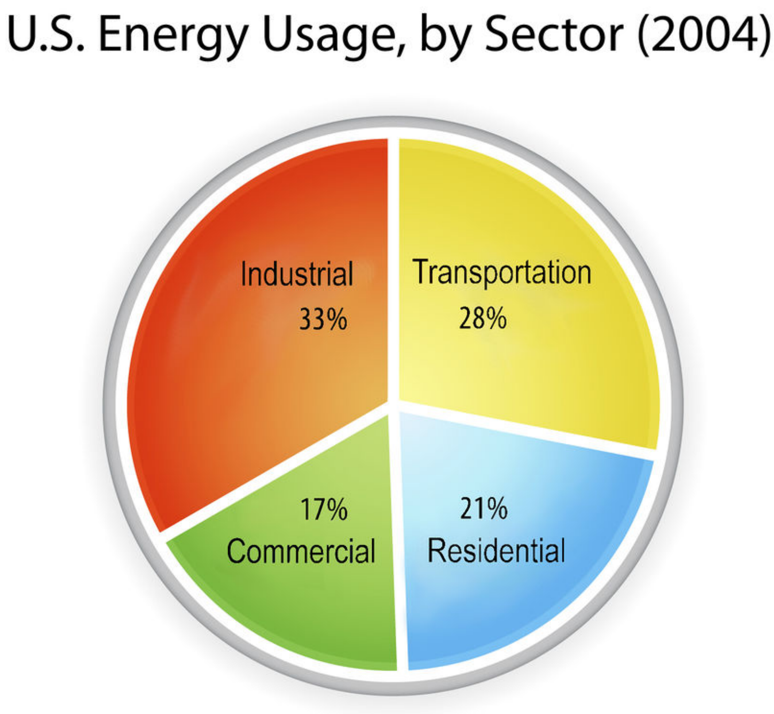


FIGURE 20.10
What percent of energy in the U.S. is used for transportation and in homes?

1. Fossil fuels must be found.
2. The resources must be removed from the ground.
3. These resources need to be refined, some more than others.
4. Fossil fuels may need to be changed to a different form of energy.
5. Energy resources must be transported from where they are produced to where they are sold or used.

Consider petroleum as an example. Oil companies explore for petroleum in areas where they think it might be. When they find it, they must determine how much is there. They must also know how hard it will be to get. If there's enough to make it worthwhile, they will decide to go for it. To extract petroleum, companies they must build huge rigs, like the one in **Figure** 20.12. An oil rig drills deep into the ground and pumps the oil to the surface. The oil is then transported to a refinery. At the refinery, the oil is heated. It will then separate into different products, such as gasoline and motor oil. Finally, the oil products are transported to gas stations, stores, and industries. At every step, energy is used. For every five barrels of oil we use, it takes at least one barrel to get the oil.

Less energy is needed to get renewable energy sources. Solar energy is a good example. Sunlight is everywhere, so no one needs to go out and find it. We don't have to drill for it or pump it to the surface. We just need to install solar panels like the ones in **Figure** 20.13 and let sunlight strike them. The energy from the sunlight is changed to electricity. The electricity is used to power lights and appliances in the house. So solar energy doesn't have to be transported.

Conserving Energy

Nonrenewable energy resources will run out before long. Using these energy resources also produces pollution and increases global warming. For all these reasons, we need to use less of these energy sources. We also need to use them more efficiently.

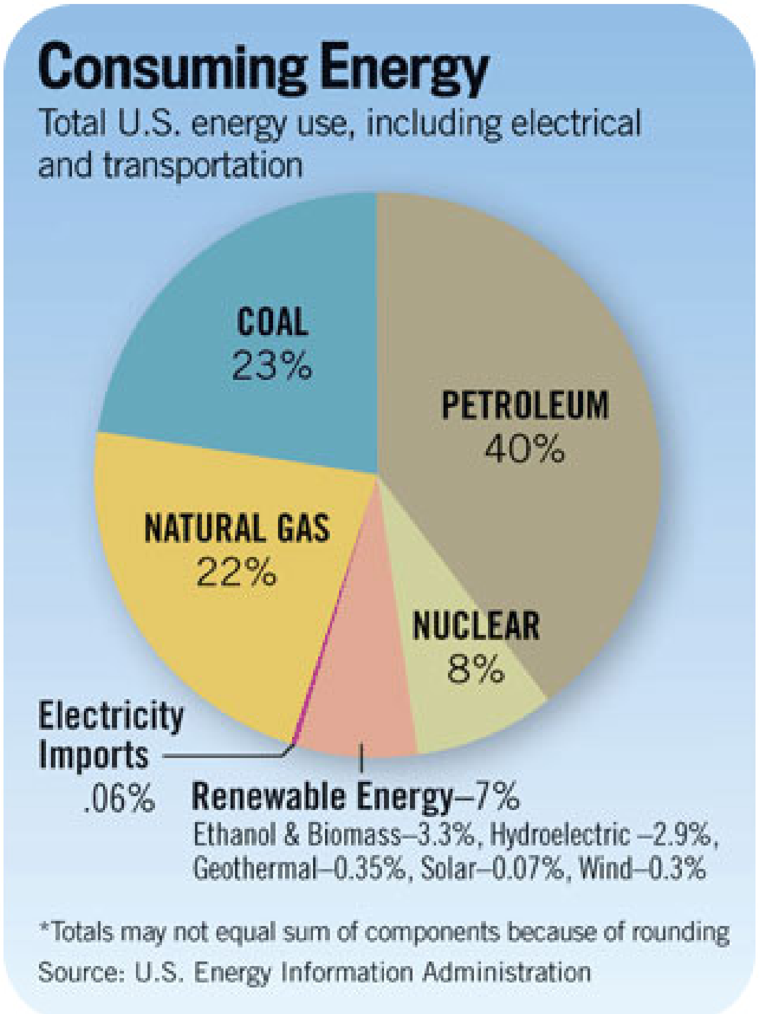


FIGURE 20.11
The U.S. gets 85 percent of its energy from fossil fuels. Where does the other 15 percent come from?

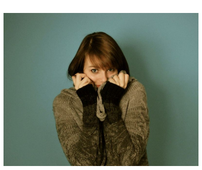
FIGURE 20.12
Energy is used to build and operate an oil well. What happens to the oil after it's pumped out of the well?

FIGURE 20.13
Solar panels collect sunlight on the roof of this house. The energy can be used to run the household.

Using Less Energy

There are many ways to use less energy. **Table** 20.2 lists some of them. Can you think of other ways to use less energy? For example, how might schools use less energy?

TABLE 20.2: Ways to Use Less Energy

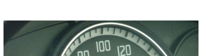
Use of Energy	How to Use Less
Transportation 	Plan ahead to reduce the number of trips you make. Take a bus or train instead of driving. Walk or bike rather than ride.
Home 	Unplug appliances when not in use. Turn off lights when you leave a room. Put on a sweater instead of turning up the heat. Run the dishwasher and washing machine only when full.

Using Energy More Efficiently

We can get more work out of the energy we use. **Table** 20.3 show some ways to use energy more efficiently. By getting more "bang for the buck," we won't need to use as much energy overall.

Does your family use energy efficiently? How could you find out?

TABLE 20.3: Ways to Use Energy More Efficiently

Use of Energy	More Efficient Use
Transportation 	Buy a fuel-efficient car. Drive no faster than 90 km/hr (55 mi/hr).

Another way to use energy more efficiently is with "Energy Star" appliances. They carry the Energy Star logo, shown in **Figure** 20.14. To be certified as Energy Star, the appliance must use less energy. Energy Star appliances save a lot of energy over their lifetime. What if millions of households used Energy Star appliances? How much energy would it save?

FIGURE 20.14
The Energy Star logo shows that an appliance uses energy efficiently.

Lesson Summary

- About half the energy used in the U.S. is used in homes and for transportation. Businesses, stores, and industry use the other half.
- The U.S. uses mainly fossil fuels. It takes energy to get energy. It takes more energy to get non-renewable than renewable energy.
- There are two basic ways to conserve energy. You can use less energy. You can also use energy more efficiently.

Lesson Review Questions

Recall

1. What are the main ways energy is used in the U.S.?

2. What percent of energy used in the U.S. comes from fossil fuels?

3. Give examples of renewable and non-renewable energy resources.

4. What are the two basic ways of conserving energy?

5. Write three tips for using energy more efficiently.

6. What are energy star appliances? How can you identify them?

Apply Concepts

7. Write a public service announcement for your school. Encourage other students to conserve energy by reducing energy use. Include practical tips for using less energy.

Think Critically

8. Explain why getting energy requires energy. Why does it take less energy to get solar energy than petroleum?

Points to Consider

In this chapter, you learned how people use natural resources such as fossil fuels. You also learned about ways to protect these natural resources. In the next chapter, you'll learn about another important natural resource: water.

- What are some ways that humans use water?
- How do human actions endanger the water supply?
- How can the water supply can be protected?

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CHAPTER 21 MS Human Actions and Earth's Water

Chapter Outline

There's nothing between you and the rushing white water except a slender kayak. The roaring rapids pummel the kayak. They rush it downhill over sheer rocks. The force of the water is amazing. What a thrilling ride!

There's no doubt about it. White water kayaking is an exciting sport. Water can be fun in lots of ways — swimming, jet skiing, sailing, snorkeling. But recreation is only one way we use water. What are some other ways that you use water? Do you ever worry about the water supply? Do you know how you can help protect it? Read on to find out.

21.1 Humans and the Water Supply

Lesson Objectives

- List ways that humans use water.
- State why some people don't have enough water.
- Explain why poor quality water is a problem.

Vocabulary

- drought
- irrigation

Introduction

All forms of life need water to survive. Humans can survive for only a few days without it. That's a lot less time than we can live without food. Besides drinking, people also need water for cleansing, agriculture, industry, and many other uses. Clearly, water is one of Earth's most important natural resources. It's a good thing that water is recycled in the water cycle.

How We Use Water

Figure 21.1 shows how people use water worldwide. The greatest use is for agriculture and then industry. Municipal use is last, but is also important. Municipal use refers to water used by homes and businesses in communities.

Water in Agriculture

Many crops are grown where there isn't enough rainfall for plants to thrive. For example, crops are grown in deserts of the American southwest. How is this possible? The answer is irrigation. **Irrigation** is any way of providing extra water to plants. Most of the water used in agriculture is used for irrigation. Livestock also use water, but they use much less.

Irrigation can waste a lot of water. The type of irrigation shown in **Figure** 21.2 is the most wasteful. The water is sprayed into the air and then falls to the ground. But much of the water never reaches the crops. Instead, it evaporates in the air or runs off the fields. Irrigation water may cause other problems. The water may dissolve agricultural chemicals such as pesticides. When the water soaks into the ground, the dissolved chemicals do, too. They may enter groundwater or run off into rivers or lakes. Salts in irrigation water can also collect in the soil. The soil may get too salty for plants to grow.

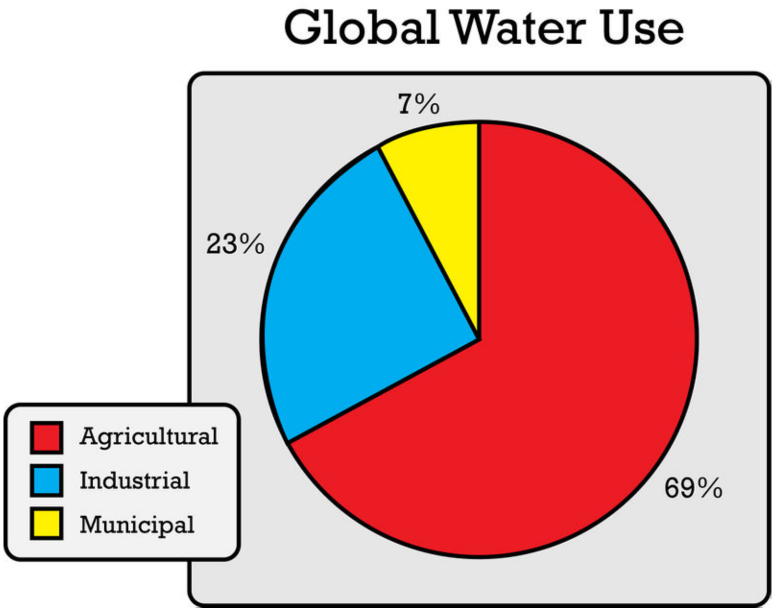

FIGURE 21.1
In this global water use chart, see how much is used for agriculture. Why do you think so much water is used in agriculture?

FIGURE 21.2
Overhead irrigation systems like this one are widely used to irrigate crops on big farms. What are some drawbacks of irrigation?

Water in Industry

Almost a quarter of the water used worldwide is used in industry. Industries use water for many purposes. Chemical processes need a lot of water. Water is used to generate electricity. An important way that industries use water is to cool machines and power plants.

Household Uses of Water

Think about all the ways people use water at home. Besides drinking it, they use it for cooking, bathing, washing dishes, doing laundry, and flushing toilets. The water used inside homes goes down the drain. From there it usually ends up in a sewer system. At the sewage treatment plant, water can be is treated and prepared for reuse.

Households may also use water outdoors. If your family has a lawn or garden, you may water them with a hose or sprinkler. You probably use water to wash the car, like the teen in **Figure** 21.3. Much of the water used outdoors evaporates or runs off into the gutter. The runoff water may end up in storm sewers that flow into a body of water, such as the ocean.

FIGURE 21.3
What will happen to the water that runs off the van? Where will it go?

Water for Fun

There are many ways to use water for fun, from white water rafting to snorkeling. When you do these activities you don't actually use water. You are doing the activity on or in the water. What do you think is the single biggest use of water for fun? Believe it or not, it's golf! Keeping golf courses green uses an incredible amount of water. Since many golf courses are in sunny areas, much of the water is irrigation water. Many golf courses, like the one in **Figure** 21.4, have sprinkler systems. Like any similar sprinkler system, much of this water is wasted. It evaporates or runs off the ground.

FIGURE 21.4
Sunshine brings golfers to the desert but a lot of water is needed to make the desert green enough to play.

Water Problems: Not Enough Water

Most Americans have plenty of fresh, clean water. But many people around the world do not. In fact, water scarcity is the world's most serious resource problem. How can that be? Water is almost everywhere. More than 70 percent of Earth's surface is covered by water.

Where Is All the Water?

One problem is that only a tiny fraction of Earth's water is fresh, liquid water that people can use. More than 97 percent of Earth's water is salt water in the oceans. Just 3 percent is freshwater. Most of the freshwater is frozen in ice sheets, icebergs, and glaciers (see **Figure** 21.5).

FIGURE 21.5
This glacier in Patagonia, Argentina stores a lot of frozen freshwater.

Rainfall and the Water Supply

Rainfall varies around the globe. About 40 percent of the land gets very little rain. About the same percentage of the world's people don't have enough water. You can compare global rainfall with the worldwide freshwater supply at the two URLs below. Drier climates generally have less water for people to use. In some places, people may have less water available to them for an entire year than many Americans use in a single day! How much water is there where you live?

- Global rainfall: http://commons.wikimedia.org/wiki/File:World_precip_annual.png
- Freshwater supply: http://commons.wikimedia.org/wiki/File:2006_Global_Water_Availability.svg

Wealth and the Water Supply

Richer nations can drill deep wells, build large dams or supply people with water in other ways. In these countries, just about everyone has access to clean running water in their homes. It's no surprise that people in these countries also use the most water. In poorer nations, there is little money to develop water supplies. Look at the people in **Figure** 21.6. These people must carry water home in a bucket from a distant pump.

FIGURE 21.6
Water is a luxury in Africa, and many people have to carry water home. How would you use water differently if you had to get your water this way?

Water Shortages

Water shortages are common in much of the world. People are most likely to run short of water during droughts. A **drought** is a period of unusually low rainfall. Human actions have increased how often droughts occur. One way people can help to bring on drought is by cutting down trees. Trees add a lot of water vapor to the air. With fewer trees, the air is drier and droughts are more common.

We already use six times as much water today as we did a hundred years ago. As the number of people rises, our need for water will grow. By the year 2025, only half the world's people will have enough clean water. Water is such a vital resource that serious water shortages may cause other problems.

- Crops and livestock may die, so people will have less food available.
- Other uses of water, such as industry, may have to stop. This reduces the jobs people can get and the products they can buy.
- People and nations may fight over water resources.
- In extreme cases, people may die from lack of water.

The **Figure** 21.7 shows the global water situation in the 2030s with water stress and water scarcity on the map.

Water Problems: Poor Quality Water

The water Americans get from their faucets is generally safe. This water has been treated and purified. But at least 20 percent of the world's people do not have clean drinking water. Their only choice may be to drink water straight from a river (see **Figure** 21.8). If the river is polluted with wastes, it will contain bacteria and other organisms that cause disease. Almost 9 out of 10 cases of disease worldwide are caused by unsafe drinking water. Diseases from unsafe drinking water are the leading cause of death in young children.

Lesson Summary

- People use water for agriculture, industry, and municipal uses. Irrigation for agriculture uses the most water.

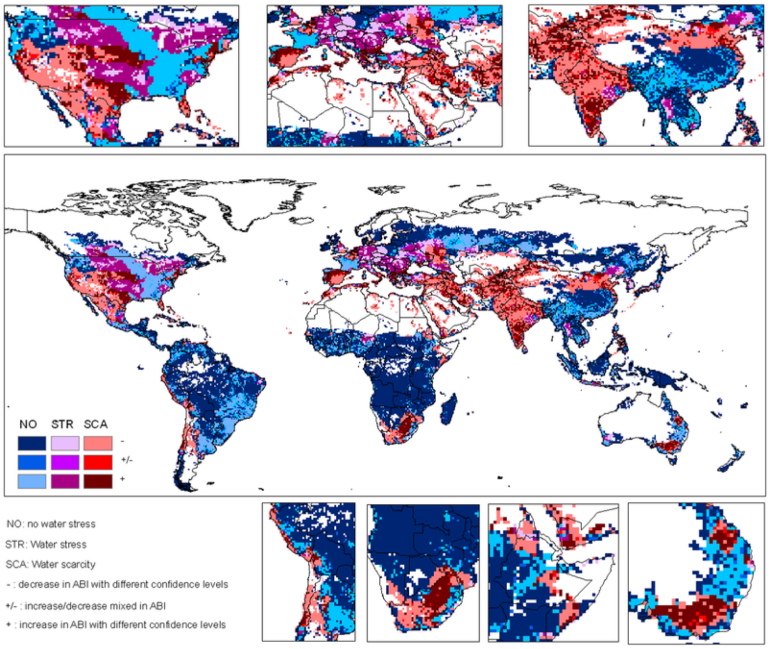

FIGURE 21.7
Blues indicate no predicted water stress; pinks and lavenders predict water stress, and salmon to brown indicates water scarcity (variations of those colors indicate the amount of irrigation that will be done to produce crops).

FIGURE 21.8
This girl is getting drinking water from a hole that has been dug. It may be the only source of water where she lives.

- Too little water is a major problem. Places with the least water get little rainfall. They also lack money to develop other water resources. Droughts make the problem even worse.
- Poor water quality is also a problem. Many people must drink water that contains wastes. This causes a lot of illness and death.

Lesson Review Questions

Recall

1. List the three major ways that humans use water.
2. What is the single biggest use of water in agriculture?
3. Give an example of an industrial use of water.
4. Why does golf use a lot of water?
5. What problems may result from serious water shortages?

Apply Concepts

6. Briefly describe a typical day in your life. Identify each time you use water. Don't forget that producing power, food, and other goods uses water.

Think Critically

7. More than 70 percent of Earth's surface is covered by water. Why is scarcity of water the world's most serious resource problem?
8. Relate droughts to water shortages. Explain why droughts are becoming more common.

Points to Consider

In this lesson, you learned that many people don't have clean water to drink. They must drink polluted water instead.

- How does water become polluted?
- Can polluted water be treated so it is safe to drink?

21.2 Water Pollution

Lesson Objectives

- Define point and nonpoint source pollution.
- List sources of water pollution.
- Describe ocean water pollution.
- Identify causes and effects of thermal pollution.

Vocabulary

- point source pollution
- non-point source pollution
- thermal pollution

Introduction

Water pollution is a worldwide problem. Almost anything released into the air or onto the land can end up in Earth's water.

Point and Nonpoint Source Pollution

Pollution that enters water at just one point is called **point source pollution**. For example, chemicals from a factory might empty into a stream through a pipe or set of pipes (see **Figure** 21.9). Pollution that enters in many places is called **non-point source pollution**. This means that the pollution is from multiple sources. With non-point source pollution, runoff may carry the pollution into a body of water. Which type of pollution do you think is harder to control?

Sources of Water Pollution

There are three main sources of water pollution:

1. Agriculture.
2. Industry.
3. Municipal, or community, sources.

FIGURE 21.9
Pollution from a factory enters a stream at a single point.

Water Pollution from Agriculture

Huge amounts of chemicals, such as fertilizers and pesticides, are applied to farm fields (see **Figure** 21.10). Some of the chemicals are picked up by rainwater. Runoff then carries the chemicals to nearby rivers or lakes. Dissolved fertilizer causes too much growth of water plants and algae. This can lead to dead zones where nothing can live in lakes and at the mouths of rivers. Some of the chemicals can infiltrate into groundwater. The contaminated water comes up in water wells. If people drink the polluted water, they may get sick.

FIGURE 21.10
This vehicle is spreading fertilizer on a field before planting.

Waste from livestock can also pollute water. The waste contains bacteria and other organisms that cause disease. In fact, more than 40 human diseases can be caused by water polluted with animal waste. Many farms in the U.S. have thousands of animals. These farms produce millions of gallons of waste. The waste is stored in huge lagoons, like the one in **Figure** 21.11. Unfortunately, many leaks from these lagoons have occurred. Two examples are described below.

- In North Carolina, 25 million gallons of hog manure spilled into a nearby river. The contaminated water killed

millions of fish.
- In Wisconsin, cow manure leaked into a city's water supply. Almost half a million people got sick. More than 100 people died.

FIGURE 21.11
From the air, this looks like a pond of water. It's really a pond of hog manure. To get an idea of how big the lagoon is, check out the vehicles at the bottom of the picture.

Water Pollution from Industry

Factories and power plants may pollute water with harmful substances.

- Many industries produce toxic chemicals. Some of the worst are arsenic, lead, and mercury.
- Nuclear power plants produce radioactive chemicals. They cause cancer and other serious health problems.
- Oil tanks and pipelines can leak. Leaks may not be noticed until a lot of oil has soaked into the ground. The oil may pollute groundwater so it is no longer fit to drink.

Municipal Water Pollution

"Municipal" refers to the community. Households and businesses in a community are also responsible for polluting the water supply. For example:

- People apply chemicals to their lawns. The chemicals may be picked up by rainwater. The contaminated runoff enters storm sewers and ends up in nearby rivers or lakes.
- Underground septic tanks can develop leaks. This lets household sewage seep into groundwater.
- Municipal sewage treatment plants dump treated wastewater into rivers or lakes. Sometimes the wastewater is not treated enough and contains bacteria or toxic chemicals.

Ocean Water Pollution

The oceans are vast. You might think they are too big to be harmed by pollution. But that's not the case. Ocean water is becoming seriously polluted.

Coastal Pollution

The oceans are most polluted along coasts. Why do you think that's the case? Of course, it's because most pollution enters the oceans from the land. Runoff and rivers carry the majority of pollution into the ocean. Many cities dump their wastewater directly into coastal waters. In some parts of the world, raw sewage and trash may be thrown into the water (see **Figure** 21.12). Coastal water may become so polluted that people get sick if they swim in it or eat seafood from it. The polluted water may also kill fish and other ocean life.

FIGURE 21.12
This coastal ocean water is full of trash and sewage.

Oil Spills

Oil spills are another source of ocean pollution. To get at oil buried beneath the seafloor, oil rigs are built in the oceans. These rigs pump oil from beneath the ocean floor. Huge ocean tankers carry oil around the world. If something goes wrong with a rig on a tanker, millions of barrels of oil may end up in the water. The oil may coat and kill ocean animals. Some of the oil will wash ashore. This oil may destroy coastal wetlands and ruin beaches. **Figure** 21.13 shows an oil spill on a beach. The oil washed ashore after a deadly oil rig explosion in the Gulf of Mexico in 2010.

FIGURE 21.13
After an oil rig explosion, hundreds of miles of beaches looked like this one. Cleaning them up was a huge task.

Thermal Pollution

Thermal pollution is pollution that raises the temperature of water. This is caused by power plants and factories that use the water to cool their machines. The plants pump cold water from a lake or coastal area through giant cooling towers, like those in **Figure** 21.14. As it flows through the towers, the cold water absorbs heat. This warmed water is returned to the lake or sea. Thermal pollution can kill fish and other water life. It's not just the warm temperature that kills them. Warm water can't hold as much oxygen as cool water. If the water gets too warm, there may not be enough oxygen for living things.

FIGURE 21.14
Nuclear power plants need huge amounts of water for cooling, so they are built close to water. The water that's returned to the lake may be warm enough to kill fish.

Lesson Summary

- Point source pollution enters water at just one place. For example, it might enter a stream through a pipe. Non-point source pollution enters water everywhere. It is carried by runoff.
- Major sources of pollution are agriculture, industry, and communities. Pollution from agriculture includes chemicals and animal waste. Industry produces toxic chemicals. Communities produce sewage.
- Ocean water is most polluted along coasts. That's because pollution usually enters the water from land. Oil spills also pollute ocean water.
- Thermal pollution raises the temperature of water. It is commonly caused by power plants and factories. The change in temperature can kill fish and other water organisms.

Lesson Review Questions

Recall

1. Describe two major ways that agriculture can pollute water.

2. List harmful substances that industry may add to water.

3. What are some municipal sources of water pollution?

4. State why ocean water is most polluted near coasts.

5. How can oil end up in ocean water?

6. What is thermal pollution? Why is it harmful for fish and other water life?

Apply Concepts

7. The nuclear power plant in the **Figure** 21.15 is located near the ocean. The plant uses ocean water for cooling. Describe two types of water pollution this plant might produce.

FIGURE 21.15
Diablo Canyon nuclear power plant in San Luis Obispo County, California.

Think Critically

8. Compare and contrast point and nonpoint source pollution. Give an example of each.

Points to Consider

People can't live without water. They need it for life itself. More than almost any other resource, water must be protected.

- How can water pollution be prevented?
- How can we use less water?

21.3 Protecting the Water Supply

Lesson Objectives

- List ways to reduce water pollution.
- Describe how water is treated.
- Identify ways to conserve water.

Vocabulary

- water treatment

Introduction

The water supply can be harmed in two major ways. The water can be polluted, and it can be overused. Protecting the water supply must address both problems. We need to reduce how much pollution ends up in the water supply. We need to treat water that's already polluted. We need to conserve water by using less.

Reducing Water Pollution

In the mid 1900s, people were startled to see the Cuyahoga River in Cleveland, Ohio, burst into flames! The river was so polluted with oil and other industrial wastes that it was flammable. Nothing could live in it. You can see the Cuyahoga River in **Figure** 21.16

FIGURE 21.16
Left: The Cuyahoga River flows through Cleveland, Ohio. In the mid 1900s, there was a lot of industry in this part of Ohio. The river became very polluted. Right: Today, the river is much cleaner.

Controlling Water Pollution

Disasters such as rivers burning led to new U.S. laws to protect the water. For example, the Environmental Protection Agency (EPA) was established, and the Clean Water Act was passed. Now, water is routinely tested. Pollution is tracked to its source, and polluters are forced to fix the problem and clean up the pollution. They are also fined. These consequences have led industries, agriculture, and communities to pollute the water much less than before.

What You Can Do

Most water pollution comes from industry, agriculture, and municipal sources. Homes are part of the municipal source and the individuals and families that live in them can pollute the water supply. What can you do to reduce water pollution? Read the tips below.

- Properly dispose of motor oil and household chemicals. Never pour them down the drain. Also, don't let them spill on the ground. This keeps them out of storm sewers and bodies of water.
- Use fewer lawn and garden chemicals. Use natural products instead. For example, use compost instead of fertilizer. Or grow plants that can thrive on their own without any extra help.
- Repair engine oil leaks right away. A steady drip of oil from an engine can quickly add up to gallons. When the oil washes off driveways and streets it can end up in storm drains and pollute the water supply.
- Don't let pet litter or pet wastes get into the water supply (see **Figure** 21.17). The nitrogen they contain can cause overgrowth of algae. The wastes may also contain bacteria and other causes of disease.

FIGURE 21.17
Why should people always clean up after their pets?

Water Treatment

Water treatment is a series of processes that remove unwanted substances from water. The goal of water treatment is to make the water safe to return to the natural environment or to the human water supply. Treating water for other purposes may not include all the same steps. That's because water used in agriculture or industry may not have to be as clean as drinking water.

You can see how water for drinking is treated in **Figure** 21.18. Treating drinking water requires at least four processes: 1. Chemicals are added to untreated water. They cause solids in the water to clump together. This is called coagulation. 2. The water is moved to tanks. The clumped solids sink to the bottom of the water. This is called sedimentation. 3. The water is passed through filters that remove smaller particles from the water. This is called filtration. 4. Chlorine is added to the water to kill bacteria and other microbes. This is called disinfection. Finally, the water is pure enough to drink.

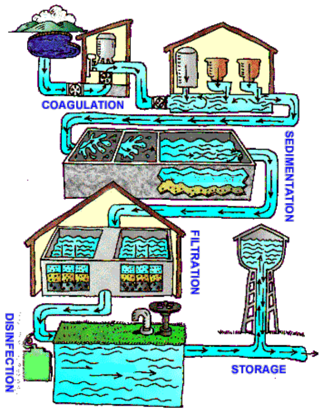

FIGURE 21.18
Four processes are used to treat water to make it safe for drinking.

Conserving Water

Conserving water means using less of it. Of course, this mostly applies to people in the wealthy nations that have the most water and also waste the most.

Saving Water in Irrigation

Irrigation is the single biggest use of water. Overhead irrigation wastes a lot of water. Drip irrigation wastes a lot less. **Figure** 21.19 shows a drip irrigation system. Water pipes run over the surface of the ground. Tiny holes in the pipes are placed close to each plant. Water slowly drips out of the holes and soaks into the soil around the plants. Very little of the water evaporates or runs off the ground.

FIGURE 21.19
This is a drip irrigation system. Look at the soil in the photo. It's damp around each plant but dry everywhere else.

Rationing Water

Some communities save water with rationing. Much rationing takes place only during times of drought. During rationing, water may not be used for certain things. For example, communities may ban lawn watering and car washing. People may be fined if they use water in these ways. You can do your part. Follow any bans where you live.

Saving Water at Home

It's easy to save water at home. If you save even a few gallons a day you can make a big difference over the long run. The best place to start saving water is in the bathroom. Toilet flushing is the single biggest use of water in the home. Showers and baths are the next biggest use. Follow the tips below to save water at home.

- Install water-saving toilets. They use only about half as much water per flush. A single household can save up to 20,000 gallons a year with this change alone!
- Take shorter showers. You can get just as clean in 5 minutes as you can in 10. And you'll save up to 50 gallons of water each time you shower. That's thousands of gallons each year.
- Use low-flow shower heads. They use about half as much water as regular shower heads. They save thousands of gallons of water.
- Fix leaky shower heads and faucets. All those drips really add up. At one drip per second, more than 6,000 gallons go down the drain in a year —per faucet!
- Don't leave the water running while you brush your teeth. You could save as much as 10 gallons each time you brush. That could add up to 10,000 gallons in a year.
- Landscape your home with plants that need little water. This could result in a huge savings in water use. Look at the garden in **Figure** 21.20. It shows that you don't have to sacrifice beauty to save water.

FIGURE 21.20
This beautiful garden contains only plants that need very little water.

Lesson Summary

- Laws have been passed to control water pollution. In many places, water is cleaner now than it used to be. Everyone can help reduce water pollution. For example, they can keep motor oil and pet wastes out of the water supply.

- Water treatment is a series of processes that remove unwanted substances from water. More processes are needed to purify water for drinking than for other uses.
- There are many ways to use less water. For example, drip irrigation wastes less than other methods. Water-saving toilets and shower heads can save a lot of water at home.

Lesson Review Questions

Recall

1. Identify three ways that people can reduce water pollution at home.

2. List the processes used to treat drinking water.

3. What is filtration? What does it remove from water?

4. Why is chlorine added to drinking water?

5. Describe how water might be rationed in a community. Why would this be done?

Apply Concepts

6. Assume a city has 50,000 households. Also assume that each household will replace all of its toilets with water-saving models. Use data in the lesson to estimate how many gallons of water the city could save in a year from this change alone.

7. Describe a model home with features that save water.

Think Critically

8. Compare and contrast drip irrigation and sprinkler irrigation. Explain which one wastes less water. Which one causes less water pollution? Why? In what regions is drip irrigation most useful?

Points to Consider

We can survive for a few days without water. We can survive for just a few minutes without air. Like water, air is polluted by human actions.

- What causes air pollution?
- What can be done to keep air clean?

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CHAPTER 22 MS Human Actions and the Atmosphere

Chapter Outline

A smelly, irritating, grayish haze blankets Los Angeles in this photo. The air isn't just dirty. It's deadly. Or at least it can be deadly to sensitive people, such as those with asthma.

Los Angeles is just one of several cities in California that have serious air pollution problems. In fact, of the ten U.S. cities with the worst air quality, six are in California. Why is the air in California so polluted? Is it because this state has more people, cars, or factories than other places? Is something else going on? In this chapter, you'll find out. You'll also learn how air pollution affects people and the environment.

22.1 Air Pollution

Lesson Objectives

- Describe factors that affect air quality.
- Identify primary and secondary air pollutants.
- List the main sources of air pollution.

Vocabulary

- air quality
- particulate
- photochemical smog
- primary pollutant
- secondary pollutant

Introduction

Earth's atmosphere is vital to life. The atmosphere provides the oxygen and carbon dioxide living things need for photosynthesis and respiration. Living things also need the ozone layer high in the atmosphere. Upper level ozone protects them from most of the Sun's harmful UV rays.

Sadly, people use the air as a dump for wastes. Vehicles, factories, and power plants all release pollutants into the air. Air pollution harms living things. Some pollutants also increase the natural greenhouse effect. In this way, air pollution is raising Earth's temperature.

Air Quality

Air quality is a measure of the pollutants in the air. More pollutants mean poorer air quality. Air quality, in turn, depends on many factors. Some natural processes add pollutants to the air. For example, forest fires and volcanoes add carbon dioxide and soot. In dry areas, the air often contains dust. However, human actions cause the most air pollution. The single biggest cause is fossil fuel burning.

The Industrial Revolution

Poor air quality started to become a serious problem after the Industrial Revolution. The machines in factories burned coal. This released a lot of pollutants into the air. After 1900, motor vehicles became common. Cars and trucks burn gasoline, which adds greatly to air pollution.

The Big Smoke

By the mid-1900s, air quality in many big cities was very bad. The worst incident came in December 1952. A temperature inversion over London, England, kept cold air and pollutants near the ground. The air became so polluted that thousands of people died in just a few days. This event was called the "Big Smoke."

Air Pollution in the U.S.

At the same time, many U.S. cities had air pollution problems. Some of the worst were in California. Cars were becoming more popular. Oil refineries and power plants also polluted the air. Mountain ranges trapped polluted air over cities. The California sunshine caused chemical reactions among the pollutants. These reactions produced many more harmful compounds.

The Clean Air Act

By 1970, it was clear that something needed to be done to protect air quality. In the U.S., the Clean Air Act was passed. It limits what can be released into the air. As a result, the air in the U.S. is much cleaner now than it was 50 years ago. But air pollution has not gone away. Vehicles, factories, and power plants still release more than 150 million tons of pollutants into the air each year.

Types of Air Pollutants

There are two basic types of pollutants in air. They are known as primary pollutants and secondary pollutants.

Primary Pollutants

Primary pollutants enter the air directly. Some are released by natural processes, like ash from volcanoes. Most are released by human activities. They pour into the air from vehicles and smokestacks. Several of these pollutants are described below.

- Carbon oxides include carbon monoxide (CO) and carbon dioxide (CO_2). Carbon oxides are released when fossil fuels burn.
- Nitrogen oxides include nitric oxide (NO) and nitrogen dioxide (NO_2). Nitrogen oxides form when nitrogen and oxygen combine at high temperatures. This occurs in hot exhausts from vehicles, factories, and power plants.
- Sulfur oxides include sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Sulfur oxides are produced when sulfur and oxygen combine. This happens when coal burns. Coal can contain up to 10 percent sulfur.
- Toxic heavy metals include mercury and lead. Mercury is used in some industrial processes. It is also found in fluorescent light bulbs. Lead was once widely used in gasoline, paint, and pipes. It is still found in some products.
- Volatile organic compounds (VOCs) are carbon compounds such as methane. VOCs are released in many human activities, such as raising livestock. Livestock wastes produce a lot of methane.
- **Particulates** are solid particles. These particles may be ash, dust, or even animal wastes. Many are released when fossil fuels burn (see **Figure** 22.1).

FIGURE 22.1
Black particulates coming out of a factory smokestack. Many particulates are too small to see, but they can still be dangerous.

Secondary Pollutants

Secondary pollutants form when primary pollutants undergo chemical reactions after they are released. Many occur as part of **photochemical smog**. This type of smog is seen as a brown haze in the air. Photochemical smog forms when certain pollutants react together in the presence of sunlight. You can see smog hanging in the air over San Francisco in **Figure** 22.2.

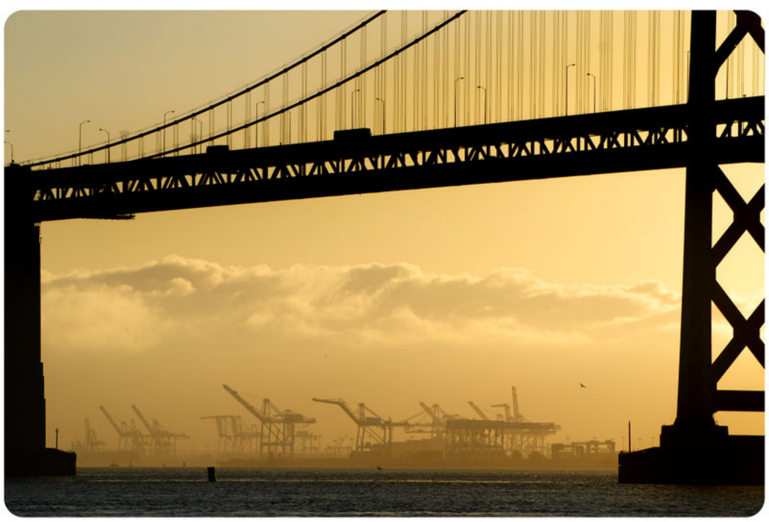

FIGURE 22.2
Photochemical smog is common in the air over many California cities.

Photochemical smog consists mainly of ozone (O_3). The ozone in smog is the same compound as the ozone in the ozone layer,(O_3). But ozone in smog is found near the ground. **Figure** 22.3 shows how it forms. When nitrogen oxides and VOCs are heated by the Sun, they lose oxygen atoms. The oxygen atoms combine with molecules of oxygen to form ozone. Smog ozone is harmful to humans and other living things.

Sources of Air Pollution

Most pollutants enter the air when fossil fuels burn. Some are released when forests burn. Others evaporate into the air.

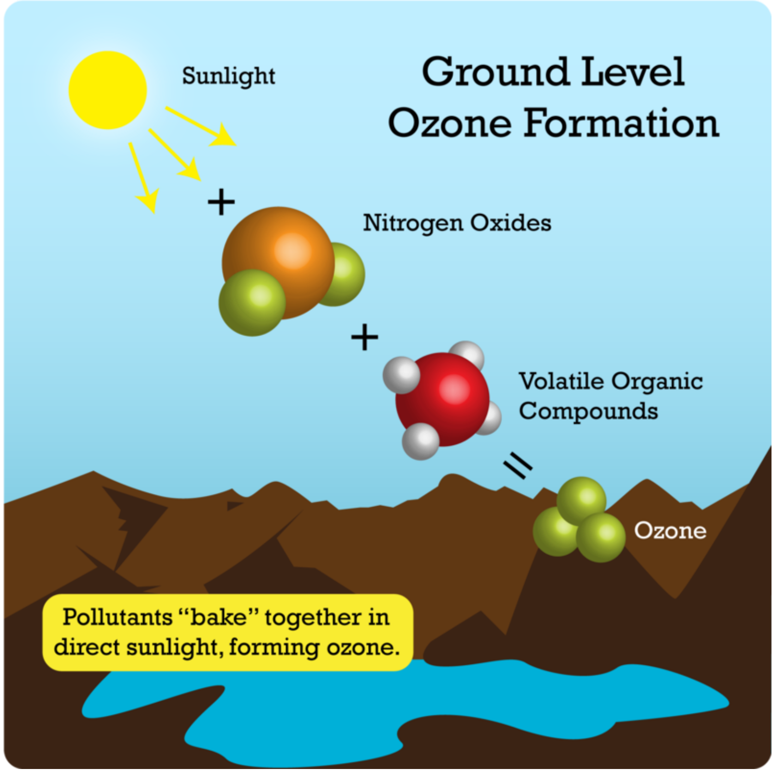

FIGURE 22.3
Ozone forms near the ground as a secondary pollutant.

Burning Fossil Fuels

Burning fossil fuels releases many pollutants into the air. These pollutants include carbon monoxide, carbon dioxide, nitrogen dioxide, and sulfur dioxide.

- Motor vehicles account for almost half of fossil fuel use. Most vehicles run on gasoline, which comes from petroleum.
- Power plants and factories account for more than a quarter of fossil fuel use. Power plants burn fossil fuels to generate electricity. Factories burn fossil fuels to power machines.
- Homes and other buildings also burn fossil fuels. The energy they release is used for heating, cooking, and other purposes.

Burning Forests

Millions of acres of forest have been cut and burned to make way for farming. **Figure** 22.4 shows an example. Burning trees produces most of the same pollutants as burning fossil fuels.

Evaporation of VOCs

VOCs enter the air by evaporation. VOCs are found in many products, like paints and petroleum products. Methane is a VOC that evaporates from livestock waste and landfills.

FIGURE 22.4
Cutting and burning trees to clear land for farming is called slash-and-burn agriculture. How does this affect the atmosphere?

Lesson Summary

- Air quality is a measure of the pollutants in air. Poor air quality started to become a serious problem during the Industrial Revolution. After 1900, motor vehicles added greatly to the problem. The Clean Air Act of 1970 improved the quality of the air over the U.S.
- Primary pollutants enter the air directly. They include carbon, nitrogen, and sulfur oxides. Toxic heavy metals, VOCs, and particulates are also primary pollutants. Secondary pollutants form when primary pollutants undergo chemical reactions after they are released. Many occur as part of photochemical smog. The main component of smog is ozone.
- Most pollutants enter the air when fossil fuels burn. Some are released when forests burn. Others evaporate into the air.

Lesson Review Questions

Recall

1. Define air quality.
2. List three factors that affect air quality.
3. Describe how air quality has changed since the Industrial Revolution.
4. List sources of nitrogen oxides in the air.
5. Outline three major sources of air pollution.

Apply Concepts

6. Photochemical smog generally peaks at midday on the sunniest days of the summer. Apply lesson concepts to explain why.

Think Critically

7. Compare and contrast primary and secondary pollutants. Give an example of each.
8. How can ozone both protect us and harm us?

Points to Consider

Despite the Clean Air Act, the air over many U.S. cities is still polluted. In some other countries, the problem is even worse. That's because they don't have laws like the Clean Air Act to protect the air.

- How do you think air pollution affects human health?
- How might it affect other living things?

22.2 Effects of Air Pollution

Lesson Objectives

- Outline the effects of pollutants in the air.
- Identify the cause and effects of acid rain.
- Relate air pollution to loss of the ozone layer.

Vocabulary

- acid rain
- bioaccumulation

Introduction

Air pollution is harmful to human beings and other living things. About 22 million people die from it each year. Breathing polluted air increases the risk of developing lung diseases such as asthma and lung cancer. Breathing bad air also increases the chances of dying from other diseases. Children are most likely to be affected by air pollution. That's because their lungs are still developing and growing. Children also take in more air for their size than adults do.

Effects of Pollutants

All air pollutants are harmful. That's why they're called pollutants. Some air pollutants damage the environment as well as the health of living things. The type of damage depends on the pollutant.

Particulates

Particulates cause lung diseases. They can also increase the risk of heart disease and the number of asthma attacks. Particulates block sunlight from reaching Earth's surface. This means there is less energy for photosynthesis. Less photosynthesis means that plants and phytoplankton produce less food. This affects whole ecosystems.

Ozone

The ozone in smog may damage plants. The effects of ozone add up over time. Plants such as trees, which normally live a long time, are most affected. Entire forests may die out if ozone levels are very high. Other plants, including crop plants, may also be damaged by ozone. You can see evidence of ozone damage in **Figure** 22.5.

FIGURE 22.5
Ozone damaged snap bean plants are shown on the left. Healthy snap bean plants are shown on the right.

The ozone in smog is also harmful to human health. **Figure** 22.6 shows the levels of ozone to watch out for. Some people are especially sensitive to ozone. They can be harmed by levels of ozone that would not affect most other people. These people include those with lung or heart problems.

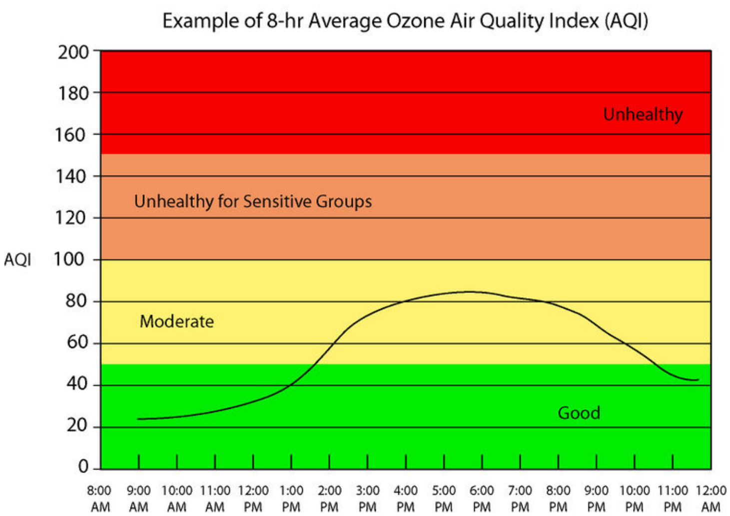

FIGURE 22.6
The ozone air quality index gives the parts of ozone per million parts of air. How many parts of ozone are unhealthy for everyone?

Nitrogen and Sulfur Oxides

Both nitrogen and sulfur oxides are toxic to humans. These compounds can cause lung diseases or make them worse. Nitrogen and sulfur oxides form acid rain, which is described below.

Carbon Monoxide

Carbon monoxide (CO) is toxic to both plants and animals. CO is deadly to people in a confined space, such as a closed home. Carbon monoxide is odorless and colorless, so people can't tell when they are breathing it. That's why homes should have carbon monoxide detectors. You can see one in **Figure** 22.7.

Heavy Metals

Heavy metals, such as mercury and lead, are toxic to living things. They can enter food chains from the atmosphere. The metals build up in the tissues of organisms by **bioaccumulation**. Bioaccumulation is illustrated in **Figure** 22.8.

FIGURE 22.7
This carbon monoxide detector will sound an alarm if the gas rises above a safe level.

As heavy metals are passed up a food chain they accumulate. Imagine a low-level consumer eating a producer. That consumer takes in all of the heavy metals from all of the producers that it eats. Then a higher-level consumer eats it and accumulates all the heavy metals from all of the lower-level consumers that it eats. In this way, heavy metals may accumulate. At high levels in the food chain, the heavy metals may be quite become quite concentrated.

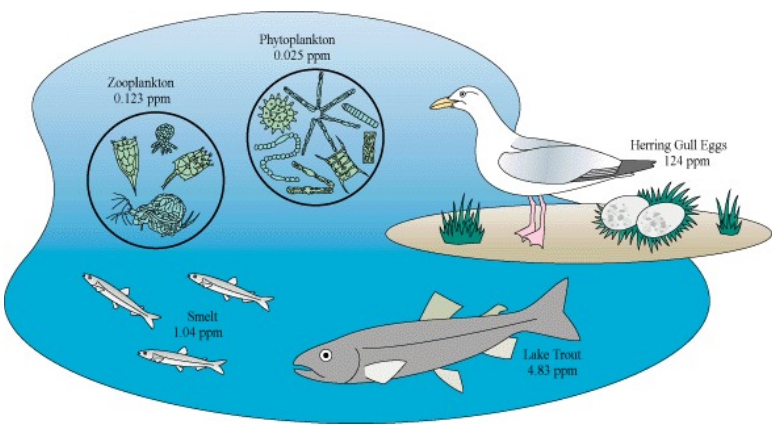

FIGURE 22.8
This diagram shows how mercury bioaccumulates. Compare the parts per million (ppm) of mercury in phytoplankton and gull eggs. Can you explain the difference?

The higher up a food chain that humans eat, the greater the levels of toxic metals they take in. That's why people should avoid eating too much of large fish such as tuna. Tuna are predators near the top of their food chains. They have been shown to contain high levels of mercury. In people, heavy metals can damage the brain and other organs. Unborn babies and young children are most affected. That's because their organs are still developing.

VOCs

VOCs are toxic to humans and other living things. In people, they can cause a wide range of problems, from eye and nose irritation to brain damage and cancer. Levels of VOCs are often higher indoors than out. That's because they are released by products such as paints, cleaning solutions, and building materials. How might you reduce your exposure to VOCs?

Acid Rain

Acid rain is rain that has a pH less than 5 (see **Figure** 22.9). The pH of normal rain is 5.6. It's slightly acidic because carbon dioxide in the air dissolves in rain. This forms carbonic acid, a weak acid.

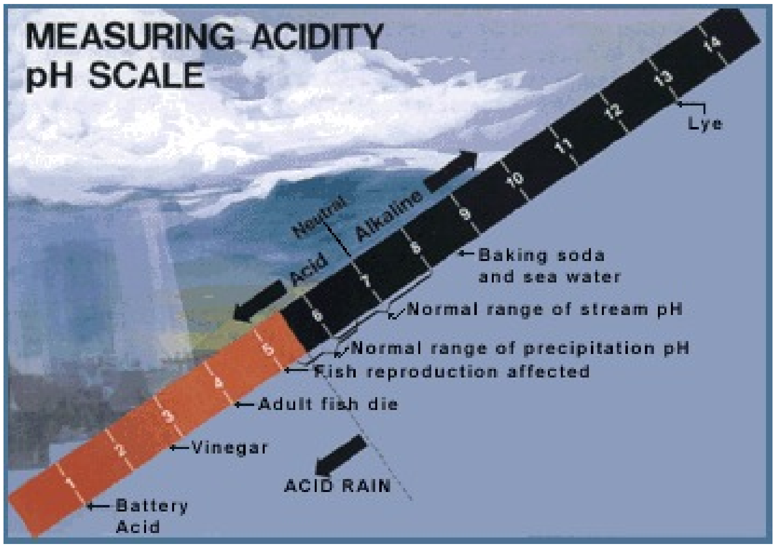

FIGURE 22.9
This pH scale includes both normal and acid rain. At what pH do fish have problems reproducing?

How Acid Rain Forms

Acid rain forms when nitrogen and sulfur oxides in air dissolve in rain (see **Figure** 22.10). This forms nitric and sulfuric acids. Both are strong acids. Acid rain with a pH as low as 4.0 is now common in many areas. Acid fog may be even more acidic than acid rain. Fog with a pH as low as 1.7 has been recorded. That's the same pH as toilet bowl cleaner!

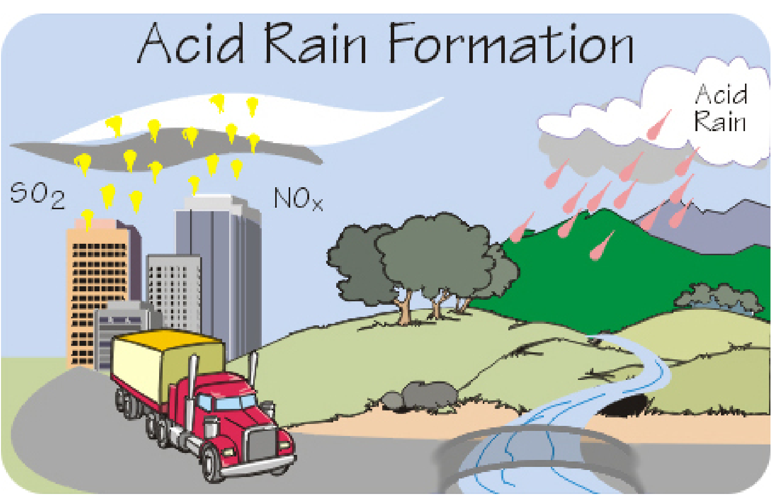

FIGURE 22.10
Nitrogen and sulfur oxides combine with rain to form acid rain.

Effects of Acid Rain

Figure 22.11 shows some of the damage done by acid rain. Acid rain ends up in soil and bodies of water. This can make them very acidic. The acid strips soil of its nutrients. These changes can kill trees, fish, and other living things. Acid rain also dissolves limestone and marble. This can damage buildings, monuments, and statues.

FIGURE 22.11
This photo shows a gargoyle that is being dissolved by acid rain on Notre Dame cathedral in Paris, France.

Loss of High-Level Ozone

Ozone near the ground harms human health. But the ozone layer in the stratosphere protects us from solar rays. That's why people were alarmed in the 1980s to learn that there was a hole in the ozone layer.

Cause of Ozone Loss

What's destroying the ozone layer? The chief cause is chlorofluorocarbons (CFCs). These are human-made chemicals that contain the element chlorine (Cl). In the past, CFCs were widely used in spray cans, refrigerators, and many other products. CFCs are stable compounds that can remain in the atmosphere for hundreds of years.

Once CFCs are in the air, they float up into the stratosphere. What happens next is shown in **Figure** 22.12. Sunlight breaks apart the molecules. This releases their chlorine atoms (Cl). The free chlorine atoms may then combine with oxygen atoms in ozone. This breaks down the ozone molecules into an oxygen molecule and an oxygen atom. One CFC molecule can break down as many as 100,000 ozone molecules in this way! These forms of oxygen do not protect the planet from ultraviolet radiation.

Ozone Hole

Most ozone loss it taking place over the South Pole and Antarctica. This is the location of the ozone hole. The ozone hole is also seasonal. The hole forms during the early part spring in the Southern Hemisphere and then grows northward. You can see the hole in **Figure** 22.13. Besides the ozone hole, the ozone layer is thinner over the Northern Hemisphere.

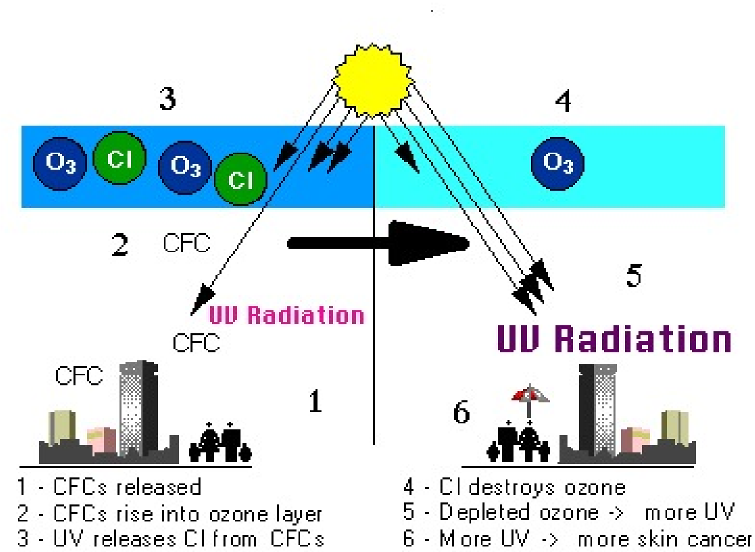

FIGURE 22.12
CFCs break down ozone in the stratosphere.

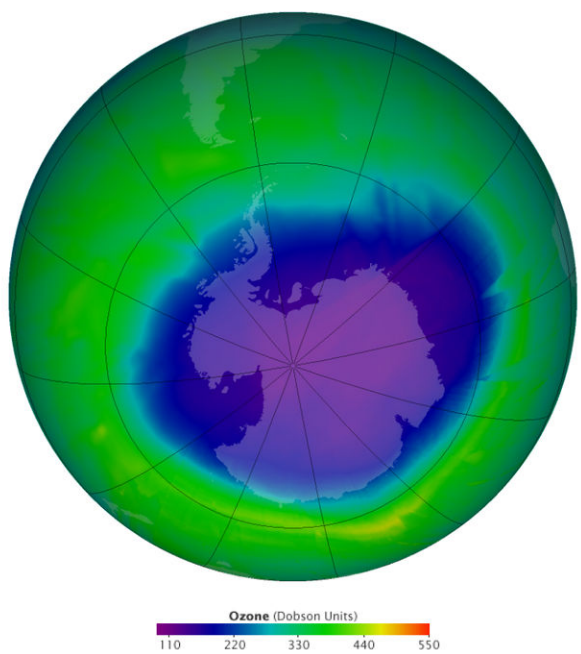

FIGURE 22.13
The hole in the ozone layer occurs over Antarctica. How do you think the hole in the ozone layer could affect life on Earth?

Effects of Ozone Loss

With less ozone in the stratosphere, more UV rays reach the ground. More UV rays increase skin cancer rates. Just a 1 percent loss of ozone causes a 5 percent increase in skin cancer. More UV rays also harm plants and phytoplankton. As a result, they produce less food. This may affect entire ecosystems.

Lesson Summary

- All air pollutants can be harmful. Some damage the environment as well as the health of living things. The type of damage depends on the pollutant. For example, particulates reduce sunlight for photosynthesis. Ozone kills forests. Both harm human health.
- Acid rain is rain that has a pH less than 5. It forms when nitrogen and sulfur oxides dissolve in rain. Acid rain kills living things and damages buildings and statues.
- CFCs destroy ozone in the stratosphere. This lets more UV light strike Earth. The UV light causes skin cancer. It also harms plants and phytoplankton.

Lesson Review Questions

Recall

1. How do particulates affect human health?
2. State why ozone is more harmful to plants that normally live a long time.
3. Define bioaccumulation. Name two air pollutants that bioaccumulate.
4. Why should you limit the amount of tuna that you eat?
5. What are some products around the house that might expose you to VOCs?
6. Describe the effects of acid rain.

Apply Concepts

7. Chloe has asthma, so she is sensitive to air pollution. Today, the ozone air quality index in her city is 100 ppm. Should Chloe be concerned? Why or why not?
8. Create an original diagram to show how CFCs affect the ozone layer.

Think Critically

9. Explain how acid rain forms. Infer how it could be reduced.
10. Relate air pollution to global warming.

Points to Consider

Air pollution damages both human health and the health of the environment.

- What steps have already been taken to reduce air pollution?
- What problems do you think remain?

22.3 Reducing Air Pollution

Lesson Objectives

- List ways to reduce air pollution from fossil fuels.
- Describe worldwide efforts to protect the ozone layer and control global warming.

Vocabulary

- cap-and-trade system
- carbon sequestration

Introduction

The Clean Air Act of 1970 regulates six major pollutants. These pollutants are carbon monoxide, lead, nitrogen oxides, ozone, sulfur dioxide, and particulates. Since 1970, these pollutants have decreased by more than 50 percent. How has air pollution been reduced? Most methods deal with the chief cause of air pollution: fossil fuel burning.

Global warming is an important effect of human activities on the atmosphere. The causes and effects of climate change were discussed in the *Climate* chapter. However, ways to deal with greenhouse gases are discussed below.

Reducing Air Pollution from Fossil Fuels

There are two basic types of strategies for reducing pollution from fossil fuels:

1. Use less fossil fuel to begin with.
2. When fossil fuels must be used, prevent the pollution from entering the air.

Using Less Fossil Fuel

We can reduce our use of fossil fuels in several ways:

- Conserve fossil fuels. For example, turning out lights when we aren't using them saves electricity. Why does this help? A lot of the electricity we use comes from coal-burning power plants.
- Use fossil fuels more efficiently. For example, driving a fuel-efficient car lets you go farther on each gallon of gas. This can add up to a big savings in fossil fuel use.
- Change to alternative energy sources that produce little or no air pollution. For example, hybrid cars run on electricity that would be wasted during braking. These cars use gas only as a backup fuel. As a result, they

produce just 10 percent of the air pollution produced by cars that run only on gas. Cars that run on hydrogen and produce no pollution at all have also been developed (see **Figure** 22.14).

FIGURE 22.14
This is a model of a hydrogen car. A major problem with hydrogen cars is the lack of hydrogen fuel.

Keeping Pollutants out of the Air

Some of the pollutants from fossil fuels can be filtered out of exhaust before it is released into the air. Other pollutants can be changed to harmless compounds before they are released. Two widely used technologies are scrubbers and catalytic converters.

- Scrubbers are used in factories and power plants. They remove particulates and waste gases from exhaust before it is released to the air. You can see how a scrubber works in **Figure** 22.15.
- Catalytic converters are used on motor vehicles. They break down pollutants in exhaust to non-toxic compounds. For example, they change nitrogen oxides to harmless nitrogen and oxygen gasses.

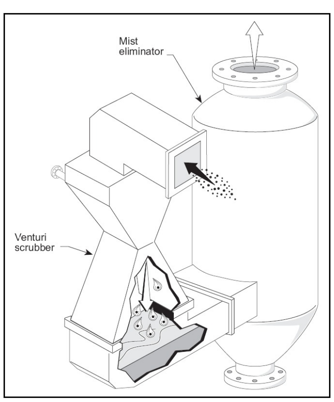

FIGURE 22.15
How a Scrubber Works. Some scrubbers use steam to remove pollutants from exhaust.

Preventing Ozone Loss and Global Warming

The problems of ozone loss and global warming were unknown in 1970. When they were discovered, worldwide efforts were made to reduce CFCs and carbon dioxide emissions.

Protecting the Ozone Layer

The Montreal Protocol is a worldwide agreement on air pollution. It focuses on CFCs. It was signed by many countries in 1987. It controls almost 100 chemicals that can damage the ozone layer. Its aim is to return the ozone layer to its normal state.

The Montreal Protocol has been effective in controlling CFCs. By 1995, few CFCs were still being used. But the ozone hole kept growing for several years after that because of the CFCs already in the atmosphere. It peaked in 2006. Since then, it has been somewhat smaller.

Controlling Global Warming

The Kyoto Protocol is another worldwide agreement on air pollution. It was passed in 1997. The Protocol focuses on controlling greenhouse gas emissions. Its aim is to control global warming.

Carbon dioxide is the main greenhouse gas causing global warming. There are several possible ways to reduce carbon dioxide emissions. They include cap-and-trade systems, carbon taxes, and carbon sequestration

- In a **cap-and-trade system**, each nation is given a cap, or upper limit, on carbon dioxide emissions. If a nation needs to go over its cap, it can trade with another nation that is below its cap. **Figure** 22.16 shows how this works.
- Carbon taxes are taxes placed on gasoline and other products that produce carbon dioxide. The taxes encourage people to use less fossil fuel, which reduces carbon dioxide emissions.
- **Carbon sequestration** is any way of removing carbon dioxide from the atmosphere and storing it in another form. Carbon is sequestered naturally by forests. Trees take in carbon dioxide for photosynthesis. Artificial methods of sequestering carbon underground are being researched.

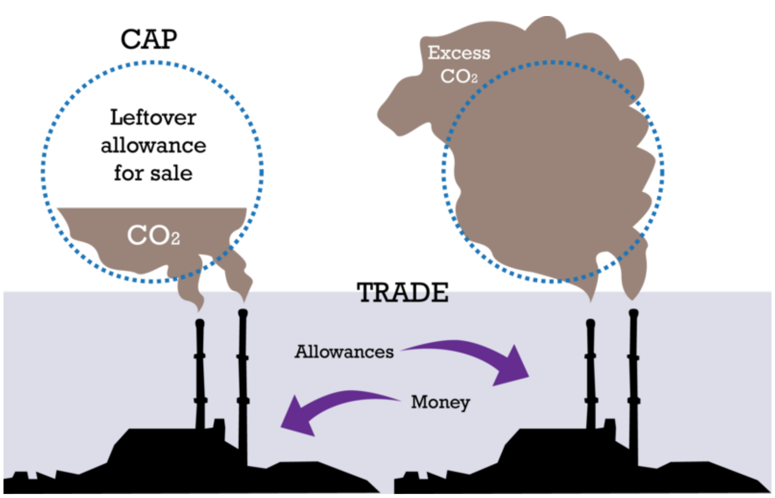

FIGURE 22.16
This diagram shows how a cap-and-trade system works.

The Kyoto Protocol has not been as successful as the Montreal Protocol. One reason is that the world's biggest producer of greenhouse gases, the U.S., did not sign the Kyoto Protocol. Of the nations that signed it, few are meeting their goals. Most scientists also think the Kyoto Protocol did not go far enough to limit greenhouse gases. A stricter agreement must be reached very soon. Unfortunately, efforts to limit greenhouse gas emissions are mired in politics. Meanwhile, crucial time is being lost.

Lesson Summary

- There are two basic strategies for reducing pollution from fossil fuels: using less fossil fuel and keeping pollution from fossil fuel use out of the air.
- The Montreal Protocol of 1987 bans CFCs. The purpose is to protect the ozone layer in the stratosphere. The Kyoto Protocol of 1997 regulates greenhouse gases. The goal is to control global warming.

Lesson Review Questions

Recall

1. Which pollutants are regulated by the Clean Air Act of 1970?

2. List three ways to use less fossil fuel.

3. What is the purpose of scrubbers? Where are they used?

4. What does a catalytic converter do?

5. What is the Montreal Protocol?

Apply Concepts

6. Create a simple board game called "Cap and Trade." Playing the game should mimic how a cap-and-trade system works. Describe your game and how it is played.

Think Critically

7. Why is planting trees a method of carbon sequestration?

8. Explain why the Kyoto Protocol has been less successful than the Montreal Protocol.

Points to Consider

The chapter focuses on the atmosphere. Beyond the atmosphere is space. The next chapter introduces the study of space.

- What do you already known about space? For example, what objects are found in space?
- How do you think scientists learn about space?

22.4 References

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CHAPTER 23 MS Observing and Exploring Space

Chapter Outline

Since the 1970s, the National Aeronautics and Space Administration (NASA) has used space shuttles like the one pictured above to move astronauts to and from space stations orbiting the Earth. From landing on the Moon to building the International Space Station, these scientists have helped improve our understanding of space by observing and exploring it. But it's possible to study our solar system and beyond without ever leaving the ground! Thanks to telescopes, observatories, and satellites, we learn more about space every day.

23.1 Telescopes

Lesson Objectives

- Explain how astronomers use light to study the universe beyond Earth.
- Describe some different types of telescopes.
- Discuss what we have learned by using telescopes.

Vocabulary

- constellation
- electromagnetic radiation
- electromagnetic spectrum
- frequency
- gamma rays
- infrared light
- light-year
- microwaves
- planet
- radio telescope
- radio waves
- reflecting telescope
- refracting telescope
- space telescope
- spectrometer
- ultraviolet
- wavelength
- visible light
- X rays

Introduction

Many scientists can touch the materials they study. Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory. Physicists can test the strength of metal or smash atoms into each other. Geologists can chip away at rocks and test their chemistry. But astronomers study the universe far beyond Earth. They have to observe their subjects at a very large distance! A meteorite that lands on Earth is one of the few actual objects that astronomers could study.

Electromagnetic Spectrum

Earth is just a tiny speck in the universe. Our planet is surrounded by lots of space. Light travels across empty space. Astronomers can study light from stars to learn about the universe. Light is the visible part of the **electromagnetic spectrum**. Astronomers use the light that comes to us to gather information about the universe.

The Speed of Light

In space, light travels at about 300,000,000 meters per second (670,000,000 miles per hour). How fast is that? A beam of light could travel from New York to Los Angeles and back again nearly 40 times in just one second. Even at that amazing rate, objects in space are so far away that it takes a lot of time for their light to reach us. Even light from the nearest star, our Sun, takes about 8 minutes to reach Earth.

Light-Years

We need a really big unit to measure distances out in space because distances between stars are so great. A **light-year**, 9.5 trillion kilometers (5.9 trillion miles), is the distance that light travels in one year. That's a long way! Out in space, it's actually a pretty short distance.

Proxima Centauri is the closest star to us after the Sun. This near neighbor is 4.22 light-years away. That means the light from Proxima Centauri takes 4.22 years to reach us. Our galaxy, the Milky Way Galaxy, is about 100,000 light-years across. So it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance. The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometers!

Looking Back in Time

When we look at stars and galaxies, we are seeing over great distances. More importantly, we are also seeing back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look. For example, the Andromeda Galaxy, shown in **Figure** 23.1, is about 2.5 million light-years from Earth. When you see an image of the galaxy what are you seeing? You are seeing the galaxy as it was 2.5 million years ago!

Since scientists can look back in time they can better understand the Universe's history. Check out http://science.nasa.gov/headlines/y2002/08feb_gravlens.htm to see how this is true.

Electromagnetic Waves

Light is one type of **electromagnetic radiation**. Light is energy that travels in the form of an electromagnetic wave. **Figure** 23.2 shows a diagram of an electromagnetic wave. An electromagnetic (EM) wave has two parts: an electric field and a magnetic field. The electric and magnetic fields vibrate up and down, which makes the wave.

The **wavelength** is the horizontal distance between two of the same points on the wave, like wave crest to wave crest. A wave's **frequency** measures the number of wavelengths that pass a given point every second. As wavelength increases, frequency decreases. This means that as wavelengths get shorter, more waves move past a particular spot in the same amount of time.

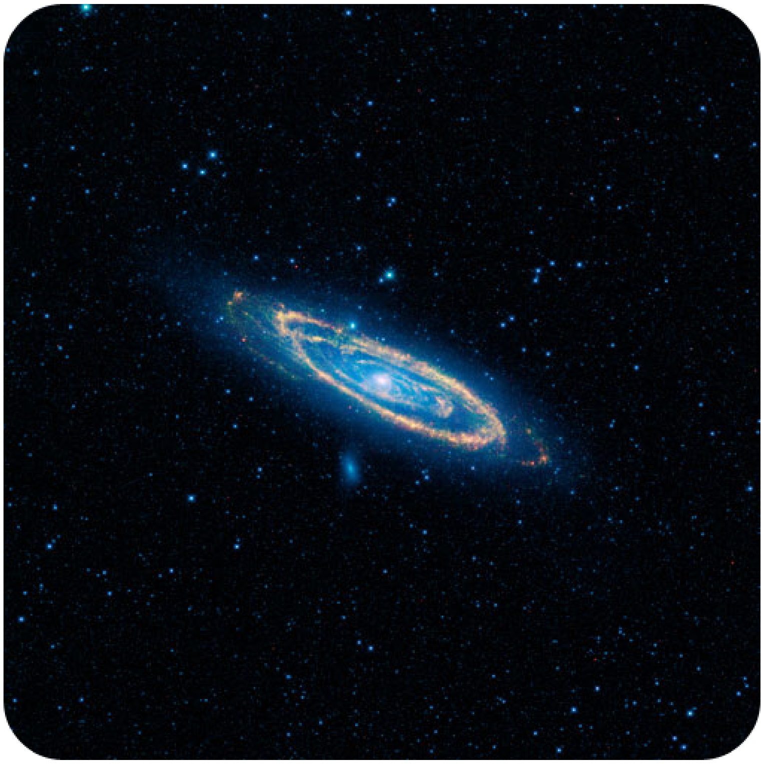

FIGURE 23.1
The Andromeda Galaxy as it appeared 2.5 million years ago. How would you find out how it looks right now?

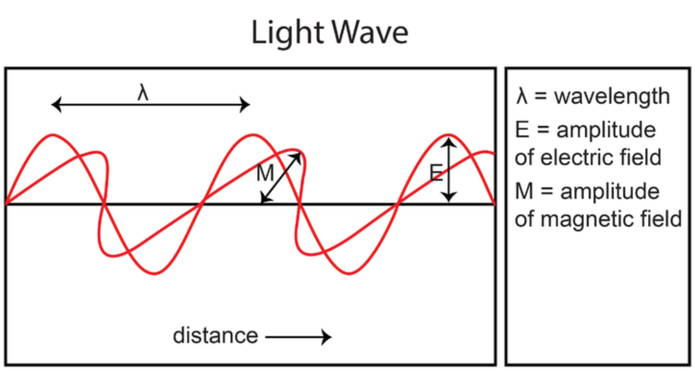

FIGURE 23.2
An electromagnetic wave has oscillating electric and magnetic fields.

The Electromagnetic Spectrum

Visible light is the part of the electromagnetic spectrum (**Figure** 23.3) that humans can see. Visible light includes all the colors of the rainbow. Each color is determined by its wavelength. Visible light ranges from violet wavelengths of 400 nanometers (nm) through red at 700 nm.

There are parts of the electromagnetic spectrum that humans cannot see. This radiation exists all around you. You just can't see it! Every star, including our Sun, emits radiation of many wavelengths. Astronomers can learn a lot from studying the details of the spectrum of radiation from a star.

Many extremely interesting objects can't be seen with the unaided eye. Astronomers use telescopes to see objects at wavelengths all across the electromagnetic spectrum. Some very hot stars emit light primarily at **ultraviolet**

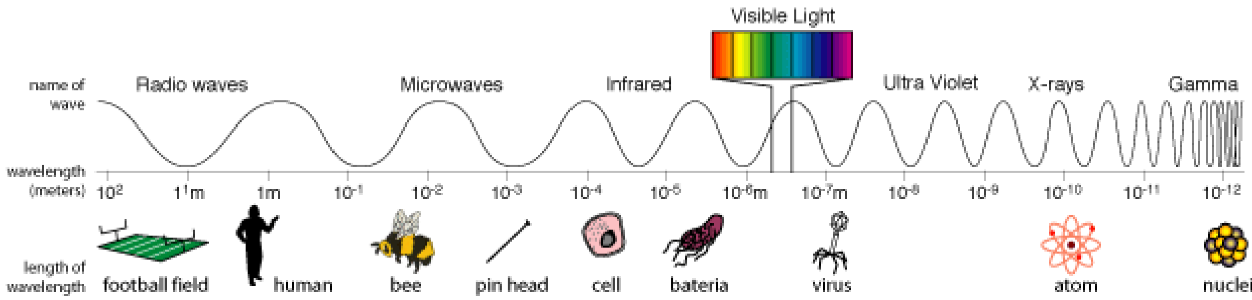

FIGURE 23.3
The electromagnetic spectrum from radio waves to gamma rays.

wavelengths. There are extremely hot objects that emit **X-rays** and even **gamma rays**. Some very cool stars shine mostly in the **infrared light** wavelengths. **Radio waves** come from the faintest, most distant objects.

To learn more about stars' spectra, visit http://www.colorado.edu/physics/PhysicsInitiative/Physics2000/quantumzone/ .

Types of Telescopes

Optical Telescopes

Humans have been making and using magnifying lenses for thousands of years. The first telescope was built by Galileo in 1608. His telescope used two lenses to make distant objects appear both nearer and larger.

Telescopes that use lenses to bend light are called **refracting telescopes**, or refractors (**Figure** 23.4). The earliest telescopes were all refractors. Many amateur astronomers still use refractors today. Refractors are good for viewing details within our solar system. Craters on the surface of Earth's Moon or the rings around Saturn are two such details.

Around 1670, Sir Isaac Newton built a different kind of telescope. Newton's telescope used curved mirrors instead of lenses to focus light. This type of telescope is called a **reflecting telescope**, or reflector (see **Figure** 23.5). The mirrors in a reflecting telescope are much lighter than the heavy glass lenses in a refractor. This is important because a refracting telescope must be much stronger to support the heavy glass.

It's much easier to precisely make mirrors than to precisely make glass lenses. For that reason, reflectors can be made larger than refractors. Larger telescopes can collect more light. This means that they can study dimmer or more distant objects. The largest optical telescopes in the world today are reflectors. Telescopes can also be made to use both lenses and mirrors.

For more on how telescopes were developed, visit http://galileo.rice.edu/sci/instruments/telescope.html .

Radio Telescopes

Radio telescopes collect radio waves. These telescopes are even larger telescopes than reflectors. Radio telescopes look a lot like satellite dishes. In fact, both are designed to collect and focus radio waves or microwaves from space.

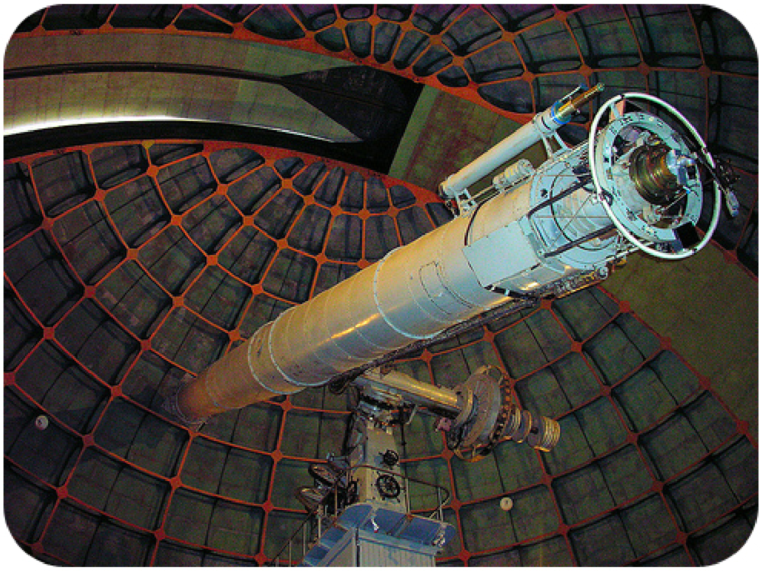

FIGURE 23.4
Refracting telescopes can be very large.

FIGURE 23.5
Newtonian reflector telescopes are fairly easy to make. These telescopes can be built by school students.

The largest single radio telescope in the world is at the Arecibo Observatory in Puerto Rico (see **Figure** 23.6). This telescope is located in a natural sinkhole. The sinkhole formed when water flowing underground dissolved the limestone. This telescope would collapse under its own weight if it were not supported by the ground. There is a big disadvantage to this design. The telescope can only observe the part of the sky that happens to be overhead at a given time.

A group of radio telescopes can be linked together with a computer. The telescopes observe the same object. The computer then combines the data from each telescope. This makes the group function like one single telescope. An example is shown in **Figure** 23.7.

To learn more about radio telescopes and radio astronomy in general, go to http://www.nrao.edu/whatisra/index.shtml .

FIGURE 23.6
The radio telescope at the Arecibo Observatory in Puerto Rico.

FIGURE 23.7
The Very Large Array in New Mexico consists of 27 radio telescopes.

Space Telescopes

Telescopes on Earth all have one big problem: Incoming light must pass through the atmosphere. This blocks some wavelengths of radiation. Also, motion in the atmosphere distorts light. You see this when you see stars twinkling in the night sky. Many observatories are built on high mountains. There is less air above the telescope, so there is less interference from the atmosphere. **Space telescopes** avoid such problems completely since they orbit outside the atmosphere.

The Hubble Space Telescope is the best known space telescope. Hubble is shown in **Figure** 23.8. Hubble began operations in 1994. Since then it has provided huge amounts of data. The telescope has helped astronomers answer many of the biggest questions in astronomy.

The National Aeronautics and Space Administration (NASA) has placed three other major space telescopes in orbit. Each uses a different part of the electromagnetic spectrum. The James Webb Space Telescope will launch in 2014.

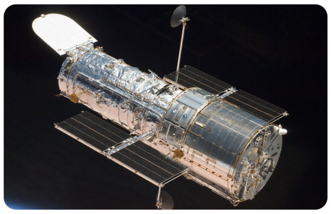

FIGURE 23.8
The Hubble Space Telescope has opened up the universe to human observation.

The telescope will replace the aging Hubble.

To learn more about NASA's great observatories, check out http://www.nasa.gov/audience/forstudents/postsecondary/features/F_NASA_Great_Observatories_PS.html .

FIGURE 23.9
Stars in the star cluster appear as points of light. Observations like these must be made with a space telescope.

Observations with Telescopes

Before Telescopes

Humans have been studying the night sky for thousands of years. Knowing the motions of stars helped people keep track of seasons. With this information they could know when to plant crops. Stars were so important that the patterns they made in the sky were named. These patterns are called **constellations**. Even now, constellations help astronomers know where they are looking in the night sky.

The ancient Greeks carefully observed the locations of stars in the sky. They noticed that some of the "stars" moved across the background of other stars. They called these bright spots in the sky **planets**. The word in Greek means "wanderers." Today we know that the planets are not stars. They are objects in the solar system that orbit the Sun. Ancient astronomers made all of their observations without the aid of a telescope.

Galileo's Observations

In 1610, Galileo looked at the night sky through the first telescope. This tool allowed him to make the following discoveries (among others):

- There are more stars in the night sky than the unaided eye can see.
- The band of light called the Milky Way consists of many stars.
- The Moon has craters (see **Figure** 23.10).
- Venus has phases like the Moon.

- Jupiter has moons orbiting around it.
- There are dark spots that move across the surface of the Sun.

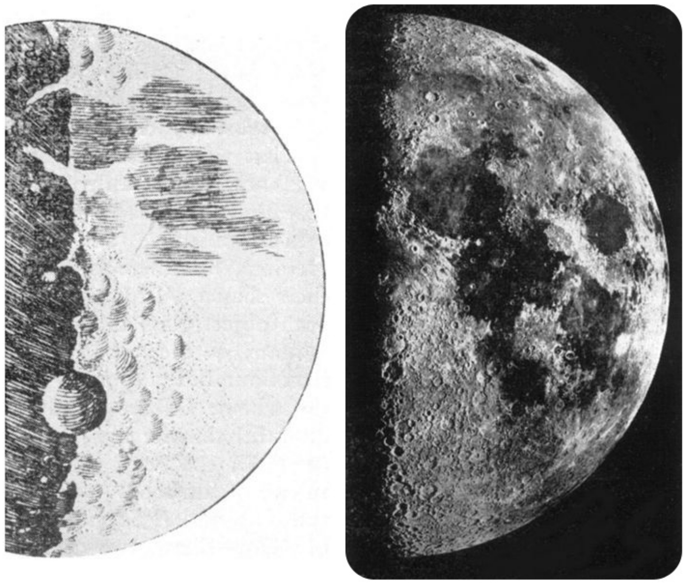

FIGURE 23.10
Galileo made the drawing on the left in 1610. On the right is a modern photograph of the Moon.

Galileo's observations made people think differently about the universe. They made them think about the solar system and Earth's place in it. Until that time, people believed that the Sun and planets revolved around Earth. One hundred years before Galileo, Copernicus had said that the Earth and the other planets revolved around the Sun. No one would believe him. But Galileo's observations through his telescope proved that Copernicus was right.

Observations with Modern Telescopes

Galileo's telescope got people to think about the solar system in the right way. Modern tools have also transformed our way of thinking about the universe. Imagine this: Today you can see all of the things Galileo saw using a good pair of binoculars. You can see sunspots if you have special filters on the lenses. (Never look directly at the Sun without using the proper filters!) With the most basic telescope, you can see polar caps on Mars, the rings of Saturn, and bands in the atmosphere of Jupiter.

You can see many times more stars with a telescope than without a telescope. Still, stars seen in a telescope look like single points of light. They are so far away. Only the red supergiant star Betelgeuse is large enough to appear as a disk. Except for our Sun, of course.

Today, astronomers attach special instruments to telescopes. This allows them to collect a wide variety of data. The data is fed into computers so that it can be studied. An astronomer may take weeks to analyze all of the data collected from just a single night!

Studying Starlight with Spectrometers

A **spectrometer** is a special tool that astronomers commonly use. Spectrometers allow them to study the light from a star or galaxy. A spectrometer produces a spectrum, like the one shown in **Figure** 23.11. A prism breaks light into all its colors. Gases from the outer atmosphere of a star absorb light. This forms dark lines in the spectrum. These dark lines reveal what elements the star contains.

Astronomers use the spectrum to learn even more about the star. One thing they learn is how hot the star is. They also learn the direction the star is going and how fast. By carefully studying light from many stars, astronomers

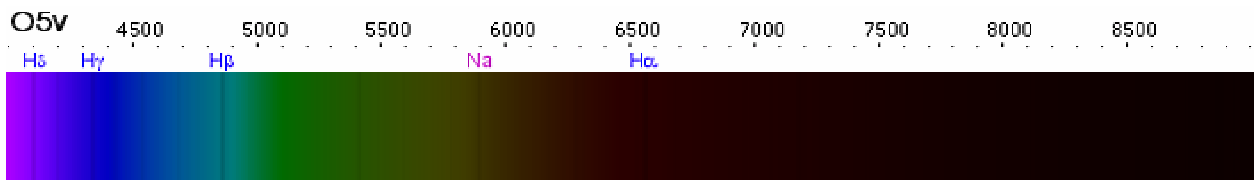

FIGURE 23.11
The dark lines indicate the elements that this star contains.

know how stars evolve. They have learned about the distribution and kinds of matter found throughout the universe. They even know something about how the universe might have formed.

To find out what you can expect to see when looking through a telescope, check out http://www.astronomics.com/main/category.asp/catalog_name/Astronomics/category_name/V1X41SU50GJB8NX88JQB360067/Page/1 .

Lesson Summary

- Astronomers study light from stars and galaxies.
- Light travels at 300,000,000 meters per second—faster than anything else in the universe.
- A light-year is a unit of distance equal to the distance light travels in one year, 9.5 trillion kilometers.
- When we see a star or galaxy, we see them as they were in the past, because their light has been traveling to us for many years.
- Light is energy that travels as a wave.
- Visible light is part of the electromagnetic spectrum.
- Telescopes make distant objects appear both nearer and larger. You can see many more stars through a telescope than with the unaided eye.
- Optical telescopes are designed to collect visible light. The two types of optical telescopes are reflecting telescopes and refracting telescopes.
- Radio telescopes collect and focus radio waves from distant objects.
- Space telescopes are telescopes orbiting Earth. They can collect wavelengths of light that are normally blocked by the atmosphere.
- Galileo was the first person known to use a telescope to study the sky. His discoveries helped change the way humans think about the universe.
- Modern telescopes collect data that can be stored on a computer.
- A spectrometer produces a spectrum from starlight. Astronomers can learn a lot about a star by studying its spectrum.

Lesson Review Questions

Recall

1. Define what is one "light year." What is a light year in numbers? Don't forget the units!

2. What is the speed of light? Why is this important to astronomers?

3. How do refracting telescopes work?

4. What are constellations? Why were they important to ancient people?

5. What did Galileo observe about Jupiter?

Apply Concepts

6. Picture the visible light spectrum. Where do ultraviolet wavelengths fall? Where do infrared wavelengths fall?

7. You look through a telescope at Rigel. Rigel is the brightest star in the Orion constellation. Rigel is around 800 light years from Earth. What are you looking at when you look through that telescope? What does Rigel look like today?

8. What can you learn from studying starlight through a spectrometer?

Think Critically

9. Why do astronomers need to look at more than just visible objects when studying space? What can they learn from objects in other wavelengths of radiation?

10. Identify four regions of the electromagnetic spectrum that astronomers use when observing objects in space.

11. How do reflecting telescopes work? What are the advantages and disadvantages of reflecting telescopes over refracting telescopes?

12. If you wanted to study the most distant galaxies what sort of tool would you design and why?

Points to Consider

- Radio waves are used for communicating with spacecraft. A round-trip communication from Earth to Mars takes anywhere from 6 to 42 minutes. What challenges might this present for sending unmanned spacecraft and probes to Mars?
- The Hubble Space Telescope is a very important source of data for astronomers. The fascinating and beautiful images from the Hubble also help to maintain public support for science. However, the Hubble is growing old. Missions to service and maintain the telescope are extremely expensive and put the lives of astronauts at risk. Do you think there should be another servicing mission to the Hubble?

23.2 Early Space Exploration

Lesson Objectives

- Explain how a rocket works.
- Describe different types of satellites.
- Outline major events in early space exploration, including the Space Race.

Vocabulary

- orbit
- rocket
- satellite
- space probe
- Space Race
- thrust

Introduction

Telescopes made objects in space seem closer. But they didn't make it any easier to visit them. Human space flight required something entirely different: rockets.

Rockets

Humans did not reach space until the second half of the 20th century. They needed somehow to break past Earth's gravity. A **rocket** moves rapidly in one direction. The device is propelled by particles flying out of it at high speed in the other direction. There are records of the Chinese using rockets in war against the Mongols as early as the 13th century. The Mongols then used rockets to attack Eastern Europe. Early rockets were also used to launch fireworks.

How Rockets Work

Rockets were used for centuries before anyone could explain how they worked. The theory came about in 1687. Isaac Newton (1643–1727) described three basic laws of motion, now referred to as Newton's Laws of Motion:

1. An object in motion will remain in motion unless acted upon by a force.
2. Force equals mass multiplied by acceleration.
3. To every action, there is an equal and opposite reaction.

Which of these three best explains how a rocket works? Newton's third law of motion. When a rocket's propulsion pushes in one direction, the rocket moves in the opposite direction, as seen in the **Figure** 23.12.

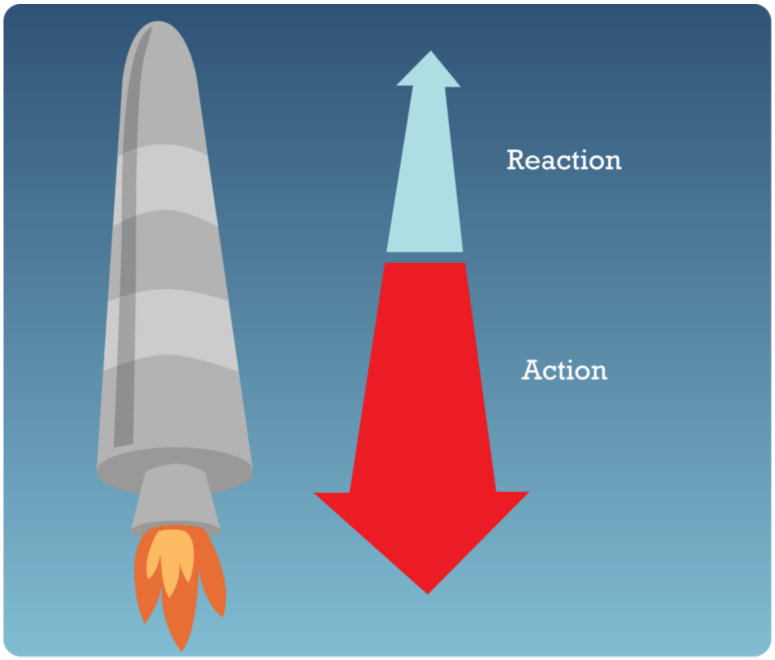

FIGURE 23.12
A rocket pushes in one direction so that it moves in the opposite direction.

For a long time, many people believed that a rocket wouldn't work in space. There would be nothing for the rocket to push against. But they do work! Fuel is ignited in a chamber. The gases in the chamber explode. The explosion creates pressure that forces the gases out of one side of the rocket. The rocket moves in the opposite direction, as shown in **Figure** 23.13. The force pushing the rocket is called **thrust**.

A Rocket Revolution

For centuries, rockets were powered by gunpowder or other solid fuels. These rockets could travel only short distances. Around the turn of the 20th century, several breakthroughs took place. These breakthroughs led to rockets that could travel beyond Earth. Liquid fuel gave rockets enough power to escape Earth's gravity (**Figure** 23.14). By using multiple stages, empty fuel containers could drop away. This reduced the mass of the rocket so that it could fly higher.

Rockets were used during World War II. The V2 was the first human-made object to travel high enough to be considered in space (**Figure** 23.15). Its altitude was 176 km (109 miles) above Earth's surface.

Wernher von Braun was a German rocket scientist. After he fled Germany in WWII, he helped the United States develop missile weapons. After the war, von Braun worked for NASA. He designed the Saturn V rocket (**Figure** 23.16), which sent the first humans to the Moon.

Satellites

One of the first uses of rockets in space was to launch satellites. A **satellite** is an object that orbits a larger object. An **orbit** is a circular or elliptical path around an object. Natural objects in orbit are called natural satellites. The Moon

FIGURE 23.13
This missile is pushed upwards into the sky by its thrust.

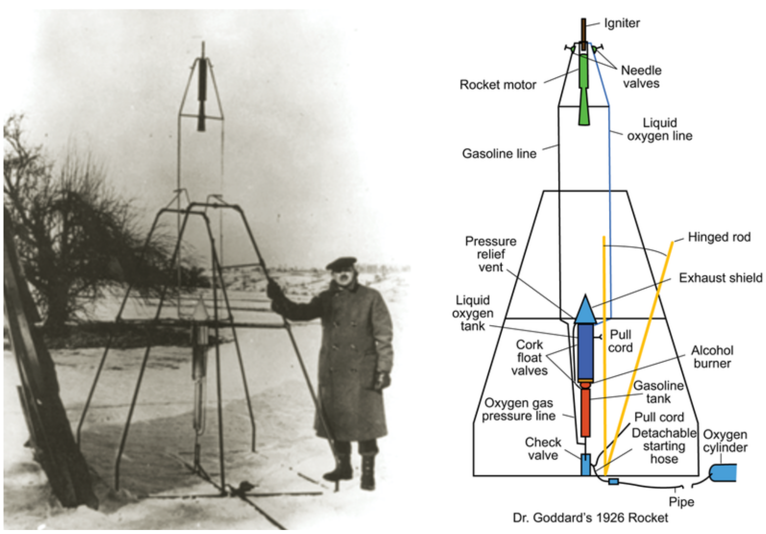

FIGURE 23.14
Robert Goddard with the first American rocket to use liquid fuel. This rocket was launched in 1926.

is a natural satellite. Human-made objects in orbit are called artificial satellites. There are more and more artificial satellites orbiting Earth all the time. They all get into space using some sort of rocket.

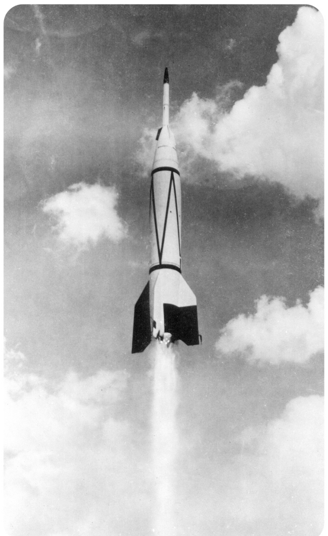

FIGURE 23.15
A captured German V2 rocket was launched in New Mexico after the war.

FIGURE 23.16
This Saturn V rocket took the first men to the Moon during Apollo 11.

How Satellites Stay in Orbit

Why do satellites stay in orbit? Why don't they crash into Earth due to the planet's gravity? Newton's law of universal gravitation describes what happens. Every object in the universe is attracted to every other object. Gravity makes an apple fall to the ground. Gravity also keeps you from floating away into the sky. Gravity holds the Moon in orbit around Earth. It keeps Earth in orbit around the Sun.

Newton used an example to explain how gravity makes orbiting possible. Imagine a cannonball launched from a high mountain, as shown in **Figure** 23.17. If the cannonball is launched at a slow speed, it will fall back to Earth. This is shown as paths (A) and (B). Something different happens if the cannonball is launched at a fast speed. The Earth below curves away at the same rate that the cannonball falls. The cannonball then goes into a circular orbit, as in path (C). If the cannonball is launched even faster, it could go into an elliptical orbit (D). It might even leave Earth's gravity and go into space (E).

Unfortunately, Newton's idea would not work in real life. A cannonball launched at a fast speed from Mt. Everest would not go into orbit. The cannonball would burn up in the atmosphere. However, a rocket can launch straight up, then steer into orbit. It won't burn up in the orbit. A rocket can carry a satellite above the atmosphere and then release the satellite into orbit.

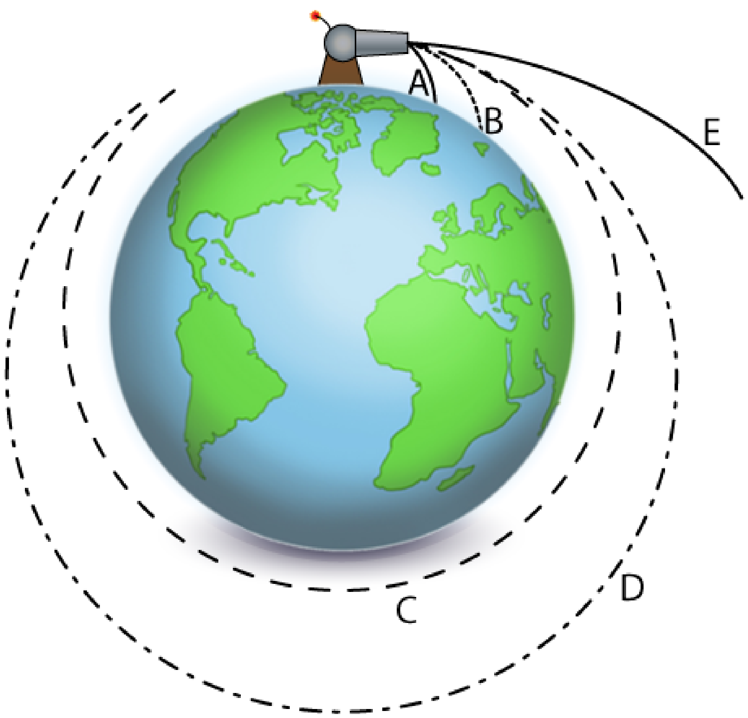

FIGURE 23.17
Isaac Newton explained how a cannonball fired from a high point with enough speed could orbit Earth.

Types of Satellites

The first artificial satellite was launched just over 50 years ago. Thousands are now in orbit around Earth. Satellites have orbited other objects in the solar system. These include the Moon, the Sun, Venus, Mars, Jupiter, and Saturn. Satellites have many different purposes.

- Imaging satellites take pictures Earth's surface. These images are used for military or scientific purposes.
- Astronomers use imaging satellites to study and make maps of the Moon and other planets.
- Communications satellites, such as the one in **Figure** 23.18, are now extremely common. These satellites receive and send signals for telephone, television, or other types of communications.
- Navigational satellites are used for navigation systems, such as the Global Positioning System (GPS).
- The largest artificial satellite is the International Space Station. The ISS is designed for humans to live in space while conducting scientific research.

Earth Science Satellites

Dozens of satellites collect data about the Earth. One example is NASA's Landsat satellites. These satellites make detailed images of Earth's continents and coastal areas. Other satellites study the oceans, atmosphere, polar ice sheets, and other Earth systems. This data helps us to monitor climate change. Other long-term changes in the planet are also best seen from space. Satellite images help scientists understand how Earth's systems affect one another. Different satellites monitor different wavelengths of energy, as in **Figure** 23.19.

Types of Orbits

Satellites have different views depending on their orbit. Satellites may be put in a low orbit. These satellites orbit from north to south over the poles. These satellites view a different part of Earth each time they circle. Imaging and

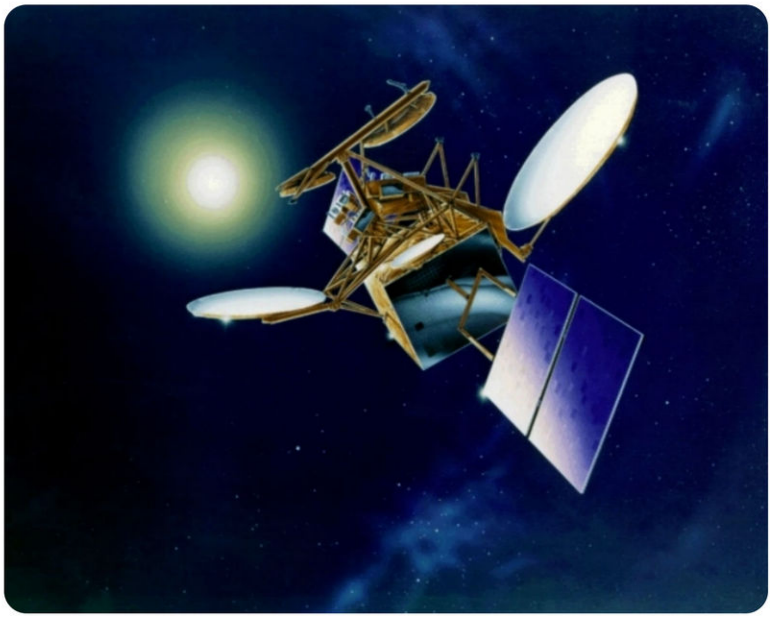

FIGURE 23.18
Communications satellites carry solar panels to provide energy for their missions.

weather satellites need this type of view.

Satellite may be placed so that they orbit at the same rate the Earth spins. The satellite then remains over the same location on the surface. Communications satellites are often placed in these orbits.

The Space Race

The Cold War was between the Soviet Union (USSR) and the United States. The war lasted from the end of World War II in 1945 to the breakup of the USSR in 1991. The hallmark of the Cold War was an arms race. The two nations spared no expense to create new and more powerful weapons. The development of better missiles fostered better rocket technologies.

Sputnik

The USSR launched Sputnik 1 on October 4, 1957. This was the first artificial satellite ever put into orbit. Sputnik 1, shown in **Figure** 23.20, sent out radio signals, which were detected by scientists and amateur radio operators around the world. The satellite stayed in orbit for about 3 months, until it burned up as a result of friction with Earth's atmosphere.

The launch of Sputnik 1 started the **Space Race** between the USSR and the USA. Americans were shocked that the Soviets had the technology to put the satellite into orbit. They worried that the Soviets might also be winning the arms race. On November 3, 1957, the Soviets launched Sputnik 2. This satellite carried the first living creature into orbit, a dog named Laika.

The Race Is On

In response to Sputnik program, the U.S. launched two satellites. Explorer I was launched on January 31, 1958 and Vanguard 1 on March 17, 1958. National Aeronautics and Space Administration (NASA) was established that same

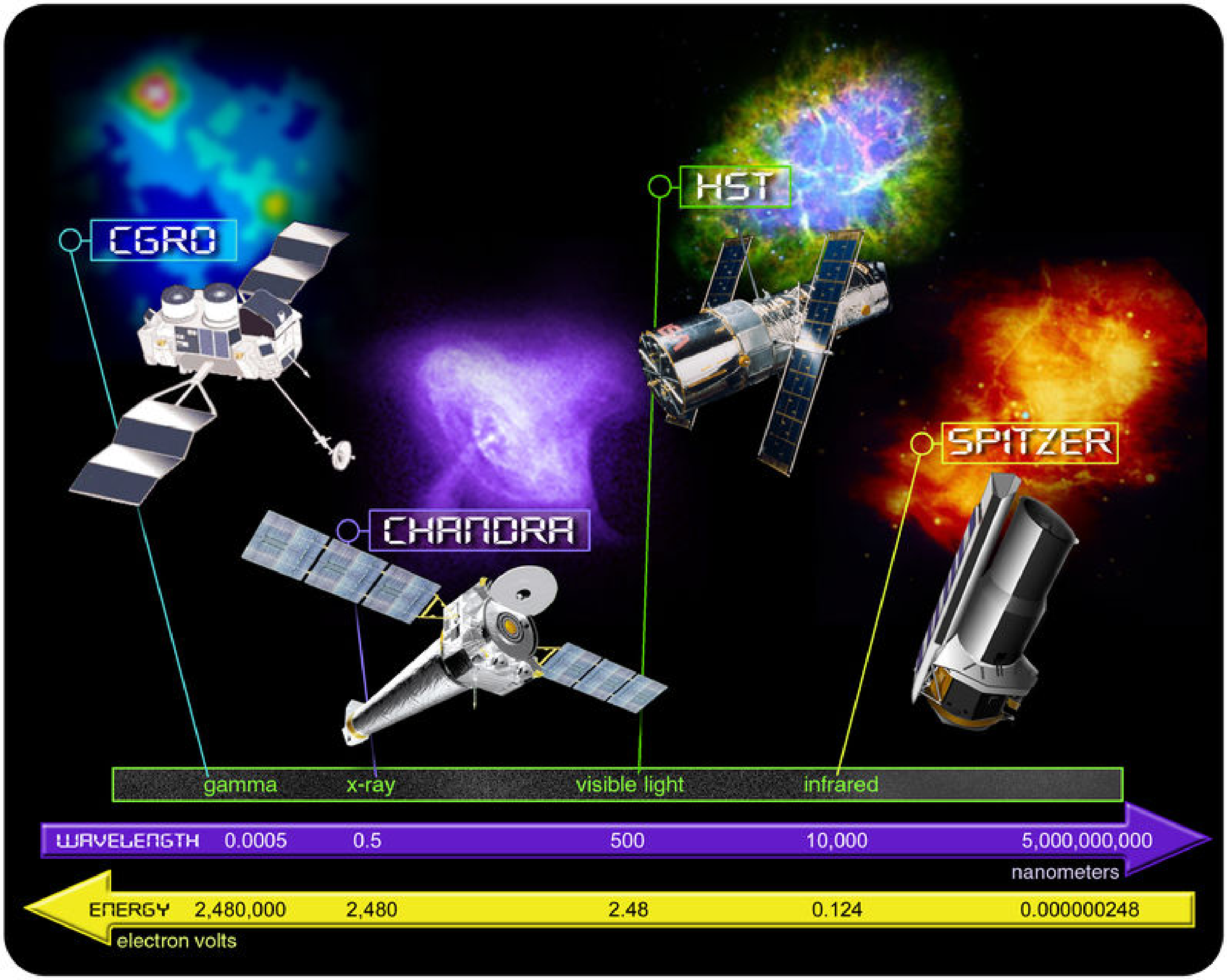

FIGURE 23.19
Satellites detect different wavelengths of energy. This means that they can find different types of objects.

year.

The race was on! On April 12, 1961, a Soviet cosmonaut became the first human in space and in orbit. Less than one month later —May 5, 1961 —the U.S. sent its first astronaut into space: Alan Shepherd. The first American in orbit was John Glenn, in February 1962. And on it went.

Reaching the Moon

On May 25, 1961, President John F. Kennedy challenged the U.S. Congress:

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him back safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish."

The Soviets were also trying to reach the Moon. Who would win? The answer came eight years after Kennedy's

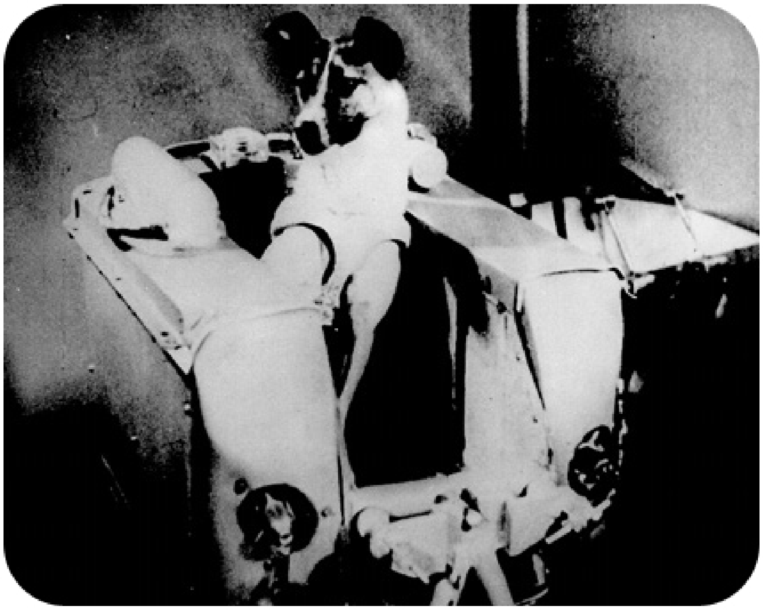

FIGURE 23.20

Laika went into orbit on the Soviet spacecraft, Sputnik 2.

challenge, on July 20, 1969. NASA's Apollo 11 mission put astronauts Neil Armstrong and Buzz Aldrin on the Moon, as shown in **Figure** 23.21.

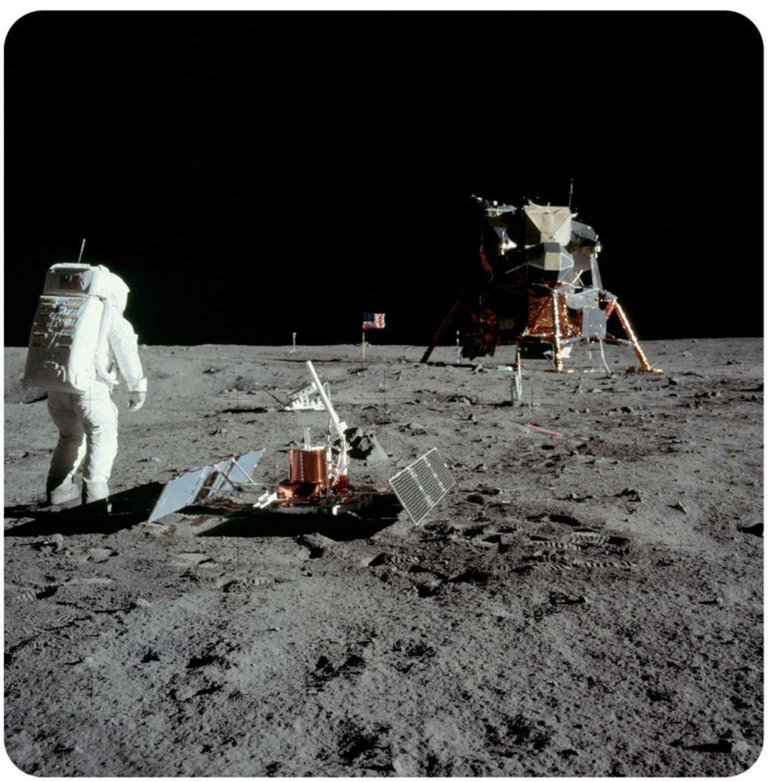

FIGURE 23.21

Apollo 11 astronaut Buzz Aldrin with the Lunar Module "Eagle" and the American flag in the background. The photo was taken by Commander Neil Armstrong.

A total of five American missions put astronauts on the Moon. The last was Apollo 17. This mission landed on December 11, 1972. No other country has yet put a person on the Moon. Today, most space missions are done by nations working together.

Exploring Other Planets

Both the United States and the Soviet Union sent space probes to other planets. A **space probe** is an unmanned spacecraft. The craft collects data by flying near or landing on an object in space. This could be a planet, moon, asteroid, or comet. The USSR sent several probes to Venus in the Venera missions. Some landed on the surface and sent back data. The U.S. sent probes to Mercury, Venus, and Mars in the Mariner missions. Two probes landed on Mars during the Viking missions.

The U.S. also sent probes to the outer solar system. These probes conducted fly-bys of Jupiter, Saturn, Uranus, and Neptune. The Pioneer and Voyager probes are now out beyond the edges of our solar system. We have lost contact with the two Pioneer probes. We hope to maintain contact with the two Voyager probes until at least 2020.

Lesson Summary

- Rockets have been used for many centuries.
- Newton's third law explains how a rocket works. The action force of the engine on the gases is accompanied by a reaction force of the gases on the rocket.
- Good ideas for rocket design included using liquid fuel and multiple stages.
- A satellite orbits a larger object. Moons are natural satellites. Artificial satellites are made by humans.
- Newton's law of universal gravitation explains how the force of gravity works, both on Earth and across space. Gravity holds satellites in orbit.
- Artificial satellites are used to take pictures of Earth and other planets, for navigation, and for communication.
- The launch of the Sputnik 1 satellite started the Space Race between the United States and the Soviet Union.
- The United States' Apollo 11 mission put the first humans on the Moon.
- The U.S. and Soviet Union also sent several probes to other planets.

Lesson Review Questions

Recall

1. How does a rocket work?

2. What was Sputnik? Why is that event so important in U.S. history?

3. What was the Space Race?

Apply Concepts

4. Why would liquid fuel be better than solid fuel to power a rocket?

5. Why are multiple stages better than a single rocket?

6. What is the value of satellites that can take images all around Earth within hours of each other?

7. What is the value of satellites that can remain in place over time?

Think Critically

8. Design an experiment that would use the capability of a satellite that can take photos of the same place on the same date each year for many years.

9. It's common to hear someone say "if we can put a man on the Moon we can do xxx." What might xxx be? What are they saying when they make this statement?

Points to Consider

- The Space Race and the USA's desire to get to the Moon brought about many advances in science and technology. Can you think of any challenges we face today that are, could be, or should be a focus of science and technology?
- If you were in charge of NASA, what new goals would you set for space exploration?

23.3 Recent Space Exploration

Lesson Objectives

- Outline the history of space stations and space shuttles.
- Describe recent developments in space exploration.

Vocabulary

- orbiter
- space shuttle
- space station

Space Shuttles and Space Stations

While the United States continued missions to the Moon in the early 1970s, the Soviets worked to build a space station. A **space station** is a large spacecraft. People can live on this craft for a long period of time.

Early Space Stations

Between 1971 and 1982, the Soviets put a total of seven Salyut space stations into orbit. **Figure** 23.22 shows the last of these, Salyut 7. These were all temporary stations. They were launched and later inhabited by a human crew. Three of the Salyut stations were used for secret military purposes. The others were used to study the problems of living in space. Cosmonauts aboard the stations performed a variety of experiments in astronomy, biology, and Earth science. Salyut 6 and Salyut 7 each had two docking ports. One crew could dock a spacecraft to one end. A replacement crew could dock to the other end.

The U.S. only launched one space station during this time. It was called Skylab. Skylab was launched in May 1973. Three crews visited Skylab, all within its first year in orbit. Skylab was used to study the effects of staying in space for long period. Devices on board were and for studying the Sun. Skylab reentered Earth's atmosphere in 1979, sooner than expected.

Modular Space Stations

The first space station designed for long-term use was the Mir space station (**Figure** 23.23). Mir was launched in several separate pieces. These pieces were put together in space. Mir holds the current record for the longest continued presence in space. There were people living on Mir continuously for almost 10 years!

Mir was the first major space project in which the United States and Russia worked together. American space shuttles transported supplies and people to and from Mir. American astronauts lived on Mir for many months. This

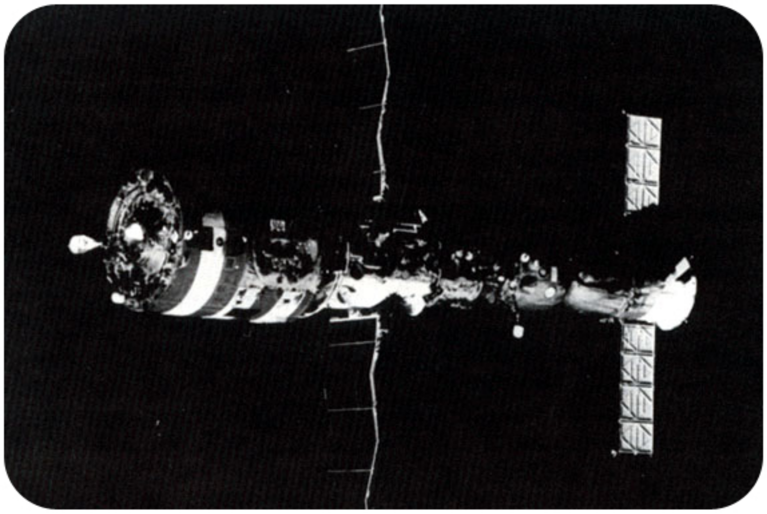

FIGURE 23.22
Salyut 7 with a docked spacecraft to bring crew on and off.

cooperation allowed the two nations to learn from each other. The U.S. learned about Russia's experiences with long-duration space flights. Mir was taken out of orbit in 2001. It fell into the Pacific Ocean.

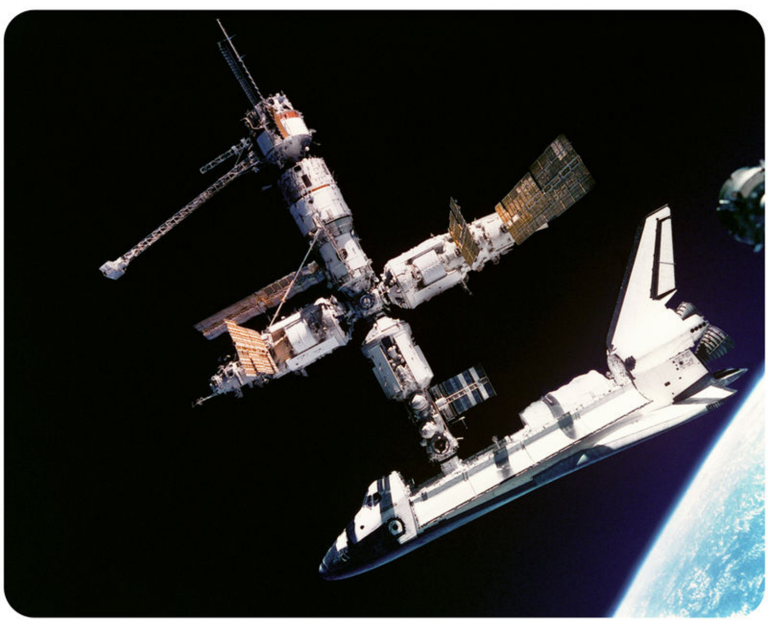

FIGURE 23.23
Mir, with an American space shuttle attached.

The International Space Station

The International Space Station, shown in **Figure** 23.24 is a joint project between the space agencies of many nations These include the United States (NASA), Russia (RKA), Japan (JAXA), Canada (CSA), several European countries (ESA) and the Brazilian Space Agency.

The International Space Station is a very large station. It has many different sections and is still being assembled. The station has had people on board since 2000. American space shuttles deliver most of the supplies and equipment to the station. Russian Soyuz spacecraft carry people. The primary purpose of the station is scientific research.

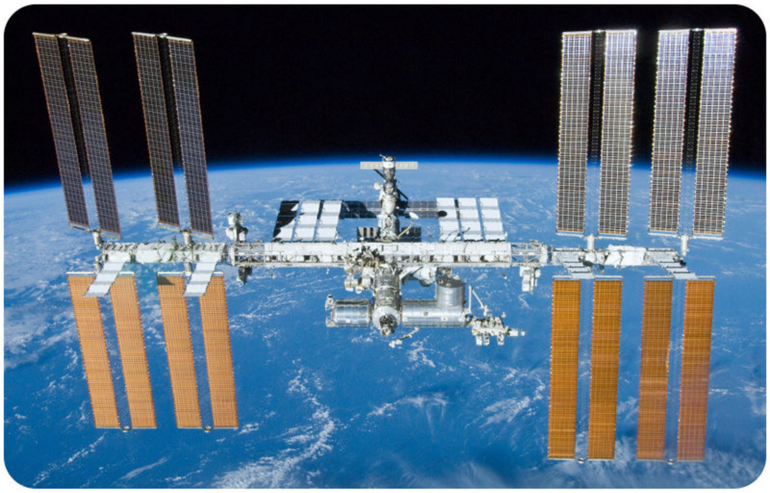

FIGURE 23.24
The International Space Station, as photographed from the Space Shuttle Atlantis in May 2010.

This is important because the station has a microgravity environment. Experiments are done in the fields of biology, chemistry, physics, physiology and medicine.

Space Shuttles

NASA wanted a new kind of space vehicle. This vehicle had to be reusable. It had to able to carry large pieces of equipment, such as satellites, space telescopes, or sections of a space station. The new vehicle was called a **space shuttle**, shown in **Figure** 23.25. There have been five space shuttles: Columbia, Challenger, Discovery, Atlantis, and Endeavor.

FIGURE 23.25
The space shuttle Atlantis rides a specialized Boeing 747 from its landing site in California back to Florida.

A space shuttle has three main parts. You are probably most familiar with the **orbiter**. This part has wings like an airplane. The shuttle is launched from Kennedy Space Center in Cape Canaveral, Florida. During launches, the orbiter is attached to a huge fuel tank that contains liquid fuel. On the sides of the fuel tank are two large booster rockets.

Figure 23.26 shows the stages of a normal space shuttle mission. Once in space, the orbiter can deliver equipment or supplies to the International Space Station. Astronauts can to repair orbiting equipment such as the Hubble Space Telescope. They may also do experiments directly on board the orbiter.

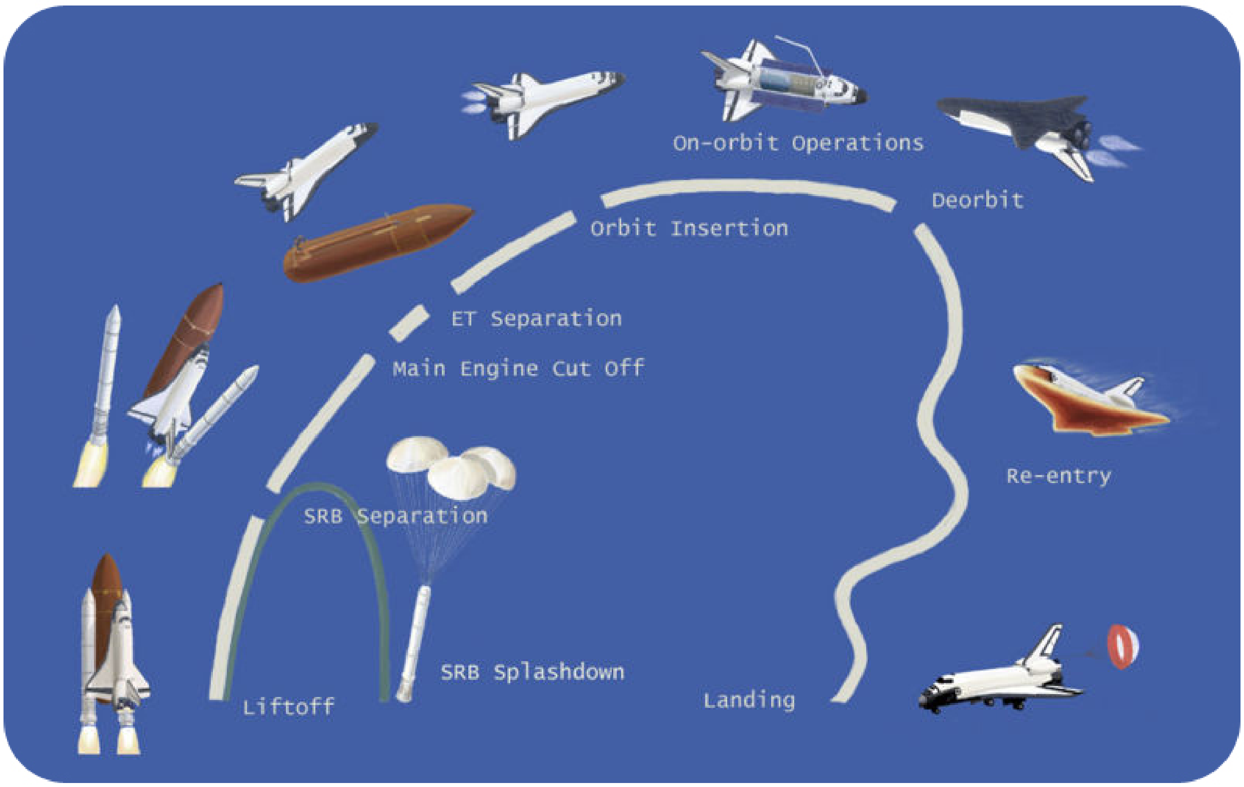

FIGURE 23.26
The stages of a shuttle mission. The orbiter takes off like a rocket and lands like an airplane.

At the end of the mission, the orbiter re-enters Earth's atmosphere. The outside heats up as it descends. Pilots have to steer the shuttle to the runway very precisely. Space shuttles usually land at Kennedy Space Center or at Edwards Air Force Base in California. The orbiter is later hauled back to Florida on the back of a jet airplane.

Space Shuttle Disasters

The space shuttle program has been very successful. Over 100 mission have been flown. Space shuttle missions have made many scientific discoveries. Crews have launched many satellites. There have been other great achievements in space. However, the program has also had two tragic disasters.

The first came just 73 seconds after launch, on January 28, 1986. The space shuttle Challenger disintegrated in mid-air, as shown in **Figure** 23.27. On board were seven crew members. All of them died. One of them was Christa McAuliffe, who was to be the first teacher in space. The problem was later shown to be an O-ring. This small part was in one of the rocket boosters. Space shuttle missions were put on hold while NASA improved the safety of the shuttles.

FIGURE 23.27
The disasters on the Challenger space shuttle mission showed just how dangerous space travel can be.

The second occurred during the takeoff of the Columbia on January 16, 2003. A small piece of insulating foam broke off the fuel tank. The foam smashed into a tile on the shuttle's wing. The tile was part of the shuttle's heat shield. The shield protects the shuttle from extremely high temperatures as it reenters the atmosphere. When Columbia returned to Earth on February 3, 2003, it could not withstand the high temperatures. The shuttle broke apart. Again, all seven crew members died.

The space shuttle will be retired in 2011. All the remaining shuttle missions will be to the ISS. Orion will replace the shuttle. Known as a Crew Exploration Vehicle, Orion is expected to be ready by 2016.

Recent Space Missions

The disasters have caused NASA to focus on developing unmanned missions. Missions without a crew are less expensive and less dangerous. These missions still provide a great deal of valuable information.

Space Telescopes

Incredible images have come from the Hubble Space Telescope (HST). Even more incredible scientific discoveries have come from HST. The Hubble was the first telescope in space. It was put into orbit by the space shuttle Discovery in 1990. Since then, four shuttle missions have gone to the Hubble to make repairs and upgrades. The last repair mission to the Hubble happened in 2009. An example of a HST image is in **Figure** 23.28,

Solar System Exploration

We continue to explore the solar system. A rover is like a spacecraft on wheels (**Figure** 23.29). It can wheel around on the surface. Scientists on Earth tell it where to go. The craft then collects and sends back data from that locations.

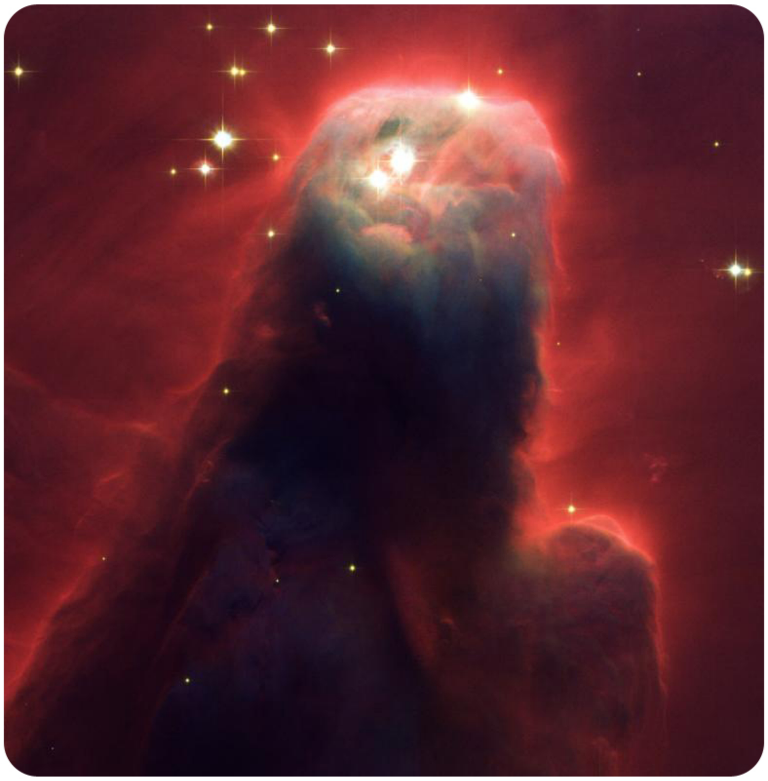

FIGURE 23.28
The Cone Nebula is a star-forming pillar of gas and dust.

The Mars Pathfinder studied the red planet for nearly three months in 1997. Two more rovers, Spirit and Opportunity, landed on Mars in 2004. Both were only designed to last 90 days, but have lasted many times longer. Spirit sent back data until it became stuck in January 2010. Opportunity continues to explore Mars. Several spacecraft are currently in orbit, studying the Martian surface and thin atmosphere.

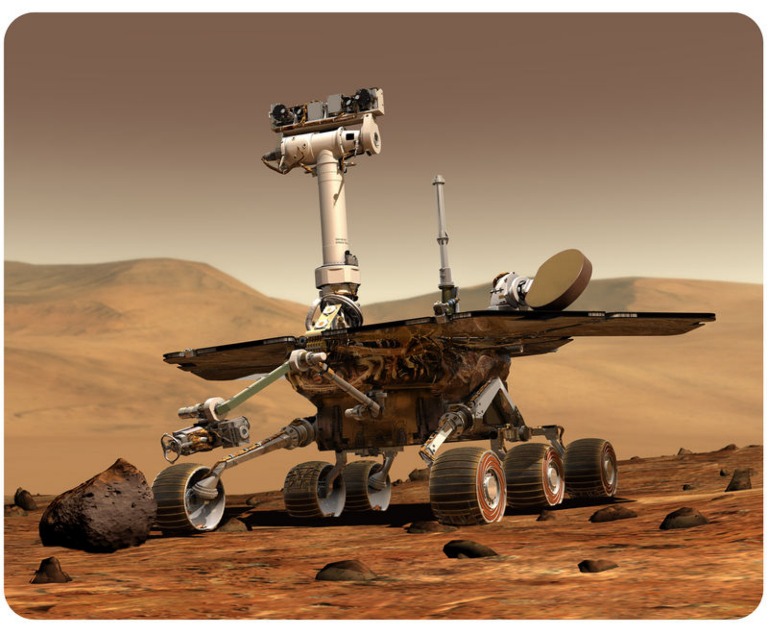

FIGURE 23.29
This artist's painting of one of the two Mars rovers shows the six wheels, as well as a set of instruments being extended forward by a robotic arm.

The Cassini mission has been studying Saturn, including its rings and moons, since 2004. The Huygens probe is studying Saturn's moon Titan. Titan has some of the conditions that are needed to support life.

Some missions visit the smaller objects in our solar system. The Deep Impact Probe collided with a comet in 2005. The probe sent back data from the impact. The Stardust mission visited another comet. There it collected tiny dust particles. Missions are underway to study some asteroids and Pluto. Small objects in our solar system may help us to understand how the solar system formed.

Future Missions

Budget concerns have impacted NASA in recent years. Many scientists have come together to discuss the goals of the U.S. space program. Some would like to further explore the Moon. Others are interested in landing on Mars. A variety of destinations in the inner solar system may also be visited. Private aerospace companies will play more of a role in the coming years.

MITK12 Videos: Science Out Loud

How to Discover a New Planet

Thousands of planets - ones that look totally different than what we're used to, and possibly could support life, exist outside of our solar system. But we're only just now starting to find them. In the video below, Ashley takes you behind the simple technique that astronomers have been using to discover these curious new planets.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/142990

Lesson Summary

- The Soviet Union put seven Salyut space stations into orbit between 1971 and 1982.
- The United States' first space station was Skylab. Skylab was in orbit from 1973 to 1979.
- The Soviet (later Russian) space station Mir was the first modular space station.
- The International Space Station involves many countries.
- Space shuttles are reusable vehicles for American astronauts to get into space.
- Recent space missions have mostly used small spacecraft, such as satellites and space probes, without crews.

Lesson Review Questions

Recall

1. What is a space station?

2. What is a space shuttle?

Apply Concepts

3. What is the purpose of a rover visiting a planet?
4. How is international cooperation helpful in space exploration?
5. How is international cooperation maybe harmful to space exploration?

Think Critically

6. Why don't we send astronauts to Mars?
7. What feature or features would you put in a future shuttle to avoid disasters?
8. Would you go into space in a shuttle? Why or why not?
9. Given the potential for disaster do you support manned space flight?

Points to Consider

- To date, a total of 22 people have died on space missions. In the two space shuttle disasters alone, 14 people died. However, space exploration and research have led to many great discoveries and new technologies. Do you think sending people into space is worth the risk? Why or why not?
- In the past several years, private companies have been developing vehicles and launch systems that can take people into space. What applications can you think of for such vehicles? What advantages and disadvantages are there to private companies building and launching spacecraft?

23.4 References

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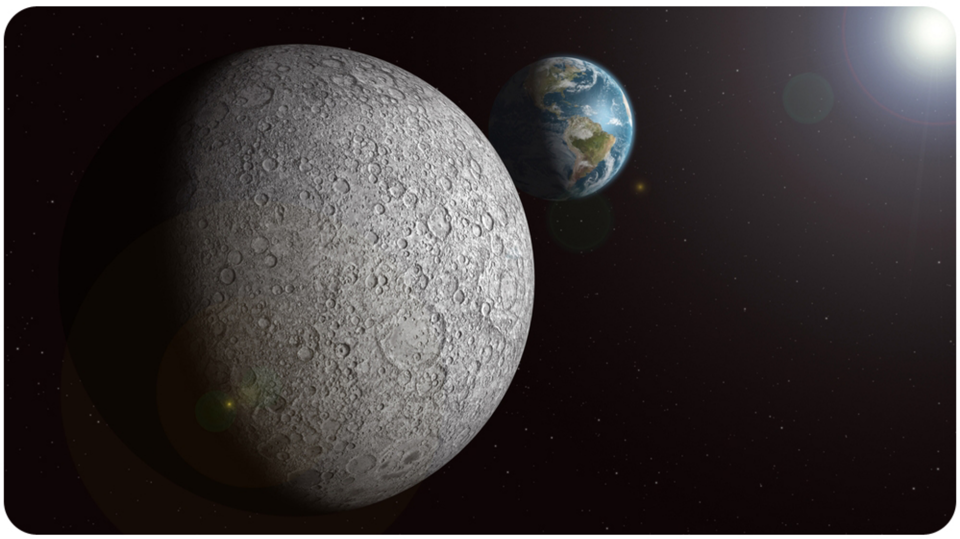
Chapter 24 MS Earth, Moon, and Sun

Chapter Outline



From out in the solar system, Earth and Moon appear as one dot of light. The two bodies are linked tightly together by their mutual gravitational attraction. Yet they could hardly look more different. One reveals nothing but craters, geologically dead. The other is covered with blue oceans, swirling clouds, and lands that vary from brown to bright green. Despite their differences, the two bodies have a shared history. Moon was born from Earth's side! Both of these bodies share the same spot in space, a spot as the 3rd object out from the Sun. The Sun may be an ordinary star, but it reveals all sorts of wonders for the interested observer.

24.1 Planet Earth

Lesson Objectives

- Describe some of the characteristics of Earth.
- Describe how gravity affects Earth in the solar system.
- Explain Earth's magnetism, and its effects.
- Describe Earth's rotation on its axis.
- Describe Earth's revolution around the Sun.

Vocabulary

- axis
- biosphere
- gravity
- hemisphere
- hydrosphere
- magnetic field
- revolution
- rotation

Introduction

This section is called *Planet Earth*. Isn't that what nearly this whole book has been about so far? Yes! In this section we will look at Earth as a planet. Some information will be review from other chapters. Some will be new information.

Earth's Shape, Size, and Mass

As you walk, the ground usually looks pretty flat, even though the Earth is round. How do we know this? We have pictures of Earth taken from space that show that Earth is round. Astronauts aboard the Apollo 17 shuttle took this one, called "The Blue Marble" (**Figure** 24.1). Earth looks like a giant blue and white ball.

Long before spacecraft took photos of Earth from space, people knew that Earth was round. How? One way was to look at ships sailing off into the distance. What do you see when you watch a tall ship sail over the horizon of the Earth? The bottom part of the ship disappears faster than the top part. What would that ship look like if Earth was flat? No part of it would disappear before the other. It would all just get smaller as it moved further away.

In the solar system, the planets orbit around the Sun. The Sun and each of the planets of our solar system are round. Earth is the third planet from the Sun. It is one of the inner planets. Jupiter is an outer planet. It is the largest planet

FIGURE 24.1
This is how the Earth looks from space - like a blue and white marble.

in the solar system at about 1,000 times the size of Earth. The Sun is about 1,000 times bigger than Jupiter! (**Figure** 24.2).

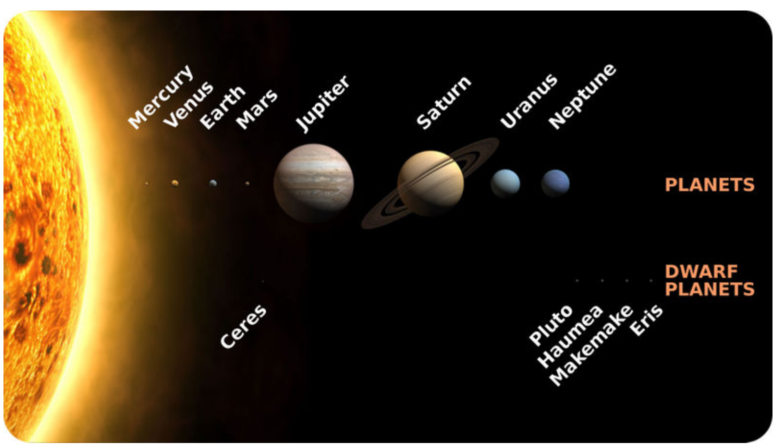


FIGURE 24.2
Compare the Sun with the other planets and see how the Sun is much bigger than all the other planets.

The outer planets in the solar system are giant balls of swirling gas. Earth and the other inner planets are relatively small, dense, and rocky. Most of Earth's surface is covered with water. As far as we know, Earth is also the only planet that has liquid water. Earth's atmosphere has oxygen. The water and oxygen are crucial to life as we know it. Earth appears to be the only planet in the solar system with living creatures. You can learn more about the planets in the *Our Solar System* chapter.

Some of the different parts of the Earth are our:

- Atmosphere: the thin layer of air, mostly nitrogen and oxygen, that surrounds the Earth.
- **Hydrosphere**: all the water on Earth.
- **Biosphere**: all the living organisms on Earth.
- Lithosphere: the solid rock part of Earth, including mountains, valleys, continents, and all of the rock beneath the oceans.

Since Earth is round, the layers all have the word sphere at the end (**Figure** 24.3). All of Earth's layers interact. Therefore, Earth's surface is constantly undergoing change.

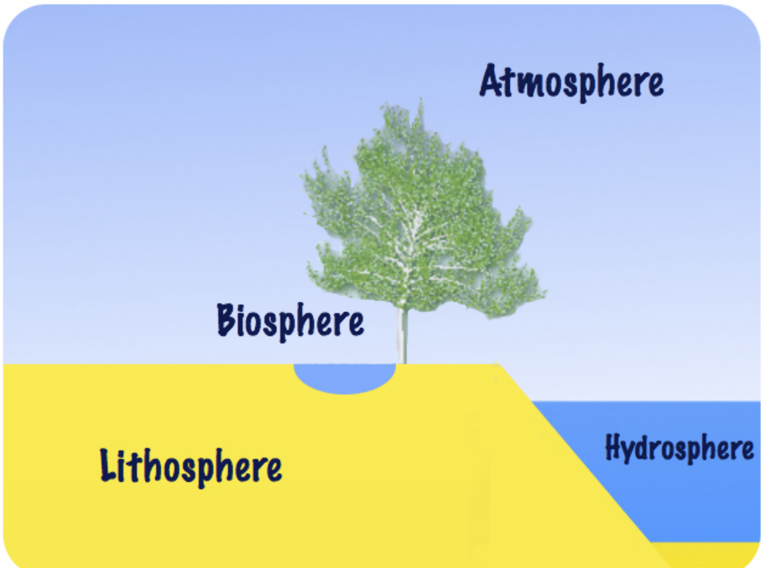


FIGURE 24.3
Earth has four layers: atmosphere, hydrosphere, biosphere, and lithosphere.

Earth's Gravity

Earth and Moon orbit each other. This Earth-Moon system orbits the Sun in a regular path (**Figure** 24.4). **Gravity** is the force of attraction between all objects. Gravity keeps the Earth and Moon in their orbits. Earth's gravity pulls the Moon toward Earth's center. Without gravity, the Moon would continue moving in a straight line off into space.

All objects in the universe have a gravitational attraction to each other (**Figure** 24.5). The strength of the force of gravity depends on two things. They are the mass of the objects and the distance between them. The greater the objects' mass, the greater the force of attraction. As the distance between the objects increases, the force of attraction decreases.

Earth's Magnetism

Earth has a **magnetic field** (**Figure** 24.6). The magnetic field has north and south poles. The field extends several thousand kilometers into space. Earth's magnetic field is created by the movements of molten metal in the outer core.

Earth's magnetic field shields us from harmful radiation from the Sun (**Figure** 24.7).

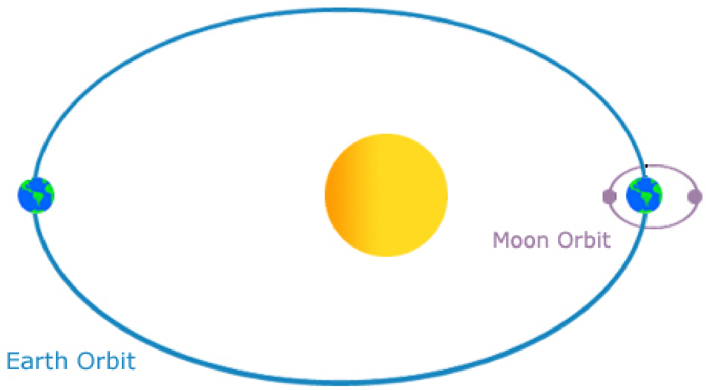


FIGURE 24.4
The Moon orbits the Earth, and the Earth-Moon system orbits the Sun.

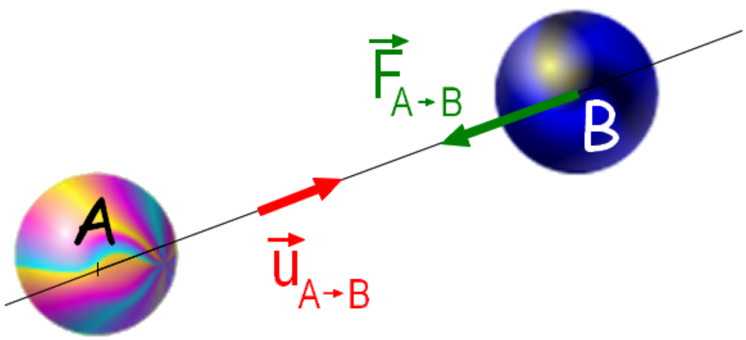


FIGURE 24.5
The strength of the force of gravity between objects A and B depends on the mass of the objects and the distance (*u*) between them.

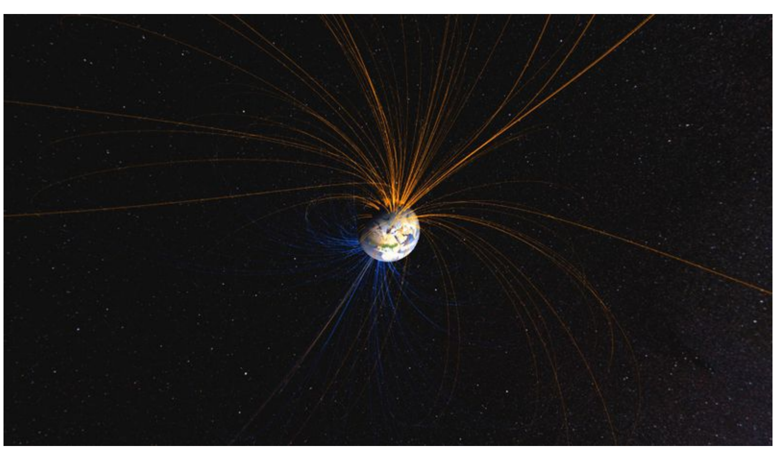


FIGURE 24.6
Earth's magnetic field extends into space.

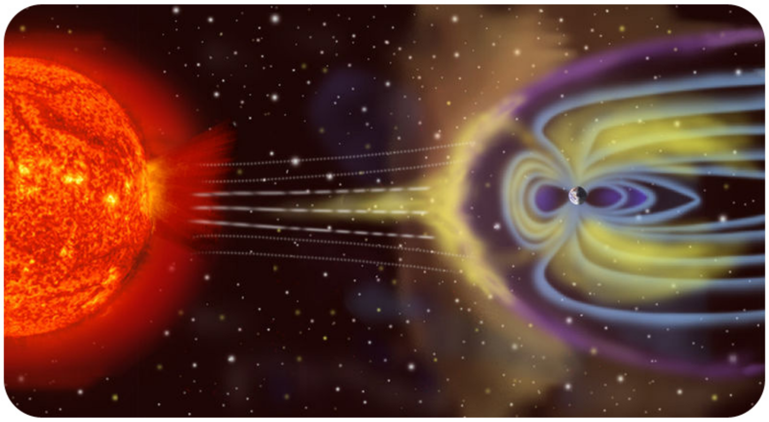


FIGURE 24.7
Earth's magnetic field protects the planet from harmful radiation.

If you have a large bar magnet, you can hang it from a string. Then watch as it aligns itself in a north-south direction, in response to Earth's magnetic field. A compass needle also aligns with Earth's magnetic field. People can navigate by finding magnetic north (**Figure** 24.8).

FIGURE 24.8
The needle of a compass will align with Earth's magnetic field, making the compass a useful device for navigation.

Earth's Motions

Earth's **axis** is an imaginary line passing through the North and South Poles. Earth's **rotation** is its spins on its axis. Rotation is what a top does around its spindle. As Earth spins on its axis, it also orbits around the Sun. This is called Earth's **revolution**. These motions lead to the cycles we see. Day and night, seasons, and the tides are caused by Earth's motions.

Earth's Rotation

In 1851, Léon Foucault, a French scientist, hung a heavy iron weight from a long wire. He pulled the weight to one side and then released it. The weight swung back and forth in a straight line. If Earth did not rotate, the pendulum would not change direction as it was swinging. But it did, or at least it appeared to. The direction of the pendulum appeared to change because Earth rotated beneath it. **Figure** 24.9 shows how this might look.

FIGURE 24.9
Imagine a pendulum at the North Pole. The pendulum always swings in the same direction. But because of Earth's rotation, its direction appears to change to observers on Earth.

A Turn of the Earth

In this video, MIT students demonstrate how a Foucault Pendulum is used to prove that the Earth is rotating. See the video at https://www.youtube.com/watch?v=_pECtfYa2Us .

MEDIA
Click image to the left or use the URL below.
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Earth's Day and Night

How long does it take Earth to spin once on its axis? One rotation is 24 hours. That rotation is the length of a day! Whatever time it is, the side of Earth facing the Sun has daylight. The side facing away from the Sun is dark. If you look at Earth from the North Pole, the planet spins counterclockwise. As the Earth rotates, you see the Sun moving across the sky from east to west. We often say that the Sun is "rising" or "setting." The Sun rises in the east and sets in the west. Actually, it is the Earth's rotation that makes it appear that way. The Moon and the stars at night also seem to rise in the east and set in the west. Earth's rotation is also responsible for this too. As Earth turns, the Moon and stars change position in the sky.

Earth's Seasons

The Earth is tilted 23 $1/2°$ on its axis (**Figure** 24.10). This means that as the Earth rotates, one hemisphere has longer days with shorter nights. At the same time the other hemisphere has shorter days and longer nights. For example, in the Northern hemisphere summer begins on June 21. On this date, the North Pole is pointed directly

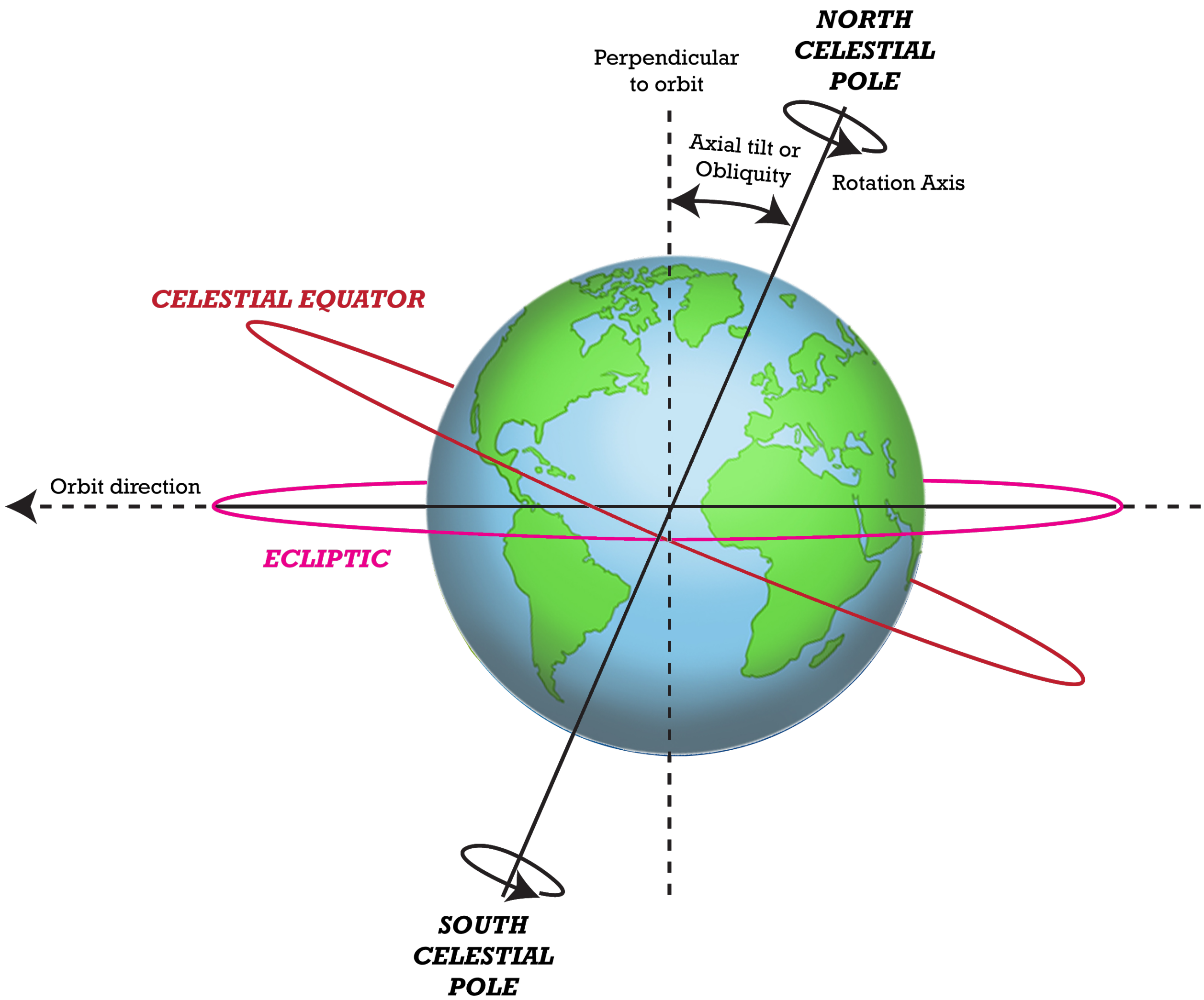

FIGURE 24.10
The Earth tilts on its axis.

toward the Sun. This is the longest day and shortest night of the year in the Northern Hemisphere. The South Pole is pointed away from the Sun. This means that the Southern Hemisphere experiences its longest night and shortest day (**Figure** 24.11).

The hemisphere that is tilted away from the Sun is cooler because it receives less direct rays. As Earth orbits the Sun, the Northern Hemisphere goes from winter to spring, then summer and fall. The Southern Hemisphere does the opposite from summer to fall to winter to spring. When it is winter in the Northern hemisphere, it is summer in the Southern hemisphere, and vice versa.

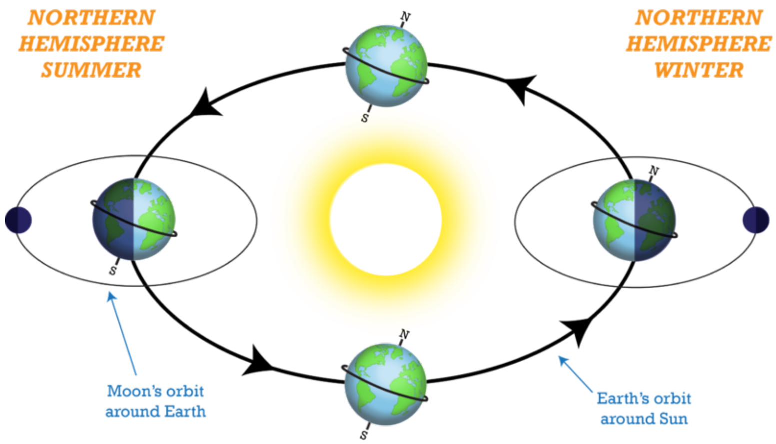

FIGURE 24.11
Earth's tilt changes the length of the days and nights during different seasons.

Earth's Revolution

Earth's revolution around the Sun takes 365.24 days. That is equal to one year. The Earth stays in orbit around the Sun because of the Sun's gravity (**Figure** 24.12). Earth's orbit is not a circle. It is somewhat elliptical. So as we travel around the Sun, sometimes we are a little farther away from the Sun. Sometimes we are closer to the Sun.

Students sometimes think the slightly oval shape of our orbit causes Earth's seasons. That's not true! The seasons are due to the tilt of Earth's axis, as discussed above.

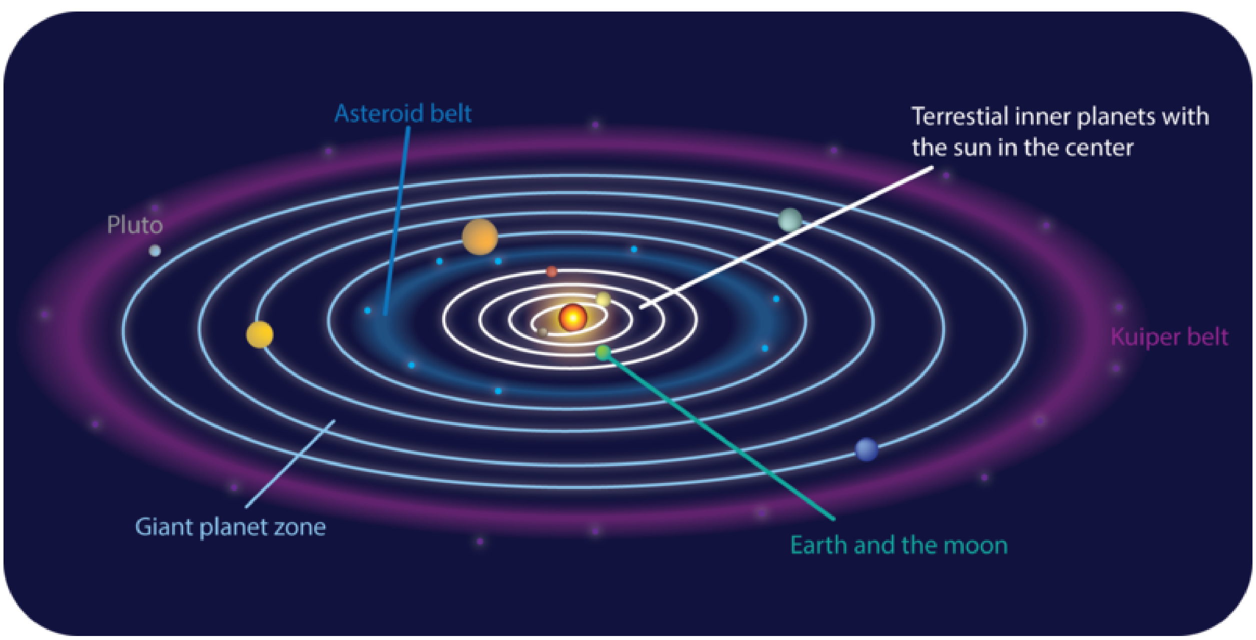

FIGURE 24.12
Earth and the other planets in the solar system make elliptical orbits around the Sun.

The distance between the Earth and the Sun is about 150 million kilometers. Earth revolves around the Sun at an average speed of about 27 kilometers (17 miles) per second. Mercury and Venus are closer to the Sun, so they take shorter times to make one orbit. Mercury takes only about 88 Earth days to make one trip around the Sun. All of the other planets take longer amounts of time. The exact amount depends on the planet's distance from the Sun. Saturn takes more than 29 Earth years to make one revolution around the Sun.

Lesson Summary

- The planets in our solar system all spin as they revolve around the Sun in fixed paths called orbits.
- The balance between gravity and our motion around the Sun, keep the planets in orbit at fixed distances from the Sun.
- Earth has a magnetic field, created by motion within Earth's outer, liquid iron core. The magnetic field shields us from harmful radiation.
- Earth rotates on its axis once each day and revolves around the Sun once every year.
- The tilt of Earth's axis produces seasons.

Lesson Review Questions

Recall

1. What was the evidence that Earth was round before there were photos from space?

2. What two substances does Earth have that allow it to support life?

3. What does a compass have that allows you to tell direction?

4. Describe Earth's rotation. Describe Earth's revolution.

Apply Concepts

5. Earth's "spheres" all interact. Given what you know about Earth science, can you give some examples?

6. What would happen to Earth-Moon if Earth suddenly shrunk to half its current size?

Think Critically

7. Why do the planets that are furthest from the Sun take longer to make one orbit around the Sun? Explain your answer.

8. Even though Earth is closest to the Sun in January, people in the Northern hemisphere experience winter weather. Why do you think people in the Northern Hemisphere have winter in January?

Points to Consider

- What would other planets need to have if they were able to support life?
- What type of experiment could you create to prove that the Earth is rotating on its axis?
- If you lived at the equator, would you experience any effects due to Earth's tilted axis?

- If Earth suddenly increased in mass, what might happen to its orbit around the Sun?

24.2 Earth's Moon

Lesson Objectives

- Find similarities and differences between Moon and Earth.
- Describe the features of the Moon.

Vocabulary

- crater
- landscape
- lunar
- maria
- meteorites
- terrae

Introduction

Between 1969 and 1972, six spaceships landed on the lunar surface. (**Lunar** means "related to the moon.") The astronauts brought back soil and rock samples. Scientists have used modern methods to study these samples. Because of the Apollo missions, we have learned a great deal about the Moon. No astronauts have visited the Moon since 1972. There is talk of someday returning, but as of now there are no concrete plans.

Lunar Characteristics

The Moon is Earth's only natural satellite. The Moon is about one-fourth the size of Earth, 3,476 kilometers in diameter. Gravity on the Moon is only one-sixth as strong as it is on Earth. If you weigh 120 pounds on Earth, you would only weigh 20 pounds on the Moon. You can jump six times as high on the Moon as you can on Earth. The Moon makes no light of its own. Like every other body in the solar system, it only reflects light from the Sun.

The Moon rotates on its axis once for every orbit it makes around the Earth. What does this mean? This means that the same side of the Moon always faces Earth. The side of the Moon that always faces Earth is called the near side. The side of the Moon that always faces away from Earth is called the far side (**Figure** 24.13). All people for all time have only seen the Moon's near side. The far side has only been seen by spacecraft.

The Moon has no atmosphere. With no atmosphere, the Moon is not protected from extreme temperatures. The average surface temperature during the day is approximately 107°C (225°F). Daytime temperatures can reach as high as 123°C (253°F). At night, the average temperature drops to -153°C (-243°F). The lowest temperatures measured are as low as -233°C (-397°F).

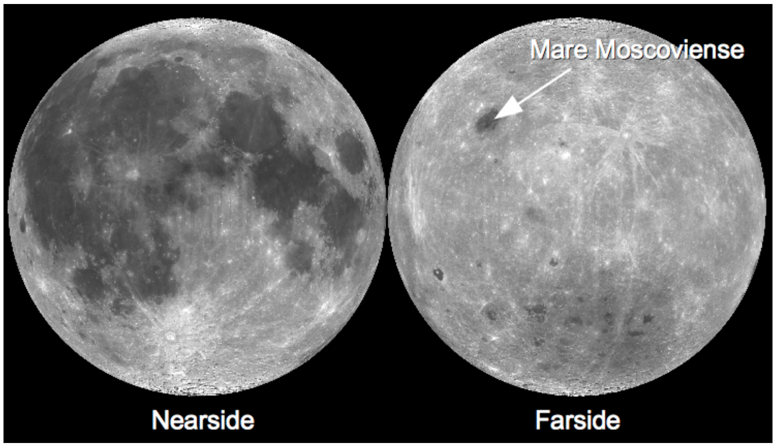

FIGURE 24.13
The Mare Moscoviense is one of the few maria, or dark, flat areas, on the far side.

The Lunar Surface

We all know what the Moon looks like. It's always looked the same during our lifetime. In fact, the Moon has looked the same to every person who has looked up at it for all time. Even the dinosaurs and trilobites, should they have looked up at it, would have seen the same thing. This is not true of Earth. Natural processes continually alter the Earth's surface. Without these processes, would Earth's surface resemble the Moon's?

Even though we can't see it from Earth, the Moon has changed recently too. Astronauts' footprints are now on the Moon. They will remain unchanged for thousands of years, because there is no wind, rain, or living thing to disturb them. Only a falling meteorite could destroy them.

Lunar Craters

The **landscape** of the Moon - its surface features - is very different from Earth. The lunar landscape is covered by **craters** caused by asteroid impacts (**Figure** 24.14). The craters are bowl-shaped basins on the Moon's surface. Because the Moon has no water, wind, or weather, the craters remain unchanged.

The Moon's coldest temperatures are found deep in the craters. The coldest craters are at the south pole on the Moon's far side, where the Sun never shines. These temperatures are amongst the coldest in our entire solar system.

Lunar Maria

When you look at the Moon from Earth, you notice dark and light areas. The **maria** are dark, solid, flat areas of lava. Maria covers around 16% of the Moon's surface, mostly on the near side. The maria formed about 3.0 to 3.5 billion years ago, when the Moon was continually bombarded by meteorites (**Figure** 24.15). Large meteorites broke through the Moon's newly formed surface. This caused magma to flow out and fill the craters. Scientists estimate volcanic activity on the Moon ended about 1.2 billion years ago.

The lighter parts on the Moon are called **terrae**, or highlands (**Figure** 24.15). They are higher than the maria and include several high mountain ranges. The rock that makes up the highlands is lighter in color and crystallized more slowly than the maria. The rock looks light because it reflects more of the Sun's light.

FIGURE 24.14
Craters, like the one shown in this image, are found on the surface of the Moon.

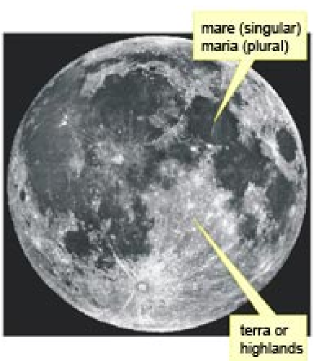

FIGURE 24.15
Maria (the dark areas) and terrae (the light areas) cover the Moon.

Not Much Water

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface. So there is no running water and no atmosphere. This means that there is no erosion. Natural processes continually alter the Earth's surface. Without these processes, our planet's surface would be covered with meteorite craters just like the Moon. Many moons in our solar system have cratered surfaces.

NASA scientists have discovered a large number of water molecules mixed in with lunar dirt. There is also surface water ice. Even though there is a very small amount of water, there is no atmosphere. Temperatures are extreme. So it comes as no surprise that there has not been evidence of life on the Moon.

Interior of the Moon

Like Earth, the Moon has a distinct crust, mantle, and core. The crust is composed of igneous rock. This rock is rich in the elements oxygen, silicon, magnesium, and aluminum. On the near side, the Moon's crust is about 60 kilometers thick. On the far side, the crust is about 100 kilometers thick. The mantle is made of rock like Earth's mantle. The Moon has a small metallic core, perhaps 600 to 800 kilometers in diameter. The composition of the core is probably mostly iron with some sulfur and nickel. We learned this both from the rock samples gathered by astronauts and from spacecraft sent to the Moon.

Lesson Summary

- The evidence suggests that the Moon formed when a Mars sized planet collided with Earth.
- The Moon makes one rotation on its axis for each orbit around the Earth.
- The Moon has dark areas, called maria, surrounded by lighter colored highland areas, called terrae.
- Because the Moon is geologically inactive and doesn't have an atmosphere, it has many thousands of craters on its surface.
- The Moon is made of materials similar to Earth and has a crust, mantle and core, just like Earth.

Lesson Review Questions

Recall

1. What features does Earth have that the Moon does not?

2. How long will astronaut footprints remain on the Moon?

3. What is the difference between maria and terrae?

Apply Concepts

4. Why doesn't the Moon have an atmosphere?

5. Why is the crust thicker on the near side of the Moon than on the far side?

6. Why is the force of gravity weaker on the Moon than on Earth?

Think Critically

7. Why doesn't the Moon have much water?

8. One idea for how the Moon formed was presented in the *Earth's History* chapter. Can you create another plausible hypothesis?

9. How much do landscape features on the Moon change over time compared to landscape features on Earth? Explain your answer.

Points to Consider

- What things would be different on Earth if Earth did not have a Moon?
- If the Moon rotated on its axis twice as fast as it does now, would we see anything different than we do now?
- How do we know that the Moon has been geologically inactive for billions of years?

24.3 The Sun

Lesson Objectives

- Describe the layers of the Sun.
- Describe the surface features of the Sun.

Vocabulary

- chromosphere
- convection zone
- core
- corona
- photosphere
- plasma
- radiative zone
- solar flare
- solar wind
- sunspots

Introduction

Our Sun is a star. This star provides light and heat and supports almost all life on Earth. The Sun is the center of the solar system. It is by far the largest part of the solar system. Added together, all of the planets make up just 0.2 percent of the solar system's mass. The Sun makes up the remaining 99.8 percent of all the mass in the solar system (**Figure** 24.16)!

Layers of the Sun

The Sun is made almost entirely of the elements hydrogen and helium. The Sun has no solid material. Most atoms in the Sun exist as **plasma**. Plasma is superheated gas with an electrical charge. Because the Sun is made of gases, it does not have a defined outer boundary. Like Earth, the Sun has an internal structure. The inner three layers make up what we would actually call "the Sun."

The Core

The **core** is the Sun's innermost layer. The core is plasma. It has a temperature of around 15 million degrees Celsius (C). Nuclear fusion reactions create the immense temperature. In these reactions, hydrogen atoms fuse to form

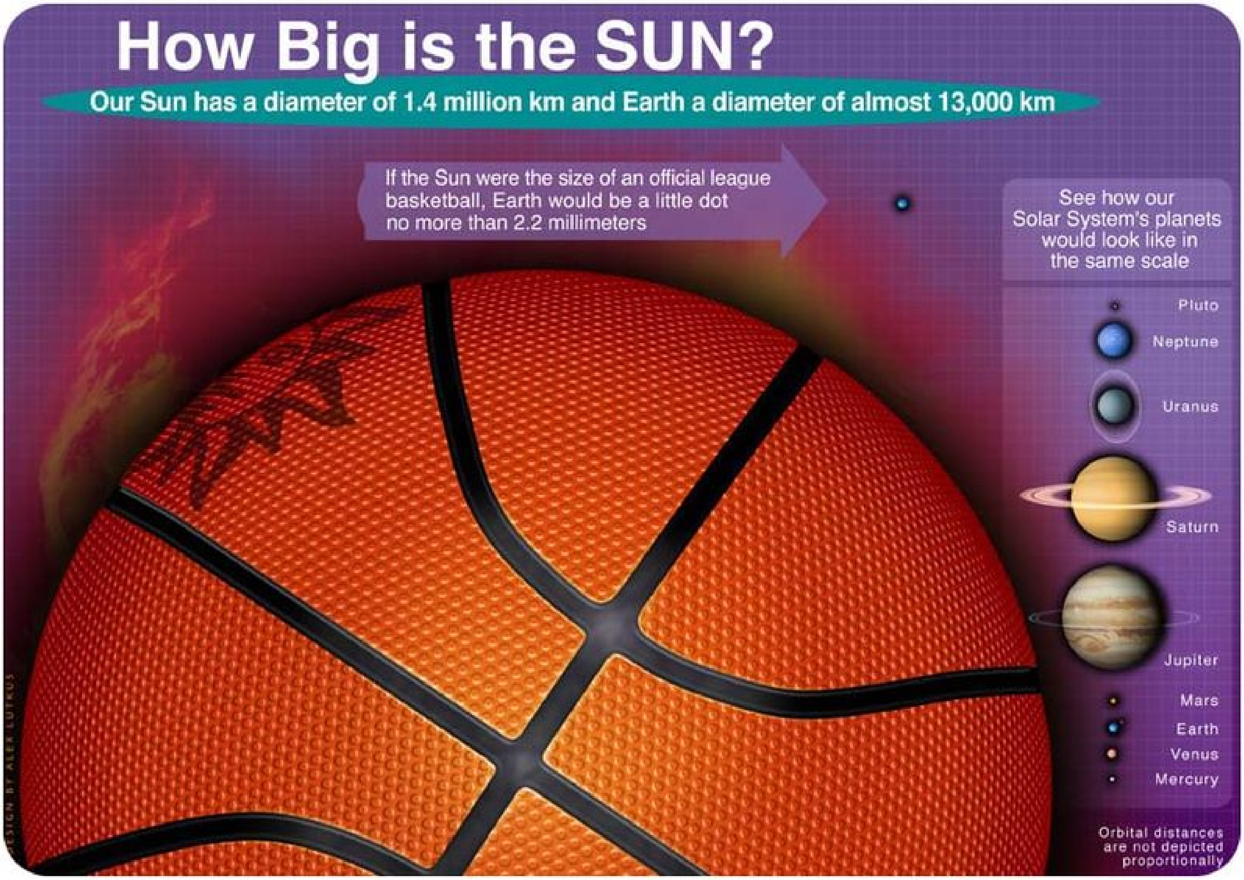

FIGURE 24.16
The sizes of the planets relative to the Sun, if the Sun was the size of a basketball.

helium. This releases vast amounts of energy. The energy moves towards the outer layers of the Sun. Energy from the Sun's core powers most of the solar system.

Radiative Zone

The **radiative zone** is the next layer out. It has a temperature of about 4 million degrees C. Energy from the core travels through the radiative zone. The rate the energy travels is extremely slow. Light particles, called photons, can only travel a few millimeters before they hit another particle. The particles are absorbed and then released again. It may take 50 million years for a photon to travel all the way through the radiative zone.

The Convection Zone

The **convection zone** surrounds the radiative zone. In the convection zone, hot material from near the Sun's center rises. This material cools at the surface, and then plunges back downward. The material then receives more heat from the radiative zone.

The Sun's Atmosphere

The three outer layers of the Sun are its atmosphere.

The Photosphere

The **photosphere** is the visible surface of the Sun (**Figure** 24.17). It's the part that we see shining. Surprisingly, the photosphere is also one of the coolest layers of the Sun. It is only about 6000 degrees C.

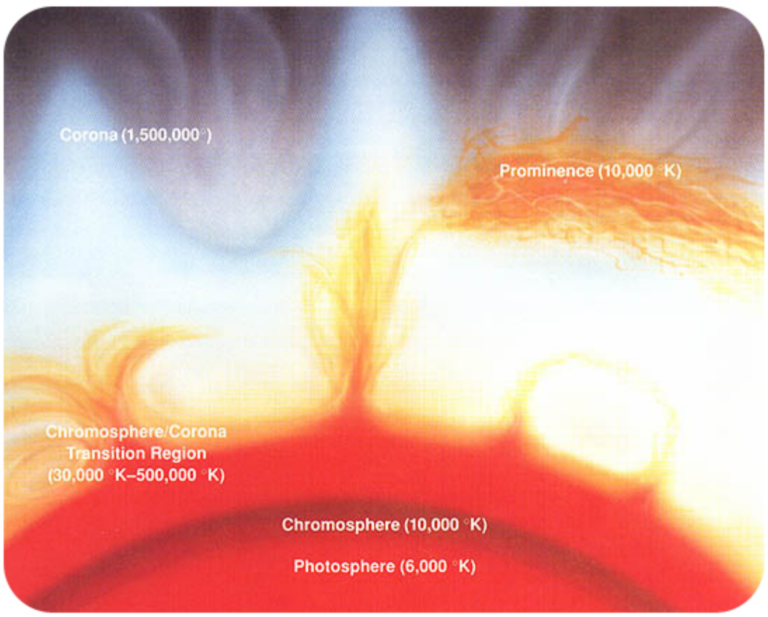

FIGURE 24.17
The Sun's atmosphere contains the photosphere, the chromosphere, and the corona. This image was taken by NASA's Spacelab 2 instruments.

The Chromosphere

The **chromosphere** lies above the photosphere. It is about 2,000 km thick. The thin chromosphere is heated by energy from the photosphere. Temperatures range from about 4000 degrees C to about 10,000 degrees C. The chromosphere is not as hot as other parts of the Sun, and it glows red. Jets of gas sometimes fly up through the chromosphere. With speeds up to 72,000 km per hour, the jets can fly as high as 10,000 kilometers.

The Corona

The **corona** is the outermost part of the Sun's atmosphere. It is the Sun's halo, or "crown." With a temperature of 1 to 3 million K, the corona is much hotter than the photosphere. The corona extends millions of kilometers into space. Sometime you should try to see a total solar eclipse. If you do you will see the Sun's corona shining out into space.

Surface Features of the Sun

The Sun has many incredible surface features. Don't try to look at them though! Looking directly at the Sun can cause blindness. Find the appropriate filters for a pair of binoculars or a telescope and enjoy!

Sunspots

The most noticeable magnetic activity of the Sun is the appearance of sunspots. **Sunspots** are cooler, darker areas on the Sun's surface (**Figure** 24.18). Sunspots occur in an 11 year cycle. The number of sunspots begins at a minimum. The number gradually increases to the maximum. Then the number returns to a minimum again.

Sunspots form because loops of the Sun's magnetic field break through the surface. Sunspots usually occur in pairs. The loop breaks through the surface where it comes out of the Sun. It breaks through again where it goes back into the Sun. Sunspots disrupt the transfer of heat from the Sun's lower layers.

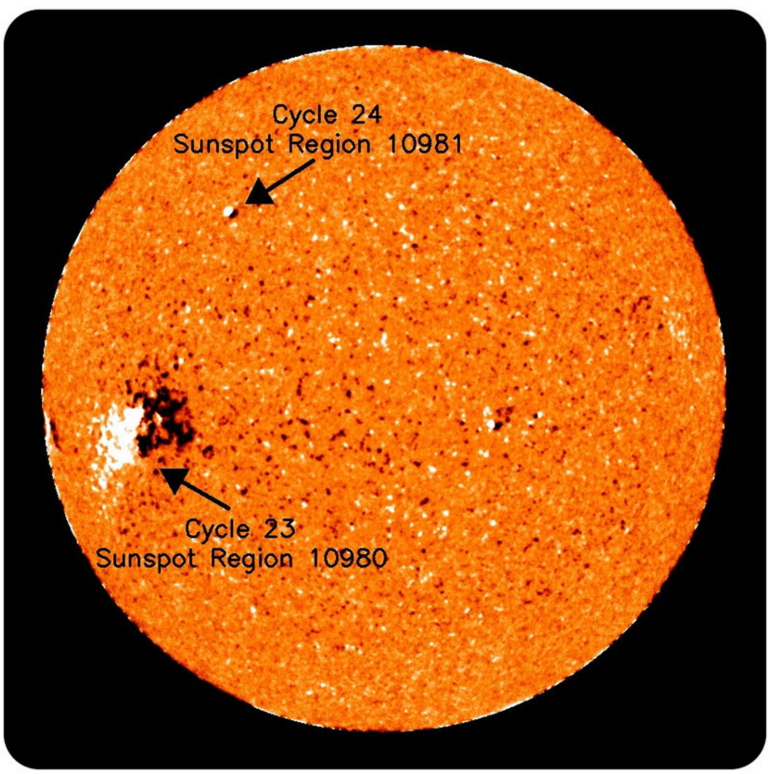

FIGURE 24.18
The darker regions in this image are sunspots.

Solar Flares

A loop of the Sun's magnetic field may break. This creates **solar flares**. Solar flares are violent explosions that release huge amounts of energy (**Figure** 24.19). The streams of high energy particles they emit make up the **solar wind**. Solar wind is dangerous to spacecraft and astronauts. Solar flares can even cause damage on Earth. They have knocked out entire power grids and can disturb radio, satellite, and cell phone communications.

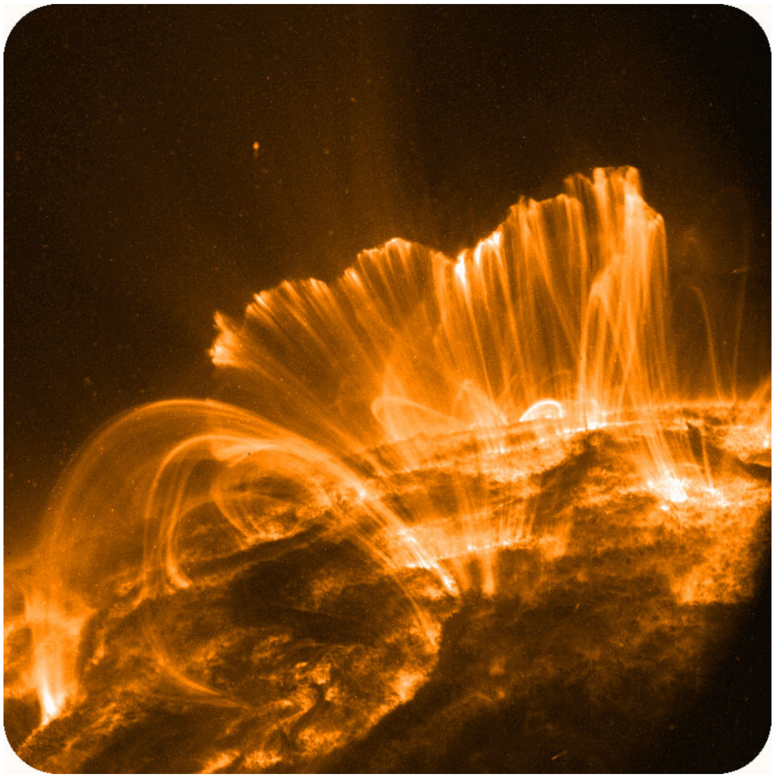

FIGURE 24.19
This image is actually made up of two successive images and shows how a solar flare develops.

Solar Prominences

Another amazing feature on the Sun is solar prominences. Plasma flows along the loop that connects sunspots. This plasma forms a glowing arch. The arch is a solar prominence. Solar prominences can reach thousands of kilometers into the Sun's atmosphere. Prominences can last for a day to several months. Prominences can be seen during a total solar eclipse.

NASA's Solar Dynamics Observatory (SDO) was launched on February 11, 2010. SDO is studying the Sun's magnetic field. This includes how the Sun affects Earth's atmosphere and climate. SDO provides extremely high resolution images. The craft gathers data faster than anything that ever studied the Sun.

To learn more about the SDO mission, visit: http://sdo.gsfc.nasa.gov

To find these videos for download, check out: http://www.nasa.gov/mission_pages/sdo/news/briefing-materials-20100421.html http://svs.gsfc.nasa.gov/Gallery/SDOFirstLight.html

There are other ways to connect with NASA. Subscribe to NASA's Goddard Shorts HD podcast (http://svs.gsfc.nasa.gov/vis/iTunes/f0004_index.html)

Lesson Summary

- The mass of the Sun is 99.8% of the mass of our solar system.
- The Sun is mostly hydrogen with smaller amounts of helium. The material is in the form of plasma.
- The main part of the Sun has three layers: the core, the radiative zone and the convection zone.
- The Sun's atmosphere also has three layers: the photosphere, the chromosphere and the corona.
- Nuclear fusion of hydrogen in the core of the Sun produces tremendous amounts of energy that radiate out

from the Sun.
- Some features of the Sun's surface include sunspots, solar flares, and prominences.

Lesson Review Questions

Recall

1. What is the Sun mostly made of?

2. Where does the Sun's energy come from?

Apply Concepts

3. What is nuclear fusion? Is it a form of energy that can be used by people?

4. How does the Sun's magnetic field affect its surface features?

Think Critically

5. Describe the energy of the Sun. Where is it generated? Where does it go? How does it move?

6. Solar wind can be dangerous to human life. Why is this fact important? What usually protects humans from harm from the solar wind?

Points to Consider

- If something were to suddenly cause nuclear fusion to stop in the Sun, how would we know?
- Are there any types of dangerous energy from the Sun? What might be affected by them?
- If the Sun is all made of gases like hydrogen and helium, how can it have layers?

24.4 The Sun and the Earth-Moon System

Lesson Objectives

- Explain solar and lunar eclipses.
- Describe the phases of the Moon and explain why they occur.

Vocabulary

- crescent
- gibbous
- lunar eclipse
- penumbra
- solar eclipse
- umbra

Introduction

The Earth, Moon and Sun are linked together in space. Monthly or daily cycles continually remind us of these links. Every month, you can see the Moon change. This is due to where it is relative to the Sun and Earth. In one phase, the Moon is brightly illuminated - a full moon. In the opposite phase it is completely dark - a new moon. In between, it is partially lit up. When the Moon is in just the right position, it causes an eclipse. The daily tides are another reminder of the Moon and Sun. They are caused by the pull of the Moon and the Sun on the Earth. Tides were discussed in the *Oceans* chapter.

Solar Eclipses

When a new moon passes directly between the Earth and the Sun, it causes a **solar eclipse** (**Figure** 24.20). The Moon casts a shadow on the Earth and blocks our view of the Sun. This happens only all three are lined up and in the same plane. This plane is called the ecliptic. The ecliptic is the plane of Earth's orbit around the Sun.

The Moon's shadow has two distinct parts. The **umbra** is the inner, cone-shaped part of the shadow. It is the part in which all of the light has been blocked. The **penumbra** is the outer part of Moon's shadow. It is where the light is only partially blocked.

When the Moon's shadow completely blocks the Sun, it is a total solar eclipse (**Figure** 24.21). If only part of the Sun is out of view, it is a partial solar eclipse. Solar eclipses are rare events. They usually only last a few minutes. That is because the Moon's shadow only covers a very small area on Earth and Earth is turning very rapidly.

Solar eclipses are amazing to experience. It appears like night only strange. Birds may sing as they do at dusk. Stars

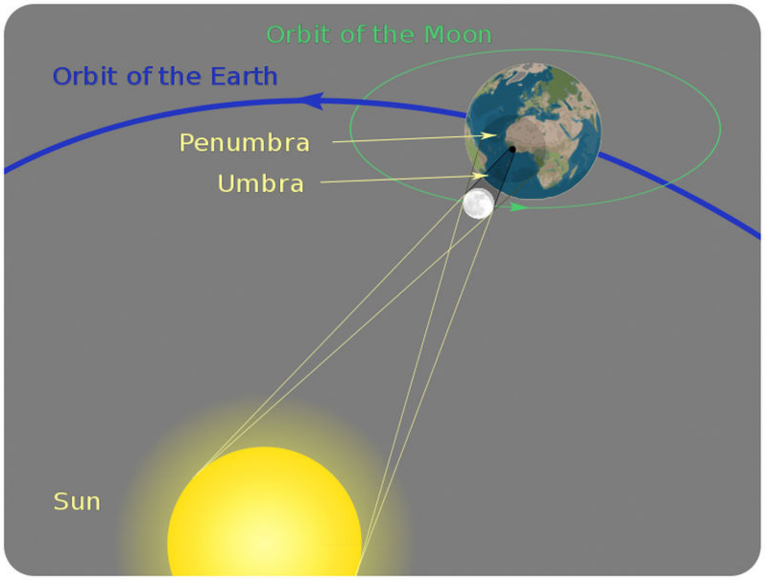

FIGURE 24.20
During a solar eclipse, the Moon casts a shadow on the Earth. The shadow is made up of two parts: the darker umbra and the lighter penumbra.

become visible in the sky and it gets colder outside. Unlike at night, the Sun is out. So during a solar eclipse, it's easy to see the Sun's corona and solar prominences. This NASA page will inform you on when solar eclipses are expected: http://eclipse.gsfc.nasa.gov/solar.html

FIGURE 24.21
A photo of a total solar eclipse.

A Lunar Eclipse

Sometimes a full moon moves through Earth's shadow. This is a **lunar eclipse** (**Figure** 24.22). During a total lunar eclipse, the Moon travels completely in Earth's umbra. During a partial lunar eclipse, only a portion of the Moon enters Earth's umbra. When the Moon passes through Earth's penumbra, it is a penumbral eclipse. Since Earth's shadow is large, a lunar eclipse lasts for hours. Anyone with a view of the Moon can see a lunar eclipse.

Partial lunar eclipses occur at least twice a year, but total lunar eclipses are less common. The Moon glows with a dull red coloring during a total lunar eclipse.

FIGURE 24.22
A lunar eclipse is shown in a series of pictures.

The Phases of the Moon

The Moon does not produce any light of its own. It only reflects light from the Sun. As the Moon moves around the Earth, we see different parts of the Moon lit up by the Sun. This causes the phases of the Moon. As the Moon revolves around Earth, it changes from fully lit to completely dark and back again.

A full moon occurs when the whole side facing Earth is lit. This happens when Earth is between the Moon and the Sun. About one week later, the Moon enters the quarter-moon phase. Only half of the Moon's lit surface is visible from Earth, so it appears as a half circle. When the Moon moves between Earth and the Sun, the side facing Earth is completely dark. This is called the new moon phase. Sometimes you can just barely make out the outline of the new moon in the sky. This is because some sunlight reflects off the Earth and hits the Moon. Before and after the quarter-moon phases are the gibbous and crescent phases. During the **crescent** moon phase, the Moon is less than half lit. It is seen as only a sliver or crescent shape. During the **gibbous** moon phase, the Moon is more than half lit. It is not full. The Moon undergoes a complete cycle of phases about every 29.5 days.

Lesson Summary

- When the new moon comes between the Earth and the Sun along the ecliptic, a solar eclipse is produced.
- When the Earth comes between the full moon and the Sun along the ecliptic, a lunar eclipse occurs.
- Observing the Moon from Earth, we see a sequence of phases as the side facing us goes from completely darkened to completely illuminated and back again once every 29.5 days.

Review Questions

Recall

1. What is happening with Earth and the Sun during Northern Hemisphere summer? What is happening in the Southern Hemisphere at that time?

2. Draw a picture of Earth, Moon, and Sun during a new moon. Draw picture during a full moon.

Apply Concepts

3. Why do lunar eclipses happen more often and last longer than solar eclipses?

4. The same side of the Moon always faces Earth. What would Earth be like if its same side always faced the Sun?

Think Critically

5. Why is it a different time in San Francisco and in Denver? Why is the time different in Denver and Chicago? What would things be like if the entire United States decided to have all places be the same time always?

6. People think that Earth's season are caused by its elliptical orbit around the Sun. Explain why this is not so.

Points to Consider

- Why don't eclipses occur every single month at the full and new moons?
- The planet Mars has a tilt that is very similar to Earth's. What does this produce on Mars?
- Venus comes between the Earth and the Sun. Why don't we see an eclipse when this happens?

24.5 References

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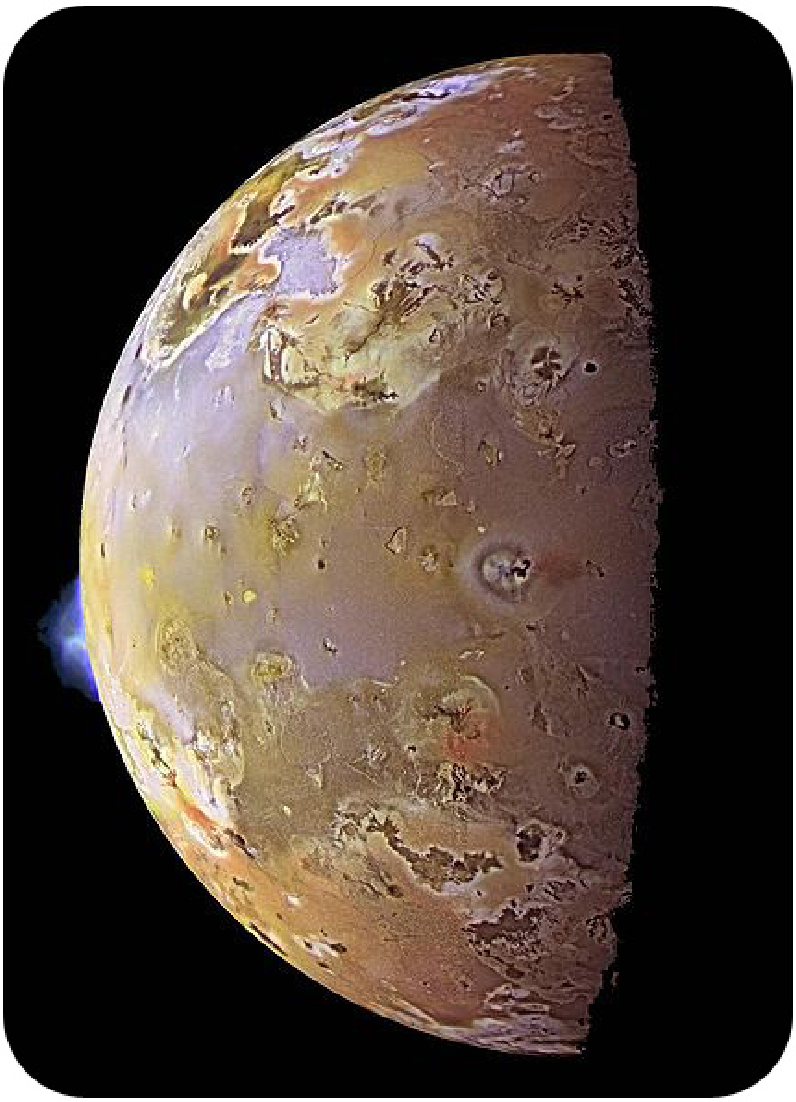
CHAPTER 25 MS The Solar System

Chapter Outline



Earth is not the only active planetary body in the solar system. Io, one of Jupiter's moons, is home to fantastic volcanic eruptions. Volcanism is much hotter than on Earth. Lava curtains and fountains are common. In this color image, the Galileo spacecraft spotted two volcanic plumes. One is spewing high above the planet on the horizon. The second is near he boundary between day and night. Besides being hotter than Earth's volcanism, eruptions on Io have a different composition. They are mostly sulfur!

Courtesy of NASA. commons.wikimedia.org/wiki/File:PIA01081–Color_Mosaic_and_Active_Volcanic_Plumes_on_Io.jpg. Public Domain.

25.1 Introduction to the Solar System

Lesson Objectives

- Describe some early ideas about our solar system.
- Name the planets, and describe their motion around the Sun.
- Explain how the solar system formed.

Vocabulary

- astronomical unit
- dwarf planet
- nebula
- nuclear fusion
- planet
- solar system

Introduction

We can learn a lot about the universe and about Earth history by studying our nearest neighbors. The solar system has planets, asteroids, comets, and even a star for us to see and understand. It's a fascinating place to live!

Changing Views of the Solar System

The Sun and all the objects that are held by the Sun's gravity are known as the **solar system**. These objects all revolve around the Sun. The ancient Greeks recognized five planets. These lights in the night sky changed their position against the background of stars. They appeared to wander. In fact, the word "planet" comes from a Greek word meaning "wanderer." These objects were thought to be important, so they named them after gods from their mythology. The names for the planets Mercury, Venus, Mars, Jupiter, and Saturn came from the names of gods and a goddess.

Earth at the Center of the Universe

The ancient Greeks thought that Earth was at the center of the universe, as shown in **Figure** 25.1. The sky had a set of spheres layered on top of one another. Each object in the sky was attached to one of these spheres. The object moved around Earth as that sphere rotated. These spheres contained the Moon, the Sun, and the five planets they recognized: Mercury, Venus, Mars, Jupiter, and Saturn. An outer sphere contained all the stars. The planets appear to move much faster than the stars, so the Greeks placed them closer to Earth. Ptolemy published this model of the solar system around 150 AD.

FIGURE 25.1
On left is a line art drawing of the Ptolemaic system with Earth at the center. On the right is a drawing of the Ptolemaic system from 1568 by a Portuguese astronomer.

The Sun at the Center of the Universe

About 1,500 years after Ptolemy, Copernicus proposed a startling idea. He suggested that the Sun is at the center of the universe. Copernicus developed his model because it better explained the motions of the planets. **Figure** 25.2 shows both the Earth-centered and Sun-centered models.

FIGURE 25.2
Copernicus proposed a different idea that had the Sun at the center of the universe

Copernicus did not publish his new model until his death. He knew that it was heresy to say that Earth was not the center of the universe. It wasn't until Galileo developed his telescope that people would take the Copernican model more seriously. Through his telescope, Galileo saw moons orbiting Jupiter. He proposed that this was like the planets orbiting the Sun.

Planets and Their Motions

Today we know that we have eight planets, five dwarf planets, over 165 moons, and many, many asteroids and other small objects in our solar system. We also know that the Sun is not the center of the universe. But it is the center of the solar system.

FIGURE 25.3
This artistic composition shows the eight planets, a comet, and an asteroid.

Figure 25.3 shows our solar system. The planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. **Table** 25.1 gives some data on the mass and diameter of the Sun and planets relative to Earth.

TABLE 25.1: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter

TABLE 25.1: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Neptune	17.2 Earth's mass	3.81 Earth's diameter

What Is (and Is Not) a Planet?

You've probably heard about Pluto. When it was discovered in 1930, Pluto was called the ninth planet. Astronomers later found out that Pluto was not like other planets. For one thing, what they were calling Pluto was not a single object. They were actually seeing Pluto and its moon, Charon. In older telescopes, they looked like one object. This one object looked big enough to be a planet. Alone, Pluto was not very big. Astronomers also discovered many objects like Pluto. They were rocky and icy and there were a whole lot of them.

Astronomers were faced with a problem. They needed to call these other objects planets. Or they needed to decide that Pluto was something else. In 2006, these scientists decided what a planet is. According to the new definition, a **planet** must:

- Orbit a star.
- Be big enough that its own gravity causes it to be round.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

If the first three are true but not the fourth, then that object is a **dwarf planet**. We now call Pluto a dwarf planet. There are other dwarf planets in the solar system. They are Eris, Ceres, Makemake and Haumea. There are many other reasons why Pluto does not fit with the other planets in our solar system.

The Size and Shape of Orbits

FIGURE 25.4
The Sun and planets with the correct sizes. The distances between them are not correct.

Figure 25.4 shows the Sun and planets with the correct sizes. The distances between them are way too small. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next.

Figure 25.5 shows those distances correctly. In the upper left are the orbits of the inner planets and the asteroid belt. The asteroid belt is a collection of many small objects between the orbits of Mars and Jupiter. In the upper right are the orbits of the outer planets and the Kuiper belt. The Kuiper belt is a group of objects beyond the orbit of Neptune.

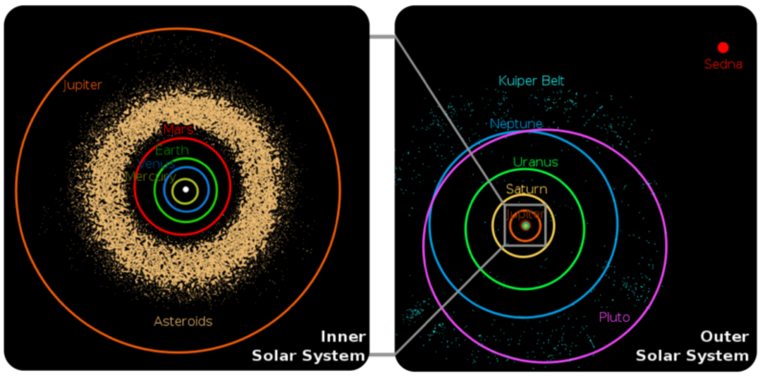


FIGURE 25.5
In this image, distances are shown to scale.

In **Figure** 25.5, you can see that the orbits of the planets are nearly circular. Pluto's orbit is a much longer ellipse. Some astronomers think Pluto was dragged into its orbit by Neptune.

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km (93 million miles). **Table** 25.2 shows the distance from the Sun to each planet in AU. The table shows how long it takes each planet to spin on its axis. It also shows how long it takes each planet to complete an orbit. Notice how slowly Venus rotates! A day on Venus is actually longer than a year on Venus!

TABLE 25.2: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

The Role of Gravity

Planets are held in their orbits by the force of gravity. What would happen without gravity? Imagine that you are swinging a ball on a string in a circular motion. Now let go of the string. The ball will fly away from you in a straight line. It was the string pulling on the ball that kept the ball moving in a circle. The motion of a planet is very similar to the ball on a string. The force pulling the planet is the pull of gravity between the planet and the Sun.

Every object is attracted to every other object by gravity. The force of gravity between two objects depends on the mass of the objects. It also depends on how far apart the objects are. When you are sitting next to your dog, there is a gravitational force between the two of you. That force is far too weak for you to notice. You can feel the force of gravity between you and Earth because Earth has a lot of mass. The force of gravity between the Sun and planets is also very large. This is because the Sun and the planets are very large objects. Gravity is great enough to hold the planets to the Sun even though the distances between them are enormous. Gravity also holds moons in orbit around planets.

Extrasolar Planets

Since the early 1990s, astronomers have discovered other solar systems. A solar system has one or more planets orbiting one or more stars. We call these planets "extrasolar planets," or "exoplanets". They are called exoplanets because they orbit a star other than the Sun. As of June 2013, 891 exoplanets have been found. More exoplanets are found all the time. You can check out how many we have found at http://planetquest.jpl.nasa.gov/.

We have been able to take pictures of only a few exoplanets. Most are discovered because of some tell-tale signs. One sign is a very slight motion of a star that must be caused by the pull of a planet. Another sign is the partial dimming of a star's light as the planet passes in front of it.

Formation of the Solar System

To figure out how the solar system formed, we need to put together what we have learned. There are two other important features to consider. First, all the planets orbit in nearly the same flat, disk-like region. Second, all the planets orbit in the same direction around the Sun. These two features are clues to how the solar system formed.

A Giant Nebula

Scientists think the solar system formed from a big cloud of gas and dust, called a **nebula**. This is the solar nebula hypothesis. The nebula was made mostly of hydrogen and helium. There were heavier elements too. Gravity caused the nebula to contract (**Figure** 25.6).

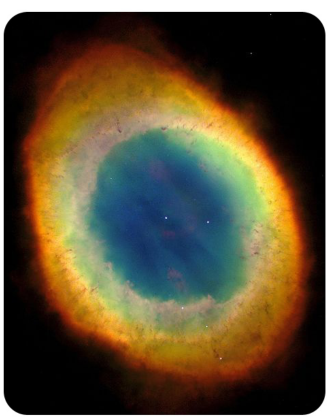


FIGURE 25.6
The nebula was drawn together by gravity.

As the nebula contracted, it started to spin. As it got smaller and smaller, it spun faster and faster. This is what happens when an ice skater pulls her arms to her sides during a spin move. She spins faster. The spinning caused the nebula to form into a disk shape.

This model explains why all the planets are found in the flat, disk-shaped region. It also explains why all the planets revolve in the same direction. The solar system formed from the nebula about 4.6 billion years ago

Formation of the Sun and Planets

The Sun was the first object to form in the solar system. Gravity pulled matter together to the center of the disk. Density and pressure increased tremendously. **Nuclear fusion** reactions begin. In these reactions, the nuclei of atoms come together to form new, heavier chemical elements. Fusion reactions release huge amounts of nuclear energy. From these reactions a star was born, the Sun.

Meanwhile, the outer parts of the disk were cooling off. Small pieces of dust started clumping together. These clumps collided and combined with other clumps. Larger clumps attracted smaller clumps with their gravity. Eventually, all these pieces grew into the planets and moons that we find in our solar system today.

The outer planets —Jupiter, Saturn, Uranus, and Neptune —condensed from lighter materials. Hydrogen, helium, water, ammonia, and methane were among them. It's so cold by Jupiter and beyond that these materials can form solid particles. Closer to the Sun, they are gases. Since the gases can escape, the inner planets —Mercury, Venus, Earth, and Mars —formed from denser elements. These elements are solid even when close to the Sun.

Lesson Summary

- The Sun and all the objects held by its gravity make up the solar system.
- There are eight planets in the solar system: Mercury, Venus, Earth, Mars, Jupiter, Saturn, and Neptune. Pluto, Eris, Ceres, Makemake and Haumea are dwarf planets.
- The ancient Greeks believed Earth was at the center of the universe and everything else orbited Earth.
- Copernicus proposed that the Sun at the center of the universe and the planets and stars orbit the Sun.
- Planets are held by the force of gravity in elliptical orbits around the Sun.
- The solar system formed from a giant cloud of gas and dust about 4.6 billion years ago.
- This model explains why the planets all lie in one plane and orbit in the same direction around the Sun.

Lesson Review Questions

Recall

1. What are the names of the planets from the Sun outward? What are the names of the dwarf planets?

2. How old is the Sun? How old are the planets?

Apply Concepts

3. Describe the role of gravity in how the solar system functions. Why don't the planets fly off into space? Why don't the planets ram into the Sun?

4. Why does the nebular hypothesis explain how the solar system originated?

Think Critically

5. Why do you think so many people for so many centuries thought that Earth was the center of the universe?

6. People were pretty upset when Pluto was made a dwarf planet. Why do you think they were upset? How do you feel about it?

Points to Consider

- Would you expect all the planets in the solar system to be made of similar materials? Why or why not?
- The planets are often divided into two groups: the inner planets and the outer planets. Which planets do you think are in each of these two groups? What do members of each group have in common?

25.2 Inner Planets

Lesson Objectives

- Describe the main features of each of the inner planets.
- Compare each of the inner planets to Earth and to one another.

Vocabulary

- inner planets
- year

Introduction

The four planets closest to the Sun - Mercury, Venus, Earth, and Mars - are the **inner planets**. They are similar to Earth. All are solid, dense, and rocky. None of the inner planets has rings. Compared to the outer planets, the inner planets are small. They have shorter orbits around the Sun and they spin more slowly. Venus spins backwards and spins the slowest of all the planets.

All of the inner planets were geologically active at one time. They are all made of cooled igneous rock with inner iron cores. Earth has one big, round moon, while Mars has two very small, irregular moons. Mercury and Venus do not have moons.

Mercury

Mercury is the smallest planet. It has no moon. The planet is also closest to the Sun and appears in **Figure** 25.7.

As **Figure** 25.8 shows, the surface of Mercury is covered with craters, like Earth's Moon. The presence of impact craters that are so old means that Mercury hasn't changed much geologically for billions of years. With only a trace of an atmosphere, it has no weather to wear down the ancient craters.

Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. The Mariner 10 spacecraft did a flyby of Mercury in 1974–1975, which was the best data from the planet for decades. In 2004, the MESSENGER mission left Earth. On its way to Mercury it did one flyby of Earth, two of Venus and three of Mercury. In March 2011, MESSENGER became the first spacecraft to enter an orbit around Mercury. During its year-long mission, the craft will map the planet's surface and conduct other studies. One of these images can be seen in **Figure** 25.9.

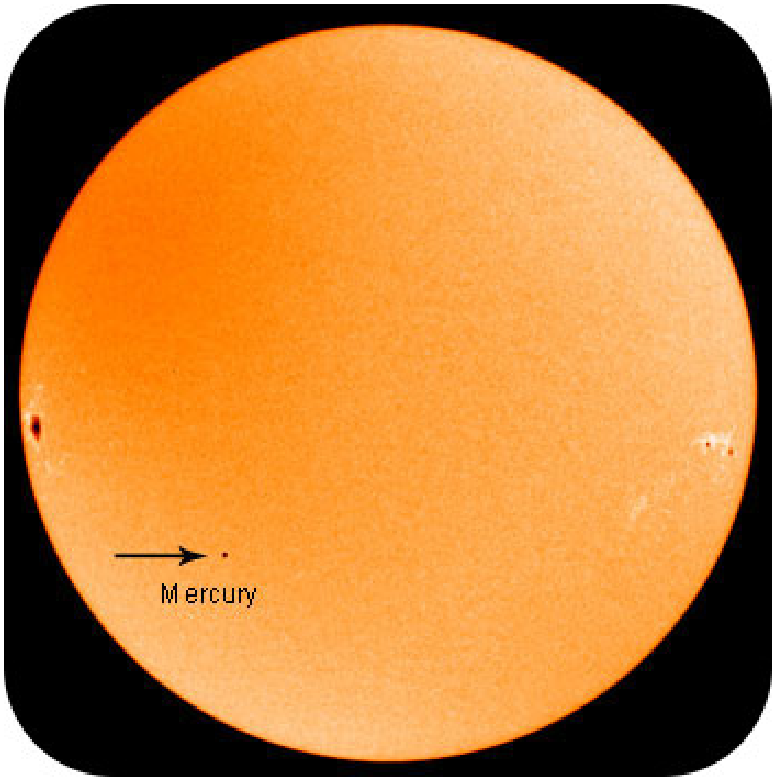


FIGURE 25.7
Tiny Mercury is the small black dot in the lower center of this picture of the Sun. The larger dark area near the left edge is a sunspot.

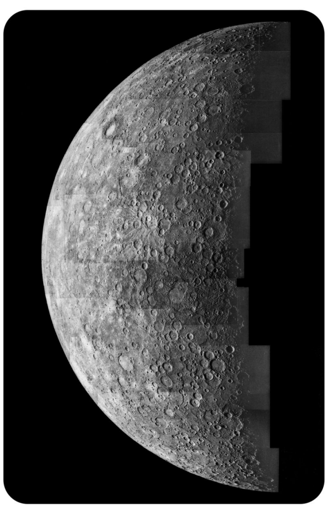


FIGURE 25.8
The surface of Mercury is covered with craters, like Earth's Moon.

Short Year, Long Days

Mercury is named for the Roman messenger god. Mercury was a messenger because he could run extremely fast. The Greeks gave the planet this name because Mercury moves very quickly in its orbit around the Sun. Mercury orbits the Sun in just 88 Earth days. Mercury has a very short year, but it also has very long days. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 58 Earth days long.

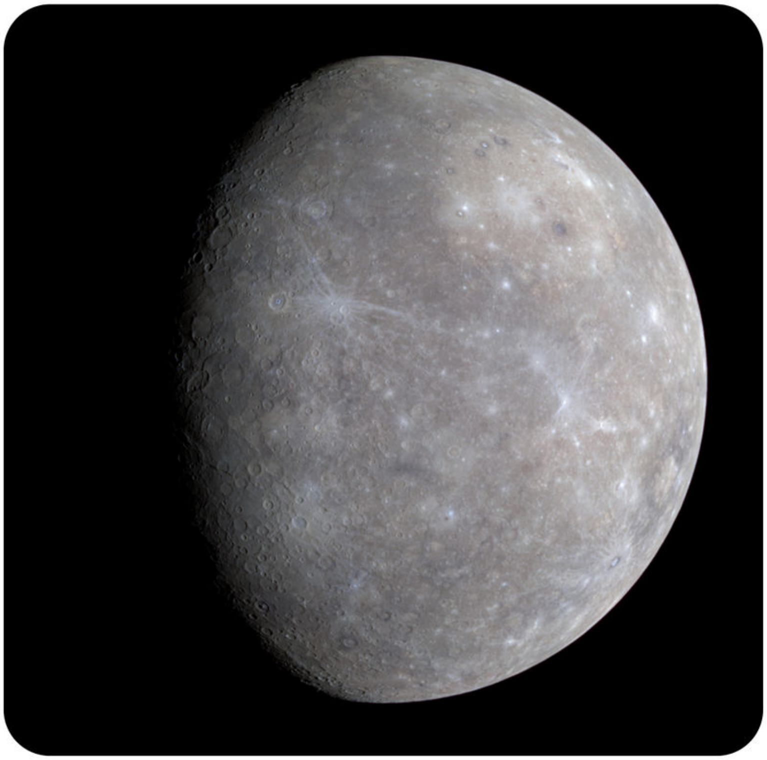


FIGURE 25.9

Extreme Temperatures

Mercury is very close to the Sun, so it can get very hot. Mercury also has virtually no atmosphere. As the planet rotates very slowly, the temperature varies tremendously. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, the surface can be as cold as –183°C (–297°F)! The coldest temperatures may be on the insides of craters. Most of Mercury is extremely dry. Scientists think that there may be a small amount of water, in the form of ice, at the planet's poles. The poles never receive direct sunlight.

A Liquid Metal Core

Figure 25.10 shows a diagram of Mercury's interior. Mercury is one of the densest planets. Scientists think that the interior contains a large core made mostly of melted iron. Mercury's core takes up about 42% of the planet's volume. Mercury's highly cratered surface is evidence that Mercury is not geologically active.

Venus

Named after the Roman goddess of love, Venus is the only planet named after a female. Venus is sometimes called Earth's "sister planet." But just how similar is Venus to Earth? Venus is our nearest neighbor. Venus is most like Earth in size.

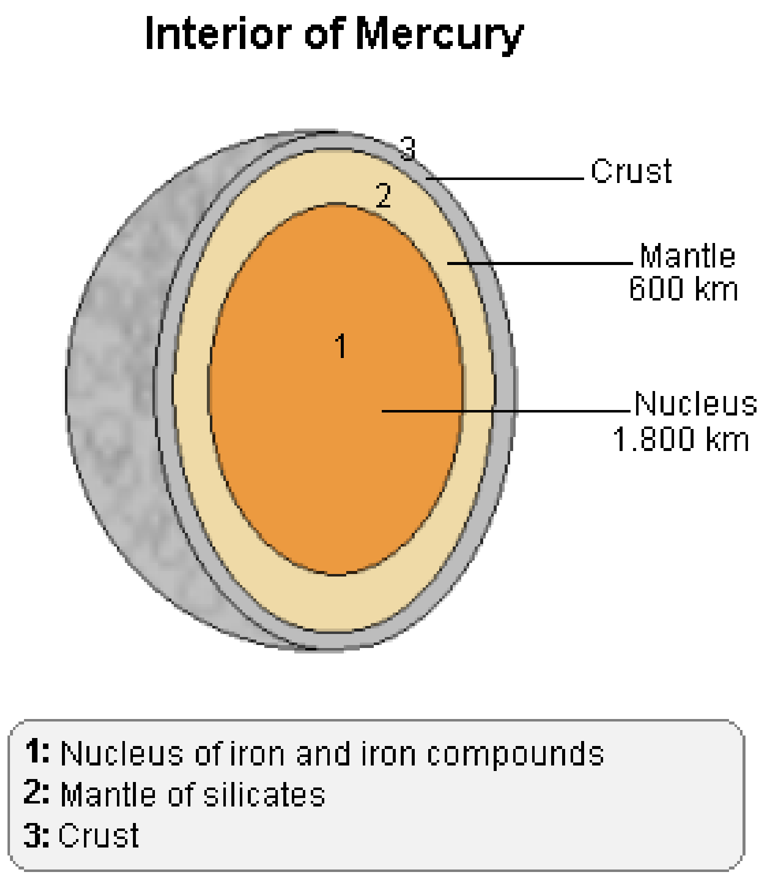


FIGURE 25.10
Mercury is one of the most dense planets, with a very large core.

A Harsh Environment

Viewed through a telescope, Venus looks smooth and featureless. The planet is covered by a thick layer of clouds. You can see the clouds in pictures of Venus, such as **Figure** 25.11. We make maps of the surface using radar, because the thick clouds won't allow us to take photographs of the surface of Venus.

Figure 25.12 shows the topographical features of Venus. The image was produced by the Magellan probe on a flyby. Radar waves sent by the spacecraft reveal mountains, valleys, vast lava plains, and canyons. Like Mercury, Venus does not have a moon.

Clouds on Earth are made of water vapor. Venus's clouds are a lot less pleasant. They are made of carbon dioxide, sulfur dioxide and large amounts of corrosive sulfuric acid! The atmosphere of Venus is so thick that the pressure on the surface of Venus is very high. In fact, it is 90 times greater than the pressure at Earth's surface! The thick atmosphere causes a strong greenhouse effect. As a result, Venus is the hottest planet. Even though it is farther from the Sun, Venus is much hotter even than Mercury. Temperatures at the surface reach 465°C (860°F). That's hot enough to melt lead!

Volcanoes

Venus has more volcanoes than any other planet. There are between 100,000 and one million volcanoes on Venus! Most of the volcanoes are now inactive. There are also a large number of craters. This means that Venus doesn't have tectonic plates. Plate tectonics on Earth erases features over time. **Figure** 25.13 is an image made using radar data. The volcano is Maat Mons. Lava beds are in the foreground. Scientists think the color of sunlight on Venus is

FIGURE 25.11
Venus in real color. The planet is covered by a thick layer of clouds.

FIGURE 25.12
A topographical image of Venus produced by the Magellan probe using radar. Color differences enhance small scale structure.

reddish-brown.

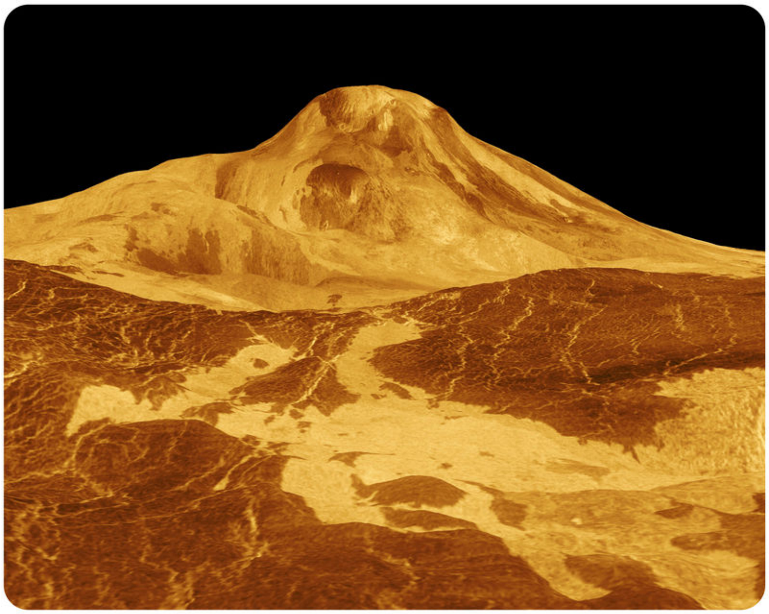


FIGURE 25.13
Maat Mons volcano on Venus, with lava beds in the foreground.

Motion and Appearance

Venus is the only planet that rotates clockwise as viewed from its North Pole. All of the other planets rotate counterclockwise. Venus turns slowly, making only one turn every 243 days. This is longer than a year on Venus! It takes Venus only 225 days to orbit the Sun.

Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. You can see Venus rising early in the morning, just before the Sun rises. For this reason, Venus is sometimes called "the morning star." When it sets in the evening, just after the Sun sets, it may be called "the evening star." Since planets only reflect the Sun's light, Venus should not be called a star at all! Venus is very bright because its clouds reflect sunlight very well. Venus is the brightest object in the sky besides the Sun and the Moon.

Earth

Earth is the third planet out from the Sun, shown in **Figure** 25.14. Because it is our planet, we know a lot more about Earth than we do about any other planet. What are main features of Earth?

Oceans and Atmosphere

Earth is a very diverse planet, seen in **Figure** 25.14. Water appears as vast oceans of liquid. Water is also seen as ice at the poles or as clouds of vapor. Earth also has large masses of land. Earth's average surface temperature is 14°C (57°F). At this temperature, water is a liquid. The oceans and the atmosphere help keep Earth's surface temperatures fairly steady.

Earth is the only planet known to have life. Conditions on Earth are ideal for life! The atmosphere filters out harmful radiation. Water is abundant. Carbon dioxide was available for early life forms. The evolution of plants introduced

FIGURE 25.14
Earth from space.

more oxygen for animals.

Plate Tectonics

The Earth is divided into many plates. These plates move around on the surface. The plates collide or slide past each other. One may even plunge beneath another. Plate motions cause most geological activity. This activity includes earthquakes, volcanoes, and the buildup of mountains. The reason for plate movement is convection in the mantle. Earth is the only planet that we know has plate tectonics.

Earth's Motions and Moon

Earth rotates on its axis once every 24 hours. This is the length of an Earth day. Earth orbits the Sun once every 365.24 days. This is the length of an Earth **year**. Earth has one large moon. This satellite orbits Earth once every 29.5 days. This moon is covered with craters, and also has large plains of lava. The Moon came into being from material that flew into space after Earth and a giant asteroid collided. This moon is not a captured asteroid like other moons in the solar system.

Mars

Mars, shown in **Figure** 25.15, is the fourth planet from the Sun. The Red Planet is the first planet beyond Earth's orbit. Mars' atmosphere is thin compared to Earth's. This means that there is much lower pressure at the surface. Mars also has a weak greenhouse effect, so temperatures are only slightly higher than they would be if the planet did not have an atmosphere.

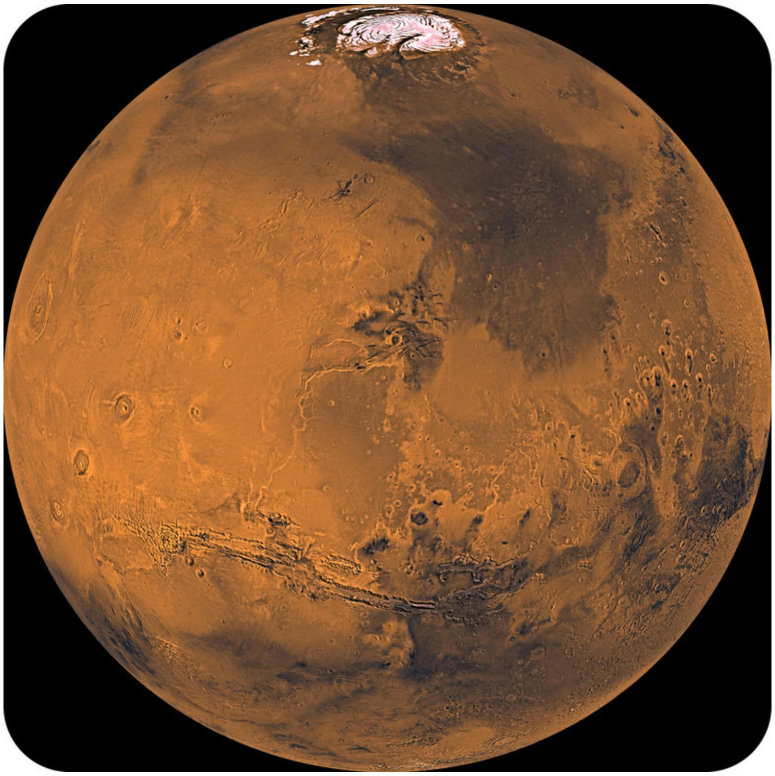


FIGURE 25.15
Mars is Earth's second nearest neighbor planet.

Mars is the easiest planet to observe. As a result, it has been studied more than any other planet besides Earth. People can stand on Earth and observe the planet through a telescope. We have also sent many space probes to Mars. In April 2011, there were three scientific satellites in orbit around Mars. The rover, Opportunity, was still moving around on the surface. No humans have ever set foot on Mars. NASA and the European Space Agency have plans to send people to Mars. The goal is to do it sometime between 2030 and 2040. The expense and danger of these missions are phenomenal.

A Red Planet

Viewed from Earth, Mars is red. This is due to large amounts of iron in the soil. The ancient Greeks and Romans named the planet Mars after the god of war. The planet's red color reminded them of blood. Mars has only a very thin atmosphere, made up mostly of carbon dioxide.

Surface Features

Mars is home to the largest volcano in the solar system. Olympus Mons is shown in **Figure** 25.16. Olympus Mons is a shield volcano. The volcano is similar to the volcanoes of the Hawaiian Islands. But Olympus Mons is a giant, about 27 km (16.7 miles/88,580 ft) tall. That's three times taller than Mount Everest! At its base, Olympus Mons is about the size of the entire state of Arizona.

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 25.17). This canyon is 4,000 km (2,500 miles) long. That's as long as Europe is wide! One-fifth of the circumference of Mars is covered by the canyon. Valles Marineris is 7 km (4.3 miles) deep. How about Earth's Grand Canyon? Earth's most famous canyon is only 446 km (277 miles) long and about 2 km (1.2 miles) deep.

Mars has mountains, canyons, and other features similar to Earth. But it doesn't have as much geological activity

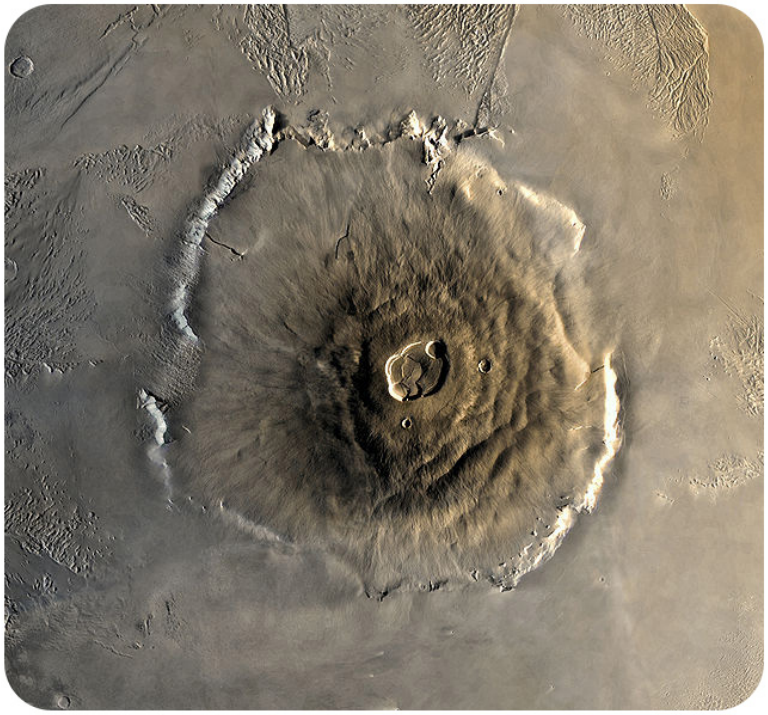


FIGURE 25.16
The largest volcano in the solar system, Olympus Mons.

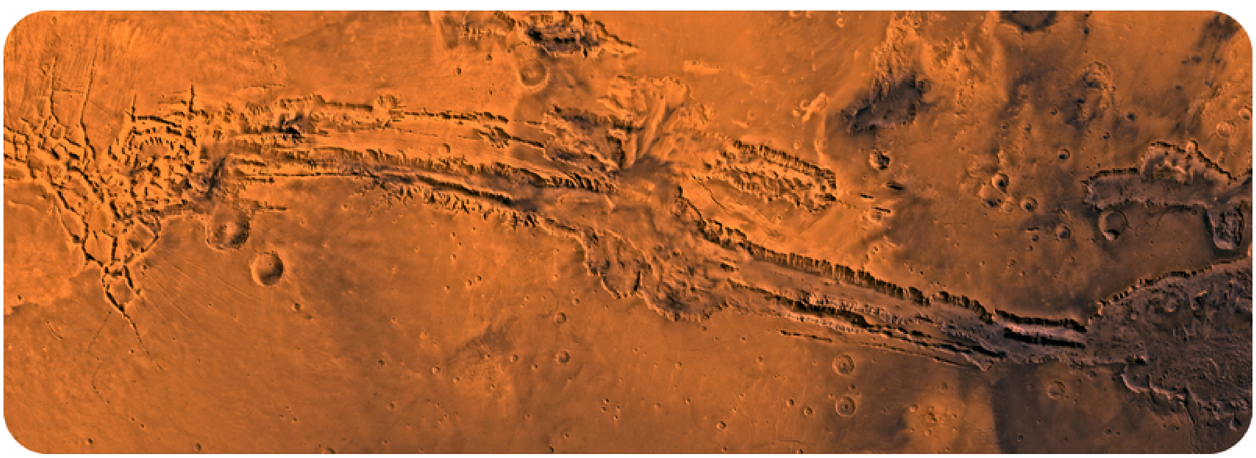


FIGURE 25.17
The largest canyon in the solar system, Valles Marineris.

as Earth. There is no evidence of plate tectonics on Mars. There are also more craters on Mars than on Earth. Buy there are fewer craters than on the Moon. What does this suggest to you regarding Mars' plate tectonic history?

Is There Water on Mars?

Water on Mars can't be a liquid. This is because the pressure of the atmosphere is too low. The planet does have a lot of water; it is in the form of ice. The south pole of Mars has a very visible ice cap. Scientists also have evidence that there is also a lot of ice just under the Martian surface. The ice melts when volcanoes erupt. At this times liquid water flows across the surface.

Scientists think that there was once liquid water on the planet. There are many surface features that look like water-eroded canyons. The Mars rover collected round clumps of crystals that, on Earth, usually form in water. If there was liquid water on Mars, life might have existed there in the past.

Two Martian Moons

Mars has two very small, irregular moons, Phobos (seen in **Figure** 25.18) and Deimos. These moons were discovered in 1877. They are named after the two sons of Ares, who followed their father into war. The moons were probably asteroids that were captured by Martian gravity.

FIGURE 25.18
Phobos is Mars' larger moon. It has a 6.9 mile (11.1 km) radius.

Lesson Summary

- The four inner planets are small, dense, solid, rocky planets.
- Mercury is the smallest planet and the closest to the Sun. It has an extremely thin atmosphere so surface temperatures range from very hot to very cold. Like the Moon, it is covered with craters.
- Venus is the second planet from the Sun and the closest planet to Earth, in distance and in size. Venus has a very thick, corrosive atmosphere, and the surface temperature is extremely high.

- Radar maps of Venus show that it has mountains, canyons and volcanoes surrounded by plains of lava.
- Venus rotates slowly in a direction opposite to the direction of its orbit.
- Earth is the third planet from the Sun. It is the only planet with large amounts of liquid water, and the only planet known to support life. Earth is the only inner planet that has a large round moon.
- Mars is the fourth planet from the Sun. It has two small, irregular moons. Mars is red because of rust in its soil. Mars has the largest mountain and the largest canyon in the solar system.
- There is a lot of water ice in the polar ice caps and under the surface of Mars.

Lesson Review Questions

Recall

1. Name the four inner planets from nearest to the Sun to farthest out from the Sun.

2. Which planet is most like Earth? Why?

3. How do scientists get maps of Venus' surface? What do you see if you look at Venus from Earth through a telescope?

Apply Concepts

4. Which planet do you think has the smallest temperature range? Why?

5. If you were told to go to one of the three inner planets besides Earth to look for life where would you go? Why?

6. Mercury is small, rocky and covered with craters. Why?

Think Critically

7. Venus is said to have runaway greenhouse effect? Why does it have such a large amount of greenhouse effect? Why do you think is meant by runaway greenhouse effect?

8. Why are there no Martians? In other words, why didn't life evolve on Mars?

Points to Consider

- We are planning to send humans to Mars sometime in the next few decades. What do you think it would be like to live on Mars? Why do you think we are going to Mars instead of Mercury or Venus?
- In what ways are the four inner planets like Earth? What might a planet be like if it weren't like Earth?

25.3 Outer Planets

Lesson Objectives

- Describe main features of the outer planets and their moons.
- Compare the outer planets to each other and to Earth.

Vocabulary

- Galilean moons
- gas giants
- Great Red Spot
- outer planets
- planetary rings

Introduction

Jupiter, Saturn, Uranus, and Neptune are the **outer planets** of our solar system. These are the four planets farthest from the Sun. The outer planets are much larger than the inner planets. Since they are mostly made of gases, they are also called **gas giants**.

The gas giants are mostly made of hydrogen and helium. These are the same elements that make up most of the Sun. Astronomers think that most of the nebula was hydrogen and helium. The inner planets lost these very light gases. Their gravity was too low to keep them and they floated away into space. The Sun and the outer planets had enough gravity to keep the hydrogen and helium.

All of the outer planets have numerous moons. They also have **planetary rings** made of dust and other small particles. Only the rings of Saturn can be easily seen from Earth.

Jupiter

Jupiter, shown in **Figure** 25.19, is the largest planet in our solar system. Jupiter is named for the king of the gods in Roman mythology.

Jupiter is truly a giant! The planet has 318 times the mass of Earth, and over 1,300 times Earth's volume. So Jupiter is much less dense than Earth. Because Jupiter is so large, it reflects a lot of sunlight. When it is visible, it is the brightest object in the night sky besides the Moon and Venus. Jupiter is quite far from the Earth. The planet is more than five times as far from Earth as the Sun. It takes Jupiter about 12 Earth years to orbit once around the Sun.

FIGURE 25.19
Jupiter is the largest planet in our solar system.

A Ball of Gas and Liquid

Since Jupiter is a gas giant, could a spacecraft land on its surface? The answer is no. There is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements. The outer layers of the planet are gas. Deeper within the planet, the intense pressure condenses the gases into a liquid. Jupiter may have a small rocky core at its center.

A Stormy Atmosphere

Jupiter's atmosphere is unlike any other in the solar system! The upper layer contains clouds of ammonia. The ammonia is different colored bands. These bands rotate around the planet. The ammonia also swirls around in tremendous storms. The **Great Red Spot**, shown in **Figure** 25.20, is Jupiter's most noticeable feature. The spot is an enormous, oval-shaped storm. It is more than three times as wide as the entire Earth! Clouds in the storm rotate counterclockwise. They make one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years. It may have been observed as early as 1664. It is possible that this storm is a permanent feature on Jupiter. No one knows for sure.

Jupiter's Moons and Rings

Jupiter has lots of moons. As of 2011, we have discovered over 60 natural satellites of Jupiter. Four are big enough and bright enough to be seen from Earth using a pair of binoculars. These four moons were first discovered by Galileo in 1610. They are called the **Galilean moons**. **Figure** 25.21 shows the four Galilean moons and their sizes relative to Jupiter's Great Red Spot. These moons are named Io, Europa, Ganymede, and Callisto. The Galilean moons are larger than even the biggest dwarf planets, Pluto and Eris. Ganymede is the biggest moon in the solar system. It is even larger than the planet Mercury!

FIGURE 25.20
The Great Red Spot has been on Jupiter since we've had telescopes powerful enough to see it.

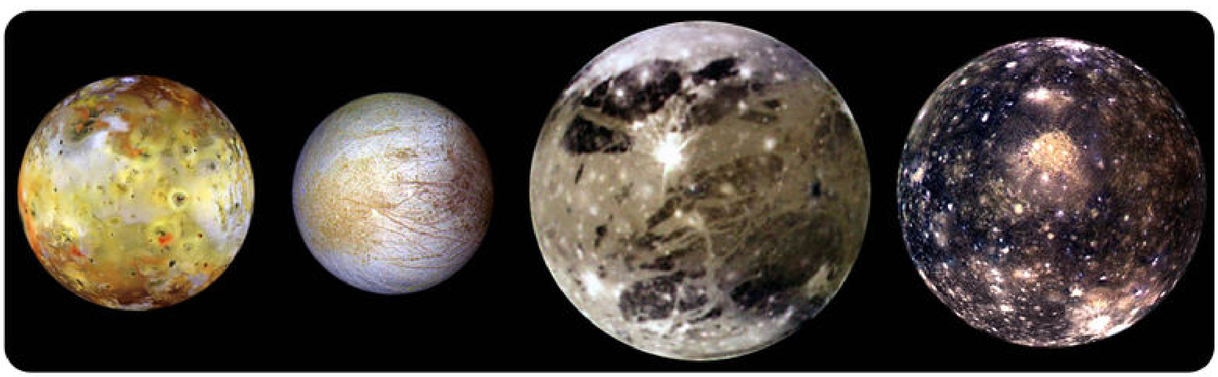


FIGURE 25.21
The Galilean moons are as large as small planets.

Scientists think that Europa is a good place to look for extraterrestrial life. Europa is the smallest of the Galilean moons. The moon's surface is a smooth layer of ice. Scientists think that the ice may sit on top of an ocean of liquid water. How could Europa have liquid water when it is so far from the Sun? Europa is heated by Jupiter. Jupiter's tidal forces are so great that they stretch and squash its moon. This could produce enough heat for there to be liquid water. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

In 1979, two spacecrafts, Voyager 1 and Voyager 2, visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is very difficult to observe from Earth.

Saturn

Saturn, shown in **Figure** 25.22, is famous for its beautiful rings. Saturn is the second largest planet in the solar system. Saturn's mass is about 95 times Earth's mass. The gas giant is 755 times Earth's volume. Despite its large size, Saturn is the least dense planet in our solar system. Saturn is actually less dense than water. This means that if there were a bathtub big enough, Saturn would float! In Roman mythology, Saturn was the father of Jupiter. Saturn orbits the Sun once about every 30 Earth years.

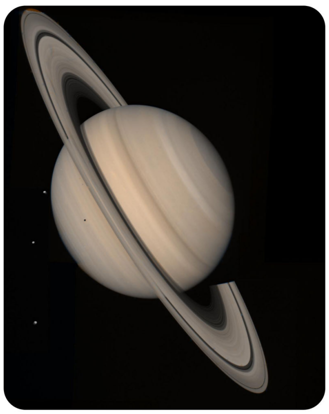


FIGURE 25.22
Saturn is the least dense planet in our solar system.

Saturn's composition is similar to Jupiter's. The planet is made mostly of hydrogen and helium. These elements are gases in the outer layers and liquids in the deeper layers. Saturn may also have a small solid core. Saturn's upper atmosphere has clouds in bands of different colors. These clouds rotate rapidly around the planet. But Saturn has fewer storms than Jupiter. Thunder and lightning have been seen in the storms on Saturn (**Figure** 25.23).

A Weird Hexagon

There is a strange feature at Saturn's north pole. The clouds form a hexagonal pattern, as shown in the infrared image in **Figure** 25.24. This hexagon was viewed by Voyager 1 in the 1980s. It was still there when the Cassini Orbiter visited in 2006. No one is sure why the clouds form this pattern.

Saturn's Rings

Saturn's rings were first observed by Galileo in 1610. He didn't know they were rings and thought that they were two large moons. One moon was on either side of the planet. In 1659, the Dutch astronomer Christiaan Huygens realized that they were rings circling Saturn's equator. The rings appear tilted. This is because Saturn is tilted about 27 degrees to its side.

The Voyager 1 spacecraft visited Saturn in 1980. Voyager 2 followed in 1981. These probes sent back detailed pictures of Saturn, its rings, and some of its moons. From the Voyager data, we learned that Saturn's rings are made of particles of water and ice with a little bit of dust. There are several gaps in the rings. These gaps were cleared out by moons within the rings. Ring dust and gas are attracted to the moon by its gravity. This leaves a gap in the rings. Other gaps in the rings are caused by the competing forces of Saturn and its moons outside the rings.

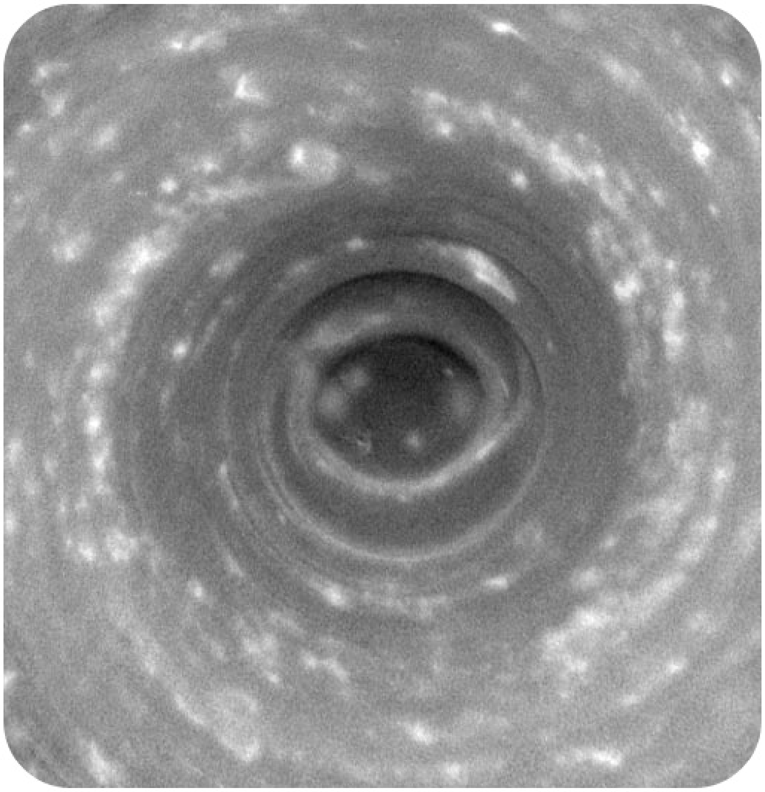


FIGURE 25.23
Cassini scientists waited years for the right conditions to produce the first movie that shows lightning on another planet - Saturn.

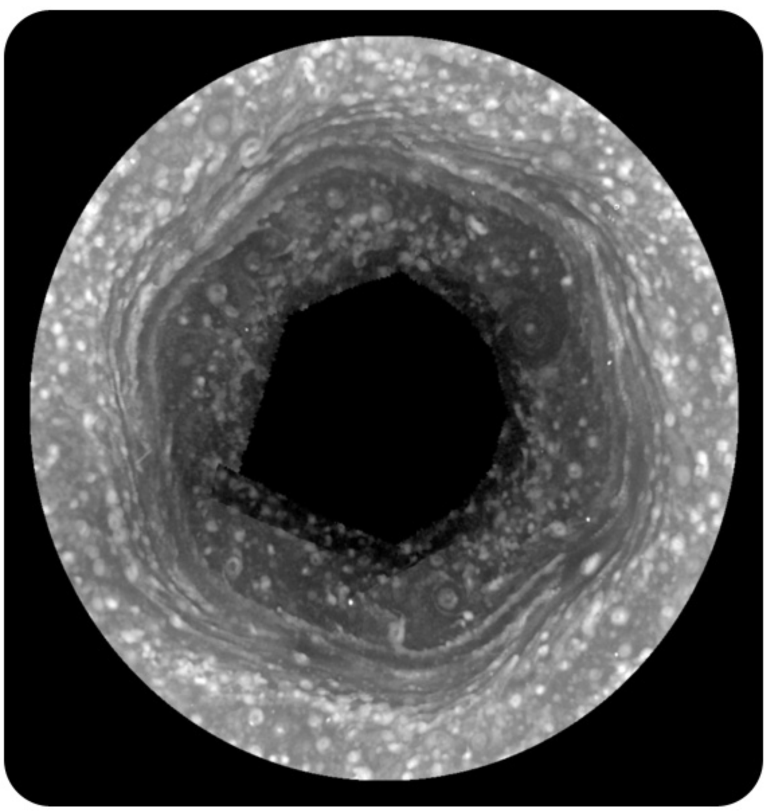


FIGURE 25.24
This hexagon has been visible for nearly 30 years.

Saturn's Moons

As of 2011, over 60 moons have been identified around Saturn. Only seven of Saturn's moons are round. All but one is smaller than Earth's Moon. Some of the very small moons are found within the rings. All the particles in the rings are like little moons, because they orbit around Saturn. Someone must decide which ones are large enough to call moons.

Saturn's largest moon, Titan, is about one and a half times the size of Earth's Moon. Titan is even larger than the planet Mercury. **Figure** 25.25 compares the size of Titan to Earth. Scientists are very interested in Titan. The moon has an atmosphere that is thought to be like Earth's first atmosphere. This atmosphere was around before life developed on Earth. Like Jupiter's moon, Europa, Titan may have a layer of liquid water under a layer of ice. Scientists now think that there are lakes on Titan's surface. Don't take a dip, though. These lakes contain liquid methane and ethane instead of water! Methane and ethane are compounds found in natural gas.

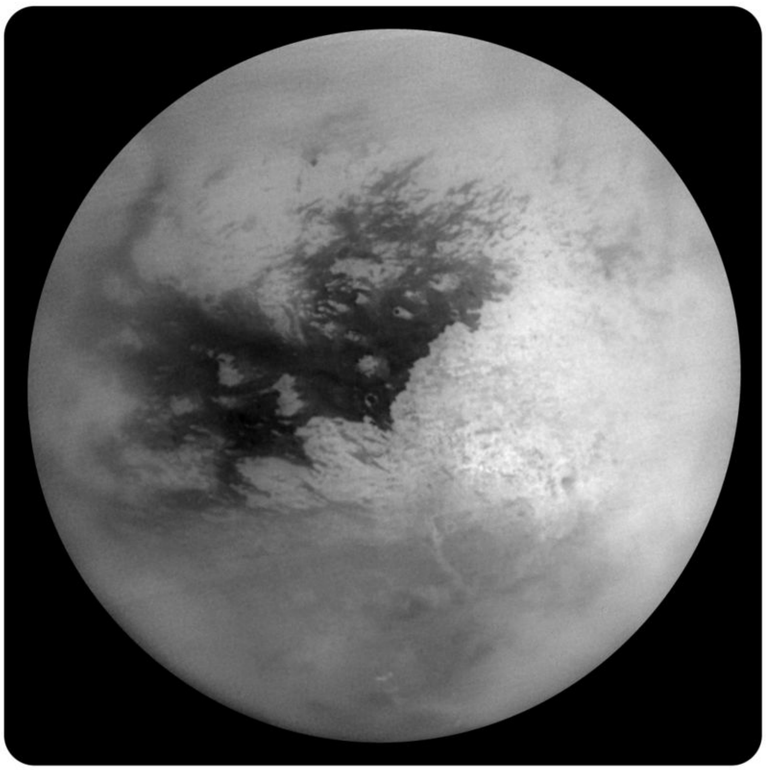


FIGURE 25.25
Titan has an atmosphere like Earth's first atmosphere.

Uranus

Uranus, shown in **Figure** 25.26, is named for the Greek god of the sky, the father of Saturn. Astronomers pronounce the name "YOOR-uh-nuhs." Uranus was not known to ancient observers. The planet was first discovered with a telescope by the astronomer William Herschel in 1781.

Uranus is faint because it is very far away. Its distance from the Sun is 2.8 billion kilometers (1.8 billion miles). A photon from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

FIGURE 25.26
Uranus is the 7th planet out from the Sun.

An Icy Blue-Green Ball

Uranus is a lot like Jupiter and Saturn. The planet is composed mainly of hydrogen and helium. There is a thick layer of gas on the outside. Further on the inside is liquid. But Uranus has a higher percentage of icy materials than Jupiter and Saturn. These materials include water, ammonia, and methane. Uranus is also different because of its blue-green color. Clouds of methane filter out red light. This leaves a blue-green color. The atmosphere of Uranus has bands of clouds. These clouds are hard to see in normal light. The result is that the planet looks like a plain blue ball.

Uranus is the least massive outer planet. Its mass is only about 14 times the mass of Earth. Like all of the outer planets, Uranus is much less dense than Earth. Gravity is actually weaker than on Earth's surface. If you were at the top of the clouds on Uranus, you would weigh about 10 percent less than what you weigh on Earth.

The Sideways Planet

All of the planets rotate on their axes in the same direction that they move around the Sun. Except for Uranus. Uranus is tilted on its side. Its axis is almost parallel to its orbit. So Uranus rolls along like a bowling ball as it revolves around the Sun. How did Uranus get this way? Scientists think that the planet was struck and knocked over by another planet-sized object. This collision probably took place billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings, as shown in **Figure** 25.27. The rings circle the planet's equator. However, Uranus is tilted on its side. So the rings are almost perpendicular to the planet's orbit.

We have discovered 27 moons around Uranus. All but a few are named for characters from the plays of William

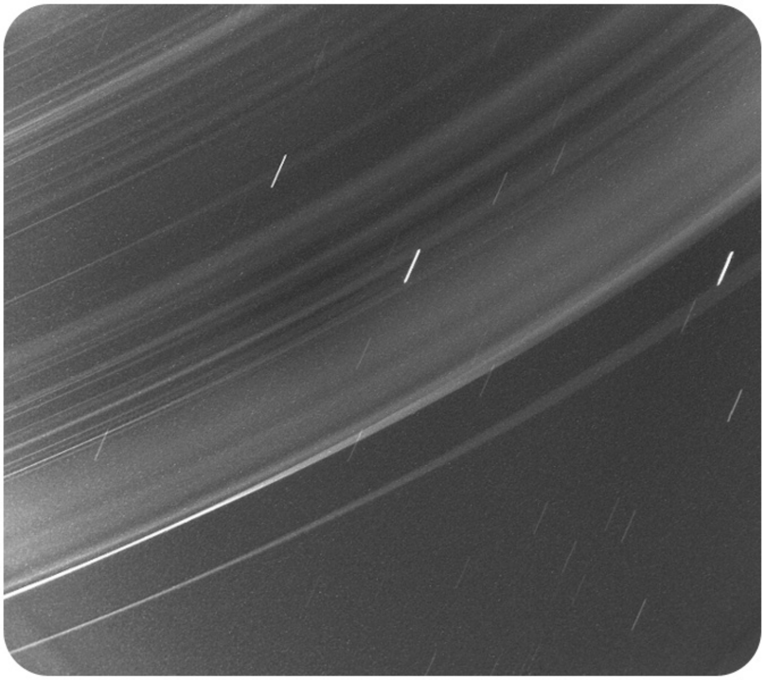


FIGURE 25.27
Uranus' rings are almost perpendicular to the planet's orbit.

Shakespeare. The five biggest moons of Uranus, Miranda, Ariel, Umbriel, Titania, and Oberon, are shown in **Figure** 25.28.

FIGURE 25.28
The five biggest moons of Uranus: Miranda, Ariel, Umbriel, Titania, and Oberon.

Neptune

Neptune is shown in **Figure** 25.29. It is the eighth planet from the Sun. Neptune is so far away you need a telescope to see it from Earth. Neptune is the most distant planet in our solar system. It is nearly 4.5 billion kilometers (2.8

billion miles) from the Sun. One orbit around the Sun takes Neptune 165 Earth years.

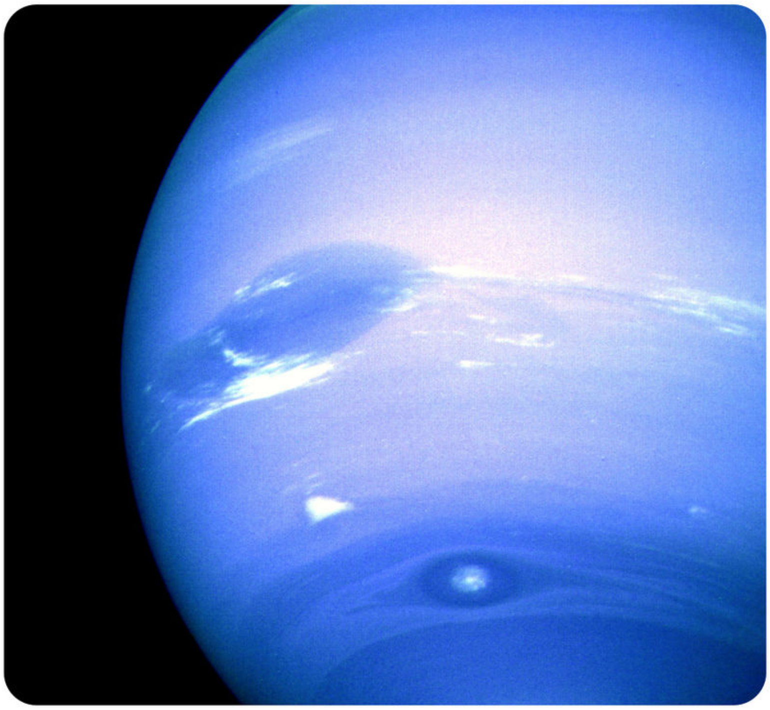


FIGURE 25.29
Neptune has a great dark spot at the center left and a small dark spot at the bottom center.

Scientists guessed Neptune's existence before it was discovered. Uranus did not always appear exactly where it should. They said this was because a planet beyond Uranus was pulling on it. This gravitational pull was affecting its orbit. Neptune was discovered in 1846. It was just where scientists predicted it would be! Due to its blue color, the planet was named Neptune for the Roman god of the sea.

Uranus and Neptune are often considered "sister planets." They are very similar to each other. Neptune has slightly more mass than Uranus, but it is slightly smaller in size.

Extremes of Cold and Wind

Like Uranus, Neptune is blue. The blue color is caused by gases in its atmosphere, including methane. Neptune is not a smooth looking ball like Uranus. The planet has a few darker and lighter spots. When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot south of the equator. This spot was called the Great Dark Spot. When the Hubble Space Telescope photographed Neptune in 1994, the Great Dark Spot had disappeared. Another dark spot had appeared north of the equator. Astronomers believe that both of these spots represent gaps in the methane clouds on Neptune.

Neptune's appearance changes due to its turbulent atmosphere. Winds are stronger than on any other planet in the solar system. Wind speeds can reach 1,100 km/h (700 mph). This is close to the speed of sound! The rapid winds surprised astronomers. This is because Neptune receives little energy from the Sun to power weather systems. It is not surprising that Neptune is one of the coldest places in the solar system. Temperatures at the top of the clouds are about –218°C (–360°F).

Neptune's Rings and Moons

Like the other outer planets, Neptune has rings of ice and dust. These rings are much thinner and fainter than Saturn's. Neptune's rings may be unstable. They may change or disappear in a relatively short time.

Neptune has 13 known moons. Only Triton, shown in **Figure** 25.30, has enough mass to be round. Triton orbits in the direction opposite to Neptune's orbit. Scientists think Triton did not form around Neptune. The satellite was captured by Neptune's gravity as it passed by.

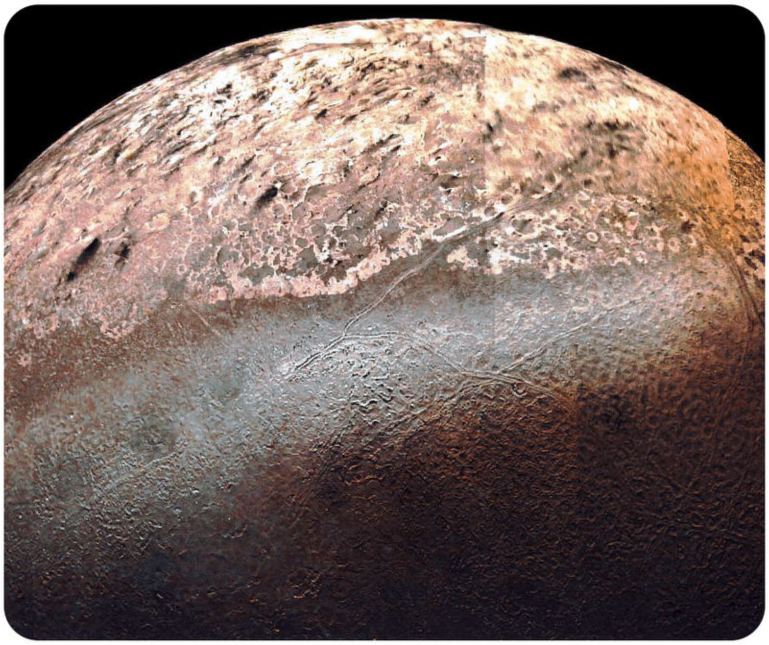


FIGURE 25.30
Neptune's moon Triton.

Pluto

Pluto was once considered one of the outer planets, but when the definition of a planet was changed in 2006, Pluto became one of the dwarf planets. It is one of the largest and brightest objects that make up this group. Look for Pluto in the next lesson, in the discussion of dwarf planets.

Lesson Summary

- The four outer planets —Jupiter, Saturn, Uranus, and Neptune —are all gas giants made mostly of hydrogen and helium. Their thick outer layers are gases and have liquid interiors.
- All of the outer planets have lots of moons, as well as planetary rings made of dust and other particles.
- Jupiter is the largest planet in the solar system. It has bands of different colored clouds, and a long-lasting storm called the Great Red Spot.
- Jupiter has over 60 moons. The four biggest were discovered by Galileo, and are called the Galilean moons.
- One of the Galilean moons, Europa, may have an ocean of liquid water under a layer of ice. The conditions in this ocean might be right for life to have developed.

- Saturn is smaller than Jupiter, but very similar to Jupiter. Saturn has a large system of beautiful rings.
- Saturn's largest moon, Titan, has an atmosphere similar to Earth's atmosphere before life formed.
- Uranus and Neptune were discovered using a telescope. They are similar to each other in size and composition. They are both smaller than Jupiter and Saturn, and also have more icy materials.
- Uranus is tilted on its side, probably due to a collision with a large object in the distant past.
- Neptune is very cold and has very strong winds. It had a large dark spot that disappeared. Another dark spot appeared on another part of the planet. These dark spots are storms in Neptune's atmosphere.

Lesson Review Questions

Recall

1. Why were the Galilean moons given that name? What are they?
2. Why are Neptune and Uranus blue?

Apply Concepts

3. How are the outer planets different from the inner planets?
4. Describe Saturn's rings? What are they and what has made them that way?
5. How can liquid be found so far out in the solar system where temperatures are so cold?

Think Critically

6. Why did Jupiter's Great Red Spot last for 300 years and Neptune's Great Dark Spot disappear in a couple of decades?
7. If you were given the task of finding life in the solar system somewhere besides Earth where would you look?
8. The atmosphere of Saturn's moon Titan because it resembles the early Earth's atmosphere. Why is this interesting to scientists?

Points to Consider

- The inner planets are small and rocky, while the outer planets are large and made of gases. Why might the planets have formed into these two groups?
- We have discussed the Sun, the planets, and the moons of the planets. What other objects can you think of that can be found in our solar system?

25.4 Other Objects in the Solar System

Lesson Objectives

- Locate and describe the asteroid belt.
- Explain where comets come from and what causes their tails.
- Discuss the differences between meteors, meteoroids, and meteorites.

Vocabulary

- asteroid
- asteroid belt
- comet
- Kuiper belt
- meteor
- meteoroid
- meteor shower

Introduction

Debris. Space junk. After the Sun and planets formed, there was some material left over. These small chunks didn't get close enough to a large body to be pulled in by its gravity. They now inhabit the solar system as asteroids and comets.

Asteroids

Asteroids are very small, irregularly shaped, rocky bodies. Asteroids orbit the Sun, but they are more like giant rocks than planets. Since they are small, they do not have enough gravity to become round. They are too small to have an atmosphere. With no internal heat, they are not geologically active. An asteroid can only change due to a collision. A collision may cause the asteroid to break up. It may create craters on the asteroid's surface. An asteroid may strike a planet if it comes near enough to be pulled in by its gravity. **Figure** 25.31 shows a typical asteroid.

The Asteroid Belt

Hundreds of thousands of asteroids have been found in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month! The majority are located in between the orbits of Mars and Jupiter. This region is called the **asteroid belt**, as shown in **Figure** 25.32. There are many thousands of asteroids in the asteroid belt. Still, their total mass adds up to only about 4 percent of Earth's Moon.

FIGURE 25.31
Asteroid Ida with its tiny moon Dactyl. The asteroid's mean radius is 15.7 km.

Asteroids formed at the same time as the rest of the solar system. Although there are many in the asteroid belt, they were never were able to form into a planet. Jupiter's gravity kept them apart.

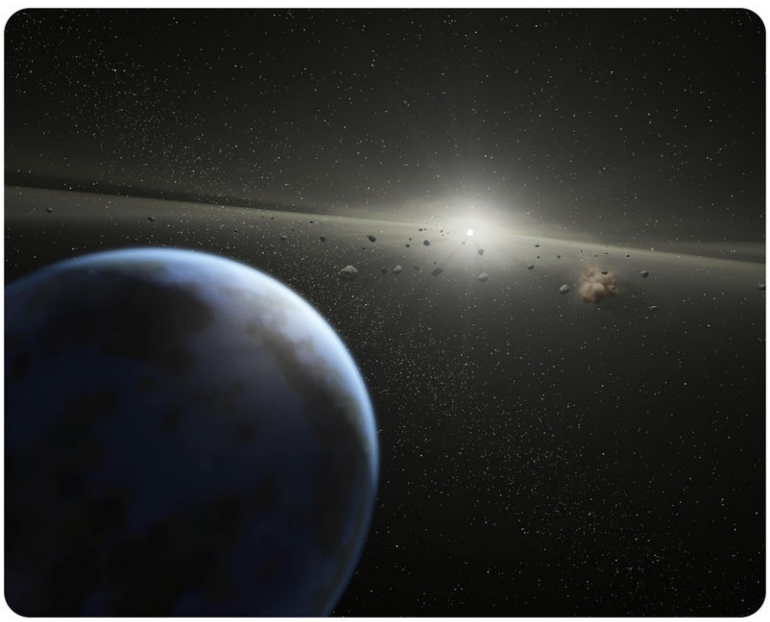


FIGURE 25.32
The asteroid belt is between Mars and Jupiter.

Near-Earth Asteroids

Near-Earth asteroids have orbits that cross Earth's orbit. This means that they can collide with Earth. There are over 4,500 known near-Earth asteroids. Small asteroids do sometimes collide with Earth. An asteroid about 5–10 m in diameter hits about once per year. Five hundred to a thousand of the known near-Earth asteroids are much bigger. They are over 1 kilometer in diameter. When large asteroids hit Earth in the past, many organisms died. At times, many species became extinct. Astronomers keep looking for near-Earth asteroids. They hope to predict a possible collision early so they can to try to stop it.

Asteroid Missions

Scientists are very interested in asteroids. Most are composed of material that has not changed since early in the solar system. Scientists can learn a lot from them about how the solar system formed. Asteroids may be important for space travel. They could be mined for rare minerals or for construction projects in space.

Scientists have sent spacecraft to study asteroids. In 1997, the NEAR Shoemaker probe orbited the asteroid 433 Eros. The craft finally landed on its surface in 2001. The Japanese Hayabusa probe returned to Earth with samples of a small near-earth asteroid in 2010. The U.S. Dawn mission will visit Vesta in 2011 and Ceres in 2015.

Meteors

If you look at the sky on a dark night, you may see a **meteor**, like in **Figure** 25.33. A meteor forms a streak of light across the sky. People call them shooting stars because that's what they look like. But meteors are not stars at all. The light you see comes from a small piece of matter burning up as it flies through Earth's atmosphere.

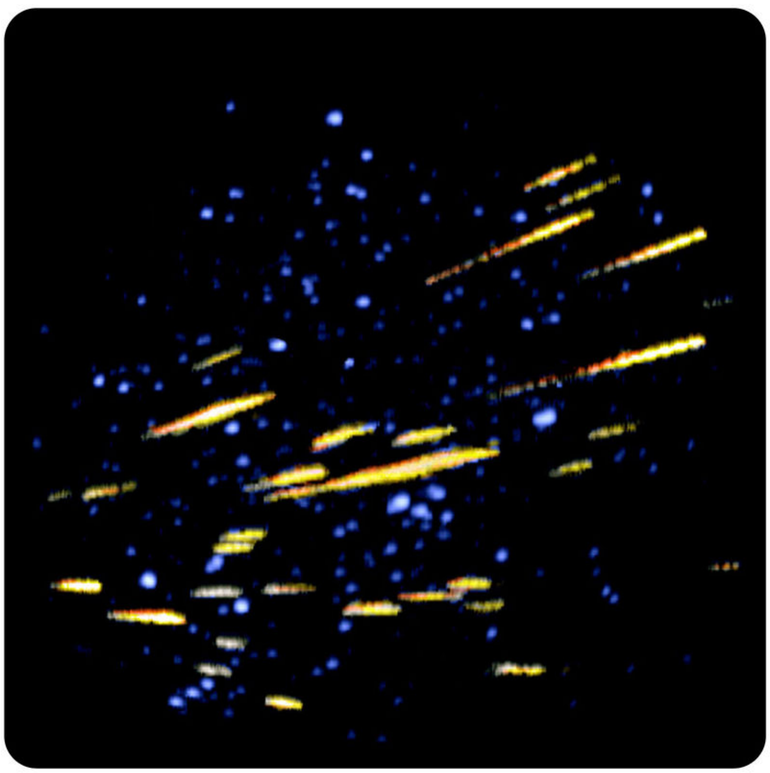


FIGURE 25.33
Meteors burning up as they fall through Earth's atmosphere.

Meteoroids

Before these small pieces of matter enter Earth's atmosphere, they are called **meteoroids**. Meteoroids are as large as boulders or as small as tiny sand grains. Larger objects are called asteroids; smaller objects are interplanetary dust. Meteoroids sometimes cluster together in long trails. They are the debris left behind by comets. When Earth passes through a comet trail, there is a **meteor shower**. During a meteor shower, there are many more meteors than normal for a night or two.

Meteorites

A meteoroid is dragged towards Earth by gravity and enters the atmosphere. Friction with the atmosphere heats the object quickly, so it starts to vaporize. As it flies through the atmosphere, it leaves a trail of glowing gases. The object is now a meteor. Most meteors vaporize in the atmosphere. They never reach Earth's surface. Large meteoroids may not burn up entirely in the atmosphere. A small core may remain and hit the Earth's surface. This is called a **meteorite**.

Meteorites provide clues about our solar system. Many were formed in the early solar system (**Figure** 25.34). Some are from asteroids that have split apart. A few are rocks from nearby bodies like Mars. For this to happen, an asteroid smashed into Mars and sent up debris. A bit of the debris entered Earth's atmosphere as a meteor.

FIGURE 25.34
The Mars Rover, Opportunity, found a metal meteorite on the Red Planet.

Comets

Comets are small, icy objects that orbit the Sun. Comets have highly elliptical orbits. Their orbits carry them from close to the Sun to the solar system's outer edges. When a comet gets close to the Sun, its outer layers of ice melt and evaporate. The vaporized gas and dust forms an atmosphere around the comet. This atmosphere is called a coma. Radiation and particles streaming from the Sun push some of this gas and dust into a long tail. A comet's tail always points away from the Sun, no matter which way the comet is moving. Why do you think that is? **Figure** 25.35 shows Comet Hale-Bopp, which shone brightly for several months in 1997.

Gases in the coma and tail of a comet reflect light from the Sun. Comets are very hard to see except when they have comas and tails. That is why they appear only when they are near the Sun. They disappear again as they move back to the outer solar system.

The time between one visit from a comet and the next is called the comet's period. The first comet whose period was known was Halley's Comet. Its period is 75 years. Halley's Comet last traveled through the inner solar system in 1986. The comet will appear again in 2061. Who will look up at it?

FIGURE 25.35
Comet Hale-Bopp lit up the night sky in 1997.

Where Comets Come From

Some comets have periods of 200 years or less. They are called short-period comets. Short-period comets are from a region beyond the orbit of Neptune called the **Kuiper Belt**. Kuiper is pronounced "KI-per," rhyming with "viper." The Kuiper Belt is home to comets, asteroids, and at least two dwarf planets.

Some comets have periods of thousands or even millions of years. Most long-period comets come from a very distant region of the solar system. This region is called the Oort cloud. The Oort cloud is about 50,000–100,000 times the distance from the Sun to Earth.

Comets carry materials in from the outer solar system. Comets may have brought water into the early Earth. Other substances could also have come from comets.

Dwarf Planets

For several decades, Pluto was a planet. But new solar system objects were discovered that were just as planet-like as Pluto. Astronomers figured out that they were like planets except for one thing. These objects had not cleared their orbits of smaller objects. They didn't have enough gravity to do so. Astronomers made a category called dwarf planets. There are five dwarf planets in our solar system: Ceres, Pluto, Makemake, Haumea and Eris.

Figure 25.36 shows Ceres. Ceres is a rocky body that orbits the Sun and is not a star. It could be an asteroid or a planet. Before 2006, Ceres was thought to be the largest asteroid. Is it an asteroid? Ceres is in the asteroid belt. But it is by far the largest object in the belt. Ceres has such high gravity that it is spherical. Is it a planet? Ceres only has about 1.3% of the mass of the Earth's Moon. Its orbit is full of other smaller bodies. Its gravity was not high enough to clear its orbit. Ceres fails the fourth criterion for being a planet. Ceres is now considered a dwarf planet along with Pluto.

Pluto

For decades Pluto was a planet. But even then, scientists knew it was an unusual planet. The other outer planets are all gas giants. Pluto is small, icy and rocky. With a diameter of about 2400 kilometers, it has only about 1/5 the mass of Earth's Moon. The other planets orbit in a plane. Pluto's orbit is tilted. The shape of the orbit is like a long, narrow ellipse. Pluto's orbit is so elliptical that sometimes it is inside the orbit of Neptune.

Pluto's orbit is in the Kuiper belt. We have discovered more than 200 million Kuiper belt objects. Pluto has 3 moons of its own. The largest, Charon, is big. Some scientists think that Pluto-Charon system is a double dwarf planet (

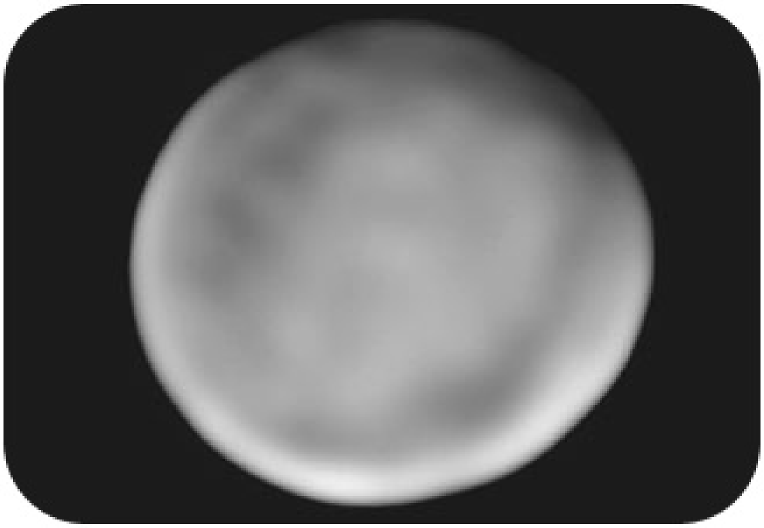


FIGURE 25.36
Ceres is a large spherical object in the asteroid belt.

Figure 25.37). Two smaller moons, Nix and Hydra, were discovered in 2005.

FIGURE 25.37
Pluto with its moons: Charon, Nix and Hydra.

Haumea

Haumea was named a dwarf planet in 2008. It is an unusual dwarf planet. The body is shaped like an oval! Haumea's longest axis is about the same as Pluto's diameter, and its shortest axis is about half as long. The body's orbit is tilted 28°. Haumea is so far from the Sun that it takes 283 years to make one orbit (**Figure** 25.38).

Haumea is the third-brightest Kuiper Belt object. It was named for the Hawaiian goddess of childbirth. Haumea has two moons, Hi'iaka and Namaka, the names of the goddess Haumea's daughters. Haumea's odd oval shape is probably caused by its extremely rapid rotation. It rotates in just less than 4 hours! Like other Kuiper belt objects, Haumea is covered by ice. Its density is similar to Earth's Moon, at 2.6 –3.3 g/cm^3. This means that most of Haumea is rocky.

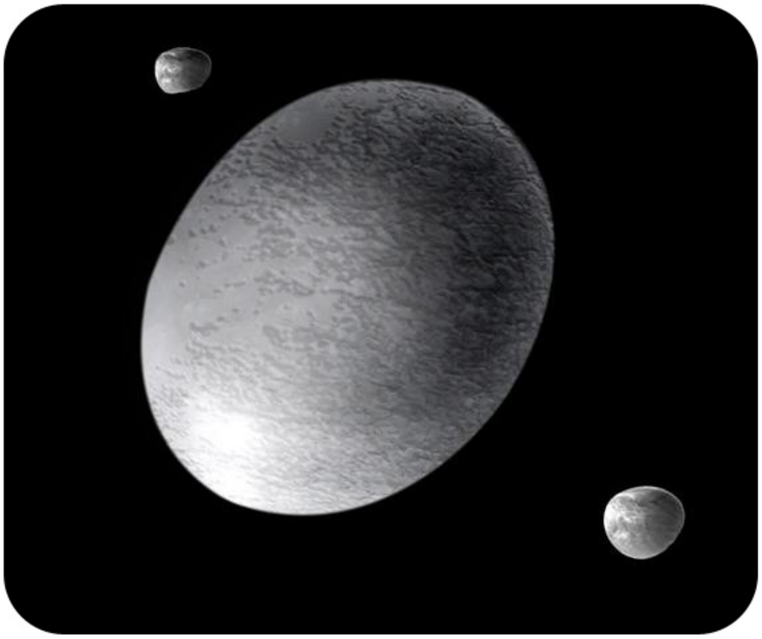


FIGURE 25.38
An artist's drawing of what Haumea and its moons might look like. The moons are drawn closer to Haumea than their actual orbits.

Haumea is part of a collisional family. This is a group of astronomical objects that formed from an impact. This family has Haumea, its two moons, and five more objects. All of these objects are thought to have formed from a collision very early in the formation of the solar system.

Makemake

Makemake is the third-largest and second-brightest dwarf planet we have discovered so far (**Figure** 25.39). Makemake is only 75 percent the size of Pluto. Its diameter is between 1300 and 1900 kilometers. The name comes from the mythology of the Eastern Islanders. Makemake was the god that created humanity. At a distance between 38.5 to 53 AU, this dwarf planet orbits the Sun in 310 years. Makemake is made of methane, ethane, and nitrogen ices.

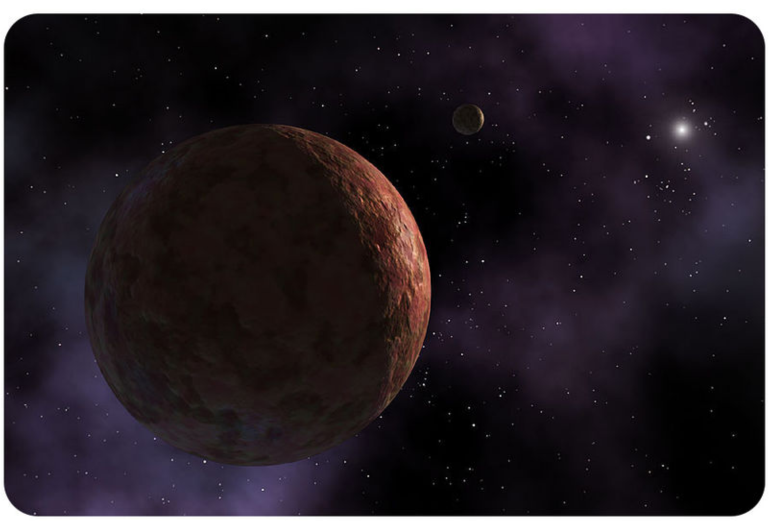


FIGURE 25.39
Makemake is a dwarf planet.

Eris

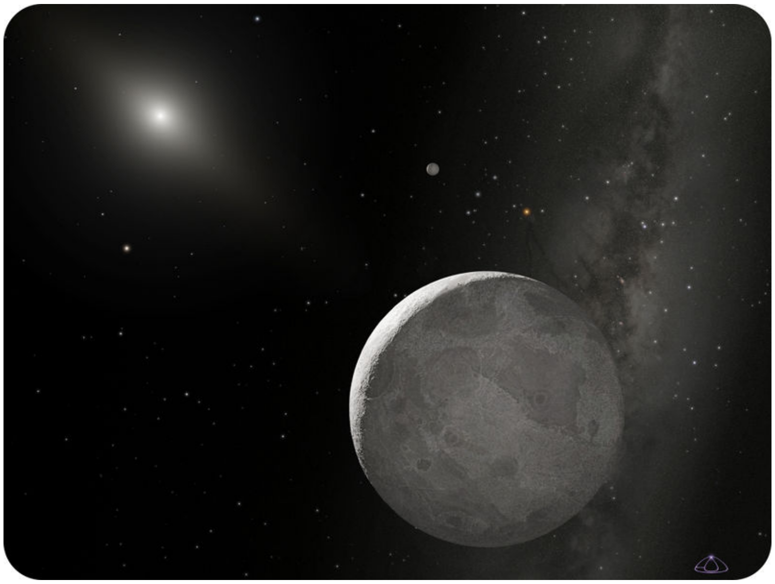


FIGURE 25.40
Eris is the largest known dwarf planet, but it's so far from the Sun that it wasn't discovered until 2005.

Eris is the largest known dwarf planet in the solar system. It is 27 percent larger than Pluto (**Figure** 25.40). Like Pluto and Makemake, Eris is in the Kuiper belt. But Eris is about 3 times farther from the Sun than Pluto. Because of its distance, Eris was not discovered until 2005. Early on, it was thought that Eris might be the tenth planet. Its discovery helped astronomers realize that they needed a new definition of "planet." Eris has a small moon, Dysnomia. Its moon orbits Eris once about every 16 days.

Astronomers know there may be other dwarf planets far out in the solar system. Look for Quaoar, Varuna and Orcus to be possibly added to the list of dwarf planets in the future. We still have a lot to discover and explore!

Lesson Summary

- Asteroids are irregularly-shaped, rocky bodies that orbit the Sun. Most of them are found in the asteroid belt, between the orbits of Mars and Jupiter.
- Meteoroids are smaller than asteroids, ranging from the size of boulders to the size of sand grains. When meteoroids enter Earth's atmosphere, they vaporize, creating a trail of glowing gas called a meteor. If any of the meteoroid reaches Earth, the remaining object is called a meteorite.
- Comets are small, icy objects that orbit the Sun in very elliptical orbits. When they are close to the Sun, they form comas and tails, which glow and make the comet more visible.
- Short-period comets come from the Kuiper belt, beyond Neptune. Long-period comets come from the very distant Oort cloud.
- Dwarf planets are spherical bodies that orbit the Sun, but that have not cleared their orbit of smaller bodies. Ceres is a dwarf planet in the asteroid belt. Eris, Pluto, Makemake and Haumea are dwarf planets in the Kuiper belt.

Lesson Review Questions

Recall

1. Define each of the following: asteroid, meteoroid, meteorite, meteor, planet, dwarf planet.

2. Which type of asteroids are most likely to hit Earth?

3. What comes from the Oort Cloud? What about the Kuiper Belt?

Apply Concepts

4. What is the asteroid belt? Why are there so many asteroids orbiting in this location?

5. What damage can an asteroid do when it hits Earth?

Think Critically

6. How well defined are the categories planet, dwarf planet and asteroid? If astronomers find a new object is it always clear which category to put it in?

7. Which type of object do you think NASA should make the subject of its next mission?

Points to Consider

- In 2006, astronomers changed the definition of a planet and created a new category of dwarf planets. Do you think planets, dwarf planets, moons, asteroids, and meteoroids are clearly separate groups?
- What defines each of these groups, and what do objects in these different groups have in common? Could an object change from being in one group to another? How?
- We have learned about many different kinds of objects that are found within our solar system. What objects or systems of objects can you think of that are found outside our solar system?

25.5 References

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CHAPTER 26 MS Stars, Galaxies, and the Universe

Chapter Outline

26.1 Stars

Lesson Objectives

- Define constellation.
- Classify stars based on their color and temperature.
- Outline the stages of a star.
- Use light-years as a unit of distance.

Vocabulary

- binary star system
- black hole
- main sequence star
- neutron star
- red giant
- supernova
- star

Introduction

When you look at the sky on a clear night, you can see hundreds of stars. A **star** is a giant ball of glowing gas that is very, very hot. Most of these stars are like our Sun, but some are smaller than our Sun, and some are larger. Except for our own Sun, all stars are so far away that they only look like single points, even through a telescope.

Constellations

The stars that make up a constellation appear close to each other from Earth. In reality, they may be very distant from one another. Constellations were important to people, like the Ancient Greeks. People who spent a lot of time outdoors at night, like shepherds, named them and told stories about them. **Figure** 26.1 shows one of the most easily recognized constellations. The ancient Greeks thought this group of stars looked like a hunter. They named it Orion, after a great hunter in Greek mythology.

The constellations stay the same night after night. The patterns of the stars never change. However, each night the constellations move across the sky. They move because Earth is spinning on its axis. The constellations also move with the seasons. This is because Earth revolves around the Sun. Different constellations are up in the winter than in the summer. For example, Orion is high up in the winter sky. In the summer, it's only up in the early morning.

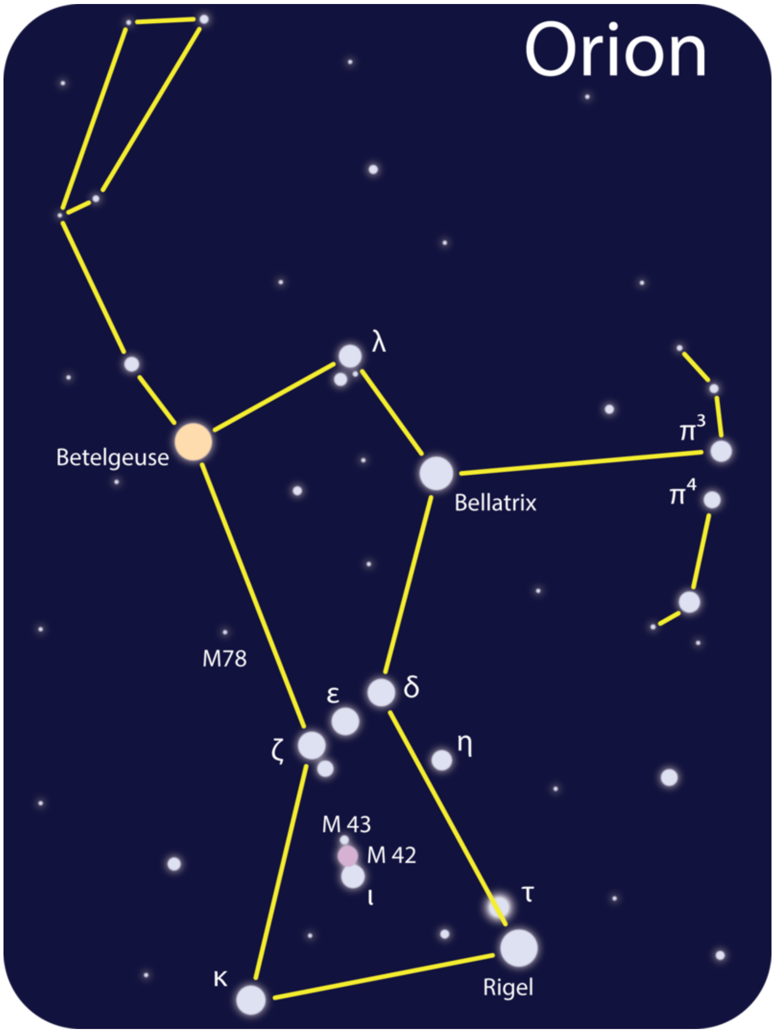


FIGURE 26.1
Orion has three stars that make up his belt. Orion's belt is fairly easy to see in the night sky.

Energy of Stars

Only a tiny bit of the Sun's light reaches Earth. But that light supplies most of the energy at the surface. The Sun is just an ordinary star, but it appears much bigger and brighter than any of the other stars. Of course, this is just because it is very close. Some other stars produce much more energy than the Sun. How do stars generate so much energy?

Nuclear Fusion

Stars shine because of nuclear fusion. Fusion reactions in the Sun's core keep our nearest star burning. Stars are made mostly of hydrogen and helium. Both are very lightweight gases. A star contains so much hydrogen and helium that the weight of these gases is enormous. The pressure at the center of a star is great enough to heat the gases. This causes nuclear fusion reactions.

A nuclear fusion reaction is named that because the nuclei (center) of two atoms fuse (join) together. In stars like our Sun, two hydrogen atoms join together to create a helium atom. Nuclear fusion reactions need a lot of energy to get started. Once they begin, they produce even more energy.

Particle Accelerators

Scientists have built machines called particle accelerators. These amazing tools smash particles that are smaller than atoms into each other head-on. This creates new particles. Scientists use particle accelerators to learn about nuclear fusion in stars. They can also learn about how atoms came together in the early universe. Two well-known accelerators are SLAC, in California, and CERN, in Switzerland.

How Stars Are Classified

Stars shine in many different colors. The color relates to a star's temperature and often its size.

Color and Temperature

Think about the coil of an electric stove as it heats up. The coil changes in color as its temperature rises. When you first turn on the heat, the coil looks black. The air a few inches above the coil begins to feel warm. As the coil gets hotter, it starts to glow a dull red. As it gets even hotter, it becomes a brighter red. Next it turns orange. If it gets extremely hot, it might look yellow-white, or even blue-white. Like a coil on a stove, a star's color is determined by the temperature of the star's surface. Relatively cool stars are red. Warmer stars are orange or yellow. Extremely hot stars are blue or blue-white.

Classifying Stars by Color

The most common way of classifying stars is by color as shown, in **Table** 26.1. Each class of star is given a letter, a color, and a range of temperatures. The letters don't match the color names because stars were first grouped as A through O. It wasn't until later that their order was corrected to go by increasing temperature. When you try to remember the order, you can use this phrase: "Oh Be A Fine Good Kid, Man."

TABLE 26.1: Classification of Stars By Color and Temperature

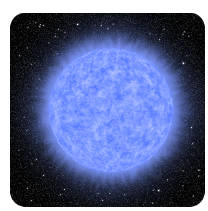
Class	Color	Temperature range	Sample Star
O	Blue	30,000 K or more	 An artist's depiction of the O class star Zeta Puppis.
B	Blue-white	10,000–30,000 K	 An artist's depiction of Rigel, a Class B star.

TABLE 26.1: (continued)

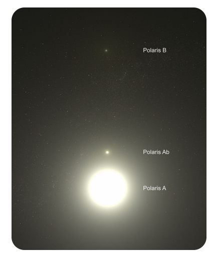
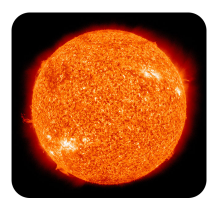
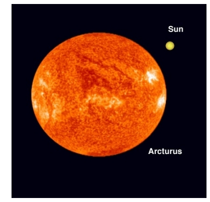
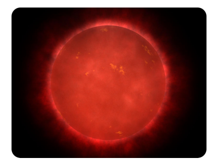
Class	Color	Temperature range	Sample Star
A	White	7,500–10,000 K	 Sirius A is the brightest star that we see in the night sky. The dot on the right, Sirius B, is a white dwarf.
F	Yellowish-white	6,000–7,500 K	 There are two F class stars in this image, the supergiant Polaris A and Polaris B. What we see in the night sky as the single star "Polaris," we also known as the North Star.
G	Yellow	5,500–6,000 K	 Our Sun: the most important G class star in the Universe, at least for humans.

TABLE 26.1: (continued)

Class	Color	Temperature range	Sample Star
K	Orange	3,500–5,000 K	 Arcturus is a Class K star that looks like the Sun but is much larger.
M	Red	2,000–3,500 K	There are two types of Class M stars: red dwarfs and red giants.  An artist's concept of a red dwarf star. Most stars are red dwarfs.
			 The red supergiant Betelgeuse is seen near Orion's belt. The blue star in the lower right is the Class B star Rigel.

The surface temperature of most stars is due to its size. Bigger stars produce more energy, so their surfaces are hotter. But some very small stars are very hot. Some very big stars are cool.

Lifetimes of Stars

We could say that stars are born, change over time, and eventually die. Most stars change in size, color, and class at least once during their lifetime.

Formation of Stars

Stars are born in clouds of gas and dust called nebulas. Our Sun and solar system formed out of a nebula. A nebula is shown in **Figure** 26.2. In **Figure** 26.1, the fuzzy area beneath the central three stars contains the Orion nebula.

FIGURE 26.2
Stars form in a nebula like this one in Orion's sword.

For a star to form, gravity pulls gas and dust into the center of the nebula. As the material becomes denser, the pressure and the temperature increase. When the temperature of the center becomes hot enough, nuclear fusion begins. The ball of gas has become a star!

Main Sequence Stars

For most of a star's life, hydrogen atoms fuse to form helium atoms. A star like this is a **main sequence star**. The hotter a main sequence star is, the brighter it is. A star remains on the main sequence as long as it is fusing hydrogen to form helium.

Our Sun has been a main sequence star for about 5 billion years. As a medium-sized star, it will continue to shine for about 5 billion more years. Large stars burn through their supply of hydrogen very quickly. These stars "live fast and die young!" A very large star may only be on the main sequence for 10 million years. A very small star may be on the main sequence for tens to hundreds of billions of years.

Red Giants and White Dwarfs

A star like our Sun will become a **red giant** in its next stage. When a star uses up its hydrogen, it begins to fuse helium atoms. Helium fuses into heavier atoms like carbon. At this time the star's core starts to collapse inward. The star's outer layers spread out and cool. The result is a larger star that is cooler on the surface, and red in color.

Eventually a red giant burns up all of the helium in its core. What happens next depends on the star's mass. A star like the Sun stops fusion and shrinks into a white dwarf star. A white dwarf is a hot, white, glowing object about the size of Earth. Eventually, a white dwarf cools down and its light fades out.

Supergiants and Supernovas

A more massive star ends its life in a more dramatic way. Very massive stars become red supergiants, like Betelgeuse.

In a red supergiant, fusion does not stop. Lighter atoms fuse into heavier atoms. Eventually iron atoms form. When there is nothing left to fuse, the star's iron core explodes violently. This is called a **supernova** explosion. The incredible energy released fuses heavy atoms together. Gold, silver, uranium and the other heavy elements can only form in a supernova explosion. A supernova can shine as brightly as an entire galaxy, but only for a short time, as shown in **Figure** 26.3.

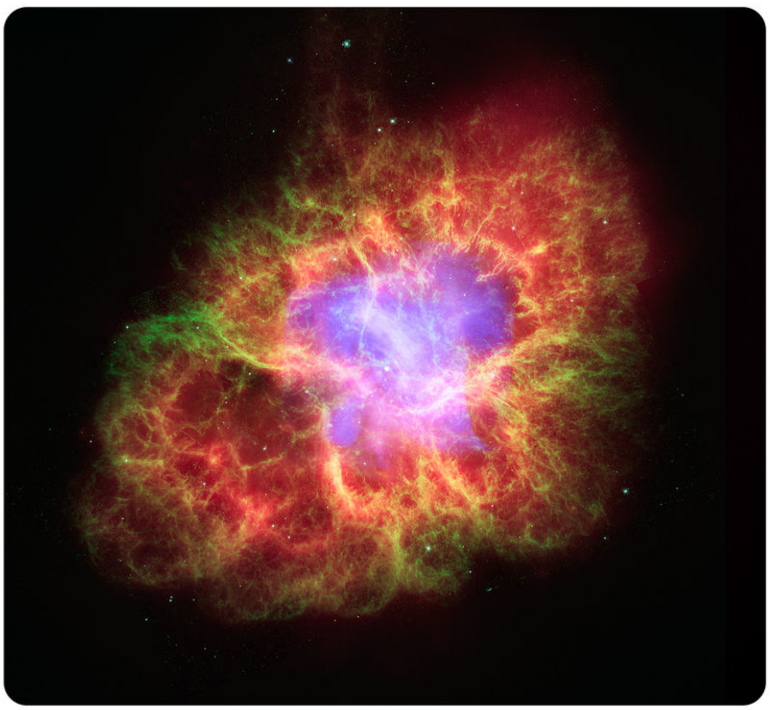


FIGURE 26.3

A supernova, as seen by the Hubble Space Telescope.

Neutron Stars and Black Holes

After a supernova explosion, the star's core is left over. This material is extremely dense. If the core is less than about four times the mass of the Sun, the star will become a neutron star. A **neutron star** is shown in **Figure** 26.4. This type of star is made almost entirely of neutrons. A neutron star has more mass than the Sun, yet it is only a few kilometers in diameter.

If the core remaining after a supernova is more than about 5 times the mass of the Sun, the core collapses to become a **black hole**. Black holes are so dense that not even light can escape their gravity. For that reason, we can't see black holes. How can we know something exists if radiation can't escape it? We know a black hole is there by the effect that it has on objects around it. Also, some radiation leaks out around its edges. A black hole isn't a hole at all. It is the tremendously dense core of a supermassive star.

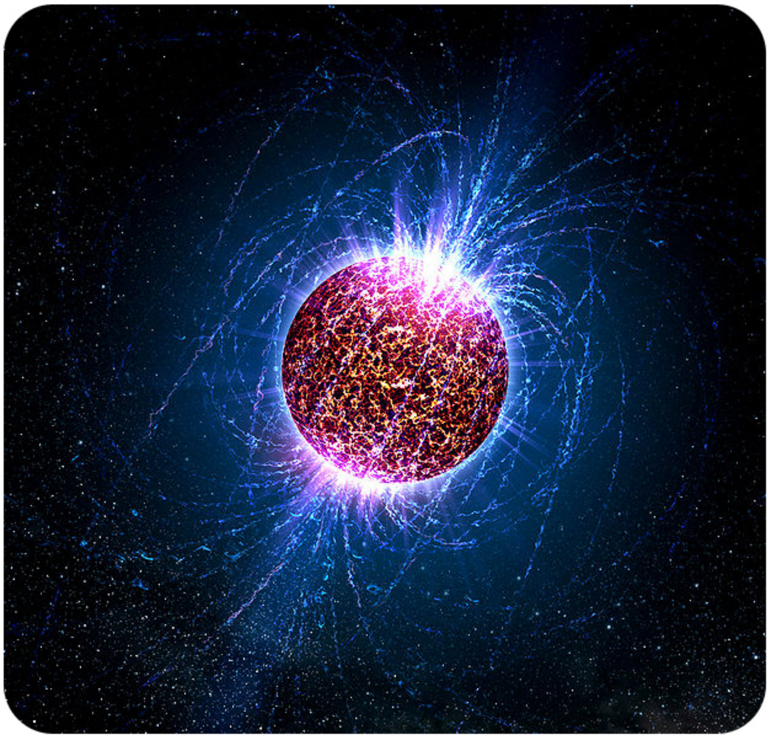


FIGURE 26.4
An artist's depiction of a neutron star.

Measuring Star Distances

Astronomers use light years as the unit to describe distances in space. Remember that a light year is the distance light travels in one year.

How do astronomers measure the distance to stars? For stars that are close to us, they measure shifts in their position over time. This is called parallax. For distant stars, they use the stars' brightness. For example, if a star is like the Sun, it should be about as bright as the Sun. They then figure out the star's distance from Earth by measuring how much less bright it is than expected.

Star Systems

Our solar system has only one star. But many stars are in systems of two or more stars. Two stars that orbit each other are called a **binary star system**. If more than two stars orbit each other, it is called a multiple star system. **Figure** 26.5 shows two binary star systems orbiting each other. This creates an unusual quadruple star system.

Lesson Summary

- A star generates energy by nuclear fusion reactions in its core.
- The color of a star is determined by its surface temperature.
- Stars are classified by color and temperature. The most common system uses the letters O (blue), B (blue-white), A (white), F (yellow-white), G (yellow), K (orange), and M (red), from hottest to coolest.
- Stars form from clouds of gas and dust called nebulas. Nebulas collapse until nuclear fusion starts.

FIGURE 26.5
This is an artist's concept of HD 98800. This is a quadruple star system made of two binary star systems. The distance separating the two pairs is about the same as the distance from our Sun to Pluto.

- Stars spend most of their lives on the main sequence, fusing hydrogen into helium.
- Sun-like stars expand into red giants, and then fade out as white dwarf stars.
- Very massive stars expand into red supergiants, explode in supernovas, then end up as neutron stars or black holes.
- Star distances can be measured in a number of creative ways.
- Many stars orbit another star to form a binary system. More than two stars may also orbit each other.

Lesson Review Questions

Recall

1. What is nuclear fusion?

2. What do the colors of stars mean?

3. What is a black hole? Why is it called that?

4. What is a binary star system?

Apply Concepts

5. Where are the stars in a constellation located relative to each other? Are they always near each other? Are they always far from each other?

6. What does a particle accelerator do? Why is it an important tool for astronomers?

Think Critically

7. Beginning with hydrogen how do the chemical elements form? You can think of them in groups.

8. Describe the Sun's life from its beginning to it eventual end.
9. How do astronomers know how stars form? What evidence do they have?

Points to Consider

- Although stars in constellations appear to be close together, they are usually not close together out in space. Can you think of any groups of astronomical objects that are relatively close together in space?
- Most nebulas contain more mass than a single star. If a large nebula collapsed into several different stars, what would the result be like?

26.2 Galaxies

Lesson Objectives

- Identify different types of galaxies.
- Describe our own galaxy, the Milky Way Galaxy.

Vocabulary

- elliptical galaxy
- galaxy
- globular cluster
- irregular galaxy
- Milky Way Galaxy
- open cluster
- spiral arm
- spiral galaxy
- star cluster

Introduction

Compared to Earth, the solar system is a big place. But galaxies are bigger - a lot bigger. A **galaxy** is a very large group of stars held together by gravity. How enormous a galaxy is and how many stars it contains are impossible for us to really understand. A galaxy contains up to a few billion stars! Our solar system is in the Milky Way Galaxy. It is so large that if our solar system were the size of your fist, the galaxy's disk would be wider than the entire United States! There are several different types of galaxies, and there are billions of galaxies in the universe.

Star Clusters

Star clusters are groups of stars smaller than a galaxy. There are two main types, open clusters and globular clusters. **Open clusters** are groups of up to a few thousand stars held together by gravity. The Jewel Box, shown in **Figure** 26.6, is an open cluster. Open clusters tend to be blue in color, and often contain glowing gas and dust. The stars in an open cluster are young stars that all formed from the same nebula.

Globular clusters are groups of tens to hundreds of thousands of stars held tightly together by gravity. Globular clusters have a definite, spherical shape. They contain mostly old, reddish stars. Near the center of a globular cluster, the stars are closer together. **Figure** 26.7 shows a globular cluster. The heart of the globular cluster M13 has hundreds of thousands of stars. M13 is 145 light years in diameter. The cluster contains red and blue giant stars.

FIGURE 26.6
These hot blue stars are in an open cluster known as the Jewel Box. The red star is a young red supergiant.

FIGURE 26.7
The globular cluster, M13, contains red and blue giant stars.

Types of Galaxies

The biggest groups of stars are called galaxies. A few million to many billions of stars may make up a galaxy. With the unaided eye, every star you can see is part of the Milky Way Galaxy. All the other galaxies are extremely far away. The closest spiral galaxy, the Andromeda Galaxy, shown in **Figure** 26.8, is 2,500,000 light years away and contains one trillion stars!

Spiral Galaxies

Galaxies are divided into three types, according to shape. There are spiral galaxies, elliptical galaxies, and irregular galaxies. **Spiral galaxies** are a rotating disk of stars and dust. In the center is a dense bulge of material. Several

FIGURE 26.8
The Andromeda Galaxy is the closest major galaxy to our own.

arms spiral out from the center. Spiral galaxies have lots of gas and dust and many young stars. **Figure** 26.9 shows a spiral galaxy from the side. You can see the disk and central bulge.

FIGURE 26.9
The Pinwheel Galaxy is a spiral galaxy displaying prominent arms.

Elliptical Galaxies

Figure 26.10 shows a typical elliptical galaxy. **Elliptical galaxies** are oval in shape. The smallest are called dwarf elliptical galaxies. Look back at the image of the Andromeda Galaxy. It has two dwarf elliptical galaxies as its companions. Dwarf galaxies are often found near larger galaxies. They sometimes collide with and merge into their larger neighbors.

Giant elliptical galaxies contain over a trillion stars. Elliptical galaxies are red to yellow in color because they contain mostly old stars. Most contain very little gas and dust because the material has already formed into stars.

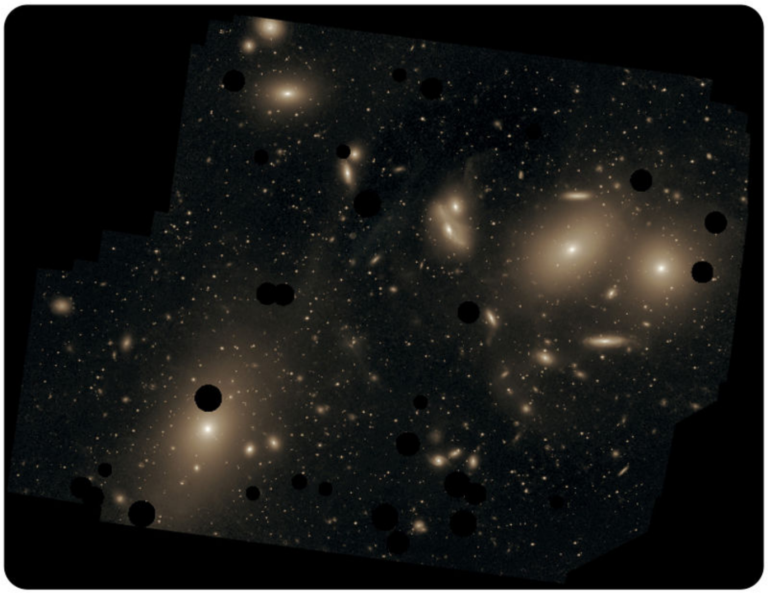


FIGURE 26.10
M87 is an elliptical galaxy in the lower left of this image. How many elliptical galaxies do you see? Are there other types of galaxies displayed?

Irregular Galaxies

Look at the galaxy in **Figure** 26.11. Do you think this is a spiral galaxy or an elliptical galaxy? It doesn't look like either! If a galaxy is not spiral or elliptical, it is an **irregular galaxy**. Most irregular galaxies have been deformed. This can occur either by the pull of a larger galaxy or by a collision with another galaxy.

The Milky Way Galaxy

If you get away from city lights and look up in the sky on a very clear night, you will see something spectacular. A band of milky light stretches across the sky, as in **Figure** 26.12. This band is the disk of the **Milky Way Galaxy**. This is the galaxy where we all live. The Milky Way Galaxy looks different to us than other galaxies because our view is from inside of it!

Shape and Size

The Milky Way Galaxy is a spiral galaxy that contains about 400 billion stars. Like other spiral galaxies, it has a disk, a central bulge, and spiral arms. The disk is about 100,000 light-years across. It is about 3,000 light years thick. Most of the galaxy's gas, dust, young stars, and open clusters are in the disk. Some astronomers think that there is a gigantic black hole at the center of the galaxy. **Figure** 26.13 shows what the Milky Way probably looks like from the outside.

Our solar system is within one of the spiral arms. Most of the stars we see in the sky are relatively nearby stars that are also in this spiral arm. We are a little more than halfway out from the center of the Galaxy to the edge, as shown in **Figure** 26.13.

Our solar system orbits the center of the galaxy as the galaxy spins. One orbit of the solar system takes about 225 to 250 million years. The solar system has orbited 20 to 25 times since it formed 4.6 billion years ago.

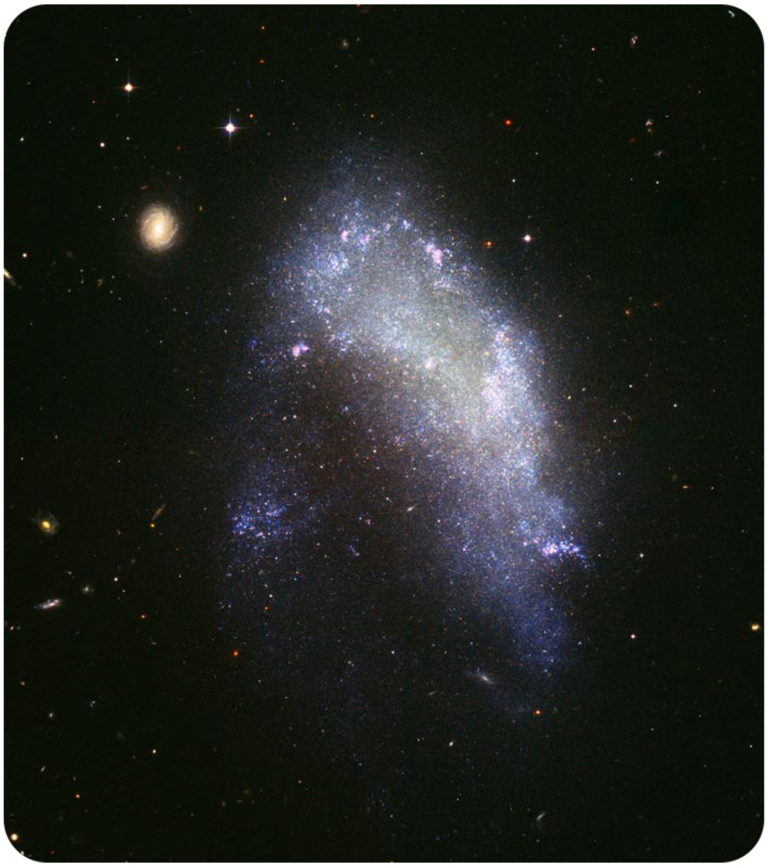


FIGURE 26.11
This irregular galaxy, NGC 55, is neither spiral nor elliptical.

FIGURE 26.12
The Milky Way Galaxy in the night sky above Death Valley.

Lesson Summary

- Open clusters are groups of young stars loosely held together by gravity.
- Globular clusters are spherical groups of old stars held tightly together by gravity.
- Galaxies are collections of millions to many billions of stars.
- Spiral galaxies have a rotating disk of stars and dust, a bulge in the middle, and several arms spiraling out from the center. The disk and arms contain many young, blue stars.
- Typical elliptical galaxies are oval shaped, red or yellow, and contain mostly old stars.
- A galaxy that is not elliptical or spiral is an irregular galaxy. These galaxies were deformed by other galaxies.
- The band of light called the Milky Way is the disk of our galaxy, the Milky Way Galaxy, which is a typical spiral galaxy.

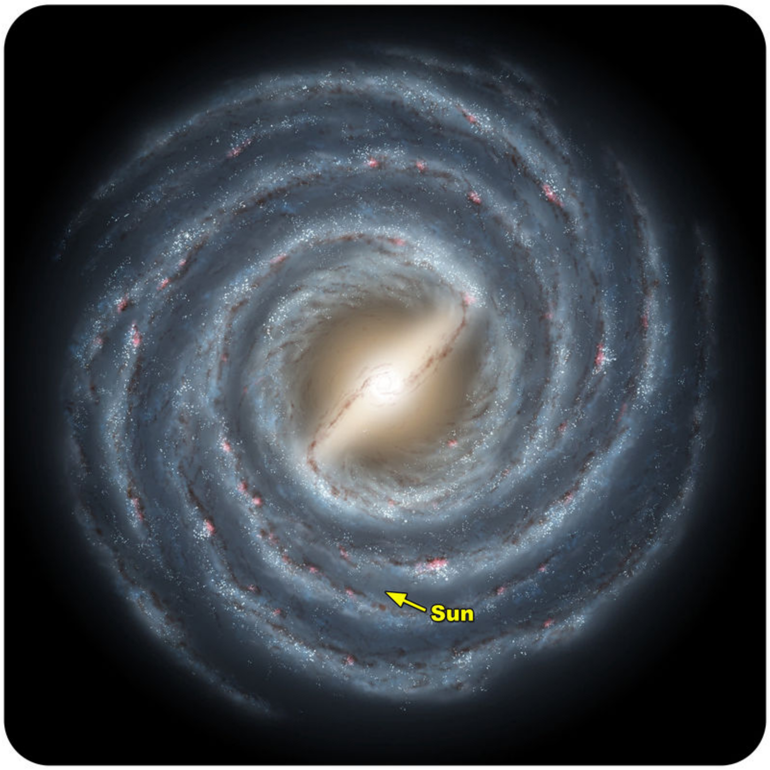


FIGURE 26.13
This is an artist's rendering of the Milky Way Galaxy seen from above. The Sun and solar system (and you!) are a little more than halfway out from the center.

- Our solar system is in a spiral arm of the Milky Way Galaxy, a little more than halfway from the center to the edge of the disk. Most of the stars we see are in our spiral arm.

Lesson Review Questions

Recall

1. What is the difference between a globular cluster and an open cluster?
2. What are the features of a spiral galaxy?
3. What are the features of an elliptical galaxy?

Apply Concepts

4. Where in the Milky Way galaxy is Earth?
5. How do irregular galaxies become irregular? Why do astronomers think that?

Think Critically

6. How do astronomers know that we live in a spiral galaxy if we're inside it?
7. How can astronomers tell the age of a galaxy?

Points to Consider

- Objects in the universe tend to be grouped together. What might cause them to form and stay in groups?
- Can you think of anything that is bigger than a galaxy?

26.3 The Universe

Lesson Objectives

- Explain the evidence for an expanding universe.
- Describe the formation of the universe according to the Big Bang Theory.
- Define dark matter and dark energy.

Vocabulary

- Big Bang Theory
- dark energy
- dark matter
- universe

Introduction

The **universe** contains all the matter and energy that exists and all of space and time. We are always learning more about the universe. In the early 20th century, Edwin Hubble used powerful telescopes to show that some distant specks of light seen through telescopes are actually other galaxies. (**Figure** 26.14) Hubble discovered that the Andromeda Nebula is over 2 million light years away. This is many times farther than the farthest distances we had measured before. He realized that galaxies were collections of millions or billions of stars. Hubble also measured the distances to hundreds of galaxies. Today, we know that the universe contains about a hundred billion galaxies.

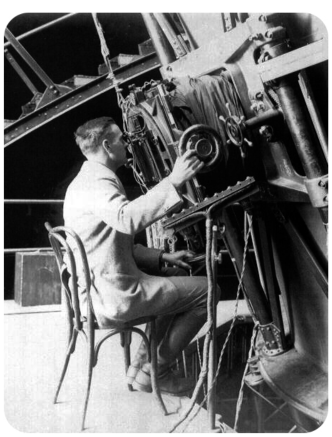


FIGURE 26.14
Edwin Hubble used the 100-inch reflecting telescope at the Mount Wilson Observatory in California.

The Expanding Universe

Hubble measured the distances to galaxies. He also studied the motions of galaxies. In doing these things, Hubble noticed a relationship. This is now called Hubble's Law: The farther away a galaxy is, the faster it is moving away from us. There was only one conclusion he could draw from this. The universe is expanding!

Figure 26.15 shows a simple diagram of the expanding universe. Imagine a balloon covered with tiny dots. When you blow up the balloon, the rubber stretches. The dots slowly move away from each other as the space between them increases. In an expanding universe, the space between galaxies is expanding. We see this as the other galaxies moving away from us. We also see that galaxies farther away from us move away faster than nearby galaxies.

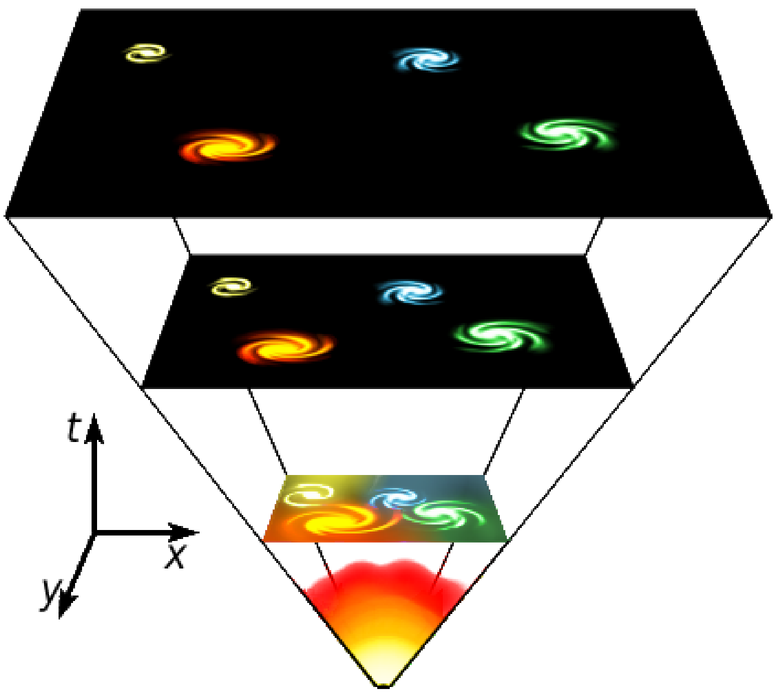


FIGURE 26.15
This is a simplified diagram of the expansion of the universe. The distance between galaxies gets bigger, but the size of each galaxy stays about the same.

The Big Bang Theory

About 13.7 billion years ago, the entire universe was packed together. Everything was squeezed into a tiny volume. Then there was an enormous explosion. After this "big bang," the universe expanded rapidly (**Figure** 26.16). All of the matter and energy in the universe has been expanding ever since. Scientists have evidence this is how the universe formed. One piece of evidence is that we see galaxies moving away from us. If they are moving apart, they must once have been together. Also, there is energy left over from this explosion throughout the universe. The theory for the origin of the universe is called the **Big Bang Theory**.

After the Big Bang

In the first few moments after the Big Bang, the universe was extremely hot and dense. As the universe expanded, it became less dense. It began to cool. First protons, neutrons, and electrons formed. From these particles came hydrogen. Nuclear fusion created helium atoms. Some parts of the universe had matter that was densely packed.

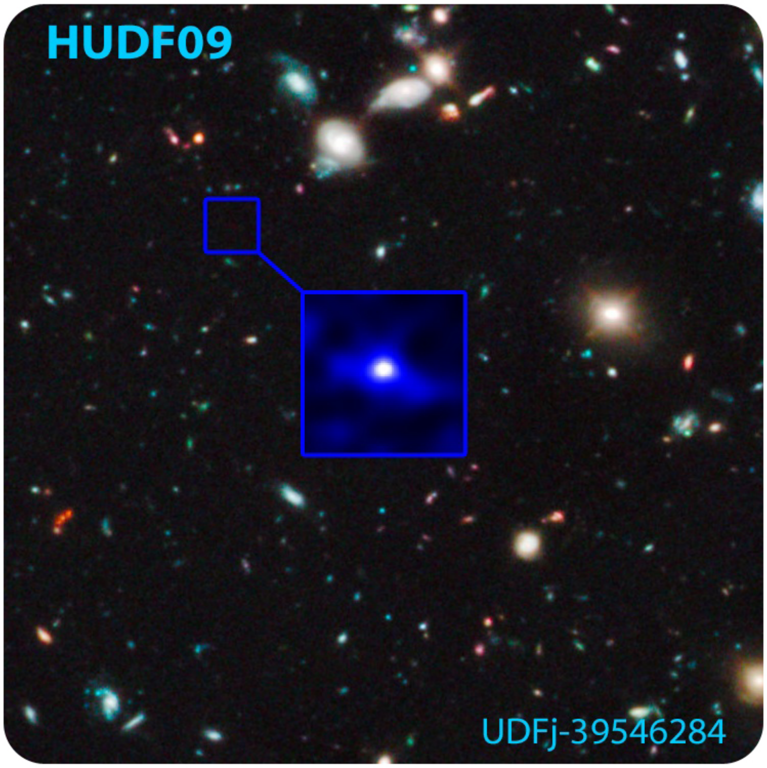


FIGURE 26.16
HUDF09 is 13.2 billion light years away from us. This is only 480 million years after the Big Bang. The smaller box shows where the galaxy is and the larger box contains a larger image of the galaxy. This is part of the Hubble Ultra Deep Field.

Enormous clumps of matter were held together by gravity. Eventually this material became the gas clouds, stars, galaxies, and other structures that we see in the universe today.

Dark Matter

We see many objects out in space that emit light. This matter is contained in stars, and the stars are contained in galaxies. Scientists think that stars and galaxies make up only a small part of the matter in the universe. The rest of the matter is called **dark matter**.

Dark matter doesn't emit light, so we can't see it. We know it is there because it affects the motion of objects around it. For example, astronomers measure how spiral galaxies rotate. The outside edges of a galaxy rotate at the same speed as parts closer to the center. This can only be explained if there is a lot more matter in the galaxy than we can see.

What is dark matter? Actually, we don't really know. Dark matter could just be ordinary matter, like what makes up Earth. The universe could contain lots of objects that don't have enough mass to glow on their own. There might just be a lot of black holes. Another possibility is that the universe contains a lot of matter that is different from anything we know. If it doesn't interact much with ordinary matter, it would be very difficult or impossible to detect directly.

Most scientists who study dark matter think it is a combination. Ordinary matter is part of it. That is mixed with some kind of matter that we haven't discovered yet. Most scientists think that ordinary matter is less than half of the total matter in the universe.

Dark Energy

We know that the universe is expanding. Astronomers have wondered if it is expanding fast enough to escape the pull of gravity. Would the universe just expand forever? If it could not escape the pull of gravity, would it someday start to contract? This means it would eventually get squeezed together in a big crunch. This is the opposite of the Big Bang.

Scientists may now have an answer. Recently, astronomers have discovered that the universe is expanding even faster than before. What is causing the expansion to accelerate? One hypothesis is that there is energy out in the universe that we can't see. Astronomers call this **dark energy**. We know even less about dark energy than we know about dark matter. Some scientists think that dark energy makes up more than half of the universe.

Lesson Summary

- The universe contains all matter and all energy as well as all of space and time.
- We can see that galaxies are moving away from us which tells us that the universe is expanding.
- In the past the universe was squeezed into a very small volume.
- The Big Bang theory proposes that the universe formed in an enormous explosion about 13.7 billion years ago.
- Recent evidence shows that there is a lot of matter in the universe that we cannot see. This matter is called dark matter.
- The rate of the expansion of the universe is increasing. The cause of this increase is unknown; one possible explanation involves a new form of energy called dark energy.

Lesson Review Questions

Recall

1. What is Hubble's law?
2. How old is the universe?
3. What is dark matter?
4. What is dark energy?

Apply Concepts

5. Describe the Big Bang theory.
6. Why do scientists think that dark matter exists?

Think Critically

7. How do you think scientists can calculate the age of the universe?
8. How is the Big Bang theory different from other explanations of how the universe came to be?

Points to Consider

- In what ways is an expanding balloon a good model of the universe, and in what ways is it incorrect? Can you think of a different way to model the expansion of the universe?

- The Big Bang theory is currently the most widely accepted scientific theory for how the universe formed. What is another explanation of how the universe could have formed? Is your explanation one that a scientist would accept?

For **Table** 26.1, from top to bottom,

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CHAPTER 27 MS Earth Science Glossary

Chapter Outline

27.1 A

abrasion
a form of mechanical weathering that occurs whenever one rock hits another

abyssal plain
flat ocean floor under the open ocean

active volcano
a volcano that is currently erupting or just about to erupt

adaptation
a trait that an organism inherits that helps it survive in its natural environment

air mass
large body of air that has about the same conditions throughout

air pressure
weight of the air pressing against a given area

alpine tundra
polar climate found at high altitudes an any latitude

altitude
distance above sea level

amplitude
the height of a wave from a center line to the top of the crest, or to the bottom of the trough

anemometer
instrument that measures wind speed

anticyclone
system of winds that rotate around a center of high air pressure

aphotic zone
ocean zone deeper than 200 meters that does not receive enough sunlight for photosynthesis

aquifer
underground layer of porous rock that is saturated with groundwater

asteroid
rocky objects larger than a few hundred meters that orbit the Sun in the asteroid belt

asteroid belt
region between the orbits of Mars and Jupiter with many asteroids

astronomers
scientists who study the universe, galaxies, and stars

astronomical unit
unit of length measurement used in astronomy; it is roughly equal to the distance between Earth and the sun

atmosphere
mixture of gases that surrounds a planet such as Earth

axis
an imaginary line that runs from the North Pole to South Pole through the center of Earth

27.2 B

barometer
instrument that measures air pressure

barrier island
a long, narrow island parallel to the shore

basin
a block of rock that has slipped downward between two normal faults

beaches
areas along the shore where sand or gravel is deposited.

benthic zone
ocean zone that consists of the ocean floor

benthos
organisms that live on the ocean floor

Big Bang Theory
the hypothesis that all matter and energy were at one time compressed into a very small volume and exploded in a "big bang," forming the universe

binary star system
two stars that orbit each other

biome
major climate type and the organisms that live there

biosphere
all of the living organisms on Earth

black hole
the super dense core left after a supergiant explodes as a supernova

blizzard
snow storm with high winds and reduced visibility because of wind-blown snow

body wave
a type of seismic wave that travels through the body of a planet, including primary waves and secondary waves

27.3 C

caldera
circular-shaped feature formed from a massive eruption of an ancient volcano, which collapses back into the ground

cemented
describes substances that have hardened or crystallized in the spaces between loose sediments

chemical compound
a substance in which the atoms of two or more elements bond together

chemical energy
energy that is stored in the connections between atoms in a chemical substance

chemical weathering
a form of weathering that changes rock, in which minerals formed at high temperatures and pressures change to minerals that are stable at the Earth's surface

chromosphere
thin layer of the sun's atmosphere that lies directly above the photosphere and glows red

cinder cone
a smaller volcano composed of small rock fragments that grows rapidly but only erupts over a short period of the time

cirrus cloud
thin, wispy cloud that forms from ice crystals high in the troposphere

cleavage
the tendency of a mineral to break along certain planes to make smooth surfaces

climate
average weather of a place over many years

coastal climate
climate that is mild and may have plenty of precipitation because it is near an ocean

cold front
boundary between two air masses that forms when a faster-moving cold air mass runs into a slower-moving warm air mass

comet
a small, icy, dusty object in orbit around the Sun

compacted
describes sediments that have hardened by being squeezed together by the weight of layers on top of them

compass
hand-held device with a magnetic needle, used to find magnetic north

compass rose
figure on a map or nautical chart for displaying locations of north, south, east and west

composite volcano
a volcano composed of alternating layers of ash and lava flows with a broad base, steep sides, and often a crater at the top; also called a stratovolcano

compression
stresses that push toward each other, which causes a decrease in the space a rock takes up

condensation
process in which water vapor changes to liquid water

conduction
transfer of heat through direct contact of molecules of matter

confining stress
stress due to the weight of material above a buried object, reducing volume but causing no deformation

conic map
a map projection made by projecting Earth's three dimensional surface onto a cone wrapped around an area of the Earth

constellation
a pattern of stars as observed from Earth.

contact metamorphism
type of metamorphism that results from temperature increases when a body of magma contacts a cooler existing rock

continent
a land mass above sea level

continental climate
climate that is harsh and may be dry because it is inland and not affected by an ocean

continental crust
the crust that makes up the continents

continental drift
hypothesis developed in the early 20th century that states that the continents move about on the surface of the Earth

continental margin
the underwater, outer edge of the continent

continental rift
a divergent plate boundary that forms in the middle of a continent

continental shelf
gently sloping ocean floor at the edges of continents

continental slope
steeply sloping ocean floor between the continental shelf and abyssal plain

continental rise
gently sloping pile of sediments that forms where the continental slope meets the ocean floor

contour interval
the constant difference in elevation between two contour lines on a topographic map

contour lines
lines drawn on a topographic map to show elevation, and which connect all the places that are the same elevation

control
factors that are kept the same in an experiment in order to focus just on the independent and dependent variables

convection
transfer of heat through a liquid or gas by a current

convection cell
a circular pattern of warm material rising and cool material sinking

convection current
current that flows through a liquid or gas because of differences in density

convection zone
layer of the sun that surrounds the radiative zone; energy in this zone moves as flowing cells of gas

convergent plate boundary
a location where two tectonic plates come together

coordinate system
numbers in a grid that locate a particular point

core
the dense metallic center of the Earth; also the term for the innermost part of the sun, where nuclear fusion reactions take place

Coriolis effect
effect of Earth's rotation on the direction of global winds and surface ocean currents

corona
outermost layer of the sun, made up of a plasma that extends millions of kilometers into space

crater
a bowl-shaped depression on the surface of the Moon, caused by impact from a meteorite

crest
the highest point of a wave

crust
The rocky outer layer of the Earth's surface; the two types of crust are continental and oceanic

crystal
a solid in which all the atoms are arranged in a regular, repeating pattern

cumulus cloud
white puffy cloud that grows vertically because it forms in a convection current

cyclone
system of winds that rotate around a center of low air pressure

27.4 D

dark energy
form of energy that we cannot see

dark matter
matter in the universe that does not emit light

deciduous trees
trees that lose their leaves once a year

deep current
convection current that flows through ocean water deep below the surface

deform
to change in shape; happens when a rock has been altered by stresses

delta
deposit of sediment at the mouth of a river, often in the shape of a triangle

density
amount of mass per unit of volume of a substance

dependent variable
the variable in an experiment that you are measuring as you change the independent variable

deposited
process by which sediments are dropped by water, wind, water or ice

desert
very dry climate that receives less than 25 centimeters (10 inches) of precipitation each year

dew point
temperature at which water vapor condenses out of the air

dip-slip fault
a fault in which the dip of the fault plane is inclined relative to the horizontal

divergent plate boundary
location where two tectonic plates spread apart

dome
a circular anticline in which the oldest rocks are in the center and the youngest on the outside

dormant volcano
a volcano that is not currently erupting, but that has erupted in the recorded past

dwarf planet
celestial body that meets three of four criteria that define a planet; a dwarf planet does not clear its orbit of other objects

27.5 E

earthquake
ground shaking caused by the release of energy stored in rocks

echo sounder
device that uses sound waves to measure the depth to the seafloor

elastic rebound theory
theory of how earthquakes are generated, which states that that stresses cause strain to build up in rocks until they can no longer bend elastically and they break, causing an earthquake

electromagnetic (EM) radiation
energy transmitted through space as a wave

electromagnetic (EM) spectrum
total range of wavelengths of energy from the sun

element
a substance in which all of the atoms have the same number of protons

elevation
height of a land feature measured relative to sea level

elliptical galaxy
an oval-shaped galaxy with older stars and little gas and dust

El Niño
short-term, worldwide climate change that occurs when the Pacific Ocean is warmer than usual

energy
ability to do work

epicenter
point on the earth's surface that lies above an earthquake's focus

erosion
the transport of weathered materials by water, wind, ice, or gravity

eruption
the release of magma and gases onto the Earth's surface

evaporation
process in which liquid water changes to water vapor

evolution
the change in an organism's traits over long periods of time, such that a new species is often the result

exosphere
top layer of Earth's atmosphere, above the thermosphere

explosive eruption
volcanic eruption that releases large amounts of gas, so that magma is violently thrown up into the air

extinct
term to describe an organism that has completely died out

extinct volcano
a volcano that has not erupted in recorded history, and is considered unlikely to erupt again

extrusive
igneous rock that forms above Earth's surface

27.6 F

fault zone
a network of related faults

fissure
a long crack from which lava erupts onto Earth's surface

focus
the point under Earth's surface where rocks rupture during an earthquake

fog
cloud that forms on the ground

fold
a bend in a set of rocks caused by compression

foliation
layers that form in some metamorphic rocks; evidence of squeezing by pressure

footwall
the block of rock that is beneath a dip-slip fault

fossil
something that is left behind by a once-living organism, such as bones or footprints

fracture
the way a mineral breaks when it is not broken along a cleavage plane

freezing rain
precipitation that falls as rain but freezes on contact with cold surfaces near the ground, forming a glaze of ice

freshwater
water that contains little or no dissolved salts

frequency
the number of wavelengths that pass a given point every second

front
boundary between two air masses

fuel
material that can release energy in a chemical change

27.7 G

galaxy
group of between a few million and a few billion stars held together by gravity

Galilean moons
the four largest moons of Jupiter, discovered by Galileo

gamma rays
the shortest wavelength form of electromagnetic radiation

gas giants
the four large outer planets - Jupiter, Saturn, Uranus, and Neptune - which are composed of the gases hydrogen and helium

gemstone
any material that is cut and polished to use in jewelry

Geographic Information System (GIS)
an information system that links data to a particular location

geologic time scale
timeline that illustrates Earth's past

geology
the study of the rocks, processes, and history of Earth

geostationary orbit
type of orbit that allows a satellite to stay in place above one location on Earth's surface

geyser
heated groundwater that erupts from the ground under pressure

giant impact hypothesis
idea that Earth's moon was formed when a planet-sized object collided with the Earth about 4.5 billion years ago

global warming
recent increase in Earth's temperature due mainly to human actions

global wind
wind that occurs in a belt that circles the planet

globular cluster
groups of tens to hundreds of thousands of stars held together by gravity

gnomonic map
map projection made by projecting onto a flat paper from just one spot on the Earth

gravity
force of attraction that exists between all objects in the universe

Great Red Spot
enormous, oval-shaped storm on Jupiter

greenhouse effect
warming of Earth by gases in the atmosphere that absorb energy

greenhouse gas
gas such as carbon dioxide or water vapor that absorbs energy in the atmosphere and keeps Earth warm

groundwater
freshwater below Earth's surface

27.8 H

hail
precipitation that falls as balls of ice and forms when strong updrafts carry rain high into the troposphere, where it freezes

hanging wall
the block of rock that is above a dip-slip fault

hardness
the ability of a rock to resist scratching

heat index
measure of what the temperature feels like because of humidity

hemisphere
one half of a sphere

hot spot
fixed region of hot material that rises through the mantle and creates volcanoes on Earth's surface

hot spring
stream of hot water that flows out of the ground continuously

humid continental climate
inland climate found between 40° and 60° north latitude

humidity
amount of water vapor in the air

humid subtropical climate
temperate climate found on the eastern sides of continents between about 20° and 40° latitude

humus
the partially decayed remains of plants and animals that forms the organic portion of soil

hurricane
large storm with high winds and heavy rains that develops from a tropical cyclone over warm ocean water

hydrocarbon
chemical compound that contains only carbon and hydrogen

hydrosphere
all the water on Earth

hygrometer
instrument for measuring humidity

hypothesis
a testable working explanation for a problem in science

27.9 I

ice age
period when Earth's temperatures are cooler than normal and glaciers spread from to lower latitudes

ice wedging
form of mechanical weathering that occurs as water expands when it freezes, wedging apart rock

independent variable
the variable in an experiment that is controlled and changed by the researcher

infiltration
process in which water seeps into the ground

infrared light
light with wavelengths longer than visible light that humans can feel as heat

inner planets
the four solid, dense, rocky planets - Mercury, Venus, Earth, and Mars - located inside the asteroid belt of our solar system

inorganic
does not come from living organisms; in soil, the portion made up of rock and mineral

intertidal zone
ocean zone that is covered with water at high tide and exposed to air at low tide

intraplate activity
geologic activity, such as volcanic eruptions and earthquakes, that takes place away from plate boundaries

intrusion
rock mass formed by magma cooling underground

intrusive
igneous rock that forms inside the Earth

ion
an atom with a different number of electrons and protons. An ion may have positive charge (more protons) or negative charge (more electrons)

irregular galaxy
category of galaxy that is neither a spiral nor an elliptical galaxy

island arc
line of volcanoes sitting on an oceanic plate above a subducting oceanic plate and near a deep sea trench

27.10 J

joint

a break in rock caused by stresses, along which there is no movement

27.11 K

kinetic energy
the energy that an object in motion has because of its motion

Kuiper belt
region of space beyond the orbit of Neptune that contains millions of frozen objects

27.12 L

lake
: large body of standing water

lake-effect snow
: heavy snow storm that occurs when winter winds pick up moisture as they pass over a relatively warm lake and then drop the moisture as snow on the other side of the lake

land breeze
: local wind that blows from sea to land during the day when air over land is warmer than air over water

La Niña
: short-term, worldwide climate change that occurs when the Pacific Ocean is colder than usual

laterite
: nutrient-poor, red, tropical soil that forms in a region with rainforest vegetation

latitude
: imaginary horizontal line drawn around the Earth parallel to the equator

landscape
: the surface features of an area

lava
: molten rock that has reached Earth's surface

lava dome
: dome-shaped plug of thick lava that cools near the vent of a volcano

lava plateau
: flat, wide surface formed when lava comes out of the ground and spreads out very quickly

Law of Conservation of Energy
: law stating that energy cannot be created or destroyed

lightning
: huge spark that jumps between oppositely charged parts of the same cloud, between one cloud and another, or between a cloud and the ground during a thunderstorm

light-year
: the distance light can travel in one year, 9.5 trillion kilometers

lithosphere
: layer of solid, brittle rock that makes up the Earth's surface, composed of the crust and the uppermost mantle

liquefy
to become liquid; when clay, silt, and sand become saturated with water they are said to liquefy, becoming like quicksand, losing their strength and behaving more like a liquid than a solid

loam
soil texture that forms from a roughly equal combination of sand, silt, and clay

local wind
wind that blows over a limited area because it is influenced by local geography, such as nearness to the ocean

longitude
imaginary vertical line drawn on the Earth from pole to pole

Love waves
surface waves that have a side-to-side motion, much like a slithering snake

Low Earth Orbit
path of satellites that orbit relatively close to Earth

lunar
related to the Moon

luster
the way light reflects off of the surface of a mineral

27.13 M

magma
molten rock deep inside the Earth

magma chamber
region within Earth surrounded by solid rock and containing magma

magnetic field
the region around a magnet that is susceptible to the magnetic force

main sequence star
star that is fusing hydrogen atoms to form helium, considered to be a star in the main portion of its "life"

mantle
the middle layer of the Earth, made of hot rock that circulates by convection and located between the crust and the core

mantle plume
a column of very hot rock that rises up through the mantle

map
two-dimensional representation of Earth's surface

maria
the dark parts of the Moon's surface, made up of ancient lava eruptions

marine organism
ocean organism that is adapted for life in salt water

marine west coast climate
temperate climate found on the western coasts of continents between 45° and 60° latitude

mechanical weathering
form of weathering that disintegrates rock, in which bigger pieces of rock are broken into smaller pieces composed of the same materials as the original rock.

Mediterranean climate
climate with dry summers that occurs on the western sides of continents between 30° and 45° latitude

Mercalli Intensity Scale
scale that measures the effects of an earthquakes seen on the land surface and felt by humans, using a scale of I-XII

Mercator projection
map projection created using a cylinder wrapped around the Earth

mesosphere
layer of Earth's atmosphere between the stratosphere and thermosphere

metamorphic
type of rock that forms when rock is exposed to high temperature and pressure

meteor

material from outer space that burns up as it enters Earth's atmosphere

meteorite
fragment of a planetary body, such as moons, planets, asteroids, and comets, that strikes Earth

meteoroid
small rock in interplanetary space that has not yet entered Earth's atmosphere

meteor shower
area of frequent meteors appearing to originate in a particular part of the sky

microclimate
local climate that differs from the major climate type around it

Milky Way Galaxy
the name of our galaxy, which includes the whitish band of stars visible in the night sky

mineral
a naturally occurring, inorganic, crystalline solid with a characteristic chemical composition

mineralogist
scientist who studies minerals

meteorologist
scientist who studies the weather and makes weather forecasts

meteorology
study of Earth's atmosphere, weather, and storms

microwave
30 cm –1mm wavelength electromagnetic wave

mid-ocean ridge
mountain range that runs through all the world's oceans where tectonic plates pull apart

molecule
the smallest possible amount of a chemical substance

moment magnitude scale

logarithmic scale that measures the total energy released by an earthquake; an increase of one integer indicates a 30-fold increase in energy released, while an increase of two integers indicates a 1,000-fold increase in energy released

monocline

a bend in a set of rocks that causes them to be inclined relative to the horizontal

monsoon

local wind that blows from water to land in the summer and from land to water in the winter due to seasonal changes in the temperatures of land and water

27.14 N

neap tide
tide with the least difference between high and low tides that occurs during the first and third quarters of the moon

nebula
cloud of gas and dust in space

neutron star
the core of a massive star after it explodes as a supernova

nekton
organisms such as fish that swim through the water

neritic zone
ocean zone that lies over the continental shelf between the intertidal zone and oceanic zone

normal fault
dip-slip fault in which the hanging wall drops down relative to the footwall

nuclear energy
energy that is released from the nucleus of an atom when it is changed into another atom

nuclear fusion
reaction in which two nuclei come together, releasing huge amounts of light and heat

27.15 O

ocean basin
: area covered by ocean water

oceanic crust
: the part of Earth's crust that underlies the oceans

oceanic trench
: deep canyon on the ocean floor where one tectonic plate slides under another

oceanic zone
: ocean zone that consists of open ocean out past the neritic zone

oceanography
: study of the ocean in all its aspects

occluded front
: boundary that forms between air masses when a warm air mass is trapped between two cold air masses

open cluster
: group of up to a few thousand stars loosely held together by gravity

orbit
: to travel in a circular or elliptical path around another object

orbiter
: the main part of the space shuttle; it has wings like an airplane

ore
: mineral deposit that contains enough minerals to be mined for profit

outcrop
: large rock formation at the surface of the Earth

outer planets
: the four large, gaseous planets - Jupiter, Saturn, Uranus, and Neptune - located beyond the asteroid belt in our solar system

ozone
: gas consisting of three oxygen atoms (O3) that absorbs UV light in the stratosphere

27.16 P

paleontologist
scientist who studies Earth's past life forms

pedalfer
fertile, dark soil that forms in mid-latitude, forested regions

pedocal
slightly less fertile soil that forms in drier, grassland regions

photic zone
ocean zone in the top 200 meters of water that receives enough sunlight for photosynthesis

photon
tiny packet of energy given off by the sun that travels in a wave

photosphere
the visible surface of the Sun

physical model
a representation of something using objects

phytoplankton
"plant-like" plankton such as algae that make food by photosynthesis

plains
low-lying continental areas that can be inland or coastal

planet
celestial object orbiting a star that has cleared its orbit of smaller objects

planetary rings
rings of dust and rock encircling a planet in a thin plane

plankton
mainly microscopic organisms that float in the water of the photic zone

plasma

high-energy, high-temperature form of matter in which electrons are removed from atoms, leaving each atom with an electrical charge

plate
slab of Earth's lithosphere that can move around on the planet's surface

plateau
flat, elevated area

plate boundary
location where two plates come together

plate tectonics
theory that the Earth's surface is divided into lithospheric plates that move about on Earth's surface

polar climate
climate found near the poles or at high latitudes that has very cool summers, frigid winters, and low precipitation

polar orbit
orbit that moves over Earth's north and south poles as Earth rotates underneath

polar tundra
polar climate found near the poles and characterized by permafrost

pond
small body of standing freshwater

potential energy
energy stored within a physical system

precipitation
water that falls from clouds to Earth's surface

primary wave (P-wave)
fastest type of longitudinal body wave, capable of traveling through solids, liquids, and gases

projection
a way to represent a three-dimensional surface in two dimensions

pyroclast
rock made up of fragments of volcanic rock thrown into the air by an explosive eruption

27.17 R

radiation
transfer of heat by waves that can travel through air or space

radiative zone
layer of the Sun immediately surrounding the core; energy moves from atom to atom as electromagnetic waves

radio telescope
radio antenna that collects radio waves

radio waves
longest wavelength wave of the electromagnetic spectrum, with a length ranging from from 1 mm to thousands of kilometers

rain gauge
instrument that measures the amount of rainfall

rain shadow
area that receives very little precipitation because of a nearby mountain range

Rayleigh waves
surface waves that have a rolling motion

red giant
stage in a star's development in which the inner helium core contracts while the outer layers of hydrogen expand

reflecting telescope
telescope that uses mirrors to collect and focus light

refracting telescope
telescope that uses convex lenses to collect and focus light

regional metamorphism
type of metamorphism that occurs when great masses of rock change over a wide area due to pressure

relative humidity
percent of water vapor in the air relative to the maximum amount the air can hold

relief
difference in height of landforms in a region

residual soil
soil that forms from the bedrock upon which it lies

reverse fault
dip-slip fault in which the hanging wall pushes up relative to the footwall

revolution
the Earth's movement around the Sun in an orbit

Richter scale
logarithmic scale that measures the largest jolt produced by an earthquake

river
large body of moving water that flows downhill in a channel

river valley
area formed as water erodes the landscape, often "V"-shaped

rock
a solid mixture of minerals or mineral grains

rocket
device propelled by particles flying out of it at high speed

rotation
the motion of the Earth spinning on its axis

runoff
precipitation that flows over the surface of the land

27.18 S

satellite
an object, either natural or human made, that orbits a larger object

sea breeze
local wind that blows from land to sea during the night when air over water is warmer than air over land

seafloor spreading
process by which new seafloor forming at spreading ridges pushes lithospheric plates on the Earth's surface, thus moving continents

seamount
volcanic mountain on the ocean floor

secondary wave (S-wave)
slower-moving, transverse body wave that can only travel through solids

sediment
particles of rock or minerals ranging in size from clay to giant boulders

sedimentary
type of rock that forms from layers of sediment compacted and cemented together

seismic wave
wave of energy that radiates out from an earthquake's focus

seismogram
printed record of seismic activity produced by a seismometer

seismograph
older type of seismometer in which a pen that is suspended and weighted writes on a drum that moved with the ground

seismometer
machine that measures seismic waves and other ground motions

shear
type of stress that pushes rocks past each other in opposite directions

shield volcano
type of volcano built almost entirely of fluid lava flows, characterized by its large width and relatively low height

silicate
mineral containing silicon atoms bonded to oxygen atoms

sleet
precipitation that falls as small ice pellets when snow falls through a layer of warm air and then refreezes as it passes through a cold layer near the ground

slip
the distance rocks move along a fault

snow gauge
instrument that measures the amount of snowfall

soil horizon
an individual layer of a complete soil profile; examples include A, B, and C horizons

soil profile
the entire set of soil layers or horizons for a particular soil

solar flare
a violent explosion on the Sun's surface.

solar system
the Sun and all the objects that revolve around the Sun, held by the Sun's gravity

solar wind
the stream of radiation emitted by a solar flare, which extends millions of kilometers out into space and can even reach Earth

sonar
tool for using sound waves to study distant objects or surfaces such as the ocean floor

sound
form of energy that travels in waves and allows us to hear

space probe
a spacecraft that is sent without a crew to collect data by flying near or landing on an object in space

Space Race
competition during the Cold War (1945-1990) between the United States and the Soviet Union, in which nation strove to have the best space technology

space shuttle
reusable spacecraft capable of carrying large pieces of equipment or pieces of a space station

space station
large spacecraft on which humans can live for an extended period of time

space telescope
telescope in orbit above Earth's atmosphere

species
a group of living things that have similar characteristics

spectrometer
tool that uses a prism to break light into all its colors

spiral arm
region of gas, dust, and young stars that winds outward from the central area of a spiral galaxy

spiral galaxy
a rotating type of galaxy containing a central bulge and spiral arms with young stars, gas, and dust

spring
water that flows out of the ground where the water table meets the surface

spring tide
tide with the greatest difference between high and low tides that occurs during new moon and full moon

stable
term for rocks that are not likely to change significantly any more

stationary front
boundary between air masses that is stalled in one place

star
a glowing sphere of gases that produces light through nuclear fusion reactions

star cluster
a group of hundreds of thousands of stars

star system
a small group of stars

steppe
semi-arid climate that receives up to 40 centimeters (16 inches) of precipitation each year

storm
episode of severe weather caused by a major disturbance in the atmosphere

storm surge
high water that rushes ashore when the eye of a hurricane passes over

strata
layers of rock that are similar in composition to one another

stratosphere
layer of Earth's atmosphere between the troposphere and mesosphere

stratus cloud
cloud that forms low in the troposphere in layers that spread horizontally

streak
the color of the powder of a mineral

stream
any body of freshwater that flows downhill in a channel

stress
force per unit area in a rock

strike-slip fault
a fault in which the dip of the fault plane is vertical.

subarctic climate
continental climate found between 60° and 70° north latitude

subduction
the sinking of one lithospheric plate beneath another

subduction zone
area where two lithospheric plates come together and one sinks beneath the other

subsoil
the B horizon of a soil; the zone where iron oxides and clay minerals accumulate

sunspot
cooler, darker area on the Sun's surface that has lower temperatures than the surrounding area

supernova
a tremendous explosion that occurs when a star's core is mostly iron

supervolcano
massive volcanic eruption that is rare but incredibly powerful

surface current
ocean current caused by wind that flows through the surface of the water

surface wave
seismic wave that travels along the ground surface and does the most damage after an earthquake; the two types of surface wave are Love waves and Rayleigh waves

syncline
a fold in rocks that bends downward, in which the youngest rocks are at the center

27.19 T

temperate climate
climate that has moderate temperatures

temperature inversion
reversal of normal temperatures in the troposphere, with cooler air closer to the ground and warmer air above it

tension
type of stress that pulls material in opposite directions, so that it is pulled apart

terrae
the light parts of the Moon's surface, composed of high crater rims

theory
a hypothesis that has been repeatedly tested and not proven false

thermometer
instrument that measures temperature

thermosphere
layer of Earth's atmosphere between the mesosphere and exosphere

thrust
forward force produced by gases escaping from a rocket engine

thrust fault
reverse fault in which the dip of the fault plane is nearly horizontal

thunder
loud sound that occurs following lightning because the air heats and expands so quickly that it explodes

thunderstorm
storm with heavy rain and lightning

tide
constant change in the level of ocean water caused by the pull of the moon's and sun's gravity

topographic map
a special type of map that shows the elevations of different geologic features of a region

topography
changes in elevation for a given region

topsoil
the most fertile layer of soil, where humus, plant roots, and living organisms are found

tornado
small but powerful storm with very strong, whirling winds that may occur with a thunderstorm or hurricane

transform fault
an earthquake fault where relative motion is sliding past

transform plate boundary
type of plate boundary where two plates slide past one another

transpiration
process in which plants release water vapor through their leaves

transported soil
soil formed from weathered components that have been transported by water, wind, or ice to a different area

trench
a deep hole in the seafloor where subduction takes place; trenches are the deepest places on Earth

tropical climate
climate found near the equator that has warm temperatures year round

tropical rainforest
forest that grows in tropical wet climates that have high rainfall year round

troposphere
lowest, densest layer of Earth's atmosphere

trough
the lowest point of a wave

tsunami
ocean wave caused by an earthquake

27.20 U

ultraviolet (UV) light
light with wavelengths shorter than visible light that harms living things

universe
everything that exists; contains all matter, energy, space, and time

upwelling
process in which deep ocean water rises to the surface and brings nutrients with it

27.21 V

variation
having many differences

visible light
range of wavelengths of light that humans can see

27.22 W

warm front
: boundary between two air masses that forms when a faster-moving warm air mass runs into a slower-moving cold air mass

water
: simple chemical compound containing two hydrogen atoms and one oxygen atom (H2O)

water cycle
: constant movement of water through the oceans, atmosphere, land, and living things

water table
: top of the underground layer of porous rock that is saturated with groundwater

water vapor
: gaseous form of water

wave
: transfer of energy from wind through water

wavelength
: the horizontal distance between two waves, as measured from crest to crest or trough to trough

weather
: conditions of the atmosphere at a given time and place

weather balloon
: balloon that rises into the troposphere where it gathers weather data and sends them to the surface

weather map
: map that shows weather conditions for a particular geographic area

weather satellite
: satellite that orbits Earth and constantly collects and transmits weather data from high above the surface

weather station
: one of thousands of devices that collects weather data at a place on Earth's surface

well
: hole that is dug or drilled through the ground to an aquifer in order to obtain groundwater

wetland
: area that has soggy soil or is covered with water for at least part of the year and that has certain types of plants

wind
air that flows over Earth's surface because of differences in heating of the atmosphere

windchill
temperature the air feels like that takes into account actual air temperature and wind speed

wind vane
instrument that measures wind direction

27.23 X

X rays

band of electromagnetic radiation with wavelength between that of between gamma rays and ultraviolet radiation

27.24 Y

year
: the time it takes for a planet to orbit the Sun

27.25 Z

zooplankton
"animal-like" organisms in plankton that consume phytoplankton