flexbook
next generation textbooks

Stratford 4th Grade

Parisa Badizadegan

To access a customizable version of this book, as well as other interactive content, visit www.ck12.org

AUTHOR
Parisa Badizadegan

Printed: June 8, 2018

Contents

CHAPTER 1 Physical Science: Energy

Chapter Outline

1.1 Types of Energy

Lesson Objectives

- Describe ways in which energy can be transferred.
- Describe kinetic energy.
- Identify types of potential energy.
- Give examples of energy conversions.

Lesson Vocabulary

- energy transfer
- potential energy
- kinetic energy

Introduction

Did you ever babysit younger children? If you did, then you probably noticed that young children are very active. They seem to be in constant motion. It may even be hard to keep up with them. Where does the ability to move quickly come from? Another way to say this is that kids have a lot of energy. But what is energy?

FIGURE 1.1
Young children seem to be full of energy.

Defining Energy

Energy is the ability to do work. Another way to say this is, the ability to cause change. Work is done when a force is used to move something. When work is done, energy is transferred. This transfer occurs between one object and another. For example, a batter swings a bat and transfers energy. She transfers her energy to the bat. The moving bat, in turn, transfers energy to the ball. Energy is measured in the joule (J).

FIGURE 1.2
It takes energy to swing a bat. Where does the batter get her energy?

Energy exists in many forms. One form of energy is called mechanical. Mechanical energy is the energy of motion. This type of energy can also include things that are not yet in motion. In these cases, they have only a potential to be in motion. In most cases, this ability comes from a position. A rock sitting on top of a cliff has potential energy. It is more than just the ability. A rock sitting on the ground could move if someone picked it up. This is not the type of potential we are referring to here. A boulder sitting on a cliff may get pushed loose. The natural force of gravity **will** pull it down because it cannot stay hanging in mid-air. This is far different to saying a rock may move because of a random event. Therefore, it has the potential to be in motion.

Another way to store energy is by changing an object's shape. If you stretch a rubber band, it is storing energy. When the rubber band is released, the rubber band moves.

Kinetic Energy

What do all the photos in 1.3 Figure below have in common? All of them show things that are moving. Kinetic energy is the energy of motion. Anything that is moving has kinetic energy. This applies to atoms as well as planets. Things with kinetic energy can do work. Therefore, they can cause change. For example, the hammer in the photo is doing the work. It is pounding the nail into the board. In other words, the hammer is causing a change by moving the nail.

The amount of kinetic energy in a moving object depends on its mass and velocity. An object with greater mass or greater velocity has more kinetic energy.

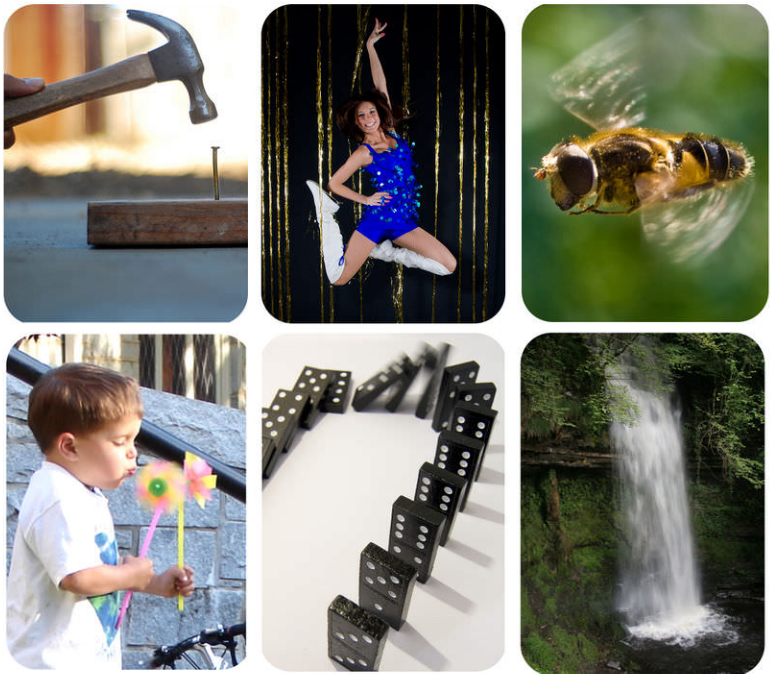


FIGURE 1.3
All of these photos show things that have kinetic energy because they are moving.

Potential Energy

Did you ever see a scene like the one in 1.4 Figure below? In many parts of the world, trees lose their leaves in autumn. The leaves turn color. Then fall from the trees to the ground. As the leaves are falling, they have kinetic energy. While they are still attached to the trees they also have energy. When they are attached they are not in motion, so how can they have energy? Instead of kinetic energy, they have stored energy. This stored energy is called potential energy.

An object has potential energy because of its position. For example, leaves on trees have potential energy because they could fall. They fall because of the pull of gravity. Potential energy can be transferred into motion. Motion can also be turned back into potential energy. Objects have potential energy due to their position. A leaf on a tree branch has potential energy. The leaf's energy can be turned into motion as it falls. Once the leaf is on the ground, it has no more potential unless it is lifted back up. What pulls these falling leaves to the ground? How does it provide potential energy for objects?

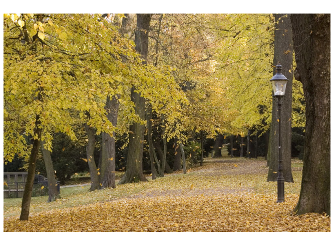


FIGURE 1.4
Before leaves fall from trees in autumn, they have potential energy. Why do they have the potential to fall?

Gravitational Potential Energy

Gravitational Potential Energy is affected by position. Like the leaves on trees, anything that is raised up has the potential to fall. It has potential energy. You can see examples of people with gravitational potential energy in 1.5

Figure below.

FIGURE 1.5
All three of these people have gravitational potential energy. Can you think of other examples?

Gravitational potential energy depends on two things. It depends on its weight, because a large falling rock can do more damage than a leaf falling from a tree. It also depends on its height above the ground. Like the skateboarder, the higher the ramp, the faster he will be going when he reaches the bottom. Like all energy, gravitational potential energy has the ability to do work. In this case, weight has the potential to deliver a force. More important for us is that it has the ability to cause change. What kind of change you may ask? Gravitational potential energy has the ability to cause motion.

Elastic Potential Energy

Another type of energy is related to its shape. This energy is called elastic potential energy. This energy results when some objects are stretched or squeezed. For something to be elastic, it must have the ability to return to its same shape. For example, the rubber band in 1.6 Figure below has been stretched. Will it spring back to its original shape when released? Some springs can be elastic when they are squeezed. Other springs are elastic when they are stretched. What will happen when the handspring is released?

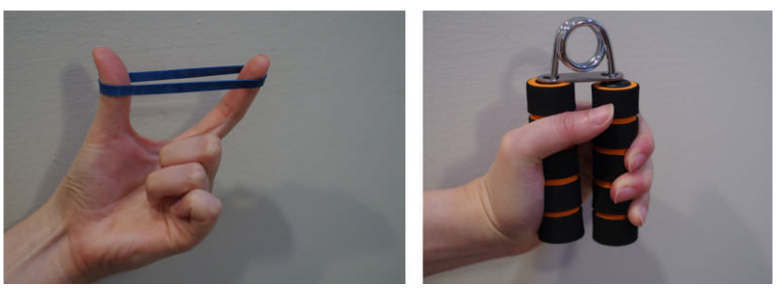


FIGURE 1.6
Changing the shape of an elastic material gives it potential energy.

Energy Conversion

What happens when a diver jumps off the diving board? His gravitational potential energy changes to kinetic energy as he falls. In other words, he falls faster and faster until reaching the water. However, he can always regain his potential energy. All he must do is get out of the water and climb back up. This requires an input of kinetic energy. These changes in energy are examples of energy conversion. Energy can be converted from one form to another. It can also be transferred from one object to another.

Think back to the leaf example. The leaf was hanging from a branch. At this time, it had gravitational potential energy. As it came loose from the branch, gravity pulled it toward the ground. The leaf started to fall, or move, toward the ground. Its potential energy was changed into motion. As it landed on the ground, it stopped moving. As it lays on the ground, it has no potential to move. If it does move it is because something else transferred energy to it. Perhaps the wind blew and lifted the leaf back into the air. Maybe a young child picked it up and then dropped it to watch it fall. It was the wind, or the child, that changed the position of the leaf to once again give it potential energy.

Conservation of Energy (Advanced Topic)

You have probably heard the saying, "What goes up must come down." This is one way of explaining conservation. This same idea applies to energy. Potential and kinetic energy are always equal to the whole. As one type of energy increases, the other decreases. You never have more than you started with. You never have less, either.

In some situations, energy can be used to overcome friction. In these cases, the energy is converted to heat. Have you ever rubbed your hands together to make them warm? That is a form of energy conservation. The energy of rubbing your hands together is not wasted. That energy is turned into heat energy.

Examples of Energy Conversions

There are many other examples of energy conversions between potential and kinetic energy. You can see this in 1.7 Figure below showing the swing and trampoline. Can you think of other examples?

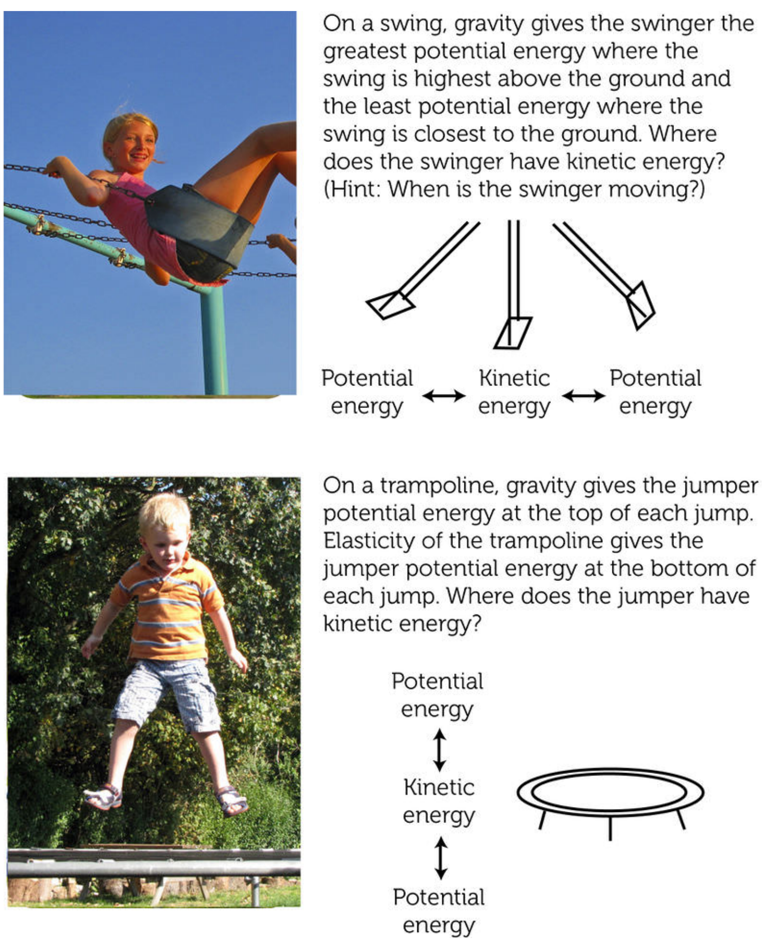


FIGURE 1.7
Energy continuously changes back and forth between potential and kinetic energy on a swing or trampoline.

KQED: Make it at Home: Table-Top Linear Accelerator

QUEST teams up with Make Magazine to construct a really cool device: a tabletop linear accelerator. This device demonstrates kinetic energy. It does so by shooting a steel ball.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/129629

Lesson Summary

- Energy is the ability to do work. When work is done, energy is transferred from one object to another. Energy can exist in different forms. Most forms of energy can also be classified as kinetic or potential energy.
- Kinetic energy is the energy of motion. Things with kinetic energy can do work. Kinetic energy depends on an object's mass and speed.
- Potential energy is stored energy. It may be because of its position or shape. It includes gravitational potential energy and elastic potential energy. Gravitational potential energy depends on an object's weight and height above the ground. Elastic energy depends on an object's ability to return to a normal shape after it is stretched or squeezed
- Energy can be converted from one type or form of energy to another. Energy often changes between potential and kinetic energy. Energy is always conserved during energy conversions.

Lesson Review Questions

Recall

1. Define kinetic energy and give an example.
2. What is potential energy?
3. Describe how energy changes on a swing.

Apply Concepts

4. Explain how energy changes in the spring toy below when it goes down stairs.

Think Critically

5. How is energy related to work?
6. Compare and contrast gravitational potential energy and elastic potential energy.

Points to Consider

The examples of kinetic and potential energy you read about in this lesson are types of mechanical energy. Mechanical energy is one of several forms of energy you can read about in the next lesson, "Forms of Energy."

- Based on the examples in this lesson, how would you define mechanical energy?
- What might be other examples of mechanical energy?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.physicsclassroom.com/mmedia/energy/ie.cfm

1.2 Characteristics of Sound

Lesson Objectives

- Describe sound waves.
- Identify properties of sound.

Lesson Vocabulary

- loudness
- pitch
- sound

Introduction

Crack, Crackle, and Thud were the sounds the tree made when it fell to the forest floor. It fell because of the very high winds during the storm. Does it make you think of an old riddle? The riddle goes like this:

"If a tree falls in the forest and there's no one there to hear it, does it make any sound?"

So what do you think? Does it make a sound or not? Was there really a crack, crackle, thud to be heard?

FIGURE 1.8
This tree cracked and fell to the ground in a storm. Can you imagine what it sounded like when it came crashing down?

What do we need to know to answer this question? You first need to know the scientific definition of sound. In science, sound is the transfer of energy. Sound energy is transferred from a vibrating object into other types of matter. Sound's energy travels through matter via waves. Typically, we think of sound waves traveling through air. Sound waves can actually travel through any type of matter, including solids and liquids. That's why we can still hear underwater.

Sound describes what they hear when sound waves enter their ears. The tree creates sound waves when it falls to the ground. The sound energy is transferred through the air by waves. Therefore, it makes sound according to the scientific definition. But the sound won't be detected by a person's ears if there's no one in the forest. So the answer to the riddle is both yes and no!

Sound Waves

Why does a tree make sound when it crashes to the ground? How does the sound reach people's ears? In general, how do sounds get started? How do they travel?

How Sounds Begin

All sounds begin when matter vibrates. It could be the ground vibrating when a tree comes crashing down. Remember that final thud? That would have been the tree hitting the ground. Sound waves can be created when guitar strings vibrate after they are plucked. You can see a guitar string vibrating in 1.9 Figure below. The vibrating string pushes against the air particles next to it. The pressure of the vibrating string causes these air particles to vibrate. The air particles in turn push together and spread apart. This starts the waves that travel through the air in all directions.

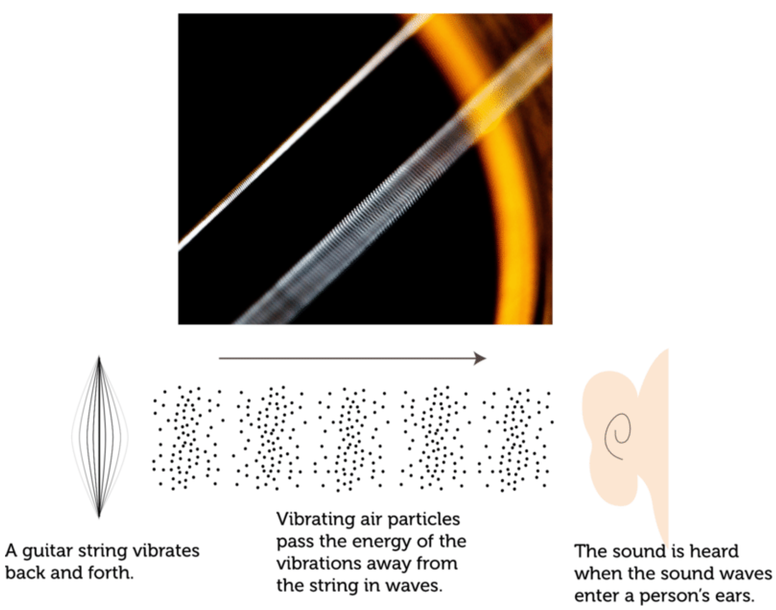


FIGURE 1.9
Plucking a guitar string makes it vibrate. The vibrating string sends sound waves through the air in all directions.

Sound and Matter

Sound waves are mechanical waves. They can travel only through matter. They cannot travel through empty space. This was demonstrated in the 1600s by a scientist named Robert Boyle. Boyle placed a ticking clock in a sealed glass jar. The clock could be heard ticking through the air and glass of the jar. Then Boyle pumped the air out of the jar. The clock was still running, but the ticking could not be heard. That's because the sound couldn't travel without air particles to transfer the sound energy.

Is there any other place where sound cannot be heard? Here is a hint: is there any other place that does not have air molecules? That's right, in space sound cannot be transferred. So can astronauts hear each other? Yes, they can, because they are in enclosed space stations or pressurized suits.In both cases, they are surrounded by air molecules. If they left their space ship and did not use their electronics, they would not be able to hear each other. Next time you watch a science fiction movie, think about this factoid. When spaceships are destroyed by hostile alien beings, there would be no sound heard.

Sound waves can travel through many kinds of matter. Most of the sounds we hear travel through air. Sound can also travel through liquids, such as water. They can also travel through material, such as glass and metal. If you swim underwater you still hear sound. That sound has traveled to your ears through water. You can tell that sounds travel through glass and other solids because you can hear loud outdoor sounds in your home. The sound energy, such as a siren, is transferred through closed windows and doors.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5041

Properties of Sound

Sound has certain characteristic properties. That is because of the way sound energy travels in waves. Properties of sound include speed, loudness, and pitch.

Speed of Sound (Advanced Topic)

The speed of sound is the distance that sound waves travel in a given amount of time. You probably already know that sound travels more slowly than light. That's why you usually see the flash of lightning before you hear the boom of thunder. However, the speed of sound can change. The speed of sound depends on the type of matter it is travelling through. Generally, sound waves travel fastest through solids.

Imagine you are standing some distance apart from your friend. What if you had a very long stick that was held between you and your friend? You push on one end of the stick and instantly the other end moves. The stick represents sound through a solid. Sound travels more slowly through gases. That's because the particles of solids are close together. The sound wave can quickly pass the energy to nearby particles. You can test this out by lining up dominoes and then knocking them over. If the dominoes are placed close together, the energy is passed more quickly. If they are spread farther apart, the energy moves more slowly.

This activity will also help in understanding how temperature affects the speed of sound. For example, in air, sound has a slower speed at lower temperatures. A lower temperature means that particles are moving more slowly and are closer together. Therefore, the energy of the sound waves can be transferred more quickly.

The **Table** 1.1 lists the speed of sound in several different media.

TABLE 1.1: The speed of sound depends on the medium

Medium (20°C)	Speed of Sound Waves (m/s)
Air	343
Water	1437
Wood	3850
Glass	4540
Aluminum	6320

Loud and Soft

A friend whispers to you in class. You can barely hear them. To hear better you have to lean very close to hear what he's saying. Later that day, your friend shouts to you across the football field. Now his voice is very loud. You have no problem hearing him clearly even though he's many meters away. Obviously, sounds can vary in loudness. **Loudness** refers to how loud or soft a sound seems to a listener. The loudness of sound is related to the intensity of sound. **Intensity** is a measure of the amount of energy in sound waves. The unit of intensity is the **decibel (dB)**.

The intensity of sound waves determines the loudness of sounds, but what determines intensity? Intensity is a function of two factors. First, the amount of energy contained in the sound waves. Second, how far away you are from the source of the sound.

Remember that sound waves start at a source of vibrations. Those sound waves spread out from the source in all directions. The farther the sound waves travel away from the source, the more spread out their energy becomes. This is illustrated in **Figure** 1.10. Even loud sounds fade away as you move further away from the source.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177697

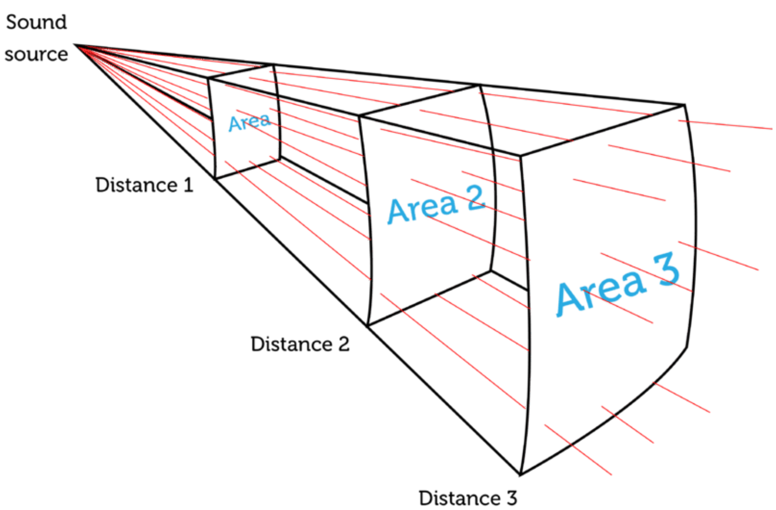


FIGURE 1.10

The energy of sound waves spreads out over a greater area as the waves travel farther from the sound source. This diagram represents just a small section of the total area of sound waves spreading out from the source. Sound waves actually travel away from the source in all directions. As distance from the source increases, the area covered by the sound waves increases, lessening their intensity.

Pitch

A marching band is coming down the street. You can hear it coming from several blocks away. When all the instruments pass by, their unique sounds can be heard. The tiny piccolos sound like birds as they play their high notes. The big tubas rumble out their booming bass notes. Clearly, some sounds are higher or lower than others. But do you know why?

How high or low a sound seems to a listener is called pitch. Pitch depends on the frequency of sound waves. Recall that the frequency of waves is the number of waves that pass a fixed point in a given amount of time. High-pitched sounds, like the sounds of a piccolo, have high-frequency waves. This means they vibrate quickly. The sound of a tuba is a low frequency. The sound waves vibrate more slowly. The length of the instrument tubing is what determines the frequency.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5042

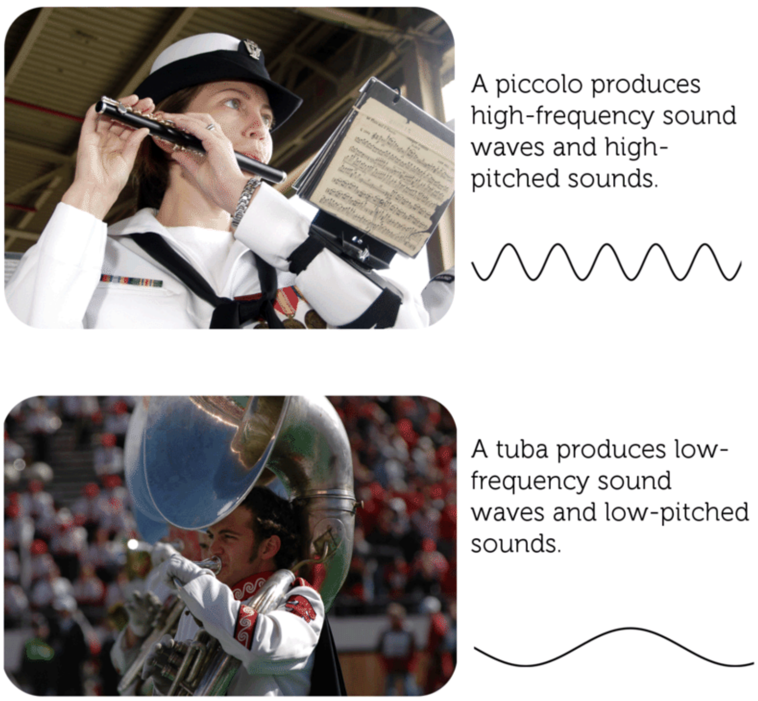


FIGURE 1.11

A piccolo and a tuba sound very different. One difference is the pitch of their sounds.

Lesson Summary

- Sound is the transfer of energy from a vibrating object. The sound travels in waves through matter.
- Properties of sound include speed and pitch. The speed of sound varies in different media. The pitch of sound depends on the frequency of sound waves.

Lesson Review Questions

Recall

1. How is sound defined in physics?
2. Identify two factors that determine the intensity of sound.
3. What is the pitch of sound?

Apply Concepts

4. A wind chime produces both high-pitched and low-pitched sounds. If you could see the sound waves from the wind chime, what would they look like?
5. Explain why it is really loud next to a stereo speaker and not as loud in the next room.

Think Critically

6. Explain why sound tends to travel faster in solids than in liquids or gases.

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.ltscotland.org.uk/resources/s/sound/speedofsound.asp?strReferringChannel=resources&strReferringPageID=tcm:4-248291-64

http://www.ltscotland.org.uk/resources/s/sound/amplitude.asp?strReferringChannel=resources&strReferringPageID=tcm:4-248294-64 http://www.physicsclassroom.com/mmedia/energy/ie.cfm

1.3 Forms and Changes of Energy

Lesson Objectives

- Identify different forms of energy.
- Describe how energy changes form.

Lesson Vocabulary

- chemical energy
- electrical energy
- electromagnetic energy
- mechanical energy
- sound energy
- thermal energy

Introduction

The man below is playing an electric guitar. He plucks the strings of the guitar with great skill. The sounds of the music thrill the crowd. The bright stage lights add to the excitement. Unfortunately, the lights can also make it uncomfortable for the musician. It can get really warm on stage. Do you know why? It has something to do with the lights. This scene represents energy in many forms. Can you name them all?

FIGURE 1.12
How many different forms of energy can you identify in this picture?

Comparing Forms of Energy

Energy can exist in many forms. It also has the ability to do work. Think about when you do work. You need a lot of energy. Maybe your energy comes from a good breakfast. Your body turns the food you eat into energy. This energy gives you the strength to do work. There are many forms of energy. They all have the ability to do work. From the picture above, can you find six forms of energy?

The guitarist can play because he eats food. Food contains chemical energy. His body then turns chemical energy into motion. His hands can move to play the guitar. The motion of the guitar player's hands is a form of mechanical energy. Chemical energy is just one form of energy. That's why it's important for you to eat right.

What about some other forms of energy in this picture? How about the stage lights? The stage lights use electrical energy. The lights give off both light and heat. Heat is sometimes called thermal energy. The guitar uses electrical energy. The guitar produces sound energy when the strings are plucked.

Mechanical Energy

Mechanical energy is a combination of the energy of motion or position. This type of energy describes objects that are moving or could move.

A moving ball can have energy from motion. An arrow can also have the energy of motion. Both are types of mechanical energy. Can you think of some other examples?

Where does the energy of motion come from? It comes from the energy created by position. This energy is stored energy. This means it is not moving yet, but it has the potential to move. How can you store energy?

In the figure 1.13, the arrow gains energy from the drawn bow. As the arrow is released, the bow releases its stored energy and puts the arrow into motion. Can you think of some other ways to store energy using position?

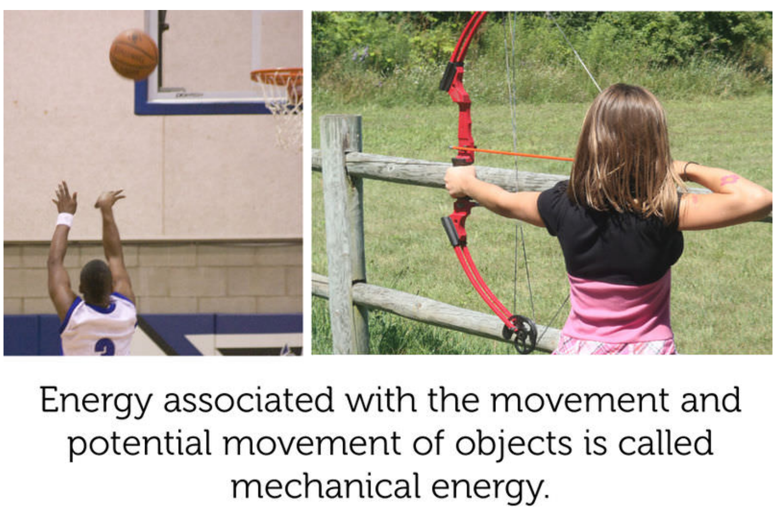


FIGURE 1.13
Kinetic and potential energy add up to mechanical energy.

Chemical Energy

Energy is stored in chemical compounds. This energy is called chemical energy. Chemical energy is a form of potential energy. When bonds between atoms are broken, energy is released. The wood in fireplaces has chemical energy. The energy is released as heat and light when the wood burns.

Most living things get their energy from food. When food molecules are broken down, the energy is released. It may then be used to do work, like playing ball or studying science. If you have ever heard, "Eat a good breakfast," that's why. You need energy to do things during the day. To do those things you need energy. You get your energy from the food you eat. That energy is stored in your body until you need it.

How did you get to school today? If you walked, you used chemical energy from the food you ate. What if you rode the bus or were driven in a car? Where did that energy come from? Gasoline also has potential energy. Just like food, when the bonds between atoms in the gas are broken, energy is released. Remember, when wood burns it gives off heat and light. When gasoline is burned in an engine, it also gives off energy. It is this energy that makes the vehicle move.

FIGURE 1.14
Chemical energy is stored in wood and released when the wood burns.

Electrical Energy

Electrons are particles in an atom. They have a negative charge. Anything that is moving has energy, even electrons. We often refer to this motion as electricity. Electricity is the result of the moving electrons. These electrons can move through wires. This motion is what makes it possible to watch TV and talk on your cell phone.

Have you ever had to live without electricity? This can happen after big storms. Any type of natural disaster can cause a loss of electricity. In what ways would a loss of electricity affect your family?

Most of the electricity we use comes from power plants. It arrives in our homes through wires. There are also other sources of electricity. You are probably very familiar with two of the most common sources. You can see both of them pictured in the **Figure** 1.15.

FIGURE 1.15
A lightning bolt is a powerful discharge of electrical energy. A battery contains stored chemical energy and converts it to electrical energy.

Nuclear Energy (Advanced Topic)

The center of an atom is held together by powerful forces. This gives them a huge amount of stored energy. This type of energy is called nuclear energy. This energy can be released and used to do work. This happens in nuclear power plants where they split apart the nucleus of an atom. This splitting apart is called nuclear fission.

Another type of nuclear energy happens in the Sun. Here the atoms' nuclei are not split apart. Instead, the nuclei of the atoms are fused, or joined together. This process is called nuclear fusion. Some of the sun's energy travels to Earth. This energy from nuclear fusion warms the planet and provides the energy for photosynthesis (see **Figure** 1.16).

FIGURE 1.16
In the sun, hydrogen nuclei fuse to form helium nuclei. This releases a huge amount of energy, some of which reaches Earth.

Thermal Energy

Atoms are in constant motion. They have kinetic energy, the energy of motion. All that motion gives matter thermal energy. The amount of motion that particles have is what we call temperature.

In **Figure** 1.16, you can see two items. They have different amounts of thermal energy, but the same temperature. How can this be?

Thermal energy depends on two factors. The first is how fast the atoms are moving, or its temperature. The second is how many atoms the object contains. Therefore, an object with more mass has greater thermal energy. An object with less mass has less thermal energy.

Think of it this way. You have a small cup of warm water. You also have a large barrel of warm water. Each are the same temperature. Which has the most energy? If you said the large barrel, you would be correct. The more mass there is, the more thermal energy. If you were in a bath tub and needed to warm the water, would you add a little warm water or a lot? Of course, you would add the larger amount. This is because it has more thermal energy.

FIGURE 1.17
Atoms are moving at the same speed in the soup on the spoon as they are in the soup in the pot. However, there are more atoms of soup in the pot, so it has more thermal energy.

Electromagnetic Energy

Our sun and other stars release light energy. At least this is what we see. Our Sun and stars also emit more than just light. Scientists call the type of energy that our Sun and stars release electromagnetic energy. This form of energy travels through space. Electromagnetic energy includes the light we see. It also includes much more. Many of these things we know about, but don't always think about. Electromagnetic energy includes radio waves, microwaves, and X rays. We now have devices in our homes and offices that release these same forms of energy. We use electromagnetic energy to make our lives better.

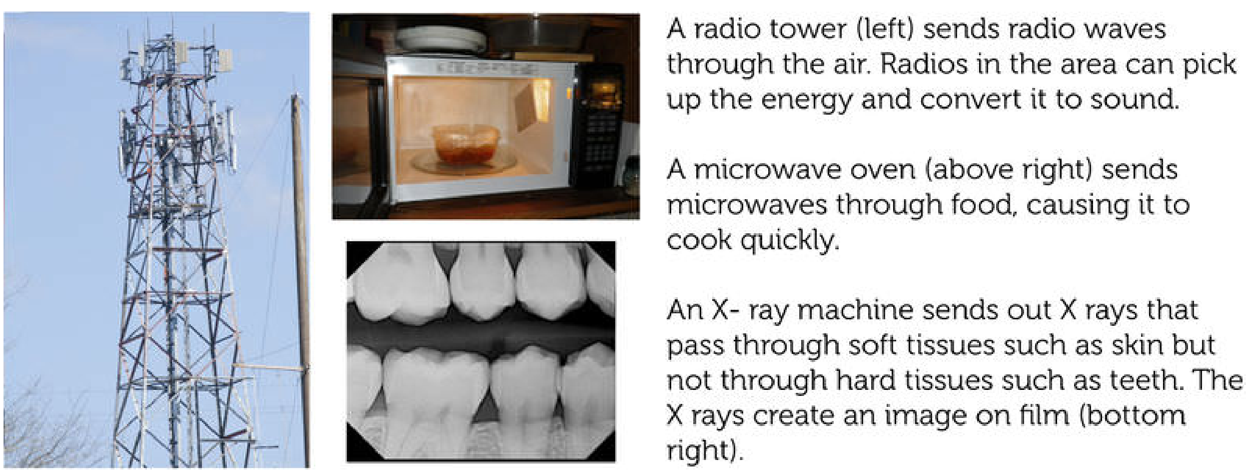


FIGURE 1.18
Radio waves, microwaves, and X rays are examples of electromagnetic energy.

Sound Energy

The drummer in **Figure** 1.18 is hitting the drumheads with drumsticks. This causes the drumheads to vibrate. The vibrations pass to surrounding air particles. Vibrations then pass from one air particle to another in a wave of energy called a sound wave. We hear sound when the sound waves reach our ears. Sound energy can travel through air, water, and other substances. Sound cannot travel through empty space. Sound needs particles of matter to pass it on.

You can think of sound moving through matter like falling dominoes. If they are lined up, one will fall, hitting the next and making it fall, and so on. What if the dominoes were too far apart to touch when they fell? This is what happens if there are no particles for sound to travel through. Fortunately for us, space is the only place sound cannot be transmitted.

FIGURE 1.19
Vibrating objects such as drumheads produce sound energy.

How Energy Changes Form

Energy often changes from one form to another. For example, the drummer transfers motion to sound energy. When the moving drumstick strikes the drum head, the drum starts to vibrate. The motion of the vibrating drum head creates the sound you hear. Any form of energy can change into any other form. Frequently, one form of energy changes into two or more different forms. Have you ever sat in front of a campfire? What are two things you notice? The fire creates light. It is also warm by the fire, meaning it creates heat. The energy of the fire comes from the stored energy in the wood. The wood contains chemical energy. As it burns, the chemical energy is changed into light and heat. Not all chemical energy changes produce light and heat. Our cars use gasoline as a fuel. Gasoline contains chemical energy. When our cars burn gasoline in their engines, it is converted into motion and heat.

When energy changes forms, energy is conserved. What does this mean? It means that no energy is lost. That does not mean all the energy that changes form goes where we want it. For example, when our cars burn gasoline, all the energy does not go into motion. Some is turned into heat. For us, this energy is wasted. Although you may start with the same amount as you end up with, some of the energy is not useful. In the case of a car engine, some energy may turn into heat energy due to friction. For example, not all of the energy put into a steam turbine in **Figure** 1.20 changes to electrical energy. Some changes to thermal energy. This, too, happens because of friction. In this case, it is because of the turning blades and other moving parts. The more efficient a device is, the less thermal energy is lost. Some new appliances are very efficient. These devices have the "Energy Star" label. You can see an Energy Star label in **Figure** 1.21. These labels tells us the appliance is efficient and reduces the use of energy.

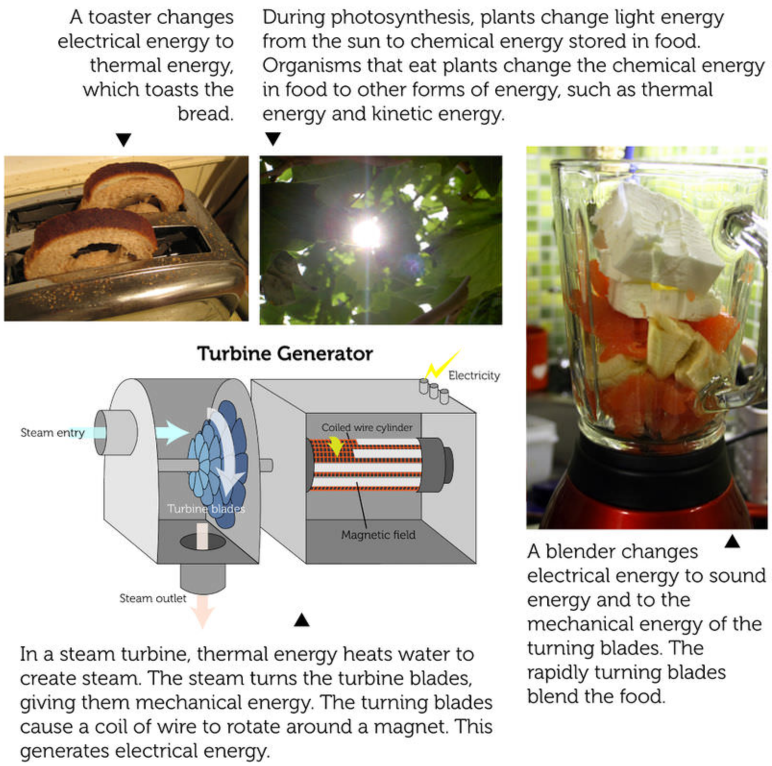


FIGURE 1.20
Energy is constantly changing form. Can you think of other examples of energy conversions?

FIGURE 1.21
The U.S. government's Energy Star program certifies the energy efficiency of appliances. Look for this label to identify those that are energy efficient.

Lesson Summary

- Forms of energy include mechanical, chemical, electrical, nuclear, thermal, electromagnetic, and sound energy. These forms of energy can occur as either kinetic or potential energy.
- Energy often changes from one form to another. Any form of energy can change into any other, and one form may change into two or more different forms. Energy is always conserved when it changes form.

Lesson Review Questions

Recall

1. Define mechanical energy.
2. Give an example of chemical energy.

3. What is electrical energy?
4. Name two processes that release nuclear energy (Advanced Topic).

Apply Concepts

5. If you were on the moon, no sound energy would be able to reach your ears. Explain why. (*Hint:* The moon has no atmosphere.)
6. State how energy is converted by the following electrical devices: light bulb, alarm clock, hair dryer.

Think Critically

7. Relate the thermal energy of an object to the object's atoms.

1.4 Transfer of Thermal Energy

Lesson Objectives

- Describe the conduction of thermal energy.
- Explain how convection transfers thermal energy. (Advanced Topic)
- Give an example of the radiation of thermal energy. (Advanced Topic)

Lesson Vocabulary

- conduction
- convection (Advanced Topic)
- convection current (Advanced Topic)
- thermal conductor
- thermal insulator

Introduction

Did you ever cook over a campfire? The man in **Figure** 1.22 is cooking his lunch. He waits as his food absorbs energy. First, the energy from the fire needs to heat the water. Soon, all the water in the pot will be boiling hot. The man also feels warm. He feels the heat from the flames. He feels the warmth even though he is not touching the flames. Thermal energy is transferred from the fire to his hands.

FIGURE 1.22
Thermal energy from the fire is transferred to the pot and water and to the man sitting by the fire.

Conduction

You may know that electricity flows through wires. Wires are good conductors of electricity. Heat too can be transferred, or conducted, through some types of materials. The term **conduction** refers to the transfer of energy. Conduction occurs when energy is passed between objects.

The transfer of thermal energy is called **heat**. Particles of matter are in constant motion. Sometimes they collide with other particles. When they do, they transfer some of their energy. The energy is transferred from particle to particle. It is sort of like a row of dominoes falling over. In this process, thermal energy moves through a substance. It can even move into other nearby substances.

In **Figure** 1.22, conduction occurs between particles of the metal in the pot. It also occurs between particles of the pot and the water. **Figure** 1.23 shows additional examples of conduction.

FIGURE 1.23

How is thermal energy transferred in each of these examples?

Thermal Conductors

Have you ever walked on hot pavement? Perhaps you jumped onto the grass to escape the heat? Why did the grass seem cooler? The grass and pavement are both in the Sun? Maybe it has to do with how well they conduct energy.

Think about a cooking utensil. Have you noticed some have wood or plastic handles? Do you know why? Think about the grass and the pavement on that sunny day.

It's all about the type of matter. Some types of matter are good at allowing heat to flow through them. Other types of matter, or materials, are good insulators. They resist the flow of heat through them, meaning they are not good conductors of heat.

Materials that are good conductors of heat are called **thermal conductors**. Metals allow heat to flow through them easily. That's why the metal pot in the **Figure** 1.22 quickly gets hot all over. This happens even if the fire is only at the bottom of the pot. The heat moves easily throughout the metal pot. The pot is able to get hot all over. It doesn't just get hot on the bottom. In **Figure** 1.23, the curling iron heats up almost instantly. It is able to transfer thermal energy to the strands of hair that it touches.

Thermal Insulators

Some materials are able to resist the transfer of heat. These materials are poor conductors of heat. Therefore, they are called **thermal insulators**. **Figure** 1.24 shows several examples. Fluffy yellow insulation inside the roof of a home is full of air. The air prevents the transfer of thermal energy. In air (a gas) the molecules are further apart. The transfer of heat is much more difficult. Again, think about that row of dominoes. If they are close together and they start to fall, the motion is quick. If they are placed further apart, the falling motion is slower. You can try this by having some domino races.

For the same reason, house insulation keeps the heat out of the house on hot days and in the house on cold days. The trapped air (a gas) is slow to transfer thermal energy. A puffy down jacket keeps you warm in the winter for the same reason. Its feather filling holds trapped air. The trapped air prevents energy transfer from your warm body to the cold air outside. Solids like plastic and wood are also good thermal insulators. That's why pot handles and cooking utensils are often made of these materials.

KQED: Darfur Stoves Project

Not everyone in the world has a stove in their kitchen. In some countries, people must search for wood. They use the wood to build fires. They then cook their food over the fire. In Darfur, Sudan, many women are living in refugee camps. They must walk many hours to collect firewood. This places them at great risk of violent attacks. Researchers at Lawrence Berkeley National Laboratory have engineered a more efficient wood-burning stove. This new type of

FIGURE 1.24
Thermal insulators have many practical uses. Can you think of others?

stove greatly reduces the amount of firewood needed. How do you think this helps the women of Darfur?

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/129631

Convection (Advanced Topic)

Convection is another way thermal energy is transferred. In convection, heat is transferred by particles moving through a fluid. Heat is transferred from warmer to cooler areas. That's how energy is transferred in the soup in **Figure** 1.24. Particles of soup near the bottom of the pot get hot first. They have more energy so they spread out and become less dense. With lower density, these particles rise to the top of the pot (see **Figure** 1.25). By the time they reach the top of the pot, they have cooled off. They have less energy to move apart. As a result, they become more dense. With greater density, the particles sink to the bottom of the pot. The cycle repeats over and over again. This loop of moving particles is called a **convection current**.

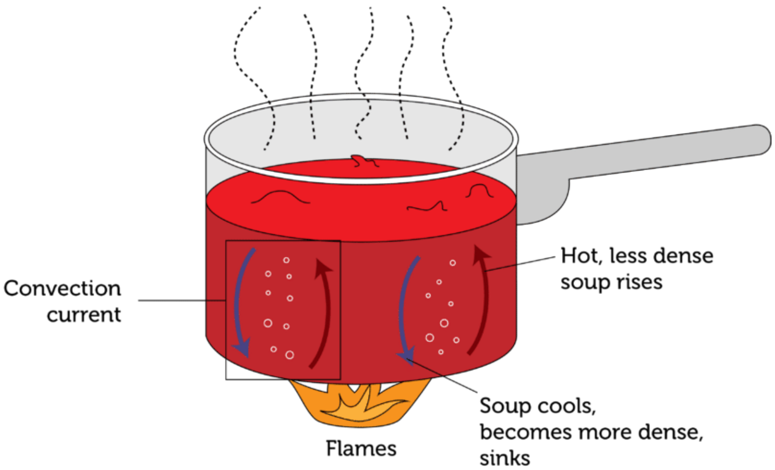


FIGURE 1.25
Convection currents carry thermal energy throughout the soup in the pot.

Convection currents move thermal energy through many fluids. Heat is transferred though molten rock (a semi-liquid) inside the Earth. Water in the oceans circulates because of this process. Even the air in the atmosphere transfers heat in this way. In the atmosphere, convection currents create wind. You can see one way this happens in **Figure** 1.26. Land heats up and cools off faster. Therefore, land is warmer during the day and cooler at night than water. Air close to the surface gains or loses heat as well. Warm air rises because it is less dense. When it does, cool air moves in to take its place. This creates a convection current that carries air from the warmer to the cooler area.

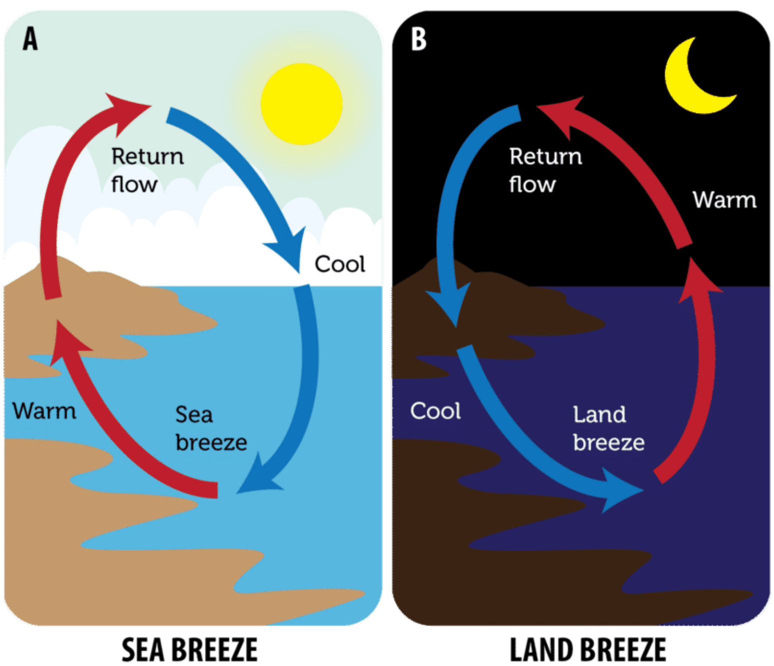


FIGURE 1.26
A sea breeze blows toward land during the day, and a land breeze blows toward water at night. Why does the wind change direction after the sun goes down?

Radiation (Advanced Topic)

Both conduction and convection transfer energy through matter. Radiation is the only way of transferring energy that doesn't require matter. Radiation is the transfer of energy by waves. These waves can travel through empty space. When these waves reach objects, they transfer energy to the objects. This causes them to warm up. This is how the Sun's energy reaches Earth and heats its surface (see **Figure** 1.27). Radiation is also how thermal energy from a campfire warms people nearby. You might be surprised to learn that all objects radiate thermal energy. This even includes you. In fact, when a room is full of people, it may feel noticeably warmer. This is because of all the thermal energy the people radiate!

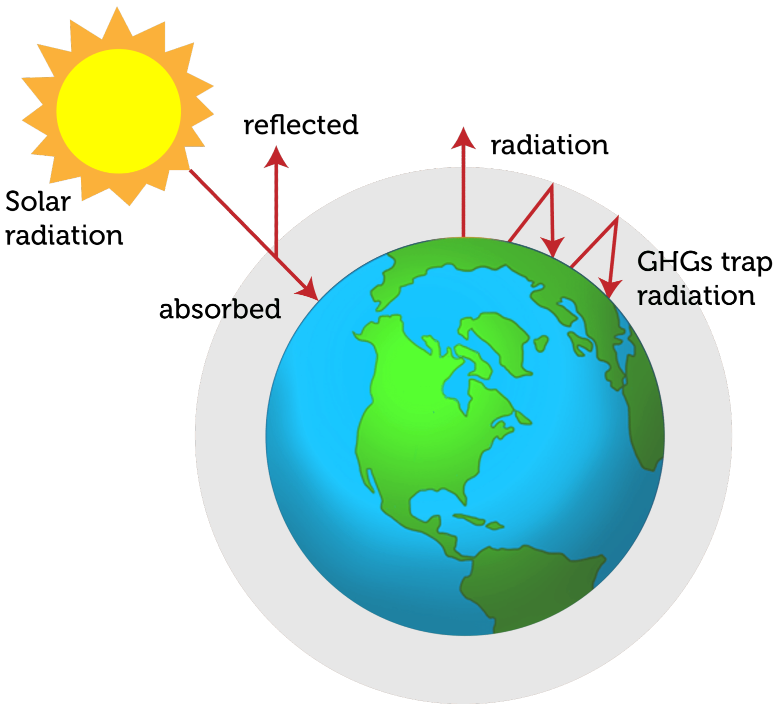


FIGURE 1.27
Earth is warmed by energy that radiates from the sun. Earth radiates some of the energy back into space. Greenhouse gases (GHGs) trap much of the re-radiated energy, causing an increase in the temperature of the atmosphere close to the surface.

Lesson Summary

- Conduction is the transfer of thermal energy. It occurs between objects or substances that are touching. Thermal conductors are materials that are good conductors of heat. Thermal insulators are materials that are poor conductors of heat. Both conductors and insulators have important uses.
- Convection is the transfer of thermal energy. This occurs as particles move within a fluid. The fluid may be a liquid or a gas. The particles within the fluid transfer energy by moving from warmer to cooler areas. They move in loops. These loops are called convection currents.
- Radiation is the transfer of thermal energy by waves. These waves can travel through empty space. When the waves reach objects, the heat is transferred to the objects. Radiation is how the Sun warms the Earth's surface.

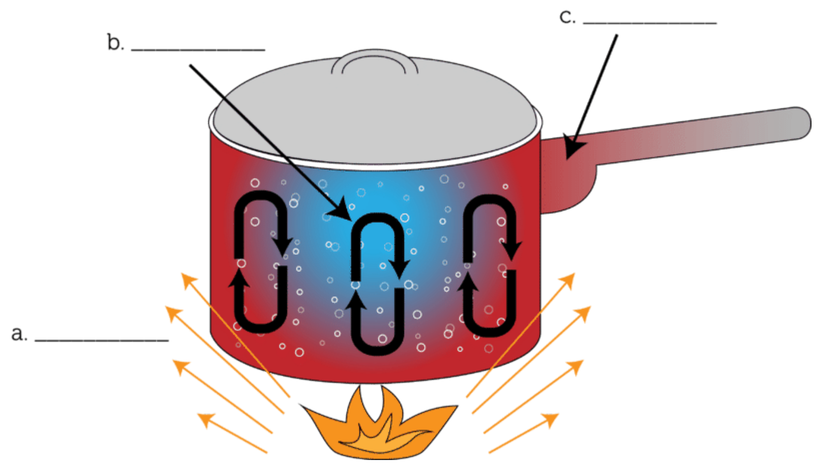
Lesson Review Questions

Recall

1. Define conduction.
2. Define convection.
3. Define the radiation of thermal energy.

Apply Concepts

4. Fill in each blank in the diagram below with the correct method of heat transfer.



5. How could you insulate an ice cube to keep it from melting? What material(s) would you use?

Think Critically

6. Why does convection occur only in fluids?
7. A friend tells you that insulation keeps out the cold. Explain why this statement is incorrect. What should your friend have said?

Points to Consider

Thermal energy is very useful. For example, we use thermal energy to keep our homes warm and our motor vehicles moving.

- How does thermal energy heat a house? What devices and systems are involved?
- How does thermal energy run a car? How does burning gas in the engine cause the wheels to turn?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.sciencehelpdesk.com/unit/science2/3

1.5 Energy Resources

Lesson Objectives

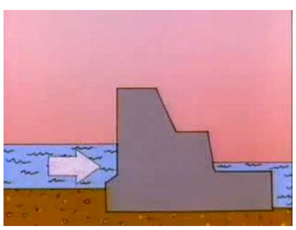
- Describe nonrenewable energy resources.
- Identify several renewable energy resources.
- Outline world energy use and ways to conserve energy.

Lesson Vocabulary

- conservation
- fossil fuel
- natural resource
- nonrenewable resource
- renewable resource

Introduction

Water is one of our most precious natural resources. A **natural resource** is anything people can use that comes from nature. Water is just one type of natural resource. There are many other natural resources. Many of these natural resources provide us with energy. This is energy we need to conduct our daily lives.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5031

Renewable or Nonrenewable, What's The Difference?

Imagine a glass of your favorite drink that never became empty. Now think about what really happens. You take a drink and there is less in the glass. You keep drinking and soon it is all gone. Good thing you have more to refill your glass. What if there would never be any more of your favorite drink. What would you do?

Now you know the difference between renewable and non-renewable. It's too bad that many things here on Earth will run out. This includes some of our natural resources we depend on. Things like oil will not last forever. There is a limited supply. Someday, we will run out, so then what? At current rates of use, coal will last about 300 years. Petroleum will be used up in just a few decades.

FIGURE 1.28
Whitewater rafting is an exciting sport.

Nonrenewable Energy Resources

Nonrenewable resources are limited in supply. Nonrenewable resources cannot be replaced in a short period of time. We are using them up far faster than they can be replaced.

It can take millions of years to produce some of our natural resources. If we used them all up today, we would have to wait a really long time. That's not even possible for humans. For this reason, we call this category of resources nonrenewable. Nonrenewable energy resources include fossil fuels such as oil and coal. It also includes radioactive elements such as uranium. Can you think of a nonrenewable resource?

Fossil Fuels

Fossil fuels are one type of nonrenewable resources. Fossil fuels have been formed over millions of years. Why are they called "fossil" fuels? It's because they formed from the remains of dead organisms. They include petroleum (commonly called oil), natural gas, and coal. Fossil fuels provide most of our energy. This is what your local power plant burns to make electricity.

Don't we use a lot of electrical energy to heat our homes? It is true, many of us heat and cool our homes with electrical energy. Do you know how most electrical energy is made? If you said from burning fossil fuel, you would be correct. You can see examples of their use in **Figure** 1.29.

Fossil fuels contain stored chemical energy. Believe it or not, this energy originally came from the Sun. Do you know how this happens?

A long time ago, plants collected the Sun's energy. They changed energy from sunlight into stored chemical energy in food. In turn, the plants will get eaten by an animal, or eventually die. Their remains will be buried by sediment. They will then get squeezed as the layers of sediment pile up. They gradually get changed into fossil fuels. Petroleum and natural gas formed from marine organisms. They are often found together. Coal formed from land plants, such as giant tree ferns and other swamp plants.

When fossil fuels burn, they release thermal energy and water vapor. They also release carbon dioxide. Carbon dioxide in the air is a major cause of global warming. The burning of fossil fuels also releases many pollutants into the air. These pollutants can kill living things. It can also do damage to metals, stonework, and other materials.

Natural gas releases the least pollution. Coal releases the most (see **Figure** 1.30). Petroleum has the additional risk of oil spills. Oil spills can harm plants and animals in the area.

Natural gas burns with a blue flame in this gas stove. Many homes also have natural gas water heaters and furnaces. Some motor vehicles burn natural gas as well.

Petroleum is used to make gasoline, which fuels most motor vehicles. It is also used to make heating oil for furnaces and kerosene for camp stoves.

The majority of electric power in the U.S. is generated by burning coal in power plants like this one.

FIGURE 1.29
Do you use any of these fossil fuels? How do you use them?

Fossil Fuel Pollution Levels
Pounds per Billion Units of Energy

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0	0.007	0.016

FIGURE 1.30
This table compares the levels of several air pollutants released by the burning of natural gas, oil, and coal.

Renewable Energy Resources

Renewable resources are natural resources that can be replaced quickly. They are almost limitless in supply. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy. Each of these energy resources is described in **Table** 1.2. Resources such as sunlight and wind will never run out. Renewable energy resources also have other advantages. Renewable energy resources produce very little, if any, pollution. This is great news. Renewable energy sources do not cause global warming. On the down side, the technology costs a lot of money. Once the purchase has been made the resource is free for the taking. Once you buy the solar panels, the sunlight is free.

TABLE 1.2: What are the pros and cons of using each of the renewable energy resources described here?

Renewable Energy Resource	Example
Sunlight Sunlight can be used to heat homes. It can also be used to produce electricity. This conversion is made possible by solar cells. However, solar energy may not always be practical. Some areas are just too cloudy.	 Solar panels on the roof of this house generate enough electricity to supply a family's needs.
Moving Water Falling water can have a lot of energy. Its energy can be converted into kinetic energy. This energy can turn a turbine and generate electricity. The water may fall naturally over a waterfall or flow through a dam. A drawback of dams is that they flood land upstream. They can also reduce water flow downstream. Either effect may harm ecosystems.	 Water flowing through Hoover dam. It is located between Arizona and Nevada. It generates electricity for both of these states and also southern California. The dam spans the Colorado River.
Wind Wind is moving air. It has kinetic energy that can do work. Wind turbines change the kinetic energy of the wind to electrical energy. Only certain areas of the world get enough steady wind. Many people also think that wind turbines are noisy and not very nice to look at.	 This old-fashioned windmill captures wind energy. It is used for pumping water out of a well. Windmills like this one have been used for centuries.
Biomass The stored chemical energy of trees and other plants is called biomass energy. When plant materials are burned, they produce thermal energy. This energy can be used for heating, cooking, or generating electricity. Wood is considered a form of biomass. Wood is an important energy source in poor countries. In these countries, people can't afford fossil fuels. Some plants can also be used to make ethanol. Ethanol is a fuel that is added to gasoline. Ethanol produces less pollution than gasoline. However, large areas of land are needed to grow the plants that are needed.	 This large machine is harvesting and grinding plants. The ground up plants are used for biomass energy.

TABLE 1.2: (continued)

Renewable Energy Resource	Example
Geothermal Earth's interior holds a lot of heat. This heat is called geothermal energy. It too can be used to produce electricity. A power plant pumps water underground, where it gets heated, then the hot water is pumped back to the plant. There it is converted into electricity. On a small scale, geothermal energy can be used to heat homes. Installing a geothermal system can be very costly. This is because it is necessary to drill a deep hole through hard soil and rock.	 This geothermal power plant is located in Italy. Here, hot magma is close to the surface.

Energy Use and Conservation

Figure 1.31 shows the mix of energy resources used worldwide in 2006. Fossil fuels still provide most of the world's energy. Oil is still the most commonly used energy resource. Natural gas is used less than the other two fossil fuels. Even natural gas, the least used of the fossil fuels, gets used more than all the other renewable energy resources. Wind, solar, and geothermal energy contribute the least to global energy. This may seem surprising as they are virtually limitless in supply. They also have the added benefit of being nonpolluting.

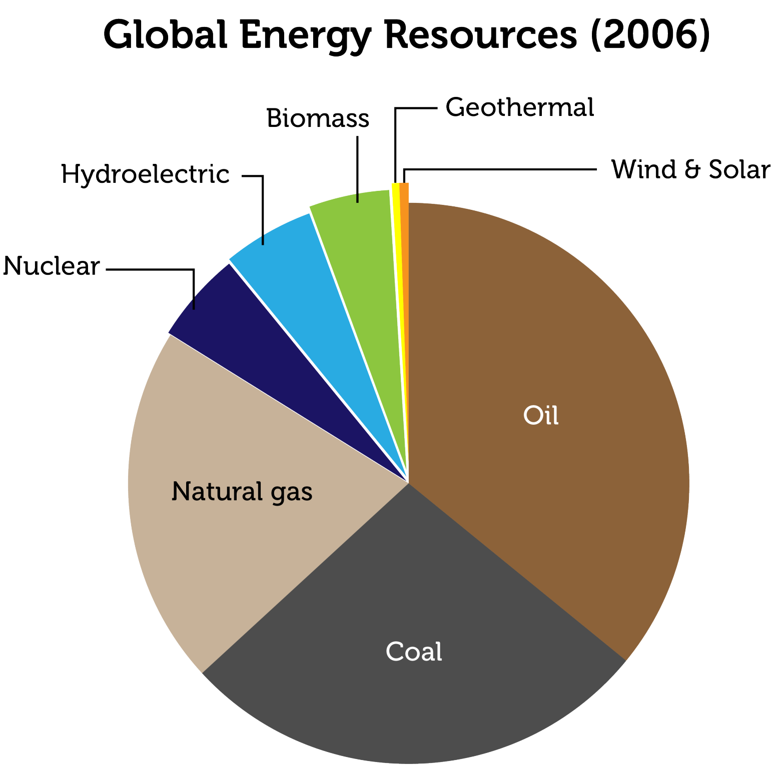


FIGURE 1.31
Which of the energy resources in this circle graph are renewable?

Energy Use by Nation

People in the richer nations of the world use far more energy than those in the poorer nations. This is true especially for energy from fossil fuels. Rich nations use far more energy from fossils fuels than poor nations. **Figure** 1.32 compares the amounts of oil used by the top ten oil-consuming nations. The U.S. uses more oil than several other top-ten countries combined. If you also consider the population size in these countries, the differences are even more stunning. The average person in the U.S. uses a whopping 23 barrels of oil a year! In comparison, the average person in India or China uses just 1 or 2 barrels a year. Because richer nations use more fossil fuels, they also cause more air pollution. Air pollution is a contributing factor to global warming.

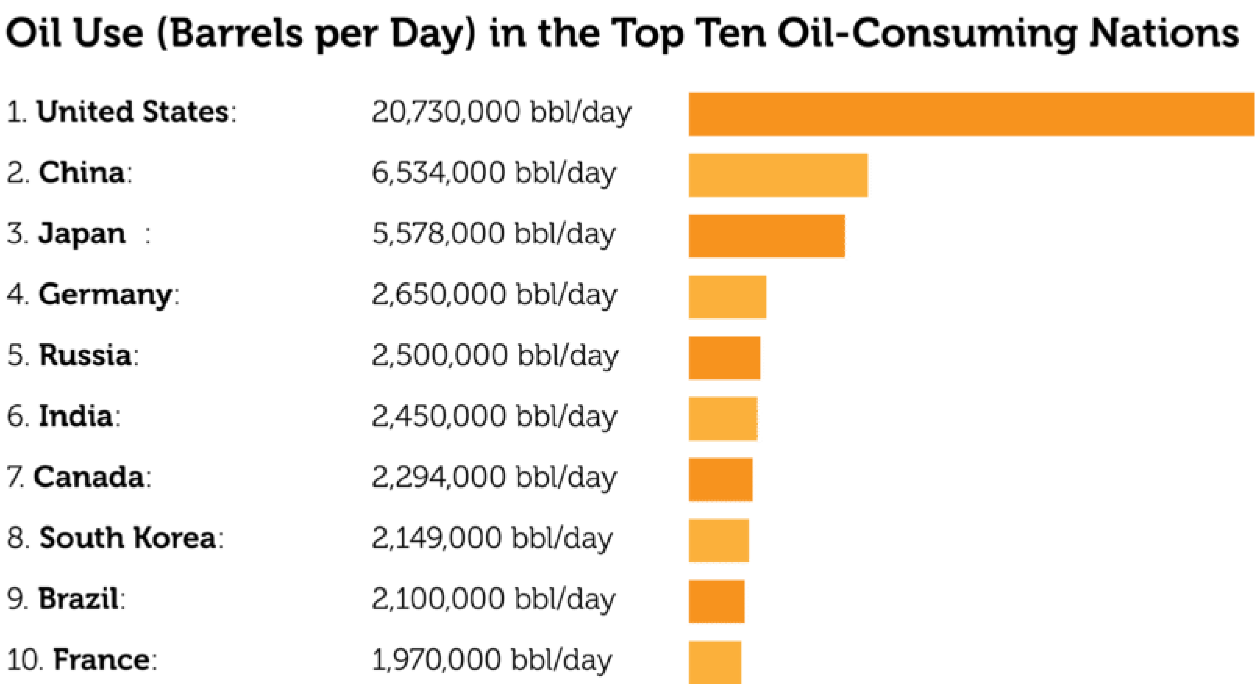


FIGURE 1.32

The U.S. uses far more oil than any other country in the world. It is even far ahead of the next largest oil user, which is China. The differences in use per person in these countries are even greater.

Conserving Energy

We can reduce our use of energy resources. As a result we can also reduce the amount of pollution. **Conservation** means to use less of something. If nothing else, we need to use the resources we have more efficiently. **Figure** 1.33 shows several ways that people can conserve energy in their daily lives. What do you do to save energy? What else could you do?

KQED: Web Extra: Home Energy Audit

QUEST teams up with Climate Watch to give you an inside look at home energy efficiency. Tag along with Sustainable Spaces on a home efficiency "green-up." Learn tips on how to make your home more energy efficient.

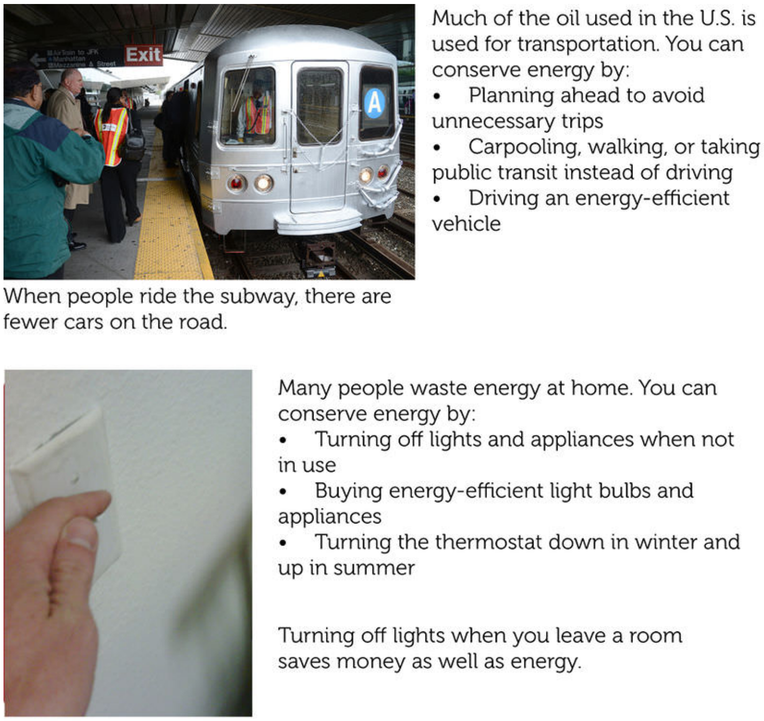
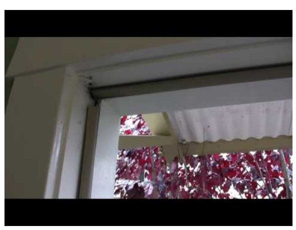


FIGURE 1.33

Small savings in energy really add up when everybody conserves energy.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/129630

Lesson Summary

- Nonrenewable resources are natural resources that are limited in supply. They cannot be replaced except over millions of years. They also release pollutants and contribute to global climate change. Nonrenewable energy resources include fossil fuels. These fuels are burned. Uranium is used for nuclear fission.
- Renewable resources are natural resources that can be replaced in a relatively short period of time. They are also virtually limitless in supply. They cause little if any pollution or global climate change. Renewable energy resources include sunlight, moving water, wind, biomass, and geothermal energy.
- Fossil fuels provide most of the energy used worldwide. Richer nations use far more energy resources than do poorer nations. This is especially true for fossil fuels. There are several ways that people can conserve energy in their daily lives.

Lesson Review Questions

Recall

1. What is a natural resource?

2. Identify three fossil fuels.
3. Describe how fossil fuels form.
4. What are drawbacks of using fossil fuels?
5. State why nuclear energy is a nonrenewable resource.

Apply Concepts

6. Create a web page or poster that encourages people to conserve energy and gives tips for how to do it.

Think Critically

7. Compare and contrast nonrenewable and renewable energy resources.
8. Argue for the use of any two renewable energy resources.

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.think-energy.co.uk/ThinkEnergy/11-14/activities/EnergyTrans.aspx

http://www.partselect.ca/resources/Home-Energy-Saving-Tips.aspx

1.6 Moving Air and Water as Energy Sources

Introduction

Wind turbines are becoming a more and more common sight on the landscape. For scientists, they represent great hope for energy production. Wind turbines do not produce pollution. As you can see in the picture above, their job is to catch the wind. Wind turbines provide us with electrical energy. This energy supports our homes, schools, and offices.

The Power of Wind

Wind is not a new form of energy. In fact, it has been used for thousands of years. Only in the last 200 years has the use of wind energy diminished. Before then, it was wind that powered the ships that sailed the oceans. In the past 200 years, ships have switched from wind power to the use of fossil fuels. Fossil fuels are burned to produce the energy to run ships engines. Around 200 years ago, ships started to use engines instead of sails. Coal became the energy source. Modern ships use diesel fuel. Diesel fuel is a product of petroleum.

Farmers too have used the power of wind. Windmills are a common feature on farms. They are used to gather wind energy. This energy is used to pump water and do other useful work. On many modern farms, windmills are now just a rusty relic. They represent a memory of a time long past. Most modern farms have now switched to electricity. Electricity now supplies their energy needs. The electricity is produced in a power plant. Most power plants burn fossil fuels. Fossil fuels have more or less taken over. Fossil fuels now produce the energy that was once supplied by wind.

Why do you think wind is so important? Simply put, wind is moving air. Moving air has kinetic energy. Anything that has kinetic energy has the ability to do work. Wind turbines change the kinetic energy of the wind into electrical energy. This form of energy production is also free of pollution. Why are there not wind turbines everywhere?

Unfortunately, only certain areas of the world are suited for wind turbines. Wind turbines need a steady wind to be cost effective. Some areas of the world are just not windy enough. Also, many people think that wind turbines are noisy and unattractive. See for yourself!

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/178605

FIGURE 1.34

This old-fashioned windmill captures wind energy that is used for pumping water out of a well. Windmills like this one have been used for centuries.

Moving Water

People have used moving water as a form of energy for thousands of years. Water power is the energy derived from moving water. Water power is sometimes called hydropower. Since ancient times, moving water has been used by many industries. Grist mills used moving water to grind wheat and corn. Lumber was cut at sawmills that were powered by moving water. Local economies prospered from being located on rivers and streams.

Historically, the power of moving water was captured by simple water wheels. Water wheels have been used for a long time. They are used to capture the energy from moving water. More recently, engineers have come up with a different way to capture the power of water. A flowing stream only contains a little energy. In contrast, falling water has a lot more useful energy.

New structures have been built to capture this energy. They are called hydroelectric plants. They are used to capture the energy from falling water. The energy of falling water is converted into electricity. Electricity can then be sent through wires to where it is needed. No longer does an industry need to be located on a river or stream. For example, the Dam at Niagara Falls supplies Buffalo, New York with electricity. The distance between these two locations is over 20 miles.

Instead of paddle wheels, hydroelectric plants use rotating turbines. Turbines contain copper wires and magnets. When wire is moved through a magnetic field, it produces an electric current. These turbines harness the power of falling water. As the water falls through these turbines, it forces them to spin. Large coils of wire spin inside a ring of magnets. This motion converts the water's kinetic energy into electricity. The power plant workers can control the flow of water. It is sort of like adjusting the water faucet in your home. By controlling the flow of water, they can regulate the amount of electricity produced. Some of these plants can produce large amounts of electricity.

Like wind power, moving water also has kinetic energy. As you know, anything that has kinetic energy has the ability to do work. It does not matter the type of device used. The process is always the same. Kinetic energy of moving water is changed into electrical energy. Electrical energy can be moved great distances. For example, the Hoover dam was built between Arizona and Nevada. It generates electricity for both of these states. It even has energy left over. With the spare it can supply parts of southern California.

A drawback of dams is that they flood land upstream. They can also reduce water flow downstream. Either effect may harm ecosystems. Dams do have advantages. They are a renewable energy resource. They also do not produce pollution.

Both wind and moving water are renewable resources. This means they will never run out. They also do not produce pollution. Pollution damages the environment and may affect the climate. Scientists are working hard to find the best ways to use wind and water effectively.

Lesson Review Questions

Recall

1. Today, wind energy is making a comeback. Do you know why?
2. What might be advantages of using the wind for energy?
3. Describe the advantages and disadvantages of using moving water for energy.

1.7 Reflection of Light

Learning Objectives

- State the law of reflection.
- Describe the difference between regular and diffuse reflection.

Lesson Objectives

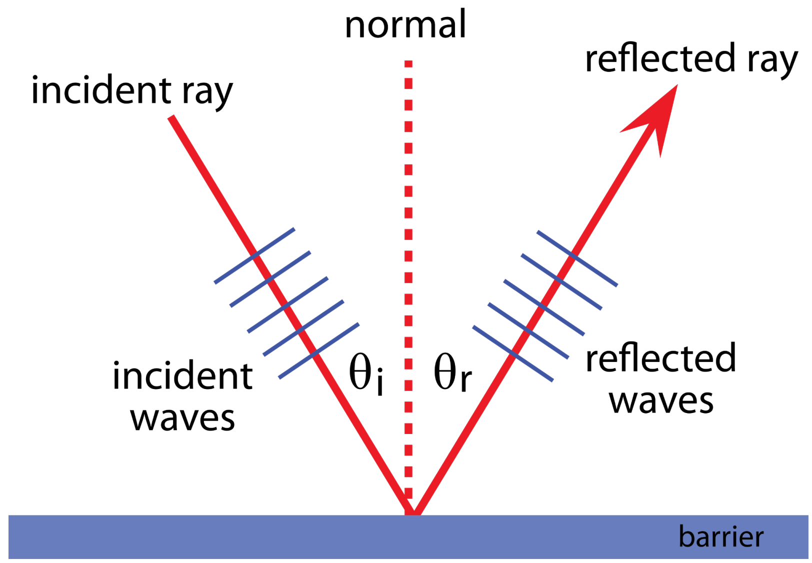
- Demonstrate that light travels in a straight line until it strikes an object or travels from one medium to another.
- Demonstrate that light can be reflected, refracted, and absorbed.

Lesson Vocabulary

- light - a form of energy that travels in waves and can move through empty space where there is no air
- transmit - pass through
- reflection - bouncing back of light from a surface
- refraction - bending of light
- absorb - light is taken in

Check out this sign. The sign is upside down. So how can you can still read it? The people who made this sign used science to make it possible to read it upside down. They knew that light can reflect off of many surfaces. Even water can reflect light. Think about how this sign was made. The words are written so that their reflection can be read.

Reflection of Light



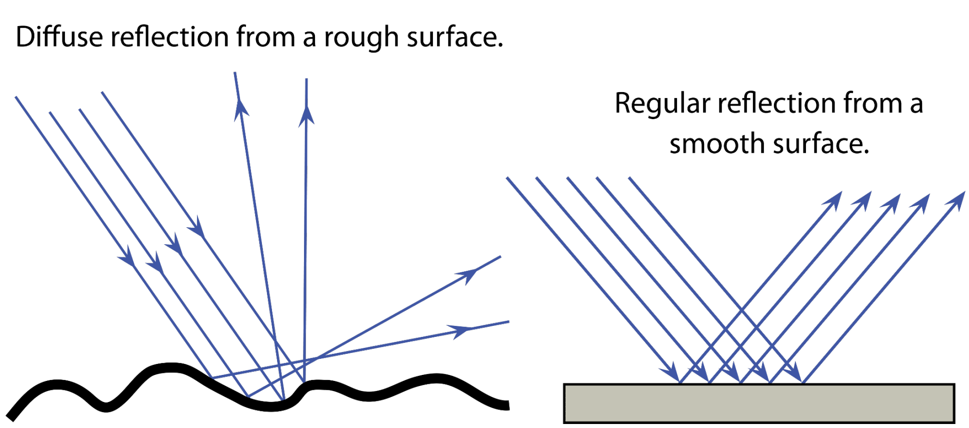
The Law of Reflection

Light rays strike a reflecting surface. They are then reflected back. You can predict the angle of the reflected light. Imagine a ball bouncing off a surface. Light can do the same thing. That is, assuming the surface is shiny. So how do you know where light will go after it strikes a shiny surface? It depends on how the light initially strikes the shiny object. Light does not always go straight toward a surface. Therefore, not all light bounces straight back. Sometimes, light can hit a surface at an angle. The angle at which it strikes the surface tells us how it will bounce off. While light is different to a ball, they react in a similar manner.

Many sports rely on knowledge of reflection. Pool players know a lot about reflection. They take great care when they strike the pool ball. They need it to go to a certain place. They know the angle it will hit the side of the pool table. Knowing this, they can predict how the ball will travel. The diagram above shows how light rays travel as they strike a surface. Incoming and outgoing light rays always react in a similar but opposite way. The angles they hit a surface are similar but opposite the angle after. This action is known as the Law of Reflection.

Reflection needs a very smooth surface to work well. When light strikes a surface that is smooth, it is called **regular reflection.** The way light rays reflect can be predicted. This also results in an image that you can see clearly.

What if the surface that light strikes is not smooth? In those cases, the reflection will be a **diffuse reflection.** The objects may not be seen clearly. Instead, they may look fuzzy or blurred.



Left and Right Reversal in a Plane Mirror

You have seen your own reflection in a mirror. The person looking back at you looks just like you. Where does that reflected person appear to be standing? Yes, they appear to be on the other side of the mirror. That is really strange to think about, but very cool. Have you ever waved at your reflection in a mirror? The reflected image will wave back at you.

Here is something to try next time you stand in front of a mirror. Wave to your reflection with your right hand. What hand do you think the reflection will wave back with? The same hand? A different hand? You will notice something interesting. The reflection waves back with the hand on the same side as you, but it is their left hand. The image in a reflection is reversed.

This is just like the image of the sign above. Light rays strike flat shiny surfaces and are reflected. The reflections are reversed. Next time you see an ambulance look at the word on the front of it? Why do you think it appears this way?

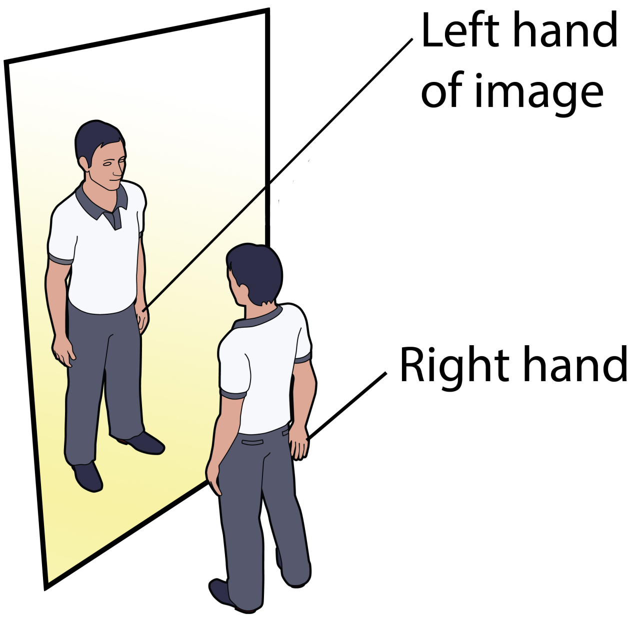


FIGURE 1.35

Lesson Summary

- The law of reflection can be used to predict how light will be reflected.
- If the reflecting surface is a very smooth surface, the reflection will be regular and the image viewed will be clear.
- If the reflecting surface is rough, the reflection will be diffuse and the image you see will be distorted.
- Images in a plane mirror are reversed left and right. They are not reversed top and bottom.

Lesson Review Questions

1. How does regular reflection differ from diffuse reflection?

Vocabulary

- **law of reflection:** The law of reflection says that the angle at which the wave is incident on the surface equals the angle at which it is reflected.
- **regular reflection:** If a parallel beams of light falls on a smooth surface, the reflected beams are also parallel.
- **diffuse reflection:** When the reflecting surface is rough, parallel incident beams of light would be reflected in non-parallel, random directions.

1.8 Refraction of Light

Learning Objectives

- Relate the speed of light to its medium.
- Describe refraction and explain when it occurs.

Lesson Objectives

- Demonstrate that light travels in a straight line until it strikes an object or travels from one medium to another.
- Demonstrate that light can be reflected, refracted, and absorbed.

Lesson Vocabulary

- light - a form of energy that travels in waves and can move through empty space where there is no air
- transmit - pass through
- reflection - bouncing back of light from a surface
- refraction - bending of light
- absorb - light is taken in

Is this a magic trick? Is this straw really broken? The answer to both questions is no. There's nothing wrong with the straw. No magic is involved, only science. This is an example of how light behaves. What you are seeing is how light reacts when it enters a new substance.

Speed of Light and Matter (Advanced Topic)

You have probably heard of the famous equation $E = mc^2$. The "E" represent the amount of energy. The "m" represents mass. The "c" represent the speed of light. Writing a "c" is much easier than writing the actual speed of light. The speed of light is a really large number.

The speed of light is about 300 million meters per second. That's really, really fast. Light always travels at the same speed through space. In outer space, there is not any matter to get in its way. Think about riding your bicycle. When you ride on a hard surface, it is easy to pedal. You can go really fast. Imagine how your speed would change if you were riding through deep sand. You would find it hard to pedal. You would not be able to go as fast. The same is true for light. When there is no matter around, like in outer space, it can go fast. When matter gets in its way, it slows down.

Light travels through some matter faster than through others. **Table** 1.3 gives the speed of light in six common materials.

TABLE 1.3: Speed of Visible Light in Various Materials

Material	Speed of Light (m/s)
Air	299 million meters per second
Water	231 million meters per second
Glass	200 million meters per second
Vegetable oil	150 million meters per second
Alcohol	140 million meters per second
Diamond	125 million meters per second

No matter how slow light travels, it still goes really, really fast. The important thing to remember is that it does travel. It is hard for us to imagine light taking time to cover a distance.

Think about when you enter your science classroom. You step through the door. You tell your teacher, "Hello." You walk to your desk and sit down. It may take around 10 to 20 seconds to walk this distance. Imagine now your teacher turns the light off. She carries a small lamp over to the door you just entered. She asks you to watch carefully as she switches on the light. She flips the switch and you immediately see the light. The light just covered the same distance you just walked. That's how fast light is. For us, it is hard to imagine that it moves.

Now let's think about light traveling between the Sun and Earth. The Sun is 93 million miles away. What if we were able to turn off the Sun for just a second? How long would it take us to notice? Would we notice instantly like in the classroom? Remember, the Sun is a long way away.

We wouldn't notice the change for a little over 8 minutes. That is because the Sun is a long way away. Even when moving as fast as light, it takes time to travel from the Sun to Earth. What do you think happens when it hits the air in our atmosphere? Air is made up of matter. When light travels through matter it slows down. How do scientists know it slows down? What evidence do scientists have?

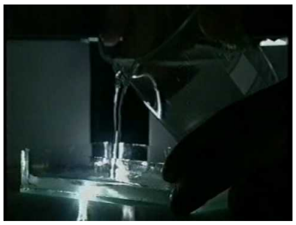
When sunlight hits Earth's atmosphere it bends just a little. If sunlight goes through water droplets it bends even more. The bending of light through droplets of water is why we can see rainbows. It also explains why the straw in a glass of water appears to be broken.

Bending Light

When light passes from one medium (or type of matter) to another, it changes speed. You can actually see this happen. If light strikes a new substance at an angle, the light appears to bend. This is what explains the straw looking broken in the picture above.

So, does light always bend as it travels into a new medium? If light travels straight into a new substance it is not bent. You may know this angle as perpendicular. The light still slows down, just does not appear to bend. Any angle other than perpendicular the light will bend as it slows down. The bending of light is called **refraction**. **Figure** 1.36 shows how refraction occurs. Notice that the angle of light changes again as it passes from the glass back to the air. In this case, the speed increases, and the ray of light resumes its initial direction.

For a more detailed explanation of refraction, watch this video:



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/177726

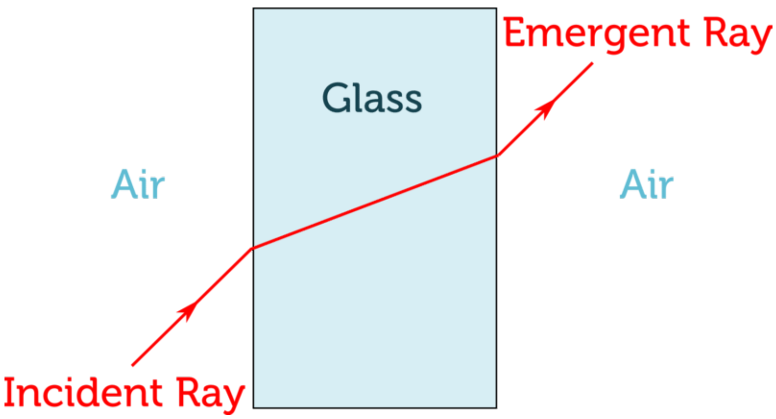


FIGURE 1.36

Lesson Summary

- Light always travels at the same speed through empty space. The speed of light is about 300 million meters per second. When light travels through matter, it travels more slowly.
- If light passes from one type of matter to another at an angle, the light changes speed and bends. This bending of light is called refraction.
- The amount at which light refracts depends on the type of matter it enters.

Lesson Review Questions

1. What is the refraction of light? When and why does it occur?
2. Draw a diagram to show how visible light refracts when it passes from air to diamond.

1.9 Static Electric Charge

Lesson Objectives

- Define electric charge and electric force. (Advanced Topic)
- Identify ways that electric charge is transferred.

Lesson Vocabulary

- electric charge
- electric force (Advanced Topic)
- static discharge
- static electricity

Introduction

You approach the door of your friend's house. What is the first thing you do before entering? Of course, you wipe your feet. You are a thoughtful visitor. Fortunately, there is a nice piece of carpet by the door to wipe your shoes. Too bad your caring comes at a price. After wiping your feet on the mat you reach out to touch the brass knocker on the door. Ouch! A spark suddenly jumps between your hand and the metal. You feel an electric shock.

Why do you think an electric shock occurs? An electric shock occurs when there is a sudden discharge of static electricity. Has this ever happened to you? You reached out to touch a metal doorknob and received an unpleasant electric shock? The reason you get a shock is because of moving electric charges. Moving electric charges also create lightning bolts. It is also the same reason electric current flows through cables and wires.

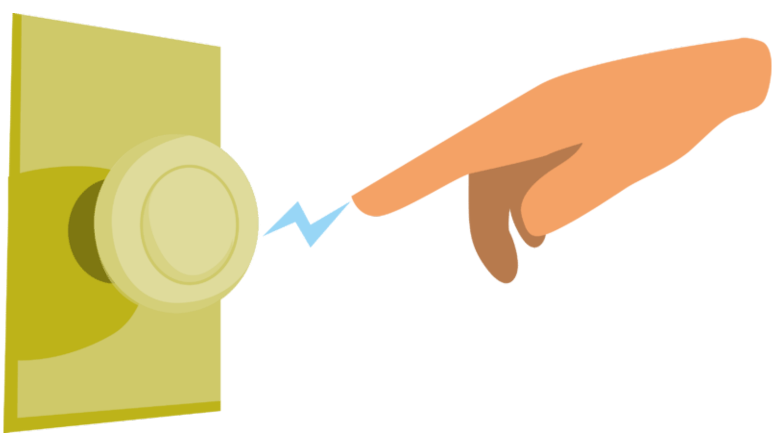


FIGURE 1.37
Moving electric charges explain why you get a shock when you touch a doorknob after walking across a carpet.

What Is Static Electricity?

You can think about static electricity like a teeter-totter. Things are fine as long as they are balanced. The same can be said about electrons. Too many or too few can be shocking! Static electricity is all about that balance.

Charges can build up through friction. Some materials freely give away electrons. Other items easily gain electrons. Have you ever rubbed your feet on a wool mat or carpet? Rubber soled shoes readily accept electrons. The wool carpet easily gives up electrons to the shoes. This combination provides for a large transfer of electrons. This buildup of electric charges is known as static electricity.

Positive charges build up on the mat and negative charges build up on you. What happens when an object becomes charged? A material is likely to remain charged until it touches another object. Sometimes it will discharge if you just come close to another object. What comes next may be shocking. "Ouch!" you say, when you get close to a metal object like a door knob. What else can happen as a result of electrical charge?

Electric Charge and Electric Force (Advanced Topic)

Electric charge is a physical property. It occurs between particles or objects. It causes them to attract or repel each other. They do not even have to touch. This is unlike the typical push or pull you may be familiar with. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge. An electron has a negative electric charge (see **Figure** below).

Forces on Charged Objects

Most atoms are balanced electrically. They have the same number of positive and negative charges. Therefore, the number of protons equals the number of electrons. Neutrons do not matter as they have no charge. When an object loses some electrons, it becomes positively charged. There are now more protons than electrons inside the atom. The lost electrons may remain free. Or, they may attach to another object. The new object now has more electrons than protons. It then becomes negatively charged.

When it comes to electric charges, opposites attract. In other words, positive and negative particles are attracted to each other. Like charges repel each other. If two positive charges are brought close to each other, they will repel. The same is true with two negative charges. They too will repel each other. What if a negative and a positive charge are brought near each other? Can you figure it out by studying **Figure** 1.38? The force of attraction or repulsion between charged particles is called **electric force**. It is illustrated in **Figure** 1.38. The strength of electric force depends on the amount of electric charge. It depends on how many extra electrons or protons there are. It also depends on the distance between the charged particles. The larger the charge, or the closer together the charges are, the greater is the electric force.

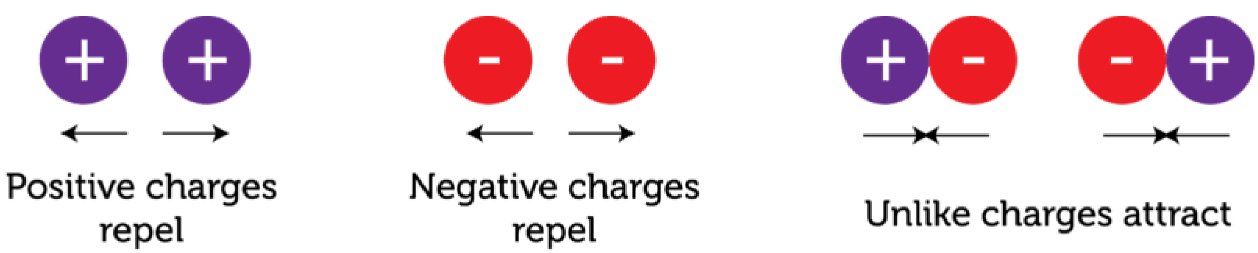


FIGURE 1.38

These diagrams illustrate the electric forces between charged particles.

FIGURE 1.39
Electrons are transferred from hair to a balloon rubbed against the hair. Then the oppositely charged hair and balloon attract each other.

Static Electricity and Static Discharge

Think back to when you wiped your feet at the front door. You were being a courteous guest. What might happen as your hand gets close to the metal doorknob? Remember that large buildup of electrons? The electrons suddenly flow from your hand to the knocker. The sudden flow of electrons is called **static discharge**. The discharge of electrons is the spark you see. It is also the shock you feel.

How Lightning Occurs

You may wonder if there are other examples of static discharge. The answer is yes. Lightning is a form of static discharge. It is much more dramatic than what happens between you and the door knocker, but it is the same principle. You can see how it occurs in the following diagram and animation.

You have no doubt seen lightning in a rainstorm. What does lighting have to do with static electricity? As it turns out, everything! During a rainstorm, clouds develop regions of different charges. This happens due to the movement of air molecules, water drops, and ice particles. The negative charges are concentrated at the base of the clouds. The positive charges are concentrated at the top. The negative charges repel electrons on the ground below. The ground then becomes positively charged. Over time the differences increase. Eventually the electrons are discharged. This is what we see as lightning.

You can watch an awesome slow-motion lightning strike below. Be sure to wait for the real-time lightning strike at the end of the video. You'll be amazed when you realize how much has occurred during that split-second.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/177793

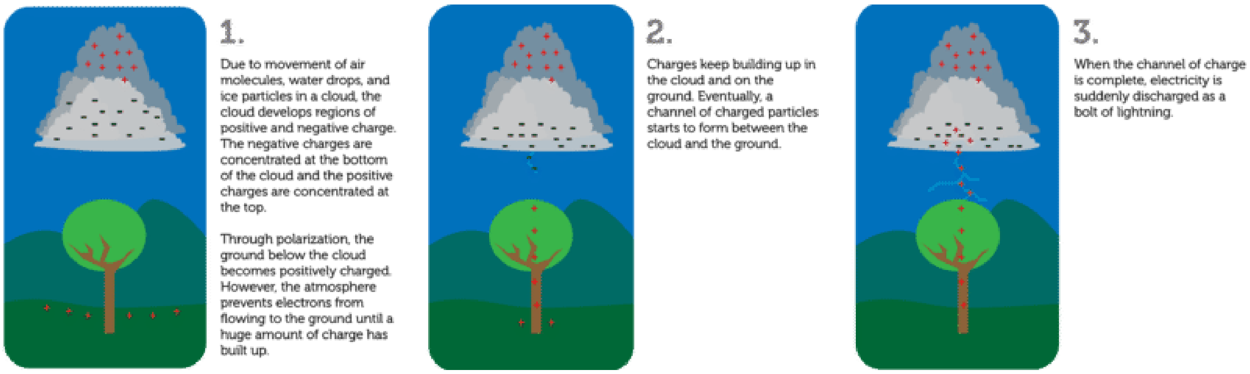


FIGURE 1.40

Lightning occurs when there is a sudden discharge of static electricity between a cloud and the ground.

Lesson Summary

- Electric charge is a physical property of particles or objects. It causes them to attract or repel each other without touching. Positive and negative particles attract each other. Particles with the same charge repel each other. The force of attraction or repulsion between charged particles is called electric force.
- A charged particle can attract or repel other, nearby particles. They do not need to be touching.
- Objects become charged when they transfer electrons. Static discharge occurs when the built-up charges suddenly flow from the object. An example of static discharge is lightning.

Lesson Review Questions

Recall

1. Define electric charge.
2. Describe the forces between charged particles.
3. Outline how lightning occurs.

Apply Concepts

4. If you rub a piece of tissue paper on a plastic comb, the paper and comb stick together. Based on lesson concepts, explain why this happens.

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.cabrillo.edu/~jmccullough/Physics/Electric_Forces_Fields.html

http://micro.magnet.fsu.edu/electromag/java/lightning/index.html

1.10 Electric Current

Lesson Objectives

- Define electric current.
- Relate electric current to materials (Insulators and Conductors).

Lesson Vocabulary

- electric conductor
- electric current
- electric insulator
- resistance
- voltage

Introduction

Have you ever felt a shock? Maybe you had just walked across the carpet and touched something metal? How is this similar to lightning? Believe it or not, they are very similar. They are both discharges of static electricity. Lightning is static electricity on a grand scale. Lightning discharges a lot of electric charge. It happens all at once. Unfortunately, this large discharge is not useful. It is so large and so fast, it cannot be controlled. You can't plug a toaster into a lightning bolt!

For most devices, a much smaller amount of electric charge is needed. It must also be steady. It can't come all in one big jolt. That's why we can't run our homes off of lightning. Our homes need to have a steady and continuous supply of electric current.

Introduction to Electric Current

Surely, you have noticed the tall poles along the roadside. Do you know what is on top of those poles? That's right, wires that carry electric current. These wires carry electric current to your home. But what is electric current?

Electric current is actually the flow of electrons. You may recall, an electron is the outer-most particle in an atom. They have a negative charge. Electricity is the continuous flow of these particles. Electrons are able to move through wires. Their speed can even be measured. The SI unit for electric current (or speed) is the ampere (A). Ampere is often shortened to amp. Electric current may flow in just one direction, or it may keep reversing direction.

- **Direct current (DC)** flows in only one direction. Direct current is what is used in devices like flashlights.
- **Alternating current (AC)** flows in two directions. This is the type of current that flows into your home through wires. When you plug something into a wall socket, it is most likely alternating current.

Electric Current and Materials (Conductors and Insulators)

Electric current cannot go through empty space. Electricity needs something to flow through. Electricity cannot flow through all materials. Some materials resist the flow of electricity. Some materials let electricity pass through easily. Scientists classify these into two groups. These groups are called conductors and insulators.

- Materials that allow electrons to flow freely are called **electric conductors**. Electricity is able to race through these materials. Copper, aluminum, and steel are good conductors.
- Materials that resist the flow of electricity are called **electric insulators**. Instead of racing, the current may travel in slow motion, if at all. Wood, rubber, and plastic are examples of electric insulators.

You probably know that electric wires are made of metal. They typically have a rubber or plastic coating. Do you know why? Metals are good electric conductors. They offer little resistance to electricity. Most of the current can pass through the wire. Rubber and plastic are good insulators. They offer a lot of resistance. They do not allow much current to pass through. Electricity always seeks the path of least resistance. That is why all the current passes only through a metal wire. It does not pass through the rubber or plastic coating. The plastic coating on the wire is there for your safety.

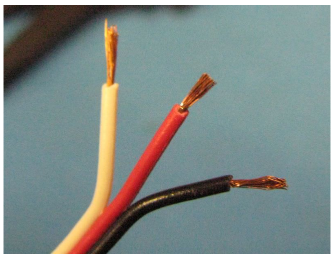


FIGURE 1.41

These electric cables are made of copper wires surrounded by a rubber coating.

Lesson Summary

- Electric current is a continuous flow of electric charge. It is measured in amperes (A).
- Direct current (DC) flows in just one direction. Alternating current (AC) keeps reversing direction.
- Electric current needs a material through which to travel. Materials differ in how much they resist electric current.
- Some materials are good conductors of electricity. Electric conductors allow electrons to flow freely.
- Some materials resist the flow of current. Electric insulators resist the flow of electrons.

Lesson Review Questions

Recall

1. What is electric current?
2. Describe the difference between conductors and insulators.
3. Compare and contrast electric conductors and electric insulators. Give an example of each.

Points to Consider

In this lesson, you learned about electric current. The next lesson, "Electric Circuits," focuses on the path that electric current travels. Think about a ceiling light with a wall switch. You probably have several in your home.

- What path does current travel to get from the switch on the wall to the light on the ceiling?
- How do you think the switch controls the flow of current to the light?

Some materials may resist the flow of current.

1.11 Electric Circuits

Lesson Objectives

- Identify the parts of an electric circuit.
- Identify electric safety features and how to use electricity safely.

Lesson Vocabulary

- electric circuit

Introduction

Look at the battery and light bulb in **Figure** 1.42. We know the light bulb works, but it won't light. Why? It's connected to a battery. What is the problem? The problem is the loose wire on the left. It must be connected to the battery. If not, the bulb will not light up. What is the reason? Electric current can flow through a material only if the material forms a closed loop. Electricity must have an unbroken path to follow.

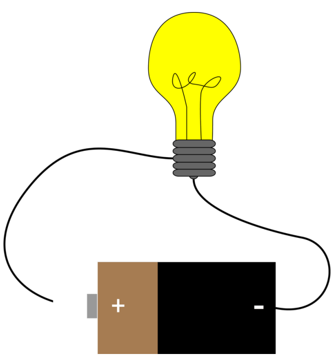


FIGURE 1.42
Electric current cannot flow through an open circuit.

Parts of an Electric Circuit

All electric circuits have at least two parts: a voltage source and a conductor.

The voltage source of the circuit in **Figure** 1.43 is a battery. You have previously learned about potential energy. In other words, something may have the potential to cause change. Voltage is the potential that causes the current to flow. It would be like the cliff the boulder is sitting on. The battery does not supply the current. Instead it supplies the potential. In a home circuit, the voltage source may be a nearby electric power plant. This local power plant may supply electricity to many homes.

The conductor in most circuits consists of one or more wires. Conductors are materials that allow the flow of electricity through them. The conductor must form a closed loop. This loop runs from the source of voltage and back again. In **Figure 1.43**, the wires are connected to both terminals of the battery. They form a closed loop. There must be a closed loop for electricity to flow.

The circuit in **Figure** 1.43 also has two other parts. There is a light bulb and a switch.

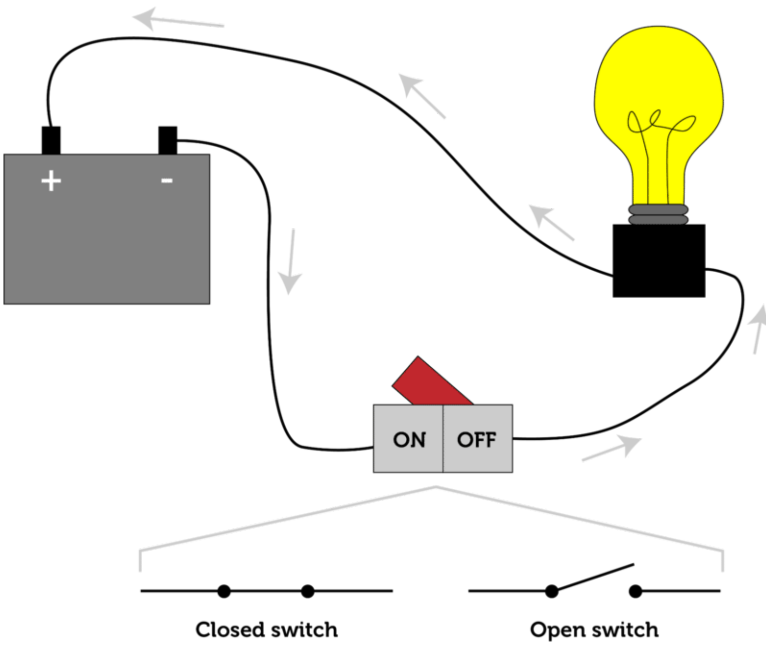


FIGURE 1.43
A circuit must be closed for electric devices such as light bulbs to work. The arrows in the diagram show the direction in which electrons flow through the circuit. The current is considered to flow in the opposite direction.

- Most circuits contain some type of device. This device converts electric energy to other forms of energy. In your home you may have a device called a light bulb. A light bulb converts electricity into light and heat. What other types of devices do you have in your home? What does it convert electricity into?
- Many circuits have switches. Switches control the flow of current through the circuit. When the switch is turned on, the circuit is closed. When the switch is closed the electricity can flow. When the switch is turned off, the circuit is open. Open circuits do not allow a current to pass through them.

Electric Safety

Electricity is dangerous. Contact with electric current can cause severe burns and even death. Electricity can also cause serious fires. A common cause of electric hazards and fires is a short circuit.

How a Short Circuit Occurs

An electric cord contains two wires. One wire carries current from the outlet to some electrical device. The other wire carries current back to the outlet. Did you ever see an old appliance with a damaged cord, like the one in **Figure** 1.44? A damaged electric cord can cause a severe shock. Damaged cords can allow current to pass from the cord to a person who touches it. A damaged cord can also cause a short circuit. A short circuit occurs when electric current follows a shorter path than is intended. For example, if the two wires in a damaged cord come into contact with each other, current flows from one wire to the other. The current will bypass the appliance and take the easiest route. This may cause the wires to overheat and start a fire.

Electric Safety Features

Electricity can be very dangerous. To reduce the risk of injury, safety features are built into electric circuits and devices. You might have noticed some of these in your home. They include three-prong plugs, circuit breakers, and GFCI outlets. Each feature is described and illustrated in **Table** 1.4.

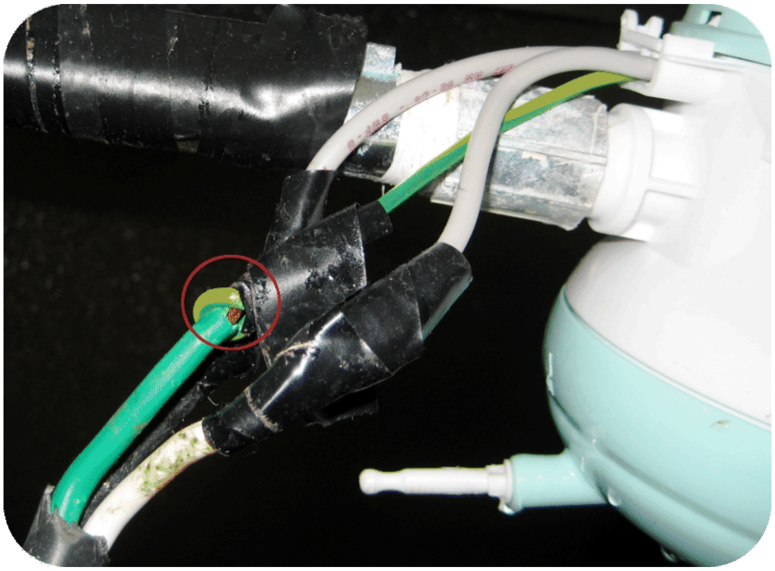
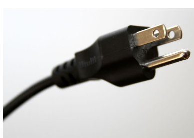
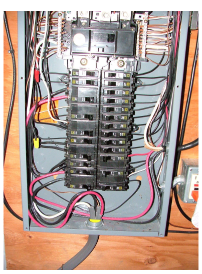


FIGURE 1.44
A damaged electric cord is a serious hazard. How can it cause an electric short?

TABLE 1.4: Can you find one or more examples of these electric safety features in your home?

Electric Safety Feature	Description
Three-Prong Plug 	A three-prong plug is generally used on metal appliances. The two flat prongs carry the current. The round prong is for safety. It connects with a wire inside the outlet. This wire connects to the ground. By redirecting the current it can pass into the ground. The ground is where it can be harmlessly absorbed.
Circuit Breaker 	A circuit breaker is another safety feature. The circuit breaker automatically opens a circuit if too much current flows through it. This could happen if too many electric devices are plugged in. It can also happen if there is an electric short. Once the problem is resolved, the circuit breaker can be switched back on. Once switched back on, the circuit is closed. Once closed, the current can once again flow. Circuit breakers are generally found in a breaker box. This box controls all the circuits in a building.
GFCI Outlet 	GFCI stands for ground-fault circuit interrupter. GFCI outlets are typically found in bathrooms and kitchens. They are used where water may pose a risk of shock. Water is a good electric conductor. A GFCI outlet contains a special device. The device monitors the amounts of current leaving and returning to the outlet. If less current is returning than leaving, this means that current is escaping. When this occurs, a tiny circuit breaker in the outlet opens the circuit. The breaker can be reset by pushing a button on the outlet cover.

MEDIA

fire.
- Never use devices with damaged cords or plugs. They can cause shocks, shorts, and fires.
- Never put anything except plugs into electric outlets. Plugging in other objects is likely to cause a serious shock that could be fatal.
- Never go near fallen electric lines. They could be carrying a lot of current. Report fallen lines to the electric company as soon as possible.

Lesson Summary

- An electric circuit is a closed loop. The closed loop allows electric current to flow through it. A circuit must include a voltage source. It also needs to have a conductor. Conductors are usually wires that carry the current. The current flows from the voltage source and back again. Circuits usually contain devices that convert electricity into other useful forms.

- Electricity is dangerous. Electric shorts can even start fires. Electric safety features include three-prong plugs, circuit breakers, and GFCI outlets. Even with electric safety features, it's important to use electricity safely.

Lesson Review Questions

Recall

1. Identify the parts of an electric circuit.
2. Identify an electric safety feature and describe how it works.
3. List three tips to reduce the risk of injury or fire from electricity.

Apply Concepts

4. Draw a simple electric circuit that includes a battery, light bulb, and switch. Use arrows to show the flow of electrons through the circuit.

Think Critically

5. Explain how a short circuit occurs.

Points to Consider

In this lesson, you read that electric devices convert electrical energy to other forms of energy. For example, a microwave oven converts electrical energy to electromagnetic energy in the form of microwaves. A blender converts electrical energy to sound energy and the kinetic energy of the whirring blades.

- Do you think all electric devices convert electrical energy to other forms of energy?
- Computers are familiar electric devices. Do you know how they use electric current?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.rkm.com.au/animations/animation-electrical-circuit.html

1.12 Speed

Lesson Objectives

- Outline how to calculate the speed of a moving object.

Lesson Vocabulary

- speed

Introduction

Did you ever play softball? You may have found it easy to hit the ball as it was tossed toward you. Well, that's only one kind of softball. Fast-pitch softball is a whole new game. The ball is not pitched slowly. Instead, it speeds in nearly as fast as a baseball.

Female athletes can throw the ball at speeds of around 120 km/h. That's about 75 mi/h. For a male athlete, the ball may travel even faster. The speed of the ball makes it hard to hit. If the ball changes course, the batter may not have time to adjust the swing to meet the ball.

FIGURE 1.45

In fast-pitch softball, the pitcher uses a "windmill" motion to throw the ball. This is a different technique than other softball pitches. It explains why the ball travels so fast.

Speed

Speed is an important aspect of motion. It is a measure of how fast or slow something moves. To determine speed you must know two things. First, you must know how far something travels. Second, you need to know how long it takes to travel that far. Speed can be calculated using this formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

A familiar example is the speed of a car. In the U.S., this is usually expressed in miles per hour (see **Figure** 1.46). Think about a trip you and your family made in the car. Maybe the trip covered 120 miles and it took 3 hours. What was the car's speed?

$$\text{speed} = \frac{120\text{ mi}}{3\text{ h}} = 40\text{ mi/h}$$

The speed of a car may also be expressed in kilometers per hour (km/h). The SI unit for speed is meters per second (m/s). This is the unit of measure a scientist would use.

FIGURE 1.46
Speed limit signs like this one warn drivers to reduce their speed on dangerous roads.

Instantaneous vs. Average Speed

When you travel by car your speed may vary. In other words, you usually don't move at a constant speed. You may go faster or slower. It may depend on the speed limits, traffic, and traffic lights. For example, you might travel 65 miles per hour on a highway. When going through a city you may only be going 20 miles per hour. You might even have to stop at traffic lights. You slow down as you turn corners. You speed up to pass other cars. It's easy to figure out the average speed, but what about your speed at any moment?

The speed you are going at any given instant is called instantaneous speed. It may vary from moment to moment, and is hard to calculate. Fortunately, we have speedometers to tell us how fast we are going in a car at any moment. You may even have a speedometer on your bike.

FIGURE 1.47
Cars race by in a blur of motion on an open highway but crawl at a snail's pace when they hit city traffic.

It's easy to figure out the average speed. The average speed is the total distance traveled divided by the total time it took to travel that distance. To calculate the average speed, you can use the general formula for speed that was given above. What if you took a 75-mile car trip with your family? Your instantaneous speed would vary throughout the trip. If the trip took a total of 1.5 hours, your average speed would be:

$$\text{average speed} = \frac{75 \text{ mi}}{1.5 \text{ h}} = 50 \text{ mi/h}$$

You Try It!

Problem: Terri rode her bike very slowly to the top of a big hill. Then she coasted back down the hill at a much faster speed. The distance from the bottom to the top of the hill is 3 kilometers. It took Terri 15 minutes to make the round trip. What was her average speed for the entire trip?

Lesson Summary

- Speed is a measure of how fast or slow something moves. It depends on the distance traveled and how long it takes to travel that distance. The average speed of an object is calculated as the change in distance divided by the change in time.

Lesson Review Questions

Recall

1. What is speed? How is it calculated?

Apply Concepts

2. Sam ran a 2000-meter race. He started at 9:00 AM and finished at 9:15 AM. He started out fast but slowed down toward the end. Calculate Sam's average speed during the race.

Think Critically

3. Explain how a distance-time graph represents speed.

Points to Consider

In this chapter, you read that the speed of a moving object equals the distance traveled divided by the time it takes to travel that distance. Speed may vary from moment to moment as an object speeds up or slows down. In the next lesson, "Acceleration," you will learn how to measure changes in speed over time.

- Do you know what a change in speed or direction is called?
- Why might measuring changes in speed or direction be important?

1.13 References

1. Angus Chan (Flickr:gusmaru). http://www.flickr.com/photos/59376848@N08/9326861459/ . CC BY 2.0
2. Flickr:MyBiggestFan. http://www.flickr.com/photos/msciba/210081711/ . CC BY 2.0
3. Hammer and nail: Robert Lopez; Jumping girl: Johan Viirok; Bees: William Warby; Boy and pinwheel: Flickr:popofatticus; Dominoes: Barry Skeates; Waterfall: Tony Hisgett. Hammer and nail: CK-12 Foundation; Jumping girl: http://www.flickr.com/photos/viirok/5287805940/; Bees: http://www.flickr.com/photos/wwarby/2990091410/; Boy and pinwheel: http://www.flickr.com/photos/barretthall/3470428667/; Dominoes: http://www.flickr.com/photos/barryskeates/6803422544/; Waterfall: http://www.flickr.com/photos/hisgett/422399097/ . Hammer and nail: CC BY-NC 3.0; Rest: CC BY 2.0
4. Flickr:unukorno. http://www.flickr.com/photos/unukorno/4089424778/ . CC BY 2.0
5. Diving: Daniel Lewis (Flickr:rattler97); Upside down girl: Flickr:DieselDemon; Skateboarder: Flickr:thefixer. Diving: http://www.flickr.com/photos/rattler97/5932298946/; Upside down girl: http://www.flickr.com/photos/28096801@N05/3647910820/; Skateboarder: http://www.flickr.com/photos/fixersphotos/3379770368/ . CC BY 2.0
6. Joy Sheng. CK-12 Foundation . CC BY-NC 3.0
7. Swing: Flickr:wsilver; Trampoline: Flickr:London looks. Swing: http://www.flickr.com/photos/psycho-pics/2722836221/; Trampoline: http://www.flickr.com/photos/londonlooks/6204272401/ . CC BY 2.0
8. Mark Hillary. http://www.flickr.com/photos/markhillary/361796692/ . CC BY 2.0
9. Guitar string photo by Flickr:jar(); illustration by Christopher Auyeung (CK-12 Foundation). Guitar string photo: http://www.flickr.com/photos/jariceiii/5343236121/ . CC BY 2.0
10. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
11. Piccolo: U.S. Navy photo by Chief Mass Communication Specialist David Rush; Tuba: Bob Fishbeck. Piccolo: http://commons.wikimedia.org/wiki/File:US_Navy_081024-N-0879R-007_A_musician_from_the_U.S._-Pacific_Fleet_Band_plays_a_piccolo.jpg ; Tuba: http://commons.wikimedia.org/wiki/File:Armen_tuba2.jpg . Public Domain
12. David Burke (Flickr:Orangedrummaboy). http://www.flickr.com/photos/cit_thmc/7219683088/ . CC BY 2.0
13. Basketball: Flickr:J R; Archery: Camp Pinewood. Basketball: http://www.flickr.com/photos/jmrosenfeld/3187299358/; Archery http://www.flickr.com/photos/camppinewood/9293493292/ . CC BY 2.0
14. Graeme Maclean (Flickr:_gee_). http://www.flickr.com/photos/gee01/153279685/ . CC BY 2.0
15. Lightning: Flickr:j_arred; Battery: Wilson Hui. Lightning: http://www.flickr.com/photos/30395273@N02/6074735344/; Battery: http://www.flickr.com/photos/wilsonhui/9572040621/ . CC BY 2.0
16. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Full_Sunburst_over_Earth.JPG . Public Domain
17. Joe Hall (Flickr:joebeone). http://www.flickr.com/photos/joebeone/2118482785/ . CC By 2.0
18. Radio tower: Mark Seymour; Microwave: Flickr:osseous; X ray: Paulo Ordoveza (Flickr:brownpau). Radio tower: http://www.flickr.com/photos/markseymour/5603632489/; Microwave: http://www.flickr.com/photos/osseous/7163044412/; X ray: http://www.flickr.com/photos/brownpau/4879544448/ . CC BY 2.0
19. Roger Blackwell. http://www.flickr.com/photos/rogerblackwell/10382353533/ . CC BY 2.0
20. Toaster: Kai Hendry ; Sun through leaves: Keith Hall; Blender: Antti T. Nissinen (Flickr:V31S70); Turbine generator: Christopher Auyeung. Toaster: http://www.flickr.com/photos/hendry/964163684/; Sun through leaves: http://www.flickr.com/photos/fire_brace/30679655/; Blender: http://www.flickr.com/photos/veisto/3422942175/; Turbine generator: CK-12 Foundation . Toaster: CC BY 2.0; Sun through leaves: CC BY 2.0; Blender: CC BY 2.0; Turbine generator: CC BY-NC 3.0
21. Courtesy of U.S. EPA and U.S. DOE. http://www.energystar.gov/index.cfm?fuseaction=globalwarming.showIdentifiers . Public Domain
22. Erik Halfacre. http://www.flickr.com/photos/erikhalfacre/8730126558/ . CC BY 2.0

23. Ice in hands: Visit Greenland (Flickr:greenland_com); Woman with iron: Maegan Tintari. Ice in hands: http://www.flickr.com/photos/ilovegreenland/6099497074/; Woman with iron: http://www.flickr.com/photos/lovemaegan/6324422379/ . CC BY 2.0
24. Insulation: Flickr:Epic Fireworks; Child in jacket: Mark Baylor; Soup: Simon Doggett. Insulation: http://www.flickr.com/photos/epicfireworks/4603519682/; Child in jacket: http://www.flickr.com/photos/baylors/5283466866/; Soup: www.flickr.com/photos/90037546@N00/3156066767/ . CC BY 2.0
25. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
26. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
27. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
28. Rob Chandler (Flickr:Rob Jules). http://commons.wikimedia.org/wiki/File:White_water_rafting,_Rangitata_Valley,_NZ.jpg . CC BY 2.0
29. Natural gas: Paul Kretek (Flickr:pa*kr); Pumping gas: futureatlas.com; Plant: Kid Cluth (Flickr:Graf Spee). Natural gas: http://www.flickr.com/photos/limemonkey/486575859/; Pumping gas: http://www.flickr.com/photos/87913776@N00/460375914/; Plant: http://www.flickr.com/photos/30901506@N06/7912828370/ . CC BY 2.0
30. Christopher Auyeung, source: EIA - Natural Gas Issues and Trends. CK-12 Foundation . CC BY-NC 3.0
31. Jon Callas. http://www.flickr.com/photos/joncallas/5586087273/. .
32. Flickr:NatureClip. http://www.flickr.com/photos/natureclip/9764092224/ .
33. Fuzzy Gerdes. http://www.flickr.com/photos/fuzzy/3772169287/ .
34. Idaho National Laboratory (INL) Bioenergy Program . http://www.flickr.com/photos/inl/7896779532/. .
35. Birgit Juel Martinsen.. http://www.flickr.com/photos/martinsen-jordenrundt/5437266214/ .
36. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
37. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
38. Subway: Metropolitan Transportation Authority of the State of New York; Light switch: wilB (Flickr:ideaablaze). Subway: http://www.flickr.com/photos/mtaphotos/8879516489/; Light switch: http://www.flickr.com/photos/ideaablaze/4932631175/ . CC BY 2.0
39. U.S. Fish and Wildlife Service Headquarters. https://www.flickr.com/photos/usfwshq/8426360101/in/photolist-dQBihH-6UB8fV-8RJ1AN-4mMCZW-cRk8A5-akPomq-4rjvuH-3B3EGX-rbksWG-9X4WSE-e3ok2a-7obLDR-5hNQmQ-dKmFLC-71Jko6-2rhYDx-bqch7h-7ofEGJ-6BGAJy-8oZpKo-5b8nWS-75aiGh-oX52HF-7DZ6FE-fAMXr6-pskKMf-4ZFSCE-cXRdv1-6JMxWP-6xAfsd-73w4JD-5AXn2c-cT689h-8Pysus-8P9kuc-5prsxZ-9WWxFi-RU2c-osyG56-61sQ-44L17-qpaccj-6GjhaJ-efdEkv-7whBaC-4RqGYD-e9sZDt-3WBGc4-QmvZ9C-FxwZ1W .
40. Ontario Power Generation. http://commons.wikimedia.org/wiki/File:Adam_Beck_Complex.jpg .
41. Flickr: foolfillment. http://www.flickr.com/photos/foolfillment/206530144/ .
42. CK-12 Foundation - Samantha Bacic. .
43. Samantha Bacic. CK-12 Foundation .
44. Samantha Bacic and Laura Guerin (CK-12 Foundation), using image copyright VolsKinvols, 2014. http://www.shutterstock.com .
45. Joy Sheng. Diagram of refraction . CC BY-NC 3.0
46. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
47. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
48. Flickr:olga.palma. http://www.flickr.com/photos/marm0ta/6981900768/ . CC BY 2.0
49. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
50. Flickr:solarbotics. http://www.flickr.com/photos/solarbotics/5414548592/ . CC BY 2.0
51. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
52. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
53. Mat Honan. http://www.flickr.com/photos/honan/2225872023/ . CC BY 2.0
54. Stuart Seeger. http://commons.wikimedia.org/wiki/File:Pitching_3.jpg . CC BY 2.0
55. User:Overpush/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:MDSHA_W13-3.svg . Public Domain
56. Left: Flickr:äquinoktium; Right: Mario Roberto Duran Ortiz (Wikimedia: Mariordo). Left: http://www

.flickr.com/photos/44080248@N03/4053247185/; Right: http://commons.wikimedia.org/wiki/File:Traffic_Congestion_Brasilia.jpg . Left: CC BY 2.0; Right: CC BY 3.0

CHAPTER 2 Physical Science: Matter

Chapter Outline

2.1 Atoms

Learning Objectives

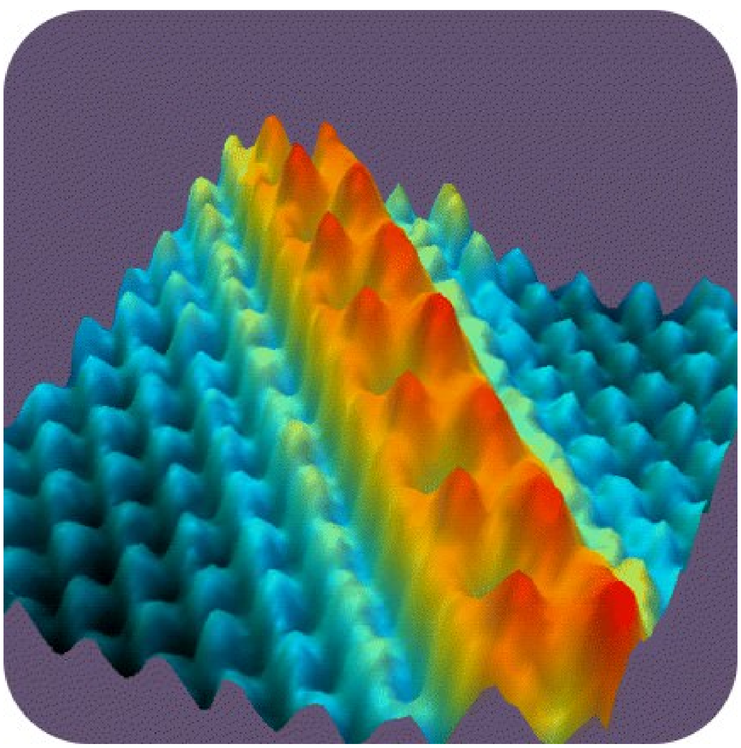
- Describe atoms and how they are related to elements.
- Identify the three main subatomic particles that make up atoms.

Lesson Objectives

- Describe atoms and how they are related to elements.
- Identify the three main subatomic particles that make up atoms.

Lesson Vocabulary

- Atom



What could this hilly surface be? Do you have any idea? The answer is row upon row of atoms. To be specific, they are nickel atoms. The picture was created using a scanning tunneling microscope. No other microscope can make images of things as small as atoms. How small are atoms?

What Are Atoms?

Atoms are the building blocks of matter. Unlike blocks that we know, these building blocks are incredibly small. In fact, they are the smallest particles of an element. Atoms still have the same properties as the elements they make up. For example, an atom of gold has the same melting point as a gold coin. If we could see it, it would have the same color. Elements are also pure substances. This means they are not mixed with anything else. Pure substances such as nickel, hydrogen, and helium make up all kinds of matter. All the atoms of a given element are identical. Atoms of different elements are not physically the same.

Think of something you might have made from LEGOs. You built some shape using the many different sized and shaped blocks. This is much like how atoms combine to become everything we know. If we took only one size and shape of block and put them together, we would make a pure substance. It would be an element. If you take apart anything that you have built, those individual parts are like the atoms. With those small parts, you build bigger things. Sometimes they are all the same type of block. Other times, they may be different kinds of blocks. We use these combinations of different blocks to make more complicated things.

Size of Atoms

Unlike LEGO bricks, atoms are extremely small. The radius of an atom is well under 1 nanometer. That's one-billionth of a meter. Such a number is hard to imagine. Consider this: trillions of atoms would fit inside the period at the end of this sentence. In other words, atoms are way too small to be seen with the naked eye.

Subatomic Particles

Although atoms are very tiny, they consist of even smaller particles. Atoms are made of protons, neutrons, and electrons:

- Protons have a positive charge.
- Electrons have a negative charge.
- Neutrons are neutral in charge.

Parts of the Atom

Figure below represents a simple model of an atom. Models help scientists make sense of things. Perhaps they are either too big or too small. Maybe they are just too complicated to make sense of. This simple model helps scientists think about the atom. Is this how the atom really looks? Not exactly! Remember, a model helps us make sense of things. They may not be an exact copy of the object. You will learn about more complex models of atoms in the coming years, but this model is a good place to start.

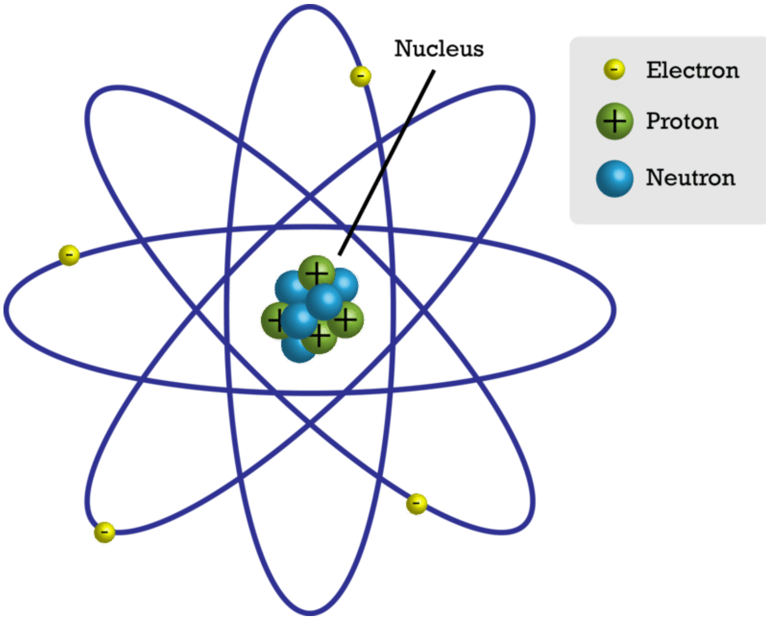


FIGURE 2.1

The Nucleus

At the center of an atom is the **nucleus** (plural, nuclei). The nucleus contains most of the atom's mass. However, in size, it's just a tiny part of the atom. The model in **Figure** above is not to scale. If an atom were the size of a football stadium, the nucleus would be only about the size of a pea.

The nucleus, in turn, consists of two types of particles, called protons and neutrons. These particles are tightly packed inside the nucleus. Constantly moving about the nucleus are other particles called electrons.

Protons

A **proton** is a particle inside the nucleus of an atom. It has a positive electric charge. All protons are identical. It is all about the number of protons in the atoms. The number of protons is what gives the atoms of different elements their unique properties. Atoms of each type of element have a characteristic number of protons. For example, each atom of carbon has six protons (see **Figure** below). No two elements have atoms with the same number of protons.

Neutrons

A **neutron** is a particle inside the nucleus of an atom. It has no electric charge. Atoms of an element often have the same number of neutrons as protons. For example, most carbon atoms have six neutrons as well as six protons. This is also shown in **Figure** below .

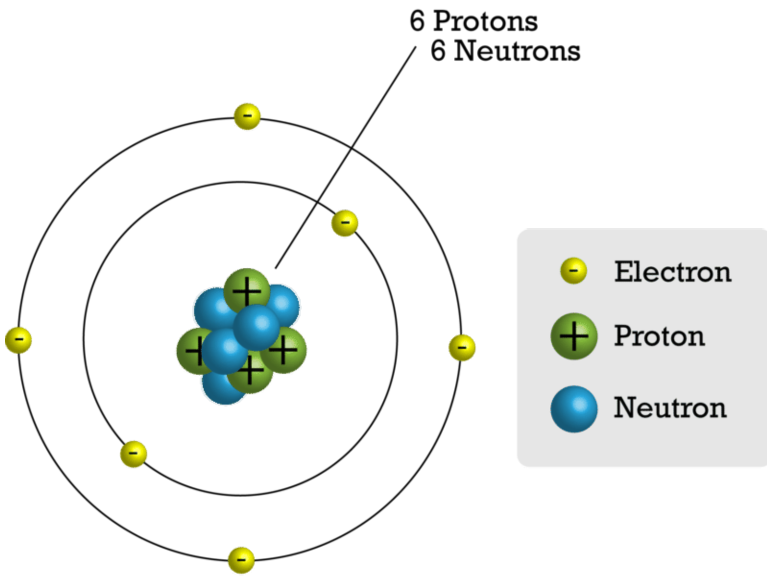


FIGURE 2.2

Electrons

An **electron** is a particle outside the nucleus of an atom. It has a negative electric charge. The charge of an electron is opposite but equal to the charge of a proton. Atoms have the same number of electrons as protons. As a result, the negative and positive charges "cancel out." This makes atoms electrically neutral. For example, a carbon atom has six electrons that "cancel out" its six protons.

Lesson Summary

- Atoms are the building blocks of matter. They are the smallest particles of an element. They still have the element's properties.
- All atoms are very small. Atoms of different elements vary in size.
- Three main types of particles that make up all atoms are protons, neutrons, and electrons.

Lesson Review Questions

1. What is an atom?
2. Which of the following statements is true about the atoms of any element:
   a. They have the same number of protons as the atoms of all other elements.
   b. They have protons that are identical to the protons of all other elements.
   c. They have the same size as the atoms of all other elements.
   d. They have the same number of protons as neutrons.

2.2 Types of Matter

Lesson Objectives

- Describe elements and atoms.
- Describe compounds, molecules, and crystals.
- Define mixture, and identify types of mixtures.

Lesson Vocabulary

- atom
- colloid
- compound
- crystal
- element
- mixture
- molecule
- solution
- suspension

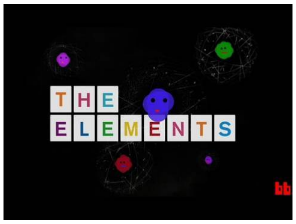
Introduction

The properties of matter depend on the types of atoms that matter is made of. Matter can exist in two forms. It can be a pure substance. This means it is not mixed with anything. It can also be a combination of different substances. This means it can be a mix of different types of atoms. You may recall that atoms differ based on the numbers of protons they contain. Some atoms contain only one proton such as Hydrogen. Other atoms contain many protons. There are many types of atoms. For example, Helium has two protons. An Oxygen atom has eight. Water is composed of a two types of atoms. Water is made of two Hydrogen atoms and one Oxygen atoms. There are only so many types of atoms. These atoms can be mixed into an almost limitless amount of substances. So what do we call a substance that has only a single type of atom?

Elements

An **element** is a pure substance. It contains only a single type of atom. Elements cannot be separated from one another. For example, water made up of hydrogen and oxygen. It can be broken apart into its elements.

There are more than 90 different elements. Some are much more common than others. Hydrogen is the most common element in the universe. Oxygen is the most common element in Earth's crust. Some elements are very rare. Gold and silver are very rare. **Figure** 2.3 shows other examples of elements. Still others are described in the video below.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5064

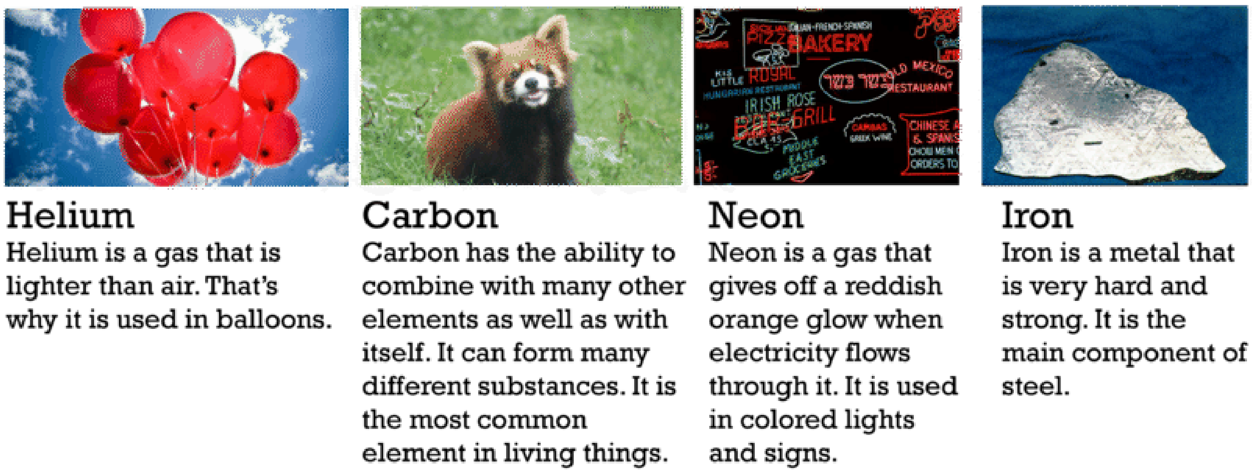


FIGURE 2.3
Each of the elements described here has different uses because of its properties.

Properties of Elements

Each element has a unique set of properties. It is this difference that makes them unique. As a result, elements can be identified by their properties. For example, the elements iron and nickel are both metals. Both are good conductors of heat and electricity. However, iron is attracted by a magnet. Nickel, another type of metal, is not. How could you use this property to separate iron from nickel?

History of Elements

The idea of elements is not new. It dates back about 2500 years. Aristotle was a famous Greek philosopher. He thought that all matter was made of just four elements. He identified the elements as earth, air, water, and fire. All matter would then be made of a mixture of these four elements.

Aristotle's ideas about elements lasted for a very long time. In fact, they lasted for 2000 years. Then, scientists started to challenge his ideas. They started to find out about what we now call elements. Scientists discovered a total of 92 naturally occurring elements.

Elements and Atoms

An **atom** is the very smallest particle that still the element's properties. All the atoms of an element are alike. They are also different from the atoms of all other elements. For example, atoms of gold are always the same. It does not matter if they are found in a gold nugget or a gold ring (see **Figure** 2.4). All gold atoms have the same structure and properties. For example, all gold atoms contain 79 protons. One of gold's unique properties is that it is a great conductor of electricity. Gold is a better conductor of electricity than copper. Gold is more rare and expensive than copper. Copper is used in house wiring. Gold is far too expensive.

FIGURE 2.4
Gold is gold no matter where it is found because all gold atoms are alike.

Compounds

There are millions of different kinds of substances. This is due to the fact that elements can combine in many ways. These many unique ways they combine are what provide us with the vast array of substances. In fact, most elements are found in compounds. A **compound** is a unique substance that forms when two or more elements combine chemically. An example is water. Water forms when hydrogen and oxygen combine chemically. A compound always has the same components in the same proportions. It also has the same composition throughout. You can learn more about compounds and how they form by watching this video.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/195

Properties of Compounds

A compound has different properties than the substances it contains. For example, hydrogen and oxygen are gases at room temperature. When they combine, the two elements form water.

Pass the salt please! A chemist would call this compound sodium chloride. It contains sodium and chlorine. Sodium is a silvery solid that reacts explosively with water. It is also a poisonous gas (see **Figure** 2.5). Together, sodium and chlorine are harmless. It also tastes great when you sprinkle it on French Fries!

FIGURE 2.5
Table salt is much different from its components. What are some of its properties?

Mixtures

Not everything you put together is a compound. Sometimes it is a mixture. A **mixture** is a combination of two or more substances. They can be in any proportion. This means the amount of each may vary. The substances in a mixture may be elements or compounds. So, what makes it a mixture and not a compound? When the substances combine, they do not form a new substance. Instead, they keep their original properties and just intermix. An example of a mixture might be sand and water. We can place them in the same container. Does anything change? The sand never becomes something else. Another well-known mixture is trail mix. Maybe you have some in your lunch bag.

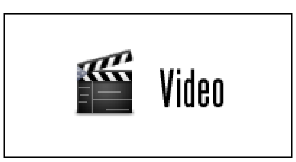
Homogeneous and Heterogeneous Mixtures (Advanced Topic)

Some mixtures are homogeneous. This means they have the same composition throughout. An example is salt water in the ocean. Ocean water is about 3.5 percent salt.

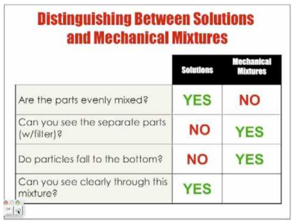
Some mixtures are heterogeneous. This means they vary in how much of each is in the mixture. An example is trail mix. No two samples of trail mix will be exactly the same. One sample might have more raisins. Another might have more nuts.

Particle Size in Mixtures (Advanced Topic)

Mixtures can have different properties. The property can depend on the size of their particles. Three types of mixtures based on particle size are described below. **Figure** 2.6 shows examples of each type.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/158741



Distinguishing Between Solutions and Mechanical Mixtures

	Solutions	Mechanical Mixtures
Are the parts evenly mixed?	YES	NO
Can you see the separate parts (w/filter)?	NO	YES
Do particles fall to the bottom?	NO	YES
Can you see clearly through this mixture?	YES	

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5066

- A **solution** is a homogeneous mixture with tiny particles. An example is salt water. The particles of a solution are too small to reflect light. As a result, you cannot see them. That's why salt water looks the same as pure water. The particles of solutions are also too small to settle or be filtered out of the mixture.
- A **suspension** is a heterogeneous mixture with large particles. An example is muddy water. The particles of a suspension are big enough to reflect light. This means you can see them. They are also big enough to settle or be filtered out. You may have seen items that say, "Shake Before Use." These items are usually a suspension. Salad dressings are a common suspension.
- A **colloid** is a homogeneous mixture with medium-sized particles. Examples include homogenized milk and gelatin. The particles of a colloid are large enough to reflect light, so you can see them. But they are too small to settle or filter out of the mixture.

FIGURE 2.6

These three mixtures differ in the size of their particles. Which mixture has the largest particles? Which has the smallest particles?

Separating Mixtures

Oh no! Your younger sister just mixed up all of your LEGO parts. Now you have to put them all back into the original categories. How can you do this? Of course, you sort them by size and shape. You can then place them back into their specific place in the tray. What do you think you could have called the mess your younger sister created? That's right, it is a mixture. Fortunately, it was a physical change and she just made a simple mixture. You are able to separate them back into order. It's a good thing she did not toss them into the fireplace. That would have caused a chemical change as they all melted together. If your LEGOs were melted, you would be out of luck for building that next big project.

Mixtures keep their own identity when they combine. Therefore, they can usually be easily separated again. Their unique physical properties are used to separate them. For example, oil is less dense than water. Therefore, a mixture of oil and water can be separated by letting it stand. During this time the oil will float to the top. Other ways of separating mixtures are shown in **Figure** 2.23 and in the videos below.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/653

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5067

FIGURE 2.7

Separating the components of a mixture depends on their physical properties. Which physical property is used in each example shown here?

Lesson Summary

- Elements are pure substances with unique properties. There are more than 100 different elements (92 of which occur naturally). The smallest particles of elements are atoms.
- Compounds are unique substances that form when two or more elements combine chemically. The smallest particles of compounds are molecules. Some compounds form crystals instead.

Lesson Review Questions

Recall

1. What is an element? Give three examples.
2. Describe compounds.
3. What are mixtures?

Apply Concepts

4. How could you use water and a coffee filter to separate a mixture of salt and sand?

Think Critically

5. Create a concept map comparing and contrasting atoms, elements, compounds and mixtures. Include an example of each.
6. How are atoms related to molecules?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.nndc.bnl.gov/content/origindc.pdf

2.3 Matter, Mass, and Volume

Learning Objectives

- Define matter.
- State what mass measures.
- State what volume measures.

Lesson Objectives

- Compare and contrast the basic properties of matter, such as mass and volume.

Lesson Vocabulary

- solid
- liquid
- gas
- mass
- volume
- physical property
- matter
- state of matter
- atom

What's the Matter?

Here is a riddle for you to ponder: What do you and a tiny speck of dust in outer space have in common? Think you know the answer?

Both you and the speck of dust consist of matter. So does the ground beneath your feet. In fact, everything you can see and touch is made of matter. The only things that are not matter are forms of energy. This would include things such as light and sound. Although forms of energy are not matter, the air and other substances they travel through are. So what is matter? Matter is defined as anything that has mass and volume. You may recall that atoms are the building blocks of matter.

Even things as small as atoms have mass and volume. The more atoms, or matter, the more mass and volume are present. Different types of atoms have different amounts of mass and volume. So, it's not enough to know the count of atoms to determine the mass. You must also know the type of atoms an item is made of. Mass and volume are just two ways to describe the physical property of a substance. Physical properties are all determined by the amounts and type of atoms that compose items.

Mass

Mass refers to the amount of matter. Mass is usually measured with a balance. A balance allows an object to be matched with other objects of known mass. The SI unit for mass is the kilogram. For smaller masses, grams are often used instead.

You may have a balance in your classroom. The balance may be either a triple-beam balance or an electronic balance. The figure below of the old-fashioned balance may give you a better idea of what mass is. What does it mean when both sides of the balance are at the same level? That's correct, it would mean the masses of each object are equal. In that case, the fruit would have a mass of 1 kg. It would have the same mass as the iron. As you can see, the fruit is at a higher level than the iron. This means the fruit has less mass than the 1 kg iron object.

Q: What If the fruit were at a lower level than the iron object?

A: The mass of the fruit would be greater than 1 kg.

Mass versus Weight

Mass is often confused with weight. The two are closely related, but they are not the same. Mass is the amount of matter. Weight is a measure of the force of gravity acting on the mass. On Earth, the force of gravity is constant. If we are comparing objects on Earth, objects with a greater mass also have a greater weight.

Weight is measured with a device called a scale. Remember, mass is measured with a balance. You might find an example of a scale in your kitchen or bathroom. Scales detect how forcefully objects are being pulled downward by gravity. The SI unit for weight is the newton (N). A mass of 10 kg has a weight of 100 newtons (N).

Problem Solving

At Earth's gravity, what is the weight in newtons of an object with a mass of 10 kg?

At Earth's gravity, 1 kg has a weight of 10 N. Therefore, 10 kg has a weight of (10 kg x 10 m/s^2) = 100 N.

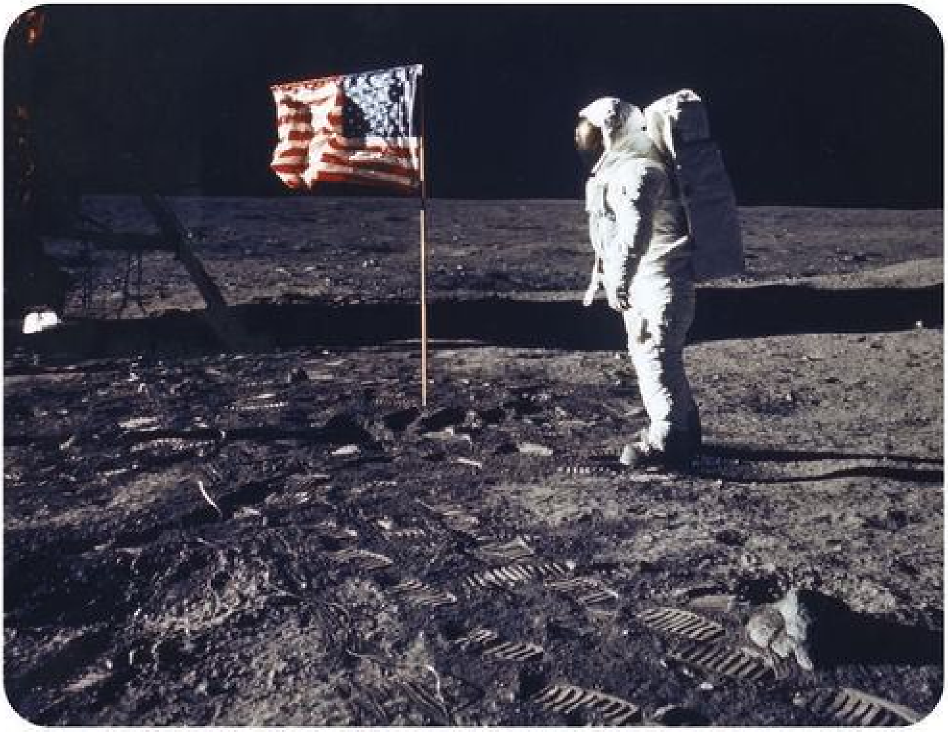
You Try It!

If you have a mass of 50 kg on Earth, what is your weight in newtons?

An object with more mass is pulled by gravity with greater force. Mass and weight are closely related. However, the weight of an object can change if the force of gravity changes. On Earth, the force of gravity is the same everywhere. So how does the force of gravity change? It doesn't if you stay on Earth. What if we travel to another planet or moon in our solar system?

Look at the photo of astronaut Edwin E. Aldrin Jr. taken by fellow astronaut Neil Armstrong in the **Figure ??**. They were the first humans to walk on the moon. An astronaut weighs less on the moon than he would on Earth. This is because the moon's gravity is weaker than Earth's. The astronaut's mass, on the other hand, did not change. He still contained the same amount of matter on the moon as he did on Earth.

If the astronaut weighed 175 pounds on Earth, he would have weighed only 29 pounds on the moon. If his mass on Earth was 80 kg, what would his mass have been on the moon? [Figure 3]



Volume

The amount of space matter takes up is its volume. How the volume of matter is measured depends on its state.

The volume of liquids is measured with measuring containers. In the kitchen, liquid volume is usually measured with measuring cups or spoons. In the lab, liquid volume is measured with containers such as graduated cylinders. Units in the metric system for liquid volume include liters (L) and milliliters (mL).

The volume of gases depends on the volume of their container. That's because gases expand to fill whatever space is available to them. For example, as you drink water from a bottle, air rushes in to take the place of the water. An "empty" liter bottle actually holds a liter of air. How could you find the volume of air in an "empty" room?

The volume of regularly shaped solids can be calculated from their dimensions. For example, the volume of a rectangular solid is the product of its length, width, and height (**l** x **w** x **h**). For solids that have irregular shapes, the displacement method is used. You can see how it works in the video below. The SI unit for solid volumes is cubic meters (m^3). However, cubic centimeters (cm^3) are often used for smaller volume measurements.

The displacement method is used to find the volume of irregularly shaped objects. It measures the amount of water that the object displaces, or moves out of the way. What is the volume of the toy dinosaur in mL? [See **Figure ??**]

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/79976

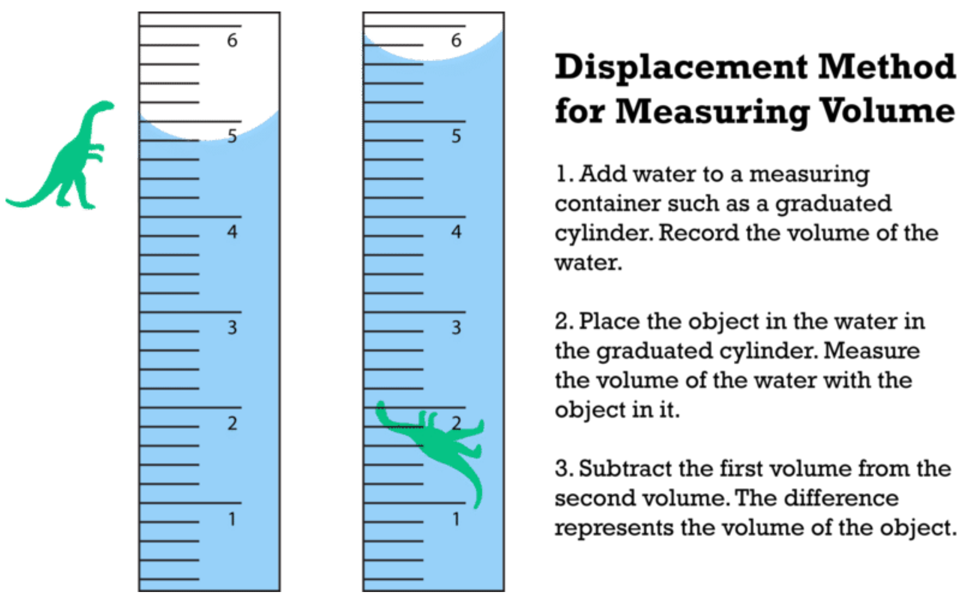
Q: How could you find the volume of air in an otherwise empty room?

A: If the room has a regular shape, you could calculate its volume from its dimensions. For example, the volume of a rectangular room can be calculated with this formula:

Volume = length $\times$ width $\times$ height

If the length of the room is 5.0 meters, the width is 3.0 meters, and the height is 2.5 meters, then the volume of the room is:

Volume = 5.0 m $\times$ 3.0 m $\times$ 2.5 m = 37.5 m^3



Q: What is the volume of the dinosaur in the diagram above?

A: The volume of the water alone is 4.8 mL. The volume of the water and dinosaur together is 5.6 mL. Therefore, the volume of the dinosaur alone is 5.6 mL - 4.8 mL = 0.8 mL.

Advanced Topic: Defining Density

Density is also an important physical property of matter. The concept of density combines what we know about an object's mass and volume. Density reflects how closely packed the particles of matter are. When particles are packed together more tightly, matter is more dense. Differences in density of matter explain many phenomena. It explains why helium balloons rise. It explains why currents such as the Gulf Stream flow through the oceans. It explains why some things float in or sink. You can see this in action by pouring vegetable oil into water. You can see a colorful demonstration in this video.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/54886

To better understand density, think about a bowling ball and volleyball, pictured in the **Figure** 2.8. Imagine lifting each ball. The two balls have about the same volume. The bowling ball feels much heavier than the volleyball, but why? It is because the bowling ball is made of solid plastic. Plastic contains a lot of tightly packed particles of matter. In contrast, the volleyball is full of a gas (air). The air atoms are further apart than in the solid bowling ball. Therefore, the matter inside the bowling ball is more dense than the matter inside the volleyball.

FIGURE 2.8

A bowling ball is denser than a volleyball. Although both balls are similar in size, the bowling ball feels much heavier than the volleyball.

Q: If you ever went bowling, you may have noticed that all the bowling balls are the same size. This means they have the same volume. Even though they are the same size, some bowling balls feel heavier than others. How can this be?

A: Bowling balls that feel lighter are made of matter that is less dense.

Calculating Density

The density of matter is actually the amount of matter in a given space. The amount of matter is measured by its mass. The space matter takes up is measured by its volume. Therefore, the density of matter can be calculated with this formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Assume, for example, that a book has a mass of 500 g and a volume of 1000 cm^3. Then the density of the book is:

$$\text{Density} = \frac{500 \text{ g}}{1000 \text{ cm}^3} = 0.5 \text{ g/cm}^3$$

Q: What is the density of a liquid that has a volume of 30 mL and a mass of 300 g?

A: The density of the liquid is:

$$\text{Density} = \frac{300 \text{ g}}{30 \text{ mL}} = 10 \text{ g/mL}$$

Lesson Summary

- Matter is all the "stuff" that exists in the universe. It has both mass and volume.
- Mass measures the amount of matter in a substance or an object. The basic SI unit for mass is the kilogram (kg).
- Volume measures the amount of space that a substance or an object takes up. The basic SI unit for volume is the cubic meter.
- Density is an important physical property of matter. It reflects how closely packed the particles of matter are.

Lesson Review Questions

1. How do scientists define matter?
2. What is mass? What is the basic SI unit of mass?
3. What does volume measure? Name two different units that might be used to measure volume.
4. Explain how to use the displacement method to find the volume of an irregularly shaped object.
5. What is density?
6. Find the density of an object that has a mass of 5 kg and a volume of 50 cm^3.
7. Create a sketch that shows the particles of matter in two substances that differ in density. Label the sketch to show which substance has greater density.
8. How does mass differ from weight?
9. Describe the displacement method for measuring the volume of an object.

Apply Concepts

10. Create a table comparing and contrasting physical properties of tap water and table salt.
11. Apply the concept of density to explain why oil floats on water.

Think Critically

12. Some kinds of matter are attracted to a magnet. Is this a physical or chemical property of matter? How do you know?

Points to Consider

- The physical and chemical properties of substances can be used to identify them. That's because different kinds of matter have different properties.
- What property could you use to tell the difference between iron and aluminum?
- How could you tell whether a liquid is honey or vinegar?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.proprofs.com/quiz-school/story.php?title=measurement-mass-volume

2.4 Solids, Liquids, and Gases

Lesson Objectives

- Describe matter in the solid state.
- State properties of liquid matter.
- Identify properties of gases.
- Explain the relationship between energy and states of matter.

Lesson Vocabulary

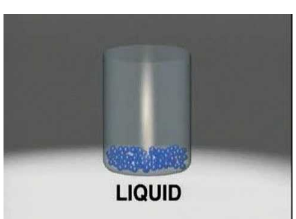
- energy
- gas
- kinetic energy
- kinetic theory of matter
- liquid
- solid
- states of matter

Introduction

Matter can be found in different forms. These different forms are called **States of Matter**. Look at **Figure** 2.9. It represents water in three states. Water can exist as a solid, like an iceberg. It can also exist as a liquid, such as the ocean. Finally, water can exist as a gas. We know this form of water as water vapor. Water vapor is completely invisible. In the figure below, you cannot see the water vapor, but it is there. The clouds you see are not water vapor. Clouds can be made of tiny droplets of liquid water. They can also contain ice crystals.

Water in all three states is still water. All three forms have the same chemical makeup. They also share the same chemical properties. That's because the state of matter is a physical property. The change in the state of water is a physical change. This means it is reversible. Water molecules can freeze into a solid and melt back to a liquid. Water molecules can change from a liquid to a gas and back again. It can pass through all of its states and it is still water.

How do solids, liquids, and gases differ? Their properties are compared in **Figure** 2.10 and described below. You can also watch videos about the three states.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/641

FIGURE 2.9
This photo represents solid, liquid, and gaseous water. Where is the gaseous water in the picture?

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5071

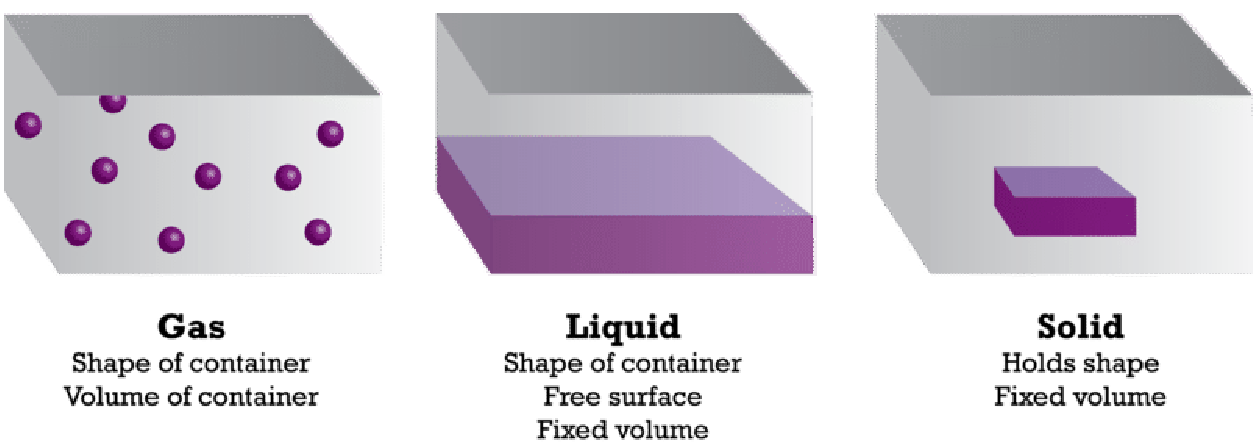


FIGURE 2.10
These three states of matter are common on Earth. What are some substances that usually exist in each of these states?

Solids

Ice is an example of a solid. A solid occurs when matter has a fixed volume and a fixed shape. The particles of solids are arranged in a regular repeating pattern. The structure of a solid is rigid. This simply means it does not change shape. Think of an ice cube. Its shape will not change unless it is melted.

FIGURE 2.11
The volume and shape of a solid can be changed, but only with outside help. How could you change the volume and shape of each of the solids in the figure without changing the solid in any other way?

Liquids

Ocean water is an example of a liquid. A liquid is matter that has a fixed volume but not a fixed shape. No matter what the shape of the container, the amount of water will stay the same. Liquids take the shape of the container they are in. We must assume the volume of a liquid is less than the volume of its container. Otherwise, it would overflow.

FIGURE 2.12
Each bottle contains the same volume of oil. How would you describe the shape of the oil in each bottle?

Gases

Water vapor is an example of a gas. A gas is matter that does not have a fixed volume or a fixed shape. Instead, a gas takes both the volume and the shape of its container. It spreads out to take up all available space. You can see an example of a gas in the **Figure** 2.13. In this case, the gas is air.

FIGURE 2.13
When you add air to a bicycle tire, you add it only through one tiny opening. But the air immediately spreads out to fill the whole tire.

Energy and Matter

Why are there different states of matter? It is because they have different amounts of energy. Energy affects the motion of particles. Atoms and molecules are the particles that make up matter. The amount of energy affects their behavior, but why?

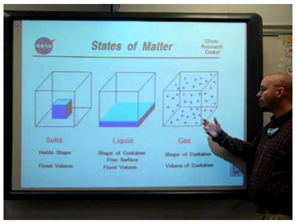
Energy

Simply put, **energy** is the ability to a cause change. Energy can cause many types of change. Think about when you have a lot of energy. You are able to do a lot of things. When you don't have a lot of energy, you may sit around and do very little. A similar thing happens to particles of matter as energy is added. The more energy there is, the faster the particles of matter move.

Energy is also the reason you are able to move around. In fact, matter is always in motion. It can even change from one form to another. For example, electrical energy can be converted into heat energy. You see this every time you use the toaster. Energy causes a change in matter when you lift your arm. Energy can be used to move matter. You use energy to take a step to move forward. Thanks to energy, your body moves. The energy of moving matter is called **kinetic energy**.

Kinetic Theory of Matter

The particles that make up matter are also constantly moving. They have kinetic energy. Scientists use **kinetic theory of matter** to explain how matter moves. You can learn more about it in the video below.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/179077

The more energy that is present, the faster matter is able to move. Particles that are moving really fast get further apart. The faster they move the more they spread apart. How do you think this happens?

Lesson Summary

- A solid is matter that has a fixed volume and a fixed shape.
- A liquid is matter that has a fixed volume but not a fixed shape.
- A gas is matter that has neither a fixed volume nor a fixed shape.
- The state of matter depends on the amount of kinetic energy.

Lesson Review Questions

Recall

1. What are states of matter?
2. What are the properties of solids?
3. State the properties of liquids.
4. Describe properties of gases.

Think Critically

5. Explain the relationship between energy and states of matter.

Points to Consider

You read in this lesson that gases expand to fill their container.

- What if gas were forced into a smaller container? Would it shrink to fit?
- What other properties of the gas might change if its particles were crowded closer together?

2.5 Physical Properties of Matter

Lesson Objectives

- Compare and contrast the basic properties of solids, liquids, and gases, such as mass, volume, color, texture, and temperature.

Lesson Vocabulary

- atom
- gas
- liquid
- mass
- matter
- physical property
- solid
- state of matter
- texture
- temperature
- volume

Introduction


Both of these people are participating in a board sport. The man on the left is snowboarding in Norway. The woman on the right is sandboarding in Dubai. Snow and sand are both kinds of matter, but they have different properties. What are some ways snow and sand differ? One difference is the temperature at which they melt. Snow melts at 0°C. In contrast, sand melts at about 1600°C! Ouch, that is really hot! That's probably why you haven't ever seen melted sand. The temperature at which something melts is its melting point. Melting point is just one of many physical properties of matter .

What Are Physical Properties?

Physical properties of matter can be measured and observed. Physical properties can be detected with your senses . For example, they may be things that you can see, hear, smell, feel, or even taste.

Q: What are some differences between snow and sand? Which senses could you use to find out the differences?

A: You can see that snow and sand have a different color . You can also feel that snow is softer than sand. Both color and hardness are physical properties of matter . You can notice that ice will melt at room temperature. Sand will remain a solid at room temperature.

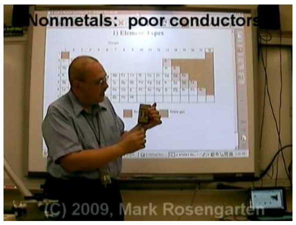
Examples of Physical Properties

Physical properties include the state of matter. We know these states as solid, liquid, or gas. Properties can also include color and odor. For example, oxygen is a gas. It is a major part of the air we breathe. It is colorless and odorless. Chlorine is also a gas. In contrast to oxygen, chlorine is greenish in color. It has a strong, sharp odor. Have you ever smelled cleaning products used around your home? If so, you have probably smelled chlorine. Another place you might smell chlorine is at a public swimming pool. The chlorine is used to kill bacteria that may grow in the water.

Other physical properties include hardness, freezing, and boiling points. Some substances have the ability to dissolve in other substances. Some substances cannot be dissolved. For example, salt easily dissolves in water. Oil does not dissolve in water. Some substances may have the ability to conduct heat or electricity. Some substances resist the flow of electricity and heat. These properties are demonstrated in **Figure** 2.14. Can you think of other physical properties?

FIGURE 2.14

The video below compares physical properties.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/179078

Lesson Summary

- Physical properties can be measured or observed. Physical properties are typically things you can detect with your senses .
- Examples of physical properties of matter include melting point, color , hardness, state of matter, odor, and boiling point.

Lesson Review Questions

1. What is a physical property of matter?
2. List three examples of physical properties.
3. Compare and contrast two physical properties of apples and oranges.

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://ga.water.usgs.gov/edu/waterproperties.html

2.6 Chemical Properties of Matter

Lesson Objectives

- Describe the chemical properties and types of changes of matter.
- Describe how to recognize and observe chemical changes of matter.
- Describe reactivity of matter.
- Describe flammability of matter.

Lesson Vocabulary

- chemical property
- reactivity
- flammability

Look at the two garden trowels pictured here. Both trowels were left outside for several weeks. One tool became rusty. The other did not. The tool that rusted is made of iron. The other tool is made of aluminum. The ability to rust is a chemical property. Iron will rust but aluminum will not.

What Are Chemical Properties?

You have already learned about the physical properties of matter. You may recall that physical properties can be measured and observed. You are able to use your senses to observe and measure them. You can easily tell if something is a certain color. You can tell what state it is in, whether solid, liquid, or gas. You can run tests to see if it conducts electricity. Also, physical changes occur without matter becoming something else. If you tear a piece of paper, each piece is still paper. Do you think this holds true for chemical properties?

Chemical properties can also be measured or observed. This is where the similarity ends. You can only see chemical properties when matter undergoes a change. This change results in an entirely different kind of matter. For example, the ability of iron to rust can only be observed after it rusts. The shiny piece of metal gives no clue to whether it will rust or not until it does. But what is rust? When iron rusts, it combines with oxygen. Iron and oxygen is new substance, called iron oxide. It is no longer just iron. It has undergone a change. It is now a different substance. Iron is very hard and silver in color. In contrast, iron oxide is flakey and reddish brown. The ability to rust is only one type of chemical property.

Reactivity

Reactivity is another type of chemical property. Reactivity is the ability of matter to combine chemically with other substances. Some kinds of matter are extremely reactive. Others kinds of matter are extremely unreactive. Have you ever mixed baking soda with vinegar in your science class? If you have, you have seen an interesting reaction. Please do not try this at home without supervision. Vinegar and baking soda both have the chemical property that causes them to react with each other. Other substances are very unreactive.

Flammability

Have you ever seen a symbol that says "Flammable"? You might see such a symbol on a gasoline can. Gasoline is highly flammable. That is why there are signs at the gas station that say, "NO SMOKING."

Flammability is the ability of matter to burn. When matter burns, it combines with oxygen. When it does, it changes to different substances. Wood is an example of flammable matter, as seen in **Figure** 2.15.

FIGURE 2.15
When wood burns, it changes to ashes, carbon dioxide, water vapor, and other gases. You can see ashes in the wood fire pictured here. The gases are invisible.

Q: How can you tell that wood ashes are a different substance than wood?

A: Ashes have different properties than wood. For example, ashes are gray and powdery. Wood is brown and hard.

Q: What are some other substances that have the property of flammability?

A: Substances called fuels have the property of flammability. They include fossil fuels such as coal, natural gas, and petroleum. For example, gasoline is used in our cars because it is flammable. This property enables car engines to run. Substances made of wood, such as paper and cardboard, are also flammable.

Lesson Summary

- Chemical properties and physical properties are properties that can be measured or observed. They can only be measured or observed when matter undergoes a change to become an entirely different kind of matter.

- Chemical properties include reactivity, flammability, and the ability to rust.
- Reactivity is the ability of matter to react chemically with other substances.
- Flammability is the ability of matter to burn.

Lesson Review

1. What is a chemical property?
2. Define the chemical property called reactivity.
3. What is flammability? Identify examples of flammable matter.

2.7 Physical and Chemical Changes in Matter

Lesson Objectives

- Define and give examples of physical changes in matter.
- Define and give examples of chemical changes in matter.
- State the law of conservation of mass.

Lesson Vocabulary

- chemical change
- law of conservation of mass
- physical change

Introduction

You hit a baseball out of the park and head for first base. You're excited. The score is now tied. Your team has a chance of getting a winning home run. Then, you hear a crash. Oh no! The baseball hit a window in a neighboring house. The glass has a big hole in it, surrounded by a web of cracks (see **Figure** 2.16). The glass has changed. It has been broken into jagged pieces. But the glass is still glass. Breaking the window is an example of a physical change in matter. It may also be bad news when the owner of the house finds out.

Physical Changes in Matter

In each of these changes, only the physical properties of matter change. The chemical properties remain the same. It didn't turn into a different type of matter. Because the type of matter remains the same with physical changes, the changes are often easy to undo. For example, braided hair can be unbraided again. Melted chocolate can be put in a fridge to re-harden. Dissolving salt in water is also a physical change. How do you think you could undo it?

FIGURE 2.16

When glass breaks, its physical properties change. Instead of one solid sheet of glass, it now has holes and cracks.

Physical Changes in Matter

A physical change in matter is a change in one or more of matter's physical properties. Glass breaking is just one example of a physical change. Some other examples are shown in **Figure** 2.17. In each example, matter may look different after the change occurs, but it's still the same. It is still the same substance with the same chemical properties. For example, smaller pieces of wood have the ability to burn just as larger logs do.

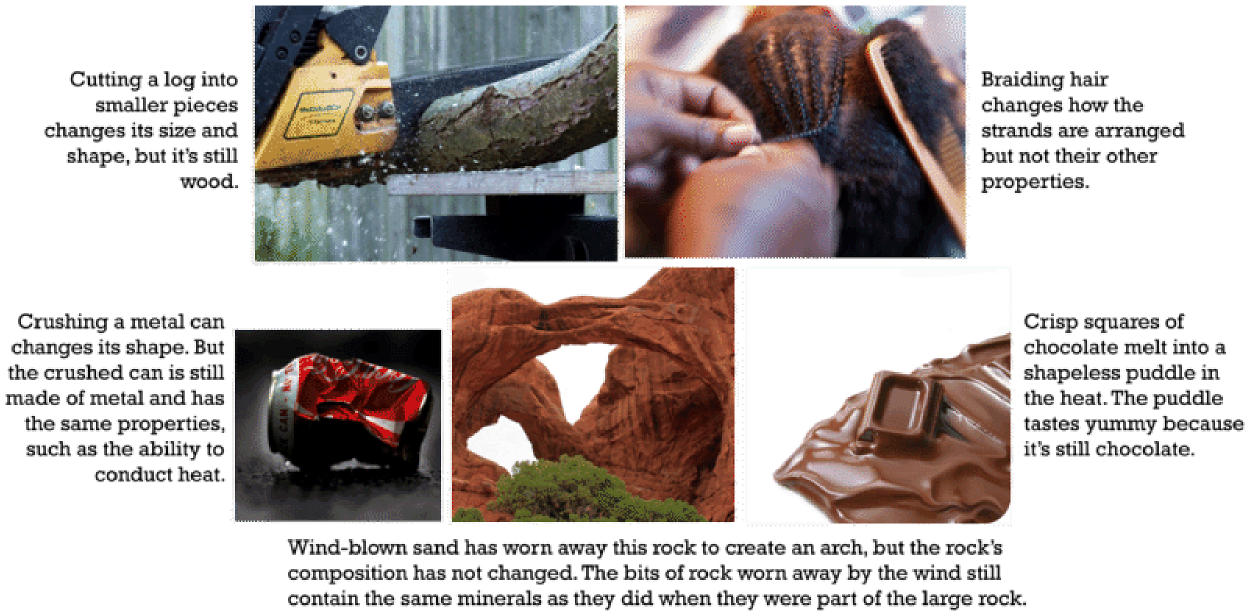


FIGURE 2.17

In each of these changes, only the physical properties of matter change. The chemical properties remain the same.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5068

Chemical Changes in Matter

Did you ever make a "volcano," like the one in **Figure** 2.18. It's easy, just mix baking soda with vinegar. What happens when they combine? They produce an eruption of foamy bubbles. This happens because of a chemical change. A chemical change occurs when matter changes into an entirely different substance. The new substance has different properties. When vinegar and baking soda combine, they form carbon dioxide. Carbon dioxide is a gas. It is this gas that causes the bubbles. It is the same gas that gives soft drinks their fizz.

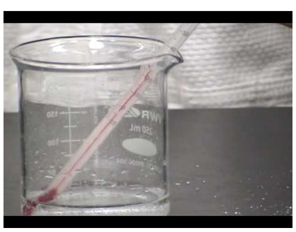
Not all chemical changes are as dramatic as this "volcano." Some are slower and less obvious. **Figure** 2.19 and the video below show other examples of chemical changes.

FIGURE 2.18
This girl is pouring vinegar on baking soda. This causes a bubbling "volcano."

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5069

Signs of Chemical Change

How can you tell whether a chemical change has occurred? Often, there are clues. Several are demonstrated in **Figures** 2.18 and 2.19 and in the video below.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5070

These chemical changes all result in the formation of new substances. These new substances have different chemical properties. Do you think any of these changes could be undone?

Signs of Chemical Change

How can you tell whether a chemical change has occurred? Often, there are clues. Several are demonstrated in Figures above.

To decide whether a chemical change has occurred, look for these signs:

- Gas bubbles are released. (Example: Baking soda and vinegar mix and produce bubbles.)
- Something changes color. (Example: Leaves turn from green to other colors.)

FIGURE 2.19

These chemical changes all result in the formation of new substances with different chemical properties. Do you think any of these changes could be undone?

- An odor is produced. (Example: Logs burn and smell smoky.)
- A solid comes out of a solution. (Example: Eggs cook and a white solid comes out of the clear liquid part of the egg.)

Reversing Chemical Changes

Chemical changes produce new substances. For this reason, they often cannot be undone. Some chemical changes can be reversed, sort of. To do so requires another chemical change to take place. For example, you can undo the tarnish on copper pennies by placing them in vinegar. The acid in the vinegar reacts with the tarnish. This is a chemical change that makes the pennies bright and shiny again. You can try this yourself at home to see how well it works. Other chemical changes cannot be reversed at all or may be difficult to do. Rusting is a chemical change. If metal rusts, the best you can do is to sand off the rust to get down to the shiny metal. Although the metal may now be shiny, the rust was removed. The rust was not changed back into the original metal.

Some chemical reactions occur in only one direction. These reactions are called irreversible reactions. For example, you cannot change a fried egg back into a raw egg. Can you think of some other irreversible reactions related to cooking? Would you like a piece of cake? To make a cake you mix items such as such as eggs and flour. They are mixed together and baked to form the cake. The cake can't be "unbaked" and "unmixed." So making a cake is irreversible change. Therefore, baking is a form of chemical change.

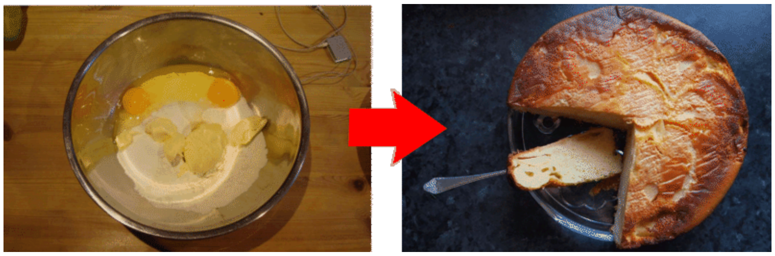


FIGURE 2.20

How Temperature Affects Changes in Matter

Have you are burned something on the stove or in the oven? Do you know why things burn? It all has to do with temperature. Changes in matter are affected by temperature. For example, what if you place a cake in the oven and you leave it in too long? What do you think will happen? That's right, it will probably burn. The same thing will happen if the oven setting is too high and you apply too much heat. In either case, heat has affected the rate of change in matter. It's probably obvious that when the temperature is increased a chemical change, like cooking, will occur faster. What about a physical change? Are physical changes affected by temperature?

Most of us have seen steam rising off a wet road after a summer rainstorm. This happens because the road surface is very warm. The warm road and warm air temperature causes the water to evaporate quickly. The liquid water is turning into water vapor, but it is still water. The evaporation of water is a physical change. So yes, temperature affects the rate that physical change occurs.

Are there other examples you can think of? What about how fast something melts? Have you ever left a candy bar outside in the sun? Just like how temperature increases the rate a substance dissolves, temperature affects the rate of change in many other ways. As temperature increases, changes in matter happen more quickly. For example, do you think an ice cube will melt faster in warm temperatures? Of course they will, which is why we keep ice in the freezer. If not, they would melt and eventually evaporate. When temperatures are lower, change happens more slowly. Think about your refrigerator. What happens if you leave the door open? Items in the refrigerator may thaw, but they may also spoil more quickly.

We use refrigerators to slow down the natural rate of change in the foods we eat. Food left out can spoil quickly. That is why it is really important to keep foods cool. The next time your mother tells you to close the refrigerator door, don't just do it because she told you so. Do it because you know a lot about physics and rates of change of matter.

Conservation of Mass

If you build a campfire, you start with a large stack of sticks and logs. As the fire burns, the stack slowly shrinks. By the end of the evening, all that is left is a small pile of ashes. What happened to the matter that you started with? Was it destroyed by the flames? It may seem that way. What do you think happened? The truth is that the same amount of matter still exists. The wood changed not only to ashes, but also to carbon dioxide, water vapor, and other gases. The gases floated off into the air, leaving behind just the ashes. Although matter was changed, it was not created or destroyed. Because the same amount of matter still exists, we can say that matter is conserved. You may wonder how it can be conserved if something is now missing?

Assume you had measured the mass of the wood before you burned it. Assume you had also trapped the gases released by the burning wood and measured their mass and the mass of the ashes. What would you find? The ashes and gases combined have the same mass as the wood you started with.

This example illustrates the **law of conservation of mass.** The law states that matter cannot be created or destroyed. Even when matter goes through physical or chemical changes, the total mass of matter always remains the same.

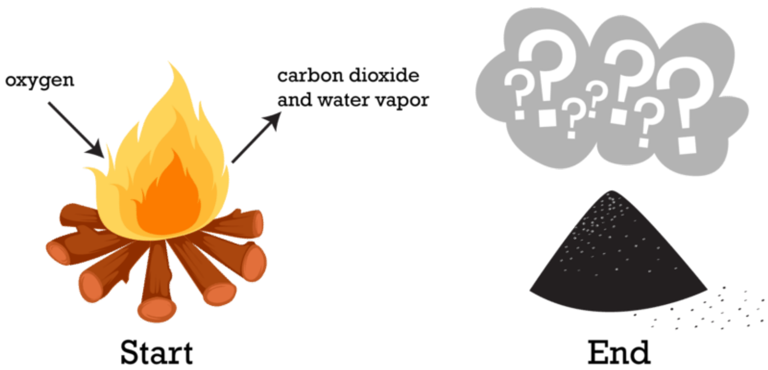


FIGURE 2.21
Burning is a chemical process. Is mass destroyed when wood burns?

Lesson Summary

- Physical changes are changes in the physical properties of matter. They do not affect the makeup of matter. An example of a physical change is glass breaking.
- Chemical changes are changes in the makeup and chemical properties of matter. An example of a chemical change is wood burning.
- Matter cannot be created or destroyed even when it changes. This is the law of conservation of mass.

Lesson Review Questions

Recall

1. What is a physical change in matter?
2. What happens during a chemical change in matter?
3. State the law of conservation of mass.

Apply Concepts

4. When a plant grows, its mass increases over time. Does this mean that new matter is created? Why or why not?
5. Butter melts when you heat it in a pan on the stove. Is this a chemical change or a physical change? How can you tell?
6. Is popping popcorn a physical or chemical change? How can you tell?

Think Critically

6. Compare and contrast physical and chemical changes in matter. Give an example of each type of change.

Points to Consider

Some physical changes in matter are changes of state.

- What are the states of matter?
- What might cause matter to change state?

2.8 Rate of Dissolving

Learning Objectives

- Identify factors that affect the rate of dissolving.

Lesson Objective

- Identify the conditions that will speed up or slow down the dissolving process.

Lesson Vocabulary

- dissolve
- mixture
- solution

Introduction

Do you prefer your iced tea sweetened with sugar? Sweetened iced tea is a solution. The solid sugar (the solute) is dissolved in cold liquid tea. The liquid tea is mostly water (the solvent). What do you think happens when you add sugar to tea? Particles of water pull apart particles of sugar. The particles of sugar spread throughout the tea. This is what makes the tea taste so good.

Factors That Affect the Rate of Dissolving

Did you ever drink the tea before all the sugar has dissolved? Did you ever notice that some of the sugar is sitting at the bottom of the glass?

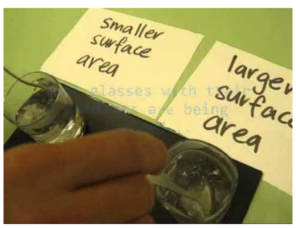
Q: What could you do to dissolve the sugar faster?

A: The rate of dissolving is caused by several factors. These factors include stirring, temperature, and the size of the particles.

MEDIA

Click image to the left or use the URL below.

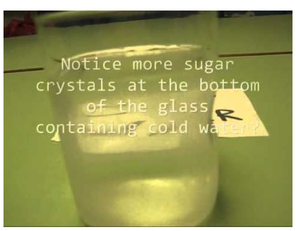
URL: http://www.ck12.org/flx/render/embeddedobject/5004



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5005



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5006

Stirring

What would happen if you added sugar to iced tea and did not stir the liquid? That's right, most of the sugar you added would fall to the bottom of the glass. Like most people, when you add sugar to a liquid, you stir it, but why? For most of us, it is automatic. How many times have you added something to a liquid and immediately grabbed our spoon and started to stir. Have you ever thought about why we stir? So, why do we stir liquids when we add other ingredients?

Stirring a liquid while you are mixing in another ingredient speeds up the rate of dissolving. This is because it helps distribute the particles that are being dissolved. What happens when you add sugar (the solute) to iced tea (the solvent) and then stir the tea? The obvious answer is that the sugar will dissolve. The more quickly you stir, the faster the sugar will dissolve. What if you don't stir the tea? Will the sugar still dissolve? It may eventually dissolve, but it will take much longer. You can think of stirring like adding energy to the process. What are other ways to add energy?

Temperature

What do you think will happen when you add the same amount of sugar to cups of hot and cold tea? Will the sugar dissolve at the same rate? Is that why people start with warm water when they make iced tea?

The temperature of the solvent is an important factor in how fast something dissolves. Temperature affects how fast a solute dissolves. Generally, a solute dissolves faster in a warmer solvent. It dissolves more slowly in a cooler solvent. Think about that next time you make iced tea.

Particle Size

There is another factor that affects the rate of dissolving. The particle size of solute particles affects the rate. Smaller particles have greater surface area. Think of a large block of Legos. When all the blocks are stuck together you can measure their surface area. Now take all the blocks apart and measure their individual surface areas. Which has more? Greater surface area provides more contact between the particles and the solvent. For example, if you put granulated sugar in a glass of iced tea, it will dissolve more quickly. If you put a sugar cube in a glass of iced tea, it will dissolve more slowly. That's because all those tiny particles of granulated sugar have greater surface area than a single sugar cube.

FIGURE 2.22

Lesson Summary

- The rate of dissolving of a solute in a solvent is faster when the solute and solvent are stirred.
- The rate of dissolving is affected if the solute consists of smaller particles with more surface area.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5006

Lesson Review

1. List three factors that affect the rate at which a solute dissolves in a solvent.
2. Gina is trying to dissolve bath salts in her bathwater. How could she speed up the rate of dissolving?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.youtube.com/watch?v=TO42FOay7rg

2.9 Separating Mixtures

Lesson Objective

- Explain that mixtures of solids can be separated based on observable properties of their parts such as particle size, shape, color, and magnetic attraction.

Lesson Vocabulary

- dissolve
- mixture
- solution

Introduction

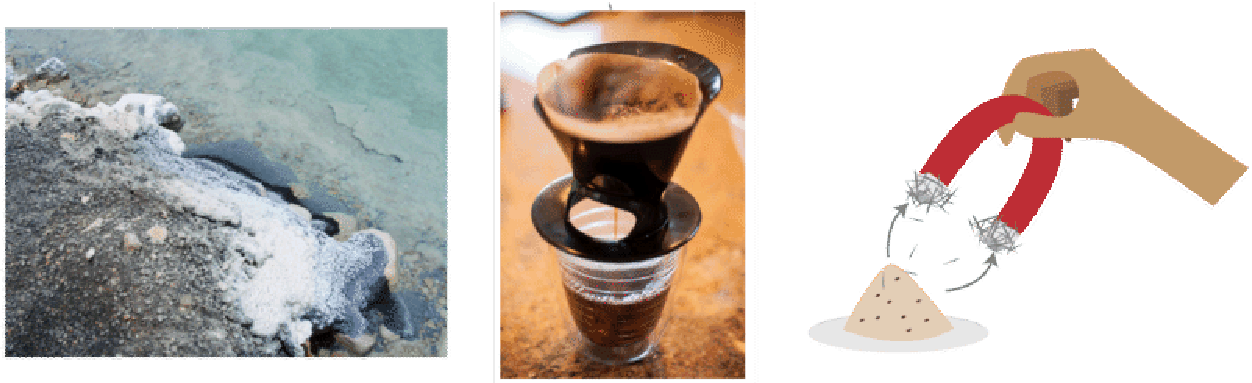
Oh no! Your younger sister just mixed up all of your LEGO parts. Now you have to put them all back into the original categories. How will you do this? You sort them by size and shape until they are each back into their specific place in the tray. What do you think you could have called the mess your younger sister created? That's right, it is a mixture. Fortunately, it was a physical change and she just made a simple mixture. You are able to separate them back into order. It's a good thing she did not toss them into the fireplace. That would have caused a chemical change as they all melted together. If your LEGOs were melted, you would be out of luck for building that next big project.

Mixtures

Mixtures keep their own identity when they combine. Therefore, they can usually be easily separated again. Their unique physical properties are used to separate them. For example, oil is less dense than water. Therefore, a mixture of oil and water can be separated by letting it stand. During this time the oil will float to the top. Other ways of separating mixtures are shown in **Figure** 2.23 and in the videos below.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/653

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5067



The sun heats salt water in this lake. This causes some of the water to evaporate, leaving the salt behind.

A coffee filter lets water but not coffee grounds pass through into the pot below.

A magnet can be used to separate iron filings from sand. Can you explain why?

FIGURE 2.23

Separating the components of a mixture depends on their physical properties. Which physical property is used in each example shown here?

Lesson Summary

- Mixtures keep their own identity when they combine.
- Mixtures can usually be easily separated again.
- A mixture's unique physical properties are used to separate them.

Lesson Review Questions

1. How could you use water and a coffee filter to separate a mixture of salt and sand?
2. What are some ways you could separate mixtures?

2.10 Magnets and Magnetism

Lesson Objectives

- Identify properties of magnets.
- Explain why some materials are magnetic.

Lesson Vocabulary

- magnet
- magnetic field
- magnetic force
- magnetic pole
- magnetism

Introduction

Take a look at this futuristic-looking train in **Figure** 2.24. Sure, it looks cool, but do you notice anything else? That's right! Unlike a typical train, this train has no wheels. How can it have no wheels you may wonder? It doesn't need wheels because it levitates, or floats, just above the track using magnets. This is not a normal train, it is a maglev train. The word "maglev" stands for "magnetic levitation." Because it doesn't have wheels that touch the track, it has no friction. Other magnets pull the train forward along the track. This train can go very fast. It can fly over the countryside. It can reach speeds to 480 kilometers (300 miles) per hour! What are magnets and how do they exert such force? In this lesson, you'll find out.

FIGURE 2.24
Magnets cause this maglev train to speed along its track.

Properties of Magnets

A **magnet** is an object that attracts certain materials. You're probably familiar with common bar magnets. You can see one in **Figure** 2.25. Like all magnets, this bar magnet has north and south poles. Magnets attract objects such as paper clips that contain iron. Iron is one type of metal that magnets attract. Magnets do not attract every type of metal. Magnets only attract iron, nickel, and cobalt. They do not attract metals like aluminum or copper. You can test this out yourself with a simple magnet.

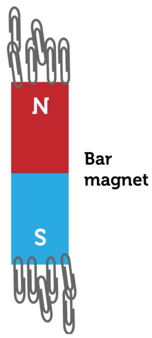


FIGURE 2.25
The north and south poles of a bar magnet attract paper clips.

Magnetic Poles

All magnets have two **magnetic poles**. The poles are regions where the magnet is strongest. The poles are called north and south. They have these names because they always line up with Earth's north-south axis. The Earth rotates, or spins, around this imaginary line, or axis. What do you suppose would happen if you cut the bar magnet in **Figure** 2.25 in half along the line between the north and south poles? Both halves would also have north and south poles. What if you cut each of them in half again? That's right! All of those pieces would have north and south poles as well. Pieces of a magnet always have both north and south poles.

Magnetic Force

Magnets are able to place a force on certain materials. This force is called a **magnetic force**. The force a magnet exerts is a little different from the forces you may normally think about. You exert a force on a book when you lift it. You also exert a force on the pedals of your bicycle. In both those cases, those forces cause a change. The change you see in both these cases is called motion. Magnets, too, can produce change. They can produce motion just like you do. Unlike you, magnets do not have to touch something to exert a force. A magnetic force is exerted over a distance. That's right, a magnet can push or pull certain items without ever touching them. That's how the maglev train works.

Do you know another type of force that does not require objects to touch? These forces are known as non-contact forces. Another type of non-contact force you may be familiar with is gravity. Gravity too can cause changes in motion. Gravity holds our moon in orbit without touching it. So how do these forces play a role in magnets?

Think about what happens when you place two magnets next to each other. Depending on how you align the poles, different motions occur. The forces the two magnets exert on each other are either an attractive or a repulsive force. North and south poles of two magnets attract each other, while two north poles or two south poles repel each other. So, where does this force come from?

Magnetic Field

Magnets have what is called a **magnetic field.** This invisible field surrounds a magnet. This is the area where a magnetic force is exerted. **Figure** 2.26 shows the magnetic field around a bar magnet. Tiny bits of iron, or iron filings, are used to help see the field. These iron filings are then placed under a sheet of glass. When the magnet is placed on the glass, it attracts the iron filings. The pattern of the iron filings shows the lines of force. These lines of force outline the magnetic field. Notice the amount of iron filings around the poles of the agent. The concentration near the poles indicates that these areas exert the strongest force.

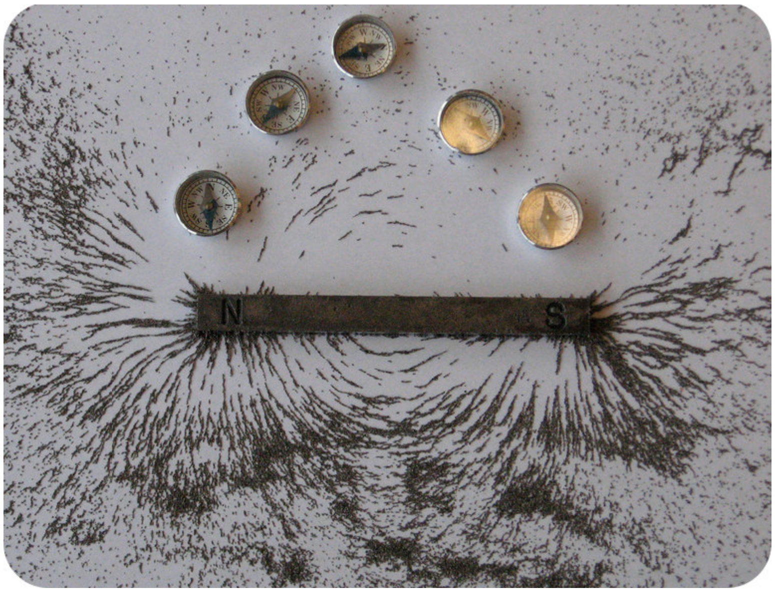


FIGURE 2.26
Lines of magnetic force are revealed by the iron filings attracted to this magnet.

What do you think happens when two magnets are brought near each other? What happens to their magnetic fields? Interestingly, their magnetic fields interact. You can see how in **Figure** 2.27. The drawings show the lines of force. You can see how the north and south poles attract. When like kind poles are near each other they repel each other.

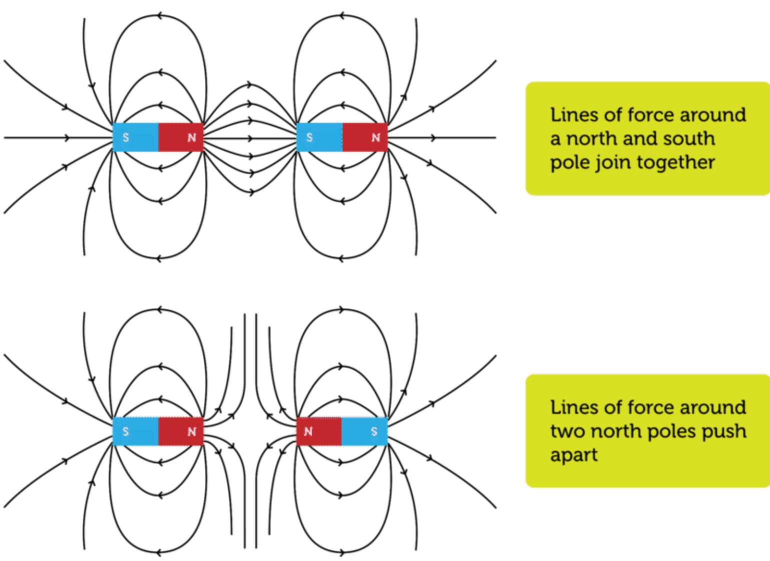


FIGURE 2.27
When it come to magnets, there is a force of attraction between opposite poles and a force of repulsion between like poles.

Magnetism and Materials

Magnetism is the ability of a material to be attracted by a magnet. It also include the ability for some material to act like a magnet. No doubt you've handled refrigerator magnets. You can see some in **Figure** 2.28. You probably know they stick to a metal refrigerator. This is what holds your homework up. Maybe your little sister's drawings are hung on the fridge in this manner. Do magnets stick to all materials? Of course not. You have probably checked and they do not stick to other surfaces. They do not stick to wooden doors or glass windows. Wood and glass are not attracted to a magnet. Obviously, only certain materials are attracted to magnets.

FIGURE 2.28
Refrigerator magnets stick to a refrigerator door because it contains iron. Why won't the magnets stick to wooden cabinet doors?

Temporary and Permanent Magnets (Advanced Topic)

Materials that have been magnetized may become temporary or permanent magnets. An example of each type of magnet is described below. Both are demonstrated in **Figure** 2.29.

- If you bring a bar magnet close to pile of paper clips, the paper clips will become temporarily magnetized. As a result, the paper clips will stick to the magnet. They will also stick to each other. What if you are no longer touching the magnet to the paperclips? Will the paperclips still stick together? Once the magnet is removed the paper clips will no longer be magnetized or stick together.
- Try something really cool. Do you think you can make a magnet? If you stroke an iron nail with a bar magnet, the nail will become a permanent (or at least long-lasting) magnet.

Some materials are natural magnets. One of the most common is called magnetite. Magnetite is a mineral found in the earth. Magnetite is sometimes called lodestone. **Figure** 2.30 shows a chunk of magnetite. It is able to attract iron nails and iron filings. People have known about magnetite for thousands of years. The earliest compasses used magnetite. Their magnetic pointers showed direction. The magnetite spoon compass in **Figure** 2.30 dates back about 2000 years.

Lesson Summary

- A magnet is an object that attracts certain materials such as iron. All magnets have two magnetic poles. Magnets have a magnetic field. It is this magnetic field that exerts a force on some materials. Opposite magnetic poles attract each other. Unlike poles repel each other.

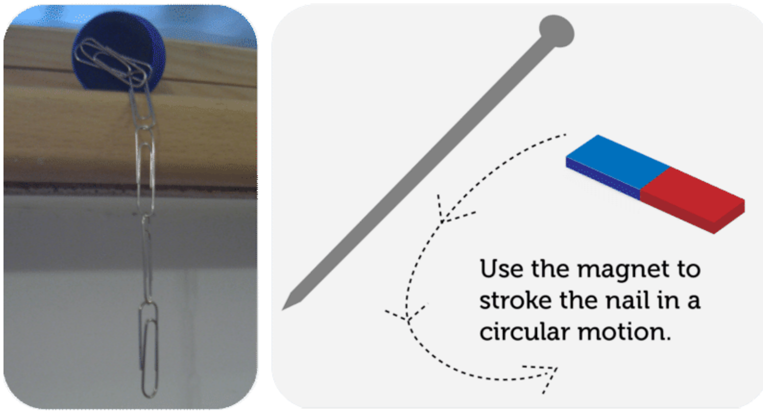


FIGURE 2.29
Paper clips become temporary magnets when placed in a magnetic field. An iron nail becomes a permanent magnet when stroked with a bar magnet.

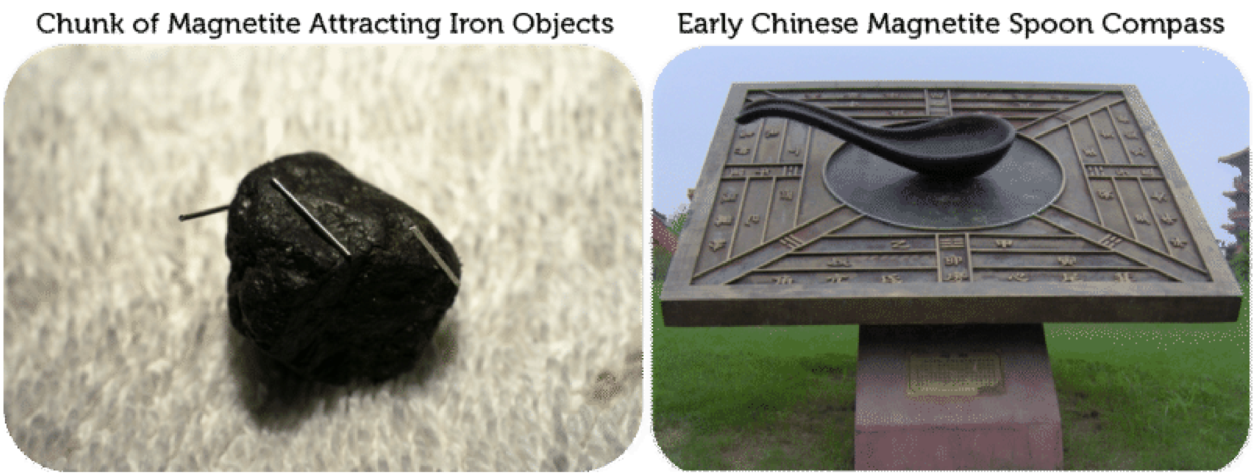


FIGURE 2.30
Magnetite naturally attracts iron nails and filings. Its natural magnetism was discovered thousands of years ago.

- Magnetism is the ability to be attracted by a magnet. Only some metals are attracted to magnets. These metals include: iron, cobalt, and nickel. When these materials are magnetized, they become temporary or permanent magnets. Magnetite is a natural permanent magnet.

Lesson Review Questions

Recall

1. What is a magnet?
2. Define magnetic force.
3. Give examples of objects that are attracted by magnets.
4. Identify ferromagnetic materials.

Apply Concepts

5. Draw magnetic field lines around the bar two magnets pictured below.

Points to Consider

The northern lights that you saw in the opening photo of this chapter are caused by Earth's magnetic field. You will read about Earth's magnetic field in the next lesson, "Earth as a Magnet."

- If you could see Earth's magnetic field, what do you think it would look like? (*Hint:* Look at **Figure** 2.26.)
- After reading this lesson, can you predict why northern lights are most likely to be visible near Earth's poles?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.coolmagnetman.com/magmotion.htm

2.11 Earth as a Magnet

Lesson Objectives

- Describe Earth as a magnet.
- State how Earth's magnetism benefits living things.

Lesson Vocabulary

- magnetosphere
- magnetic field
- magnet
- magnetic poles
- compass

Introduction

Did you ever use a compass? Maybe you were out hiking? Maybe you have seen one on a car's dashboard. Did it look like the one in **Figure** 2.31? Did you notice how it always moves? It moves as you go around corners. Do you know why? It spins around because it must always point north. It moves because the Earth is a giant magnet. In this lesson, you'll learn why. You will also learn how Earth's magnetism helps all living things.

FIGURE 2.31
A compass pointer is aligned by Earth's magnetism to point north.

Magnet Earth

Think about a huge bar magnet. Now imagine it running through the Earth. One end enters the south pole. The other end sticks out the north pole of the earth. You can see an example in **Figure** 2.32. This is a good model for Earth as a magnet. Like a bar magnet, Earth has north and south poles. Like all magnets it also has a magnetic field.

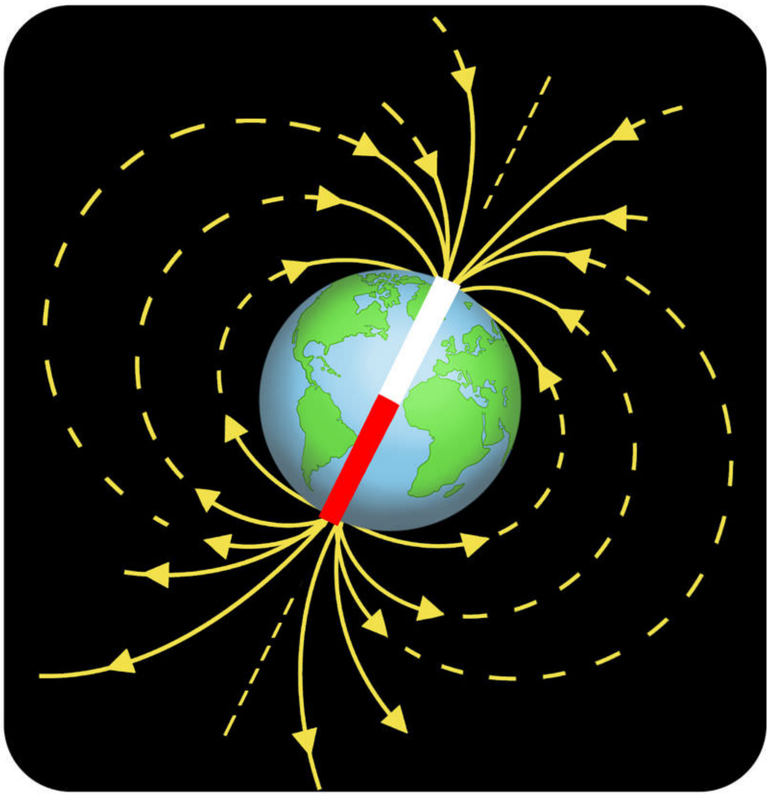


FIGURE 2.32
Earth is like a giant bar magnet.

Earth's Magnetic Poles

It is true that a compass needle always points north. That does not mean it points exactly north. Earth's geographic north pole is not the same as its magnetic north pole. Those two locations are fairly close. That does not mean they are the same place. Earth's magnetic south pole is also not the same as its geographic south pole.

A compass pointer has north and south poles. A magnet's north pole points to Earth's magnetic north pole. How can this happen. Aren't like poles supposed to repel? Shouldn't the north pole of the compass be pointing to the south pole of the Earth? The answer may surprise you. Earth's magnetic north pole is actually the south pole of magnet Earth! It's called the magnetic north pole to avoid confusion. Because it's close to the geographic north pole, it would be confusing to call it the magnetic south pole.

Earth's Magnetic Field

Like all magnets, Earth has a magnetic field. Earth's magnetic field is called the **magnetosphere**. It is a huge region that extends outward into space. It stretches from the surface to several thousand kilometers into the sky. It is strongest at the poles. You can see the extent of the magnetosphere in **Figure** 2.34.

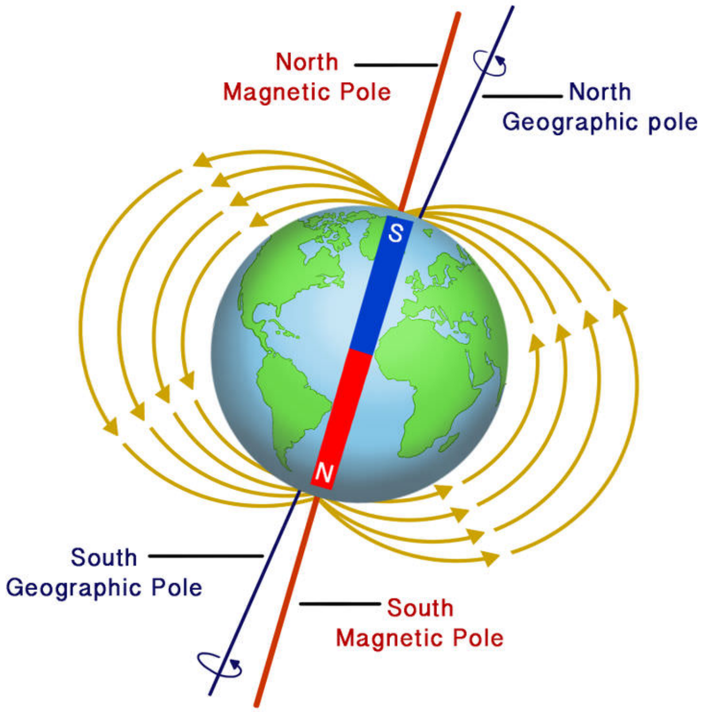
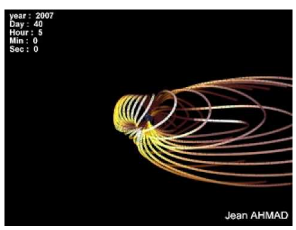


FIGURE 2.33
Earth's magnetic north pole is close to the geographic north pole.



MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/5060

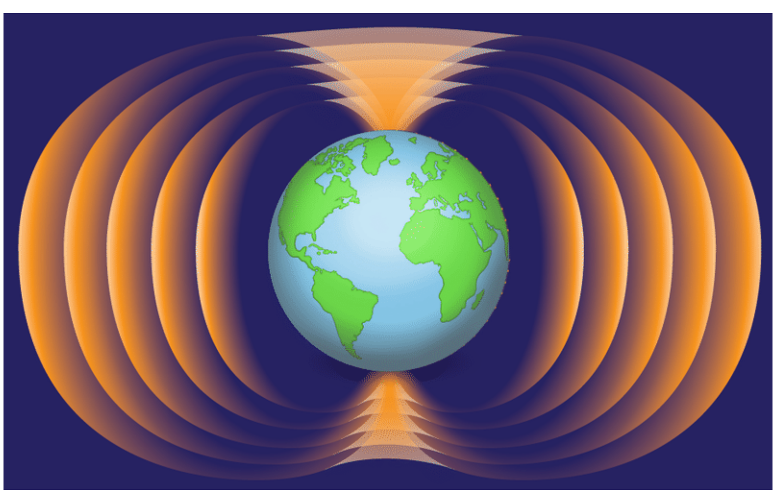
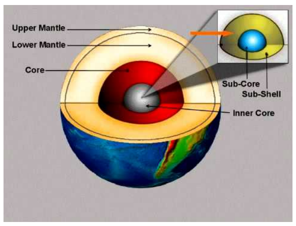


FIGURE 2.34
The magnetosphere extends outward from Earth in all directions.

Why Is Earth a Magnet? (Advanced Topic)

The idea that Earth is a magnet is far from new. It was first proposed in 1600 by a British physician named William Gilbert. Knowing it acts like a magnet is one thing. Knowing why it acts like a magnet is more difficult. In fact, finding out why is a fairly recent discovery. To find out why required new technology. It was the seismograph that made it possible to learn why the Earth acted like a magnet. Seismograph are used to study earthquakes. By studying earthquake waves they were able to learn about Earth's interior (see **Figure** 2.35). They discovered that Earth has an inner and outer core. The outer core consists of liquid metals, mainly iron and nickel. Scientists think that Earth's magnetic field is generated here. It is caused by the motion of this liquid metal. The liquid metal moves as Earth spins on its axis.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/5061

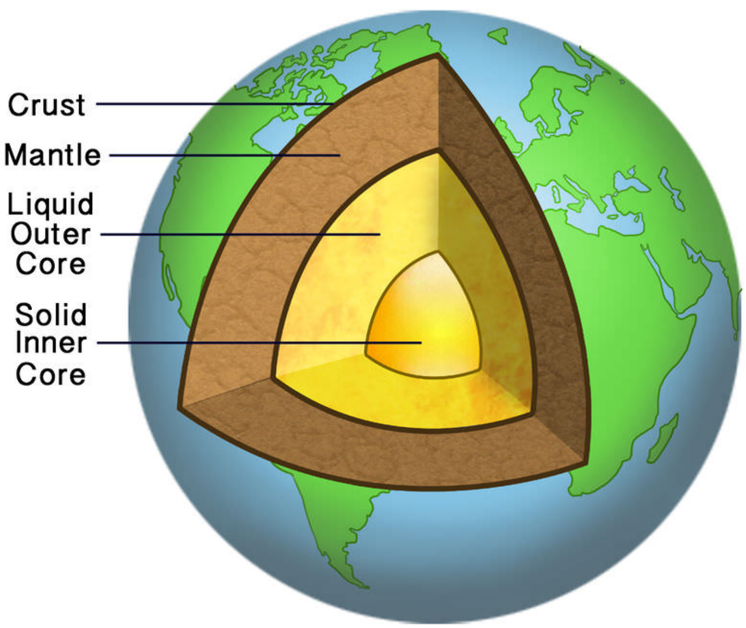


FIGURE 2.35

Charged particles flow through Earth's liquid outer core, making Earth a giant magnet.

Benefits of Earth's Magnetic Field

Earth's magnetic field helps protect Earth and its organisms. It protects us from harmful particles given off by the sun. Most of the particles are attracted to the north and south magnetic poles. This is where Earth's magnetic field is strongest. This is also where relatively few organisms live.

Another benefit of Earth's magnetic field is its use for navigation. People use compasses to detect Earth's magnetic north pole. Knowing this helps them tell direction. Many animals have natural "compasses" that work just as well.

Birds like the garden warbler in **Figure** 2.36 use Earth's magnetic field. They use it to guide their annual migrations. Recent research suggests that warblers and other migrating birds have structures in their eyes. These structures let them see Earth's magnetic field as a visual pattern.

FIGURE 2.36
The garden warbler flies from Europe to central Africa in the fall and returns to Europe in the spring. Its internal "compass" helps it find the way.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/116508

Lesson Summary

- Earth is a giant magnet. It has a north and south magnetic pole. It also has a magnetic field called the magnetosphere. Evidence in rocks shows that Earth's magnetic poles have switched positions. They have done so hundreds of times in the past. Scientists think that Earth's magnetic field is caused by the movement of charged particles within the outer core.
- Earth's magnetic field helps protect Earth's surface. It also helps to protect organisms from harmful solar particles. Earth's magnetic field is also used for navigation by humans and many other animals.

Lesson Review Questions

Recall

1. What is the magnetosphere?

2. Identify evidence for magnetic reversals in Earth's past.
3. List two benefits to organisms of Earth's magnetic field.

Apply Concepts

4. Use a bar magnet, a globe or large ball, and any other props you need to demonstrate to another student how Earth is like a bar magnet.

Think Critically

5. What is the relationship between Earth's magnetic poles and Earth's geographic poles?
6. Explain why Earth is a magnet.

Points to Consider

In this chapter, you learned that Earth is a magnet because of moving charged particles in its outer core. In the chapter "Electricity," you learned that moving charged particles create electric current. The next chapter explains how electric current and magnetism are related.

- Based on what you now know about electricity and magnetism, can you predict how they are related?
- Do you think electric current could be used to create a magnet? How might this be done?

Physical Science

2.12 References

1. Balloon: LeAnn E. Crowe (Flickr:technicolor76); Red panda: Matthijs Koster; Neon signs: Dane A. Penland; Iron: Courtesy of NASA. Balloon: http://www.flickr.com/photos/86044507@N00/3705507804; Red panda: http://www.flickr.com/photos/matthijskoster/746427079/; Neon signs: http://www.flickr.com/photos/publicresourceorg/493866748/; Iron: http://commons.wikimedia.org/wiki/File:Widmanstatten_IronMet.JPG . Balloon: CC BY 2.0; Red panda: CC BY 2.0; Neon signs: CC BY 2.0; Iron: Public Domain
2. Nugget: Eden, Janine and Jim (Flickr:edenpictures); Ring: Flickr:certified su. Nugget: http://www.flickr.com/photos/edenpictures/9769105003/; Ring: http://www.flickr.com/photos/certified_su/2940891731/ . CC BY 2.0
3. Sodium and Chlorine: User:Greenhorn1/Wikimedia Commons; Salt: Dubravko Sorić (Flickr: SoraZG). Sodium: http://commons.wikimedia.org/wiki/File:Sodium.jpg; Chlorine: http://commons.wikimedia.org/wiki/File:Chlorine2.jpg; Salt: http://commons.wikimedia.org/wiki/File:Salt_shaker_on_white_background.jpg .
4. Muddy and salt water: Image copyright Alena Brozova, 2013; Gelatin: Image copyright Jan Kaliciak, 2013. http://www.shutterstock.com . Used under licenses from Shutterstock.com
5. Lake: User:xta11/Wikimedia Commons; Coffee filter: Robert S. Donovan; Magnet: Christopher Auyeung. Lake: http://commons.wikimedia.org/wiki/File:DeadSeaIsrael3.jpg; Coffee filter: http://www.flickr.com/photos/booleansplit/7181874752/; Magnet: CK-12 Foundation . Lake: Public Domain; Coffee filter: CC BY 2.0; Magnet: CC BY-NC 3.0
6. Bowling ball: Matthew (Flickr: falcon1961); Volleyball: User:Amada44/Wikimedia Commons. A bowling ball is denser than a volleyball . Bowling ball: CC BY 2.0; Volleyball: Public Domain
7. Etienne Berthier, Université de Toulouse, NASA Goddard Space Flight Center. http://www.flickr.com/photos/gsfc/8741348325/ . CC BY 2.0
8. Christopher Auyeung. . CC BY-NC 3.0
9. Salt: Nate Steiner; Steaks: Jon Sullivan/pdphoto.org; Wood: Horia Varlan; Candle: Jon Sullivan/pdphoto.org;. Salt: http://www.flickr.com/photos/nate/27476159/; Steaks: http://commons.wikimedia.org/wiki/File:Steaks.jpg; Wood: http://www.flickr.com/photos/horiavarlan/4273110809; Candle: http://commons.wikimedia.org/wiki/File:Candle_flame_%281%29.jpg . Salt and Wood: CC BY 2.0; Steaks and Candle: Public Domain
10. Christopher Auyeung. . CC BY-NC 3.0
11. Joe Shlabotnik. http://www.flickr.com/photos/joeshlabotnik/1856962308/ . CC BY 2.0
12. James Thompson. Wood burning in a fire . CC BY 2.0
13. Jef Poskanzer. http://commons.wikimedia.org/wiki/File:Broken_glass.jpg . CC BY 2.0
14. Log: Alex Murphy (Flickr: APM Alex); Braiding hair: Steven Depolo; Can: James Mackintosh Photography ; Arch: Frank Kovalchek; Candy: Image copyright Anteromite, 2013. Log: http://www.flickr.com/photos/28misguidedsouls/5128954613/; Braiding hair: http://www.flickr.com/photos/stevendepolo/4886397967/; Can: http://www.flickr.com/photos/59207552@N08/8565955392/; Arch: http://www.flickr.com/photos/72213316@N00/5242351183/; Candy: http://www.shutterstock.com . Log, Braiding hair, Can, Arch: CC BY 2.0; Candy: Used under license from Shutterstock.com
15. Leaves: Kenny Louie (Flickr:kennymatic); Eggs: Image copyright Fotografas Edgaras, 2013; Pennies: F Delventhal (Flickr:krossbow); Fire: Dawn Huczek. Leaves: http://www.flickr.com/photos/kwl/6282684630/; Eggs: http://www.shutterstock.com; Pennies: http://www.flickr.com/photos/krossbow/4252686414/; Fire: http://www.flickr.com/photos/31064702@N05/3810662879/ . Leaves: CC BY 2.0; Eggs: Used under licenses from Shutterstock.com; Pennies: CC BY 2.0; Fire: CC BY 2.0
16. Ingredients: Gemma Bardsley; Cake: The Integer Club. Baking a cake is an irreversible reaction . CC BY 2.0
17. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
18. Image copyright Gayvoronskaya_yana, 2014. http://www.shutterstock.com . Used under license from Shut-

terstock.com
19. Lake: User:xta11/Wikimedia Commons; Coffee filter: Robert S. Donovan; Magnet: Christopher Auyeung. Lake: http://commons.wikimedia.org/wiki/File:DeadSeaIsrael3.jpg; Coffee filter: http://www.flickr.com/photos/booleansplit/7181874752/; Magnet: CK-12 Foundation . Lake: Public Domain; Coffee filter: CC BY 2.0; Magnet: CC BY-NC 3.0
20. Max Talbot-Minkin. http://www.flickr.com/photos/maxtm/6823667554/ . CC-BY 2.0
21. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
22. Marc Spooner. http://www.flickr.com/photos/marcspooner/5287991784/ . CC BY 2.0
23. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
24. Neil Piddock (Flickr: piddy77). http://www.flickr.com/photos/piddysplace/145287597/ . CC BY 2.0
25. Magnet and paperclip: User:Havelock/He.Wikipedia; Magnet and nail: Christopher Auyeung. Magnet and paperclip: http://commons.wikimedia.org/wiki/File:Magpins1.JPG; Magnet and nail: CK-12 Foundation . Magnet and paperclip: The copyright holder of this file allows anyone to use it for any purpose, provided that the copyright holder is properly attributed; Magnet and nail: CC BY-NC 3.0
26. Left: User:Teravolt/Wikipedia; Right: User:Yug/Wikimedia Commons. Left: http://commons.wikimedia.org/wiki/File:Lodestone_%28black%29.jpg; Right: http://commons.wikimedia.org/wiki/File:Antic_chinese_-Compass.jpg . Left: CC BY 3.0; Right: Public Domain
27. Flickr:Alberto.... http://www.flickr.com/photos/albertoalerigi/2886121661/ . CC BY 2.0
28. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
29. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
30. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
31. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
32. Flickr:Biillyboy. http://commons.wikimedia.org/wiki/File:Sylvia_borin_%28%C3%96rebro_County%29.jpg . CC BY 2.0

CHAPTER 3 Life Science: Systems of Animals and Plants

Chapter Outline

3.1 Learned Behavior of Animals

Learning Objectives

- Distinguish between learned behavior and innate behavior.
- Describe habituation.
- Explain observational learning
- Give examples of conditioning.
- Summarize learning by playing.
- Define insight learning.

Lesson Objectives

- Describe how some animal behaviors may be shaped by heredity, while others are learned behaviors.

Lesson Vocabulary

- heredity
- inherited trait
- instinct
- learned behavior

Do you play a sport?

Maybe you play soccer? If so, you realize it takes a lot of work. There are lots of things to learn. There are many rules. There are also a lot of skills to practice. You were not born with this knowledge. You needed to learn how to play this sport. Learning to play any sport is an example of a learned behavior.

Learned Behavior

Almost all the things we do in our lives we have learned how to do. **Learned behavior** is something animals do only after having done it or having practiced it. For an animal, learning something may be better than having a natural ability. A learned behavior is flexible. This means that if the rules change you can quickly adapt. If you were an animal in the wild, you could learn how to find food in different areas.

Here is one example of a learned behavior. It also demonstrates why learned behaviors may be better than innate ability. Innate ability is a trait you are born with. You may walk each day from your house to school and back. On your first day of school, did you know how to get there? Of course not, it was learned. Now assume your family has moved. You may be a couple of streets over and a little further away. You now have to take a different route to school.

What if following the old route was an innate behavior? You would not be able to adapt. You would not be able to find your way from the new house. Fortunately, this behavior is a learned behavior. You can learn the new route just as you learned the old one.

Although most animals can learn, animals with greater intelligence are better at learning. Humans are the most intelligent animals. They depend on learned behaviors more than any other species. Other highly intelligent species include apes. Our closest relatives in the animal kingdom are apes, such as chimpanzees and gorillas, which are also very good at learning new things.

You may have heard of a gorilla named Koko. The psychologist, Dr. Francine Patterson, raised Koko. Dr. Patterson wanted to find out if gorillas could learn human language. Starting when Koko was just one year old, Dr. Patterson taught her to use sign language. This is not so different than when you learned how to read and write words. Dr. Patterson taught Koko to use sign language. Koko learned more than 1,000 signs. Koko showed how much gorillas can learn.

Think about some of the things you have learned. They might include riding a bicycle. Perhaps you are great at computers or playing a sport. Maybe you are a terrific musician. You probably did not learn all of these behaviors in the same way. Perhaps you learned some behaviors on your own, just by practicing. Other behaviors you may have learned from other people. Humans and other animals can learn behaviors in several different ways.

Forming Habits (Advanced Topic)

Forming a habit, or **habituation**, is simply getting used to something. If you do something enough it becomes a habit. You no longer have to think about it. Think about how you learn to play an instrument. You may learn to play notes. You then learn to read music. With repetition, you no longer have to think about hitting the right keys. You see the note and your fingers respond. It is all about getting used to something. Forming a habit is is one of the simplest ways of learning. It occurs in just about every species of animal.

Another example of forming a habit is shown in **Figure** 3.1. Crows, and most other birds, are usually afraid of people. They avoid coming close to people. Have you noticed how they fly away when people come near them? Farmers have used this instinct to keep birds way from their crops. The scarecrow below looks like a person. It keeps birds from eating the crops. However, the birds in this photo have gotten used to the scarecrow. They have learned that the scarecrow poses no danger. They are no longer afraid to come close.

FIGURE 3.1

This scarecrow is no longer scary to this crow. The crow has become used to its being in this spot and learned that it is not dangerous. This is an example of habituation.

Can you see why habituation is useful? It lets animals ignore things that will not harm them. Without forming habits, animals might waste time trying to escape from things that are not a threat when they could be doing more important things, such as gathering food.

Learning by Observing (Advanced Topic)

You can learn a lot by making observations. Perhaps you watch someone else do a task. Human children learn many behaviors this way. When you were a young child, you may have watched people turn a door knob. By watching, you soon learned to open doors yourself. More recently, you may have watched people dance on TV. Through watching, you may have learned to dance. Most likely, you have learned how to do math problems by watching and listening. You watch your teacher explain how to solve a type of problem on the board. You learn to apply this math rule. Soon you are able to solve math problems using this learned method. Can you think of other behaviors you have learned by watching and copying other people?

Other animals also learn by observing. For example, young wolves learn to be better hunters by watching older wolves. They copy their skills, just like you copy your teacher's methods. Another example of learning by observing is how some monkeys have learned to wash their food. They learned this behavior by watching other monkeys.

Conditioning (Advanced Topic)

Conditioning is another way animals learn. This method uses either a reward or punishment. Did you ever train a dog to fetch? You might have given the dog a treat for bringing the ball back. This treat was a reward. For humans, this reward may be in the form of praise. If you did, you were using conditioning. Another example of conditioning is shown in the video below. The rats have been taught to "play basketball" by being rewarded with food pellets. What do you think would happen if the rats were no longer rewarded for this behavior?

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/179123

Conditioning also occurs in wild animals. For example, bees learn to find nectar in certain types of flowers. Their reward comes each time they find a flower with nectar. By doing this, they learn which flowers contain nectar.

Humans learn behaviors through conditioning as well. Young children learn to put away their toys. As a reward for this task, they may be read a bedtime story. An older child might learn to study for tests in school. Their reward comes in the form of grades. Can you think of behaviors you have learned by being rewarded for them?

Conditioning does not always involve a reward. It can involve a punishment. A toddler might be punished for misbehaving. Perhaps he gets punished each time he grabs a toy from his baby brother. Perhaps the punishment comes in the form of a time-out. After several time-outs, he may learn to stop taking his brother's toys.

A dog might be scolded each time she jumps up on the sofa. After repeated scolding, she may learn to stay off the sofa. A bird might become ill after eating a poisonous insect. The bird may learn from this "punishment" to avoid eating the same kind of insect in the future.

Learning by Playing (Advanced Topic)

Most young mammals, including humans, like to play. Play is one way they learn the skills that they will need as adults. Think about how kittens play. They pounce on toys and chase each other. This helps them learn how to be better predators. Big cats also play. The lion cubs pictured below are playing. At the same time, they are also practicing their hunting skills (**Figure** 3.2). The dogs are playing tug-of-war with a toy (**Figure** 3.2). What do you think they are learning by playing together this way?

Human children learn by playing as well. For example, playing games and sports can help them learn to follow rules. They also learn to work together. The young child pictured below is playing in the sand (**Figure** 3.3). She is learning about the world through play. What do you think she might be learning?

Lesson Summary

- Learned behavior is behavior that occurs only after experience or practice.

FIGURE 3.2
Left: These two lion cubs are playing. They are not only having fun, but they are also learning how to be better hunters. Right: These dogs are really playing. This play fighting can help them learn how to be better predators.

FIGURE 3.3
Playing in a sandbox is fun for young children. It can also help them learn about the world.

- Methods of learning include habituation, learning by observing, conditioning, and play.

Lesson Review Questions

1. What is observational learning? Give an example.
2. What is conditioning?
3. Why are some crows not afraid of scarecrows?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://www.pbs.org/wnet/nature/koko

3.2 Nervous System

Learning Objectives

- Define nerve.
- Describe the role of a nerve.
- Explain the functions of the nervous system.

Lesson Objectives

- Identify the parts and describe the functions of the nervous system.

Lesson Vocabulary

- organ
- function

What body system helps you learn?

As these girls are studying, many things are taking place. Their eyes have to see the words. Their brains then have to figure out what the words mean. The brain also has to store the information coming in. It may be needed later. It will then have to be retrieved. All these processes are controlled by the nervous system.

Introduction to the Nervous System

Michelle was riding her scooter. She hit a hole in the street. She started to lose control of her scooter. She thought she would fall. In the blink of an eye, she shifted her weight. This quick action helped her to keep her balance. Her heart was pounding. The good news is that she did not get hurt. How was she able to react so quickly? Michelle can thank her nervous system (**Figure** 3.4).

FIGURE 3.4
Staying balanced when riding a scooter requires control over the body's muscles. The nervous system controls the muscles and maintains balance.

The nervous system does not work alone. It works with the endocrine system. Together, they control all the other organ systems. The nervous system sends one type of signal. The nervous system sends electrical pulses. The endocrine system sends another type of signal. These chemical signals are called hormones. Hormones tell other body parts that a change is needed.

The nervous system does not just control muscles and balance. The nervous system also lets you sense the world around you. What type of things do you think it controls?

- Sense conditions inside of your body, such as temperature
- Control your internal body systems and keep them in balance
- Prepare your body to fight or flee
- Use language, think, learn, and remember

The main organs of the nervous system are the brain and the spinal cord. They carry signals to the rest of the body. The messages released by the nervous system traveled through nerves. Just like the electricity that travels through wires. The nerves quickly carry the electrical messages around the body. The signals travel through the spinal cord and up to the brain. Signals travel back and forth along this pathway.

For example, think of what happens when Michelle started to fall off her scooter. Her nervous system sensed something was wrong. She realized she was losing her balance. Her brain immediately sent messages to her muscles. Some muscles tightened while others relaxed. These actions also moved her hips and her arms. All these actions together helped her keep her balance.

The nervous system works together with your muscles and bones. All the body systems work together. This includes the muscular and skeletal systems. Together these systems allowed Michelle to react. As a result, Michelle's body became balanced again.

Lesson Summary

- The nervous system sends electrical messages throughout the body. They control all other body systems.
- The nervous system allows you to think, learn, and sense your surroundings. This system also controls your internal body systems.

Lesson Review Questions

1. What are three functions of the nervous system?
2. What type of signals does the nervous system send? What carries these signals?
3. What are the main organs of the nervous system?

3.3 The Respiratory System

Lesson Objectives

- Define respiration.
- Identify structures of the respiratory system.
- Explain breathing mechanisms.

Lesson Vocabulary

- lung
- respiration
- respiratory system

Introduction

You just got done with a long run. You are gasping for air. Why does your body react this way? What is the purpose of breathing?

All the cells of your body need oxygen to work properly. Your body's circulatory system works with the respiratory system to deliver the oxygen. Your blood carries red blood cells. The main job of red blood cells is to carry oxygen throughout your body. The red blood cells get oxygen in the lungs. The lungs are the main organs of the respiratory system. The respiratory system is the body system that takes in oxygen. It then releases carbon dioxide back to the atmosphere. The carbon dioxide is the waste material from the cells.

What Is Respiration?

Respiration is the exchange of oxygen with carbon dioxide. This process consists of two stages. In one stage, air is taken into the body. Carbon dioxide is then released to the outside air. In the other stage, oxygen is delivered to all the cells of the body. Carbon dioxide is carried away from the cells. Oxygen and carbon dioxide are the two gases exchanged through respiration.

Structures of the Respiratory System

You can see the main structures of the respiratory system in **Figure** 3.5. They include the nose, trachea, lungs, and diaphragm. Use the figure to trace how air moves through the respiratory system.

Steps in Respiration

Take in a big breath of air through your nose. As you breathe in, you may feel the air pass down through your throat. Your chest expands. Now breathe out and observe the opposite events occurring. Breathing in and out may seem like simple actions. They are just one part of a complex process. Respiration actually occurs in four steps:

1. breathing (inhaling and exhaling)
2. gas exchange between the air and blood

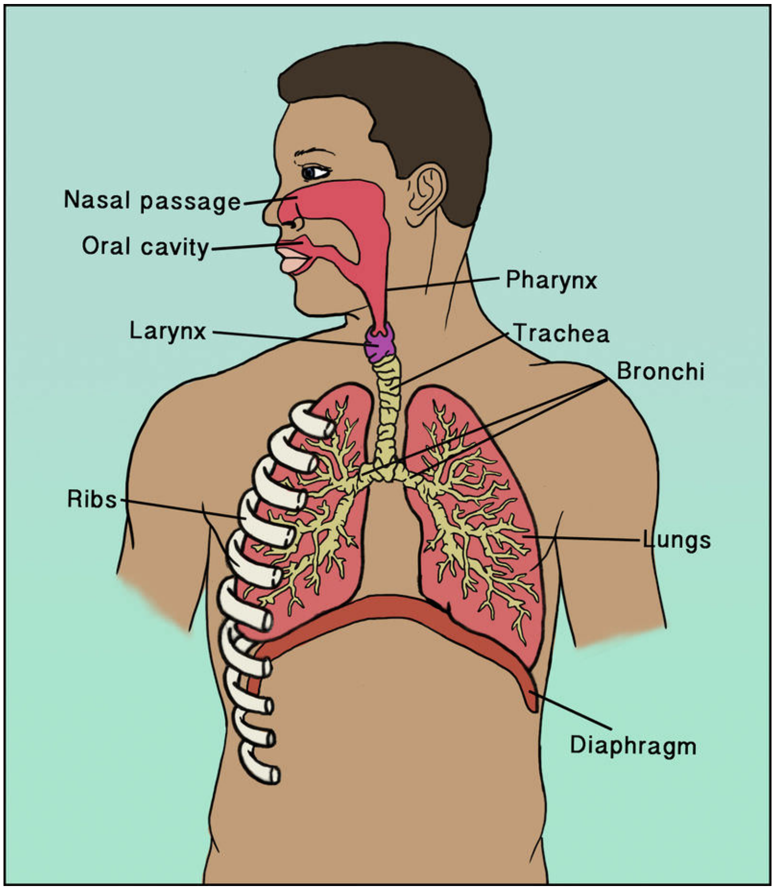


FIGURE 3.5
Structures of the respiratory system

3. gas transport by the blood
4. gas exchange between the blood and cells

Note: gas exchange refers to the exchange of oxygen and carbon dioxide.

Breathing

Breathing is the process of moving air into and out of the lungs. The process depends on a muscle called the diaphragm. This is a large, sheet-like muscle below the lungs.

- Inhaling, or breathing in, occurs when the diaphragm muscle tightens. This increases the size of the chest. This too decreases air pressure inside the lungs. This action allows air and gases to enter the lungs.
- Exhaling, or breathing out, occurs when the diaphragm muscle relaxes. This decreases the size of the chest. This increases air pressure inside the lungs. This action allows for air to leave the lungs.

When you inhale, air enters the respiratory system through your nose and ends up in your lungs, where gas exchange with the blood takes place. What happens to the air along the way?

- In the nose, mucus and hairs trap any dust or other particles in the air. The air is also warmed and moistened.
- Next, air passes through a passageway that is connected to the windpipe.
- The air then finds its way to the lungs.

- In the chest, the windpipe splits so that air enters both the right and left lung. These passages are covered with mucus and tiny hairs called cilia. The mucus traps any remaining particles in the air. The cilia move and sweep the particles and mucus toward the throat so they can be expelled from the body.

Gas Exchange Between Air and Blood

Within the lungs there are thin pockets. It is in these thin pockets that gases are exchanged between the lungs and the blood. Here, oxygen enters red blood cells and carbon dioxide leaves the red blood cells.

Gas Transport in the Blood

Once red blood cells are rich in oxygen, they leave the lungs. They travel through the heart. The heart pumps the oxygen-rich blood into arteries. The arteries carry the oxygen-rich blood throughout the body.

Gas Exchange Between the Blood and Cells

Once red blood cells reach the cells, they exchange the oxygen for carbon dioxide wastes. The carbon dioxide travels back to the lungs. The carbon dioxide is then passed into the lungs where it is exhaled out of the body.

Every time you breathe in and out your body is exchanging gases. Each time you breathe in you take in oxygen. Each time you breathe out you get rid of carbon dioxide. Breathing allows for the continuous process of exchanging these gases.

Lesson Summary

- The respiratory system is the body system that exchanges gases with the outside air. It brings air containing oxygen into the body for the cells. It also releases carbon dioxide from the cells into the air. This exchange of gases is called respiration.
- Breathing is the process of moving air into and out of the lungs. It depends on the muscle called the diaphragm.
- The lungs are the main organs of the respiratory system. This is where gases are exchanged between the air and the blood. Gases are also carried by the blood throughout your body. The blood carries back the waste gases from your cells so they can be exhaled through your lungs.

Lesson Review Questions

Recall

1. What is the function of the respiratory system?
2. List steps in the process of respiration.

Apply Concepts

3. Why do you think you need to breathe heavily after exercise?

Think Critically

4. Explain how the diaphragm controls breathing.

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://science.nationalgeographic.com/science/health-and-human-body/human-body/lungs-article/

3.4 The Cardiovascular System

Lesson Objectives

- Identify parts of the cardiovascular system.
- State functions of the cardiovascular system.

Lesson Vocabulary

- cardiovascular system

Introduction

What do you do for "cardio"?

"Cardio" has become slang for exercise. Cardio is the type of exercise that keeps your heart rate high. Cardio can include biking, running, or swimming. Cardio is short for cardiovascular system. Your heart is in this system. So are your blood and blood vessels. The cardiovascular system is the system of organs that delivers blood to all the cells of the body. It's like the body's lifeline. Without the cardiovascular system circulating your blood, you couldn't survive.

Parts of the Cardiovascular System

Of course, everyone has heard of the heart. It is the engine of your body. The heart and a network of blood vessels make up the cardiovascular system. The network of blood vessels runs throughout the body. The blood in the cardiovascular system is a liquid connective tissue. **Figure** 3.6 shows the heart and major vessels. You will notice it affects the entire body. The heart is basically a pump. It is what keeps the blood moving through the blood vessels.

Functions of the Cardiovascular System

Your cardiovascular system has many jobs. At times the cardiovascular system can work like a pump. This pump pushes your blood through your body. It helps you regulate temperature. It also supplies the cells with what they need to do their job. The cardiovascular system works with all the other organ systems in the body.

Every cell in your body depends on your cardiovascular system. If your cells don't receive what they need, they cannot survive. The main function of this system is to deliver oxygen to your cells. Blood receives oxygen in your lungs, which are a part of the respiratory system. Oxygen-rich blood is then pumped by your heart all around your body.

The cardiovascular system also plays a role in keeping your body temperature just right. It helps to keep you warm by moving warm blood around your body. Your blood vessels keep you from getting too hot or too cold. Your brain acts as the control center. If you are getting too hot, it sends a signal to the blood vessels in your skin. The skin receives these messages and the blood vessels expand. This action increases the amount of blood and heat to move near the skin's surface. The heat is then released from the skin. This helps you cool down. What do you think happens when you are cold? How would your blood vessels react?

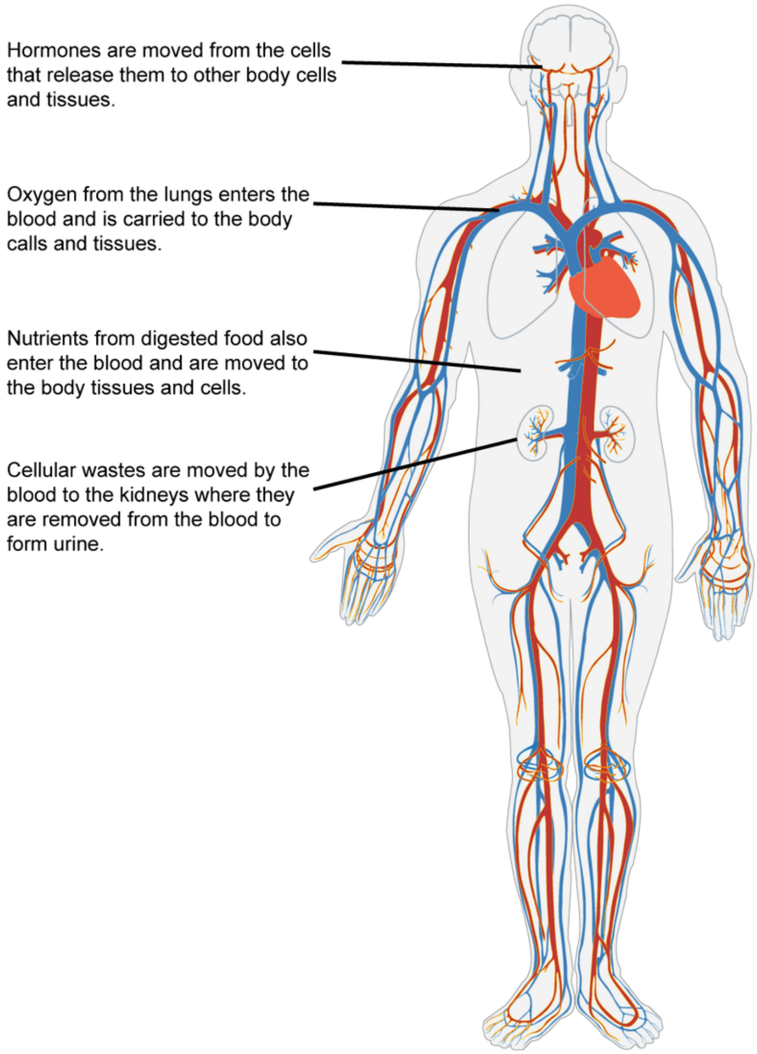


FIGURE 3.6
The cardiovascular system transports many substances to and from cells throughout the body.

MEDIA
Click image to the left or use the URL below.
URL: http://www.ck12.org/flx/render/embeddedobject/137140

The blood also carries other special chemicals. These special chemicals are produced by organs of the endocrine system and carried through your body. These special chemicals are produced in one area of your body and have an effect on another. To get to that other area, they must travel through your blood. You may have heard of adrenaline. You may have heard the term, "My adrenaline is pumping." Adrenaline is produced by the adrenal glands on top of the kidneys . Adrenaline has multiple effects on the heart . We mostly feel its effects as a quicker heart rate.

Lesson Summary

- The cardiovascular system consists of the heart, a network of blood vessels, and blood. Blood is a liquid tissue. The heart is a pump that keeps blood flowing through the vessels of the system.
- The main function of the cardiovascular system is transport. It carries special chemicals, oxygen, nutrients, and cellular wastes around the body. The cardiovascular system also helps regulate body temperature by controlling blood flow.

Lesson Review Questions

Recall

1. List the parts of the cardiovascular system.
2. State two general functions of the cardiovascular system.

Apply Concepts

3. The cardiovascular system has been called the highway system of the body. Do you think this is a good analogy for the cardiovascular system? Why or why not?

3.5 The Digestive System

Lesson Objectives

- Identify the major organs and general functions of the digestive system.
- Outline the digestive functions of the mouth, esophagus, and stomach.
- Explain how digestion and absorption occur in the small intestine.

Lesson Vocabulary

- absorption
- chemical digestion
- digestion
- digestive system
- elimination
- esophagus
- large intestine
- mechanical digestion
- nutrients
- small intestine
- stomach

Introduction

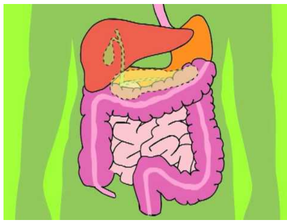
Have you ever heard the saying, "You are what you eat?" It's true, our bodies take in food. All our energy comes from this food, but how? Our body breaks the food down into nutrients. These nutrients are the fuel that keeps our body running. Do you know how this works? Read on to find out.

Food contains nutrients. These nutrients are needed by the cells of your body. How do they get from your sandwich to your cells? What organs and processes break down the food? How are these nutrients made available to cells? The answer is your digestive system. It is this system that controls the digestion and absorption of nutrients. Don't think it is that simple though. All the systems of your body work together to keep your body running at its best.

The respiratory and circulatory systems work together. Together, they provide cells with the oxygen they need to operate. Cells also need glucose. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. Glucose is not the only thing we get from food. Our bodies also require proteins and fats. Let's learn a little about the digestive process.

Overview of the Digestive System

The digestive system supports the body in three ways. First, it breaks down food. Second, it enables nutrients to be absorbed into the body. It is also responsible for the elimination of waste from the body. The major organs of the digestive system are shown in **Figure** 3.7.



MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/137139

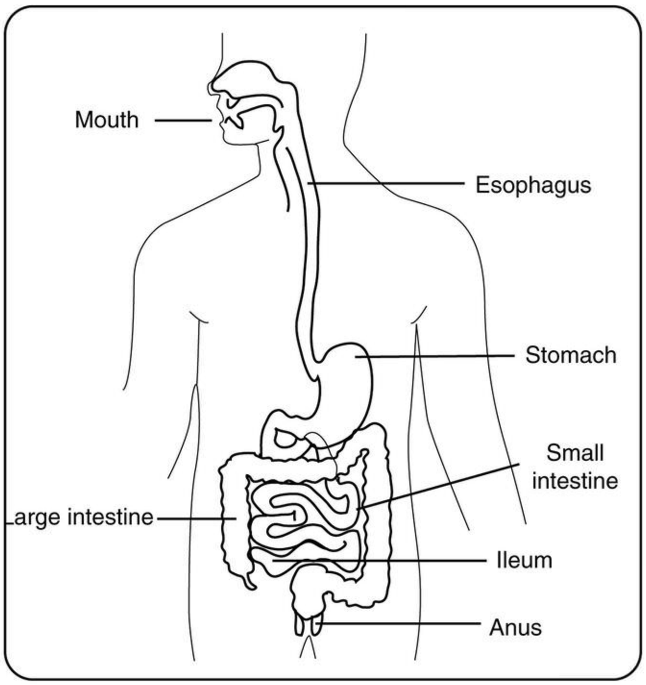


FIGURE 3.7

Major organs of the digestive system make up the GI tract.

The Digestive Tract

The digestive system is essentially a long tube that passes through your body. Do you know how long your digestive tract is? Food enters the mouth and then travels more than 9 meters (30 feet). This distance is needed to process the food you eat. The food that is not digested is passed as waste.

The organs in the digestive tract are covered by a special type of muscle. These muscles contract to help move the food along. This muscle movement is like a wave through a spring toy.

Think about when you brush your teeth. You squeeze the toothpaste from the tube. The toothpaste moves out of the tube. This action is similar to how food is passed through your digestive tract. The diagram in **Figure** 3.8 shows how this process works.

Digestion

As food is pushed along, it undergoes digestion. Digestion is the process of breaking down food into nutrients. There are two types of digestion: mechanical digestion and chemical digestion.

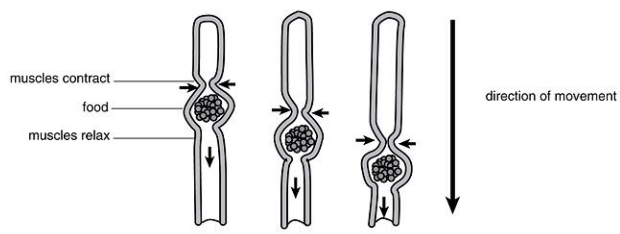


FIGURE 3.8
Peristalsis

- Mechanical digestion occurs when large chunks are turned into smaller chucks. Perhaps not surprisingly, this happen when you chew your food. Once you swallow the food, your stomach also does some of this work.
- Chemical digestion occurs when food is broken down into useful nutrients. This is a chemical process that begins as you start to chew your food. The saliva in your mouth starts this process. Once you swallow, the acid in your stomach further breaks down food. From the stomach, the foods moves into the small intestine. In the small intestines, another set of chemicals goes to work. Are you surprised? Your small intestine, and not your stomach, does most of the work!

Absorption

After food is broken down into nutrient molecules, then what? Once the food is broken down into nutrients, the nutrients can now be moved through the blood. This process is called absorption. Nutrients travel through the bloodstream to feed all your cells.

Elimination

Some substances in food can't be broken down into nutrients. They remain behind after digestion has occurred. These materials cannot be absorbed. Any food that can't be digested is passed out of the body as solid waste. This process is called elimination.

The Start of Digestion: Mouth to Stomach

Does the sight or smell of your favorite food make your mouth water? When this happens, you are getting ready for digestion.

Mouth

The mouth is the first digestive organ that food enters. The sight, smell, or taste of food stimulates the start of the digestive process. Your body starts with the release of saliva. Saliva wets the food, which makes it easier to break up and swallow. Other special chemicals start the chemical digestive process.

Your teeth help to mechanically digest food. Look at the different types of human teeth in **Figure** 3.9. Sharp teeth in the front of the mouth cut or tear food when you bite into it. Broad teeth in the back of the mouth grind food when you chew. Your tongue helps mix the food with saliva and helps you swallow.

FIGURE 3.9
Teeth are important for mechanical digestion.

Esophagus

The esophagus is a long, narrow tube that carries food from the back of your mouth to the stomach. It has no other purpose. Food is pushed through the esophagus by special muscles. The muscles contract and relax, pushing the food along. The action is similar to when you squeeze your toothpaste from the tube.

Stomach

The stomach is a sac-like organ at the end of the esophagus. It has thick muscular walls that contract and relax to squeeze and mix food. It's like having a washing machine inside your body tossing around food. This helps break the food into smaller pieces. It also helps mix the food with special chemicals that further aid the breaking down of food into nutrients.

Water, salt, and simple sugars can be absorbed in the stomach. These nutrients absorb directly into the blood from the lining of the stomach. However, most substances must undergo further digestion. This happens in the small intestine before they can be absorbed.

The Small Intestine

The small intestine is a narrow tube that starts at the stomach and ends at the large intestine. In adults, it's about 7 meters (23 feet) long. Most chemical digestion, and almost all nutrient absorption, takes place in the small intestine.

The small intestine is made up of three parts:

1. The duodenum is the first part of the small intestine. It is also the shortest part. This is where most chemical digestion takes place.
2. The jejunum is the second part of the small intestine. This is where most nutrients are absorbed into the blood.
3. The ileum is the last part of the small intestine. A few remaining nutrients are absorbed in the ileum. From the ileum, any remaining food waste passes into the large intestine.

The Large Intestine

The large intestine is the last section of the digestive tract. It is a wide tube that connects to the small intestine. The large intestine carries the remaining food out of the body as waste. In the large intestine, water is absorbed into the body. The large intestine is about 1.5 meters (5 feet) long. It is larger in width, but shorter in length, than the small intestine.

Lesson Summary

- The digestive system is the body system that digests food. It digest food in two ways, mechanically and chemically. Both help in the process of turning food into nutrients. The digestive system also eliminates solid food waste.
- The major organs of the digestive system include the mouth, esophagus, stomach, and small and large intestines. These organs all work together to help you gain energy from the food you eat.
- Digestion starts in the mouth. When food is swallowed, it travels through the esophagus to the stomach. In the stomach, digestion continues and a small amount of absorption of nutrients takes place.
- Most chemical digestion and nearly all absorption of nutrients take place in the small intestine. This organ consists of three parts: duodenum, jejunum, and ileum.
- The large intestine is the last stop in the digestive system. This is where water is absorbed. The food not digested is released as waste.

Lesson Review Questions

Recall

1. What organs help in the digestion of food?
2. Describe the roles of the mouth, esophagus, stomach, and intestines in digestion.

Apply Concepts

3. How are the mechanical and chemical digestive processes similar and different?

Points to Consider

In the digestive system, food is digested and its nutrients are carried by the blood to the cells around our body. The blood is part of the cardiovascular system.

1. What organs make up the cardiovascular system?
2. Besides nutrients, what other things are transported by the blood?

3.6 The Skin

Lesson Objectives

- Describe the layers of the skin.
- Identify functions of the skin.
- Explain what you can do to help keep your skin healthy.

Lesson Vocabulary

- dermis
- epidermis
- hair follicle
- sweat gland

Introduction

Whoa! It's really hot. Your skin gets warm and you start to sweat. The sweat is pouring out of you. Sweating is your body's way of keeping you from getting too warm.

Skin is a major organ. It helps to protect you. It is the outer covering of your body.

Skin Structure

From the outside, the skin looks plain and simple. You can see a closer look in **Figure** 3.10. Can you believe your eyes? There is nothing plain or simple about skin. A single square inch of skin contains about 20 blood vessels. There are also hundreds of sweat glands.

Your skin is filled with nerve endings. This is what enables you to feel things. When you feel something rough or smooth, you can thank your skin. Your skin also contains tens of thousands of cells that produce pigment. Pigment is what gives your skin its color. Clearly, there is much more to skin than meets the eye!

The skin is only about 2 mm thick. Although it is very thin, it consists of two distinct layers. These layers are called the epidermis and the dermis. You can see both layers and some of their structures in **Figure** 3.11.

Epidermis

The epidermis is the outer layer of skin. There are no blood vessels, nerve endings, or glands in this skin layer. Though it may not seem like it, this layer of skin is very active. It is constantly being renewed. How does this happen?

1. The cells at the bottom of this layer are always being produced.
2. The new cells slowly move up to the surface.
3. By the time the cells reach the surface, they have died. It's true, the outermost layer of your skin is dead. Don't worry, this is what forms the protective layer. This outer layer is even waterproof.
4. Dead cells are gradually falling off. As they are shed, they are replaced by other dead cells.

FIGURE 3.10
The skin is much more complex that it appears from the outside.

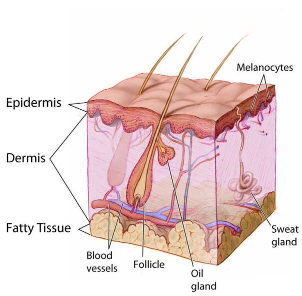


FIGURE 3.11
Layers and structures of the skin

The epidermis also contains cells that give skin its color. These cells are what produces the brown pigment in skin. Everyone's skin has about the same number of these cells. However, these cells of people with darker skin produce more pigment. The amount of pigment depends on two things. Some of it depends on what you inherit from your parents. It also depends on how much sunlight strikes your skin. The more light that hits your skin, the more tanned you get.

Dermis

The dermis is the inner layer of skin. The dermis has blood vessels and nerve endings. The nerve endings explain why your skin is sensitive. You can sense pain, pressure, and temperature.

Ouch! You cut your finger and it starts to bleed. What has happened? If your skin bleeds, it means you have cut the dermis layer and damaged blood vessels. The cut really hurts. It hurts because of the nerve endings in this skin layer.

The dermis also contains hair follicles and two types of glands. You can see some of these structures in **Figure** 3.12.

- Hair follicles are structures where hairs originate. Each hair grows out of a follicle. Hair passes up through the epidermis. It then extends above the skin surface.
- Oil glands produce an oily substance. The oil is secreted into hair follicles. Then it makes its way along the hair to the surface of the skin. This oil waterproofs the hair and skin. It helps prevent them from drying out.

- Another type of gland produces sweat. Sweat contains excess water, salts, and other waste products. Sweat travels up through the layers of the skin to the surface.

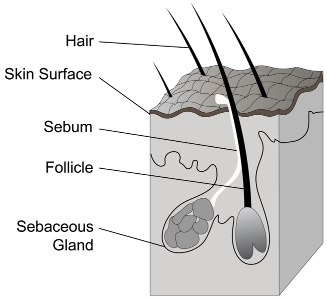


FIGURE 3.12
Structures in the dermis include hair follicles and sebaceous glands, which produce sebum.

Skin Functions

You couldn't survive without your skin. It has many important functions. The main function of the skin is controlling what enters and leaves the body. It prevents the loss of too much water from the body. It also prevents bacteria and other microorganisms from entering the body.

The skin helps maintain a constant body temperature. It keeps the body cool in two ways. Sweat from sweat glands in the skin evaporates to cool the body. Blood vessels in the skin dilate, or widen. This action increases blood flow to the body surface. This allows more heat to reach the surface. The heat is then able to radiate off the body. The opposite happens to retain body heat. Blood vessels in the skin constrict, or narrow. This decreases blood flow to the body surface. This reduces the amount of heat that reaches the surface. When this happens, less heat can be lost to the air.

Lesson Summary

- The skin consists of two distinct layers. The skin has an outer layer called the epidermis and an inner layer called the dermis. The epidermis is constantly being renewed. Dead cells on the surface are shed. This layer produces the pigment that gives skin its color. The dermis contains blood vessels, nerve endings, hair follicles, and oil and sweat glands.
- The skin prevents loss of water from the body. It keeps out microorganisms. Blood vessels get bigger and smaller to enable the release of sweat. By doing so, skin helps maintain a constant body temperature.

Lesson Review Questions

Recall

1. Outline how the epidermis is constantly being renewed.
2. Identify functions of the skin.
3. How do oil glands and sweat glands help us?

Apply Concepts

4. Why does it usually hurt to cut the skin but not the hair or nails?

Think Critically

5. Compare and contrast the epidermis and dermis.

Points to Consider

You can see all the organs of your integumentary system because they cover the outside surface of your body. Most of the organs of your other body systems are hidden inside your body. For example, your skeletal system is completely hidden by your skin and other tissues.

1. What organs do you think make up the skeletal system?
2. What are some of the functions of the skeletal system?

3.7 The Skeletal System

Lesson Objectives

- Identify components of the skeletal system.
- List functions of the skeletal system.
- Describe the structure of bone, and explain how bones grow and develop.
- Describe different types of joints, and explain how they function.

Lesson Vocabulary

- bone fracture
- bone marrow
- compact bone
- joint
- ligament
- skeletal system
- spongy bone

Introduction

Are bones alive? From seeing a skeleton, you might think that bones are just dead, hollow structures. But in a living person, those hollow spaces are full of living cells. Bones also have blood supply and nerves. Both are living organs. Bones are a living tissue.

Can you imagine not having bones? What would you look like? You would be a soft, wobbly pile of skin, muscles, and internal organs. You might look like a lump of clay! Clearly, bones are needed to support and shape the body. They have several other important roles as well.

Components of the Skeletal System

Bones are the main organs of the skeletal system. In adults, the skeleton consists of a whopping 206 bones. Many of those bones are in your hands and feet. You can see many of the bones of the human skeleton in **Figure** 3.13.

Have you thought about how your bones are connected together? There are actually two ways that bones are connected. The skeletal system includes cartilage and ligaments.

- Cartilage is tough and flexible. It covers the ends of bones where they meet. The gray sections in **Figure** 3.13 represent cartilage.
- A ligament is like a stretchy band. Ligaments connect your bones together. You can think of ligaments like rubber bands. Rubber bands are used to hold things together. Just like rubber bands, ligaments allow bones to move a bit.

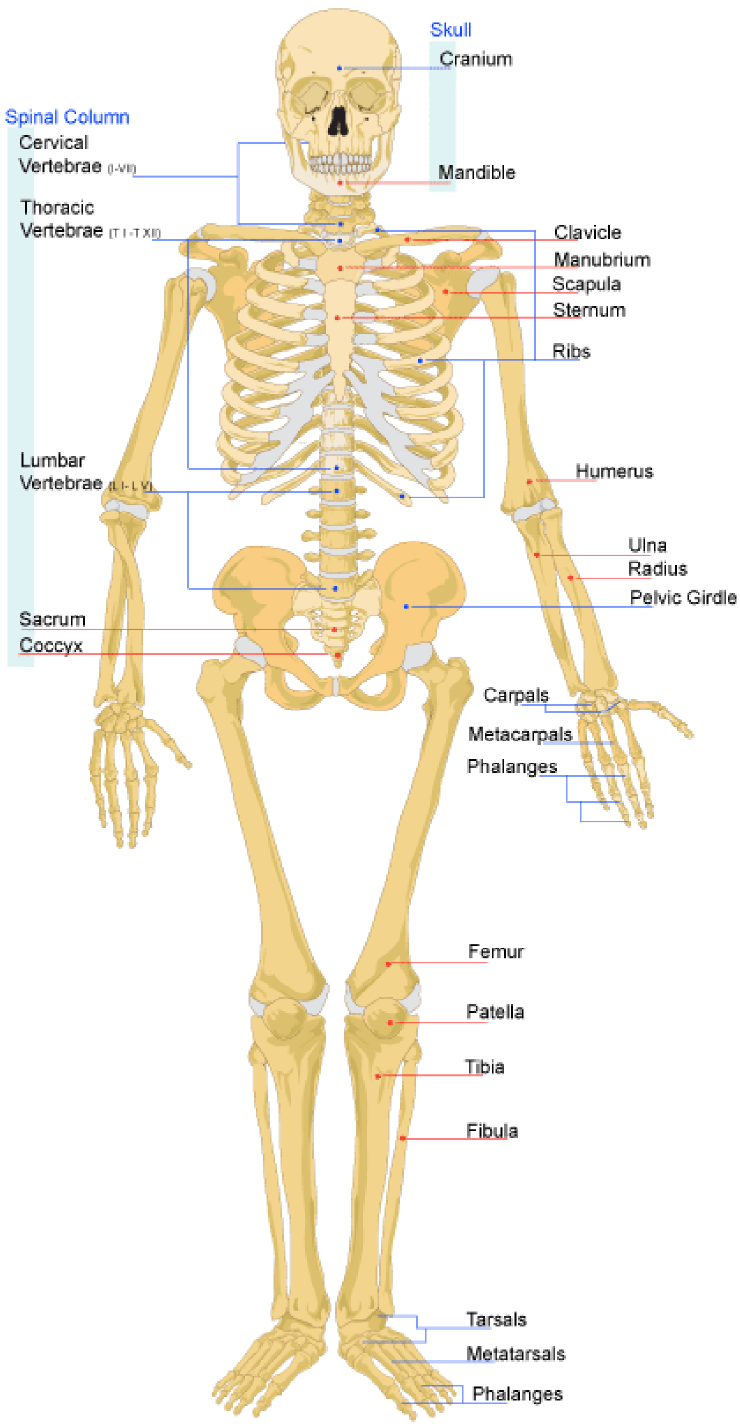


FIGURE 3.13
The human skeleton includes bones and cartilage.

Functions of the Skeletal System

Your skeletal system gives shape and form to your body, but it also plays other important roles. The main functions of the skeletal system include:

- Support—the skeleton supports the body against the pull of gravity. This means you won't fall over when you

stand up. The bones in your lower body carry all your weight. They are larger than the bones in your upper body. The lower limb bones support your body when standing.
- Protection—the skeleton supports and protects your soft organs. For example, the skull protects the brain. Ribs in your chest help protect the heart and lungs.
- Movement—bones work together with muscles to move the body.
- Making blood cells —blood cells are mostly made inside certain types of bones.
- Storage—bones store calcium. They contain more calcium than any other organ. Calcium is released by the bones when it is needed.

Bones

Some people think bones are like chalk: dead, dry, and brittle. In reality, bones are very much alive. Bones are living organs. They are supplied with blood and nerves just like other parts of your body.

How Bones Grow and Develop

An unborn developing baby's skeleton is made entirely of cartilage. The relatively soft cartilage slowly changes to hard bone. By the time a baby is born, only several areas of cartilage remain. These areas include the ends of the long bones in the arms and legs. This allows these bones to keep growing in length during childhood.

By the late teens or early twenties, bones stop growing. By this time almost all cartilage has been replaced by bone. Bones cannot grow in length after this point. However, bones can continue to grow in width. This is due to being placed under more stress. Weightlifters develop very thick bones because they are lifting a lot of weight on a regular basis. To have strong bones, exercise is important.

Joints

A joint is a place where two or more bones meet. There are three different types of joints. These types are based on the amount of movement in the joint. These are called immovable, partly movable, and movable joints.

- Immovable joints do not allow the bones to move at all. In these joints, the bones are fused together. A human skull has immovable joints. You can see them in **Figure** 3.14.
- Partly movable joints allow very limited movement. In these joints, the bones are held together by cartilage. Cartilage is somewhat flexible. Examples of partly movable joints, can be found in the rib cage.
- Movable joints allow the greatest movement. Movable joints are the most notable. Movable joints are complex. They contain ligaments, special cushions, and liquids. The cushions and liquids help reduce friction. Fortunately, these features help our joints move freely. You can think of this like needing to add oil to a squeaky door hinge. There are several different types of movable joints. You can see three of them in **Figure** 3.15. Move these three joints in your own skeleton to experience the range of motion each allows.

Lesson Summary

- Bones are the main organs of the skeletal system. The skeletal system also includes cartilage and ligaments.
- Functions of the skeletal system include supporting and shaping the body, allowing movement, protecting inner organs, producing blood cells, and storing calcium.
- Joints connect bones to help protect vital organs and allow movement.
- Joints may be immovable, partly movable, or movable. Types of movable joints include ball-and-socket, hinge, and pivot joints.

FIGURE 3.14
Example of immovable joint: skull

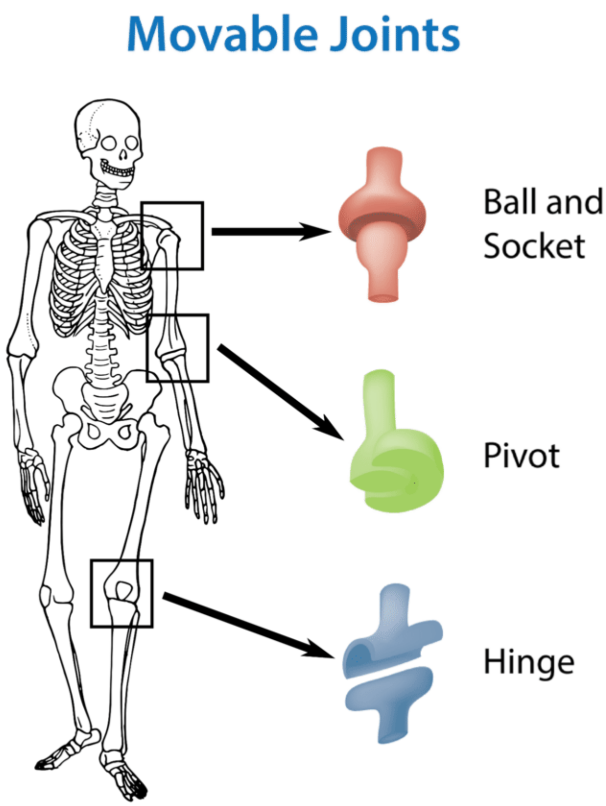


FIGURE 3.15
Examples of movable joints: shoulder, elbow, and knee

Lesson Review Questions

Recall

1. List components of the skeletal system.
2. What are some functions of the skeletal system?
3. Outline how human bones grow and develop, from the unborn developing baby to the adult.

Apply Concepts

4. Explain why people stop growing in height.
5. Regular weight-bearing exercise can increase the width of bones. Explain why this might be important.
6. How do bones help to protect vital organs?

Extend

7. How would knowledge about skeletal function help you design more effective protective athletic gear?

Points to Consider

The skeletal system allows the body to move, but the muscular system is also needed.

1. How do muscles and bones work together to move the body?

3.8 Introduction to Plants

Lesson Objectives

- Describe plants, their needs, and their importance.
- Describe the structure and function of roots, stems, and leaves.

Lesson Vocabulary

- leaf
- plant
- root
- stem

Introduction

It's Mom's birthday today. Tonight your father is having a party for her. Everyone is helping out, even you. The table needs to be set with dinnerware. Mom is making your father's favorite meal. You are helping by picking up your things and putting them away. You are almost finished when the doorbell rings. You run to the door to answer and there stands friends of your parents. They are here for the party.

You notice one person holding cut flowers. Another person is holding a plant. Flowers and plants are a common gift in our society. You are thinking that you would rather have a video game. Why are flowers and plants so important to us? Sure, they look nice. Might there be some other reasons? Perhaps!

What Are Plants?

Plants are not like animals. Plants cannot move to find food. Instead, they must have the ability to survive where they are. They also must have the ability to make their own food. They also cannot move around to find a mate, so they have evolved unique ways to reproduce.

Needs of Plants

Plants are somewhat limited by temperature in terms of where they can grow. They need temperatures above freezing. The can survive temperatures below freezing, but cannot grow during this period of time. They also need light, carbon dioxide, and water. These are the ingredients they need to make their own food. Like most other living things, plants need oxygen. Oxygen is required for cellular respiration. In addition, plants need minerals. The minerals are required to make proteins and other organic molecules.

Importance of Plants

Life as we know it would not be possible without plants. Why are plants so important?

- Plants supply food to nearly all land organisms, including people. We mainly eat either plants or other living things that eat plants.

- Plants produce oxygen. Oxygen is needed by almost all the Earth's organisms.
- Plants absorb carbon dioxide from the air. This helps control the greenhouse effect and global warming.
- Plants recycle matter in ecosystems. For example, they are an important part of the water cycle. They take up liquid water from the soil through their roots. They release water vapor to the air from their leaves.
- Plants provide many products for human use. They include timber, medicines, dyes, oils, and rubber.
- Plants provide homes for many other living things. For example, a single tree may provide food and shelter to many species of animals. One example is **Figure** 3.16 of a bird's nest.

FIGURE 3.16
Many birds build their nests in trees. Plant materials are often used to build them.

Plant Structures

Most modern plants have several structures that help them survive and reproduce. Major structures of most plants include roots, stems, and leaves.

Roots

Roots are important organs in most modern plants. There are two types of roots. First, there are the primary roots, which grow downward. Secondly, there are the secondary roots. These roots branch out to the sides. Together, all the roots of a plant make up the plant's root system. **Figure** 3.17 shows two different types of plant root systems. A taproot system has a very long primary root, called a taproot. A fibrous root system has many smaller roots and no large, primary root.

The roots of plants have three major jobs. They must absorb water and minerals, anchor and support the plant, and store food.

- Roots have special features that are well suited to absorb water and dissolved minerals from the soil.
- Root systems help anchor plants to the ground. They allow plants to grow tall without falling over.
- In many plants, roots store food produced by the leaves. This process is called photosynthesis.

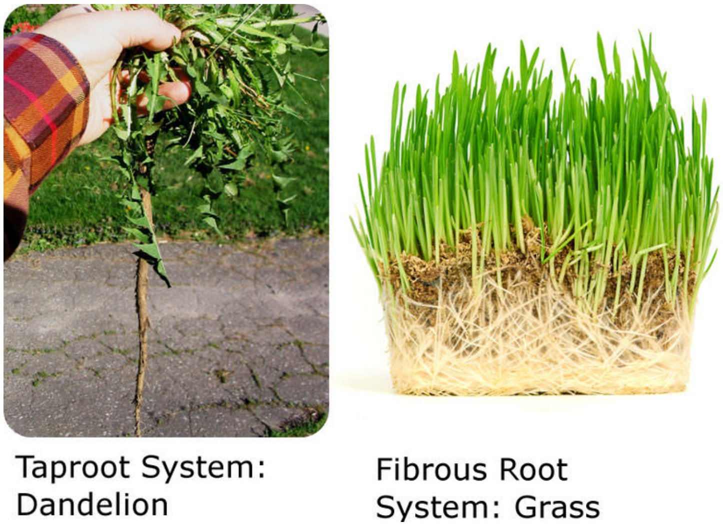


FIGURE 3.17
Two types of root systems

Stems

Stems are organs that hold plants upright. They allow plants to get the sunlight and air they need. Stems also bear leaves, flowers, cones, and smaller stems. These structures grow at points called nodes. The stem between nodes is called an internode. (See **Figure** 3.18.)

FIGURE 3.18
Nodes and internode of a stem

Stems are needed for transport and storage. They carry water and minerals from roots to leaves. It carries dissolved sugar from the leaves to the rest of the plant. The stem is like an elevator for the plant. The stem allows movement from the top of the plant to the bottom and vice versa. Without this connection between roots and leaves, plants could not survive. In many plants, stems also stores food or water during cold or dry seasons.

Leaves

Leaves are the keys not only to plant life but to virtually all life on land. The primary role of leaves is to collect sunlight. This sunlight is needed for the plant to make food. Leaves vary in size, shape, and how they are arranged on stems. You can see examples of different types of leaves in **Figure** 3.19.

Each type of leaf is well suited for the plant's environment. It maximizes light exposure while conserving water. They are also reduces wind resistance. Leaves also benefit the plant in some other way in its particular habitat. For example, some leaves are divided into many smaller leaflets. This reduces wind resistance and water loss.

Leaves are basically factories for photosynthesis.

- A factory has specialized machines to produce a product. In a leaf, the "machines" are the chloroplasts.
- A factory is connected to a transportation system that supplies it with raw materials and carries away the finished product. In a leaf, transport is carried out by veins containing vascular tissue. Veins carry water and minerals to the cells of leaves. They carry away dissolved sugar.
- A factory has bricks, siding, or other external protection. A leaf is covered with dermal cells. They secrete waxy cuticle to prevent evaporation of water from the leaf.
- A factory has doors and windows to let some materials enter and leave. The surface of the leaf has tiny pores called stomata (stoma, singular). They can open and close to control the movement of gases between the leaves and the air. You can see a close-up of a stoma in **Figure** 3.20.

What is Photosynthesis?

If a plant gets hungry, it cannot walk to a local restaurant and buy a slice of pizza. So, how does a plant get the "food" it needs to survive? Plants are **producers**, which means they are able to make, or produce, their own "food." They also produce the "food" for other organisms. Plants collect the energy from the sun and turn it into special chemicals. Using the energy from the sun, they produce the special chemicals using air, water and nutrients from the soil. So once again, how does a plant get the food it needs to survive? The plants is able to make its own "food" from the sun 's energy , carbon dioxide from the air, and water .

Actually, almost all organisms obtain their energy from plants. For example, if a bird eats a caterpillar, then the bird gets the energy that the caterpillar. The caterpillar gets its energy from the plants it eats. So the bird indirectly gets energy from the plant. Therefore, the process of photosynthesis is central to sustaining life on Earth.

Lesson Summary

- Plants feed most other organisms. They also perform many other services.
- Three organs (structures) commonly found in modern plants are roots, stems, and leaves.

Lesson Review Questions

Recall

1. What are plants? What do plants need?
2. How do plants grow?

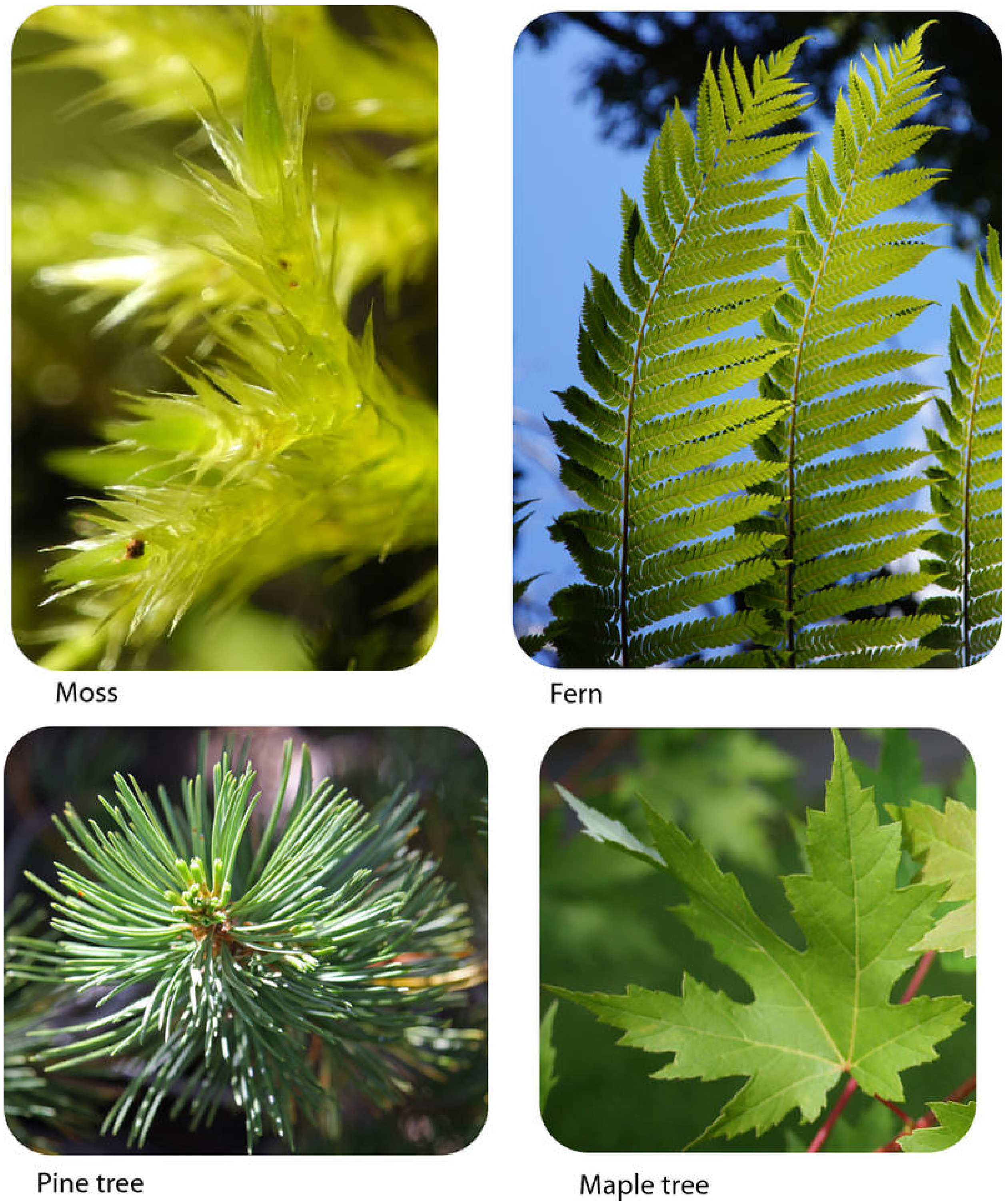


FIGURE 3.19

Variation in plant leaves

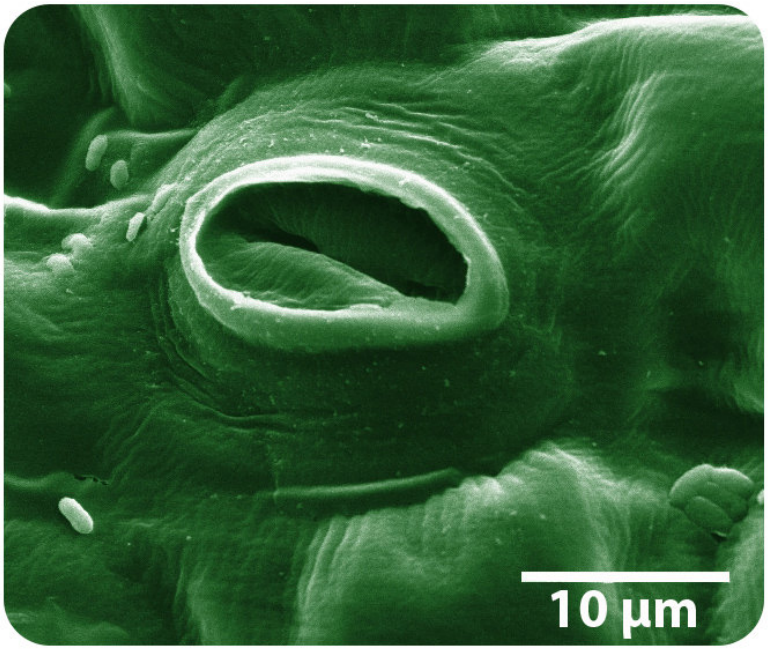


FIGURE 3.20
Stoma on the surface of a leaf, greatly enlarged

3. Outline the general life cycle of a plant.

Apply Concepts

4. Choose one of the three main organs of plants: roots, stems, or leaves. State the primary function of the organ, and then explain how the organ's structure suits it for its function.

Think Critically

6. Why would life as we know it be impossible without plants?

3.9 Plant Reproduction

Lesson Objective

- Identify processes of sexual reproduction in flowering plants, including pollination, fertilization (seed production), seed dispersal, and germination.

Lesson Vocabulary

- reproduction
- pollination
- pollen
- fertilization
- seed dispersal

So what exactly is a flower?

This view is of a beautiful lily flower. Notice the fine detail. There is a reason why this flower looks like it does. Do you know why flowers so colorful? What is the purpose of all the parts?

Flowering Plants

Flowering plants evolved millions of years ago. Unlike animals, there are no boy or girl plants. Plants have both male and female parts. That does not mean that plants do not need help to reproduce.

Some plants form seeds. These are called flowering seed plants. The seeds form in the plant's ovaries. A plant's fruit may fall to the ground and start to grow. A plant's fruit may get eaten by animals. If eaten, the seeds of the fruit are passed through the animal's digestive tract. As the animal eliminates its waste, the seeds are spread around. Because animals do not stay in one place, they help the plant populate a bigger area. The animal gets a tasty treat and helps the plant reproduce.

The ovaries are just one of the structures of a plant. The flower's job is to attract animals, such as bees and birds. The animals are able to spread the pollen to other plants. Animals are needed to get the pollen from the male to the female parts of the plant. It is important for diversity that the pollen is passed from one plant to another.

Parts of a Flower

Flowers have both male and female reproductive parts. The main parts of a flower are shown in **Figure** 3.21. They include the stamen, pistil, petals, and sepals.

The stamen is the male reproductive structure of a flower. It consists of a stalk-like filament. At the end of the filament is the anther. The anther contains pollen sacs. It is here the pollen grains form. The filament raises the anther up high. This helps the pollen to be more likely to be carried away. It may blow in the wind. It may be picked up by an animal and carried away. Many animals are pollinators. A pollinator is any animal who carries the pollen from one plant to another.

The pistil is the female reproductive structure of a flower. It consists of a stigma, style, and ovary. The stigma is raised. It is also sticky to help catch pollen. The style supports the stigma and connects it to the ovary. The ovary contains the egg.

Petals attract animals to the flower. Petals are often brightly colored. Bright colors make them easier for animals to see.

Sepals protect the developing flower while it is still a bud. Sepals are usually green. Sepals camouflage the bud from animals that may eat it for food.

Flowers and Pollinators

Some flowers may have bright colors. Others may have strong scents. Some may have sweet nectar. All these traits help to attract animals. Why do you think it is important to attract animals? Animals are able to carry around pollen from one plant to another. The animals they attract may include insects, birds, mammals, and even reptiles. While visiting a flower, an animal picks up pollen from the anthers. The animal then travels to another flower. While there, some of the pollen brushes off on the stigma. This allows cross-pollination. By spreading pollen to different plants, it helps increase plant diversity.

MEDIA

Click image to the left or use the URL below.

URL: http://www.ck12.org/flx/render/embeddedobject/167079

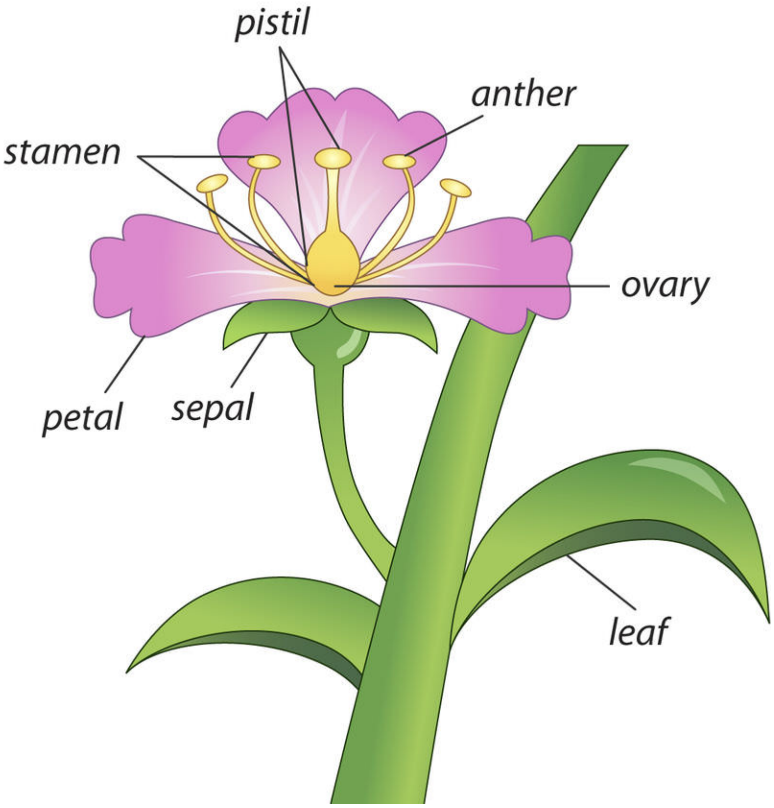


FIGURE 3.21
A flower includes both male and female reproductive structures.

FIGURE 3.22
Brightly colored fruits attract animals that may disperse their seeds. It's hard to miss the bright red apples on these trees.

Evolution of Flowering Plants

Flowering plants have been around for a really long time. Scientists think they evolved over 200 million years ago. Fossil flowers have male and female reproductive organs just like today. There have been changes over time as plants evolved new and better traits to help them reproduce. From fossil evidence, the ancient plants did not have petals or sepals as they do today.

Just like now, the earliest flowers most likely attracted insects and other animals. The insects and animals spread the pollen from flower to flower. This was a big help to flowers. Animals can be better than the wind at carrying pollen. Wind-spread pollen may or may not land on another flower. To take better advantage of this "animal labor," plants evolved certain traits. These traits can include brightly colored petals, strong scents, and sweet nectar. These are all traits that help attract animals. The flowers are able to move around their pollen. The animals get a free meal.

Other plants developed additional traits that helped them reproduce. (See **Figure** 3.23.)

FIGURE 3.23
Dandelion seeds have tiny "parachutes." Maple seeds have "wings" that act like little gliders. Burdock seeds are covered with tiny hooks that cling to animal fur.

Some plants rely on seeds getting stuck in animal fur. Once stuck, the seeds are carried off to another location. Eventually, the seeds fall off.

Other plants developed traits to better disperse their seeds using the wind. With time, plants develop better and better traits to help them reproduce.

Developing Specialized Traits

Relying on an animal to come by is risky. A flower may have to wait a long time for the right animals to come by. What if one never passes close enough to the flower?

Hoping the wind will blow is also risky for a plant. What if the wind does not blow? What if the blowing pollen does not land on another flower? The wind could even blow the pollen over the ocean where it is wasted.

Giving free nectar is costly. It is not a good use of the plant's energy. A plant uses a lot of energy to produce nectar. Some animals may just drink the nectar. They may not carry off any pollen in return. To improve their chances, plants evolved special traits. For example, they developed ways to "hide" their nectar. Only certain animals were able to get at the plant's hidden nectar. These specific animals might be more likely to visit only flowers of the same species. This was also a benefit for some animals. Animals also evolved special traits to get to the nectar. This is called co-evolution of traits. Two examples of this type of co-evolution are shown in **Figure** 3.9.

The hummingbird has a long narrow bill. The long narrow bill enables it to reach nectar at the bottom of the tube-shaped flowers. The bat is active at night. Bright white, night-blooming flowers attract it. In each case, the flowering plant and its animal co-evolved. They have become better suited for their roles.

Lesson Summary

- Most modern seed plants produce seeds in the ovaries. Ovaries may develop into fruits.
- Flowers attract pollinators and fruits are eaten by animals. Both traits aid the dispersal of seeds.

Lesson Review Questions

Recall

1. Describe the male and female reproductive structures of flowers and their functions.
2. State how fruits help flowering plants reproduce.
3. Explain how flowering plants and their animal pollinators co-evolved.

3.10 Seasonal Changes in Plants

Learning Objectives

led

- Describe how plants sense changes of season.
- Explain photoperiodism.

Lesson Objectives

- Describe the seasonal changes in plants.

Lesson Vocabulary

- region
- ecosystem
- biome

How does this plant know it's Christmas?

This plant is known as a Christmas cactus. It only blooms once a year. Can you guess when that is? Of course, the Christmas cactus blooms during the Christmas season. But how can it tell that it's Christmas time? How can a plant know the time of the year?

Seasonal Changes

Have you seen the leaves of plants change colors? During what time of year does this happen? What causes it to happen? Plants can sense changes in the seasons. Leaves change color and drop each autumn in some climates (**Figure** 3.24).

FIGURE 3.24
Leaves changing color is a response to the shortened length of the day in autumn.

Certain plants only bloom during the winter. The Christmas cactus is one of these plants. Another plant that is popular during the holiday season is the poinsettia. It also blooms in the winter months. In the spring, the winter buds on the trees break open. From these buds, the leaves start to grow. How do plants detect time of year?

You detect seasonal changes by the change in temperature. Plants do not sense temperature change. Instead, plants sense the length of daylight. Because of the tilt of the Earth, the length of daylight varies. In the winter months there are less hours of light than during summer days. That's why, in the winter, it starts getting dark very early in the evening. It also stays dark longer. You may notice it is still dark when you get ready for school. In the summer, it will be bright early in the morning. The Sun will not set until late at night. We use a clock to determine this amount of time. With the special chemical that helps it sense light, plants can tell how long a day is.

For example, in the fall, the days start to get shorter. Trees can sense that there is less sunlight. The plant is stimulated by the shortening of the day. Chemical messages tell the leaves to change colors and fall. Not all plants use daylight as a cue.

Some flowering plants sense the length of night as a signal to flower. Each plant has a different photoperiod, or night length. When the plant senses the appropriate length of darkness, it flowers. Flowering plants are classified as long-day plants or short-day plants. Long-day plants flower when the length of daylight is long. Short-day plants flower when the day length is shorter. Long-day plants include carnations, clover, lettuce, wheat, and turnips. Short-day plants include cotton, rice, and sugar cane.

Lesson Summary

- Plants can respond to the change of season by losing their leaves, flowering, or breaking dormancy.
- Plants go through seasonal changes after detecting differences in day length.

Lesson Review Questions

Recall

1. How do plants detect the change in seasons?
2. What signals a tree to drop its leaves?
3. Distinguish between long-day plants and short-day plants.
4. Give two examples of long-day plants.

3.11 Habitat Destruction

Learning Objectives

- Define habitat destruction.
- Give examples of habitat destruction.
- Discuss what causes the destruction of habitats.
- Explain the effects of slash-and-burn agriculture.
- Give examples of invasive species.
- Describe the effects of non-native species.

Lesson Objectives

- Describe ways plants and animals, including humans, can impact the environment.

Lesson Vocabulary

- environment
- extinction
- habitat
- impact

What's happening to this land?

This does not look very pretty. It certainly is not how it used to look. Why does the land look this way? This picture was taken in southern Mexico. It shows land being cleared for agriculture. The forest has been cut down. The fallen trees have been burned to make room for a farm. Think about how many plants and animals used to live here. In comparison, think about what would happen if your city was burned down. Where would you go? How would you survive? In the case of this picture, many plants and animals lost their homes. This is an example of habitat destruction.

Habitat Destruction

From a human point of view, a habitat is where you live. It might be your city, town, or neighborhood. Your habitat can be altered. Most people move a few times in their lives. But a plant cannot move. An animal may not be suited to live in another area. A **habitat** is the natural home or environment of an organism. Humans often destroy the habitats of other organisms. The loss of habitat can cause the extinction of species. **Extinction** is when a species disappears forever. Once a species is extinct, it can never be brought back. Humans cause habitat destruction in many ways. There are two common ways this happens. Land may be cleared. Another way is when an animal or plant is brought to an area where it does not belong.

Land Loss

When land is cleared, habitats are lost. It may be cleared for agriculture. It may also be used for building new homes or businesses. Within the past 100 years, the amount of land used for agriculture has almost doubled. Land used for grazing cattle has more than doubled. Many wetlands have also been lost to agriculture (**Figure** 3.25). The U.S. has lost almost all the natural tall-grass prairies. Thee areas of tall thick grass have virtually disappeared. These areas of land had thick fertile soil. Their grasses had very deep root systems. These deep and thick roots reduced the amount of soil erosion. They also were home to many plants and animals. Prairies were wonderful places. They were home to colorful flowers, prairie dogs, and herds of bison.

FIGURE 3.25
Wetlands such as this one in Cape May, New Jersey, filter water and protect coastal lands from storms and floods.

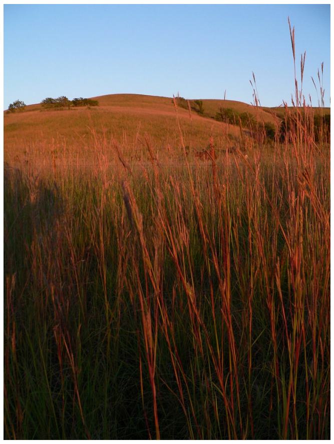


FIGURE 3.26
The Flint Hills contain some of the largest remnants of tallgrass prairie habitat remaining in North America.

FIGURE 3.27
Herds of bison also made up part of the tallgrass prairie community.

Slash-and-Burn Agriculture

Types of habitats that are rapidly being lost include forests. This is especially true for tropical rainforests. The largest cause of this loss is **slash-and-burn agriculture**. To gain farmland, people cut down trees. They then burn the area. This technique is used in many areas around the world. It is very damaging.

What happens due to the use of slash-and-burn methods? First, nutrients are quickly lost from the soil. This often results in people abandoning the land within a few years. Then, the top soil erodes. What is left is not well suited for life. Very few things can grow in the soil. **Desertification** turns forests into a desert. Plants have adapted for wet and shady conditions. They may not survive in drier and heavily sunlit areas. Half of the Earth's mature tropical forests are gone. At this rate, it does not look good for rainforests. Given the current rate of deforestation, all tropical forests will be gone by the year 2090!

Non-native Species

Imagine you are in a baseball league. The league is made up of several schools. All the players on the teams are the same age. Now imagine a new team joins the league. This teams has students that are much older. They may be bigger and stronger. This new team certainly has an advantage. Their pitcher can throw the ball faster. Their hitters can hit the ball farther. This isn't fair to the other teams. This is sort of what it can be like when a new species is introduced into an animal's habitat.

Habitats are changed by new members. These new members are called non-native species. Non-native means they are not from this area. You can think of them as uninvited guests. They may not have natural predators. In most habitats there is a balance. This balance controls the size of groups of animals. Invasive species have an unfair advantage over their rivals. They are able to out-compete the native species for resources. At times, invasive species are very successful. In some areas, they have taken over the habitat. In this case, the native species goes extinct (**Figure** 3.28).

Recently, cargo ships have transported new species to the Great Lake. These include the zebra mussel, spiny waterflea, and ruffe (a freshwater fish)(**Figure** 3.29). These new species are better at hunting for food. They have caused some of the native species to go extinct.

Invasive species can disrupt food chains. They can carry disease. They may also prey on native species directly. More importantly, they out-compete native species for limited resources, like food. All of these effects can lead to extinction of the native species.

FIGURE 3.28
An exotic species, the brown tree snake, hitchhiked on an aircraft to the Pacific Islands, causing the extinctions of many bird and mammal species which had evolved in the absence of predators.

Other Causes

Above were just a few things that caused habitat loss or change. There are many ways in which living organisms can affect their ecosystem. In some areas, it is because of fire management. Fire is a natural event, so managing fire correctly is very important.

In other areas, fisherman have taken too many fish from one area. This places the species at risk of extinction. It also affects other living things that may rely on these fish for food.

The image below shows a picture of a mine. Mining changes the Earth's surface. This area may once have been a forest or a prairie. Think about how many plants and animals may once have lived here. Now it is a giant hole in the ground.

Pollution is also a major factor in habitat loss and change.

FIGURE 3.29
These zebra mussels, an invasive species, live on most man-made and natural surfaces. Here they have infested the walls of the Arthur V. Ormond Lock on the Arkansas River. They have caused significant damage to American waterways, locks, and power plants.

FIGURE 3.30
Strip coal mining, pictured here, has destroyed the entire ecosystem.

Examples of Habitat Destruction

One type of habitat that is under great threat is **wetlands**. By the 1980s, most of the U.S. wetlands were lost. Things are even worse in Europe. In their wetlands, many species have already gone extinct. One country that is known for its wetlands is Scotland. In Scotland, these wetland areas are called **bogs.** Many of Scotland's bogs have been lost due to human development.

Another example of species loss happened in Madagascar. From 1970 to 2000, slash-and-burn agriculture was used. Over time, 10% of the country's total native plants were lost. The area turned into a wasteland. The soil was exposed to the forces of water. Soil from erosion entered the waterways. Much of the country's river ecosystems have since been destroyed. Several fish species are almost extinct. The runoff from the erosion has also affected ocean life. Some coral reef formations in the Indian Ocean are completely lost.

Lesson Summary

- There are many causes of habitat destruction. These include clearing of land and introduction of invasive species.
- Slash-and-burn agriculture can lead to desertification. This means fertile top soil is lost.

Lesson Review Questions

Recall

1. What is a habitat?
2. What are the primary ways that humans destroy habitats?
3. Why may invasive species thrive in a new area? Why is this an issue?
4. Describe slash-and-burn agriculture.

3.12 References

1. Image copyright Svetolk, 2013. A crow that has habituated to a scarecrow . Used under license from Shutterstock.com
2. Katie Hunt; Bill Mulder. Lion cubs and dogs playing . CC BY 2.0
3. Image copyright Danila, 2014. Child playing in a sandbox . Used under license from Shutterstock.com
4. Flickr:FaceMePLS. Staying balanced on a scooter requires control of the body's muscles and awareness of th e surroundings . CC BY 2.0
5. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
6. Mariana Ruiz Villarreal (User:LadyofHats/Wikimedia Commons), modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Circulatory_System_no_tags.svg . Public Domain
7. NIDDK. http://commons.wikimedia.org/wiki/File:Digestivetract.gif . Public Domain
8. CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
9. Image copyright Zoltan Pataki, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
10. Flickr:fringefalcon. http://www.flickr.com/photos/rummell/4254828276 . CC BY 2.0
11. National Cancer Institute, NIH. http://commons.wikimedia.org/wiki/File:Anatomy_The_Skin_-_NCI_Visuals_Online.jpg . public domain
12. Jodi So and Marianna Ruiz Villarreal (LadyofHats). CK-12 Foundation . CC BY-NC 3.0
13. Mariana Ruiz Villarreal (LadyofHats). http://commons.wikimedia.org/wiki/File:Human_skeleton_front_en.svg . Public Domain
14. Alex Grichenko. http://www.publicdomainpictures.net/view-image.php?image=50580&picture=human-skull-on-display . Public Domain
15. Zachary Wilson, using skeleton by User:GregorDS/Wikimedia Commons. CK-12 Foundation (skeleton available at http://commons.wikimedia.org/wiki/File:Human_skeleton_diagram_trace.svg) . CC BY-NC 3.0 (using skeleton in public domain)
16. Tomwsulcer. Bird nests are often constructed in trees . Public domain
17. Taproot: Robbie Sproule; Fibrous: Image copyright Nata-Lia, 2014. Taproot: http://www.flickr.com/photos/robbie1/501522313/; Fibrous: http://www.shutterstock.com . Taproot: CC BY 2.0; Fibrous: Used under license from Shutterstock.com
18. Hardyplants. Nodes and internodes of a stem . Public domain
19. Moss (upper left): Thomas Bresson, Fern (upper right): Allie_Caulfield, Pine tree (bottom left): Dcrjsr, Maple tree (bottom right): Jean-Pol GRANDMONT. Plant leaves come in a variety of shapes and sizes . Moss (upper left): CC-BY 3.0,Fern (upper right): CC-BY 2.0,Pine tree (bottom left): CC-BY 3.0,Maple tree (bottom right): CC-BY 3.0
20. Dartmouth Electron Microscope Facility. Microscope image magnifying the stomata on a tomato leaf . Public Domain
21. Christopher Auyeung and Hana Zavadska. CK12 Foundation .
22. Liz West. http://www.flickr.com/photos/calliope/54070473/ .
23. Bat: Courtesy of the US Fish and Wildlife Service; Hummingbird: Thomas Bresson. Hummingbird and flowering plant symbiotic relationship .
24. Flickr:Leesa0502. Leaves change color in a response to the shortened length of the day in autumn . CC BY 2.0
25. Courtesy of Anthony Bley, U.S. Army Corps of Engineers. Wetlands help to filter water and protect coastal lands from storms and floods . Public Domain
26. USFWS Mountain Prairie. The Flint Hills contain some of the largest remnants of tallgrass prairie habitat remaining in North America . CC BY 2.0

27. User:Reservoirhill/Wikipedia. Herds of bison make up a part of the tallgrass prairie community . Public Domain
28. Courtesy of the National Park Service. Exotic species such as the brown tree snake can cause the mass extinction of many species . Public Domain
29. Courtesy of Laurie Driver, U.S. Army Corps of Engineers. Zebra mussels are invasive species that have cause significant economic damage to waterways. . Public Domain
30. Stephen Codringto. Strip coal mining destroys entire ecosystems . CC BY 2.5

Chapter 4 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.

4.1 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** 4.1.

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

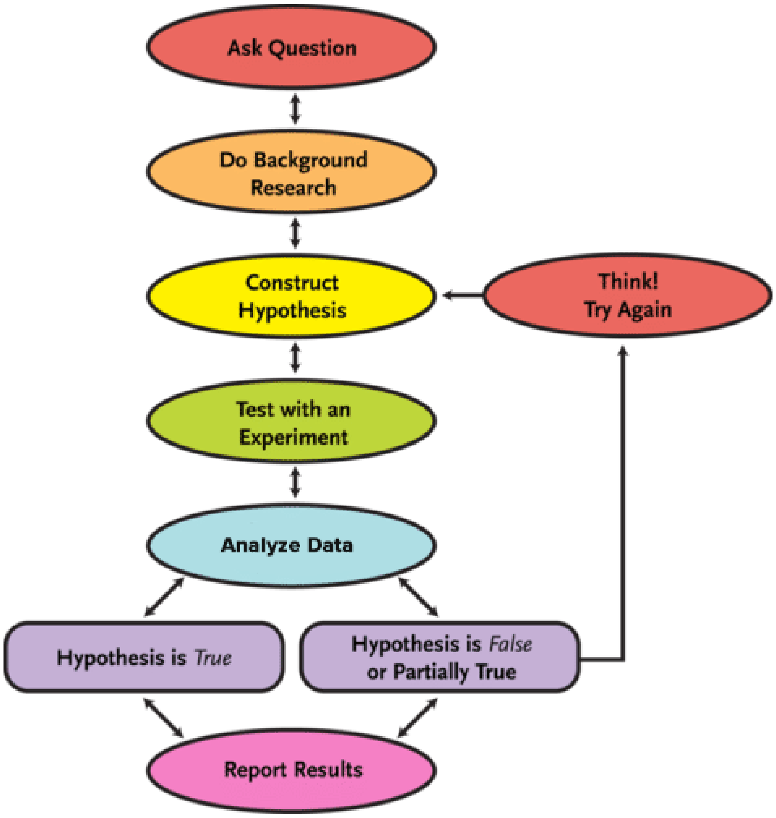


FIGURE 4.1
The Scientific Method.

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** 4.2).

FIGURE 4.2
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** 4.3.

FIGURE 4.3
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.

FIGURE 4.4
A pair of farmers take careful measurements in the field.

Data and Experimental Error

During an experiment, a scientist collects data. The data might be measurements, like the farmer is taking in **Figure** 4.4. 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.

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** 4.5). 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.

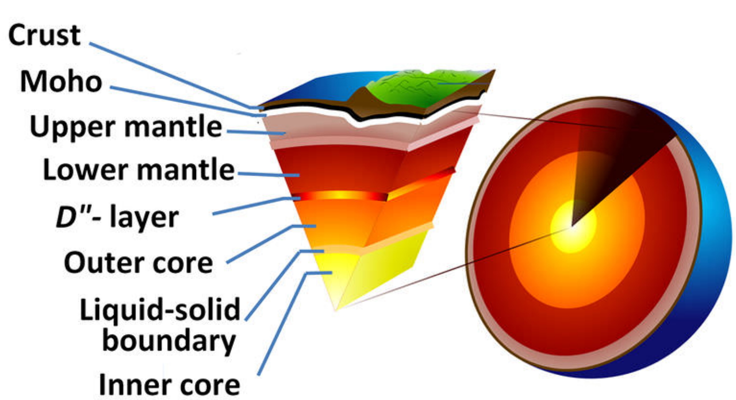


FIGURE 4.5
Earth's Center.

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** 4.6). 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.

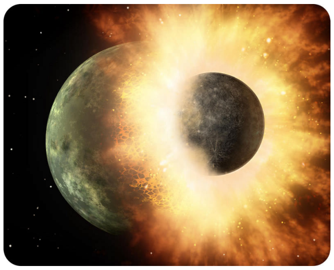


FIGURE 4.6
A collision showing a meteor striking Earth.

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** 4.7). We must also be sure to treat any injury or accident appropriately.

FIGURE 4.7
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** 4.8). 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 4.8
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** 4.9). 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.

FIGURE 4.9
Outdoor Excursions.

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.

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?

4.2 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** 4.10).

FIGURE 4.10

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** 4.11).

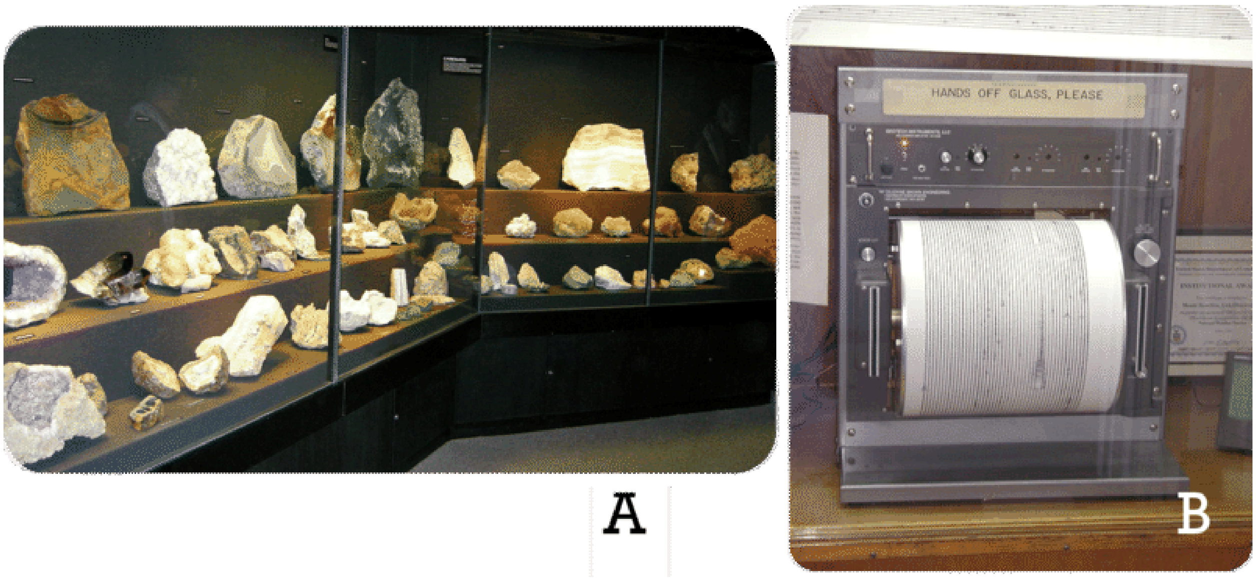


FIGURE 4.11
(A) Mineralogists focus on all kinds of minerals. (B) Seismographs are used to measure earthquakes and pinpoint their origins.

Some volcanologists brave molten lava to study volcanoes. Seismologists monitor earthquakes worldwide to help protect people and property from harm (**Figure** 4.11). 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** 4.12).

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.

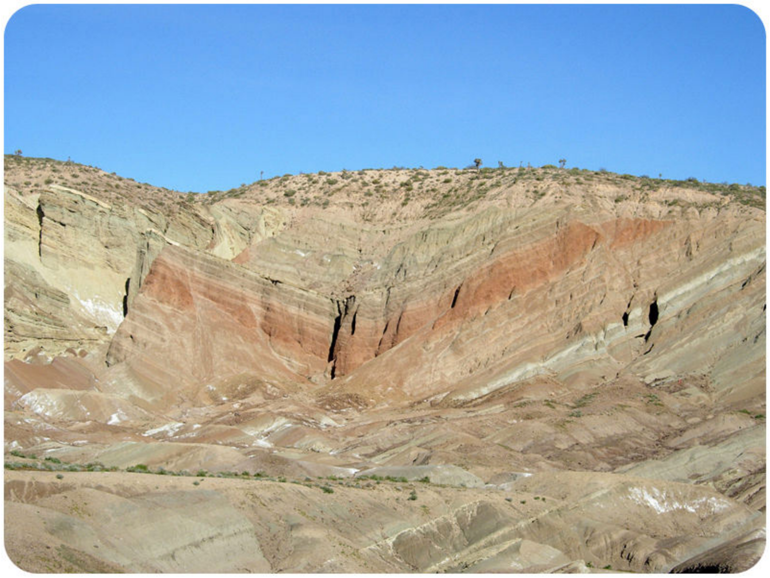


FIGURE 4.12
These folded rock layers have bent over time. Studying rock layers helps scientists to explain these layers and the geologic history of the area.

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 4.13
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** 4.13). 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** 4.14).

FIGURE 4.14
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** 4.15).

FIGURE 4.15
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** 4.16). They try to predict the chain reactions that could occur when one part of the ecosystem is disrupted.

FIGURE 4.16
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** 4.17). 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.

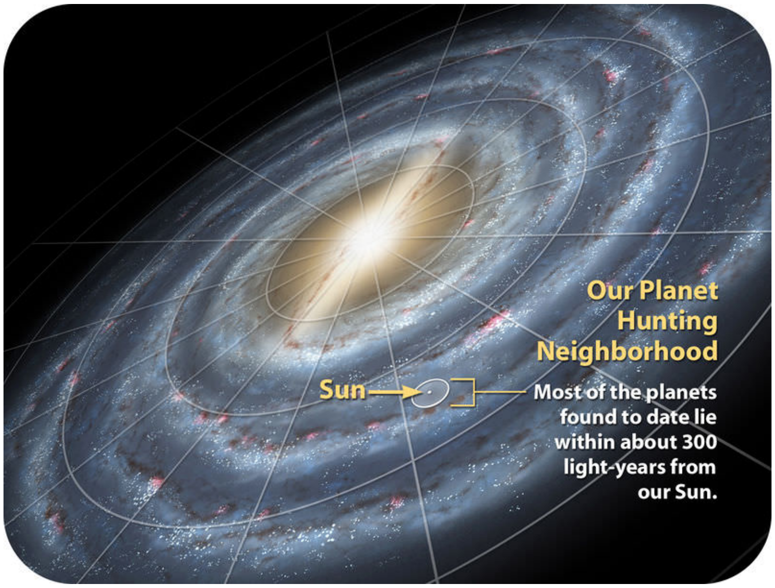


FIGURE 4.17
Scientists are using telescopes to search for other planets that may have conditions favorable for life. The places they can look are near our solar system in our galaxy.

- 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?

4.3 References

1. Image copyright Vitalez, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Christopher Auyeung. The Scientific Method .
3. Carl Wycoff. Soil Erosion .
4. Martin Pettitt. http://www.flickr.com/photos/95012874@N00/8024374063/ . CC BY 2.0
5. Courtesy Tim McCabe, USDA Natural Resources Conservation Service. http://commons.wikimedia.org/wiki/File:NRCSIA99093_-_Iowa_%282885%29%28NRCS_Photo_Gallery%29.jpg .
6. User:Washiucho/Wikimedia Commons and User:Brews ohare/Wikimedia Commons. Earth's Center. .
7. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:090810161208-large.jpg . Public Domain
8. A-C: European Chemicals Bureau; D: User:Maxxl2/Wikimedia Commons. http://wikimedia.commons.org/wiki/File:Hazard_C.svg; http://wikimedia.commons.org/wiki/File:Hazard_O.svg; http://wikimedia.commons.org/wiki/File:Hazard_T.svg; http://commons.wikimedia.org/wiki/File:ISO_7010_W012.svg . Public Domain
9. Image copyright Stephen McSweeney, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
10. Eric Gelinas. Outdoor Excursions . CC BY 2.0
11. Courtesy of NASA. Earth as seen from Apollo 17 . Public Domain
12. (A) Linda Spashett (User:Storye book/Wikimedia Commons); (B) Oleg Alexandrov. (A) http://commons.wikimedia.org/wiki/File:Cliffecastlemus_008.jpg (B) http://commons.wikimedia.org/wiki/File:Seismometer_at_Lick_Observatory.JPG . (A) CC BY 3.0; (B) Public Domain
13. Mark A. Wilson (Department of Geology, The College of Wooster). http://commons.wikimedia.org/wiki/File:Rainbow_Basin.JPG . Public Domain
14. Julian Mason. http://commons.wikimedia.org/wiki/File:S.A._Agulhas.jpg . CC BY 2.0
15. Jan Smith (Flickr:jemasmith). http://www.flickr.com/photos/26085795@N02/6837760467/ . CC BY 2.0
16. Flickr:Smeet Chowdury. http://www.flickr.com/photos/50628848@N07/6904295597/ . CC BY 2.0
17. Hannes Grobe/AWI. http://commons.wikimedia.org/wiki/File:Red_sea-reef_3641.jpg . CC BY 3.0
18. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Planet_Discovery_Neighbourhood_in_Milky_-Way_Galaxy.jpeg . Public Domain

CHAPTER 5 Earth Science: Basics

Chapter Outline

5.1 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.

Lesson Vocabulary

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

Introduction

Beautiful mountain ranges, deep canyons, flat plains. You can see all these features on Earth's surface. Beneath the sea are similar features. Only a few people have actually seen them directly. Some scientists study life on Earth. Some study outer space. Some scientists learn about Earth's surface. Earth is our home. We need to learn as much as possible about it. We need to study Earth's structures. There are many questions that need to be answered. Why are some mountains taller than others? Why are there volcanoes on the ocean floor? Why are some mountain chains on the edges of continents? Knowing the answers to these questions can give us clues to Earth's past and future. As you recall, scientist need to share what they learn. To do so, they must also be able to explain a feature's location.

Location

How can you describe your location? You might use a familiar system. You might say, "I live at 1234 Main Street, Springfield, Ohio." You could also say, "I live right behind the Elementary School." This method uses the school as a point of reference. Another example is, "I am at the corner of Maple Street and Main Street." Both streets may be a good reference for anyone living in your town.

Scientists must be able to pinpoint a feature they are studying. Scientists use a special system to describe locations. They use latitude and longitude as a reference. Lines of latitude and longitude form a grid. You may have used a grid system while doing graphing. This grid is centered on a reference point. Zero latitude is the equator. Lines of latitude run east to west. They divide the Earth from North to South. Lines of longitude run from north to south. They divide the Earth from East to West. Zero longitude runs through Greenwich, England. You may have heard the term, Greenwich Mean Time, or GMT.

The system of latitude and longitude works well for objects that do not move. Some things we study on Earth are in motion. How can we describe an object that is in motion?

Direction

It is not enough to describe some objects by their location. We may also need to know its direction. For example, a wind blows a storm over your school. Where is that storm coming from? Where is it going?

How can we describe a direction? The most common way is by using a **compass**. A compass is a device with a floating needle (**Figure** 5.1). The needle is a small magnet. The needle 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**.

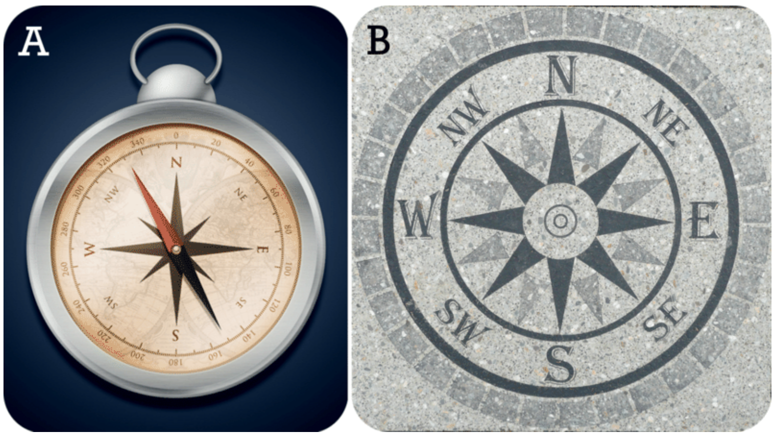


FIGURE 5.1
(A) A compass is a device that is used to determine direction. The needle points to Earth's magnetic north pole. (B) A compass rose shows the four major directions. It may also show intermediate directions between them.

The Earth has two poles. It has a magnetic north pole. It also has a geographic north pole. These two poles are close to each other but not the exact same place. The geographic north pole runs through the Earth's axis. It is on this imaginary axis that the Earth rotates. The geographic north pole is much like the spindle of a spinning top. The location of this pole does not change. However, the magnetic north pole does move over time. Compass users will need to correct for the difference in the two poles (**Figure** 5.2).

Some maps have a double compass rose. It will show both magnetic and geographic north. This allows users to make the corrections. An example is a nautical chart that boaters use. They use it to keep track of their positions at sea (**Figure** 5.3).

Topography

As you know, the surface of Earth is not flat. Some places have very high mountains. Other places have very deep canyons and valleys. For example, mountain ranges may be high above the surrounding areas. How can we describe a region's topography?

To describe it we need two things. First, we need to know how high or low it is. Then, we need to know how it compares to sea level. You might measure your height relative to your classmates. When your class lines up, some kids make high "mountains." Other students are more like small hills! Height is measured from the top of your head to the floor.

Continents and Landforms

What if you could drain all of Earth's oceans (**Figure** 5.4)? What would it look like? You might be really surprised. You see that the surface has two main features. It has continents and ocean basins. **Continents** are large land areas. These are the areas that are mostly above sea level. **Ocean basins** extend from the edges of continents. They include the ocean floor and Earth's deep ocean trenches. You will also notice the ocean floor is not flat. It too has many

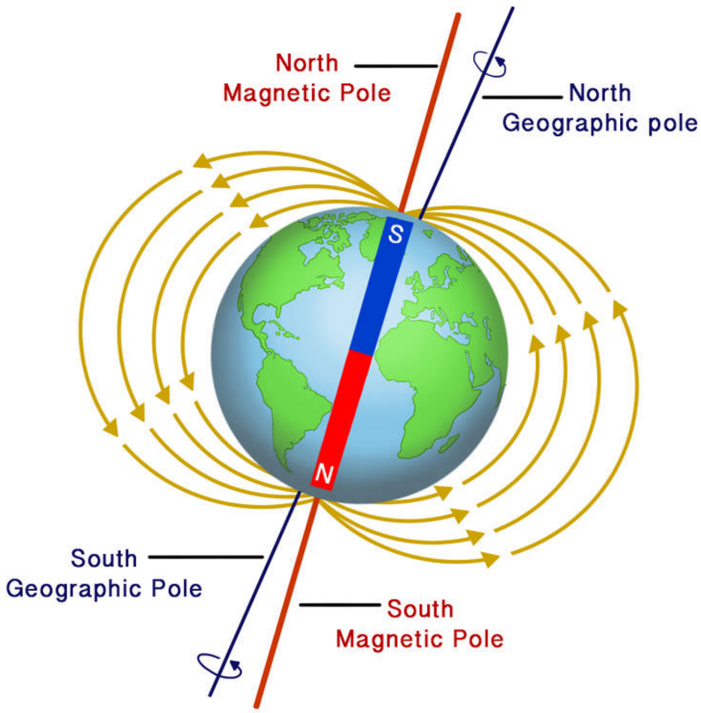


FIGURE 5.2
Earth's magnetic north pole is about 11 degrees offset from its geographic north pole.

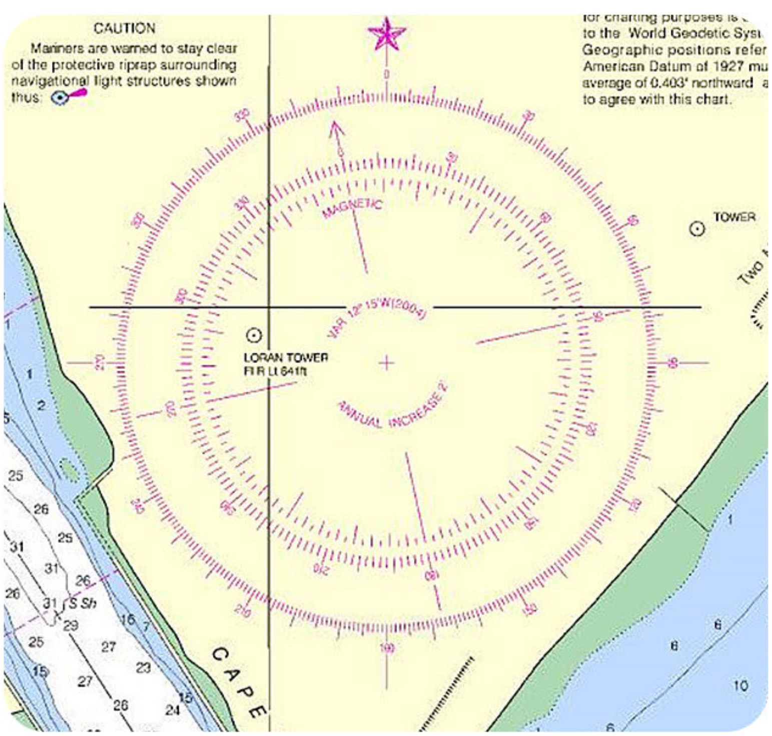


FIGURE 5.3
Nautical maps include a double compass rose that shows both magnetic directions (inner circle) and geographic compass directions (outer circle).

features similar to the continents. There are deep valleys, or trenches. There are large mountain ranges. There are also volcanoes. All of these features provide clues to Earth's geologic past and future.

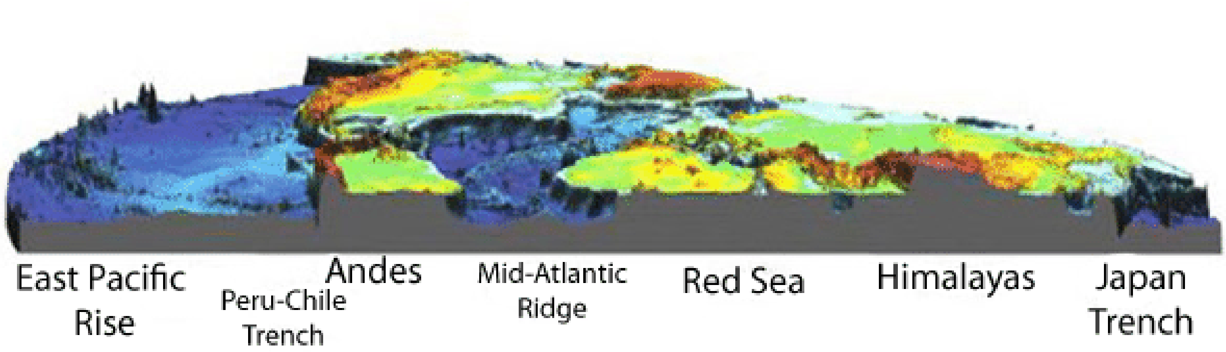


FIGURE 5.4

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 may only be millions of years old. 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. These features change over time, but how? There are actually two types of forces at work. One force builds the Earth up and the other tears it down.

Constructive forces cause landforms to grow. Lava flowing into the ocean creates new land. A volcano can be a constructive force. The Islands of Hawaii are good examples of the constructive force of volcanoes.

Destructive forces may blow landforms apart. A volcano blowing its top off is a destructive force. A volcano is a very fast change. Some changes to the Earth happen more slowly. The destructive forces of weathering and erosion change landforms more slowly. Over millions of years, mountains are worn down by erosion. The Appalachian Mountains are good examples of weathering and erosion. They were once as tall as the Rocky Mountains. They have been worn down over time.

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

Rivers and streams flow across continents. They cut away at rock. They may form river valleys (**Figure** 5.6). These are destructive forces. The bits and pieces of rock can be carried downstream by rivers. They are eventually deposited where rivers meet the oceans. These can form deltas, like the Mississippi River delta. They can also form barrier islands. Padre Island in Texas is an example of a barrier island. Rivers bring sand to the shore. The sand forms beaches. These are constructive forces.

Ocean Basins

The continental margin begins at the shore. It extends down to the ocean floor. It includes the continental shelf, slope, and rise. The continental shelf is part of the continent. It is about 100-200 meters deep. It is much shallower

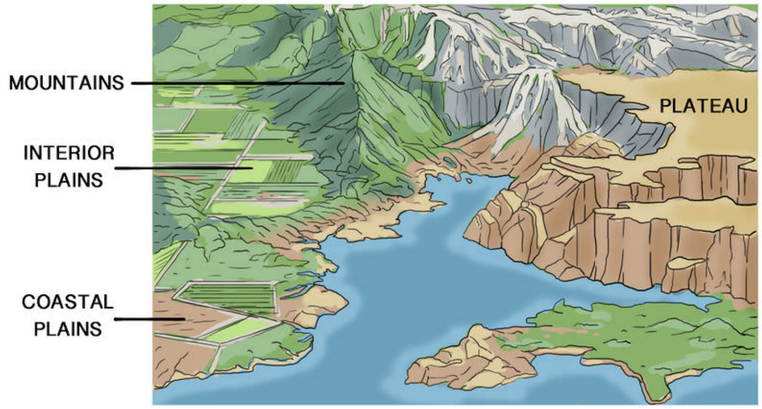


FIGURE 5.5
Features of continents include mountain ranges, plateaus, and plains.

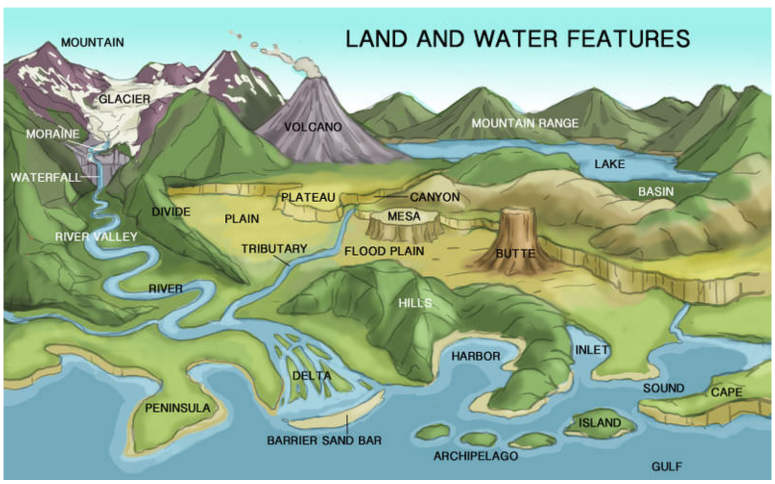


FIGURE 5.6
Summary of major landforms on continents and features of coastlines.

than the rest of the ocean. The continental shelf usually extends out about 100 to 200 kilometers from the shore (**Figure** 5.7).

The continental slope marks the edge of the continent. This is where the ocean basins begin.

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** 5.8). Some rise more than 1000 m above the seafloor.

There are also long and very tall (about 2000 m) mountain ranges. These ranges are connected. They form huge ridge systems. These ridge systems extend from ocean to ocean. These ridges usually occur at the centers of ocean basins. For this reason, they are called mid-ocean ridges (**Figure** 5.9). The mid-ocean ridges form from volcanic eruptions. Lava from inside Earth breaks through the crust. As a result, mountains are created.

You may have heard of the Grand Canyon. It is a mile wide and mile deep. That is a small scratch in Earth's surface compared to deep sea trenches.

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** 5.10). It is almost 11 km deep. To compare, Mt. Everest is a little less than 9 km tall. It is the tallest mountain on Earth. If placed in the trench, its peak would not reach the top of the trench.

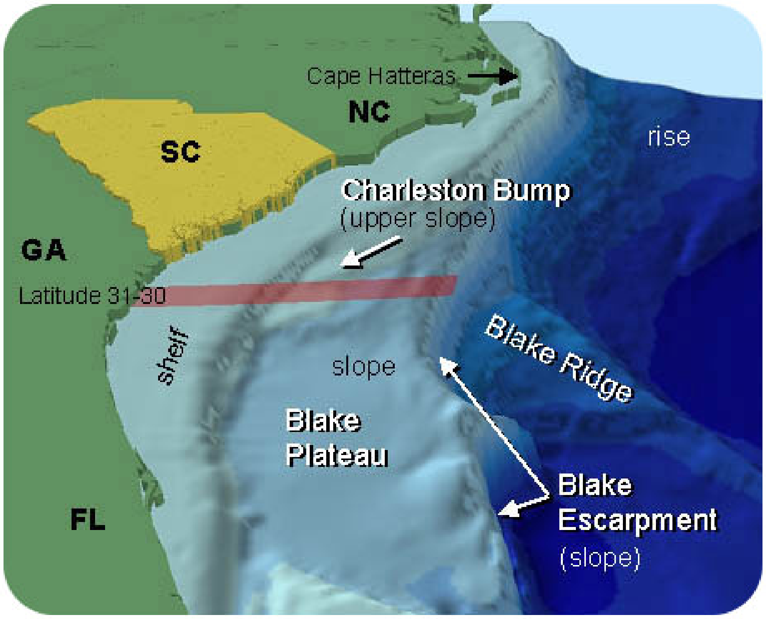


FIGURE 5.7
The continental shelf and slope of the southeastern United States goes down to the ocean floor.

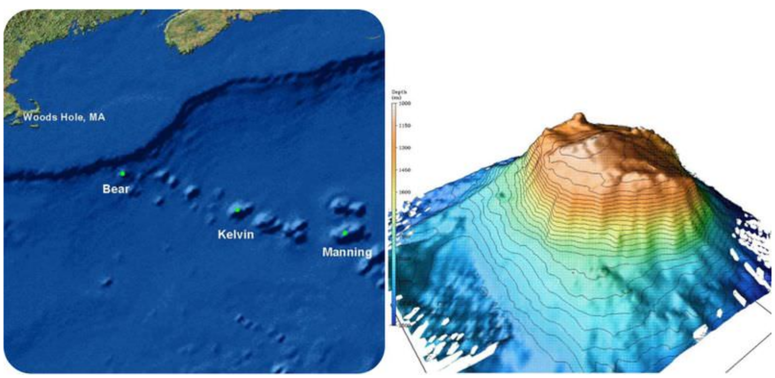


FIGURE 5.8
A chain of seamounts off the coast of New England (left). Oceanographers mapped one of these seamounts, called Bear Seamount, in great detail (right).

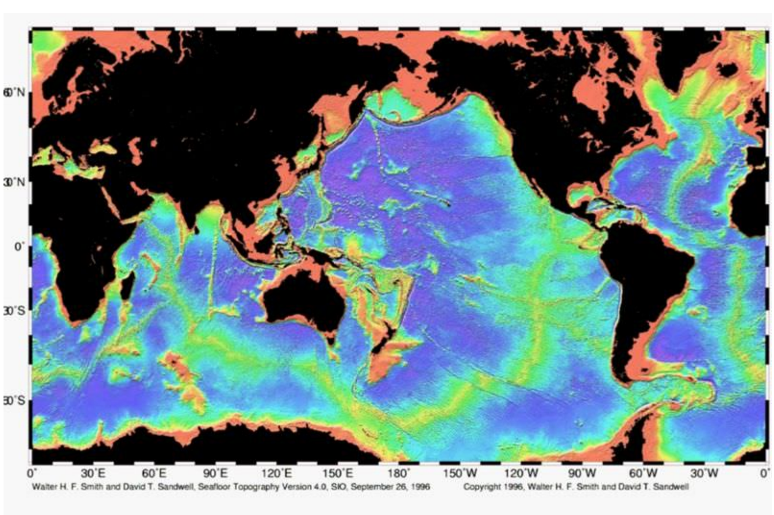


FIGURE 5.9
Map of the mid-ocean ridge system (yellow-green) in Earth's oceans.

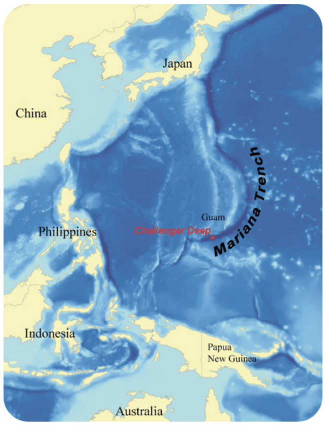


FIGURE 5.10
The Mariana Trench is east of Guam in the Pacific Ocean.

Lesson Summary

- Earth scientists must be able to describe exact locations of features on Earth's surface.
- Locations often include distances and directions.
- A compass has a tiny magnetic needle. This needle points toward Earth's magnetic North Pole. Once you have found north, you can find east, west, and south, using your compass for reference.
- Topography describes how Earth's surface varies in elevation.
- Constructive forces create landforms. Destructive forces wear landforms down. Together, they shape the Earth's surface.

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?

5.2 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.

Lesson 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

Have you ever looked closely at a globe? That continents look like a giant jig-saw puzzle. North America looks like it could fit next to Europe. The edge of South America matches Africa. Scientists noticed these same features. It caused them to start asking questions. They wanted to know if these continents were was connected? If so, how can something so large move so far? What could possibly have enough force to move such a giant slab of rock? Is there other evidence that can provide clues to the past positions of continents? How can answering these questions help us?

A scientist named Alfred Wegener had these same questions. Wegener look at rocks on both sides of the Atlantic Ocean. He noticed they were the same type and age. He thought that the rocks must have formed side by side. He proposed that the rocks then drifted apart. One part went with North America. The other part stayed with Europe. .

Wegener also matched up mountain ranges. The Appalachian Mountains were just like mountain ranges in other places across the Atlantic. They looked like mountains in eastern Greenland, Ireland, Great Britain, and Norway. Wegener thought they must have formed as a single mountain range. This mountain range must have broke apart as the continents split up. The mountain range separated as the continents drifted.

Wegener's ideas are now well accepted in the science community. Science now knows a lot about this process that causes continents to move. The theory that explains how continents move is called plate tectonics. Plate tectonics is the key to many of Earth's mysteries. The **theory of plate tectonics** explains most of the features of Earth's surface. This knowledge helps us to know where and why mountains form. We know where new ocean floor will be created. We also know where it will be destroyed. We know why earthquakes and volcanic eruptions happen. More important, we know where they will happen. Having this knowledge also helps us find new mineral resources.

Earth's Tectonic Plates

So how did scientists learn so much about Earth? Believe it or not, it had to do with the Cold War. The military funded seismograph networks to be built. Seismographs measure the movement of Earth's surface. The purpose was to see if other nations were testing atomic bombs.

The seismographs were used to detect bomb tests. They also gave scientist detailed information about earthquakes around the world. What can earthquakes tell us about our planet?

Earthquake Locations

The evidence about earthquakes was curious. Earthquakes did not happen everywhere. In some places they were common. In other places they were rare. They were very common along mid-ocean ridges. At the deep sea trenches they also happened frequently. In fact, earthquakes were common all around the Pacific Ocean. Volcanoes were also found in these same areas. Scientists named this region the Pacific Ring of Fire (**Figure** 12.13).

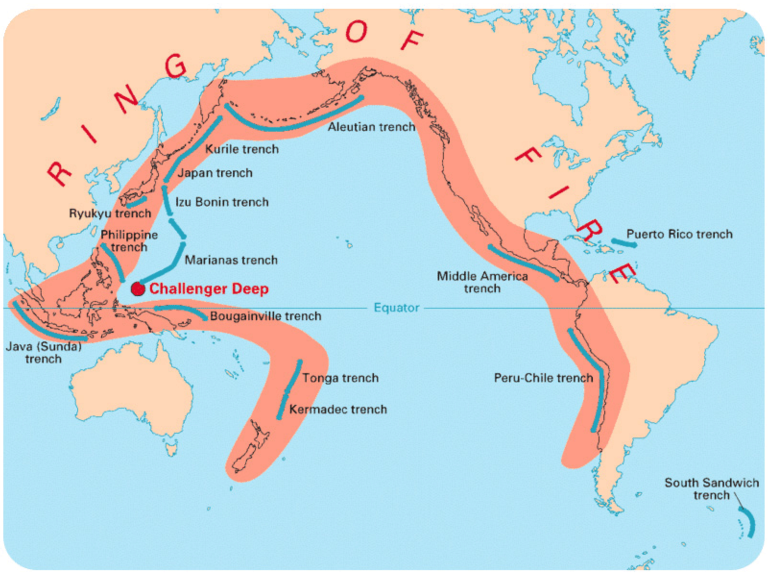


FIGURE 5.11
The Ring of Fire that circles the Pacific Ocean is where the most earthquakes and volcanic eruptions take place.

Earthquakes and Plate Boundaries

Earthquakes seemed to outline a special feature of earth's crust. Earthquakes let scientists know where the crust was moving. This led to the discovery that Earth's crust was broken up into regions, or plates. Earthquakes happen most often along these plate boundaries (**Figure** 12.14). This was evidence that continents can move. The movements of the plates are called plate tectonics.

Earth's crust is divided into plates. There are about a dozen large plates and several small ones. Each plate is named for the continent or ocean basin it contains.

Scientists know he plates are in motion. They now know the direction and speed of this motion (**Figure** 12.15). Plates don't move very fast. They move only a few centimeters a year. This is about the same rate fingernails grow. So you might wonder, what could cause this motion? What supplies the energy to cause this change?

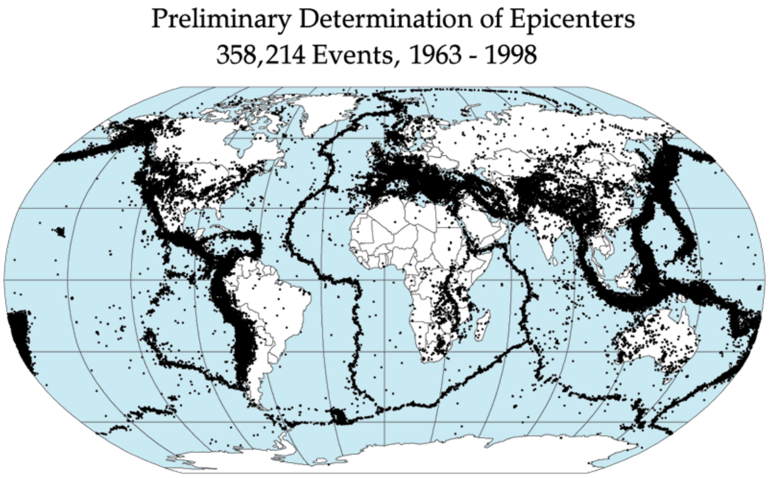


FIGURE 5.12

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.

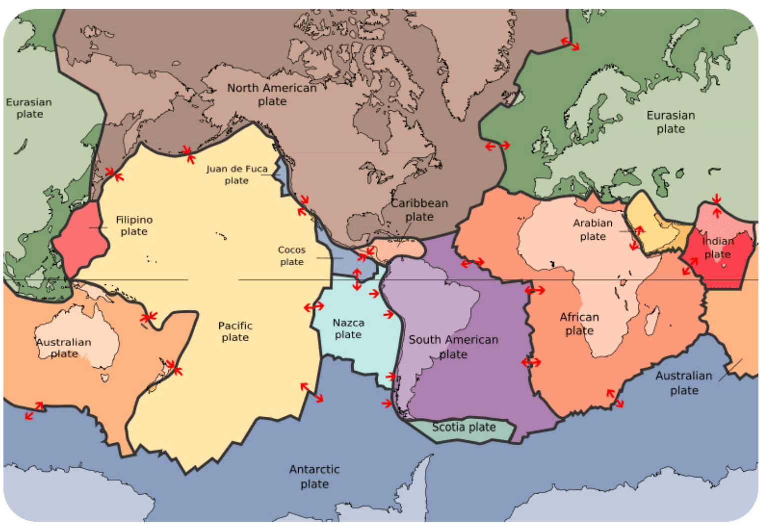


FIGURE 5.13

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

How Plates Move

Heat supplies the energy that causes motion. The deeper you go into toward Earth's core, the hotter it gets. At the core it is really hot. All that heat tries to rise toward the surface. In the mantle, the rock is partially melted and is able to move. As it is heated, the material in the mantle moves toward the surface (**Figure** 12.16). As the mantle material rises, it cools. When it reaches Earth's crust, it is mostly stopped. A little of the material can break through the surface, but not all. Instead, it begins to move horizontally. The mantle material moves horizontally away from a mid-ocean ridge crest. Toward the surface, the mantle material starts to cool. As it cools it sinks back down into the mantle. These areas are where deep sea trench occur. The material sinks back down to the core. The system operates like a giant conveyor belt. The motion due to heating and cooling is called convection.

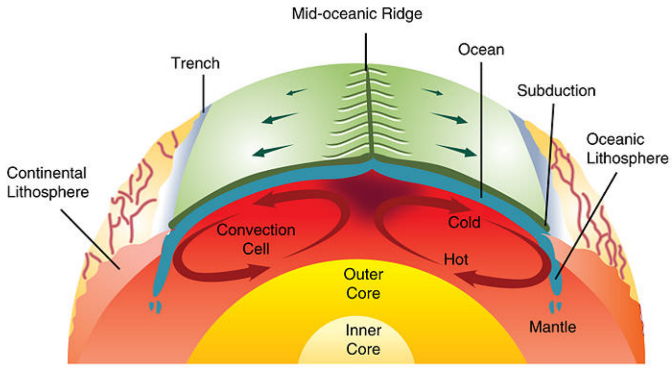


FIGURE 5.14
Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

Plate Boundaries

Plate boundaries are where two plates meet. These are dynamic areas. Most geologic activity takes place at plate boundaries. As plates interact, they cause many of the large features we see on Earth's surface. As plates interact they can cause volcanoes, earthquakes. They can even cause mountain ranges to form. Plates can interact in different ways. 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:

- At **divergent plate boundaries** the two plates move away from each other.
- At **convergent plate boundaries** the two plates move towards each other.
- At **transform plate boundaries** the two plates slip past each other.

The features created vary by the boundary type. They also vary 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. As it gets pulled apart it gets thinner and thinner. Eventually, magma can break through. Lava rises upward, erupts, and cools. Lava is the name given to magma that has reached the surface. Over time, the layers of lava will push the seafloor outward. An example is how North America is moving away from Europe. There is a mid-ocean ridge in the center of the Atlantic Ocean.

At these types of boundaries, new crust is formed. The rising of magma causes earthquakes. Most mid-ocean ridges are located deep under water. In a few areas the ridge is very tall. In a few places the ridge can be above water. The island of Iceland is one of those places. It is part of the Mid-Atlantic ridge (**Figure** 12.17). What makes the sea floor spread apart?

Continental Rifting

A divergent plate boundary is not always beneath the ocean. Sometimes they occur on land. This is called **continental rifting** (**Figure** 12.18). Magma rises beneath the continent. The crust thins, breaks, and then splits

FIGURE 5.15
The rift valley in Iceland that is part of the Mid-Atlantic Ridge is seen in this photo.

apart. A valley is formed. These valleys are called "rift valleys." The East African Rift is a rift valley. Yes, Africa is breaking apart. Eastern Africa is splitting away from the rest of Africa. Eventually, the whole continental will break apart. The valley will get larger and larger. Magma will rise up. Lava will create a new surface. Has this ever happened before?

There was once a super continent called Pangaea. It broke apart just like Africa is doing now. This is how the Atlantic Ocean formed. It explains why North America and Europe could fit together.

FIGURE 5.16
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

Sometimes plates collide. These regions are called convergent plate boundaries. These collisions can happen anywhere. They can happen between a continent and oceanic crust. It can happen between two oceanic plates. It can even happen between two continents.

Ocean-Continent Convergence

What do you think will happen when plates collide? Oceanic crust may collide with a continent. The oceanic crust is denser than continental crust. As a result, oceanic crust **subducts.** Subduction occurs when on plate dives under the other during the collision. This occurs at an ocean trench (**Figure** 12.19). **Subduction zones** are where subduction takes place.

These areas have intense earthquakes and volcanic eruptions. What happens to the subducted plate? It actually melts as it reenters the mantle. The magma it creates rises to the surface. It will eventually erupt onto the surface. This creates a volcanic mountain range. These occur near the coast of the continent. The Andes Mountains were formed along a subduction zone. The Andes Mountains run along the western edge of South America (**Figure** 12.20).

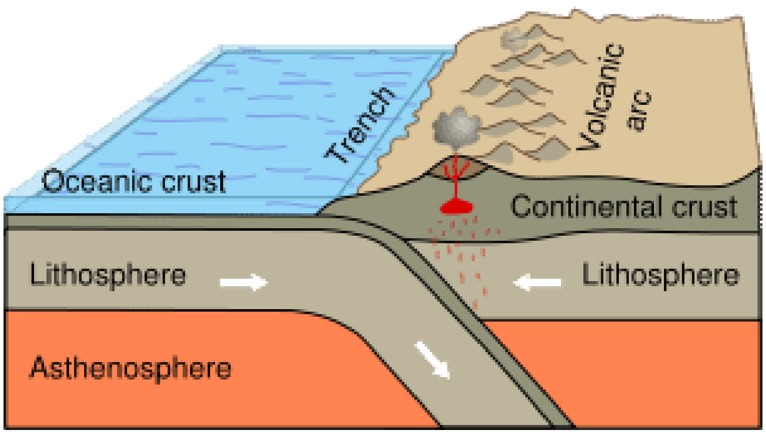


FIGURE 5.17
Subduction of an oceanic plate beneath a continental plate forms a line of volcanoes known as a continental arc and causes earthquakes.

Ocean-Ocean Convergence

What happens when two oceanic plates collide? One of the plates will sink beneath the other. The plate that subducts starts to melt as it is pushed deeper into the mantle. The melted rock works its way up toward the surface. It will eventually erupt onto the surface. It will form a volcano. Along the subduction zone a line of volcanoes will form (**Figure** 12.21). The volcanoes start to build new land. Japan, Indonesia, the Philippine Islands, and the Aleutian Islands of Alaska formed along subduction zones (**Figure** 12.22).

Continent-Continent Convergence

Continental crust is lighter than oceanic crust. It is also very thick compared to oceanic crust. Continental crust is too thick to subduct. When continental plates collide, they smash together. It's just like when 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** 12.23)! This violent collision will cause many earthquakes. Unlike other types of collisions, volcanoes are not formed. The crust is too think for magma to get through.

Mountain Building

In places where continents collide, very large mountain ranges are formed. You may know some of these mountain ranges. Have you ever hear of the Himalayas (**Figure** 12.24)? They contain the world's tallest mountains. They are still getting higher. Every year they gain about an inch in height. They formed because two continents are colliding. The Indian plate is colliding with the Asian plate.

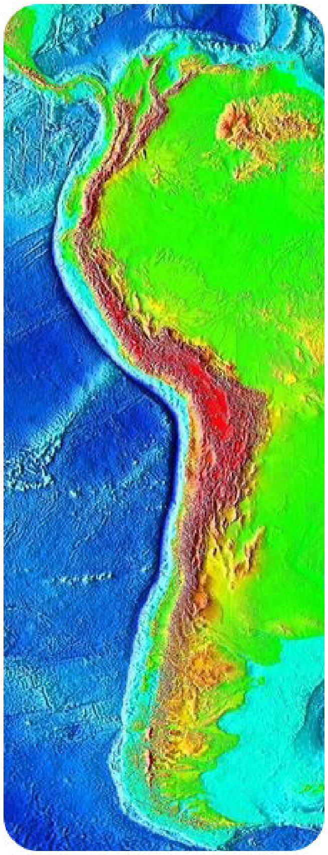


FIGURE 5.18
A relief map of South America shows the trench west of the continent. The Andes Mountains line the western edge of South America.

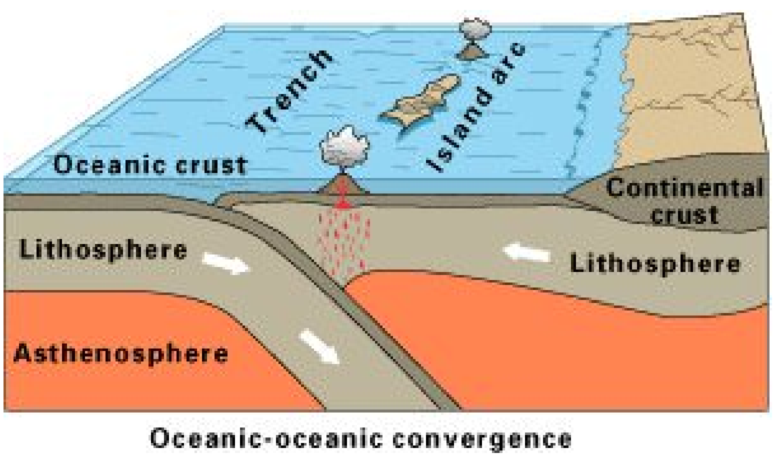


FIGURE 5.19
A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.

The Appalachian Mountains formed this same way. The Appalachian Mountains formed a long time ago. They have been worn down through time. At one time they were taller than the Rocky Mountains. This range formed when two continents collided.

FIGURE 5.20
The Aleutian Islands that border southern Alaska are an island arc. In this winter image from space, the volcanoes are covered with snow.

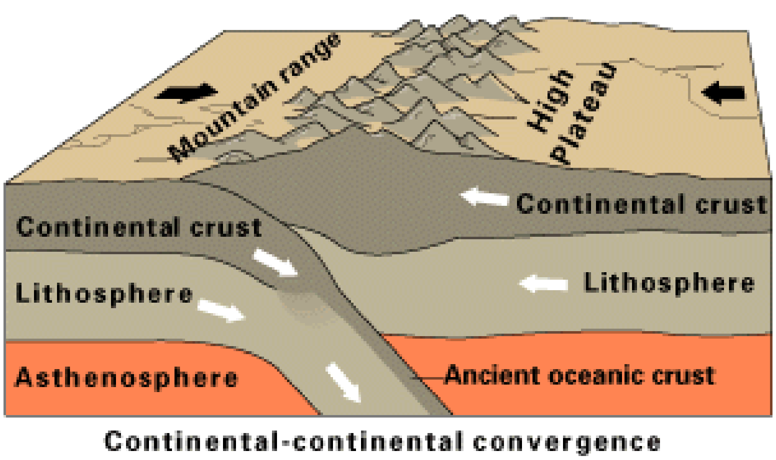


FIGURE 5.21
When two plates of continental crust collide, the material pushes upward, forming a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

Transform Plate Boundaries

In some places plates slide past each other. This is called a transform plate boundary. These plate boundaries experience huge earthquakes. You may have heard of the San Andreas Fault. It is a famous transform boundary. This fault runs through the State of California (**Figure** 12.25). At this fault, two plates slowly grin past each other. The Pacific plate is rotating counterclockwise. The North American plates is moving south. At transform plate boundaries, crust is not created nor destroyed.

FIGURE 5.22
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.

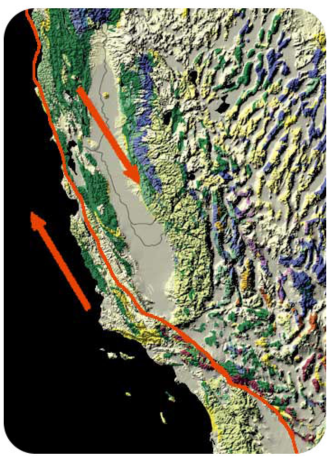


FIGURE 5.23
The red line is the San Andreas Fault. On the left is the Pacific Plate, which is moving northeast. On the right is the North American Plate, which is moving southwest. The movement of the plates is relative to each other.

Intraplate Activity

Most geological activity takes place at plate boundaries. But some activity does not. Hot spots are location where the Earth is active. Hotspot volcanoes form as plumes of hot magma rise. These plumes of magma come from deep in the mantle.

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** 12.27).

The Hawaiian Islands formed due to a Hotspot. The Kilauea volcano is still erupting. It is directly over the hotspot. Hotspots can tell us the speed and direction of plates.

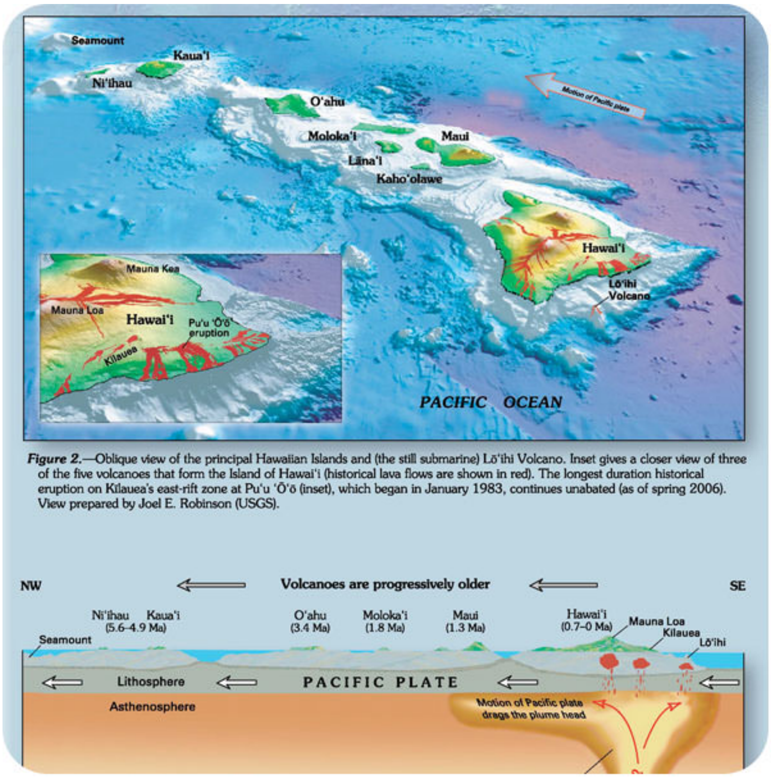


FIGURE 5.24

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.

Hotspots Beneath Continents

Hot spots are also found under the continental crust. Remember, continental crust is very think. It is more difficult for magma to make it through the thick crust. This makes them far less common. One exception is the Yellowstone hotspot (**Figure** 12.28). 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. It is what causes the crust to move over the Earth's surface. New oceanic crust forms at the ridge. It pushes the older seafloor away. It causes it to move horizontally away from the ridge.
- Plates interact at three different types of plate boundaries. These three types are divergent, convergent and transform fault boundaries. This is where most of the Earth's geologic activity takes place.
- These processes acting over long periods of time. They are responsible for the geographic features we see today.

Lesson Review Questions

Recall

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

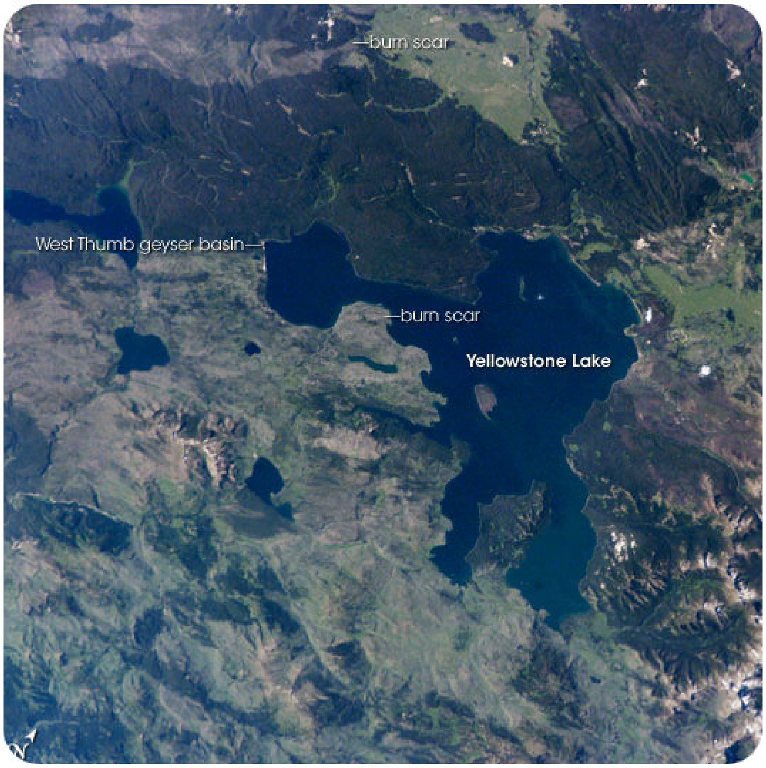


FIGURE 5.25
Yellowstone Lake lies at the center of a giant caldera. This hole in the ground was created by enormous eruptions at the Yellowstone hotspot. The hotspot lies beneath Yellowstone National Park.

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?

Points to Consider

- On the map in **Figure** 12.15, 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?

5.3 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.

Lesson Vocabulary

- geologic time scale
- key bed
- law of superposition
- relative age
- stratigraphy
- unconformity

Introduction

Earth processes have not changed over time. The way things happen now is the same way things happened in the past. Mountains grow and mountains slowly wear away. The same process is at work the same as it was 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.** Becoming extinct means they die out completely.

Some geologists study the history of the Earth. They want to learn about Earth's past. They use clues from rocks and fossils. They use these clues to make sense of events. The goal is to place things in the order they happened. They also want to know how long it took for those events to happen.

Laws of Stratigraphy

Consider the study of the layers of rock. Layers of rock are called strata. The study of strata is called **stratigraphy**. A lot can be learned by looking at layers of rock. Scientists can learn about past environments. From fossils, they can learn about what plants and animals once lived in the area. If they know what type of plant or animal lived in an area, they can get a good idea about the type of climate. The fossil evidence will tell them if the area was land or marine. Even the type of rock can tell them about the past environment. The laws of stratigraphy can help scientists learn many things about Earth's past.

Law of Superposition

Superposition refers to the position of rock layers. A lot can be learned by the position of rocks. We know the rocks on top are always younger than the rocks below. Knowing the relative age of rocks is very important to scientists. **Relative age** means age in comparison with other rocks. Are rocks older or younger than other rocks? The relative ages of rocks are important. They help scientists learn more about Earth's history. 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** 15.7.

FIGURE 5.26
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 large areas. This is especially true if they formed at the bottom of ancient seas. Seas are very large areas of water. Over time, sediment builds up on the seabed. They will be covered with the same types of material. As rocks form out of this sediment it will all be the same type. The rocks may be forced up above the water as Earth's plates move. Rivers may eventually run across this area. The river will cut into the rock and erode it away. The layers of exposed rock on either side of the river will still "match up."

Look at the Grand Canyon in **Figure** 15.8. 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. They are the same age.

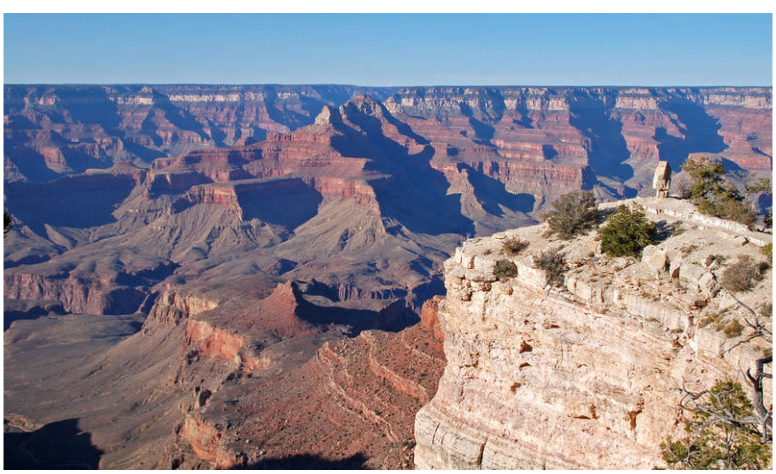


FIGURE 5.27
Lateral Continuity. Layers of the same rock type are found across canyons at the Grand Canyon.

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** 15.9. 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.

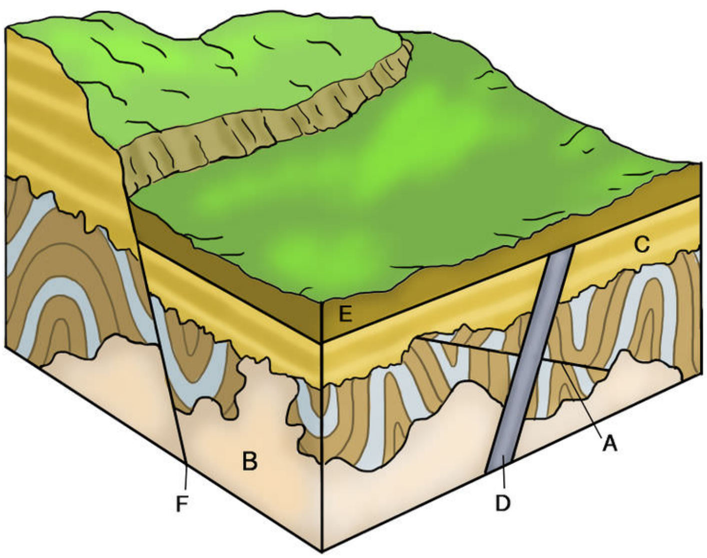


FIGURE 5.28
Cross-cutting relationships in rock layers. Rock D is a dike that cuts across all the other rocks. Is it older or younger than the other rocks?

Matching Rock Layers

It is easy to match rock layers across a river. Unfortunately, matching rock layers is not always that easy. Sometimes, rock layers are not in the same place. They may be on different continents. So how do we match rock layers in this case? What evidence can we use to match the layers?

Widespread Rock Layers

Some rock layers extend over a very wide area. They may even be found on more than one continent. For example, the famous White Cliffs of Dover are on the coast of southeastern England. These are very distinctive rocks. They can be matched to similar white cliffs in France, Belgium, Holland, Germany, and Denmark (see **Figure** 15.11). Why is this important to us? As it turns out, these cliffs are made of chalk. Chalk is a very soft rock. This rock extends from England to Europe. It extends under the English Channel. Because it is soft the Channel Tunnel connecting England and France was carved into it!

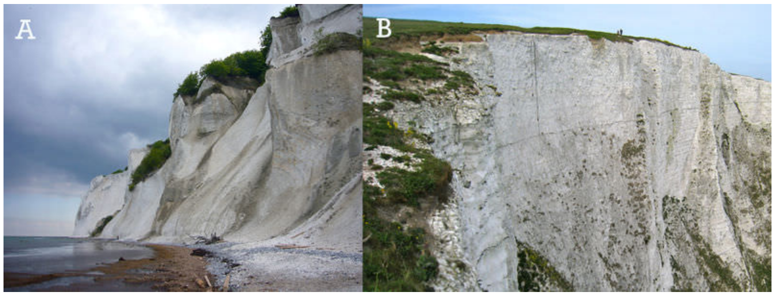


FIGURE 5.29
Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

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 a 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 layers all over the world. It also led to the hypothesis that a giant asteroid struck Earth. It was this event that may have caused dinosaurs to go extinct.

Using Index Fossils

Fossils can be used to match up rock layers. As organisms change over time, they look different. Older fossils will look different than younger fossils. Some organisms only survived for a short time before going extinct. Knowing what organisms looked like at certain times also helps date rock layers. Some fossils are better than others for this use. The fossils that are very distinct at certain times of Earth's history are called index fossils. Index fossils are commonly used to match rock layers. You can see how this works in **Figure** 15.12. If two rock layers have the same index fossils, then they're probably about the same age.

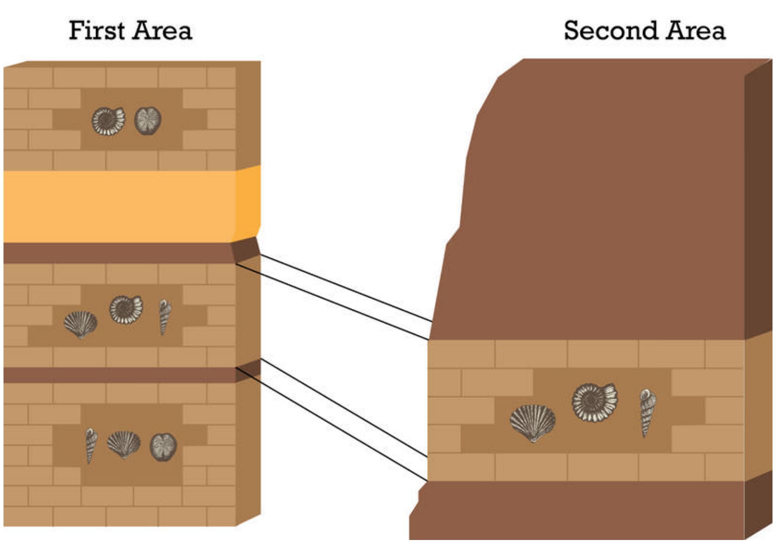


FIGURE 5.30
Using Index Fossils to Match Rock Layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

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.
- Other clues help determine the relative ages of rocks in different places. They include key beds and index fossils.

Lesson Review Questions

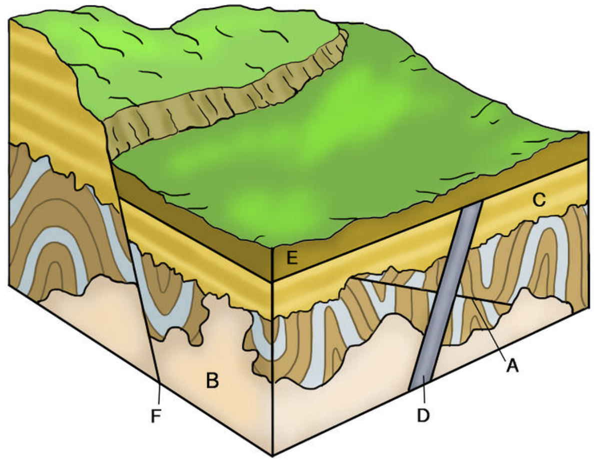
Recall

1. Define stratigraphy.
2. What is the relative age of a rock?
3. State the law of superposition.
4. How do key beds help date rock layers?

Apply Concepts

5. Apply laws of stratigraphy to explain the rock formation below.

6. Which rock in the illustration below formed first, the igneous rock (A) or the sedimentary rock (B)? Apply lesson concepts to support your answer.



Think Critically

7. Use the law of lateral continuity to explain why the same rock layers are found on opposite sides of the Grand Canyon.

8. 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?

5.4 Fossils

Lesson Objectives

- Explain what fossils are.
- Describe how fossils form.
- State what scientists can learn from fossils.

Lesson Vocabulary

- fossilization
- index fossil

Introduction

For thousands of years, people have found fossils. The fossils caused curiosity about Earth's past. How did these organisms live? What type of world did they live in? Fossils can tell us a lot about Earth's history.

In ancient times, fossils inspired myths and stories. These stories included tales of monsters and other incredible creatures. What type of creature do you know that could inspire such stories? Of course, dinosaur fossils were once mistaken for dragon's bones.

Two thousand years ago, people discovered fossils in China. At the time, they were thought to be dragon bones. We know now that these were not bones, but fossils. So what is the difference?

What Are Fossils?

Fossils are preserved in two ways. They can be the remains of organisms or traces of them. These organisms lived in Earth's past.

Most fossils that are found are hard parts from ancient organisms. These hard parts are remains such as teeth, bones, and shells. Examples of these kinds of fossils are pictured in **Figure** 15.1.

Preserved traces can include footprints, burrows, or even wastes. Examples of trace fossils are also shown in **Figure** 15.1.

How Fossils Form

The process by which fossils form is called **fossilization**. Most fossils form in sedimentary rocks.

Fossils in Sedimentary Rock

Most fossils form from a dead organism. These organisms are then buried in sediment. Layers of sediment slowly build up. The sediment is buried by even more sediment. Over time, the sediment turns into sedimentary rock. The remains of the organisms also turn to rock. The remains are replaced by minerals. The remains of the old plants and animals literally turn to stone. This process is shown in **Figure** 15.2.

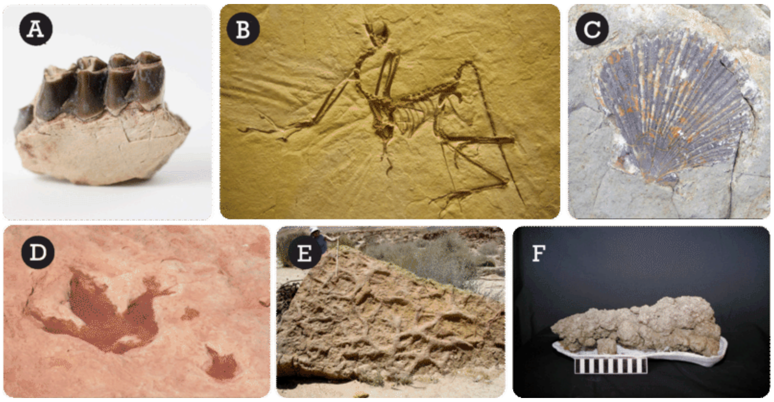


FIGURE 5.31
A variety of fossil types are pictured here. Preserved Remains: (A) teeth of a cow, (B) nearly complete dinosaur skeleton embedded in rock, (C) sea shell preserved in a rock. Preserved Traces: (D) dinosaur tracks in mud, (E) fossil animal burrow in rock, (F) fossil feces from a meat-eating dinosaur in Canada.

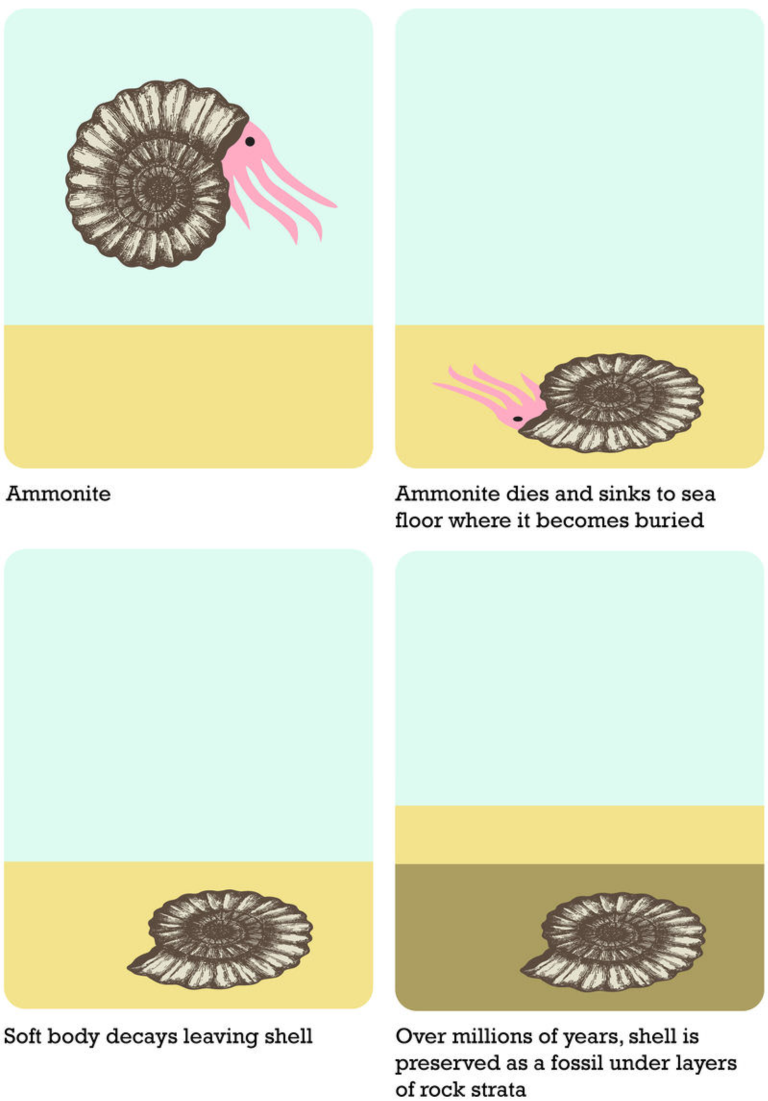


FIGURE 5.32
Fossilization. This flowchart shows how most fossils form.

Other Ways Fossils Form

Fossils may form in other ways. Sometimes fossils are preserved almost completely. In this process, the organism doesn't change much. As seen below, tree sap may cover an organism. With time, the sap turns into amber. The original organism is preserved. This is very exciting for scientists. They are able to study the DNA of the fossilized organism. Organisms can also be completely preserved in tar or ice.

Have you ever walked in soft mud and left footprints? In just the right situation, these types of traces of organisms can be preserved. In this case, nothing is left of the organism. Molds and casts are another way organisms can be fossilized. A mold is an imprint of an organism that is preserved in rock. The organism's remains break down completely. The impression left behind by the organism forms a mold, or impression. This mold is then filled with other rock. The fossil that forms in the mold is called a cast. Molds and casts usually form in sedimentary rock. You can read about them in **Figure** 15.3.

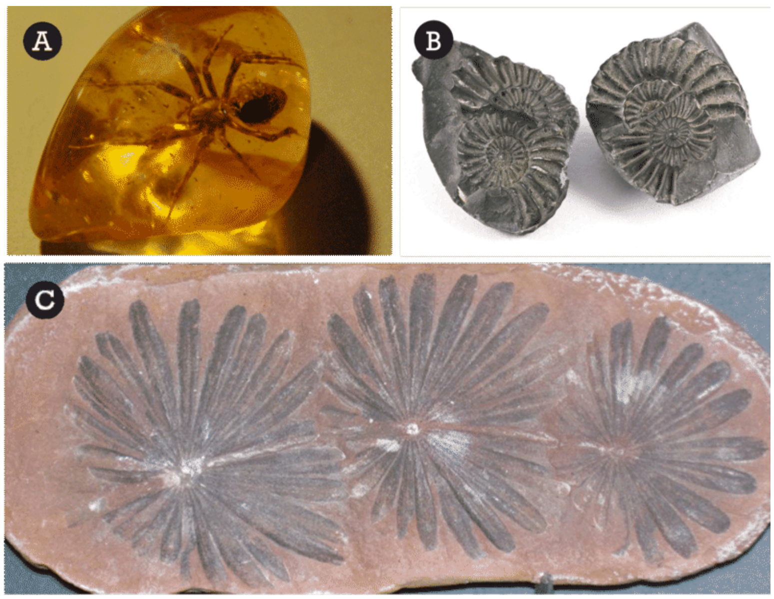


FIGURE 5.33

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

For fossils to form, conditions must be just right. It's very unlikely organisms will become a fossil. Why don't many dead organisms get turned into fossils?

The soft remains of many organisms are eaten by other animals. Insects may break down remains. Others may be broken down by the elements. Insects too may break down remains.

Hard parts are much more likely to become fossils than soft parts. Even an animal's hard parts are unlikely to become a fossil. Fossils of soft organisms, from bacteria to jellyfish, are very rare.

Learning From Fossils

There have been many organisms that have lived in Earth's past. Only a tiny number of them became fossils. Still, scientists learn a lot from fossils. Fossils are our best clues about the history of life on Earth.

Fossils provide evidence about life on Earth. They tell us that life on Earth has changed over time. Fossils in younger rocks look like animals and plants that are living today. Fossils in older rocks are less like living organisms.

Fossils can tell us about where the organism lived. Was it land or marine? Fossils can even tell us if the water was shallow or deep. Fossils can even provide clues to ancient climates.

Fossil Clues

Fossils give clues about major geological events. Fossils can also give clues about past climates.

- Fossils of ocean animals on the top of Earth's tallest mountain? It's hard to believe, but it is true. These fossils were found on at the top of Mt. Everest. Mt. Everest is the highest mountain on Earth. These fossils showed that this entire area was once at the bottom of a sea. It can only mean that Mt Everest was uplifted. In fact, the entire Himalaya mountain range was raised. It was forced up from the collision of two continents. An example is shown in **Figure** 15.4.

- Fossils of plants are found in Antarctica. Now, Antarctica is almost completely covered with ice. Plants do not grow in Antarctica. According to fossils, they once did. This means that Antarctica was once warmer than it is now. These fossils tell us about Antarctica's past climate.

FIGURE 5.34

What can we learn from fossil clues like this fish fossil found in the Wyoming desert?

Lesson Summary

- Fossils are preserved remains or traces of organisms. They lived in Earth's past.
- Most fossils form in sedimentary rock. Fossils can also be preserved in other ways.
- Fossils in younger rocks look like animals and plants that are living today. Fossils in older rocks are less like living organisms.
- It is rare for any given organism to become a fossil.
- Fossils are the best form of evidence about the history of life on Earth. Fossils also provide clues about Earth's past. They can tell us about major geological events and past climates.

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** 15.3 and the fossil dinosaur tracks in **Figure** 15.1. 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?

5.5 Weathering

Lesson Objectives

- Define mechanical and chemical weathering.
- Discuss agents of weathering.
- Give examples of each type of weathering.

Lesson Vocabulary

- abrasion
- chemical weathering
- erosion
- ice wedging
- mechanical weathering

Introduction

Have you ever heard the term weathering? It may not be what you think. Weathering does not explain the conditions at a certain place. That would be weather. The terms sound alike, but they are different. **Weathering** refers to the breaking apart of rocks. Rocks and even entire mountains are slowly broken up by the process of weathering. **Erosion** is the process that moves these broken pieces. Weathering and erosion work together to reshape the land. Weathering occurs on or near Earth's surface.

What Is Weathering?

Weathering breaks down rocks into smaller pieces. These small pieces of rock are called sediment. Sediments can be any size and shape. Giant boulders can be sediments. They may have started as part of a mountain and then broken up. You may have small decorative rocks around your home. These too came from even larger rock. Therefore, they have been through the process of weathering. Even soil has been broken down from larger and larger rocks.

It takes a long time for a rock or mountain to weather. Have you ever traveled to a colder part of the world? If so, you may have noticed all the holes in the roads. These holes appear in the spring after a cold winter (**Figure** 5.35). This breaking apart of the roadway is a form of weathering. Its causes are the same as what happens to large mountains. The difference is that a road can change more quickly.

Mechanical Weathering

Mechanical weathering breaks rock into smaller pieces. These smaller pieces are just like the bigger rock. They are just smaller! The rock is still the same type of rock. It has not changed into a different kind of rock. The smaller pieces have the same minerals. They are also in the same proportions. You could use the expression "a chip off the old block" to describe this type of weathering! The main agents of mechanical weathering are water, ice, and wind.

FIGURE 5.35
A hard winter has damaged this road.

Ice Wedging

How do you think ice plays a role in breaking apart a rock? Ice is just the solid form of water. Ice is not harder than a rock, so how can it be the cause of weathering? It's simple really, water is special.

Water is very unique. On Earth, it can exist in all three states. It can be a liquid at room temperature. When heated, it changes into a gas. Even more interesting is when it becomes a solid. When liquid water changes into ice, it actually gets larger. It is this change that causes ice wedging. **Ice wedging** is common in cold climates. It can also be found in mountainous regions.

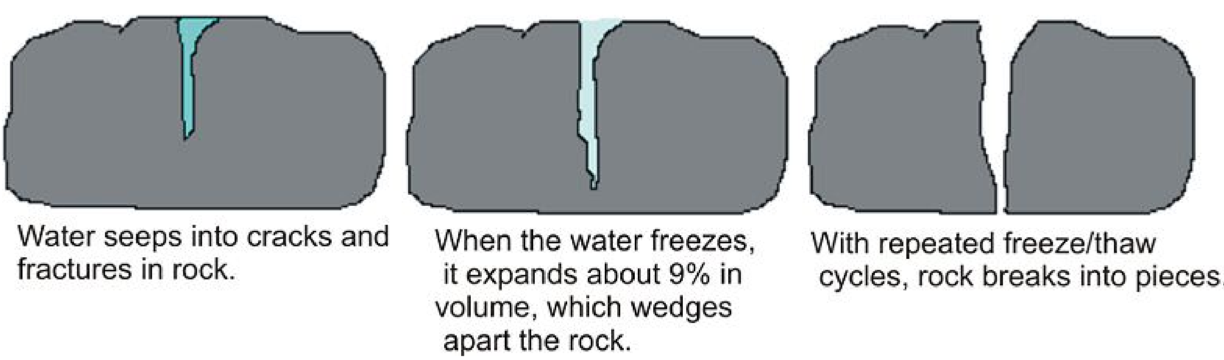


FIGURE 5.36
Diagram showing ice wedging.

How does ice wedging occur? First, liquid water is needed to begin the process. Liquid water runs into the crack in the rock. This happens when the temperatures are above freezing. As temperatures drop below freezing, the liquid water turns to ice. During this physical change, the water expands. This expansion is what breaks apart the rock.

You can see this effect when you fill an ice cube tray with water and put it in the freezer. Note the level of the water in the tray. With time, the water freezes into ice. You can now see the ice will be at a higher level in the tray.

Have you ever put a can of soda in the freezer? Have you left it there accidentally? What happened or what do you think might happen? Yes, it will expand. If you are lucky, the can will bulge. If you are unlucky, the can may have split open. (For the record, water is very unusual. Most substances get smaller when they get colder.)

Over time, freezing and thawing of water forces the rock apart. Ice wedging is very good at breaking apart rocks. Look around and you may find some evidence at the base of a mountain slope. You will probably 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 weathering. Like ice wedging, it is a form of mechanical weathering. Like ice wedging, abrasion does not change the rock into another type of rock.

With abrasion, one rock or piece of sediment bumps against another rock. Rocks don't normally roll around on their own, so why do they move? There are a couple of reasons a rock may move.

Gravity can cause rocks to move. They may roll downhill or fall off a cliff. As they roll down a hill, they bump into each other. Maybe a moving rock hits a rock that is not moving at the bottom of the hill.

Moving water causes rocks and sediment to move. Rocks are bounced along the bottom and bump against one another (**Figure** 5.37). As they collide, they begin to chip away at each other. Angular rocks become more rounded with each collision.

Strong winds cause abrasion. The wind carries sediment. This sediment is thrown against other rocky surfaces by the wind. It is like sand-blasting a rock.

Finally, the ice in glaciers causes abrasion. Pieces of rock embedded in ice grind away at the rock below. Have you ever collected beach glass? Maybe you have seen rounded pebbles in the bottom of a stream? If so, you have witnessed the work of abrasion.

FIGURE 5.37
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 plants and animals cause 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. You can see this in action by looking at sidewalks. Smalls plants grow in the cracks. Over time, the plants can grow large enough to break apart the concrete.

Burrowing animals can also cause weathering. Animals may dig for food or create a hole to live in. This process may cause rock to break apart.

Today, human beings do a lot of weathering of rocks. They dig and blast rock for many purposes. Small pieces of rock and sediment are needed for the building of homes and roads. Places where humans break apart large rocks into smaller ones are called quarries.

Chemical Weathering

Chemical weathering is different to mechanical weathering. The minerals in the rock change. The rock changes composition. The rock becomes a different type of rock.

There are many agents of chemical weathering. Remember that water is a main agent of mechanical weathering. 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. It is able to do many things. It can exist in three forms on Earth. It can freeze and expand. Lots of things dissolve easily in water. Some types of rock can even completely dissolve in water!

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 as they are hard. Water cannot easily penetrate them. Granite is a very stable igneous rock. Other types of rock are easily weathered. They dissolve easily in weak acids. Limestone is a sedimentary rock. It dissolves easily. When softer rocks wear away, more resistant rocks are left behind. These more resistant rocks form ridges or hills.

Devil's Tower in Wyoming shows how different types of rock weather at different rates (**Figure** 5.38). The softer materials of the surrounding rocks were worn away. The resistant center of the volcano remains behind.

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.

FIGURE 5.38
Devil's Tower shows differential weathering. Hard rock from inside a volcano makes up the tower.

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?

5.6 Erosion and Deposition by Glaciers

Lesson Objectives

- Describe how continental and valley glaciers form.
- Explain how glaciers cause erosion.
- Identify landforms deposited by glaciers.

Lesson Vocabulary

- continental glacier
- glacial till
- glacier
- moraine
- plucking
- valley glacier

Introduction

Imagine you are standing in a farm field in central Illinois. The land is so flat you can see for miles and miles. On a clear day, you might see a grain silo 20 miles away. You might think to yourself, it sure is flat around here. If you drive one hundred miles to the south, the landscape changes. In southern Illinois, there are rolling hills. Why do you think this is? What could have caused these features? There are no big rivers that may have eroded and deposited this material. The ground is capable of supporting grass and trees, so wind erosion would not explain it. To answer the question, you need to go back 12,000 years.

Around 12,000 years ago, a giant ice sheet covered much of the midwest United States. Springfield, Illinois, was covered by over a mile of ice. It's hard to imagine a mile thick sheet of ice. The massive ice sheet, called a glacier, caused the features on the land you see today. Where did glaciers go? Where can you see them today?

Glaciers are masses of flowing ice. Today, they cover only about 10 percent of Earth's surface. They are getting smaller and smaller. As the Earth's temperatures have risen, the glaciers retreated. About 12,000 years ago, much of Europe was also covered with glaciers.

Glaciers erode large areas of land. They leave behind features on the surface. These landforms are like clues. They show the direction a glacier flowed. They also tell scientists how far they advanced. Did glaciers leave clues where you live? Would you know what to look for?

How Glaciers Form

You may be wondering, how can a glacier get so big? Why does it move? These are both good questions.

In the winter months, precipitation falls as snow. This solid form of water builds up on the ground as long as the temperatures stay cold enough. As the temperature rises, the snow starts to melt. The frozen water changes state back into a liquid state. Nearer the poles, summer does not last very long. If the summer is long enough and warm enough, all the snow may melt. This is what typically happens now. The earth was a little cooler 12,000 years ago. As a result, during the summer months, that amount of snow did not melt. It may have only been an inch or so of snow that melted. The following winter, snow fell on top of this left-over snow. This next winter's snowfall had a head start. Year after year, the snow that did not melt became thicker and thicker. Inch by inch the snow started to build up. Over many years, layer upon layer of snow compacted and turned to ice. As this ice grew thicker and thicker, it began to spread out. Gravity was pulling it down, so it had no place to go but out. This spreading out at the bottom of the ice sheet is what caused the glaciers to "move," or advance. Starting near the poles, the glaciers were forced southward in all directions.

There are two different types of glaciers. Continental glaciers are the type that is described above. There are also valley glaciers. Instead of forming at the far northern or southern reaches of the Earth, they form in cold mountain regions. Each type forms some unique features. These features are caused by erosion and deposition of material. An example of each type is pictured in **Figure** 5.39.

- 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 larger.
- A **valley glacier** is long and narrow. Valley glaciers form in mountains. They flow downhill through mountain river valleys.

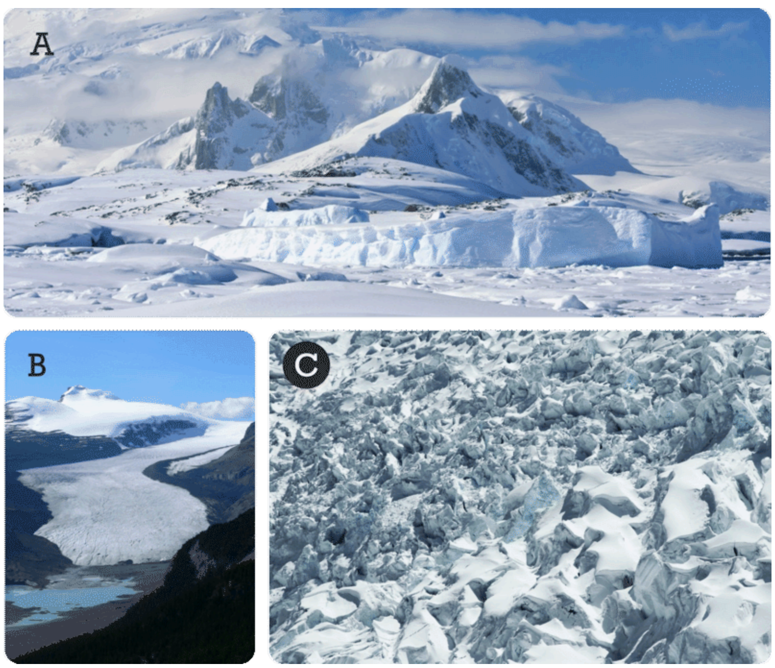


FIGURE 5.39

(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. It also can deposit the material elsewhere. Glaciers cause erosion in two main ways: plucking and abrasion.

- **Plucking** is caused when sediments are picked up by a glacier. They freeze to the bottom of the glacier and are carried away by the flowing ice.
- Abrasion occurs when glaciers scrape over the Earth's surface. The ice sheet acts like sandpaper. The ice contains sediments and rocks frozen in the ice. The rocks and sediment grind away as the glacier moves. They wear away rock. They may also leave scratches and grooves in them. Scientists use these grooves to learn about the direction the glacier has moved.

Erosion by Valley Glaciers

Just like continental glaciers, valley glaciers leave clues. Even 12,000 years later, evidence of valley glaciers can be seen on the landscape. One such feature is the presence of a U-shaped valley.

- Glaciers on mountains flow down river valleys. Fast moving mountain streams carve deep V-shaped valleys. Valley glaciers partially fill the valley. The rock and sediment they pick up scrape on the sides of the valley. The scraping causes the sides of the valley to be eroded. Glaciers carve out a U-shaped valley.

Deposition by Glaciers

While glaciers erode the landscape, they also deposit materials. 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. It can be of all sizes, called **glacial till**. Water from the melting ice may form lakes or other water features. **Figure** 5.40 shows some of the landforms.

- **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. These groups are called drumlin fields. The narrow end of each drumlin points in the direction of an advancing glacier.
- 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 melt as they are left behind as a glacier retreats. When the huge chuck of ice melts it leaves a depression. The meltwater fills it to form a lake.

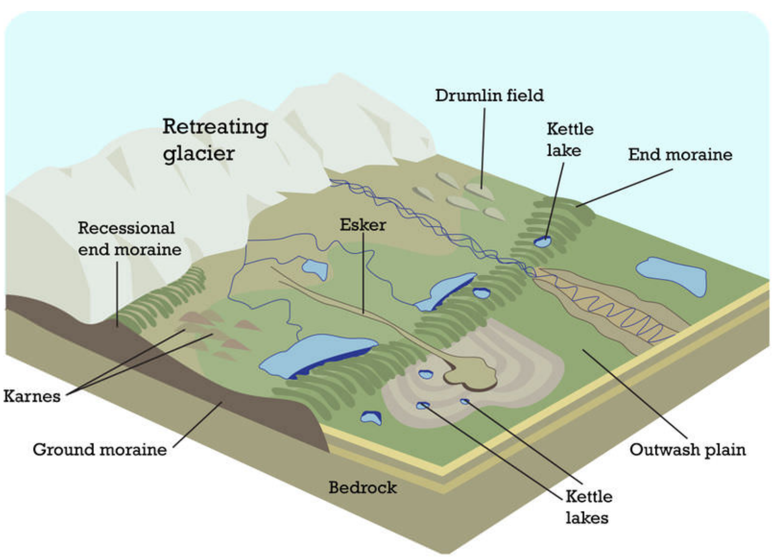


FIGURE 5.40
Take a look at the glacial deposits. How far did the glacier in the diagram advance before it started retreating?

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.
- Glaciers cause erosion by plucking and abrasion.
- 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?

5.7 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** 5.41. 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 5.41
Dust storm over Arizona desert. Have you ever experienced a dust storm like this one?

Wind Erosion

Dust storms like the one in **Figure** 5.41 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 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** 5.42.

- 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.

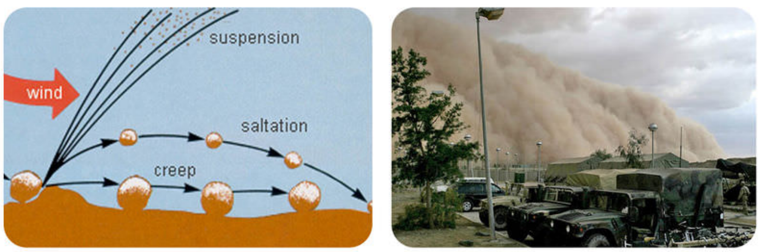


FIGURE 5.42
Wind transports particles in different ways depending on their size (left). A dust storm in the Middle East (right).

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** 5.43. 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?

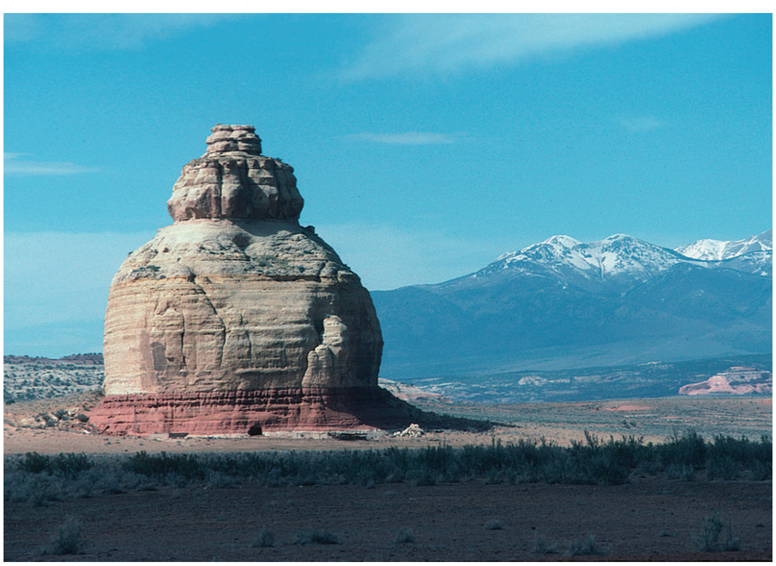


FIGURE 5.43
Sand blown by fierce winds have carved this rock into an interesting shape.

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 examples of sand dunes in **Figure** 5.44.

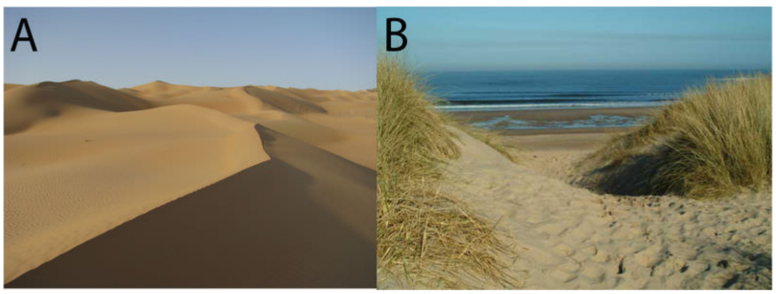


FIGURE 5.44
Sand dunes form where the wind deposits sand. (A) Desert sand dunes. (B) Sand dunes line many beaches like this one in Australia.

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** 5.45.

FIGURE 5.45
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** 5.46.

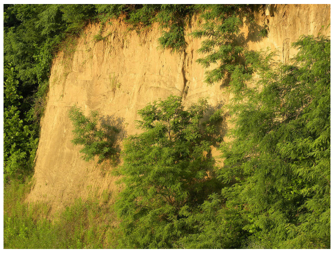


FIGURE 5.46
Loess cliffs in Mississippi.

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** 5.47 serve the same purpose. The fence in the figure is preventing erosion and migration of sand dunes on a beach.

FIGURE 5.47
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 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.

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?

5.8 Erosion and Deposition by Gravity

Lesson Objectives

- Identify causes and effects of landslides and mudslides.
- Explain how slump and creep occur.

Lesson Vocabulary

- creep
- landslide
- mass movement
- mudslide
- slump

Introduction

Gravity is the indirect cause of most erosion. 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. 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. It may take many years.

Landslides and Mudslides

The most destructive types of mass movement are landslides and mudslides. Both occur suddenly. If you are in their path, they can be deadly.

Landslides

A **landslide** happens when a large amount of soil and rock suddenly fall. The rock and soil fall down a slope because of gravity. You can see an example in **Figure** 5.48. 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 can also cause landslides. In these cases, the ground does not need to be wet and slippery. It is the shaking of the ground that causes the soil and rock to break loose and move. Sometimes, debris from landslides falls into water. When this happens, it may cause a huge wave called a tsunami.

Mudslides

A **mudslide** is the sudden flow of mud down a slope. Mudslides occur where the soil is mostly clay. Clay soil is composed of very small particles. The space between these particles is able to hold a lot of water. Wet clay forms very slippery mud that slides easily. You can see an example of a mudslide in **Figure** 5.49.

FIGURE 5.48
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.

FIGURE 5.49
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** 5.50. All the material moves together in big chunks. Slump may be caused by a layer of slippery, wet clay. The wet clay may be under 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.

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** 5.51. The slowly moving

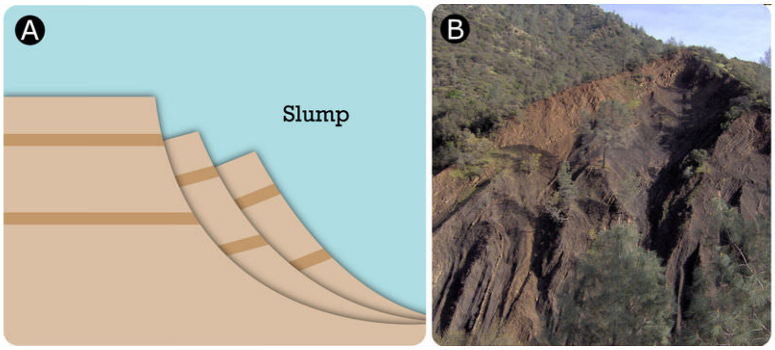


FIGURE 5.50
Slump takes place suddenly, like a landslide. How does slump differ from a landslide?

ground causes everything to move with it. This includes trees, fence posts, and other structures on the surface.

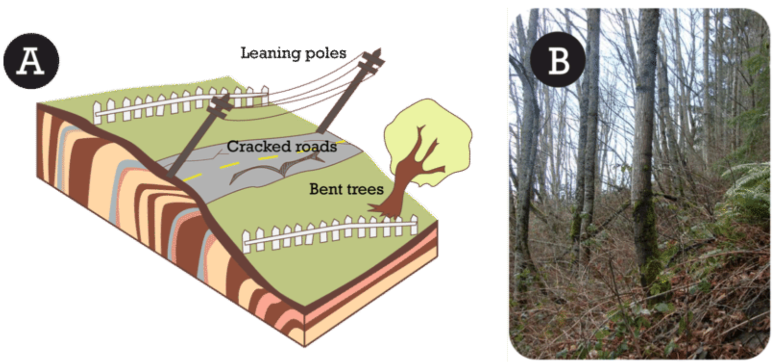


FIGURE 5.51
Creep is seen on a hillside. What evidence shows creep has occurred?

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. They generally have little warning before they happen. 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?

5.9 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.

Lesson 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?

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** 5.52 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.

Wave Erosion

Runoff, streams, and rivers carry sediment to the oceans. The sediment in ocean water acts like sandpaper. Over time, the sediment in waves erodes the shore. The bigger the waves are, and the more sediment they carry, the more erosion they cause.

FIGURE 5.52
Ocean waves transfer energy from the wind through the water. This gives waves the energy to erode the shore.

Landforms From Wave Erosion

Erosion by waves can create unique landforms (**Figure** 5.53).

- 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 5.53
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 the 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** 5.54. Many beaches include bits of rock and shell. You can see a close-up photo of beach deposits in **Figure** 5.55.

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

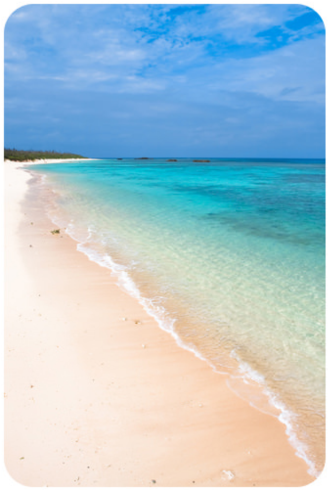


FIGURE 5.54
Sand deposited along a shoreline creates a beach.

FIGURE 5.55
Beach deposits usually consist of small pieces of rock and shell in addition to sand.

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** 5.56.

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** 5.57.

Waves may also deposit sediments to form **sandbars** and **barrier islands**. You can see examples of these landforms in **Figure** 5.58.

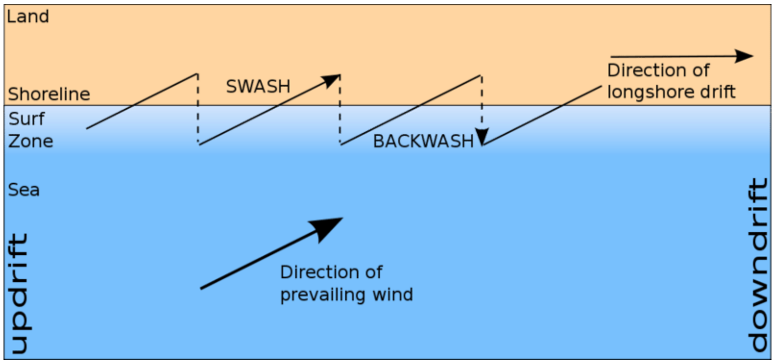


FIGURE 5.56
Longshore drift carries particles of sand and rock down a coastline.

FIGURE 5.57
Spit from Space. Farewell Spit in New Zealand is clearly visible from space. This photo was taken by an astronaut orbiting Earth.

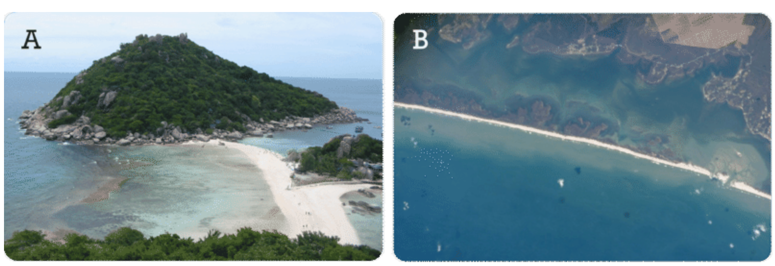


FIGURE 5.58
Wave-Deposited Landforms. These landforms were deposited by waves. (A) Sandbars connect the small islands on this beach on Thailand. (B) A barrier island is a long, narrow island. It forms when sand is deposited by waves parallel to a coast. It develops from a sandbar that has built up enough to break through the water's surface. A barrier island helps protect the coast from wave erosion.

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.

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** 5.59. It runs parallel to the coast like a barrier island.

FIGURE 5.59
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 a 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 up-current side and reduces beach erosion. You can see how groins work in **Figure** 5.60.

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?

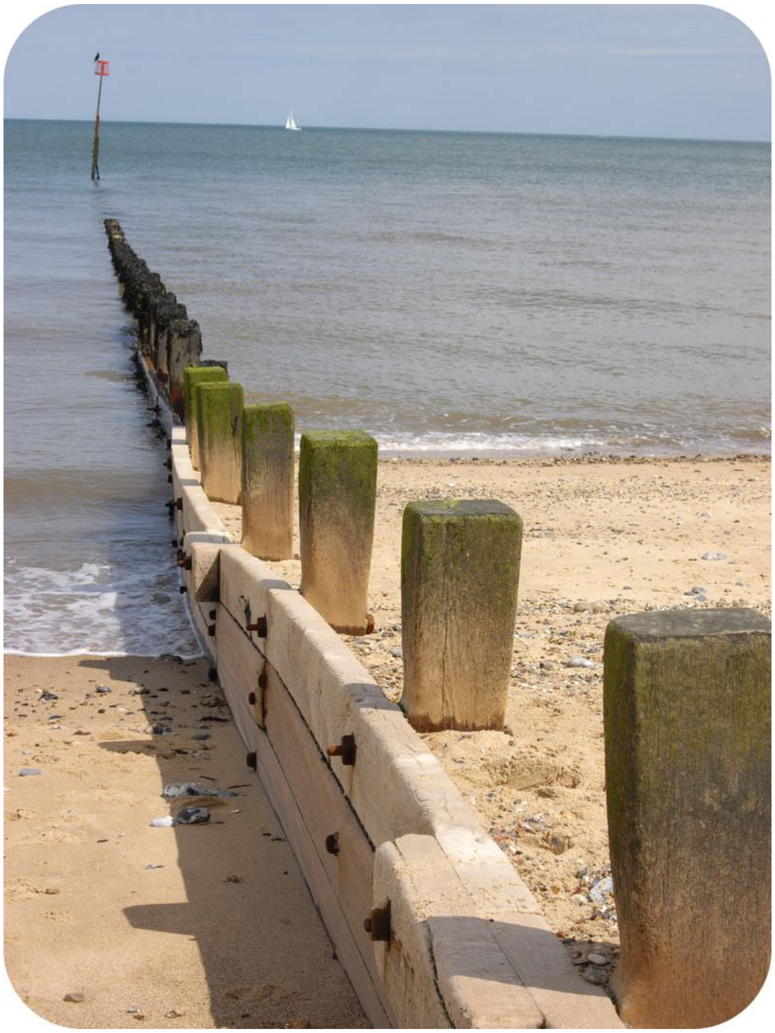


FIGURE 5.60
A groin is built perpendicular to the shoreline. Sand collects on the up-current side.

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?

External Resources

By clicking a link below, you will leave the CK-12 site and open an external site in a new tab. This page will remain open in the original tab.

http://oceanica.cofc.edu/an%20educator'sl%20guide%20to%20folly%20beach/guide/driftanimation.htm

5.10 Erosion and Deposition by Flowing Water

Lesson Objectives

- Explain how flowing water causes erosion.
- Describe how runoff, streams, and rivers change Earth's surface.
- Identify features caused by groundwater erosion.

Lesson Vocabulary

- alluvial fan
- cave
- delta
- deposition
- erosion
- floodplain
- levee
- meander
- oxbow lake
- saltation
- sinkhole
- suspension
- traction

Introduction

Erosion causes changes to Earth's surface. **Erosion** is what causes pieces of rock and soil to move. These pieces of rock and soil are called sediment. There are several causes of erosion. These causes are flowing water, waves, wind, ice, and gravity.

How Flowing Water Causes Erosion and Deposition

Flowing water causes sediment to move. Flowing water can erode both rocks and soil.

You have already learned that materials can dissolve in water. With enough time, even rocks can be dissolved by water. This process happens really slowly. It may take over a million years to dissolve a rock. It doesn't matter how big the rock is. With enough time, flowing water can dissolve it.

Moving water also has the ability to move small pieces of rock and soil. How can water move a rock? Doesn't it need energy? Of course, water gets its energy because it is moving. Moving water has kinetic energy. Things that have more energy can do more work. When water stops moving it will have no energy. It will no longer be able to move the rock and soil. When this happens the rock and soil will settle to the bottom of the calm water. Scientists call this process deposition.

Water Speed and Erosion

Faster-moving water has more kinetic energy. Therefore, it can carry larger particles. It can also carry more particles. What causes water to move faster? The steeper the slope, the faster the water flows. It's just like a toy car rolling down a ramp. It will roll the fastest when the ramp is steep. It will roll slower when the ramp is less steep. If the ramp is flat, it may have no motion. The slope of the land causes water to move faster. If a stream or a river is flowing down a mountain, it will move more quickly. If it is flowing across a flat area, it will move slowly.

Particle Size and Erosion

The size of particles determines how they are carried by flowing water. This is illustrated in **Figure** 5.61.

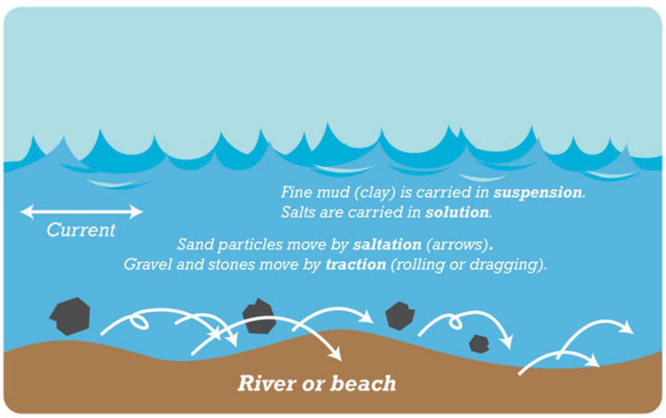


FIGURE 5.61

How Flowing Water Moves Particles. How particles are moved by flowing water depends on their size.

Some minerals dissolve in water. The minerals are then carried along in the solution. 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 bounce along the bottom. Particles, such as sand, move in little jumps near the stream bottom. They are nudged along by moving water. The biggest particles move in a different way. They are too big to hop. Instead, they roll along the bottom. Gravel and pebbles move in this way. These particles roll or drag along the bottom of the water.

Deposition by Water

Flowing water slows down when it reaches flatter land. Maybe it flows into a small lake or pond. 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 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

Sometimes it rains a lot at one time. It rains so hard that the rain cannot soak into the ground. Instead, it runs over the land. Gravity causes the water to flow downhill. As the runoff flows, it may pick up loose material. These materials may include bits of soil and sand. It is carried off by this running water across the surface of the land.

Runoff is likely to cause more erosion if the land is bare. Plants help hold the soil in place. The runoff water in **Figure** 5.62 is brown. It has turned brown because it eroded soil. It leaves behind only bare soil. Does erosion happen around where you live? Can you find evidence of erosion? What should you look for?

FIGURE 5.62
Erosion by Runoff. Runoff has eroded small channels through this bare field.

Much of the material eroded by runoff makes its way into a body of water. These bodies of water include 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. Farmland is especially under danger from this type of erosion. Farmers can lose much of their topsoil. They take great care to prevent soil erosion. Without topsoil, crops cannot grow.

Erosion by Mountain Streams

Streams often start high in the mountains. Their slopes of mountains are very steep. As a result, the streams flow very quickly. You can see an example in **Figure** 5.63. The quick speed of the water causes a lot of erosion. The fast moving water carves deep into the rock and soil it flows over. Mountains streams cut narrow V-shaped channels.

How a Waterfall Forms

Have you ever seen a waterfall? Perhaps you have seen a picture of one? Waterfalls may be formed by mountain streams. They typically form where water is moving quickly. As shown in **Figure** 5.64, waterfalls need special conditions to form. They form where the stream flows from an area of harder onto an area of softer rock. The water erodes the softer rock faster than the harder rock. This causes a step-like feature to form. This process is what creates a waterfall. As erosion continues, the waterfall slowly moves upstream.

Erosion by Slow-Flowing Rivers

Rivers flowing over gentle slopes move more slowly. They move much more slowly than a mountain stream. These slow moving streams create different types of features than mountain streams. Slow moving water erodes the sides of their channels more than the bottom. Also, large curves in the stream form. These curves are called **meanders**. Meanders are caused by erosion and deposition.

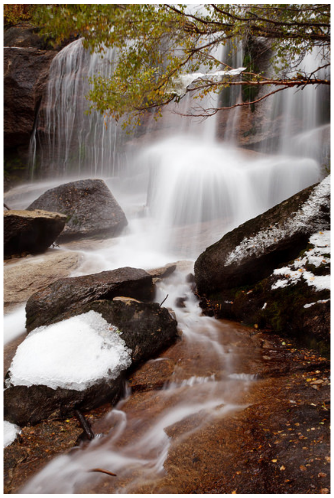


FIGURE 5.63
Mountain Stream. This mountain stream races down a steep slope.

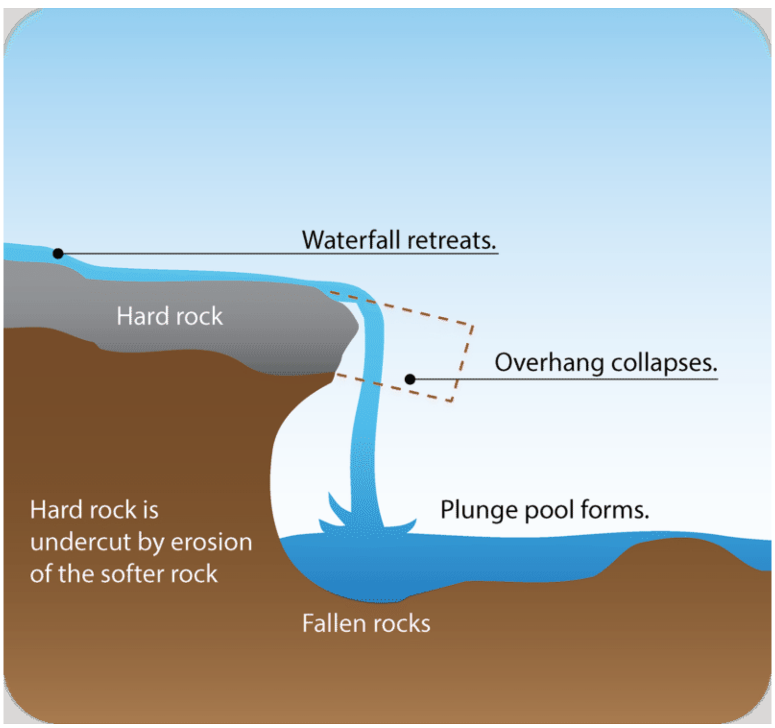


FIGURE 5.64
How a Waterfall Forms and Moves. Why does a waterfall keep moving upstream?

Remember, faster moving water causes erosion more quickly. Slower moving water erodes material more slowly. If water is moving slowly enough, the sediment being carried may settle out. This settling out, or dropping off, of sediment is deposition. The curves are called meanders because they slowly "wander" over the land. You can see how this happens in **Figure** 5.65.

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** 5.65.

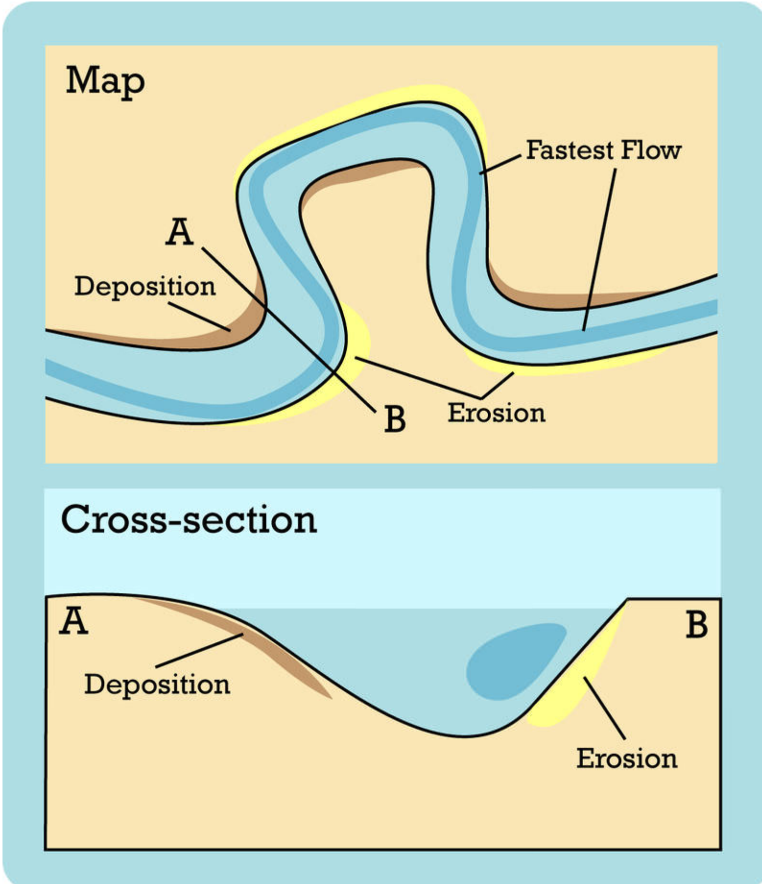


FIGURE 5.65
Meanders form because water erodes the outside of curves and deposits eroded material on the inside. Over time, the curves shift position.

Deposition by Streams and Rivers

When a stream or river slows down, it starts dropping its sediments. Larger sediments are dropped in steep areas. Some smaller sediments can still be carried by a slow moving stream or river. 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** 5.66.

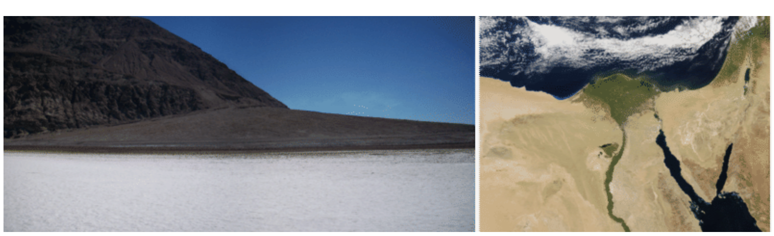


FIGURE 5.66
An alluvial fan in Death Valley, California (left), Nile River Delta in Egypt (right).

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** 5.66.

Deposition by Flood Waters

A flood occurs when a river overflows its banks. This might happen because of heavy rains.

Floodplains

In very flat regions, flood water may spread out on the surface of the land. It then slows down and drops its sediment. If a river floods often, a floodplain develops. A floodplain is an area where a thick layer of rich soil is left behind as the floodwater recedes. That's why floodplains are usually good places for growing plants. They are very flat areas and they have very rich soils.

The Nile River valley is a great example of a floodplain. Each year, the Nile River rises over its banks. This floodwater carries a lot of sediment. This sediment has been eroded off areas of land from upstream. This sediment is dropped as the water slows down after spreading across the land. What is left behind is a very rich soil. That's why crops can be raised 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** 5.67.

Erosion and Deposition by Groundwater

Not all water travels on the surface. Some water travels underground. How does this happen? Some water soaks into the ground. It travels down through tiny holes in soil. It seeps through cracks in rock. The water moves slowly. It is pulled deeper and deeper into the ground by gravity. Underground water can also erode and deposit material.

Caves

As water flows through, it causes changes. The flowing water dissolves some types of rock. Some rocks dissolve more easily than others. Over time, the water may dissolve large areas of rocks. With enough time, holes, or **caves,** can form. Groundwater drips from the ceiling to the floor of a cave. Even deep in the ground, water is still pulled by gravity. This falling water is rich in dissolved minerals. Some of these minerals do not stay dissolved. When this happens, the minerals start to build up. They build up on the ceiling of the cave to create formations called stalactites. A stalactite is a pointed, icicle-like mineral. They form on the ceiling of a cave. They drip to the floor of the cave. It is there the minerals in the water harden to form stalagmites. A stalagmite is a more rounded mineral deposit. It forms on the floor of a cave (**Figure** 5.68). Both types of formations grow in size as water keeps dripping and more minerals are deposited.

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** 5.69. Some sinkholes

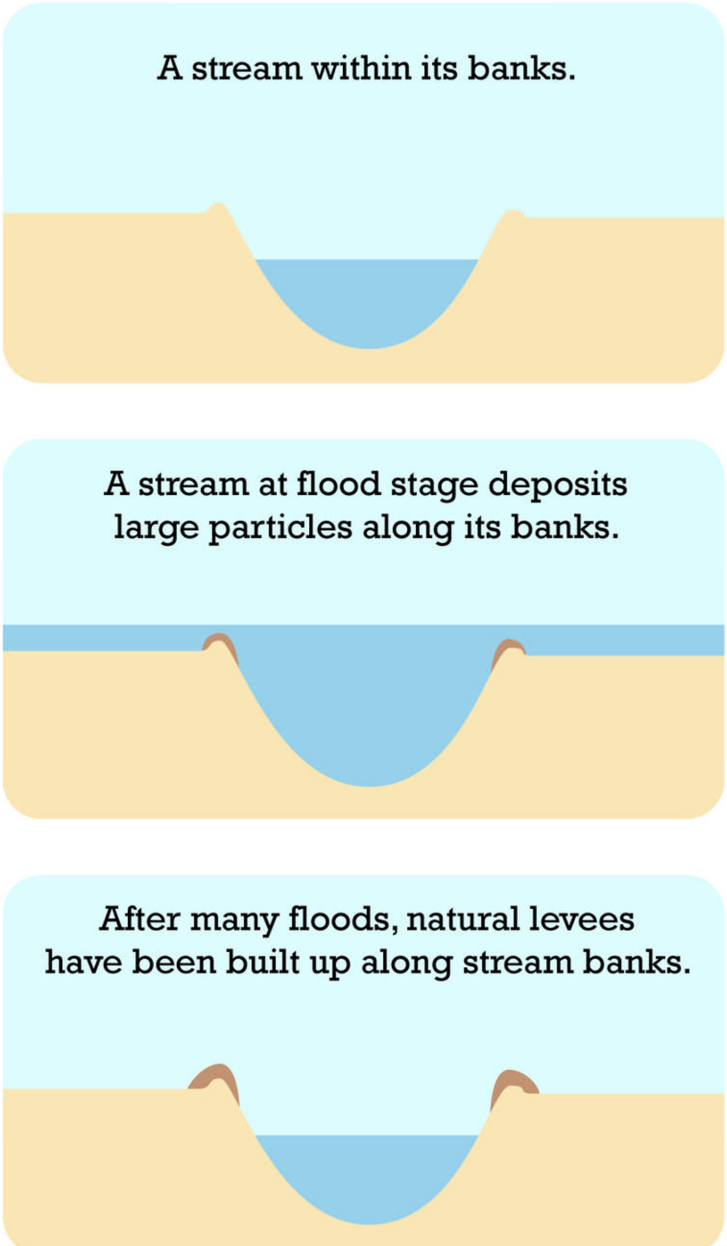


FIGURE 5.67
This diagram shows how a river builds natural levees along its banks.

are big enough to swallow vehicles and buildings. Florida has a lot of sinkholes. Look at a map of Florida and notice the numerous round lakes. These lake are sinkholes that have filled with water.

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. This process starts with the largest particles first.
- Runoff erodes the land after a heavy rain. It picks up sediment. Runoff carries most of the sediment to bodies of water. Mountain streams erode narrow, V-shaped valleys and waterfalls.

FIGURE 5.68
This cave has both stalactites and stalagmites.

FIGURE 5.69
A sinkhole.

- Erosion and deposition by slow-flowing rivers create 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. They 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?

5.11 Ocean Movements and Waves

Lesson Objectives

- Describe how waves move through water.

Lesson Vocabulary

- 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** 5.70. 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.

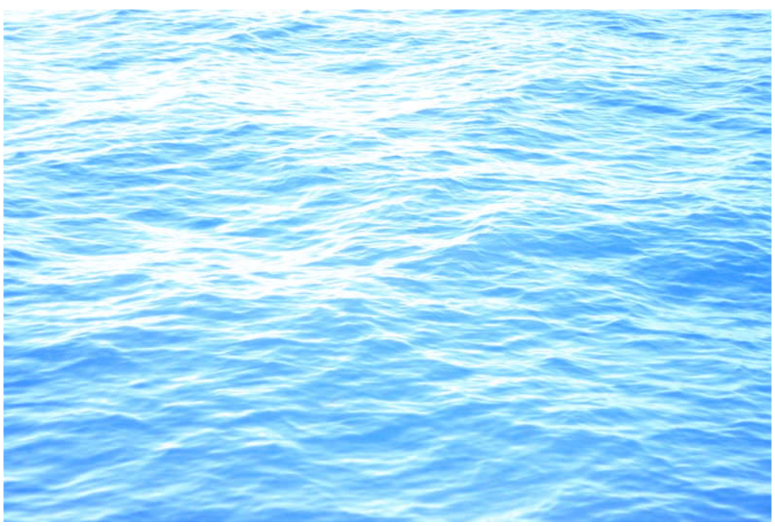


FIGURE 5.70
Waves cause the rippled surface of the ocean.

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** 5.71 shows how water molecules move when a wave goes by.

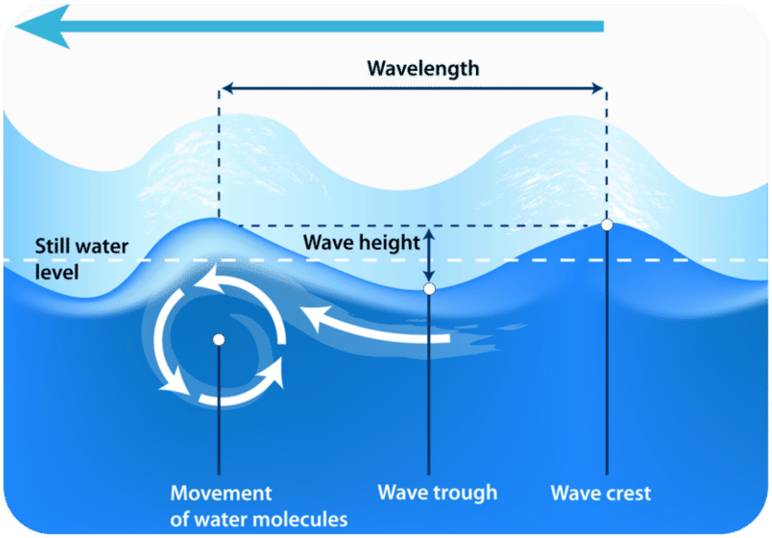


FIGURE 5.71
A wave travels through the water. How would you describe the movement of water molecules as a wave passes through?

The Size of Waves

Figure 5.71 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

As waves move into shallow water, they start to touch the land at the bottom. 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** 5.72 shows what happens to waves near shore.

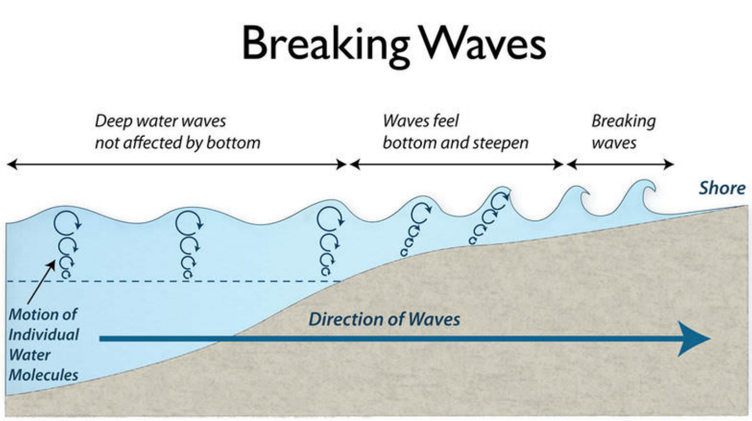


FIGURE 5.72
Waves break when they reach the shore.

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. Tsunamis can travel at speeds of 800 kilometers per hour (500 miles per hour). Usually tsunami waves travel through the ocean unnoticed.

Tsunami waves have very small wave heights. In contrast, they have very long wavelengths. If you were at sea, you would not notice it pass under your ship. But when they reach the shore they become enormous. Tsunami waves can flood entire regions. They destroy property and cause many deaths. **Figure** 5.73 shows the damage caused by a tsunami from the Indian Ocean in 2004.

FIGURE 5.73
A 2004 tsunami caused damage like this all along the coast of the Indian Ocean. Many lives were lost.

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.

Lesson Review Questions

Recall

1. Identify two causes of ocean waves.
2. What factors determine how big a wave is?

Apply Concepts

3. 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.

Think Critically

4. Explain why waves break on the shore.

5.12 References

1. (A) Alan Klim; (B) Margaret W. Carruthers. (A) http://www.flickr.com/photos/61203681@N08/8231264538/; (B) http://www.flickr.com/photos/64167416@N03/7022634029/ .
2. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
3. Courtesy of NOAA. http://celebrating200years.noaa.gov/new_york_charts/compass_rose.html . Public Domain
4. Peter W. Sloss. http://www.magazine.noaa.gov/stories/mag26.htm . Public Domain
5. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
6. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
7. Courtesy of the National Oceanic and Atmospheric Administration. http://oceanexplorer.noaa.gov/explorations/04etta/background/profile/profile.html . Public Domain
8. Courtesy of the National Oceanic and Atmospheric Administration. (left) http://oceanexplorer.noaa.gov/explorations/03mountains/background/plan/media/sites.html; (right) http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/sep13/media/bear_seamount.html . Public Domain
9. Courtesy of the National Oceanic and Atmospheric Administration. http://www.ngdc.noaa.gov/mgg/image/global_topo_large.gif . Public Domain
10. User:Kmusser/Wikimedia Commons. Mariana Trench in the Pacific Ocean . CC BY 2.5
11. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Pacific_Ring_of_Fire.png . Public Domain
12. Courtesy of NASA. http://commons.wikimedia.org/wiki/Image:Quake_epicenters_1963-98.png . Public Domain
13. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Plates_tect2_en.svg . Public Domain
14. CK-12 Foundation. . CC BY-NC 3.0
15. User:Mangwanani/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Mid_Atlantic_Ridge.jpg . Public Domain
16. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Greatrift.jpg . Public Domain
17. User:Booyabazooka/Wikipedia. http://commons.wikimedia.org/wiki/File:Active_Margin.svg . Public Domain
18. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Peru-Chile_trench.jpg . Public Domain
19. User:Booyabazooka/Wikipedia. http://commons.wikimedia.org/wiki/File:Active_Margin.svg . Public Domain
20. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Aleutians-space.jpg . Public Domain
21. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Continental-continental_convergence_Fig21contcont.gif . Public Domain
22. Maria Ly (Flickr:mariachily). http://www.flickr.com/photos/mariachily/3330744786/ . CC BY 2.0
23. Courtesy of Kate Barton, David Howell, Joe Vigil, US Geological Survey. http://commons.wikimedia.org/wiki/File:Sanandreas.jpg . Public Domain
24. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Hawaii_hotspot_poster.jpg . Public Domain
25. Courtesy of NASA Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=5816 . Public Domain
26. Ron Sanderson. http://www.publicdomainpictures.net/view-image.php?image=26142&picture=coastal-scene-tasmania&large=1 . Public Domain
27. Courtesy of Michael Quinn/Grand Canyon National Park. http://www.flickr.com/photos/grand_canyon_nps/7556098142/ . CC BY 2.0

28. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
29. (A) Chad K; (B) Kyle Taylor. (A) http://www.flickr.com/photos/chad_k/248461570/; (B) http://www.flickr.com/photos/kyletaylor/3540955820/ . CC BY 2.0
30. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
31. Image copyright branislavpudar, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
32. (A) Flickr:furtwangl; (B) Hannes Grobe/AWI; (C) Ben Salter (Flickr:Capt' Gorgeous); (D) edmondo gnerre; (E) Mark A. Wilson (Department of Geology, The College of Wooster); (F) Courtesy of the U.S. Geological Survey. (A) http://www.flickr.com/photos/furtwangl/3283595757/; (B) http://commons.wikimedia.org/wiki/File:Archaeopteryx-8-senkenberg_hg.jpg; (C) http://www.flickr.com/photos/ben_salter/2103829606/; (D) http://www.flickr.com/photos/edgnerre/2891672667/; (E) http://commons.wikimedia.org/wiki/File:ThalassinoidesIsrael.JPG; (F) http://commons.wikimedia.org/wiki/File:Coprolite.jpg . (A) CC BY 2.0; (B) CC BY 3.0; (C) CC BY 2.0; (D) CC BY 2.0; (E) Public Domain; (F) Public Domain
33. Christopher Auyueng. CK-12 Foundation . CC BY-NC 3.0
34. (A) Elisabeth; (B) Image copyright ribeiroantonio, 2013; (C) James St. John (Flickr:jsj1771). (A) http://commons.wikimedia.org/wiki/File:Spider_in_amber_%281%29.jpg; (B) http://www.shutterstock.com; (C) http://www.flickr.com/photos/jsjgeology/8281567838/ . (A) CC BY 3.0; (B) Used under license from Shutterstock.com; (C) CC BY 2.0
35. Courtesy of the National Park Service. http://www.nps.gov/imr/photosmultimedia/photogallery.htm?id=F17B1C64-155D-451F-6765341D9B8E553F . Public Domain
36. Flickr:The Tire Zoo. http://www.flickr.com/photos/new_and_used_tires/6842127640/ . CC BY 2.0
37. Julie Sandeen. CK-12 Foundation . CC BY-NC 3.0
38. Alex Brown. http://commons.wikimedia.org/wiki/File:On_Chesil_Beach_-2_-_alexbrn.jpg . CC BY 2.0
39. Tim Pearce. http://commons.wikimedia.org/wiki/File:Devils_Tower_Wyoming.jpg . CC BY 2.0
40. Image copyrights (A) Volodymyr Goinyk, 2013; (B) Jason Cheever, 2013; (C) Galyna Andrushko, 2013. http://www.shutterstock.com . Used under licenses from Shutterstock.com
41. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
42. Greg Gorman. http://www.flickr.com/photos/gwgpix/9272456826/ . CC BY 2.0
43. Left: Courtesy of NASA; Right: Courtesy of Corporal Alicia M. Garcia/U.S. Marine Corps. Left: http://commons.wikimedia.org/wiki/File:Saltation-mechanics.gif; Right: http://commons.wikimedia.org/wiki/File:Sandstorm.jpg . Public Domain
44. Natural Resources Conservation Service. http://commons.wikimedia.org/wiki/File:NRCSUT03016_-_Utah_-(6401)(NRCS_Photo_Gallery).jpg .
45. (A) Peter (Flickr:Pedronet); (B) ECP (Flickr:Shamanic Shift). (A) http://www.flickr.com/photos/pedronet/4184952159/; (B) http://www.flickr.com/photos/shamanic-shift/409524420/ . CC BY 2.0
46. Courtesy of the National Park Service/U.S. Geological Survey. http://commons.wikimedia.org/wiki/File:Sand_dune_formation.png . Public Domain
47. Mark A. Wilson (Department of Geology, The College of Wooster). http://commons.wikimedia.org/wiki/File:LoessVicksburg.jpg . Public Domain
48. U.S. Army (Flickr:familymwr). http://www.flickr.com/photos/familymwr/5547472879/ . CC BY 2.0
49. Courtesy of Edwin L. Harp, USGS. http://nasadaacs.eos.nasa.gov/articles/2006/2006_hotspots.html . Public Domain
50. Raymond D. Petersen III. http://commons.wikimedia.org/wiki/File:Southern_Leyte_mudslide_2006_pic01.jpg . Public Domain
51. (A) Christopher Auyeung; (B) Alisha Vargas. (A) CK-12 Foundation; (B) http://www.flickr.com/photos/alishav/3354150985/ . (A) CC BY-NC 3.0; (B) CC BY 2.0
52. (A) Christopher Auyeung; (B) User:G310stu/Wikipedia. (A) CK-12 Foundation; (B) http://commons.wikimedia.org/wiki/File:Trees_showing_the_presence_of_creep.jpg . (A) CC BY-NC 3.0; (B) Public Domain
53. Image copyright Lynne Carpenter, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
54. (A) J Wynia; (B) David Sim (Flickr:victoriapeckham); (C) Herry Lawford. (A) http://www.flickr.com/photos

/jwynia/2664793599/; (B) http://www.flickr.com/photos/victoriapeckham/4402299200/; (C) http://www.flickr.com/photos/herry/2639799683/ . CC BY 2.0
55. Image copyright tororo reaction, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
56. Flickr:fdecomite. http://www.flickr.com/photos/fdecomite/5608724551/ . CC BY 2.0
57. User:Yefi/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Longshore_drift.svg . Public Domain
58. Courtesy of NASA. http://earthobservatory.nasa.gov/IOTD/view.php?id=5754 . Public Domain
59. (A) Flickr:w00kie; (B) Courtesy of NASA. (A) http://www.flickr.com/photos/w00kie/3957762/; (B) http://eol.jsc.nasa.gov/scripts/sseop/photo.pl?mission=ISS012&roll=E&frame=8705 . (A) CC BY 2.0; (B) Public Domain
60. Flickr:chop1n. http://www.flickr.com/photos/chop1n/6980321335/ . CC BY 2.0
61. Rev Stan. http://www.flickr.com/photos/revstan/3547075472/ .
62. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
63. Courtesy of Lynn Betts, USDA Natural Resources Conservation Service. http://commons.wikimedia.org/wiki/File:NRCSIA99142_-_Iowa_%282985%29%28NRCS_Photo_Gallery%29.jpg . Public Domain
64. Flickr:jar. http://www.flickr.com/photos/jariceiii/6287119489/ . CC BY 2.0
65. Jodi So. CK-12 Foundation . CC BY-NC 3.0
66. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
67. Left: Alisha Vargas (Flickr:AlishaV); Right: NASA/GSFC/Jeff Schmaltz/MODIS Land Rapid Response Team. Left: http://www.flickr.com/photos/alishav/3261819099/; Right: http://www.flickr.com/photos/gsfc/5635018418/ . CC BY 2.0
68. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
69. Meetu Singal. http://www.flickr.com/photos/meetusinghal/7926046500/ . CC BY 2.0
70. Image copyright Zack Frank, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
71. kyle wyss. http://www.flickr.com/photos/blindmanscolour/5270022831/ . CC BY 2.0
72. Hana Zavadska. Anatomy of a wave . CC BY-NC 3.0
73. Hana Zavadska. Breaking waves . CC BY-NC 3.0
74. Courtesy of Dr. Bruce Jaffe/U.S. Geological Survey. http://gallery.usgs.gov/photos/356 . Public Domain

CHAPTER 6 Earth Science: Water and Climate

Chapter Outline

6.1 Water on Earth

Lesson Objectives

- Describe water and where it occurs on Earth.
- Give an overview of the water cycle.
- Explain how the ocean is an integral part of the water cycle and is connected to all of Earth's water reservoirs via evaporation and precipitation processes.

Lesson 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% 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** 6.1 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.

Most of Earth's water is salt water in the oceans. As **Figure** 6.2 shows, only 3% 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 Cascade Range in North America and the Alps in Europe are

FIGURE 6.1
Take a look at this image. Do you think that Earth deserves the name "water planet"?

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.

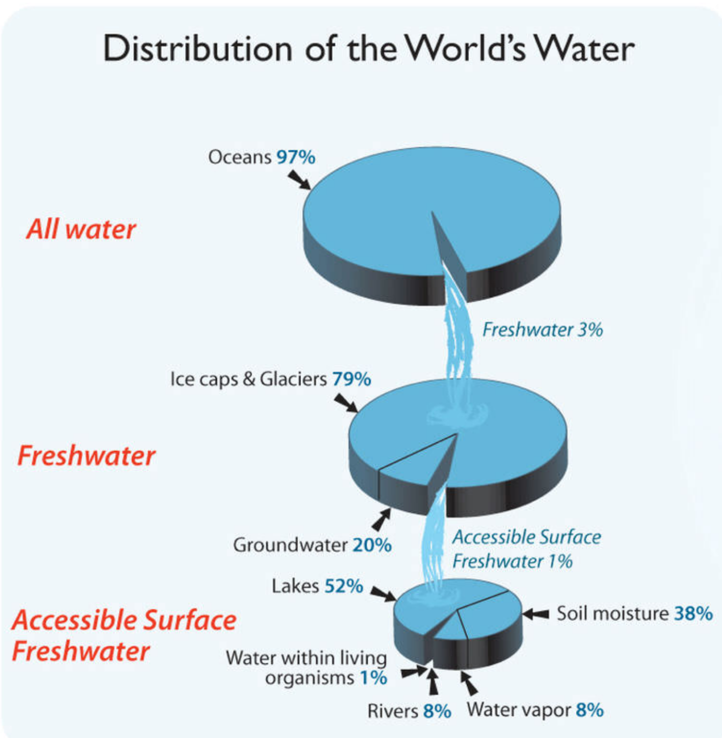


FIGURE 6.2
What percentage of Earth's surface freshwater is water vapor in the air?

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** 6.3 diagrams the water cycle.

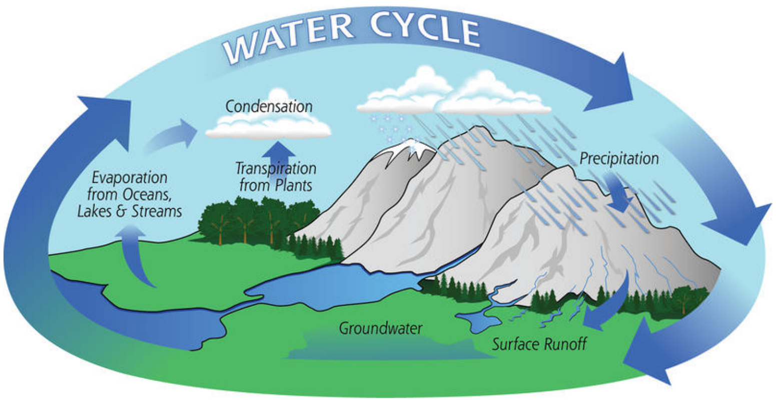


FIGURE 6.3
The water cycle has no beginning or end. Water just keeps moving along.

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** 6.3 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.

If you look at the image above, it looks like the water cycle occurs mostly over land. That is far from the reality. In fact, the oceans are a critical part of the water cycle. Can you think why that may be?

The oceans are an essential part of Earth's water cycle for one simple reason. Oceans cover about 2/3 of the Earth's surface. As a result, most evaporation comes from oceans. Most precipitation also occurs over the oceans.

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?

Vocabulary

6.2 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.

Lesson Vocabulary

- drought
- irrigation

Introduction

All forms of life need water to survive. Humans can survive for only a few days without it. That's not very long. It is far less time than humans can go without food. Besides drinking, people also need water for other purposes. For example, water is used 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 6.4 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 small businesses.

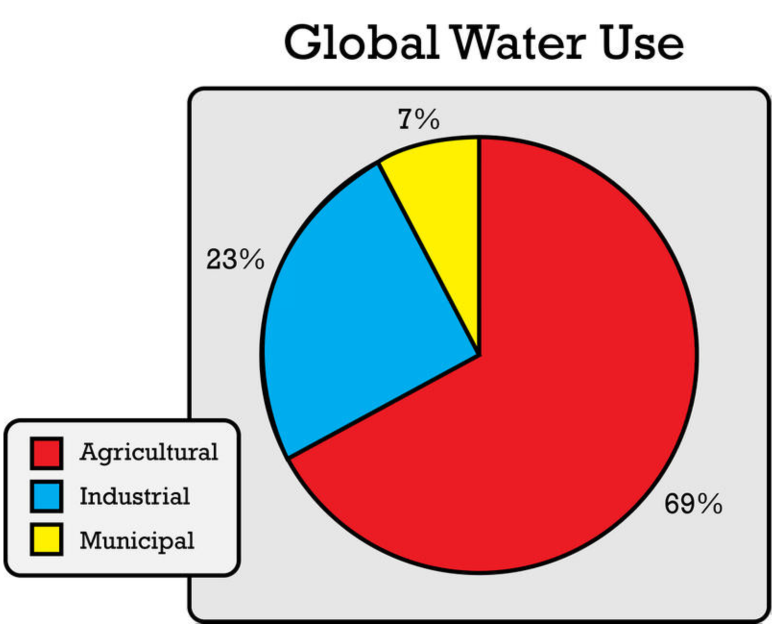


FIGURE 6.4
In this global water use chart, see how much is used for agriculture. Why do you think so much water is used in agriculture?

Water in Agriculture

You know that plants need water. It would seem obvious that a desert would not be a great place to grow crops. That is not the case. Many crops are grown where there is limited water. 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** 6.5 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. Do you know why? Of course, some of it evaporates into the air. It never reaches the ground. Even when the water does reach the ground, it may just run off, never reaching the plants. Irrigation water may cause other problems. The water may dissolve chemicals. These chemicals include pesticides and fertilizers. When the water soaks into the ground so do the chemicals. They may enter groundwater. They may run off into nearby rivers or lakes.

FIGURE 6.5
Overhead irrigation systems like this one are widely used to irrigate crops on big farms. What are some drawbacks of irrigation?

Industry Uses of Water

Almost a quarter of the available water is used in industry. Industries use water for many purposes. Chemical processes need a lot of water. Water is used to generate electricity. Sometimes water is used to cool machines and power plants.

Household Uses of Water

Think about all the ways people use water at home. Certainly you drink water, but there are many other ways you use it. You may use it to cook. Think about the pot of boiling water needed to cook spaghetti. You also use water to clean up the mess after eating your spaghetti. You may take a shower or bath at night, or in the morning before school. Can you think of some other uses of water in your home?

Most of the water used in your home goes down the drain. From there it usually ends up in a sewer system. It ends up at the sewage treatment plant. That's not the end of the road for water. The treatment plant prepares the water for reuse.

Households may also use water outdoors. Maybe you water your lawn or garden? You may use water to wash the family car. Much of the water used outdoors evaporates or runs off into the gutter. The runoff water may end up in storm sewers. From there it may move into a nearby body of water. Maybe it is a local lake. It might eventually make it to the ocean.

FIGURE 6.6
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. Maybe you want to try white water rafting or snorkeling someday. It sure looks like fun! 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 large amounts of water. Golf courses use irrigation to keep them looking green. Many golf courses, have large sprinkler systems. Much of this water is wasted. It evaporates or runs off the ground.

FIGURE 6.7
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. Many plants and animals need fresh liquid water to survive. More than 97 percent of Earth's water is salt water in the oceans. Salt water will kill most land plants and animals. Only 3 percent of Earth's water is freshwater. Most of the freshwater is frozen in ice sheets, icebergs, and glaciers (see **Figure** 6.8). That does not leave us with much water. That's why it is important to conserve and protect our freshwater.

FIGURE 6.8
This glacier in Patagonia, Argentina stores a lot of frozen freshwater.

Rainfall and Water Supply

Rainfall varies around the globe. About 40 percent of the land gets very little rain. As a result, many people do not have enough water. Drier climates generally have less water for people to use. Imagine this, what you may use in one day is what other people may get in a year.

Wealth and Water Supply

Richer nations can drill deep wells. They can build large dams. They can extract freshwater from ocean water. 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** 6.9. These people must carry water home in a bucket from a distant pump.

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. In some areas, humans have cut down all the trees. This action can bring on a drought. Trees add a lot of water vapor to the air. With fewer trees, the air is drier and droughts are more common.

FIGURE 6.9
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?

We 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 a vital resource. Water shortages may even lead to other problems.

- Crops and livestock may die. As a result, people will have less food available.
- Other uses of water, such as industry, may have to stop. This reduces the number of jobs available to people of that area.
- People and nations may fight over water resources.
- In extreme cases, people may die from lack of water.

Figure 6.10 shows the global water situation in the 2030s with water stress and water scarcity on the map.

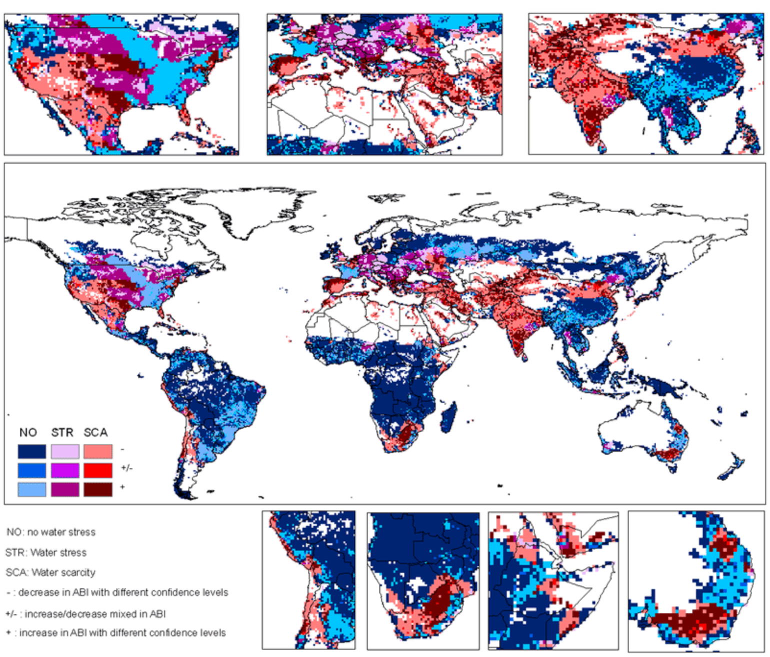


FIGURE 6.10
Blues indicate no predicted water stress; pinks and lavenders predict water stress, and salmon to brown indicates water scarcity (variations of those colors indicate the amount of irrigation that will be done to produce crops).

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** 6.11). Some rivers are polluted. It may contain bacteria and other organisms that cause disease. Almost 9 out of 10 cases of disease worldwide are caused by unsafe drinking water. The drinking of unsafe water is the leading cause of death in young children.

FIGURE 6.11
This girl is getting drinking water from a hole that has been dug. It may be the only source of water where she lives.

Lesson Summary

- People use water for agriculture, industry, and municipal uses. Irrigation for agriculture uses the most water.
- 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?

6.3 Protecting the Water Supply

Lesson Objectives

- List ways to reduce water pollution.
- Identify ways to conserve water.

Lesson Vocabulary

- conservation

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 must protect our water supply from pollution. We also 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 chemicals that it was flammable. Nothing could live in it. You can see the Cuyahoga River in **Figure** 6.12.

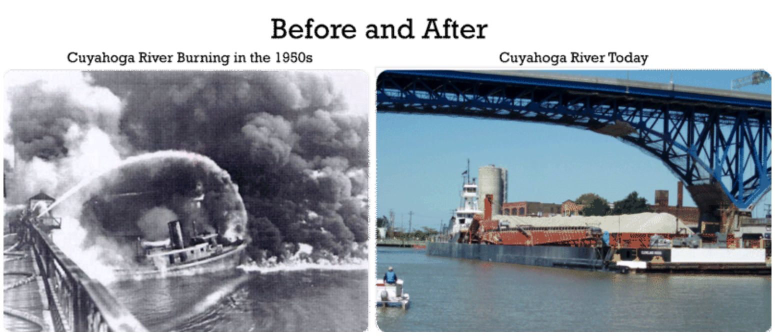


FIGURE 6.12
Left: The Cuyahoga River flows through Cleveland, Ohio. In the mid 1900s, there was a lot of industry in this part of Ohio. The river became very polluted. Right: Today, the river is much cleaner.

Controlling Water Pollution

Disasters, such as rivers burning, led to new U.S. laws to protect the water. As a result of these laws, water is routinely tested. Pollution is tracked to its source. Polluters are forced to fix the problem and clean up the pollution. They are also fined. With these new laws in place, pollution has become less of a threat. That does not mean the threat has been eliminated.

What You Can Do

Most water pollution comes from industry, agriculture, and municipal sources. Homes are part of the municipal source. Individuals and families that live in them can also 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** 6.13). The nitrogen they contain can cause overgrowth of algae. The wastes may also contain bacteria and other causes of disease.

FIGURE 6.13
Why should people always clean up after their pets?

Conserving Water

Conserving water means using less of it. Some areas barely have enough to supply their people. Other areas have an abundance of water. It is the wealthy nations that have the most water, and that 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** 6.14 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. The water soaks into the soil around the plants. Very little of the water evaporates or runs off the ground.

Rationing Water

Some communities save water with rationing. Rationing usually takes place only in times of drought. During rationing, water may not be used for certain things. For example, communities may ban, or limit, lawn watering. They may also ban car washing. People may be fined if they use water in these ways. You can do your part. Follow any bans where you live.

FIGURE 6.14
This is a drip irrigation system. Look at the soil in the photo. It's damp around each plant but dry everywhere else.

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. 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!
- 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 huge savings in water use. Look at the garden in **Figure** 6.15. It shows that you don't have to sacrifice beauty to save 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.
- 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. Describe how water might be rationed in a community. Why would this be done?

FIGURE 6.15
This beautiful garden contains only plants that need very little water.

Apply Concepts

3. 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.
4. Describe a model home with features that save water.

Think Critically

5. 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?

6.4 Use and Conservation of Resources

Lesson Objectives

- Describe how people use natural resources.
- List ways to conserve natural resources.

Lesson 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** 6.1 gives examples of how we use natural resources. Can you think of other ways we use natural resources?

TABLE 6.1: Use of Natural Resources

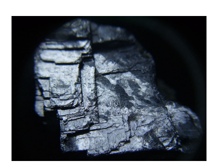
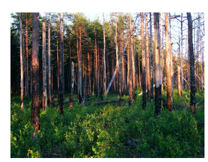
Use	Resources	Example
Vehicles 	Rubber for tires from rubber trees Steel frames and other metal parts from minerals such as iron	iron ore 
Electronics 	Plastic cases from petroleum products Glass screens from minerals such as lead	lead ore 

TABLE 6.1: (continued)

Use	Resources	Example
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** 6.16 shows another example.

FIGURE 6.16
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.

Non-renewable 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** 6.17 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** 6.18.

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.

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?

FIGURE 6.17
This oil rig was pumping oil from below the ocean floor when it exploded.

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** 6.19. 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.

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!)

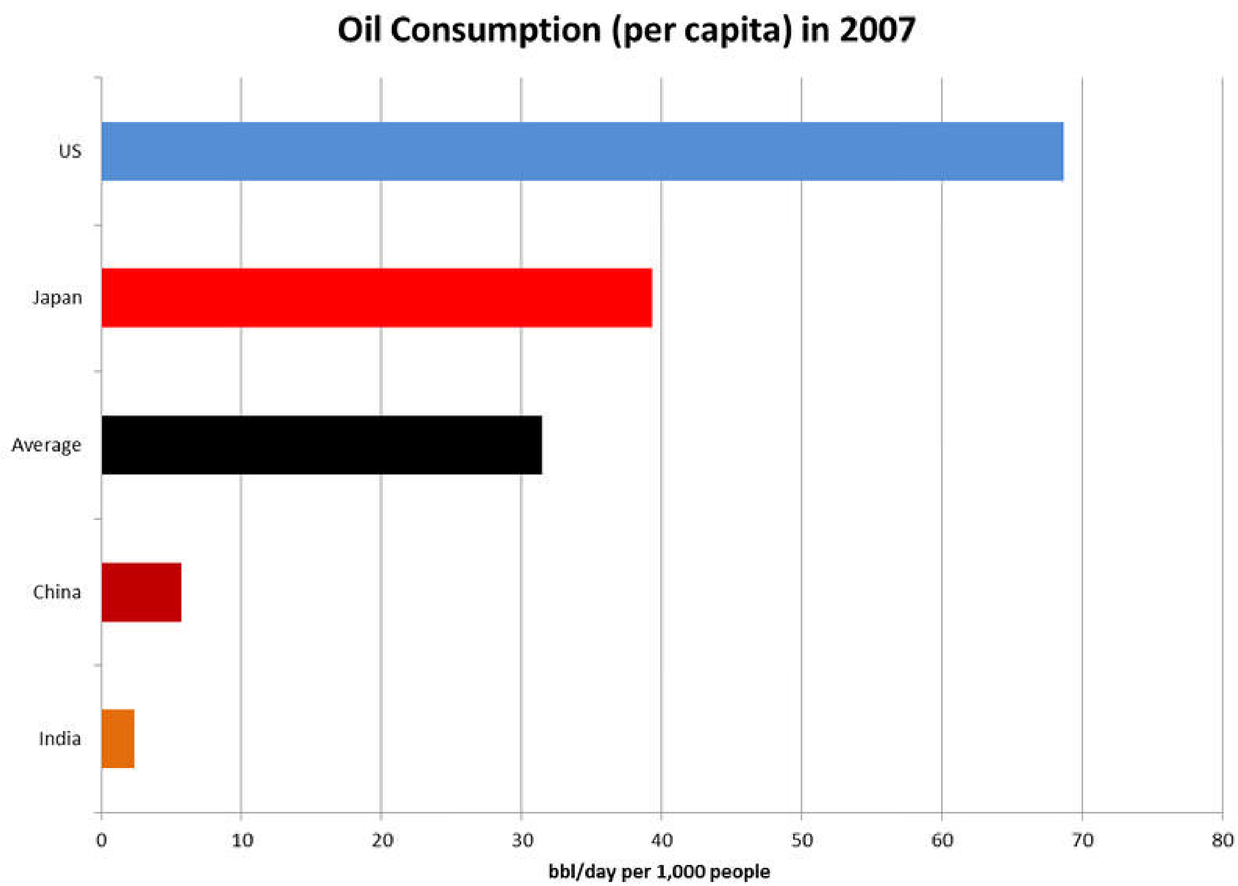


FIGURE 6.18
The U.S. uses more than its share of oil. What if everyone used resources this way? (Note: Per capita means "per person.")

- Buy local. For example, buy local produce at a farmer's market, like the one in **Figure** 6.20. 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 reused or recycled. This is called **precycling**. Soda 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** 6.21. 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.

FIGURE 6.19
Bulldozers crush a mountain of trash.

FIGURE 6.20
Buying locally grown produce at a farmer's market saves resources.

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** 6.22.

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 and made into textbooks. When you shop for new products, look for those that are made of recycled materials (see **Figure** 6.23). Even food scraps and lawn waste can be recycled. They can be composted and turned used 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** 6.24 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!

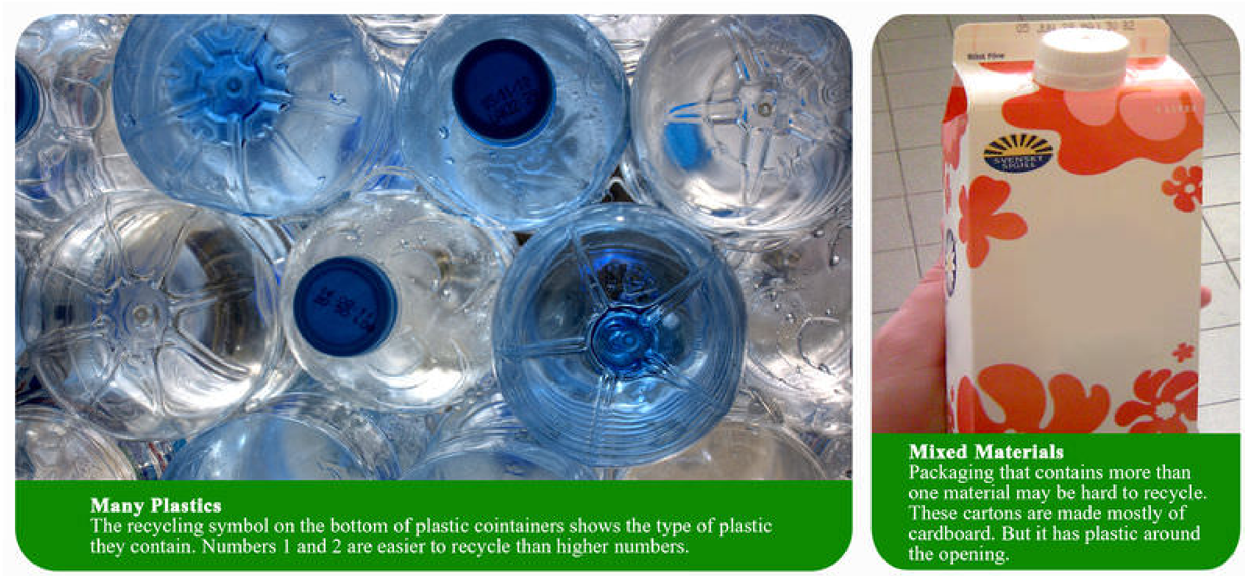


FIGURE 6.21

These types of packaging are hard to recycle. Could you reuse any of them?

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.
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.

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?

FIGURE 6.22
Do you reuse products such as these? Can you think of other ways to reuse resources?

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?

FIGURE 6.23
This label shows that the product was made from recycled materials.

FIGURE 6.24
Are there recycling stations like this one where you live?

6.5 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.

Lesson 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.

All **weather** takes place in the atmosphere. Nearly all of it takes place in the lower atmosphere. **Weather** refers to the conditions of the atmosphere at a given time and place. **Climate** is the average of weather over a long time.

Imagine your grandmother who lives in a distant place calls you up. She asks what your weather is like today. What would you say? Is it warm or cold? Is it sunny or cloudy? Is it calm or windy? Is it clear or rainy? What features of weather are important to mention?

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 and Heat

Humidity is the amount of water vapor in the air. High humidity increases the chances of clouds and precipitation.

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 is saturated with water vapor. It is like trying to dry yourself off with a soaking wet towel. It doesn't work very well.

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 overnight. 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** above, the dew point occurs at 100 percent relative humidity. Can you explain why?

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 (Advanced Topic)

Clouds are classified on the basis of where and how they form. Three main types of clouds are cirrus, stratus, and cumulus. **Figure** 7.3 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.

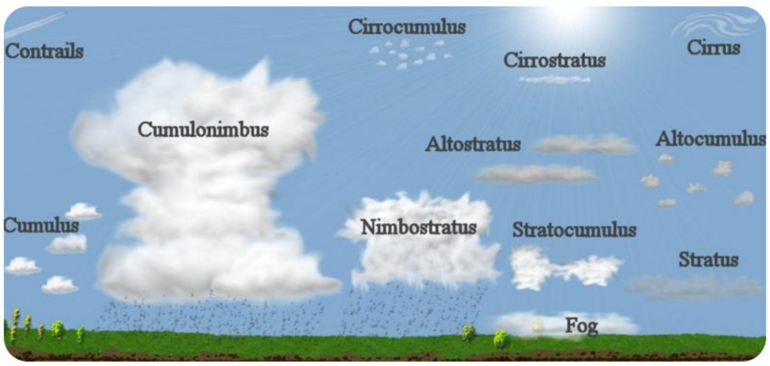


FIGURE 6.25

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** 7.4.

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.

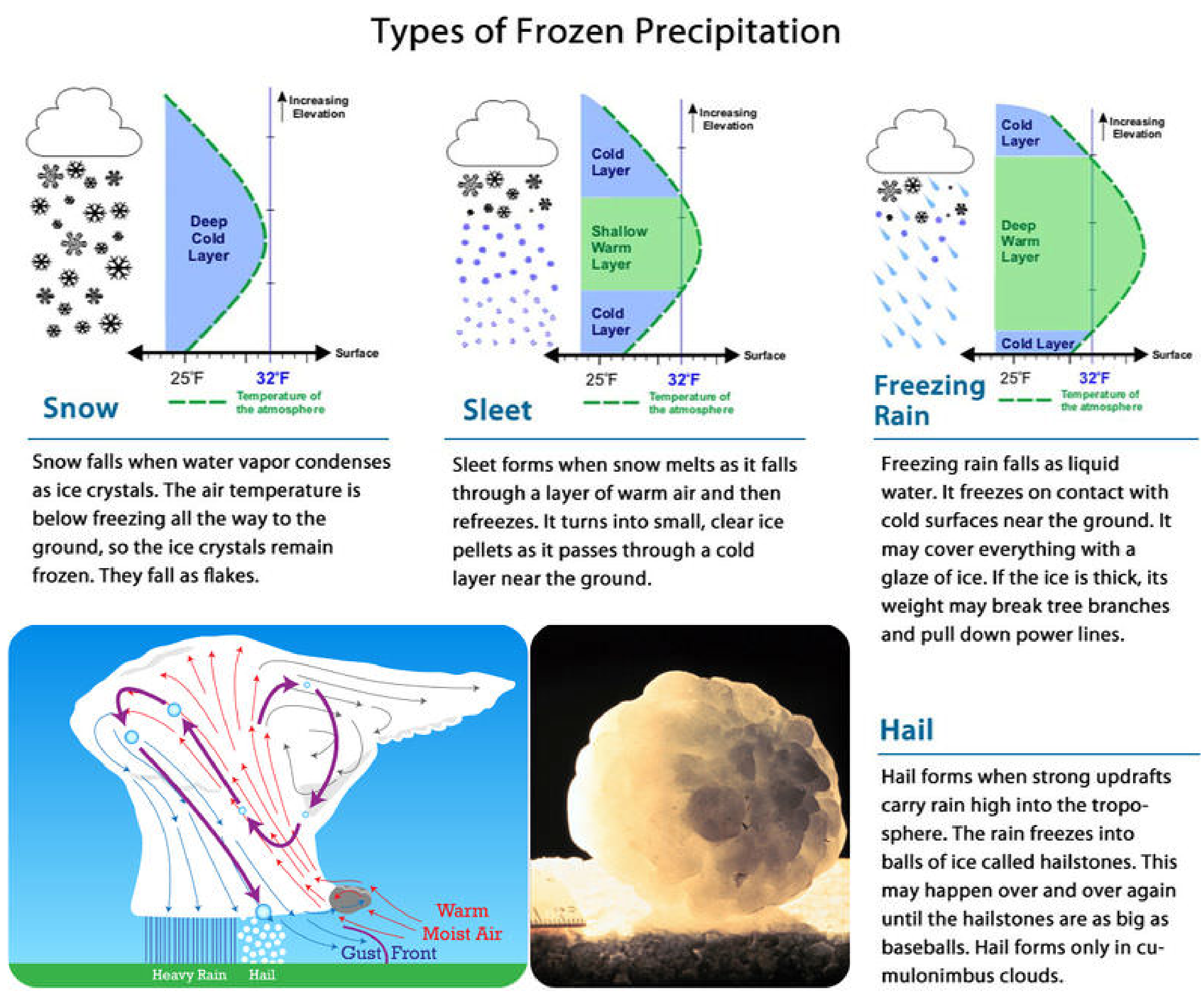


FIGURE 6.26

Frozen precipitation may fall as snow, sleet, or freezing rain.

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** 7.5. (Advanced Topic)

FIGURE 6.27

Think Critically

7. Explain how dew point is related to air temperature and 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?
- What causes weather to change?

6.6 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.

Lesson 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** 9.1 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 6.28
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** 9.2

- 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.

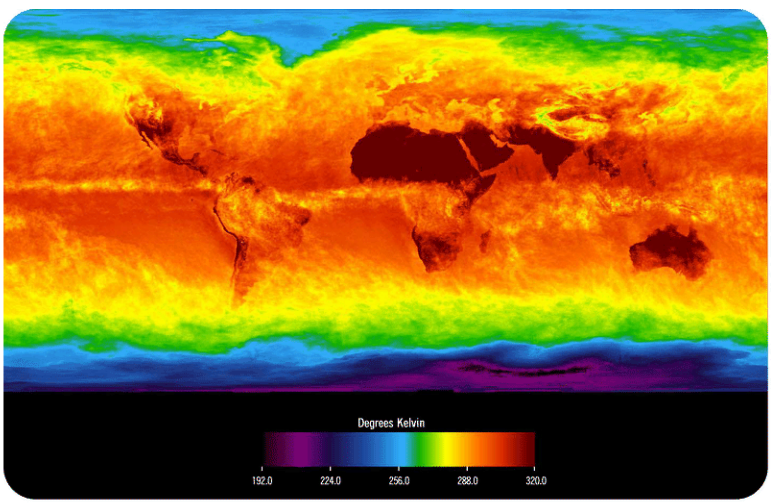


FIGURE 6.29
Find the cool spot in Asia at 30° north latitude. Why is it cool for its latitude? (Hint: What else might influence temperature?)

Latitude and Precipitation

Global air currents affect precipitation. How they affect it varies with latitude. You can see why in **Figure** 9.3.

Latitude and Prevailing Winds

Global air currents cause global winds. **Figure** 9.4 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.

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?

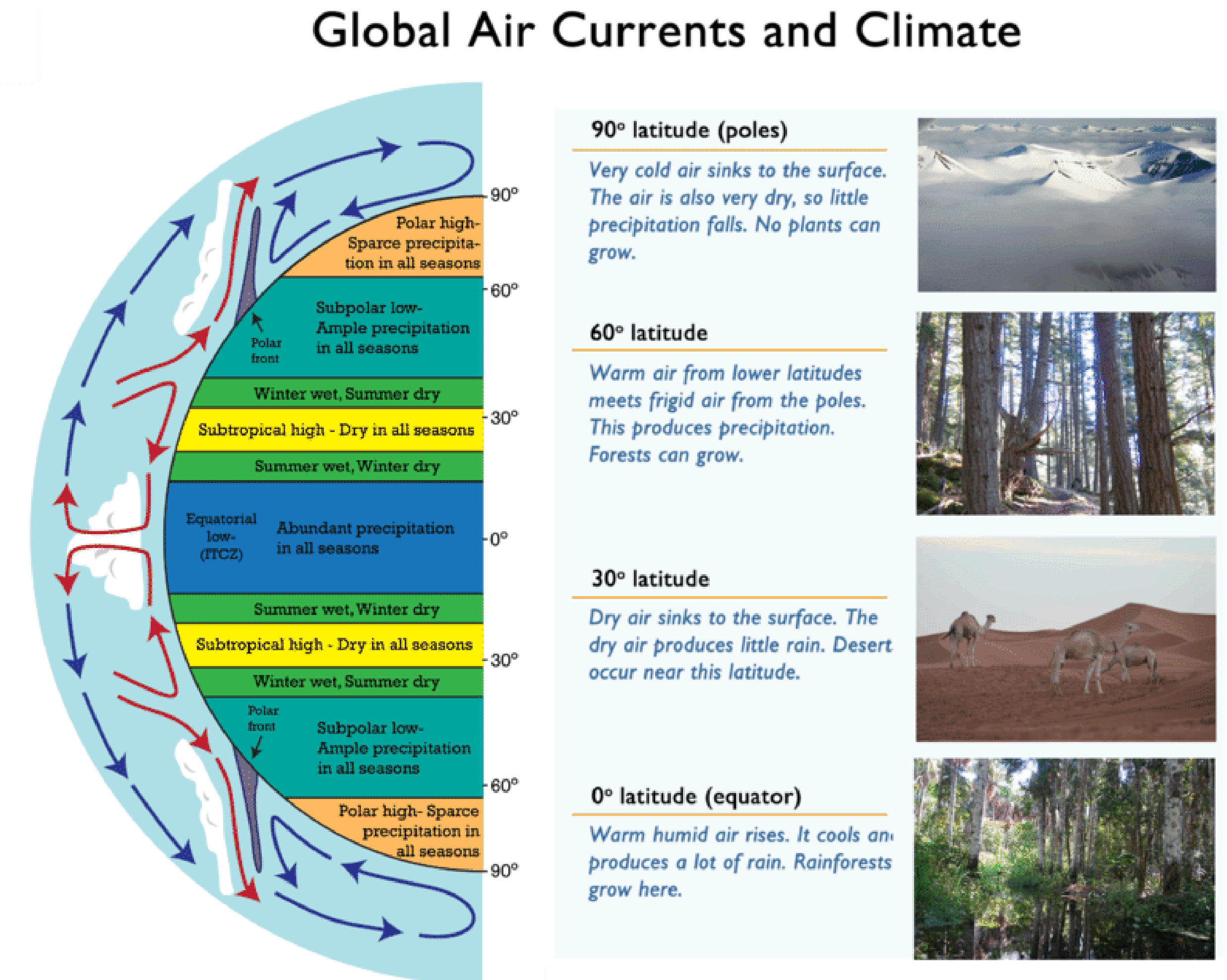
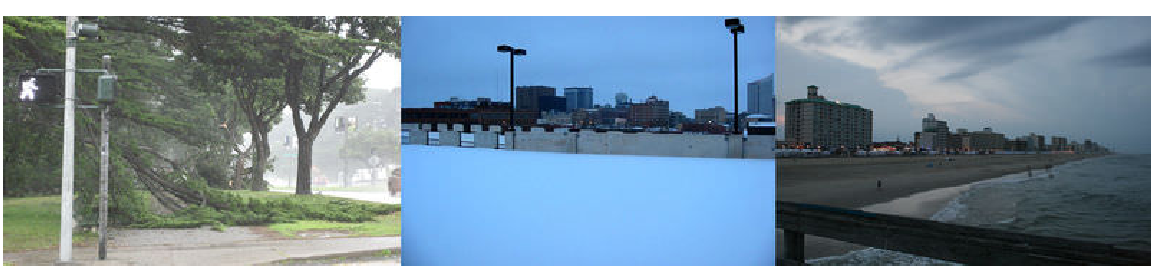


FIGURE 6.30
Global air currents are shown on the left. You can see how they affect climate on the right.

Oceans and Climate

Coastal and Inland Climates

When a place is near an ocean, the water can have a big effect on the climate.



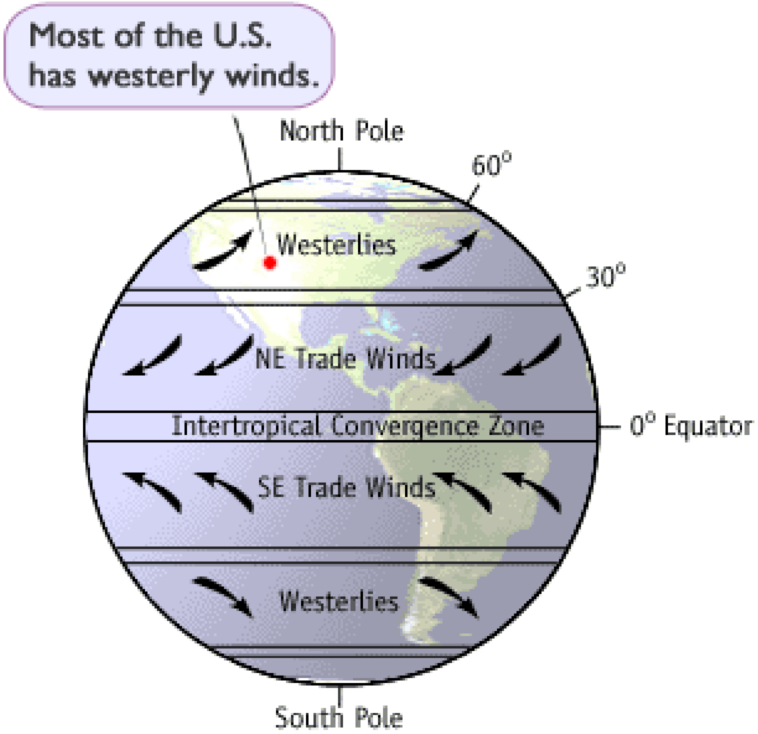


FIGURE 6.31
The usual direction of the wind where you live depends on your latitude. This determines where you are in the global wind belts.

These three cities are at the same latitude. They are San Francisco, CA; Wichita, KS; and Virginia Beach, VA. How close these cities are to the ocean is important. Also important is the direction the winds are blowing at this location.

When a place is near an ocean, the water can have a big effect on the climate.

Places at the same latitude may have very different climates if one is on a coast and one is inland.

- On the coast, the climate is affected 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. This is a **maritime climate.**
- Further inland, the climate is affected 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. This is a **continental climate.**

The ocean has a big effect on climate. This is obvious when you compare the temperatures of these three cities. Each of these cities is located at 37°N latitude. They are within the westerly winds. (**Figure** below)

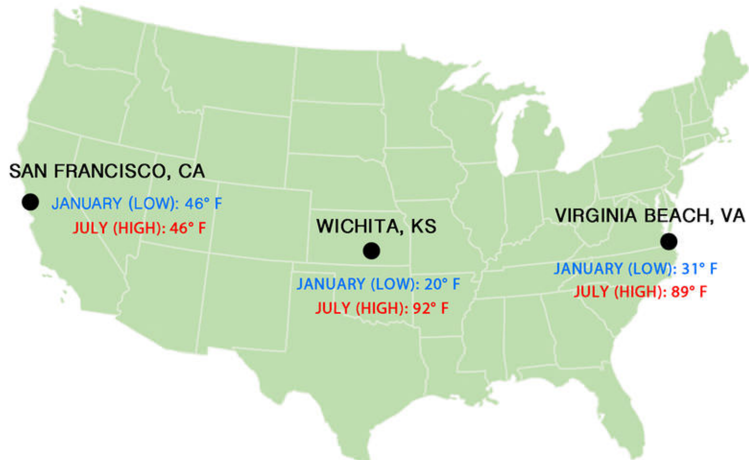


FIGURE 6.32
Difference in climate between San Francisco Wichita and Virginia Beach

The climate of San Francisco is affected by the Pacific Ocean. The cool California current comes from the north. Upwelling brings cold water from the deep. So the water offshore is cold. Virginia Beach is near the Atlantic Ocean. But its temperatures are more like Wichita than San Francisco. Why is the climate in Virginia Beach less influenced by the ocean than San Francisco? *Hint*: Think about the normal direction of the winds at that latitude. The weather in San Francisco comes from over the Pacific Ocean. Much of the weather in Virginia comes from the continent.

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** 9.5.

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.

Altitude and Temperature

Air temperature falls at higher altitudes. You can see this in **Figure** 9.6. 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** 9.7. 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** 9.8 shows how this happens.

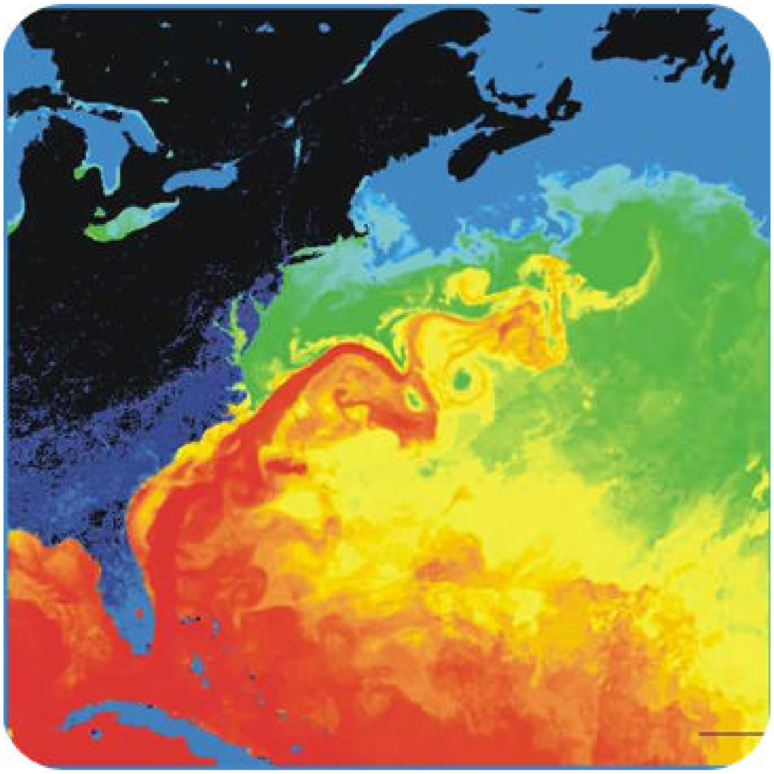


FIGURE 6.33
The Gulf Stream moves warm equatorial water up the western Pacific and into northern Europe, where it raises temperatures in the British Isles.

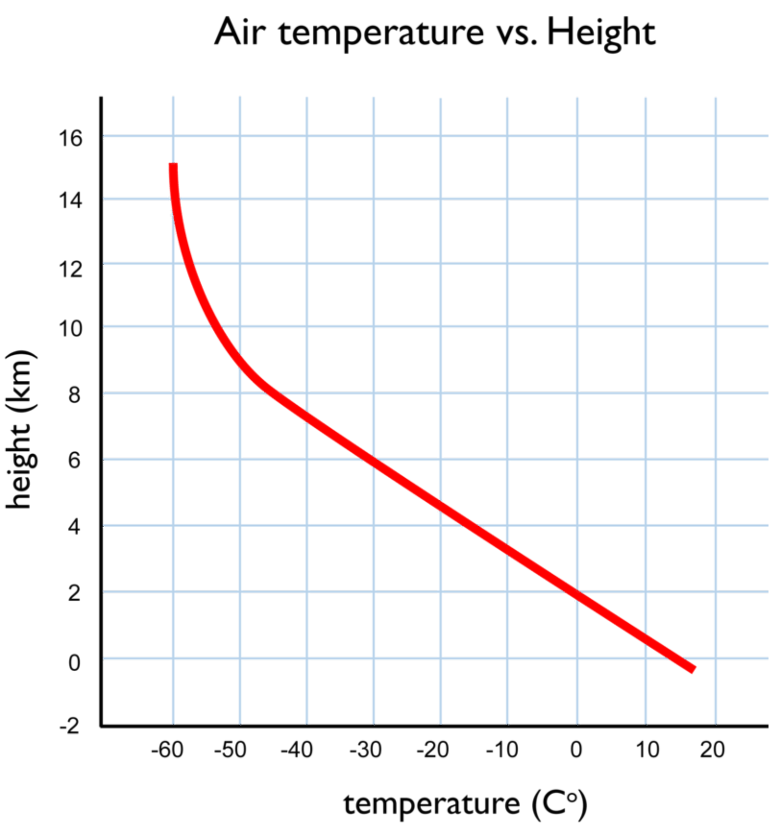


FIGURE 6.34
Air temperature drops as you go higher.

FIGURE 6.35
Mount Kilimanjaro has very different climates at the top and bottom.

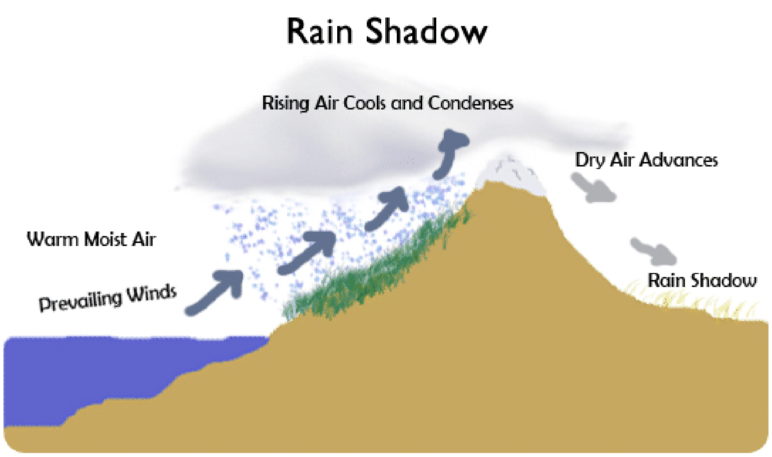


FIGURE 6.36
What role do prevailing winds play in a rain shadow?

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.
- The air is cooler as you go higher up a mountain. Mountain ranges can also cast rain shadows.

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?

6.7 World Climates

Lesson Objectives

- Identify world climate zones and where they are found.
- Identify world climate types based on precipitation amounts and vegetation.
- Define microclimate and give an example.

Lesson 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

There are basically three climate zones around the world: polar, temperate, and tropical. Each climate zone has unique traits. They are located in specific latitudes.

- **Polar zones** often have long, very cold winters. They have short, cool summers. Very cold air masses from the arctic often move in. The temperature range is larger than any other climate. Precipitation increases during summer months. Annual precipitation amounts are still small.
- **Tropical zones** are often warmer areas. They tend to have an abundance of rainfall. These are generally located near the equator.
- **Temperate zones** fall between the polar and the tropical zones. They tend to have milder climate conditions than both tropical and polar.

You might expect places near the equator to be hot and wet. That's not always the case. Sometimes there are other factors at work. These factors can affect the local climate type or a region. Oceans and mountain ranges can have a major impact. They can greatly influence the climate of an area. You can see this in **Figure** 9.9. Many factors influence an area's climate. Only one of those factors is the distance from the equator. You can see where the climate types are on the map below.

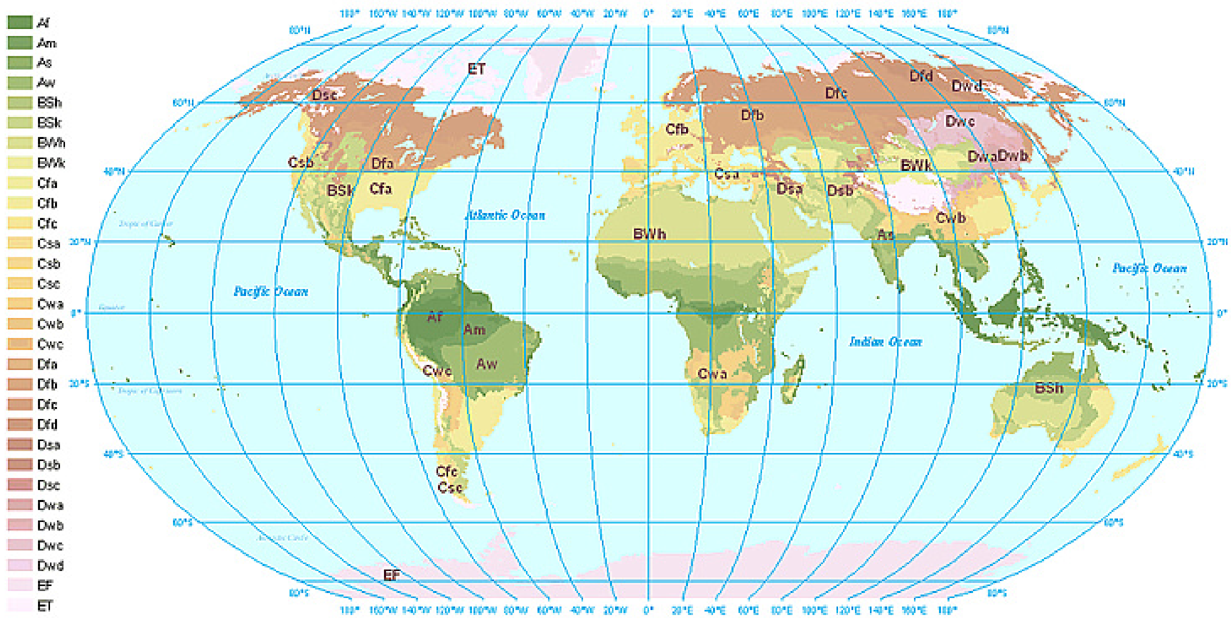


FIGURE 6.37

Find where you live on the map. What type of climate do you have?

Climate Zones versus Climate Types

Why isn't the climate of an area only impacted by its latitude? How can oceans and mountain ranges have such an impact on local climate types? Read on to find out more.

Florida is at the same latitude as North Africa. North Africa contains the world's largest desert. Following the line of latitude to the west, you can also find arid climates. West Texas, Mexico, and the Baja Peninsula of California are all arid climates. These areas fall along the same latitude and within the temperate climate zone. How can they have such a diverse local climate?

Think about where Florida is located. It is a long sliver of land mostly surrounded by water. It is much smaller than North Africa. It is wider than the Baja Peninsula in Mexico. Florida is very wet and the other two locations are extremely arid. It just so happens the size of Florida is just right for the development of thunderstorms. The Baja Peninsula is too narrow to cause such a weather effect. North Africa is far too large. In this case it was the size of land and proximity to water that made the difference.

Mountain ranges too can cause local climates to vary. For example, mountain ranges can block moisture. This can cause arid conditions at latitudes that should get adequate rainfall. There are only three major climate zones. These zones can contain climates caused by oceans and mountains.

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. Each climate is related to the types of living things. A major type of climate and its living things make up a **biome**.

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. The main plants are grasses (see **Figure** 9.10).

FIGURE 6.38
Africa is famous for its grasslands and their wildlife.

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**. Deserts receive less than 25 centimeters (10 inches) of rain per year. They may be covered with sand dunes. They can also be home to sparse but hardy plants (see **Figure** 9.11). With few clouds, deserts have hot days and cool nights.
- Other dry climates get a little more moisture. They are called **steppes**. These regions have short grasses and low bushes (see **Figure** 9.11). Steppes occur at higher latitudes than deserts.

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** 9.12.

- **Mediterranean climates** are found on the western coasts of continents. 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. 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. 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 6.39
Dry climates may be deserts or steppes. Sonoran Desert in Arizona (33° north latitude), Utah Steppe (40° north latitude).

FIGURE 6.40
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** get plenty of precipitation year round. The northeastern U.S. has this type of climate. Summers are warm to hot, and winters are cold. Deciduous trees grow in this climate. They lose their leaves in the fall and grow new ones in the spring.

- **Subarctic climates** have cool and short summers. Winters are long and cold. Much of Canada and Alaska have this type of climate. Little precipitation falls, and most of it falls during the summer. Conifer forests grow in this climate (see **Figure** 9.13).

FIGURE 6.41
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** 9.14.

- **Polar tundra** climates occur near the poles. Tundra climates have permafrost. Permafrost is layer of ground that stays 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 6.42
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** 9.15. The south-facing side of the hill gets a lot of sunlight. It gets much more than the north side of a hill. This gives the south side a warmer microclimate. A microclimate can also be due to a place being deeper. As you already know, cold air sinks. Hot air rises. Cold air sinks to the bottom of a valley. It becomes colder than the nearby areas.

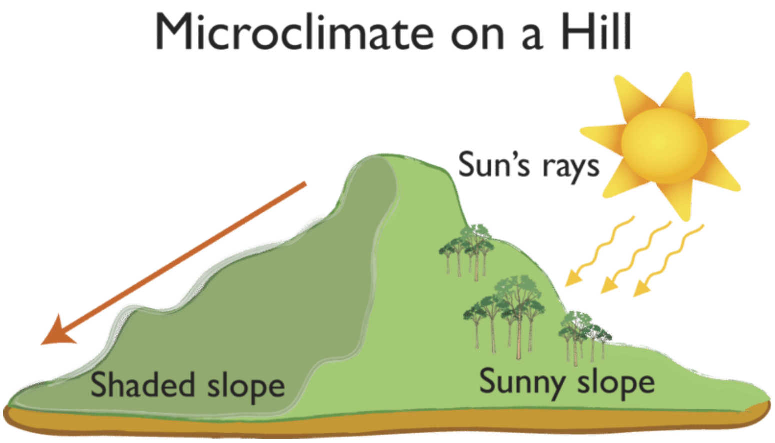


FIGURE 6.43
Hills and other features can create microclimates.

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.

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** 9.16. Describe this type of climate.

Think Critically

9. Some tropical climates have rainforests. Others have grasslands. What explains the difference?

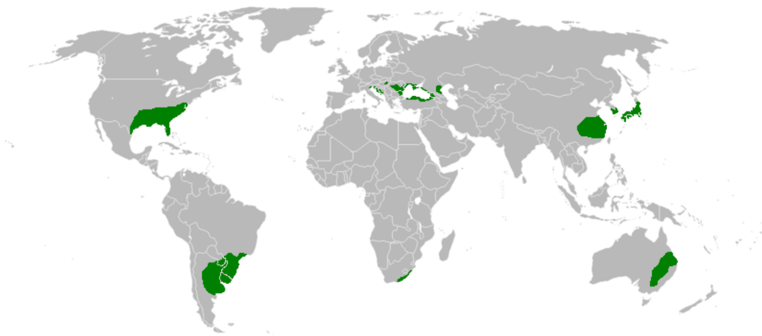


FIGURE 6.44

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?

Earth Science

6.8 References

1. Courtesy of NASA's Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=46209 . Public Domain
2. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
3. Atmospheric Infrared Sounder. http://www.flickr.com/photos/atmospheric-infrared-sounder/8265046380/ . CC BY 2.0
4. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
5. Flickr:Jellaluna. http://www.flickr.com/photos/90859240@N00/5983016558/ . CC BY 2.0
6. Courtesy of Chief Mass Communication Specialist Steve Carlson, U.S. Navy. http://commons.wikimedia.org/wiki/File:US_Navy_110831-N-NT881-079_Sailors_assigned_to_the_guided-missile_submarine_USS_Ohio_-(SSGN_726)_and_Navy_Operational_Support_Center_Cincinnati_part.jpg . Public Domain
7. Flickr:lele3100. http://www.flickr.com/photos/13878737@N05/1413021987/ . CC BY 2.0
8. David (Flickr:longhorndave). http://www.flickr.com/photos/davidw/2296411989/ . CC BY 2.0
9. Image copyright Lucian Coman, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
10. J Liu, C Folberth, et al.. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0057750 . CC BY 2.5
11. Bob Metcalf. http://commons.wikimedia.org/wiki/File:Mwamongu_water_source.jpg . Public Domain
12. Left: Courtesy of NOAA; Right: Flickr:Eddie~S. Left: http://oceanservice.noaa.gov/education/kits/pollution/media/supp_pol02d.html; Right: http://www.flickr.com/photos/pointshoot/1297923459/ . Left: Public Domain; Right: CC BY 2.0
13. Eva Luedin. http://www.flickr.com/photos/40819389@N04/3758123620/ . CC BY 2.0
14. Dwight Sipler. http://www.flickr.com/photos/62528187@N00/2552390830/ . CC BY 2.0
15. Paul Joseph. Cactus . CC BY 2.0
16. Left: Image copyright Hurst Photo, 2013; Right: Image copyright by Mary Terriberry, 2013. http://www.shutterstock.com . Used under licenses from Shutterstock.com
17. Courtesy of the U.S. Coast Guard. http://commons.wikimedia.org/wiki/File:Deepwater_Horizon_offshore_drilling_unit_on_fire.jpg . Public Domain
18. Peter Lai, using data from http://www.nationmaster.com/graph/ene_oil_con_percap-energy-oil-consumption-per-capita. CK-12 Foundation . CC BY-NC 3.0
19. Raquel Baranow. http://www.flickr.com/photos/666_is_money/5388515887/ .
20. Flickr:momentcaptured1. http://commons.wikimedia.org/wiki/File:Farmer%27s_Market_in_Colombia.jpg . CC BY 2.0
21. Left: Klearchos Kapoutsis; Right: Karl Baron (Flickr:kalleboo). Left: http://www.flickr.com/photos/klearchos/3380660968/; Right: http://www.flickr.com/photos/kalleboo/2541853069/ . CC BY 2.0
22. Left to right, top to bottom: Flickr:lululemon athletica; Zappy's; Flickr:DeusXFlorida; Mo Riza; Rubbermaid Products; Flickr:funkblast; User:Nyttend/Wikimedia Commons. Left to right, top to bottom: http://www.flickr.com/photos/lululemonathletica/4309131261/; CK-12 Foundation; http://www.flickr.com/photos/8363028@N08/3213244182/; http://www.flickr.com/photos/moriza/2080224868/; http://www.flickr.com/photos/rubbermaid/4116876417/; http://www.flickr.com/photos/funkblast/9365424/; http://commons.wikimedia.org/wiki/File:Cotton-Ropkey_House_for_sale.jpg . Left to right, top to bottom: CC BY 2.0; CC BY-NC 3.0; CC BY 2.0; CC BY 2.0; CC BY 2.0; CC BY 2.0; Public Domain
23. Image copyright Mark Poprocki, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
24. Flickr:epSos.de. http://www.flickr.com/photos/epsos/5575089139/ . CC BY 2.0
25. Christopher M. Klaus. http://commons.wikimedia.org/wiki/File:Cloud_types.jpg . Public Domain

26. 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)
27. (a) Flickr:oatsy40; (b) User:Natasha2006/Wikimedia Commons; (c) User:Kr-val/Wikimedia Commons. (a) http://www.flickr.com/photos/68089229@N06/8024820584/; (b) http://commons.wikimedia.org/wiki/File:Stratus_Cloud.jpg; (c) http://commons.wikimedia.org/wiki/File:Cumulusmediocrissweden.jpg . (a) CC BY 2.0; (b) Public Domain; (c) Public Domain
28. Image copyright David Lee, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
29. Courtesy of NASA/JPL. http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA00427 . Public Domain
30. Global Circulation Diagram: CK-12 Foundation - Christopher Auyeung; Snow: Kitty Terwolbeck; Forest: Thomas Quine (Flickr:quinet); Desert: John Yavuz Can; Rainforest: Ivan Mlinaric. Snow: http://www.flickr.com/photos/kittysfotos/7902668768/; Forest: http://www.flickr.com/photos/quinet/7406208974/; Desert: http://www.flickr.com/photos/yavuzcan/8177337117/; Rainforest: http://www.flickr.com/photos/eye1/3187012243/ . Global circulation diagram: CC BY-NC 3.0; Remaining images: CC BY 2.0
31. Courtesy of National Park Services and Parks as Classroom. http://www.nps.gov/archive/grsa/resources/curriculum/mid/dunes/photo_files/global_wind.htm . Public Domain
32. . Difference in climate between San Francisco, Wichita, and Virginia Beach.
33. . Difference in climate between San Francisco, Wichita, and Virginia Beach.
34. . Difference in climate between San Francisco, Wichita, and Virginia Beach.
35. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Golfstrom.jpg . Public Domain
36. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
37. Dan Heap (Flickr:danheap77). http://www.flickr.com/photos/69166407@N06/6565397705/ . CC BY 2.0
38. User:Bariot/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Rainshadow_copy.jpg . Public Domain
39. Courtesy of the National Weather Service. http://www.srh.noaa.gov/jetstream/global/climate_max.htm . Public Domain
40. Flickr:sheilapic76. http://www.flickr.com/photos/53344659@N05/4979035890/ . CC BY 2.0
41. Left: Bob Wick, BLM California; right: Courtesy of the U.S. Geological Survey. Left: http://www.flickr.com/photos/mypubliclands/9403761949/; Right: http://www.werc.usgs.gov/OLDsitedata/fire/lv/fireandinvasives/study_ecosystems.htm .
42. Mediterranean climate: Piarou, Humid climate: User:Ricraider/Wikimedia Commons; Marine: Flickr:wonderlane. Mediterranean climate: http://commons.wikimedia.org/wiki/File:Garrigue_2007-09-20.JPG; Humid climate: http://commons.wikimedia.org/wiki/File:Cumbres_del_Ajusco.jpg; Marine climate: http://www.flickr.com/photos/wonderlane/4564202646/ . Mediterranean climate: CC BY 2.0; Humid climate: Public Domain; Marine climate: CC BY 2.0
43. Frank Kovalchek. http://commons.wikimedia.org/wiki/File:South_side_of_Jasper_National_Park.jpg . CC BY 2.0
44. Left: david adamec; Right: John Holm. Left: http://commons.wikimedia.org/wiki/File:Northwest_Territories_tundra_stones.jpg; Right: http://commons.wikimedia.org/wiki/File:Alpine_tundra_Copper_Mountain_Colorado.jpg . Left: Public Domain; Right: CC BY 2.0
45. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
46. User:Example/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Subtropicworldmap.png . Public Domain

CHAPTER 7 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.

Image copyright Zastolskiy Victor, 2013. www.shutterstock.com. Used under license from Shutterstock.com.

7.1 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** 7.1.

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** 7.2.

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** 7.1, the dew point occurs at 100 percent relative humidity. Can you explain why?

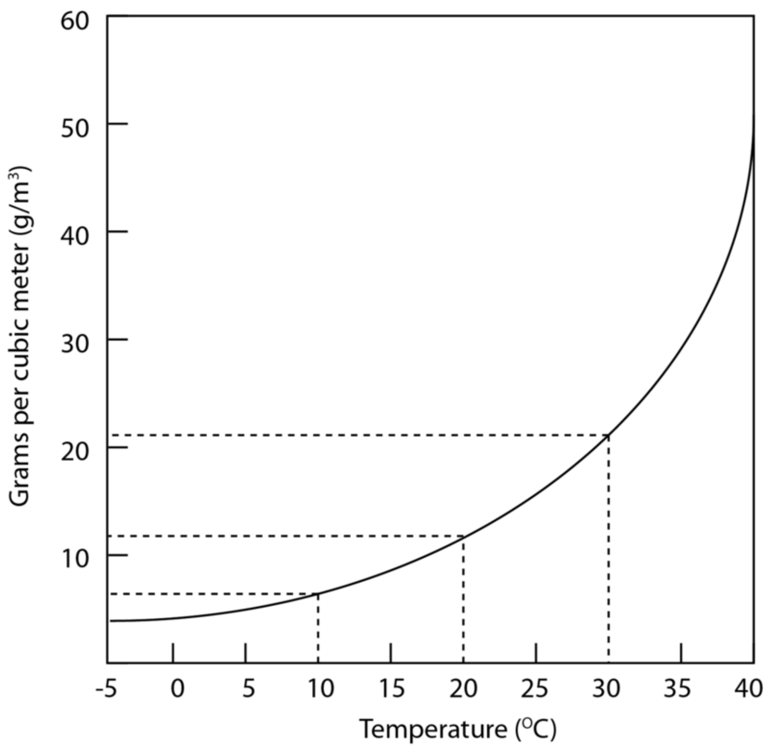


FIGURE 7.1
How much water vapor can the air hold when its temperature is 40 ° C?

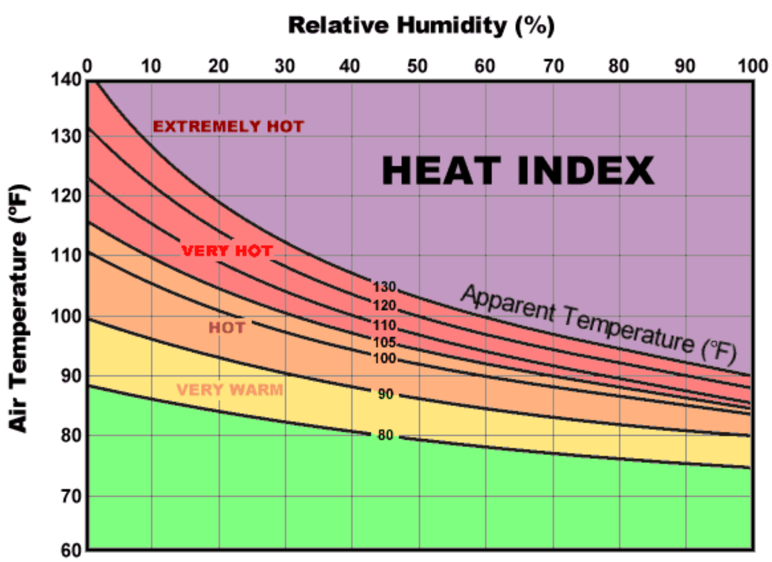


FIGURE 7.2
How hot does it feel when the air temperature is 90 °F? It depends on the humidity.

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** 7.3 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.

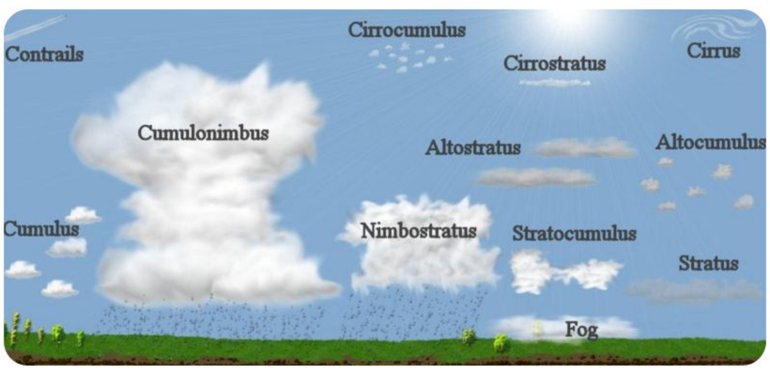


FIGURE 7.3

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** 7.4.

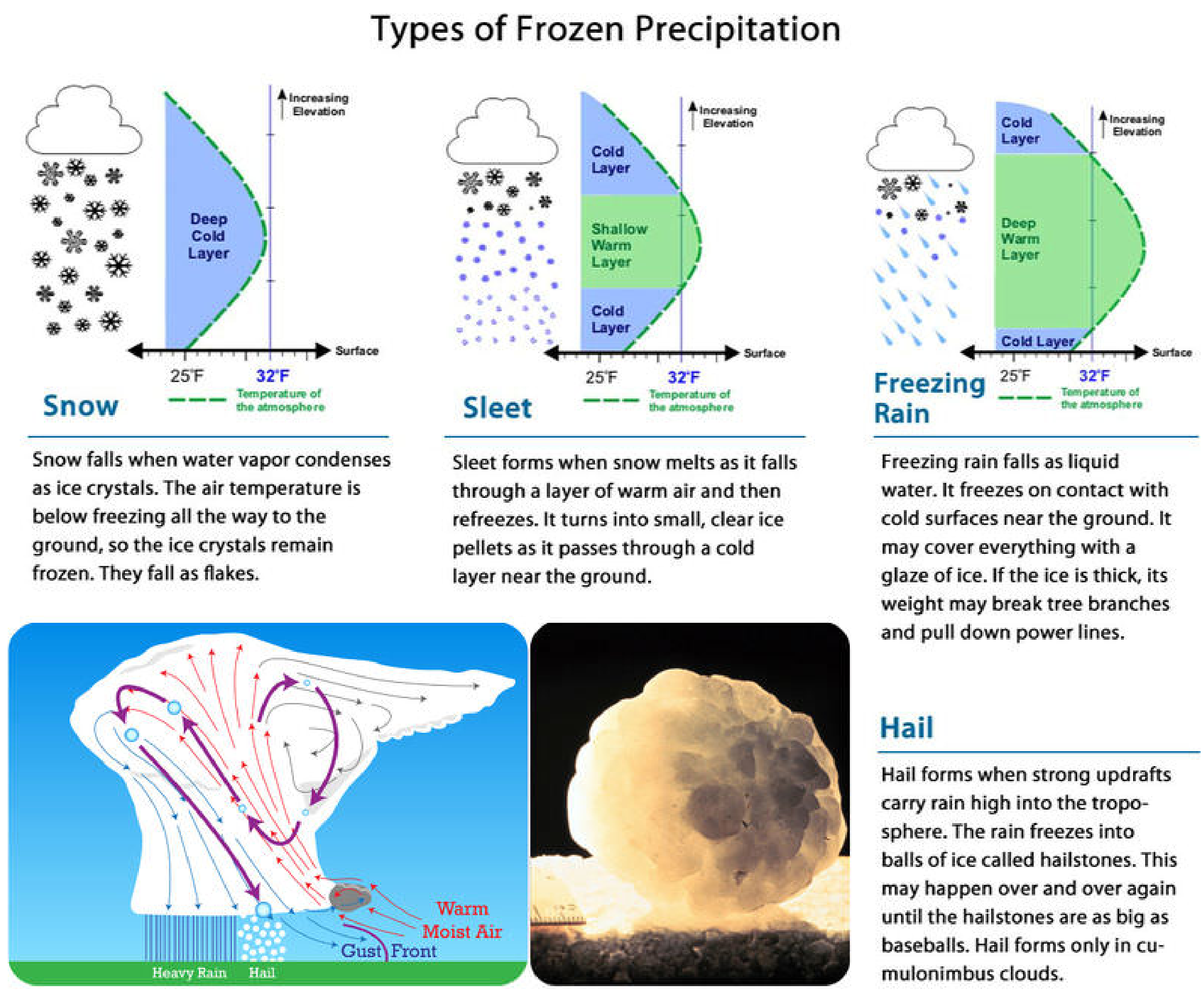


FIGURE 7.4

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** 7.5.

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 7.5

- What causes weather to change?

7.2 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** 7.6 shows air masses that form over or near North America.

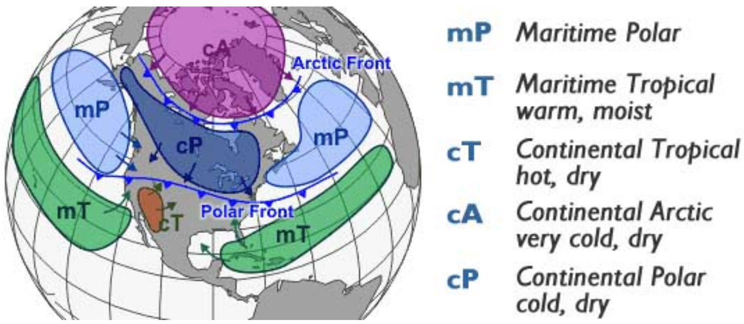


FIGURE 7.6
North American air masses.

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** 7.7. 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,

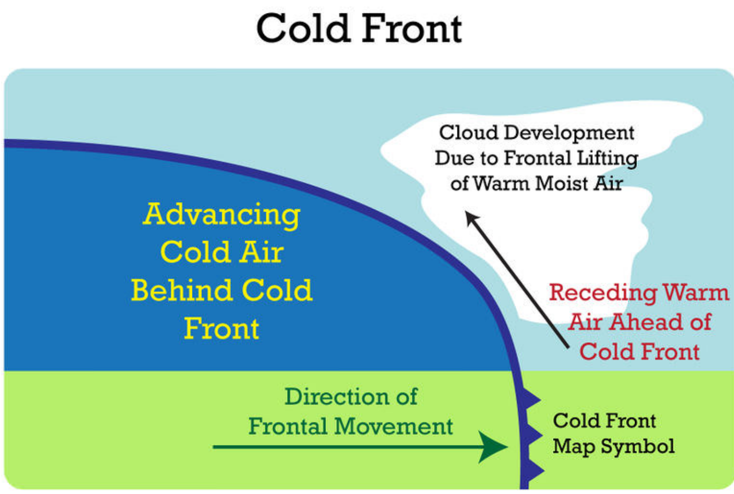


FIGURE 7.7
Cold fronts often bring stormy weather.

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** 7.8. 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.

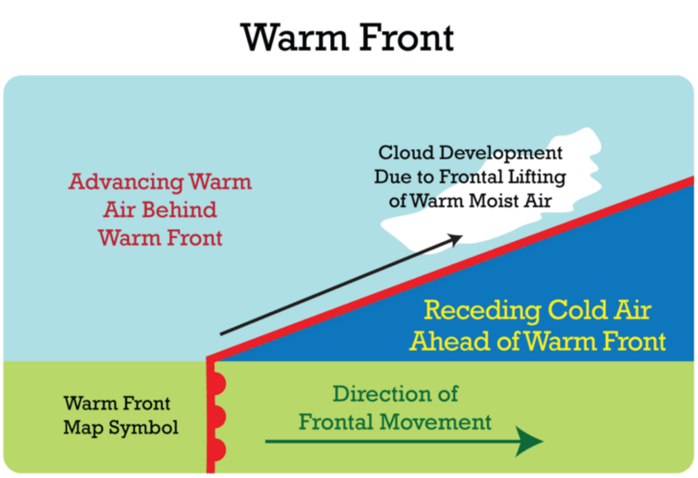


FIGURE 7.8
Warm fronts generally bring cloudy weather.

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** 7.9. Cloudy weather and precipitation along the front are typical.

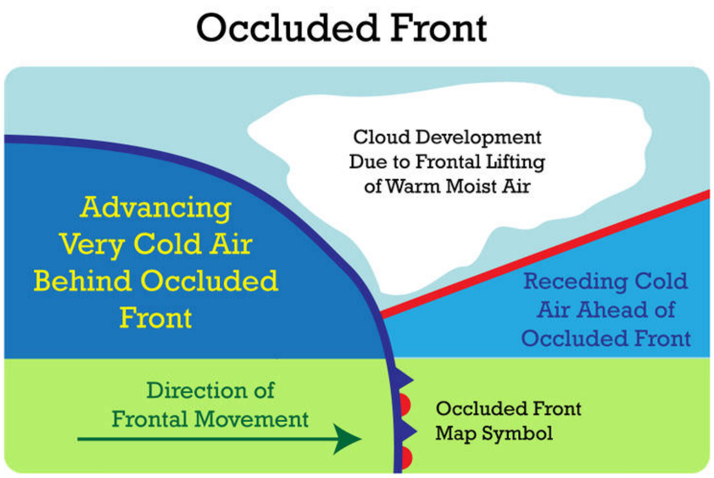


FIGURE 7.9
How does an occluded front differ from a warm or cold front?

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** 7.10.

- 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.

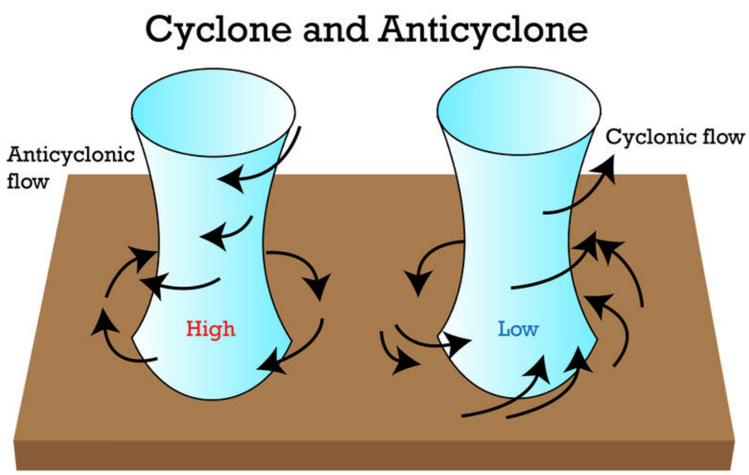


FIGURE 7.10
In the Northern Hemisphere, cyclones rotate counterclockwise and anticyclones rotate clockwise. This is the reverse in the Southern Hemisphere.

- 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?

7.3 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** 7.11 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 7.11
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** 7.12.

FIGURE 7.12
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** 7.13. 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 7.13
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** 7.14. 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** 7.1 shows how.

FIGURE 7.14
Tornadoes are small but mighty storms.

TABLE 7.1: 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
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

Tornado Alley

Look at the map in **Figure** 7.15. 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.

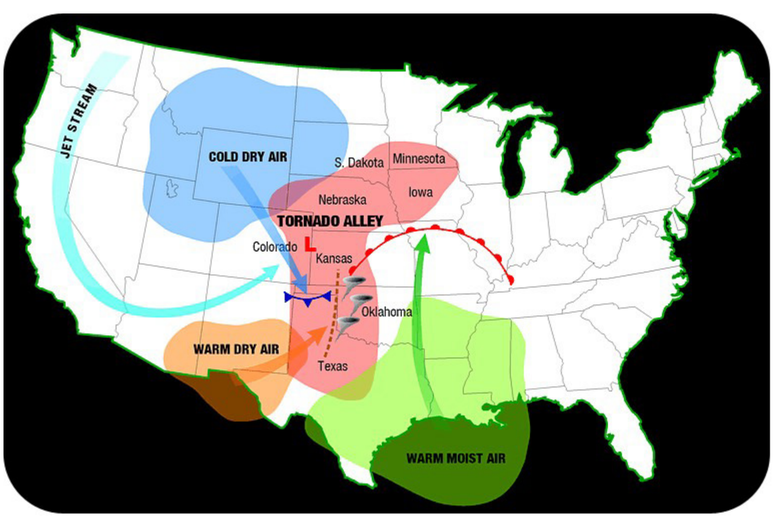


FIGURE 7.15
Tornadoes are most common in the central part of the U.S.

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** 7.16.

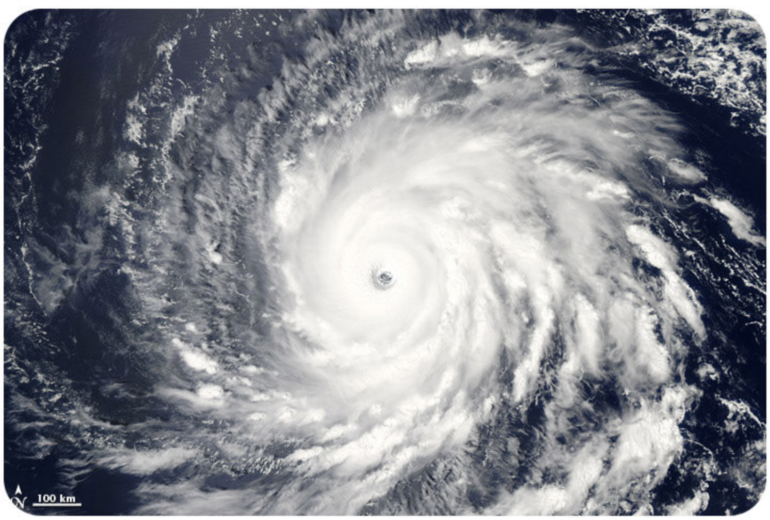


FIGURE 7.16
The eye of this hurricane is easy to see from space.

Classifying Hurricanes

Like tornadoes, hurricanes are classified on the basis of wind speed and damage. **Table** 7.2 shows how.

TABLE 7.2: 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 7.2: (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** 7.17. 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.

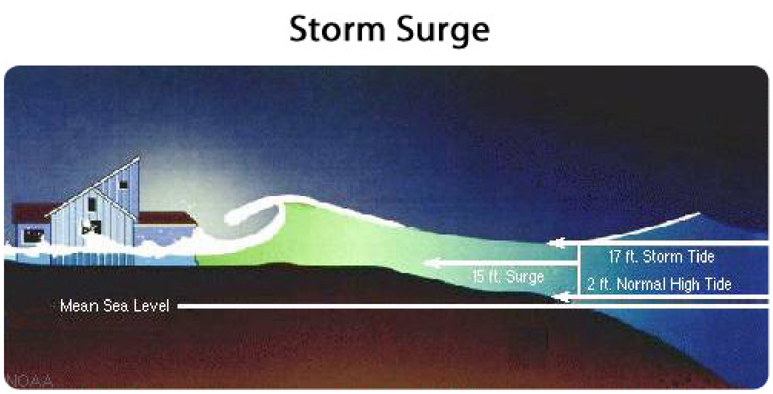


FIGURE 7.17
Storm surge can cause serious flooding.

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** 7.18.

FIGURE 7.18

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** 7.19. 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** 7.20 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

Temperature (°F)

Wind (mph) / 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

$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T = Air Temperature (°F) V = Wind Speed (mph)

Effective 11/01/01

FIGURE 7.19

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?

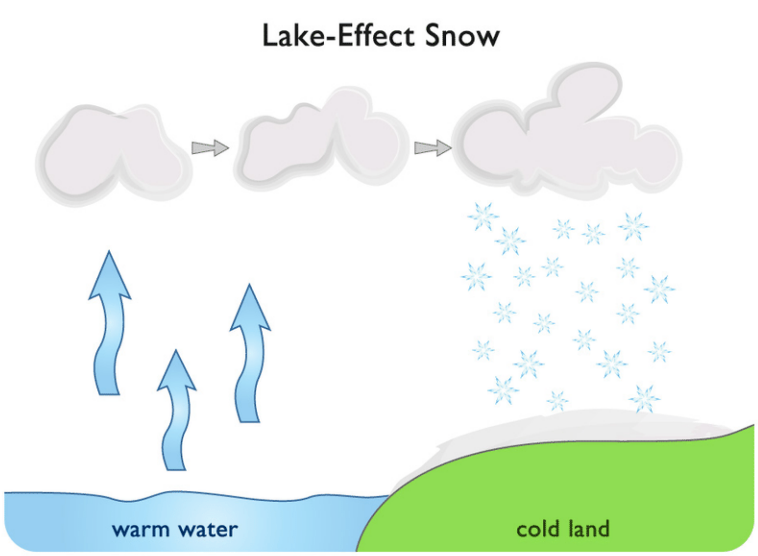


FIGURE 7.20

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** 7.21 shows damage caused by a tornado. Explain how you could use the photo to classify the tornado.

FIGURE 7.21

7. Describe in words what this graph shows (see **Figure** 7.22). 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.

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.

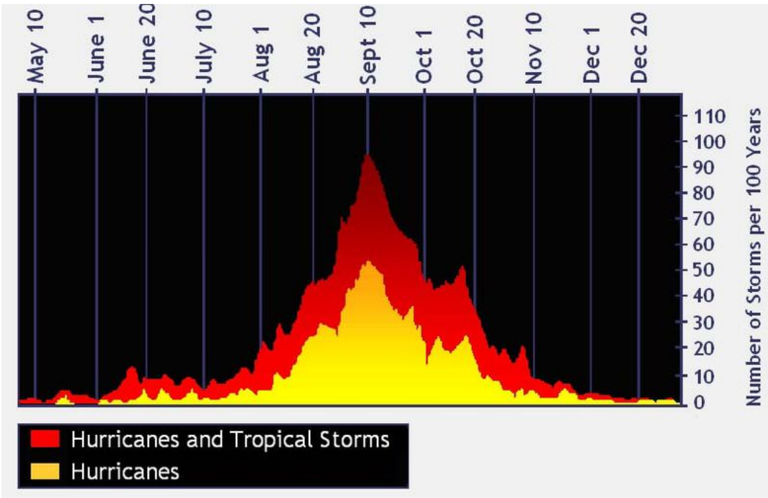


FIGURE 7.22

- How can storms be predicted?
- What data are needed? How are the data collected?

7.4 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** 7.23 shows how a barometer works. There are also a number of other commonly used weather instruments (see **Figure** 7.24):

- 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.

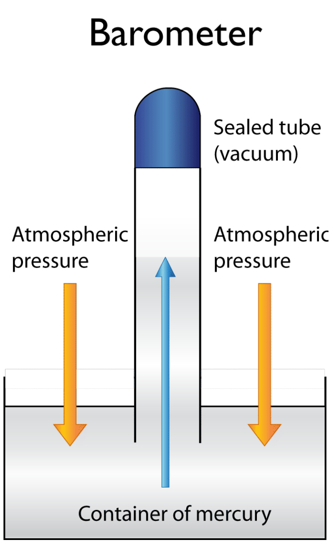


FIGURE 7.23
The greater the air pressure outside the tube, the higher the mercury rises inside the tube. Mercury can rise in the tube because there's no air pressing down on it.

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** 7.25. 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** 7.25.

Weather stations contain many instruments for measuring weather conditions. The **weather balloon** in **Figure** 7.25 will rise into the atmosphere until it bursts. As it rises, it will gather weather data and send it to the surface. Many

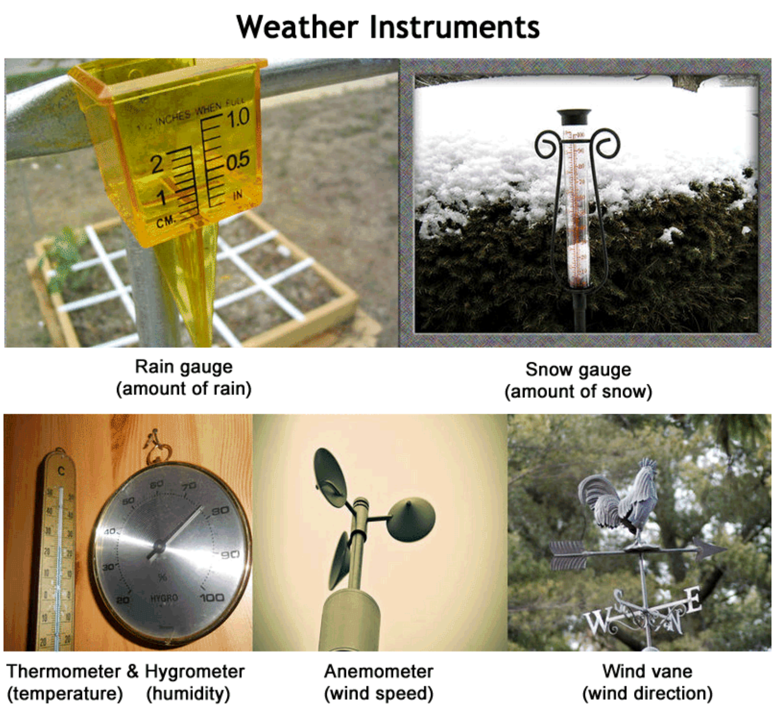


FIGURE 7.24
Some of the most commonly used weather instruments. (a) Thermometer: temperature, (b) Anemometer: wind speed, (c) Rain gauge: amount of rain, (d) Hygrometer: humidity, (e) Wind vane: wind direction, (f) Snow gauge: amount of snow.

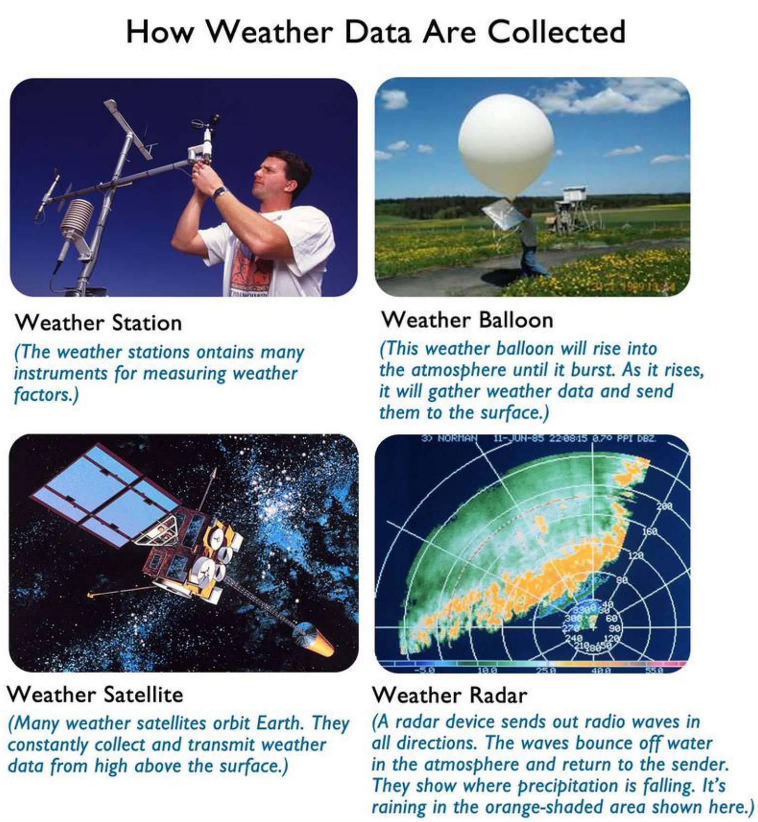


FIGURE 7.25
Weather stations collect data on land and sea. Weather balloons, satellites, and radar collect data in the atmosphere.

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** 7.26. 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.

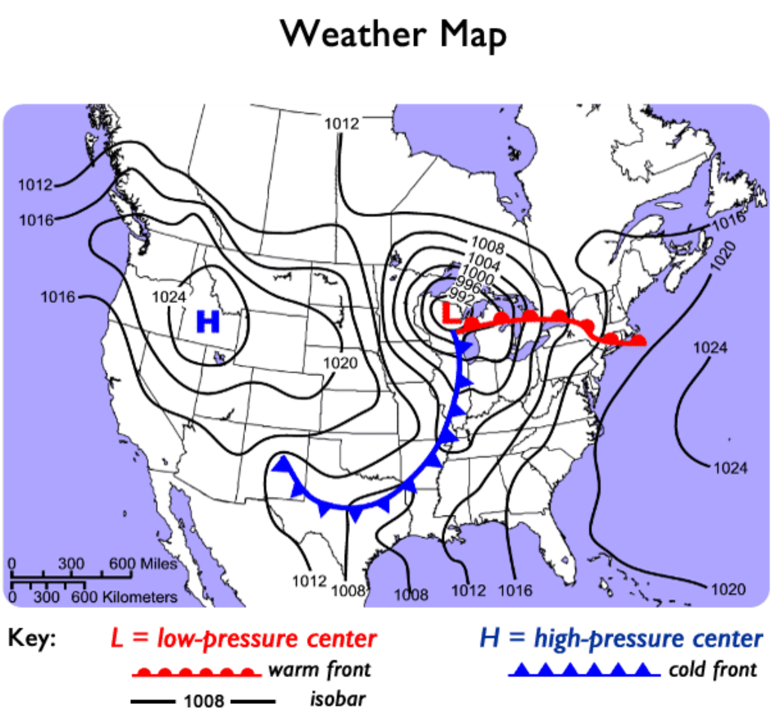


FIGURE 7.26
This weather map shows air pressure contours. Which state has the lowest air pressure shown on the map?

Air Pressure Maps

The weather map in **Figure** 7.26 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** 7.26, 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?

7.5 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)
5. (a) Flickr:oatsy40; (b) User:Natasha2006/Wikimedia Commons; (c) User:Kr-val/Wikimedia Commons. (a) http://www.flickr.com/photos/68089229@N06/8024820584/; (b) http://commons.wikimedia.org/wiki/File:Stratus_Cloud.jpg; (c) http://commons.wikimedia.org/wiki/File:Cumulusmediocrissweden.jpg . (a) CC BY 2.0; (b) Public Domain; (c) Public Domain
6. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Airmassesorigin.gif . Public Domain
7. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
8. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
9. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
10. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
11. Courtesy of Petty Officer 2nd Class NyxoLyno Cangemi, U.S. Coast Guard. http://commons.wikimedia.org/wiki/File:New_Orleans_Survivor_Flyover.jpg . Public Domain
12. Flickr:Nicholas_T. http://commons.wikimedia.org/wiki/File:Thunderhead_%28nicholas_t%29.jpg . CC BY 2.0
13. sandro visintin. http://www.flickr.com/photos/sandro87v/7346419324/ . CC BY 2.0
14. Courtesy of Jarrod Cook/NWS. http://commons.wikimedia.org/wiki/File:AbingdonTornado_2.JPG . Public Domain
15. Courtesy of National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Tor_alley.jpg . Public Domain
16. Courtesy of Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC. http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=45770 . Public Domain
17. NOAA. http://www.nhc.noaa.gov/HAW2/english/surge/surge_big.jpg . Public domain
18. Dave Newman (Flickr:newmanchu). http://www.flickr.com/photos/groovysoup/4343759488/ . CC BY 2.0
19. Courtesy of NOAA. http://www.nws.noaa.gov/om/windchill/ . Public Domain
20. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
21. User:Nubilt/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Windsor-co-tornado-2008-05-22.jpg . Public Domain
22. Courtesy of NOAA. http://www.tampagov.net/appl_tampa_announcements/UploadedFiles/Images/peakofseason.gif . Public Domain
23. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
24. Rain: Flickr:wssst; Snow: KaCey97007; Thermometer/Hygrometer: Karl-Ludwig G. Poggemann (Flickr:quapan); Anemometer: Aidan (Flickr:asgw); Wind vane: Flickr:BobMacInnes. Rain: http://www.flickr.com/photos/28451957@N06/3893749914/; Snow: http://www.flickr.com/photos/kacey/361574480/; Thermometer/Hygrometer: http://www.flickr.com/photos/hinkelstone/9373361762/; Anemometer: http://www.flickr.com/photos/aidanwojtas/2307169752/; Wind vane: http://www.flickr.com/photos/lonetown/402414353/ . CC BY 2.0
25. Weather Station: Courtesy of Scott Bauer, USDA; Weather Balloon: Wolke; Weather Satellite, Weather Radar: Courtesy of NOAA. Weather Station: http://commons.wikimedia.org/wiki/File:Weather_Station_USDA.jpg;

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

26. South Carolina State Climatology Office. http://www.dnr.sc.gov/climate/sco/Education/wxmap/wxmap.php . Public Domain

CHAPTER 8 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.

8.1 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** 8.1 models this role of the atmosphere.

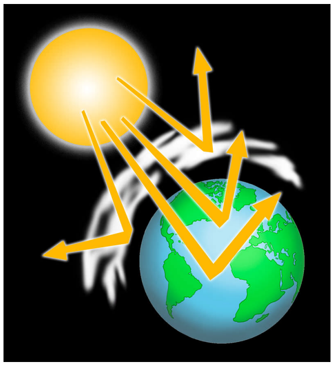


FIGURE 8.1
The atmosphere shields Earth from harmful solar rays.

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 8.2 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.

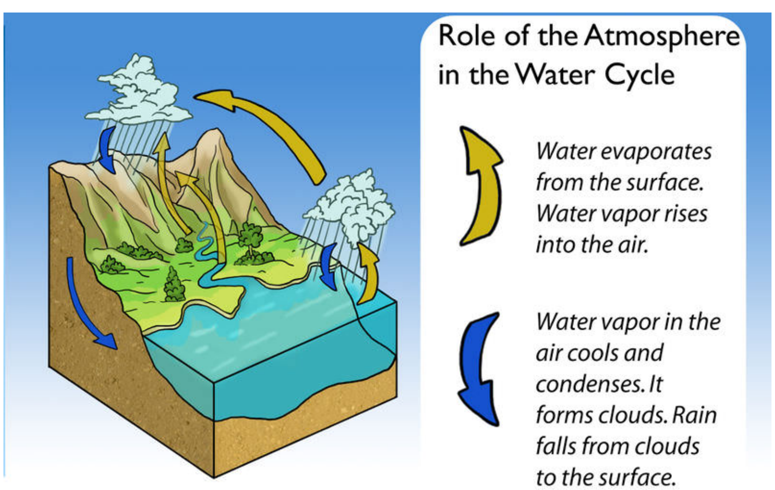


FIGURE 8.2
The atmosphere is a big part of the water cycle. What do you think would happen to Earth's water without it?

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 8.3 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** 8.3. 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.

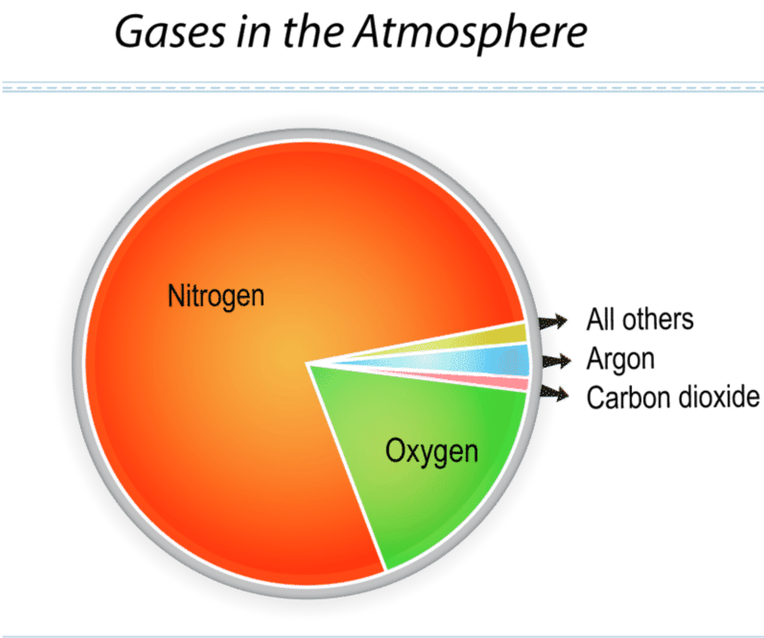


FIGURE 8.3
This graph identifies the most common gases in air.

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** 8.4.

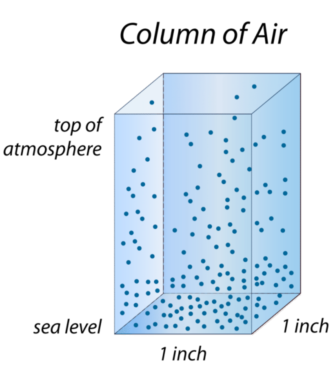


FIGURE 8.4
This drawing represents a column of air. The column rises from sea level to the top of the atmosphere. Where does air have the greatest density?

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** 8.5. 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 8.5
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** 8.1 as a guide.

TABLE 8.1: 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** 8.5 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?

8.2 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** 8.6. 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 8.6
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** 8.7 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** 8.8.

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.

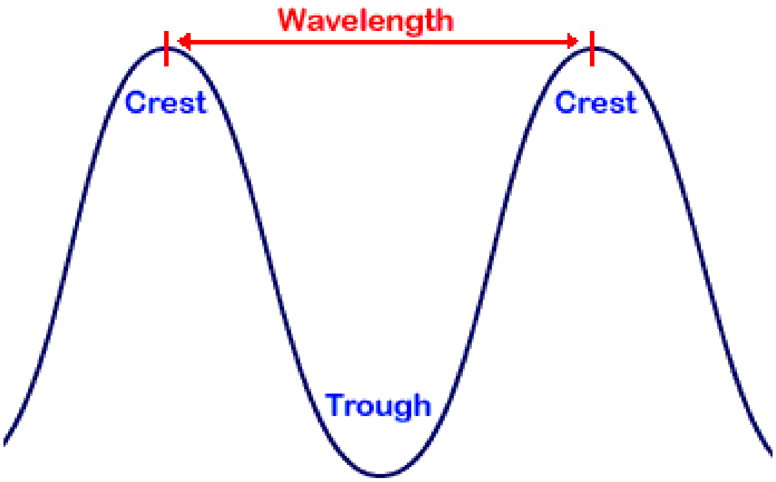


FIGURE 8.7
This curve models a wave. Based on this figure, how would you define wavelength?

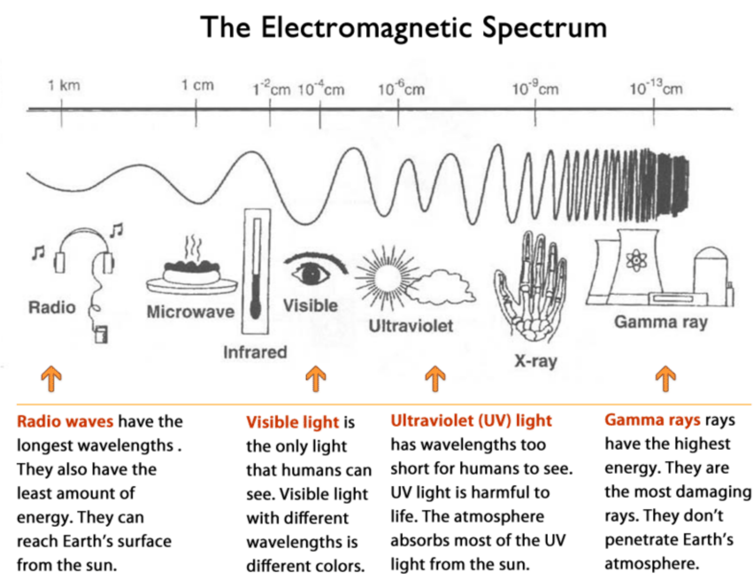


FIGURE 8.8
Compare the wavelengths of radio waves and gamma rays. Which type of wave has more energy?

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** 8.9. Convection is the most important way that heat travels in the atmosphere.

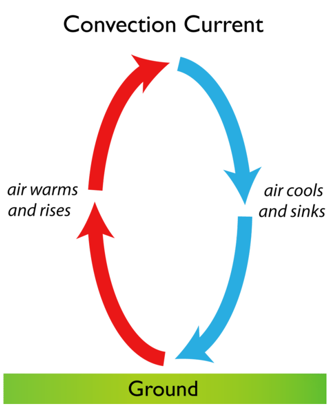


FIGURE 8.9
Convection currents are the main way that heat moves through the atmosphere. Why does warm air rise?

Energy and Latitude

Different parts of Earth's surface receive different amounts of sunlight. You can see this in **Figure** 8.10. 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.

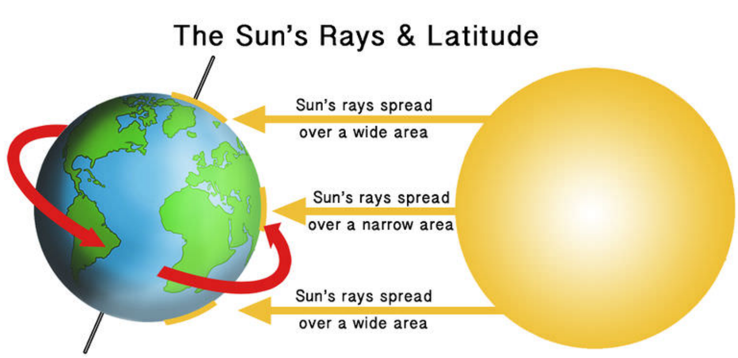


FIGURE 8.10
The lowest latitudes get the most energy from the Sun. The highest latitudes get the least.

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** 8.11. The added gases have caused a greater greenhouse effect. How do you think this affects Earth's temperature?

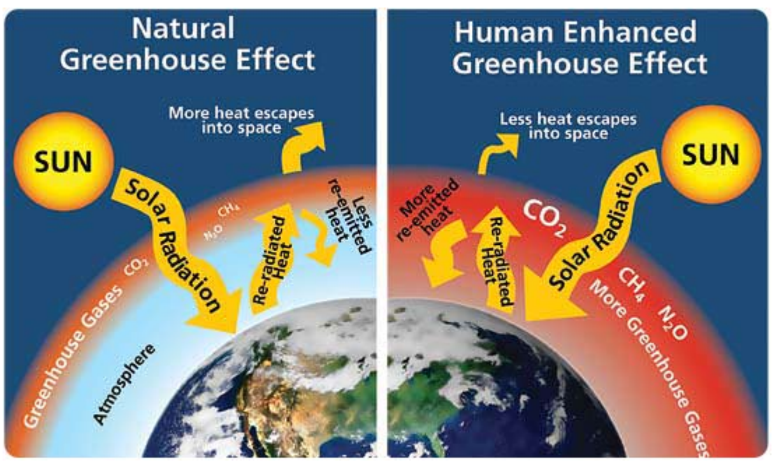


FIGURE 8.11
Human actions have increased the natural greenhouse effect.

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** 8.6. 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?

8.3 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** 8.12. 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.

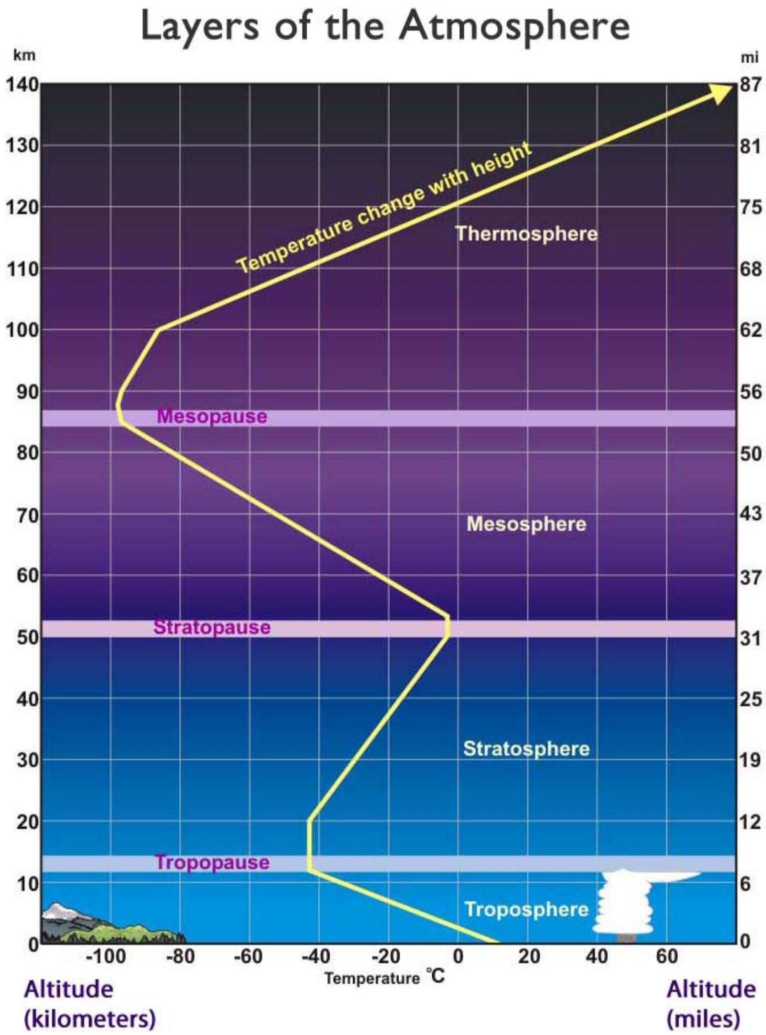


FIGURE 8.12
How does air temperature change in the layer closest to Earth?

Properties of the Troposphere

Look at the troposphere in **Figure** 8.12. 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 8.13
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** 8.12. 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** 8.14, 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.

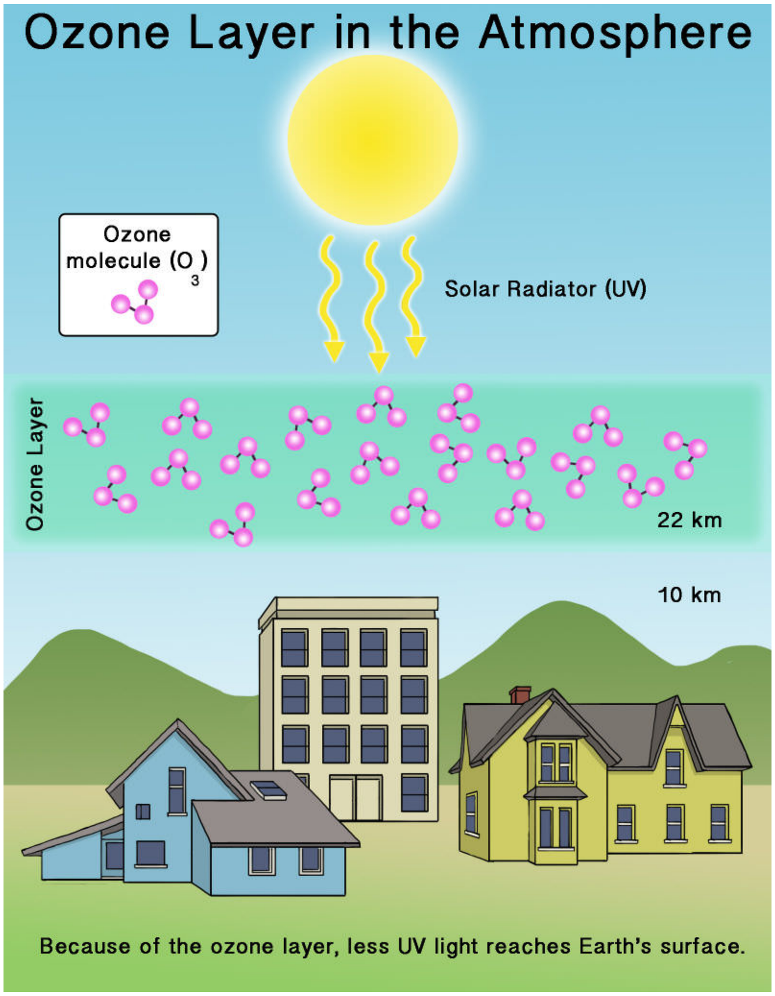


FIGURE 8.14
How does the ozone layer protect Earth's surface from UV light?

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** 8.15? 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 8.15
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** 8.16.

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.

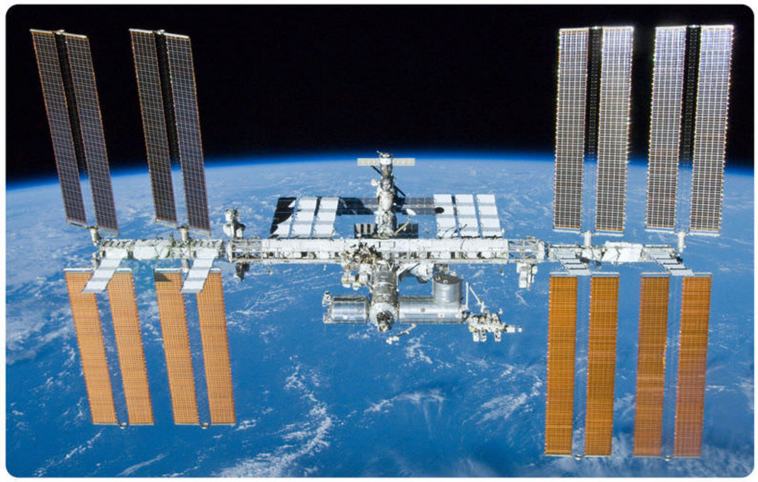


FIGURE 8.16
The International Space Station orbits in the thermosphere.

FIGURE 8.17
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?

8.4 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** 8.18 shows some examples.

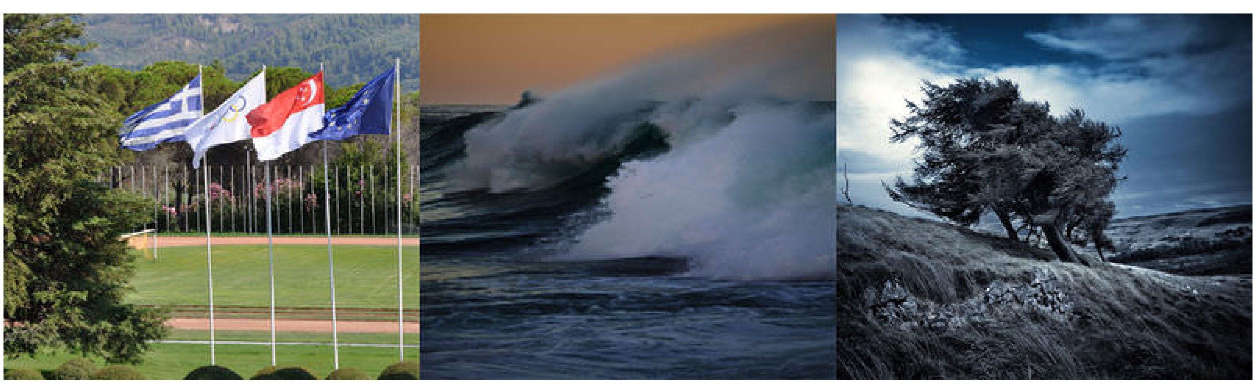


FIGURE 8.18
How can you tell the wind is blowing in these photos?

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** 8.19 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.

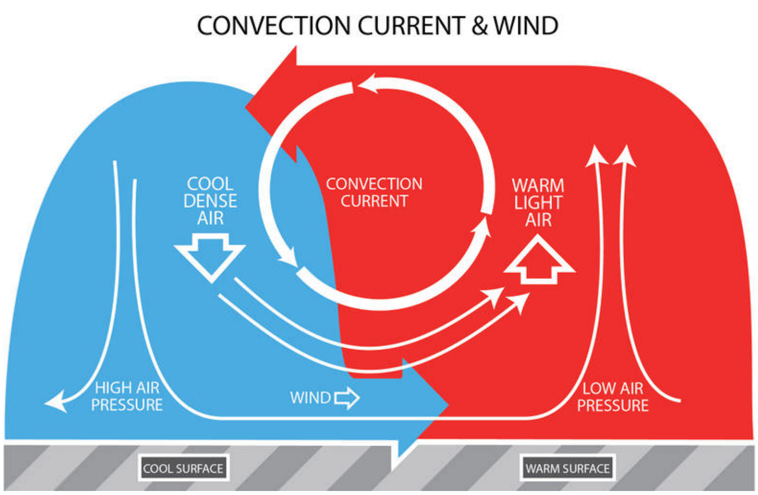


FIGURE 8.19
Differences in air temperature cause convection currents and wind.

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** 8.20.

- 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.

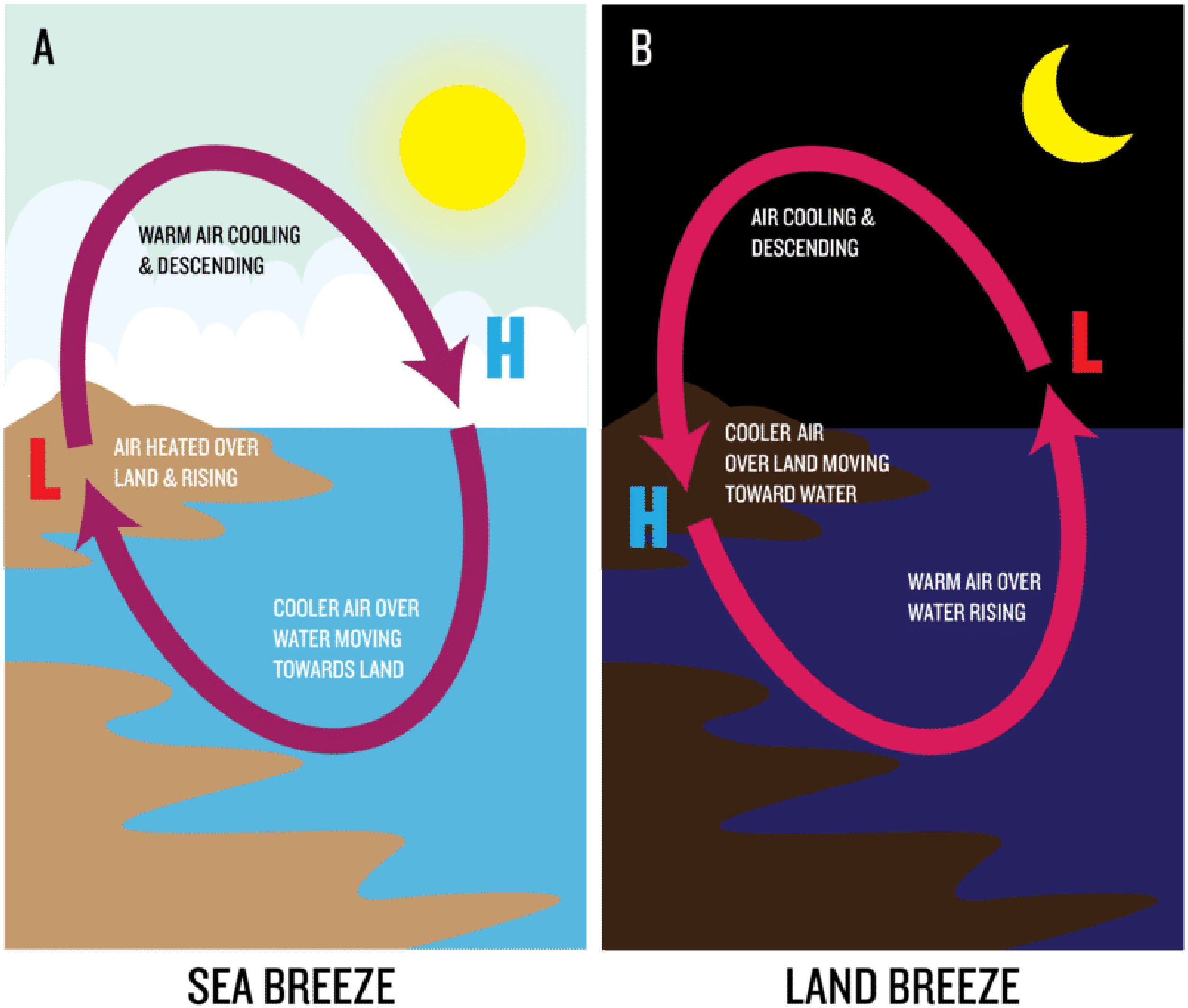


FIGURE 8.20
Land and sea breezes blow because of daily differences in heating.

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** 8.21. These monsoons are important because they carry water to the many people who live there.

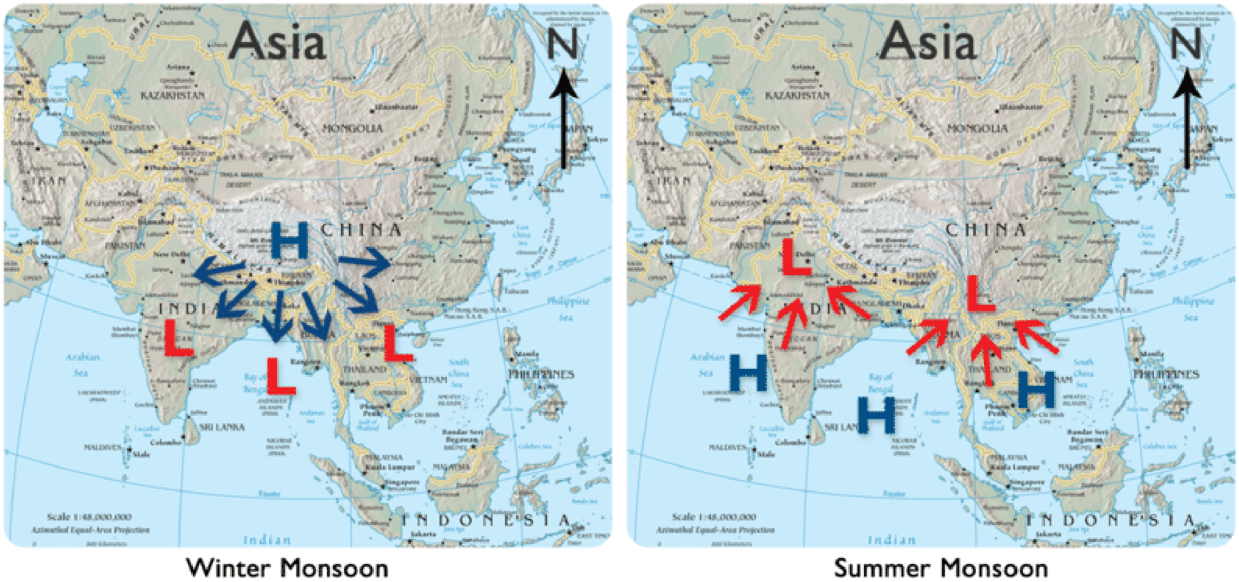


FIGURE 8.21
Monsoons blow over southern Asia.

Global Winds

Global winds are winds that occur in belts that go all around the planet. You can see them in **Figure** 8.22. Like local winds, global winds are caused by unequal heating of the atmosphere.

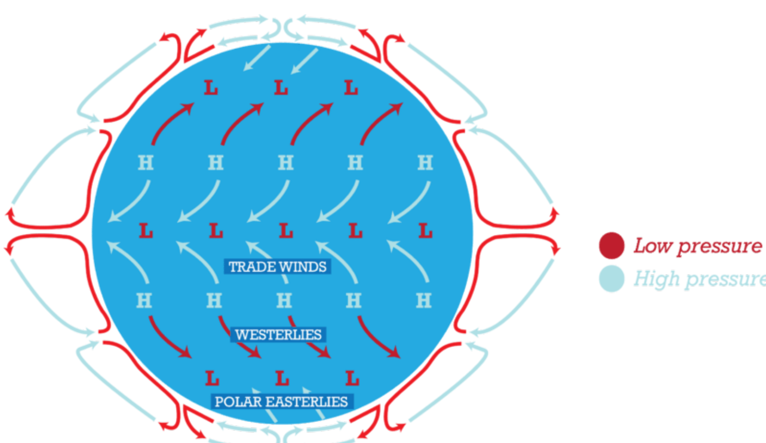


FIGURE 8.22
Global winds occur in belts around the globe.

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** 8.23.

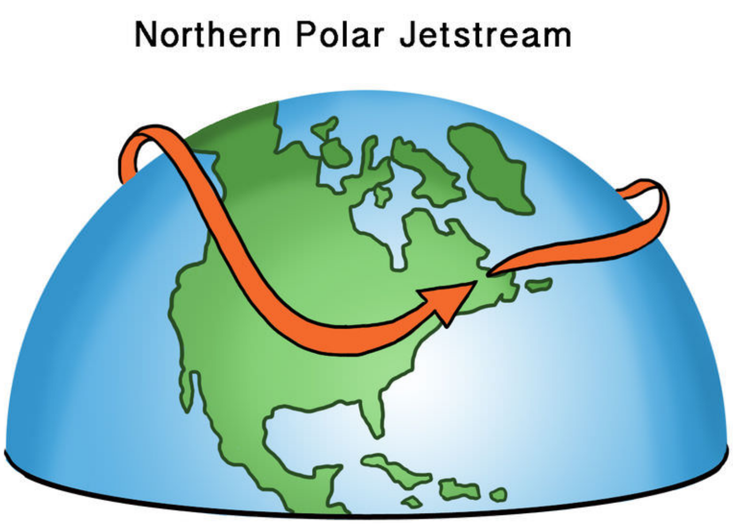


FIGURE 8.23
This jet stream helps planes fly quickly from west to east over North America. How do you think it affects planes that fly from east to west?

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** 8.22, 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?

8.5 References

1. Image copyright Corepics VOF, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
3. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
4. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
5. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
6. User:Quantockgoblin/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Plastic_bottle_at_14000_feet,_9000_feet_and_1000_feet,_sealed_at_14000_feet.png . Public Domain
7. Image copyright Anton Gvozdikov, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
8. Courtesy of NASA. http://science.hq.nasa.gov/kids/imagers/ems/waves3.html . Public Domain
9. Courtesy of NASA; modified by CK-12 Foundation. http://www.centennialofflight.gov/essay/Dictionary/ELECTROSPECTRUM/DI159G1.jpg . Public Domain
10. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
11. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
12. Courtesy of Will Elder/National Park Service. http://www.nps.gov/goga/naturescience/climate-change-causes.htm . Public Domain
13. Courtesy of JetStream/National Weather Service/National Oceanic and Atmospheric Administration. http://www.srh.noaa.gov/jetstream//atmos/atmprofile.htm . Public Domain
14. Courtesy of National Weather Service/National Oceanic and Atmospheric Administration. http://www.wrh.noaa.gov/slc/climate/TemperatureInversions.php . Public Domain
15. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
16. Flickr:WillRogersPhotography. http://www.flickr.com/photos/jackbimble/9507430738/ . CC BY 2.0
17. Courtesy of NASA/Crew of STS-132. http://commons.wikimedia.org/wiki/File:International_Space_Station_-after_undocking_of_STS-132.jpg . Public Domain
18. Flickr:zhengxu. http://www.flickr.com/photos/efz3x/231570209/ . CC BY 2.0
19. From left to right: Julian Lim (Flickr:julianlimjl); Nico Nelson; Euan Morrison (Flickr:euan1234). From left to right: http://www.flickr.com/photos/julianlim/4838480578/; http://www.flickr.com/photos/niconelson/4289796215/; http://www.flickr.com/photos/euanzkamera/7909241274/ . CC BY 2.0
20. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
21. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
22. Map courtesy of the Central Intelligence Agency's World Factbook; modified by CK-12 Foundation. http://commons.wikimedia.org/wiki/File:Asia-map.png . Public Domain
23. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
24. Laura Guerin, based on image by US Centennial of Flight Commission/NASA. CK-12 Foundation (based on image at http://commons.wikimedia.org/wiki/File:Jet_Stream.jpg) . CC BY-NC 3.0

Chapter 9 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.o*

9.1 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** 9.1 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 9.1
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** 9.2

- 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.

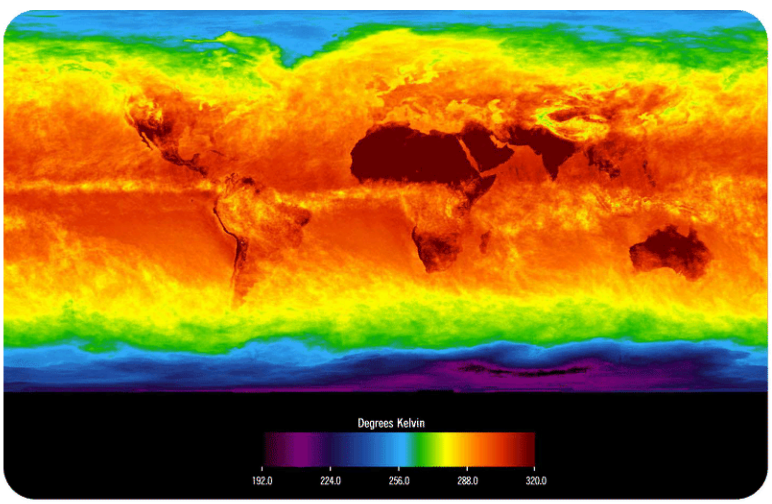


FIGURE 9.2
Find the cool spot in Asia at 30° north latitude. Why is it cool for its latitude? (Hint: What else might influence temperature?)

Latitude and Precipitation

Global air currents affect precipitation. How they affect it varies with latitude. You can see why in **Figure** 9.3.

Latitude and Prevailing Winds

Global air currents cause global winds. **Figure** 9.4 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.

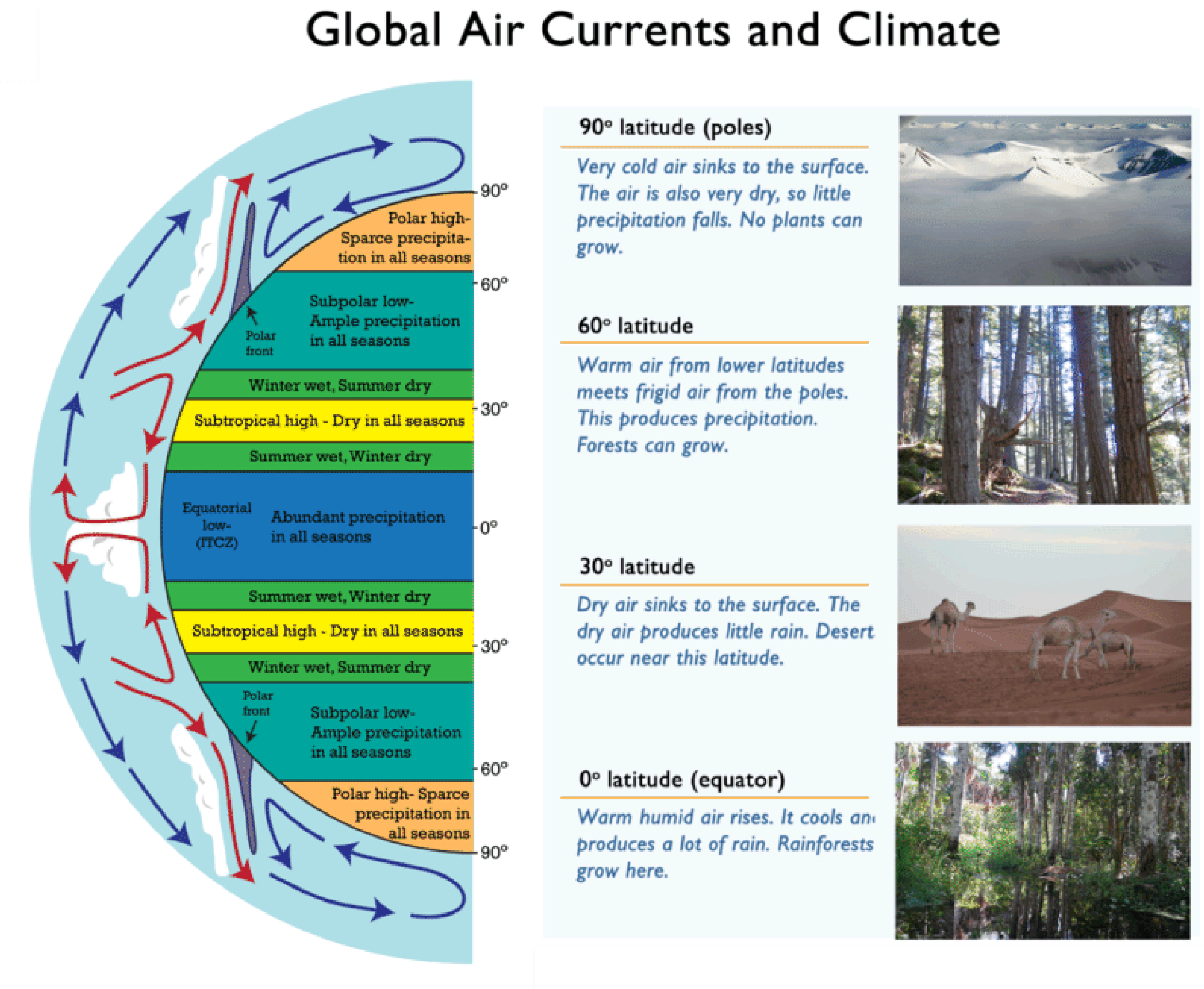


FIGURE 9.3
Global air currents are shown on the left. You can see how they affect climate on the right.

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.

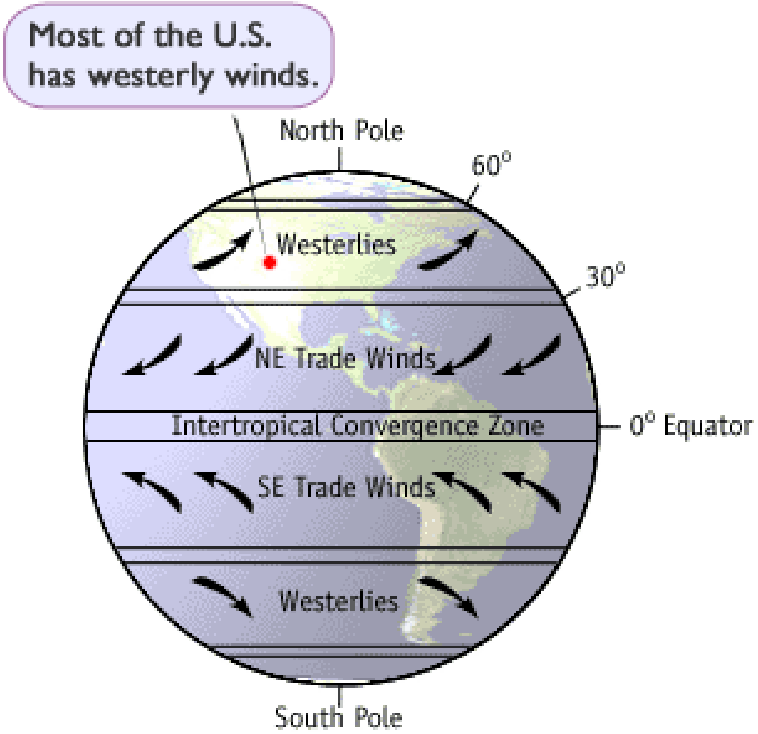


FIGURE 9.4
The usual direction of the wind where you live depends on your latitude. This determines where you are in the global wind belts.

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** 9.5.

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.

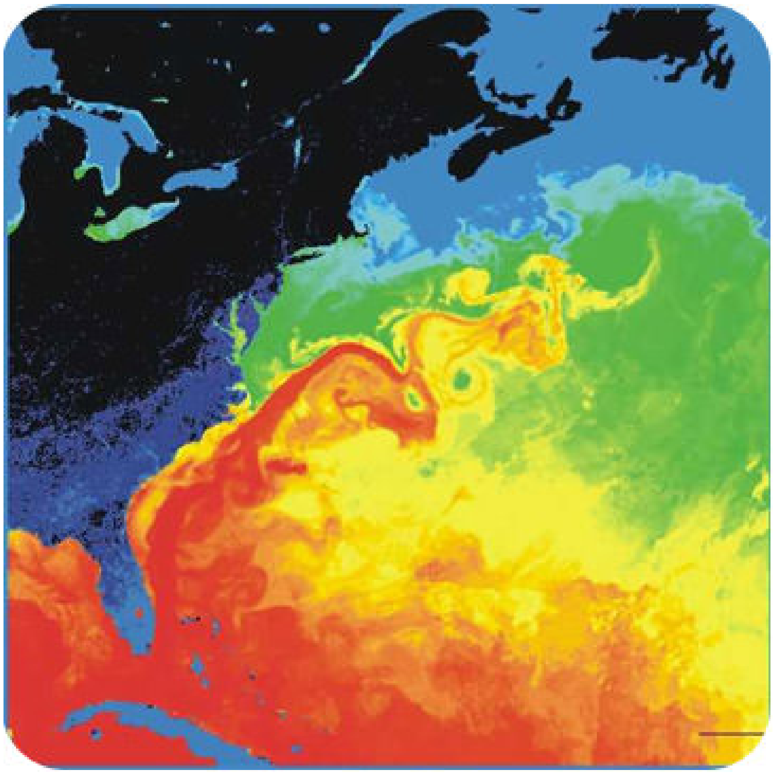


FIGURE 9.5
The Gulf Stream moves warm equatorial water up the western Pacific and into northern Europe, where it raises temperatures in the British Isles.

Altitude and Temperature

Air temperature falls at higher altitudes. You can see this in **Figure** 9.6. 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** 9.7. 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** 9.8 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.

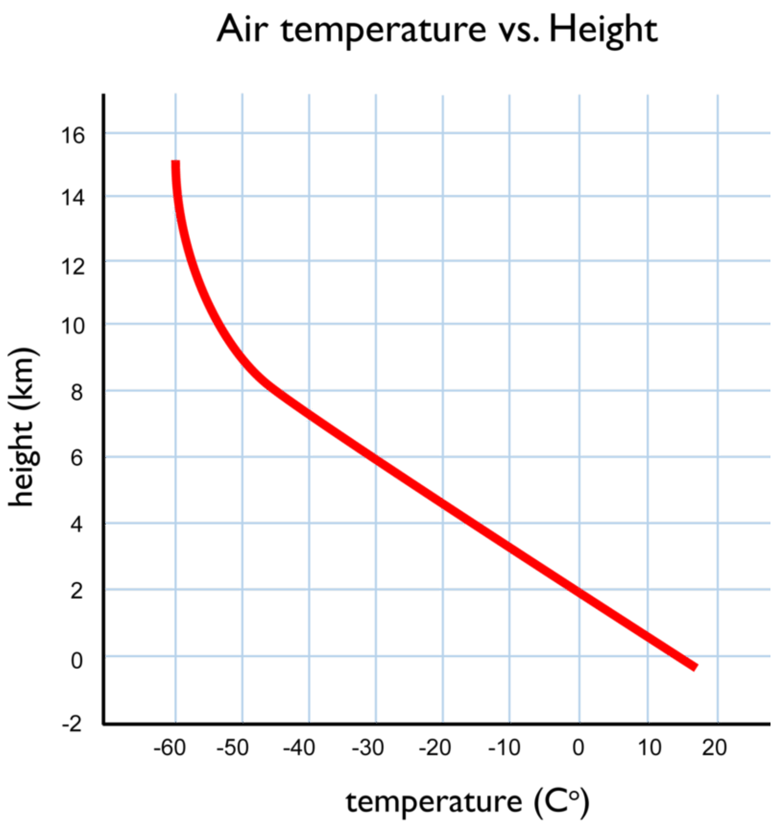


FIGURE 9.6
Air temperature drops as you go higher.

FIGURE 9.7
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.

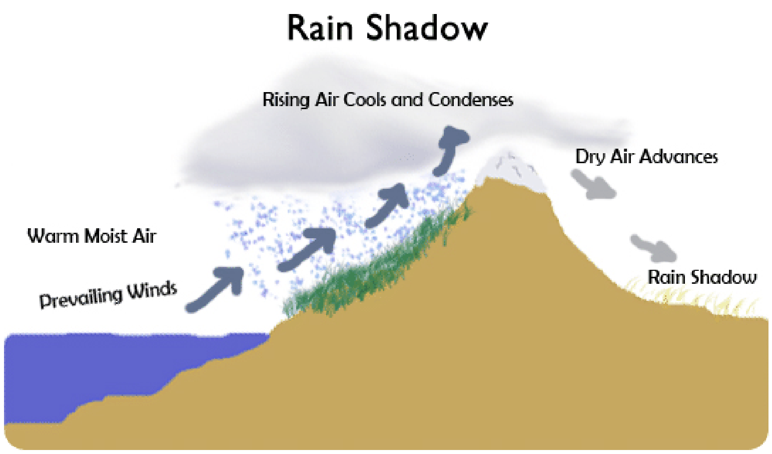


FIGURE 9.8
What role do prevailing winds play in a rain shadow?

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?

9.2 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** 9.9. 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** 9.9.

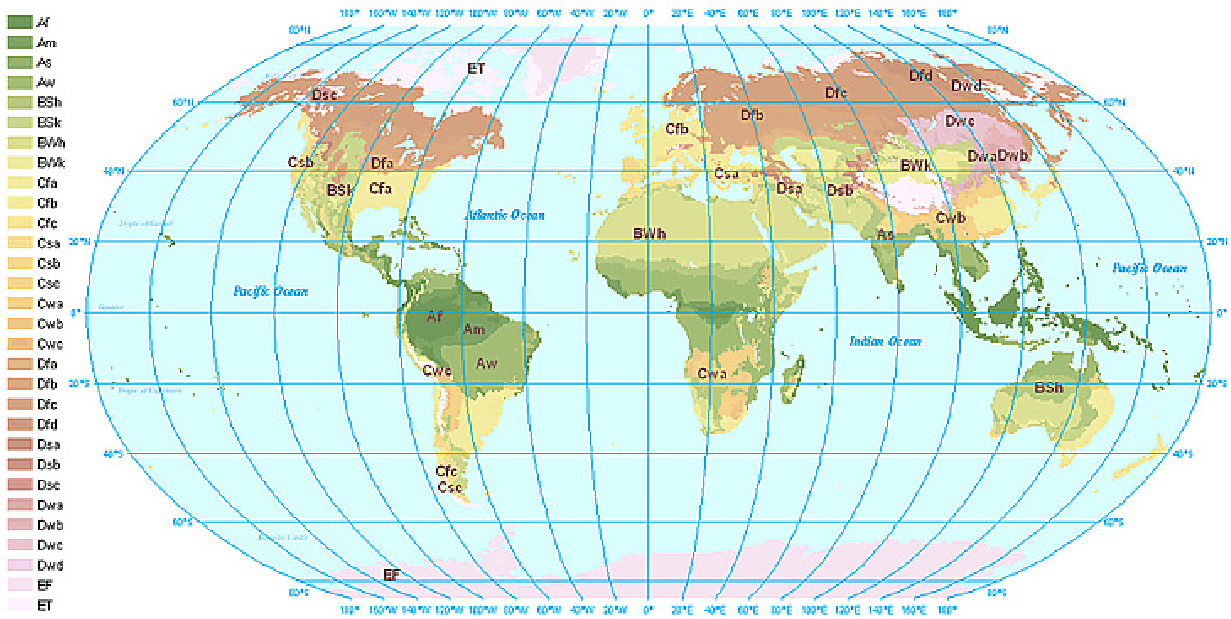


FIGURE 9.9

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** 9.10).

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** 9.11). 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** 9.11). Steppes occur at higher latitudes than deserts. They are dry because they are in continental interiors or rain shadows.

FIGURE 9.10
Africa is famous for its grasslands and their wildlife.

FIGURE 9.11
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** 9.12.

- **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 9.12
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** 9.13).

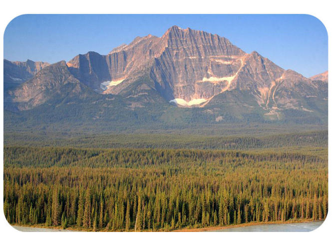


FIGURE 9.13
Conifer forests are typical of the subarctic.

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** 9.14.

- **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 9.14

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** 9.15. 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.

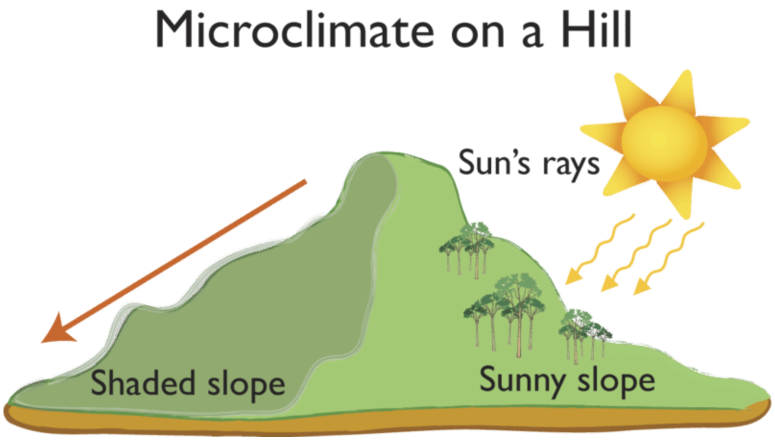


FIGURE 9.15
Hills and other features can create microclimates.

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** 9.16. Describe this type of climate.

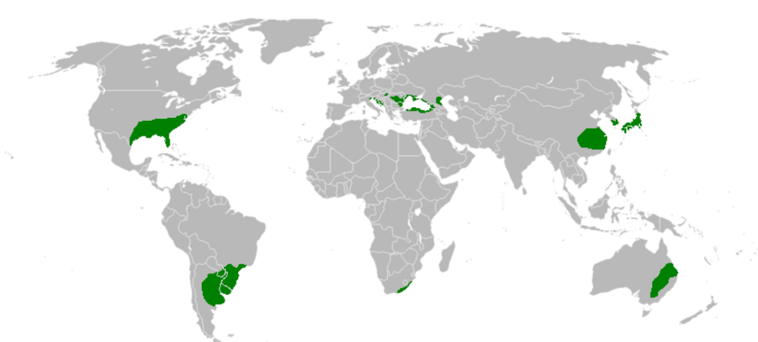


FIGURE 9.16

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?

9.3 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 9.17, 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 9.17
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** 9.18 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).

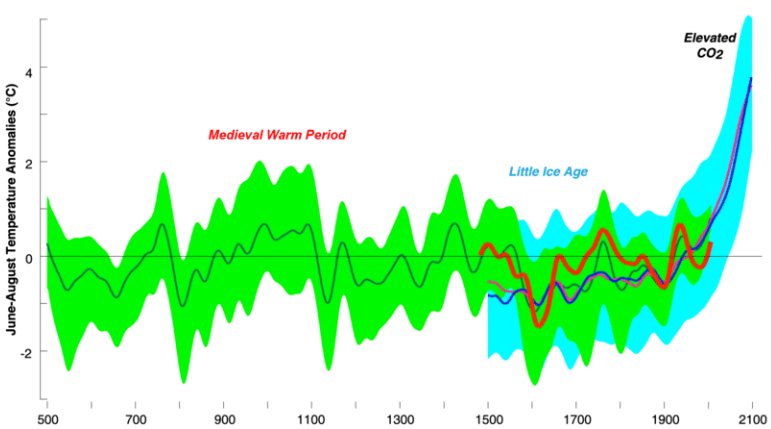


FIGURE 9.18
Earth's temperature. Different sets of data all show an increase in temperature since about 1880 (the Industrial Revolution).

Since the mid 1800s, Earth has warmed up quickly. Look at **Figure** 9.19. 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**.

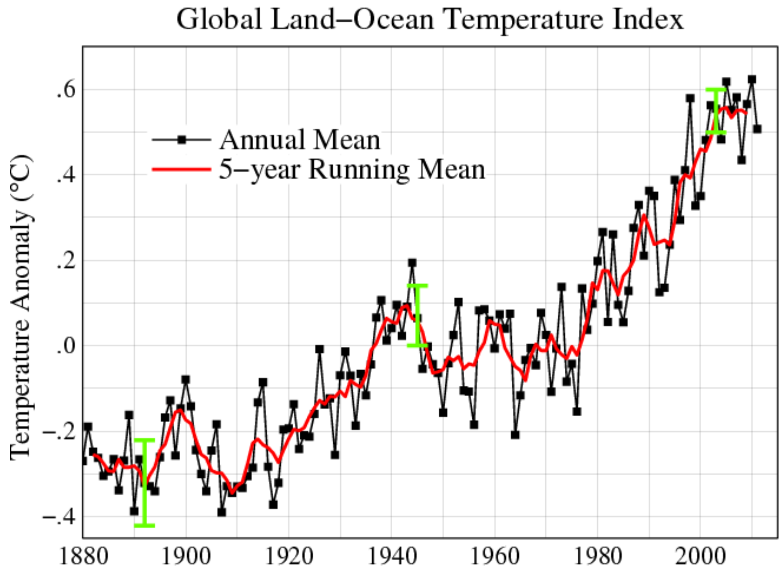


FIGURE 9.19
Earth's temperature (1850–2007). Earth has really heated up over the last 150 years. Do you know why?

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** 9.20 shows the increase in carbon dioxide since 1960.

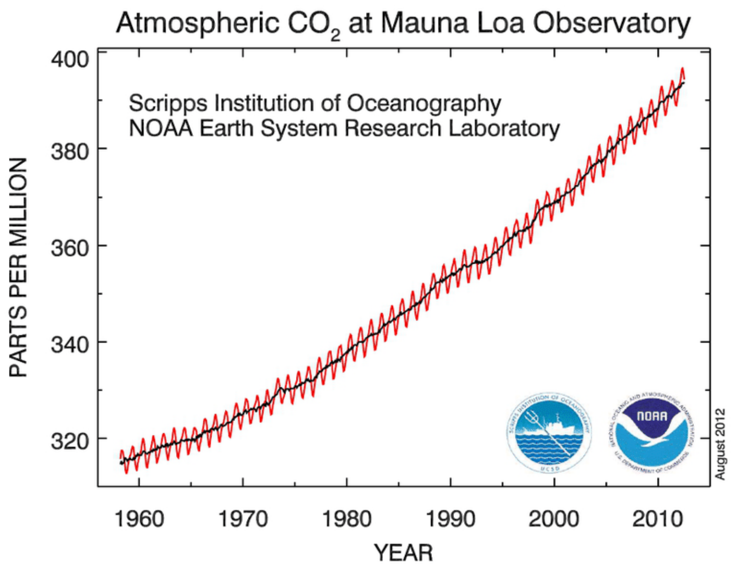


FIGURE 9.20

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** 9.21 shows how much sea level has risen since 1880.

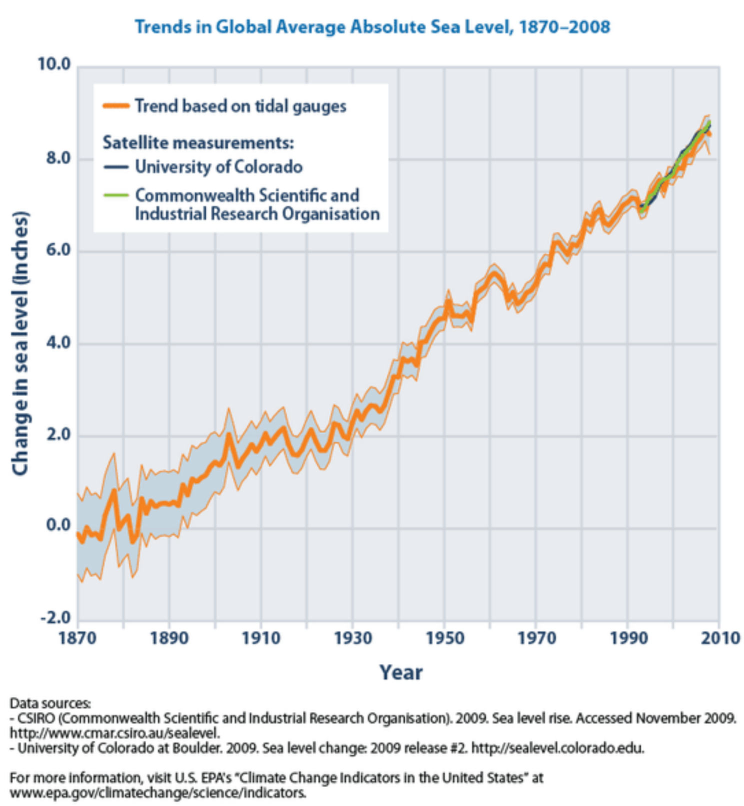


FIGURE 9.21

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** 9.22 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?

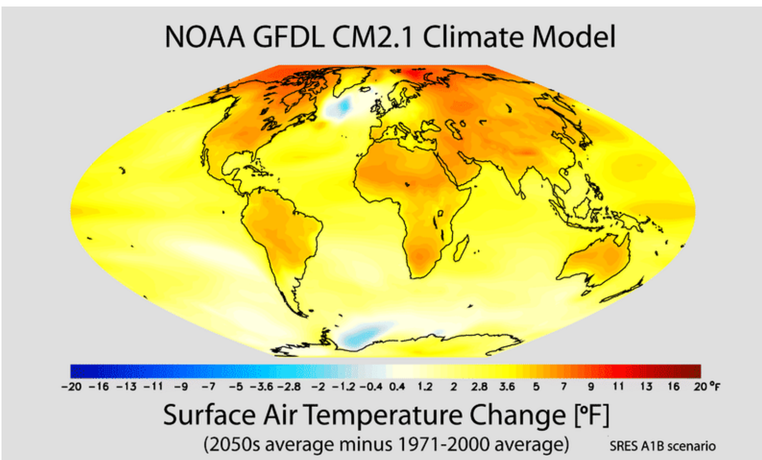


FIGURE 9.22
The Arctic will experience the greatest temperature changes.

As temperature rises, more sea ice will melt. **Figure** 9.23 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** 9.24.

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** 9.25. 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?

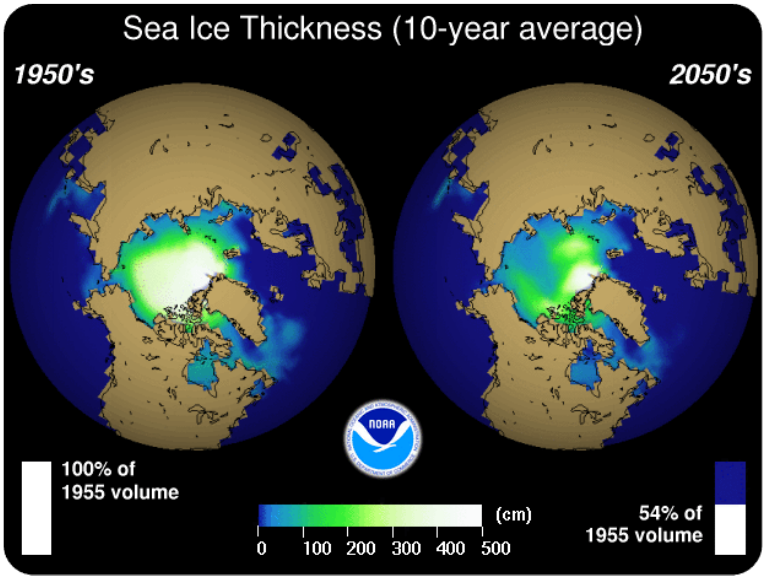


FIGURE 9.23
In the 2050s, there may be only half as much sea ice as there was in the 1950s.

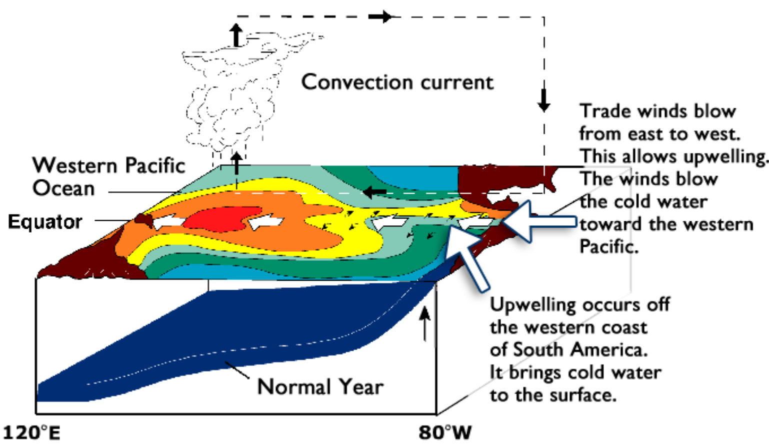


FIGURE 9.24
This diagram represents the Pacific Ocean in a normal year. North and South America are the brown shapes on the right.

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** 9.26 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.

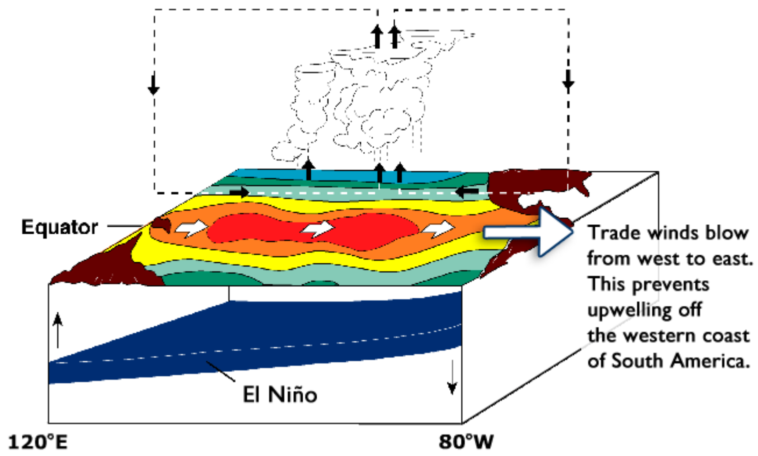


FIGURE 9.25
How do you think El Niño affects climate on the western coast of South America?

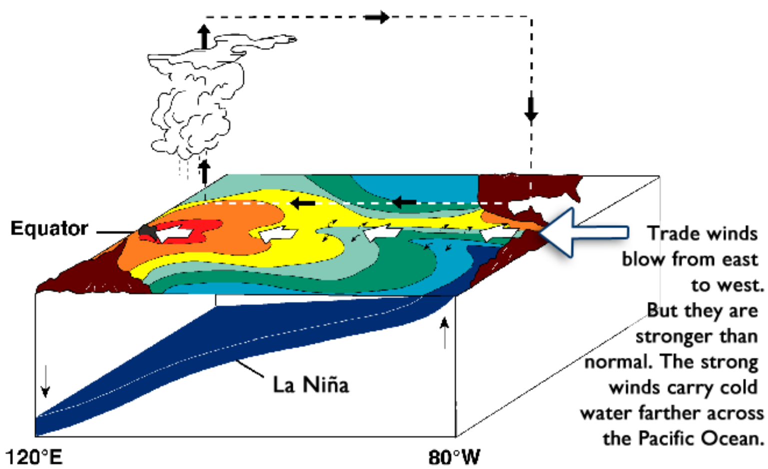


FIGURE 9.26
How do you think La Niña affects climate on the western coast of South America?

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?

9.4 References

1. Image copyright David Lee, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Courtesy of NASA/JPL. http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA00427 . Public Domain
3. Global Circulation Diagram: CK-12 Foundation - Christopher Auyeung; Snow: Kitty Terwolbeck; Forest: Thomas Quine (Flickr:quinet); Desert: John Yavuz Can; Rainforest: Ivan Mlinaric. Snow: http://www.flickr.com/photos/kittysfotos/7902668768/; Forest: http://www.flickr.com/photos/quinet/7406208974/; Desert: http://www.flickr.com/photos/yavuzcan/8177337117/; Rainforest: http://www.flickr.com/photos/eye1/3187012243/ . Global circulation diagram: CC BY-NC 3.0; Remaining images: CC BY 2.0
4. Courtesy of National Park Services and Parks as Classroom. http://www.nps.gov/archive/grsa/resources/curriculum/mid/dunes/photo_files/global_wind.htm . Public Domain
5. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Golfstrom.jpg . Public Domain
6. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
7. Dan Heap (Flickr:danheap77). http://www.flickr.com/photos/69166407@N06/6565397705/ . CC BY 2.0
8. User:Bariot/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Rainshadow_copy.jpg . Public Domain
9. Courtesy of the National Weather Service. http://www.srh.noaa.gov/jetstream/global/climate_max.htm . Public Domain
10. Flickr:sheilapic76. http://www.flickr.com/photos/53344659@N05/4979035890/ . CC BY 2.0
11. Left: Bob Wick, BLM California; right: Courtesy of the U.S. Geological Survey. Left: http://www.flickr.com/photos/mypubliclands/9403761949/; Right: http://www.werc.usgs.gov/OLDsitedata/fire/lv/fireandinvasives/study_ecosystems.htm . Left: CC BY 2.0; Right: Public Domain
12. Mediterranean climate: Piarou, Humid climate: User:Ricraider/Wikimedia Commons; Marine: Flickr:wonderlane. Mediterranean climate: http://commons.wikimedia.org/wiki/File:Garrigue_2007-09-20.JPG; Humid climate: http://commons.wikimedia.org/wiki/File:Cumbres_del_Ajusco.jpg; Marine climate: http://www.flickr.com/photos/wonderlane/4564202646/ . Mediterranean climate: CC BY 2.0; Humid climate: Public Domain; Marine climate: CC BY 2.0
13. Frank Kovalchek. http://commons.wikimedia.org/wiki/File:South_side_of_Jasper_National_Park.jpg . CC BY 2.0
14. Left: david adamec; Right: John Holm. Left: http://commons.wikimedia.org/wiki/File:Northwest_Territories_tundra_stones.jpg; Right: http://commons.wikimedia.org/wiki/File:Alpine_tundra_Copper_Mountain_Colorado.jpg . Left: Public Domain; Right: CC BY 2.0
15. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
16. User:Example/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Subtropicworldmap.png . Public Domain
17. Courtesy of U.S. Geological Survey. http://commons.wikimedia.org/wiki/File:Pleistocene_north_ice_map.jpg . Public Domain
18. U Büntgen, C Raible, et al.. http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0025133 . CC BY 2.5
19. Courtesy of NASA. http://data.giss.nasa.gov/gistemp/graphs_v3/ . Public Domain
20. Courtesy of Dr. Pieter Tans, NOAA/ESRL and Dr. Ralph Keeling, Scripps Institution of Oceanography. http://www.esrl.noaa.gov/gmd/ccgg/trends/ . Public Domain
21. Courtesy of US EPA. http://commons.wikimedia.org/wiki/File:Trends_in_global_average_absolute_sea_level,_1870-2008_%28US_EPA%29.png . Public Domain
22. Courtesy of the NOAA Geophysical Fluid Dynamics Laboratory. http://www.gfdl.noaa.gov/patterns-of-greenhouse-warming-ar4 . Public Domain
23. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Arctic_Ice_Thickness.gif . Public Domain

24. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Enso_normal.png . Public Domain
25. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Enso_elnino.png . Public Domain
26. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Enso_lanina.png . Public Domain

Chapter 10 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.

Image copyright chiakto, 2014. www.shutterstock.com. Used under license form Shutterstock.com.

10.1 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** 10.1). 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 10.1
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** 10.2). All water molecules have the same ratio: two hydrogen atoms to one oxygen atom.

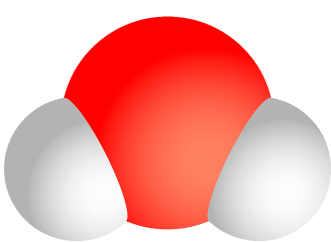


FIGURE 10.2
A water molecule has two hydrogen atoms (shown in gray) bonded to one oxygen molecule (shown in red).

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** 10.3 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.

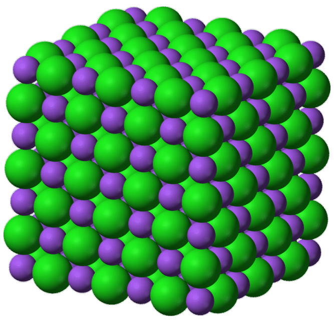


FIGURE 10.3
Sodium ions (purple balls) bond with chloride ions (green balls) to form halite crystals.

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** 10.4. 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.

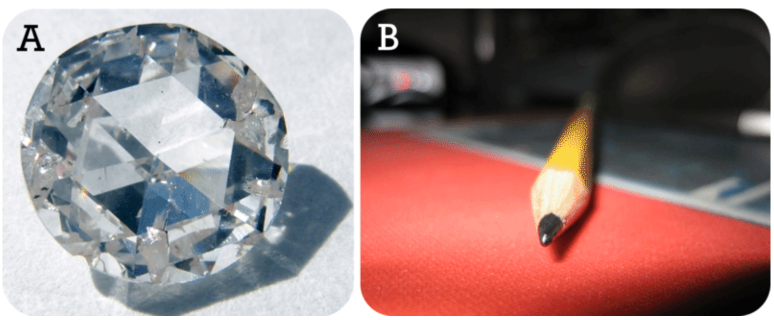


FIGURE 10.4
Diamonds (A) and graphite (B) are both made of only carbon, but they're not much alike.

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** 10.3. You can see how salt crystals look under a microscope in **Figure** 10.5. Salt crystals are all cubes whether they're small or large.

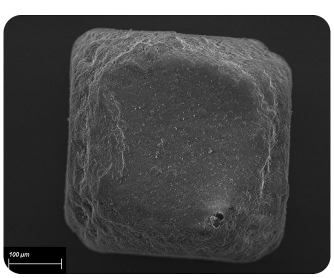


FIGURE 10.5
Under a microscope, salt crystals are cubes.

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

- Color: the color of the mineral.

- Streak: the color of the mineral's powder.
- 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** 10.6). The silicate pyramid is the building block of silicate minerals. Most silicates contain other elements. These elements include calcium, iron, and magnesium.

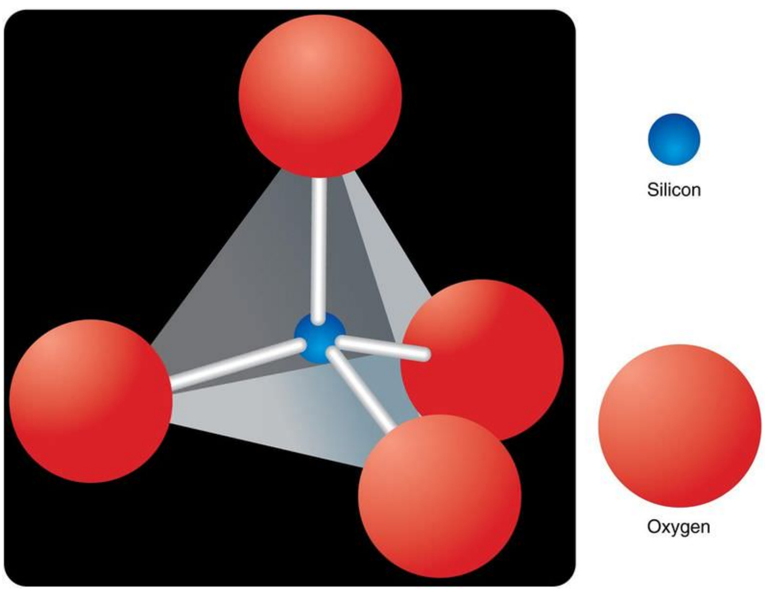


FIGURE 10.6
One silicon atom bonds to four oxygen atoms to form a pyramid

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** 10.7.

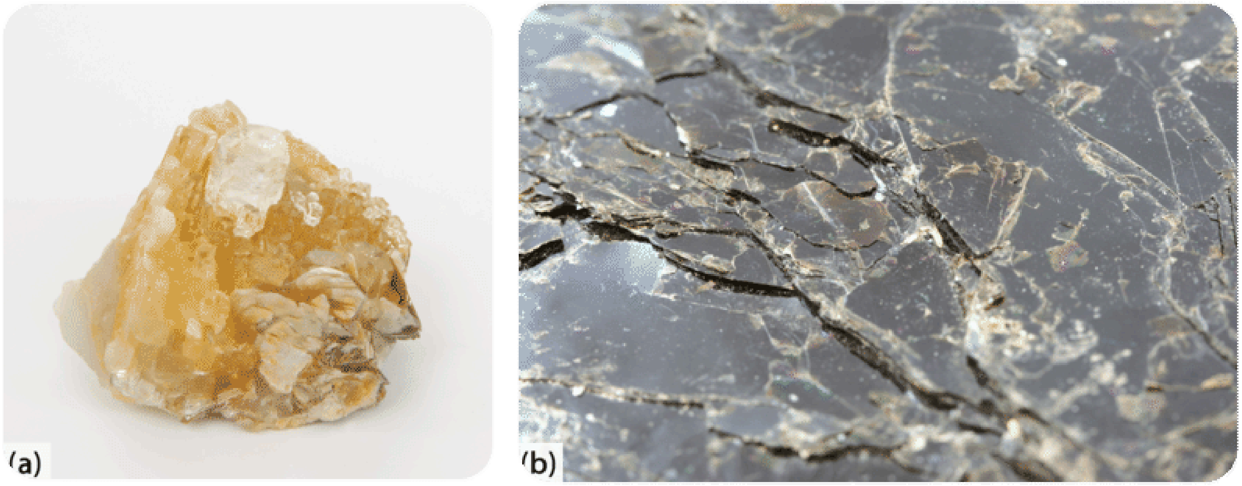


FIGURE 10.7
Beryl (a) and biotite (b) are both silicate minerals.

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** 10.8 that they are very colorful.

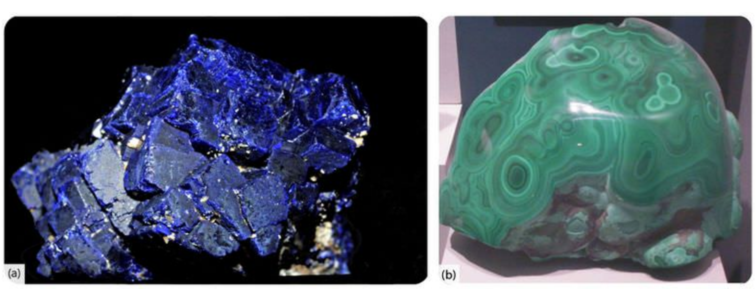


FIGURE 10.8
The deep blue mineral is azurite and the green is malachite. Both of these carbonate minerals are used for jewelry.

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** 10.9.

FIGURE 10.9

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?

10.2 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** 10.10. 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 10.10
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** 10.11 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** 10.12 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.

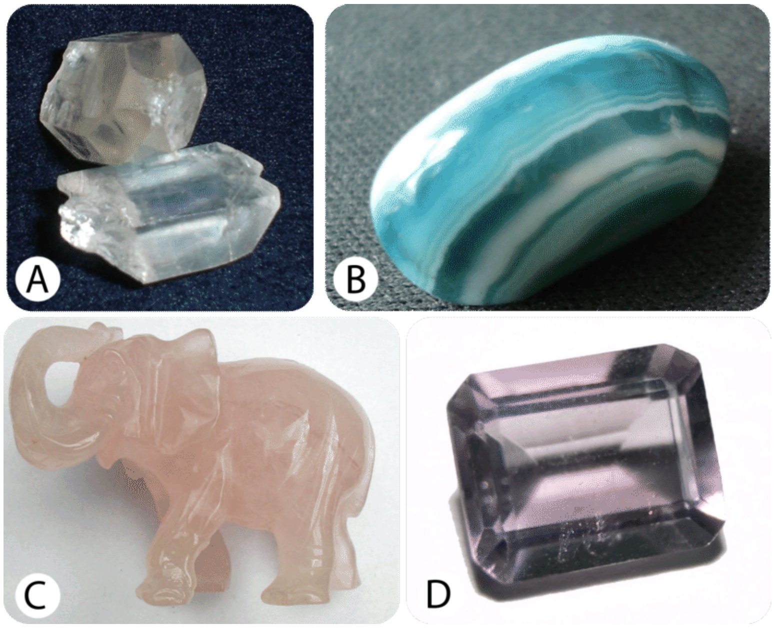


FIGURE 10.11

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

FIGURE 10.12

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** 10.1.

TABLE 10.1: 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** 10.13 with the correct luster from **Table** 10.1 without looking at the caption?

FIGURE 10.13

(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.

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** 10.2, 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 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 10.2: Mohs Scale

Hardness	Mineral
1	Talc
2	Gypsum

TABLE 10.2: (continued)

Hardness	Mineral
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** 10.14. Halite tends to form cubes with smooth surfaces. Mica tends to form sheets. Fluorite can form octahedrons.

FIGURE 10.14
Minerals with different crystal structures have a tendency to break along certain planes.

Minerals can form various shapes. Polygons are shown in **Figure** 10.15. 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.

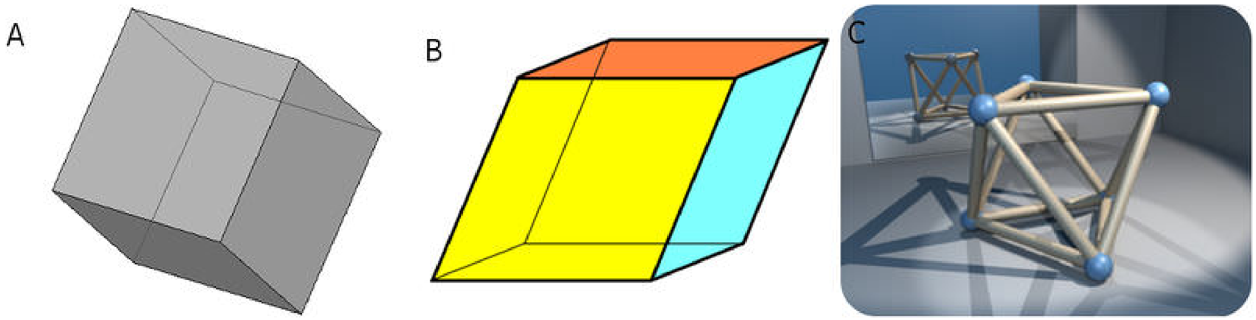


FIGURE 10.15
Cubes have six sides that are all the same size square. All of the angles in a cube are equal to 90°. Rhombohedra also have six sides, but the sides are diamond-shaped. Octahedra have eight sides that are all shaped like triangles.

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** 10.16.

FIGURE 10.16
This mineral formed a smooth, curved surface when it fractured.

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 10.3. An example of a mineral that has each property is also listed.

TABLE 10.3: 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)

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?

10.3 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** 10.17 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 10.17
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** 10.18 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.

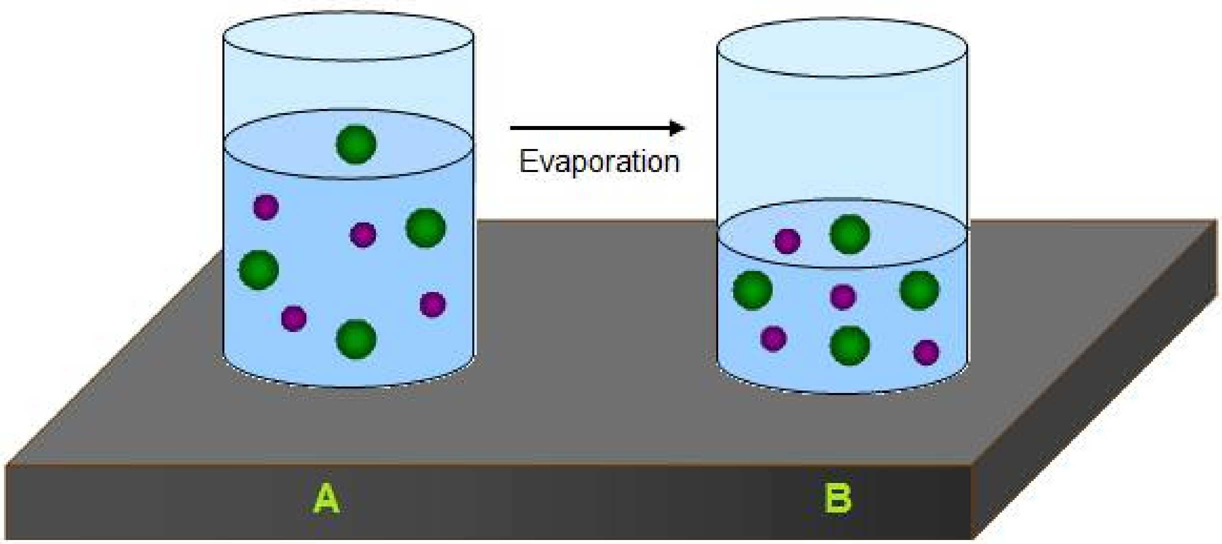


FIGURE 10.18
When the water in glass A evaporates, the dissolved mineral particles are left behind.

Salt easily precipitates out of water, as does calcite, as **Figure** 10.19 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 10.19
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** 10.20 shows a white quartz vein. When the minerals are deposited in open spaces, large crystals grow. These rocks are called geodes. **Figure** 10.20 shows a "geode" that was formed when amethyst crystals grew in an open space in a rock.

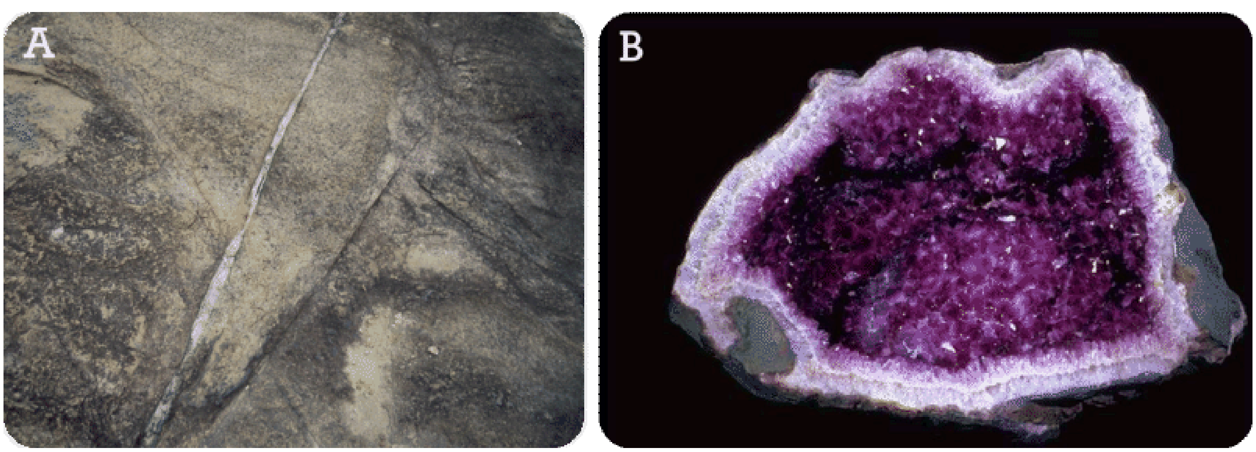


FIGURE 10.20
(A) A quartz vein formed in this rock. (B) Geodes form when minerals evaporate out in open spaces inside a rock.

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?

10.4 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** 10.21 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 10.21
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** 10.22 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 10.22
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** 10.23.

FIGURE 10.23
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** 10.24, are minerals.

FIGURE 10.24
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** 10.25 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 10.25
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** 10.26 shows water that is contaminated from a nearby mine. The United States government has mining standards to protect water quality.

FIGURE 10.26
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?

10.5 References

1. Image copyright chiakto, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. Necklace: Flickr:Tikanchay handcrafted jewelry from Peru; Salt mill: User:ElinorD/Wikimedia Commons; Glass: Will Murray (User:Willscrlt/Wikimedia Commons); Silver: Courtesy of US Geological Survey and Mineral Information Institute; Salt: Courtesy of US Geological Survey and Mineral Information Institute; Quartz: Courtesy of Ken Hammond/US Department of Agriculture. Necklace: http://www.flickr.com/photos/29874248@N06/2811981846/; Salt mill: http://commons.wikimedia.org/wiki/File:Saltmill.jpg; Glass: http://commons.wikimedia.org/wiki/File:Highball_Glass_%28Tumbler%29.svg; Silver: http://commons.wikimedia.org/wiki/File:SilverUSGOV.jpg; Salt: http://commons.wikimedia.org/wiki/File:ImgSalt.jpg; Quartz: http://commons.wikimedia.org/wiki/File:USDA_Mineral_Quartz_Crystal_93c3951.jpg . Necklace: CC BY 2.0; Rest: Public Domain
3. User:Sakurambo/Wikimedia Commons. http://commons.wikimedia.org/wiki/Image:Water_molecule.svg . Public Domain
4. Ben Mills (Wikimedia: Benjah-bmm27). http://commons.wikimedia.org/wiki/File:Sodium-chloride-3D-ionic.png . Public Domain
5. (A) Steve Jurvetson; (B) User:Infratec/Wikimedia Commons. (A) http://www.flickr.com/photos/10506540@N07/3853300537/; (B) http://commons.wikimedia.org/wiki/File:Sharpened_Pencil.jpg .
6. User:Chhe/Wikipedia. http://commons.wikimedia.org/wiki/File:Salt2.JPG .
7. CK-12 Foundation. CK-12 Foundation . CC BY-NC 3.0
8. Beryl: Image copyright Manamana, 2013; Biotite: Image copyright Tyler Boyes, 2013. Beryl and biotite are both silicate minerals . Used under licenses from Shutterstock.com
9. (a) User:Parent Géry/Wikimedia Commons; (b) User:Alkivar/Wikimedia Commons. Two carbonate minerals - blue azurite and green malachite . Public Domain
10. Miles Orchinik. CK-12 Foundation .
11. Guilhem Vellut. http://www.flickr.com/photos/22539273@N00/8101950433/ . CC BY 2.0
12. (A) Eurico Zimbres FGEL/UERJ; (B) User:Bordercolliez/Wikimedia Commons; (C) Adrian Pingstone; (D) Michelle Jo. (A) http://commons.wikimedia.org/wiki/File:Quartz.jpg; (B) http://commons.wikimedia.org/wiki/File:Blue_agate_1.jpg; (C) http://commons.wikimedia.org/wiki/File:Ele.rose.750pix.jpg; (D) http://en.wikipedia.org/wiki/File:Amethyst.JPG . (A-C) Public Domain; (D) CC BY 3.0
13. Zappy's. CK-12 Foundation .
14. (A) FancyDiamonds.net; (C) Tony Hisgett (Flickr:ahisgett); (B) Emanuele Longo; (D) Deidre Woollard; (E) Kevin Walsh (Flickr:kevinzim); (F) Dave Dyet; (G) Courtesy of the US Geological Survey and Mineral Information Institute; (H) Beesnest McClain. (A) http://www.flickr.com/photos/fancy-diamonds/5511634443/; (B) http://www.flickr.com/photos/em4nu/2700330797/; (C) http://www.flickr.com/photos/hisgett/8030287889/; (D) http://www.flickr.com/photos/deidrew/4918639189/; (E) http://www.flickr.com/photos/86624586@N00/5945787093/; (F) http://commons.wikimedia.org/wiki/File:Ulexite_w-clay_and_realgar_Hydrous_sodium_calcium_borate_Boron_Kern_County_California_1866.jpg; (G) http://commons.wikimedia.org/wiki/File:Sphalerite2USGOV.jpg; (H) http://commons.wikimedia.org/wiki/File:WLA_lacma_Mayan_jadeite_pendant.jpg . (A-E) CC BY 2.0; (F-H) Public Domain
15. (A) Image copyright Nadezda Boltaca, 2014; (B) Image copyright Tyler Boyes, 2014; (C) Image copyright Nicholas Sutcliffe, 2014. http://www.shutterstock.com . Used under licenses from Shutterstock.com
16. (A) User:PDD/Pl.Wikipedia; (B) User:Tomruen/Wikipedia; (C) User:KoenB/Wikimedia Commons. (A) http://commons.wikimedia.org/wiki/File:Hexahedron_grey.png; (B) http://commons.wikimedia.org/wiki/File:Rhombohedron.png; (C) http://commons.wikimedia.org/wiki/File:Octahedron-wireframe.jpg . Public Domain
17. User:Karelj/Wikimedia Commons. This mineral formed a smooth, curved surface when it fractured .
18. Flickr:schizoform. Lava is melted rock that erupts onto Earth's surface. . CC BY 2.0

19. Rebecca Calhoun. CK-12 Foundation . CC BY-NC 3.0
20. Clinton Steeds. http://www.flickr.com/photos/cwsteeds/98597918/ . CC BY 2.0
21. (A) Eryn Vorn; (B) User:Juppi66/Wikimedia Commons. (A) http://www.flickr.com/photos/36521972608@N01/8461005810/; (B) http://commons.wikimedia.org/wiki/File:Ametyst-geode.jpg . (A) CC BY 2.0; (B) Public Domain
22. James St. John (Flickr:jsj1771). Aluminum is made from the minerals in rocks known as bauxite . CC BY 2.0
23. Vladimir. This diamond mine is more than 500 m deep . CC BY 3.0
24. Flickr:jglazer75. http://commons.wikimedia.org/wiki/File:Connecticut_State_Capitol,_Hartford.jpg . CC BY 2.0
25. MAURO CATEB. http://www.flickr.com/photos/69102917@N06/6395134089/ . CC BY 2.0
26. Left: Adrian Pingstone; Right: User:Humanfeather/Wikimedia Commons. Ruby is cut and polished to make the gemstone sparkle .
27. Courtesy of the U.S. Department of Interior, U.S. Geological Survey. Scientists test water that has been contaminated by a mine . Public Domain

CHAPTER 11 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.

User:Example/Wikimedia Commons. commons.wikimedia.org/wiki/File:Devils_Tower_CROP.jpg. Public Domain.

11.1 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** 11.1 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** 11.2).

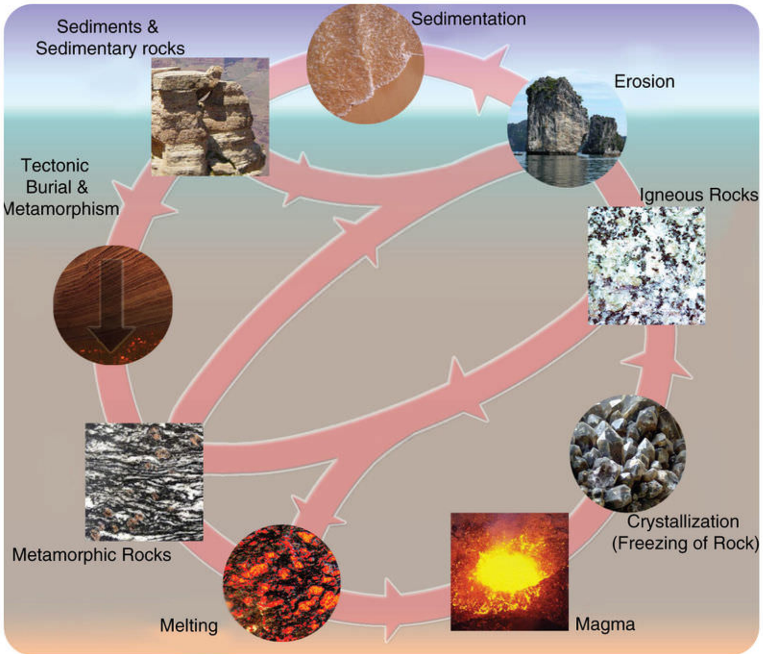


FIGURE 11.1
The rock cycle.

FIGURE 11.2
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** 11.3).

2. Sedimentary rocks form when sediments are compacted and cemented together (**Figure** 11.4). 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** 11.5). The rock experiences these changes within the Earth.

FIGURE 11.3
Lava is molten rock. This lava will harden into an igneous rock.

FIGURE 11.4
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 11.5
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?

11.2 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** 11.6). 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!

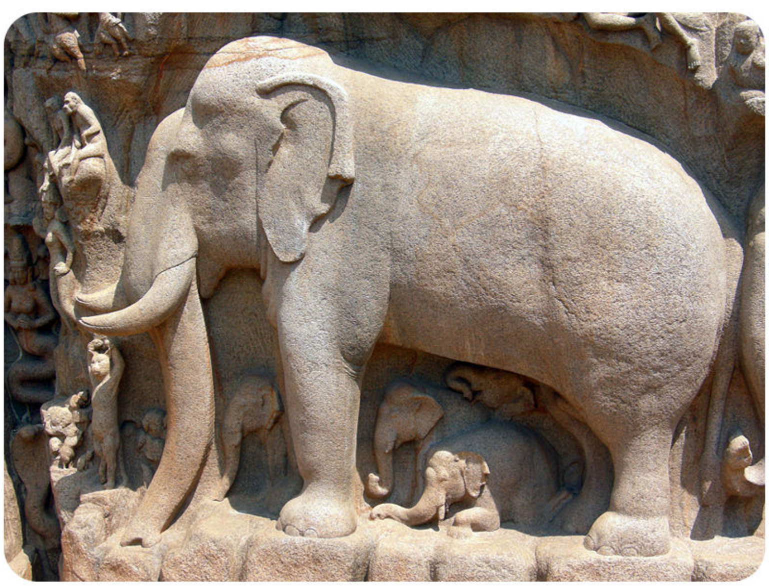


FIGURE 11.6
This life-size elephant is carved from granite.

Forming Crystals

Igneous rocks form when magma cools and forms crystals. These rocks can form at Earth's surface or deep underground. **Figure** 11.7 shows a landscape in California's Sierra Nevada that consists entirely of granite.

FIGURE 11.7
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** 11.8 shows four types of intrusive rocks.

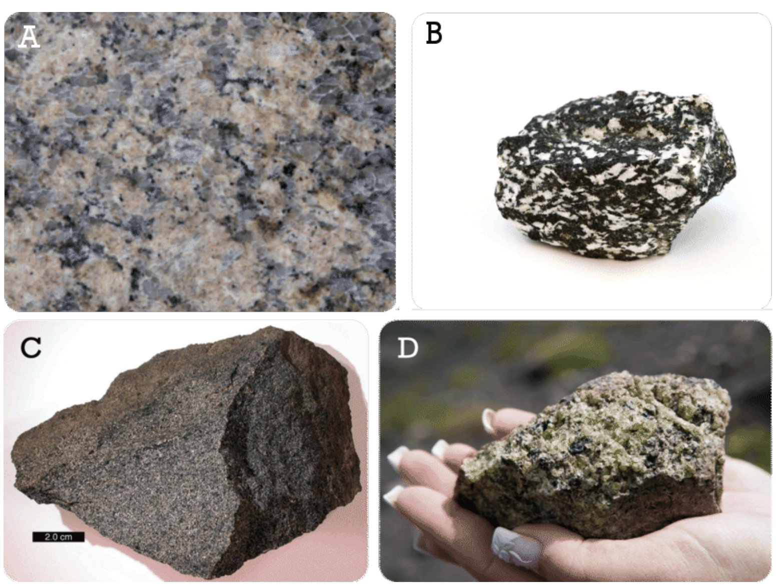


FIGURE 11.8
(A) This granite has more plagioclase feldspar than many granites. (B) Diorite has more dark-colored minerals than granite. (C) Gabbro. (D) Peridotite is an intrusive igneous rock with olivine and other mafic minerals.

Extrusive igneous rocks form above the surface. The lava cools quickly as it pours out onto the surface (**Figure** 11.9). 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** 11.10 shows four types of extrusive igneous rocks.

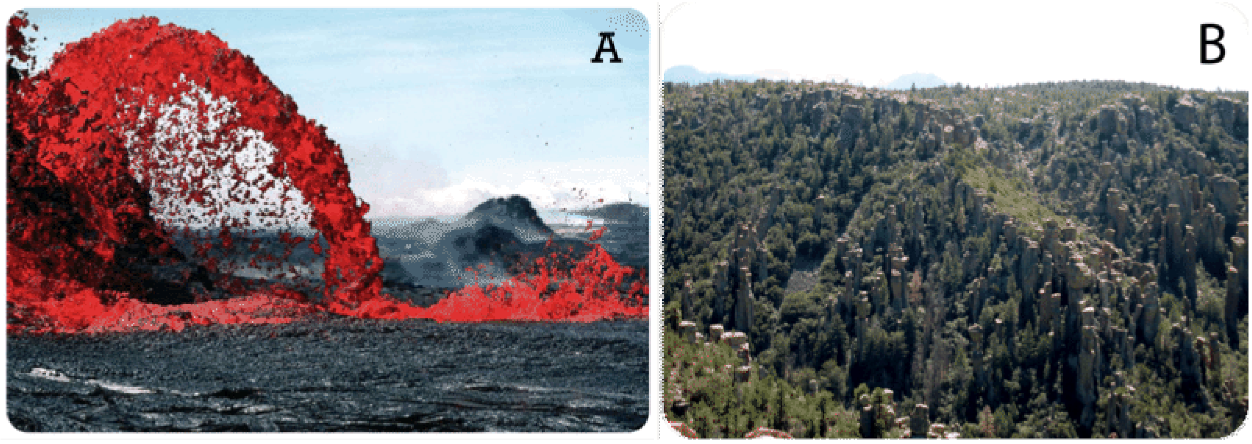


FIGURE 11.9
(A) Lava cools to form extrusive igneous rock. The rocks here are basalts. (B) The strange rock formations of Chiricahua National Monument in Arizona are formed of the extrusive igneous rock rhyolite.

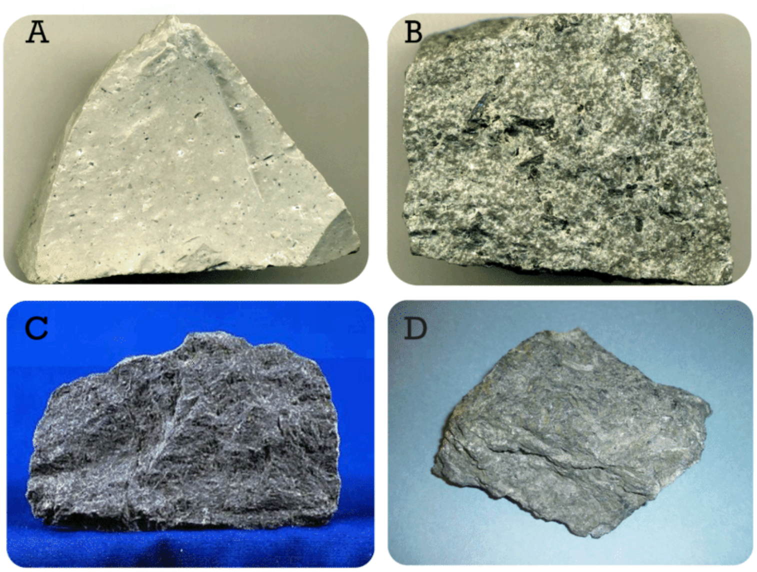


FIGURE 11.10
(A) This rhyolite is light colored. Few minerals are visible to the naked eye. (B) Andesite is darker than rhyolite. (C) Since basalt crystals are too small to see, the rock looks dark all over. (D) Komatiite is a very rare ultramafic rock. This rock is derived from the mantle.

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** 11.11).

FIGURE 11.11
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?

11.3 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 11.12
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** 11.12? 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** 11.13). 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 11.13
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 11.1 shows some common types of sedimentary rocks and the types of sediments that make them up.

TABLE 11.1: Common Sedimentary Rocks

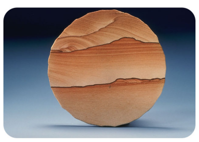
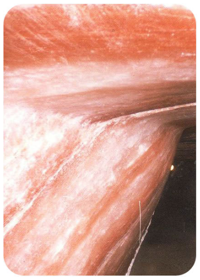
Picture	Rock Name	Type of Sedimentary Rock
	Conglomerate	Clastic
	Breccia	Clastic
	Sandstone	Clastic
	Siltstone	Clastic
	Limestone	Bioclastic
	Coal	Organic

TABLE 11.1: (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?

11.4 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** 11.14).

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** 11.14). The minerals in hornfels separate by density. The

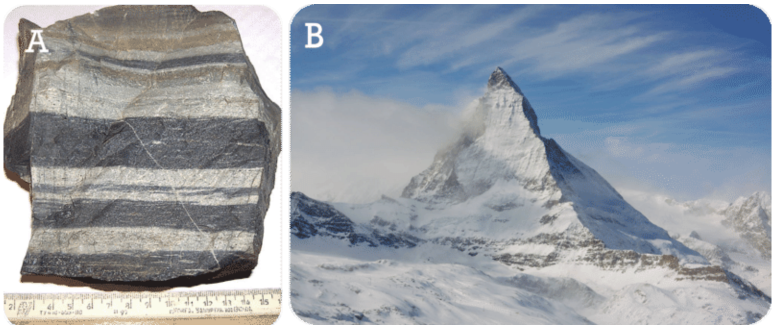


FIGURE 11.14
(A) Hornfels is a rock that is created by contact metamorphism. (B) Hornfels is so hard that it can create peaks like the Matterhorn.

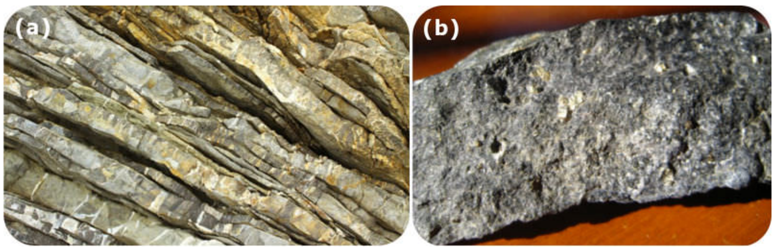


FIGURE 11.15
(A) Regional metamorphic rocks often display layering called foliation. (B) Regional metamorphism with high pressures and low temperatures can result in blue schist.

result 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** 11.16). 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.

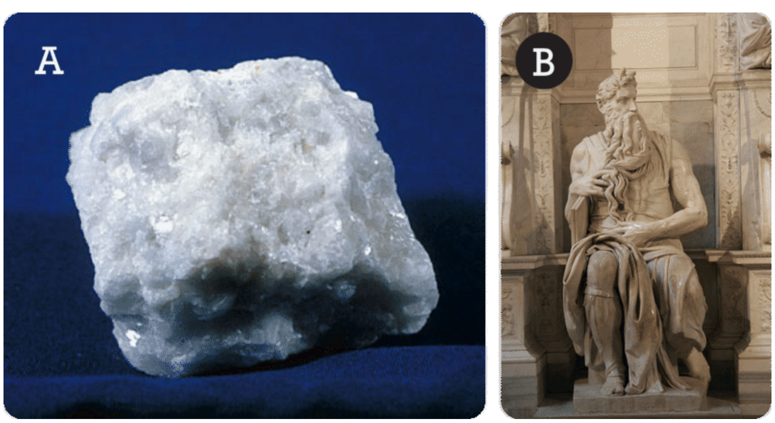


FIGURE 11.16
(A) Marble is a beautiful rock that is commonly used for buildings. (B) Many of the great statues of the Renaissance were carved from marble. Michelangelo created this Moses between 1513 and 1515.

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?

For **Table** 11.1,

- User:Jstuby/Wikipedia. http://commons.wikimedia.org/wiki/File:Lehigh_conglom.jpg . Public Domain.
- Mark A. Wilson (Department of Geology, The College of Wooster). http://commons.wikimedia.org/wiki/File:UpperTriassicYorkCountyPA.jpg . Public Domain.
- Courtesy of Ken Hammond, US Department of Agriculture. http://commons.wikimedia.org/wiki/File:USDA_-Mineral_Sandstone_93c3955.jpg . Public Domain.
- Courtesy of United States Geological Survey/Mineral Information Institute. http://commons.wikimedia.org/wiki/File:ShaleUSGOV.jpg . Public Domain.
- P K (Flickr:uair1). http://www.flickr.com/photos/56759497@N00/3870660087/ . CC BY 2.0.
- Flickr:oatsy40. http://www.flickr.com/photos/68089229@N06/9333525319/ . CC BY 2.0.
- User:ALM scientist/Wikipedia. http://en.wikipedia.org/wiki/File:Kehora_Salt_Cave.jpg . Public Domain.

11.5 References

1. User:Woudloper/Woodwalker; modified by CK-12 Foundation. The Rock Cycle . Public Domain
2. Leon Brooks. http://commons.wikimedia.org/wiki/File:Balancing_rock_at_castle_rock_porongurup.jpg . Public Domain
3. Courtesy of the U.S. Geological Survey. http://commons.wikimedia.org/wiki/File:Aa_large.jpg . Public Domain
4. Kevin Walsh (Flickr:kevinzim). http://www.flickr.com/photos/86624586@N00/17086401/ . CC BY 2.0
5. Charles de Mille-Isles. http://www.flickr.com/photos/46639194@N05/6433049943 . CC BY 2.0
6. Mark A. Wilson. http://commons.wikimedia.org/wiki/File:GraniteElephant.jpg . Public Domain
7. Jon Sullivan. http://commons.wikimedia.org/wiki/File:Yosemite_Valley_with_Half_Dome_in_the_distance.jpg . Public Domain
8. (A) Image copyright MARGRIT HIRSCH, 2013; (B) Image copyright Tyler Boyes, 2013; (C) Mark A. Wilson (Department of Geology, The College of Wooster); (D) Image copyright Marcin Sylwia Ciesielski, 2013. (A, B, D) http://www.shutterstock.com; (C) http://commons.wikimedia.org/wiki/File:GabbroRockCreek1.jpghttp://www.flickr.com/photos/jsjgeology/8455579081/ . (A, B, D) Used under licenses from Shutterstock.com; (C) Public domain
9. (A) Courtesy of the US Geological Survey; (B) Flickr:SonoranDesertNPS. (A) http://commons.wikimedia.org/wiki/File:Pahoeoe_fountain_edit2.jpg; (B) http://www.flickr.com/photos/65466304@N04/6127118377/ . (A) Public Domain; (B) CC BY 2.0
10. (A, B) James St. John (Flickr:jsj1771); (C) Courtesy of the US Geological Survey; (D) User:GeoRanger/Wikipedia. (A) http://www.flickr.com/photos/jsjgeology/8456708386/; (B) http://www.flickr.com/photos/jsjgeology/8455600595/; (C) http://commons.wikimedia.org/wiki/File:BasaltUSGOV.jpg; (D) http://commons.wikimedia.org/wiki/File:KomatiiteCanada_682By512.jpg . (A, B) Used under license from Shutterstock.com; (C, D) Public Domain
11. David McSpadden. http://www.flickr.com/photos/familyclan/8847886370/ . CC BY 2.0
12. Steve Dunleavy. http://www.flickr.com/photos/stevedunleavy/5126762996/ . CC BY 2.0
13. Steven Depolo. http://www.flickr.com/photos/stevendepolo/3902888070/ . CC BY 2.0
14. (A) User:Fed/Ru.Wikipedia; (B) Flickr:CoreForce. (A) http://commons.wikimedia.org/wiki/File:Hornfels.jpg; (B) http://commons.wikimedia.org/wiki/File:East_Face.jpg . (A) Public Domain; (B) CC BY 2.0
15. (A) Image copyright katatonia82, 2013; (B) Renee French. (A) http://www.shutterstock.com; (B) CK-12 Foundation . (A) Used under license from Shutterstock.com; (B) CC BY-NC 3.0
16. (A) Courtesy of the US Geological Survey and the Mineral Information Institute; (B) User:Prasenberg/Wikipedia. (A) http://commons.wikimedia.org/wiki/File:MarbleUSGOV.jpg; (B) http://commons.wikimedia.org/wiki/File:Moses_San_Pietro_in_Vincoli.jpg . (A) Public Domain; (B) CC BY 2.0

CHAPTER 12 Plate Tectonics: Review

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.

12.1 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** 12.1). 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.

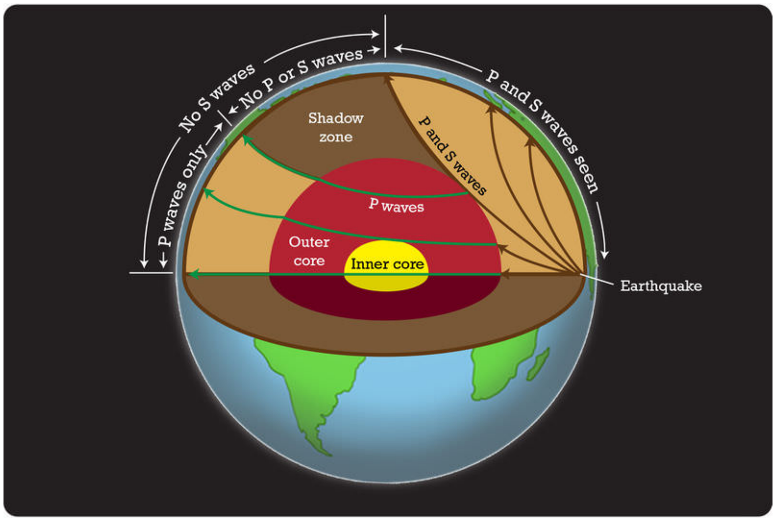


FIGURE 12.1
The properties of seismic waves allow scientists to understand the composition of Earth's interior.

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** 12.2). An iron meteorite is the closest thing to a sample of the core that scientists can hold in their hands!

FIGURE 12.2
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** 12.3). 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.

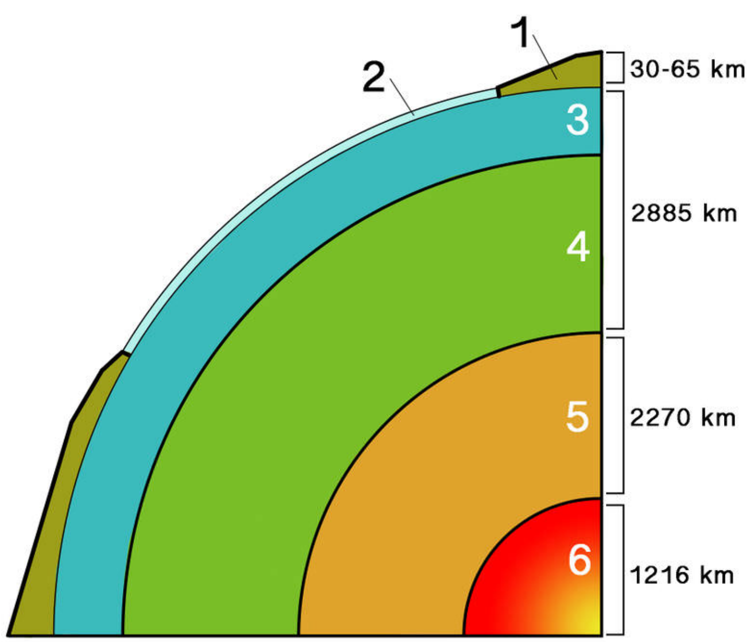


FIGURE 12.3
A cross-section of Earth showing the following layers: (1) continental crust, (2) oceanic crust, (3) upper mantle, (4) lower mantle, (5) outer core, (6) inner core.

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** 12.4). The lower mantle is heated directly by conduction from the core.

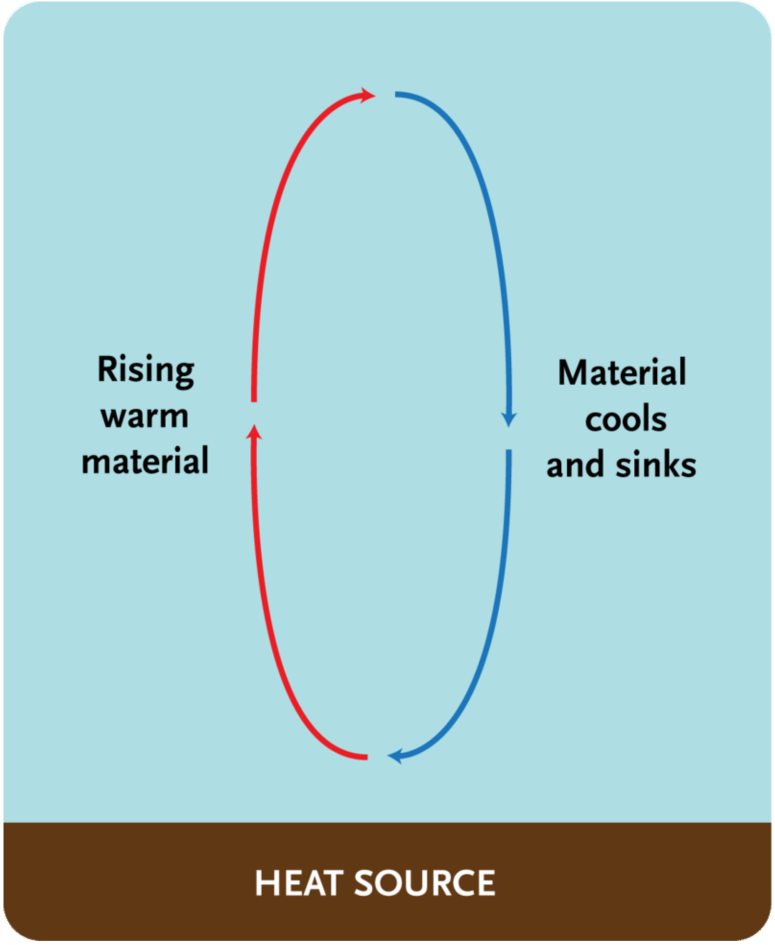


FIGURE 12.4
How a convection cell is formed in the mantle.

Hot lower mantle material rises upwards (**Figure** 12.5). 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.

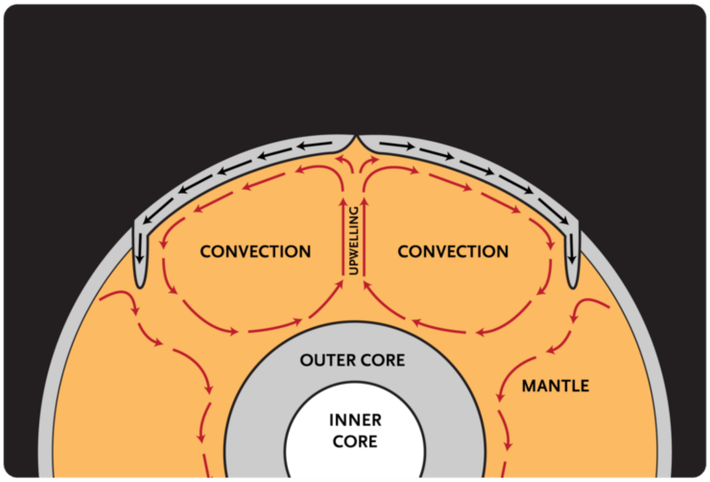


FIGURE 12.5
The rising and sinking of mantle material of different temperatures and densities creates a convection cell.

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?

12.2 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** 12.6). This idea is called continental drift.

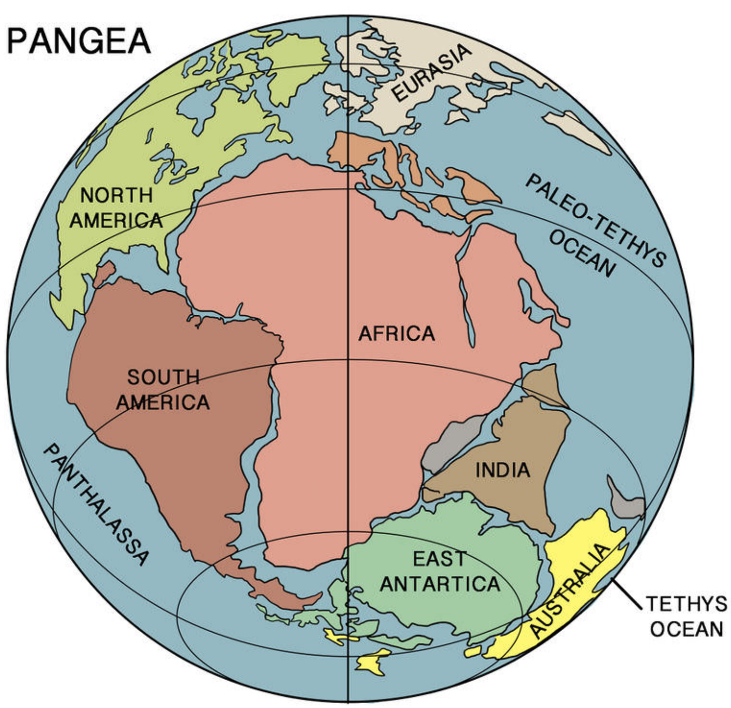


FIGURE 12.6
The supercontinent Pangaea contained all of the modern day continents.

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** 12.7). 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.

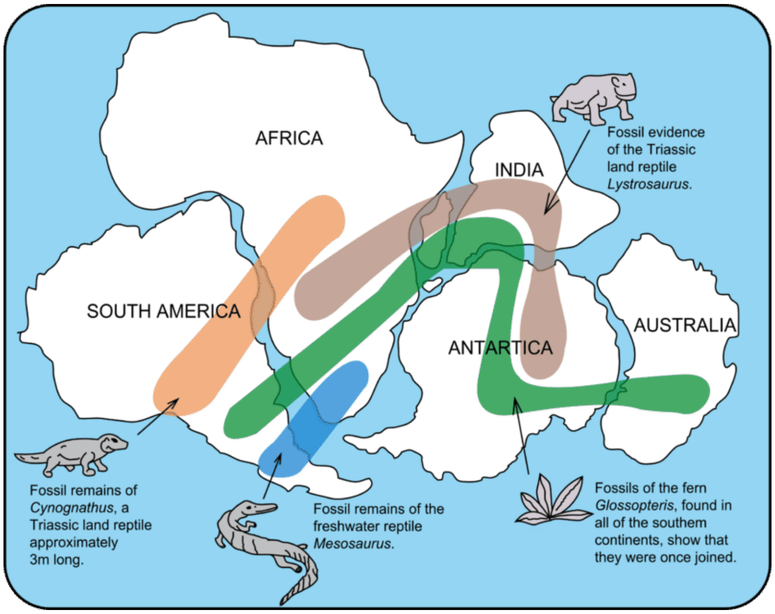


FIGURE 12.7
Wegener used fossil evidence to support his continental drift hypothesis. The fossils of these organisms are found on lands that are now far apart. Wegener suggested that when the organisms were alive, the lands were joined and the organisms were living side-by-side.

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** 12.8).

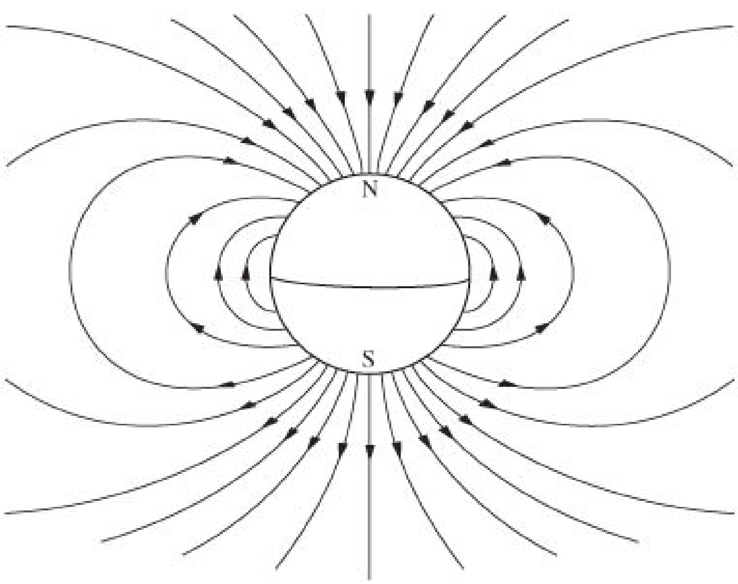


FIGURE 12.8
Earth's magnetic field is like a magnet with its north pole near the geographic north pole and the south pole near the geographic south pole.

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

12.3 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** 12.9). **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** 12.10).

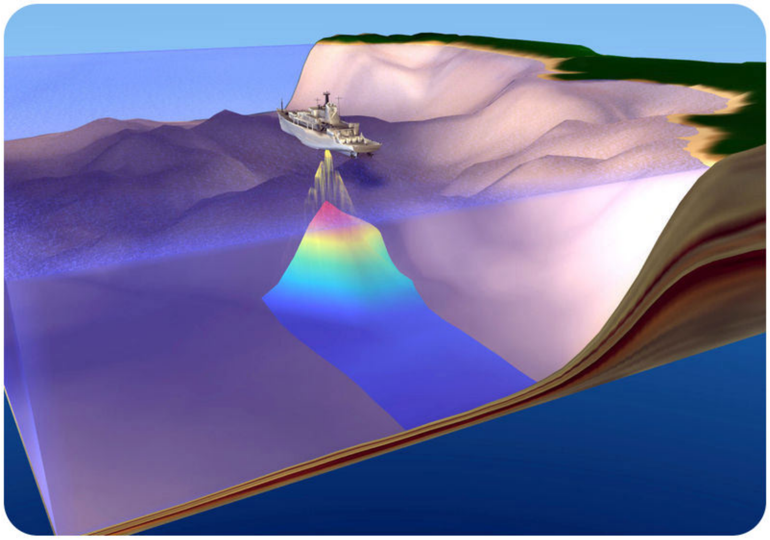


FIGURE 12.9

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.

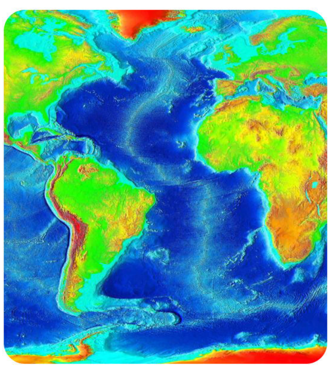


FIGURE 12.10

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** 12.11).

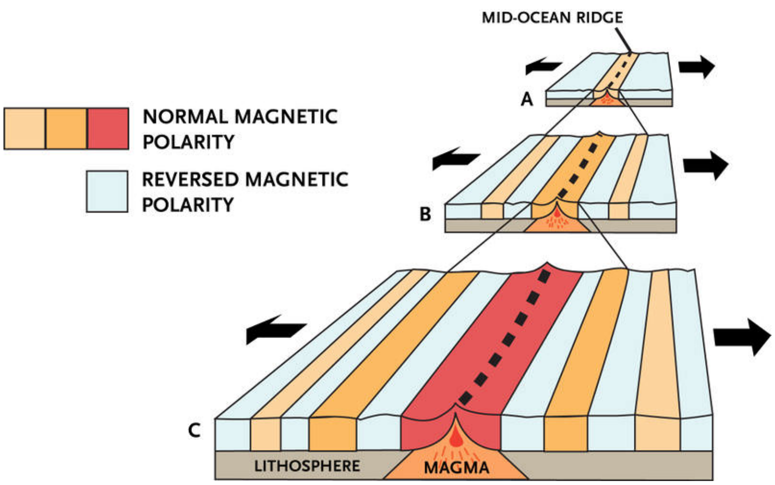


FIGURE 12.11
Scientists found that magnetic polarity in the seafloor was normal at mid-ocean ridges but reversed in symmetrical patterns away from the ridge center. This normal and reversed pattern continues across the seafloor.

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** 12.12). 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!

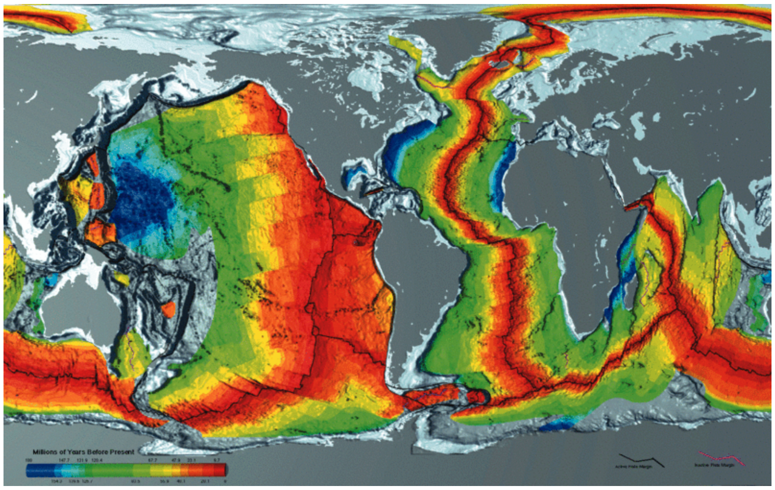


FIGURE 12.12
Seafloor is youngest near the mid-ocean ridges and gets progressively older with distance from the ridge. Orange areas show the youngest seafloor. The oldest seafloor is near the edges of continents or deep sea trenches.

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 hadn'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.

12.4 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** 12.13). Earthquakes are also common in the world's highest mountains, the Himalaya Mountains of Asia. The Mediterranean Sea also has many earthquakes.

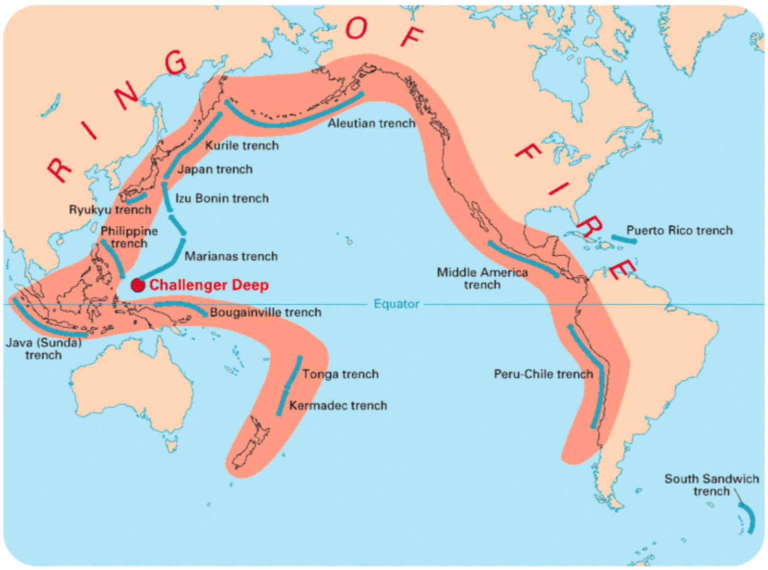


FIGURE 12.13
The Ring of Fire that circles the Pacific Ocean is where the most earthquakes and volcanic eruptions take place.

Earthquakes and Plate Boundaries

Earthquakes are used to identify plate boundaries (**Figure** 12.14). When earthquake locations are put on a map, they outline the **plates**. The movements of the plates are called plate tectonics.

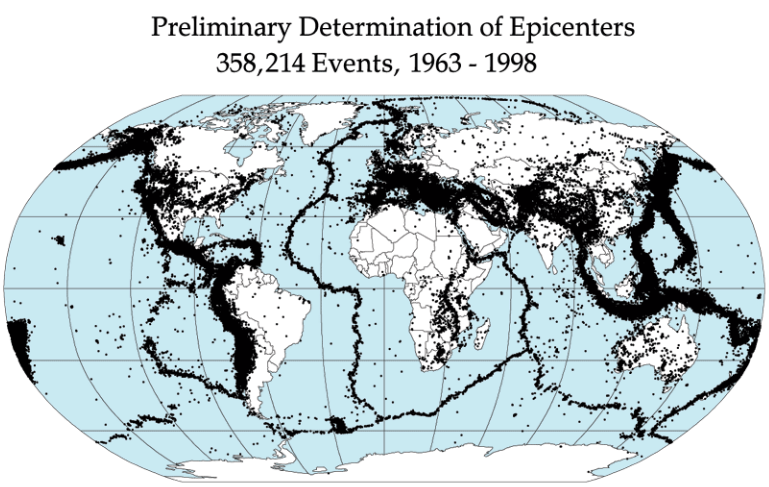


FIGURE 12.14
A map of earthquake epicenters shows that earthquakes are found primarily in lines that run up the edges of some continents, through the centers of some oceans, and in patches in some land areas.

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** 12.15). Plates move around the Earth's surface at a rate of a few centimeters a year. This is about the same rate fingernails grow.

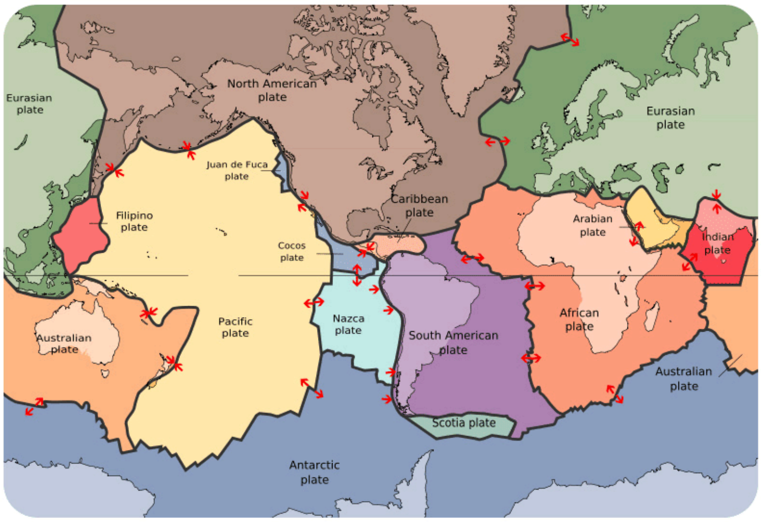


FIGURE 12.15
Earth's plates are shown in different colors. Arrows show the direction the plate is moving.

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** 12.16). 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.

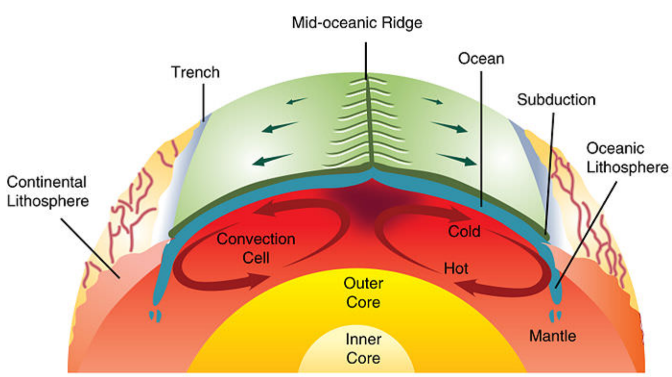


FIGURE 12.16
Plates move for two reasons. Upwelling mantle at the mid-ocean ridge pushes plates outward. Cold lithosphere sinking into the mantle at a subduction zone pulls the rest of the plate down with it.

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** 12.17).

FIGURE 12.17
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** 12.18). 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 12.18

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** 12.19). **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** 12.20).

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** 12.21). Japan, Indonesia, the Philippine Islands, and the Aleutian Islands of Alaska are examples of island arcs (**Figure** 12.22).

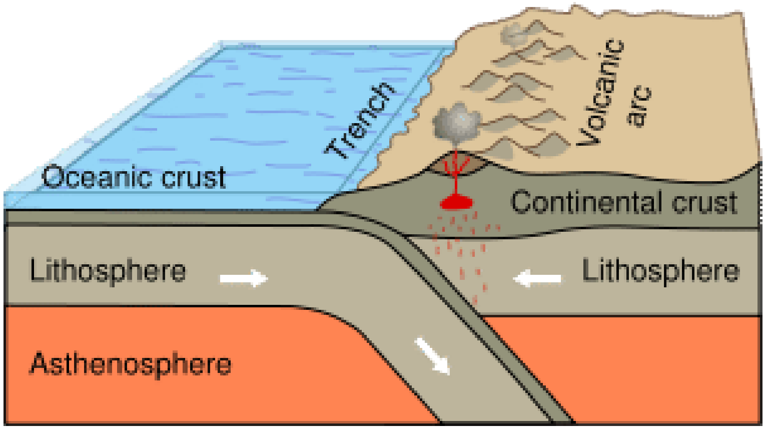


FIGURE 12.19
Subduction of an oceanic plate beneath a continental plate forms a line of volcanoes known as a continental arc and causes earthquakes.

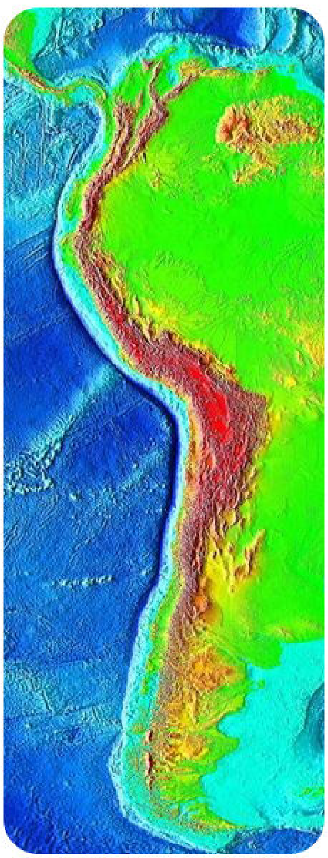


FIGURE 12.20
A relief map of South America shows the trench west of the continent. The Andes Mountains line the western edge of South America.

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** 12.23)! 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.

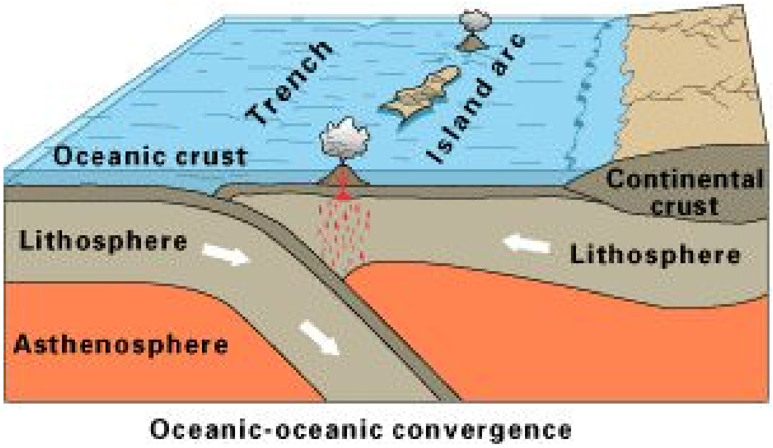


FIGURE 12.21
A convergent plate boundary subduction zone between two plates of oceanic lithosphere. Melting of the subducting plate causes volcanic activity and earthquakes.

FIGURE 12.22
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** 12.24) 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.

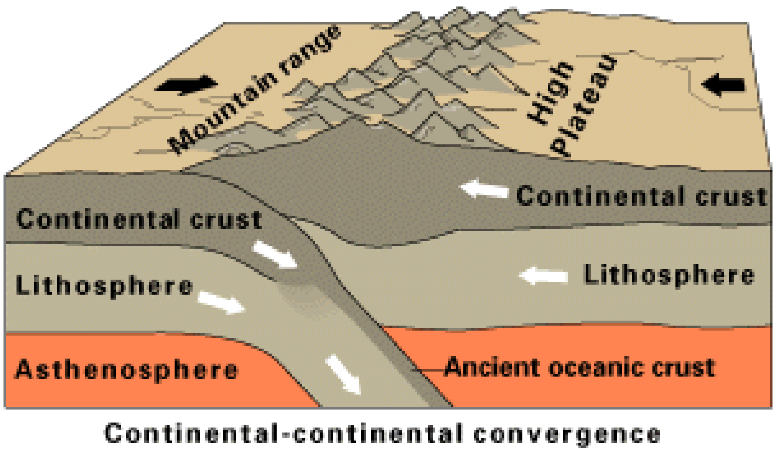


FIGURE 12.23
When two plates of continental crust collide, the material pushes upward, forming a high mountain range. The remnants of subducted oceanic crust remain beneath the continental convergence zone.

FIGURE 12.24
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** 12.25). 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.

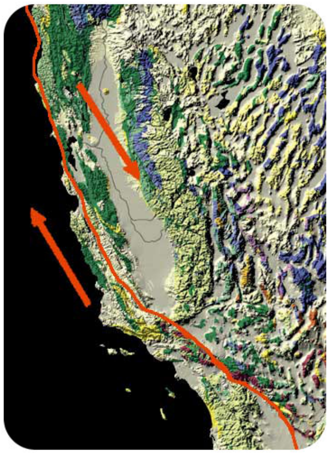


FIGURE 12.25
The red line is the San Andreas Fault. On the left is the Pacific Plate, which is moving northeast. On the right is the North American Plate, which is moving southwest. The movement of the plates is relative to each other.

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** 12.26)! 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 12.26
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** 12.27).

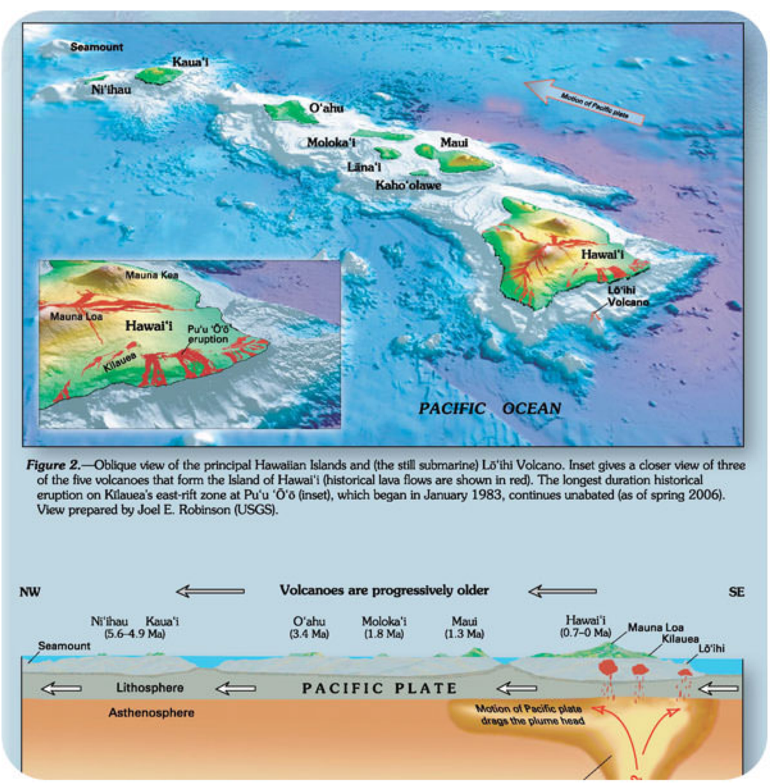


FIGURE 12.27
This view of the Hawaiian islands shows the youngest islands in the southeast and the oldest in the northwest. Kilauea volcano, which makes up the southeastern side of the Big Island of Hawaii, is located above the Hawaiian hotspot.

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

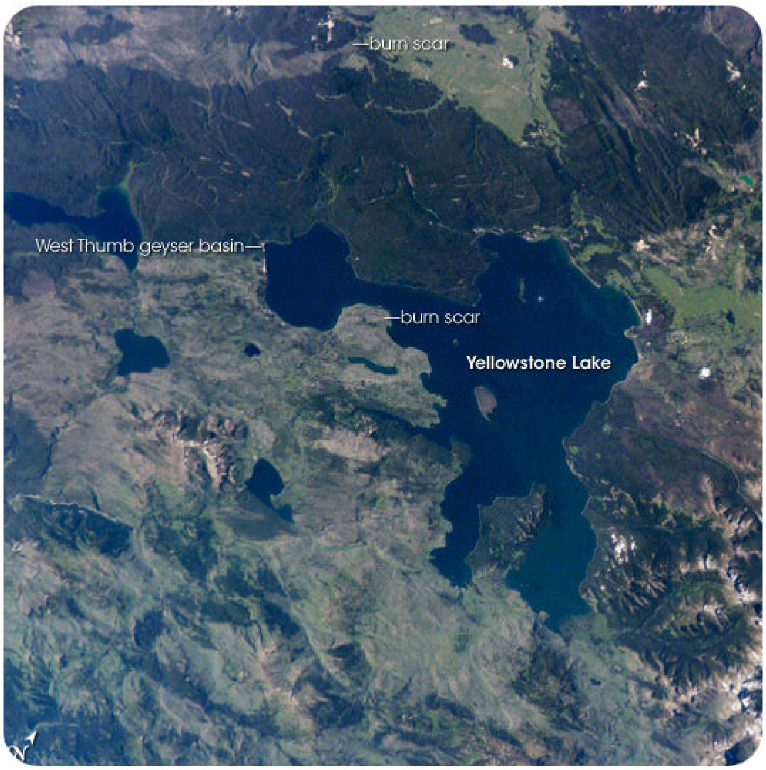


FIGURE 12.28
Yellowstone Lake lies at the center of a giant caldera. This hole in the ground was created by enormous eruptions at the Yellowstone hotspot. The hotspot lies beneath Yellowstone National Park.

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** 12.28). 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** 12.15, 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?

12.5 References

1. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
2. Flickr:herval. http://commons.wikimedia.org/wiki/File:Willamette_meteorite_AMNH.jpg . CC BY 2.0
3. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
4. Christopher Auyeung. CK-12 Foundation .
5. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
6. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
7. Courtesy of the US Geological Survey, User:Osvaldocangaspadilla/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Snider-Pellegrini_Wegener_fossil_map.svg . Public Domain
8. Courtesy of the US Geological Survey, User:Heron/Wikipedia, and User:Kevin Saff/Wikipedia. http://commons.wikimedia.org/wiki/File:Dipole_field.jpg . Public Domain
9. Courtesy of United States Navy. http://www.navy.mil/view_image.asp?id=2767 . Public Domain
10. Courtesy of NOAA. http://www.ngdc.noaa.gov/mgg/image/2minrelief.html . Public Domain
11. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
12. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Earth_seafloor_crust_age_1996.gif . Public Domain
13. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Pacific_Ring_of_Fire.png . Public Domain
14. Courtesy of NASA. http://commons.wikimedia.org/wiki/Image:Quake_epicenters_1963-98.png . Public Domain
15. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Plates_tect2_en.svg . Public Domain
16. CK-12 Foundation. . CC BY-NC 3.0
17. User:Mangwanani/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Mid_Atlantic_Ridge.jpg . Public Domain
18. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Greatrift.jpg . Public Domain
19. User:Booyabazooka/Wikipedia. http://commons.wikimedia.org/wiki/File:Active_Margin.svg . Public Domain
20. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Peru-Chile_trench.jpg . Public Domain
21. User:Booyabazooka/Wikipedia. http://commons.wikimedia.org/wiki/File:Active_Margin.svg . Public Domain
22. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Aleutians-space.jpg . Public Domain
23. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Continental-continental_convergence_Fig21contcont.gif . Public Domain
24. Maria Ly (Flickr:mariachily). http://www.flickr.com/photos/mariachily/3330744786/ . CC BY 2.0
25. Courtesy of Kate Barton, David Howell, Joe Vigil, US Geological Survey. http://commons.wikimedia.org/wiki/File:Sanandreas.jpg . Public Domain
26. Bryan Pocius. http://www.flickr.com/photos/pocius/5792332417/ . CC BY 2.0
27. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Hawaii_hotspot_poster.jpg . Public Domain
28. Courtesy of NASA Earth Observatory. http://earthobservatory.nasa.gov/IOTD/view.php?id=5816 . Public Domain

CHAPTER 13 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.

George Lawrence. commons.wikimedia.org/wiki/File:6a34659r.jpg. Public Domain.

13.1 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** 13.1). When two cars collide, compression causes them to crumple. Compression is the most common stress at convergent plate boundaries.

FIGURE 13.1

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** 13.2). 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** 13.3). 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** 13.4). The lowest layers are the oldest and the higher layers are younger.

Folds, joints and faults are caused by stresses. **Figure** 13.5 shows joints in a granite hillside.

If a sedimentary rock is tilted or folded, we know that stresses have changed the rock (**Figure** 13.6).

FIGURE 13.2
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.

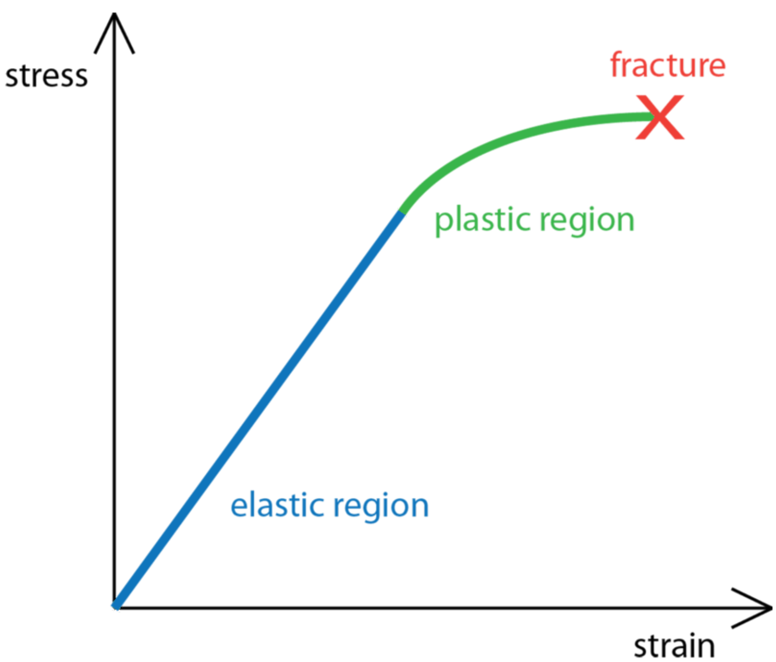


FIGURE 13.3
With increasing stress, the rock deforms and may eventually fracture.

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** 13.6, 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** 13.7). In a monocline, the oldest rocks are still at the bottom and the youngest are at the top.

FIGURE 13.4
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.

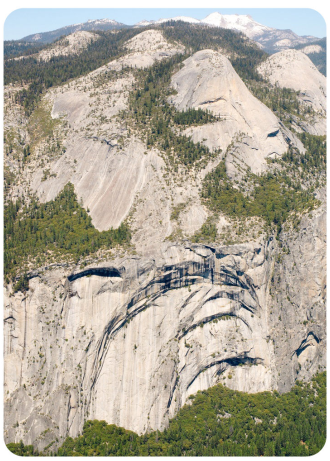


FIGURE 13.5
Joints in this granite created a zone of weakness. The rock below the joints fell, leaving scars in this hillside.

An **anticline** is a fold that arches upward. The rocks dip away from the center of the fold (**Figure** 13.8). The oldest 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** 13.9). 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** 13.10.

If the rocks on one or both sides of a fracture move, the fracture is called a **fault** (**Figure** 13.11). 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.

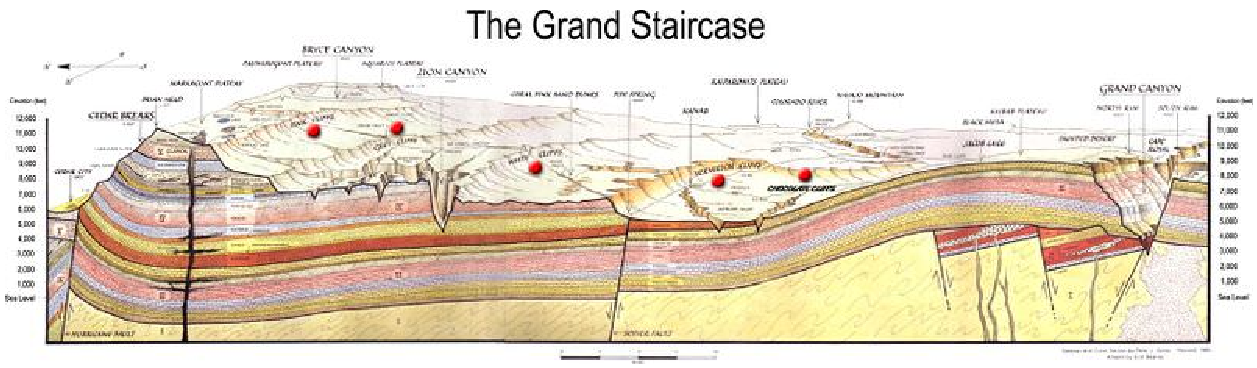


FIGURE 13.6
This is a geologic cross section of the Grand Staircase in Utah. A small fold, called an syncline, is revealed at the left of the diagram.

FIGURE 13.7
The rock layers in the center right are tilted in one direction, forming a monocline.

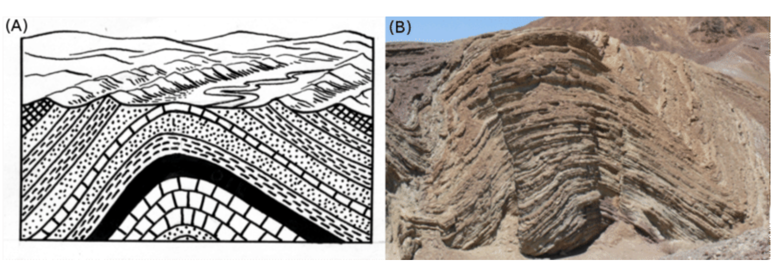


FIGURE 13.8
An anticline is a convex upward fold, as shown in (A). An anticline is well displayed in (B), which was taken at Calico Ghost Town, California.

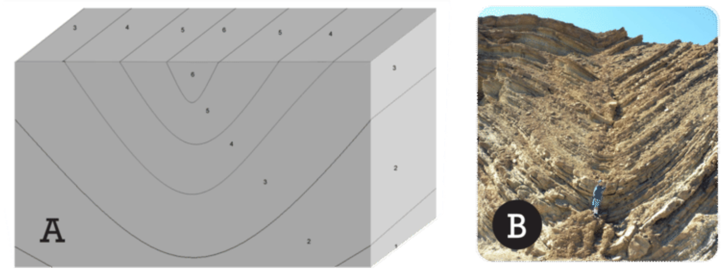


FIGURE 13.9
(A) A syncline is a concave downward fold. (B) This syncline is seen at Calico Ghost Town near Barstow, California.

FIGURE 13.10
Joints in boulders in the Arizona desert. The rock on either side of the joints has not moved.

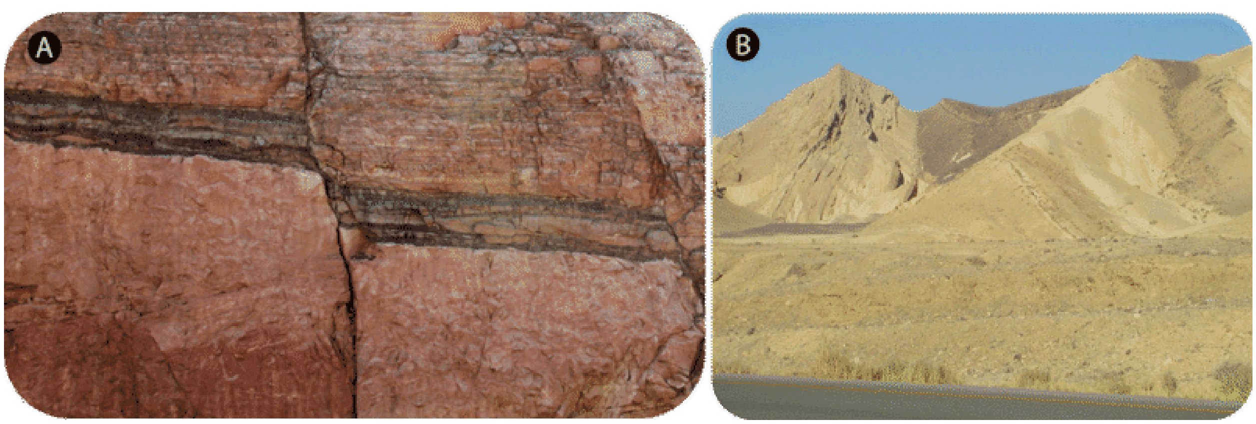


FIGURE 13.11
(A) This image shows a small fault. The black rock layer is not a line because a fault has broken it. Rock on each side of the fault has moved. (B) A large fault runs between the lighter colored rock on the left and the darker colored rock on the right. There has been so much movement along the fault that the darker rock doesn't resemble anything around it.

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 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** 13.12).

FIGURE 13.12
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** 13.13).

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** 13.14).

San Andreas Fault

The San Andreas Fault in California is a right-lateral strike-slip fault (**Figure** 13.15). 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!

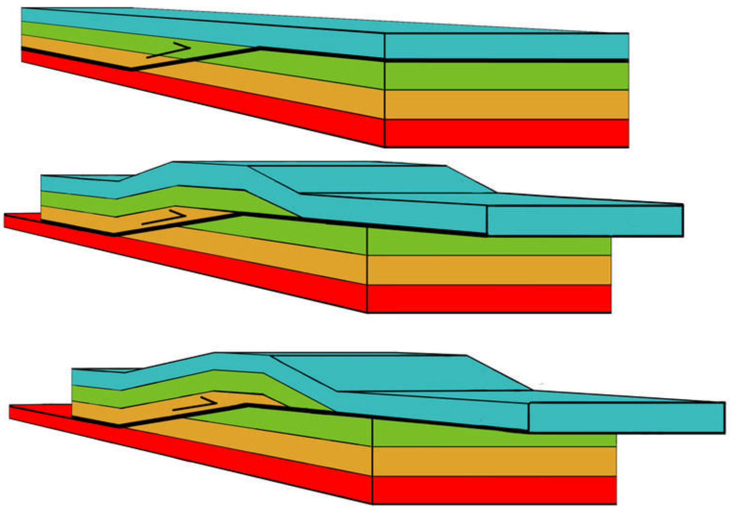


FIGURE 13.13
In this thrust fault, the rock on the left is thrust over the rock on the right.

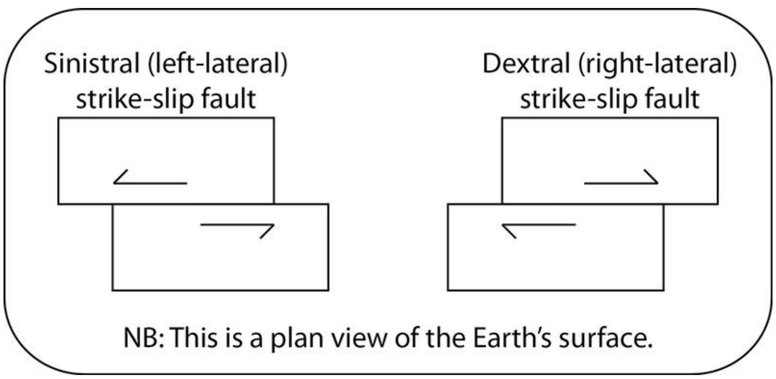


FIGURE 13.14
Diagram of strike-slip faults.

FIGURE 13.15
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** 13.16). 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** 13.17).

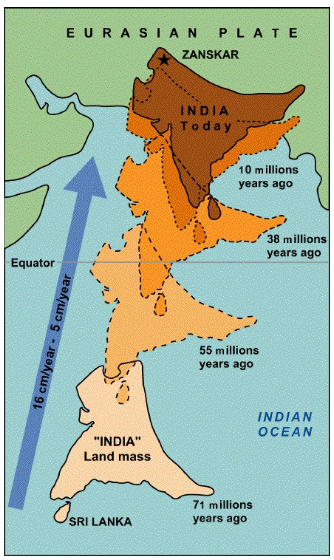


FIGURE 13.16
As India rams into Eurasia, the Himalaya Mountains rise.

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** 13.18).

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

FIGURE 13.17
The Himalayas.

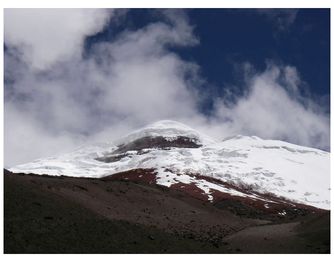


FIGURE 13.18
Cotopaxi is in the Andes Mountains of Ecuador. The 19,300 foot tall mountain is the highest active volcano in the world.

basin-and-range (**Figure** 13.19). The area near Death Valley, California is the center of a classic basin-and-range province (**Figure** 13.20).

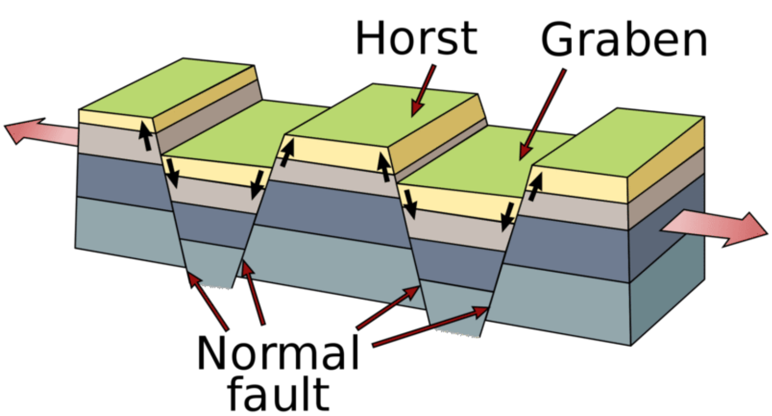


FIGURE 13.19
This diagram shows how a basin-and-range forms.

FIGURE 13.20
This photograph was taken from a basin with a range in the distance near Death Valley, California.

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.
- 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?

13.2 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** 13.21).

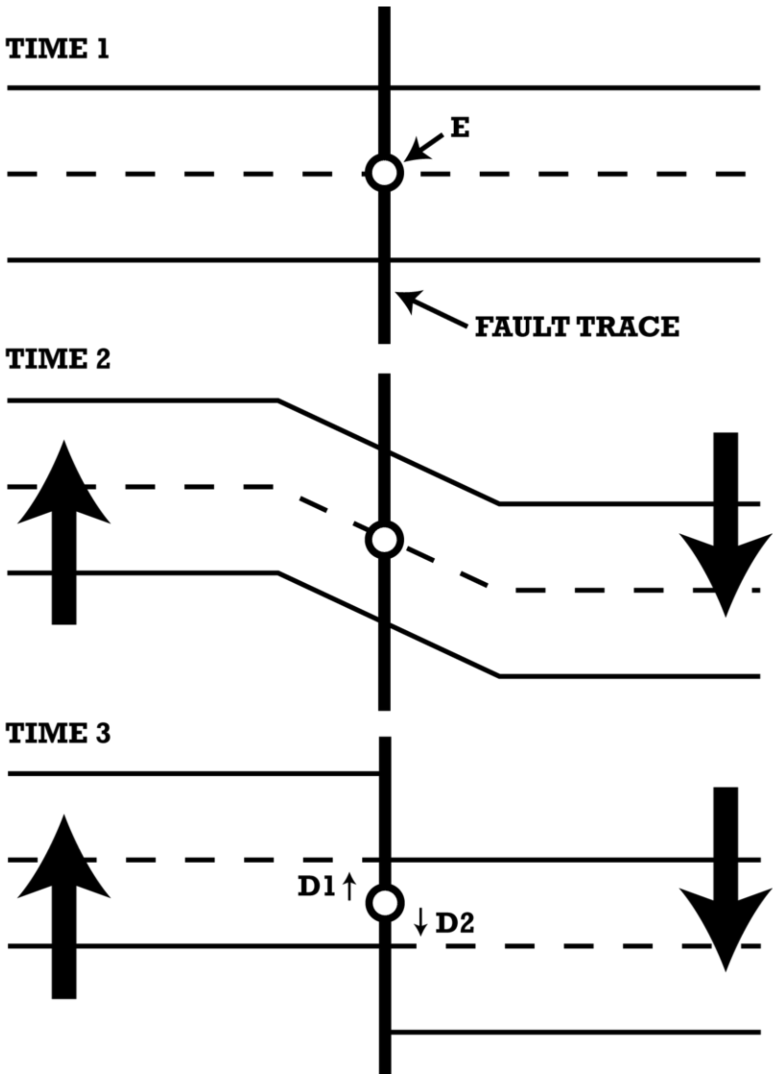


FIGURE 13.21

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** 13.22). The towns or cities near the epicenter will be strongly affected by the earthquake.

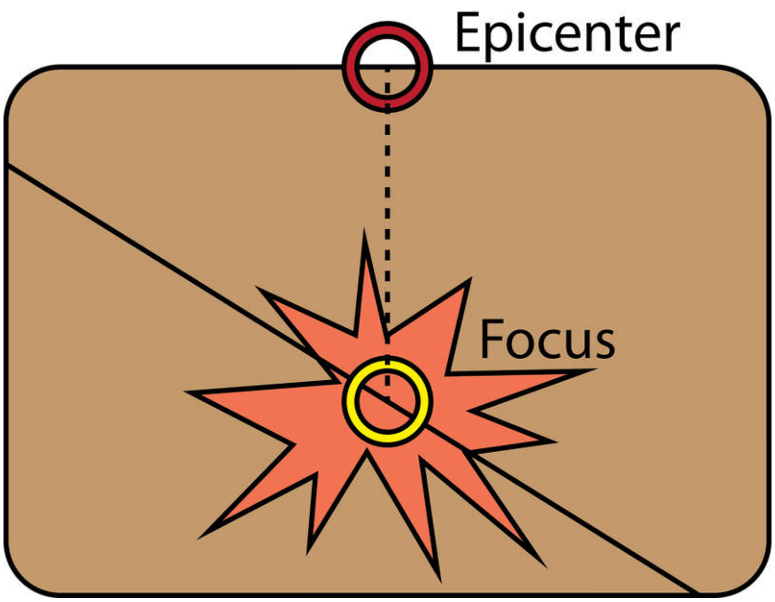


FIGURE 13.22
The focus of an earthquake is in the ground where the ground breaks. The epicenter is the point at the surface just above the focus.

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** 13.23) 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** 13.24). While most of those earthquakes cannot even be felt by people nearby, occasionally one is very strong.

FIGURE 13.23
Three people died in this mall in Santa Cruz during the 1989 Loma Prieta earthquake.

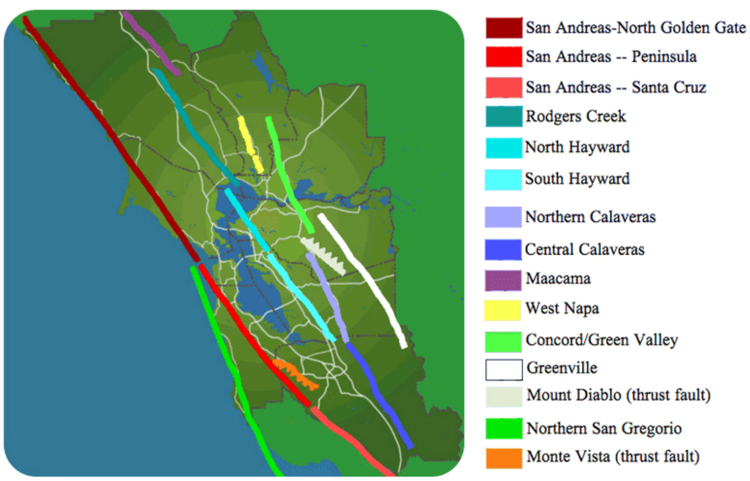


FIGURE 13.24
The San Andreas Fault runs through the San Francisco Bay Area. Other related faults cross the region. Lines indicate strike slip faults. Lines with hatches are thrust faults.

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** 13.25). 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 13.25
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** 13.26). 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.

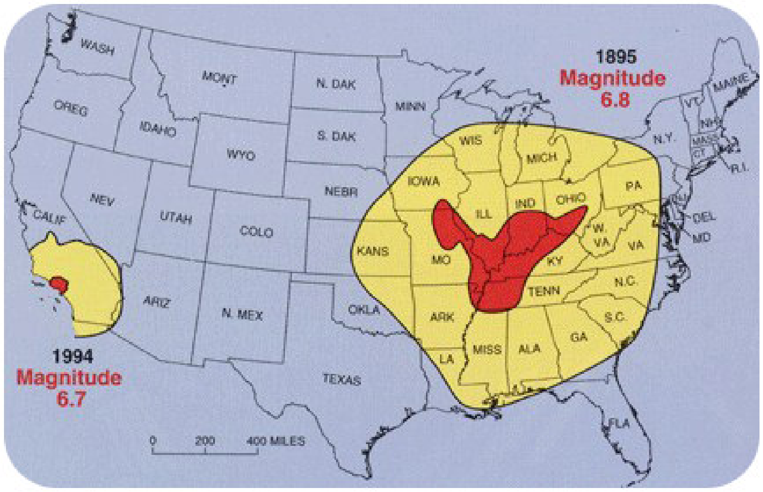


FIGURE 13.26
The range of damage in the 1895 New Madrid earthquake and the 1994 Los Angeles earthquake. New Madrid activity affected a much larger area.

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** 13.27).

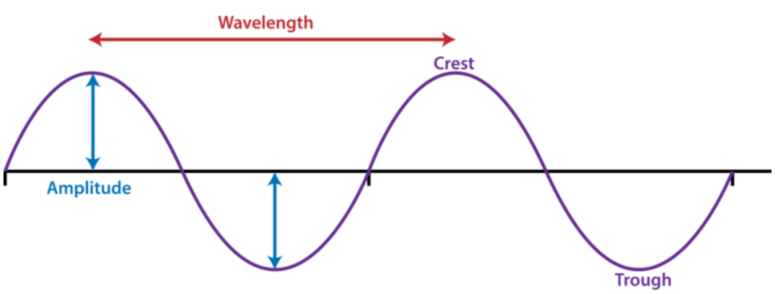


FIGURE 13.27
The energy from earthquakes travels in waves, such as the one shown in this diagram.

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** 13.28). 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.

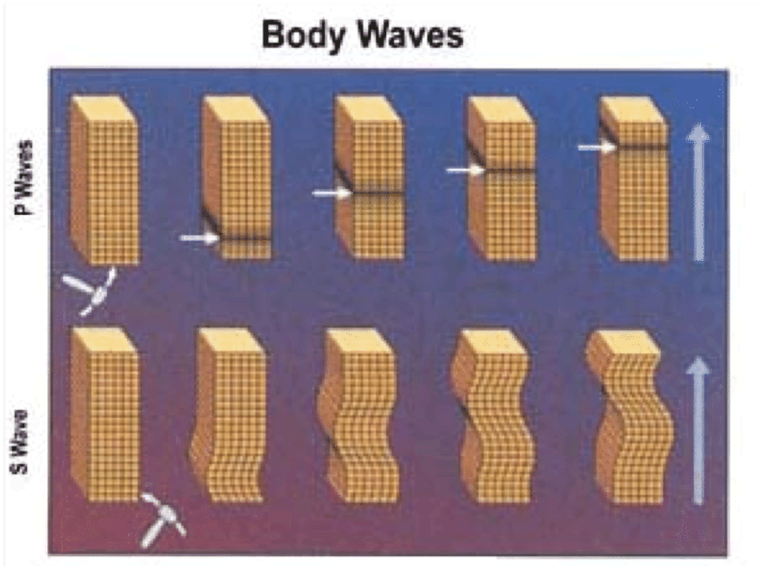


FIGURE 13.28
P-waves and S-waves are the two types of body waves.

Surface Waves

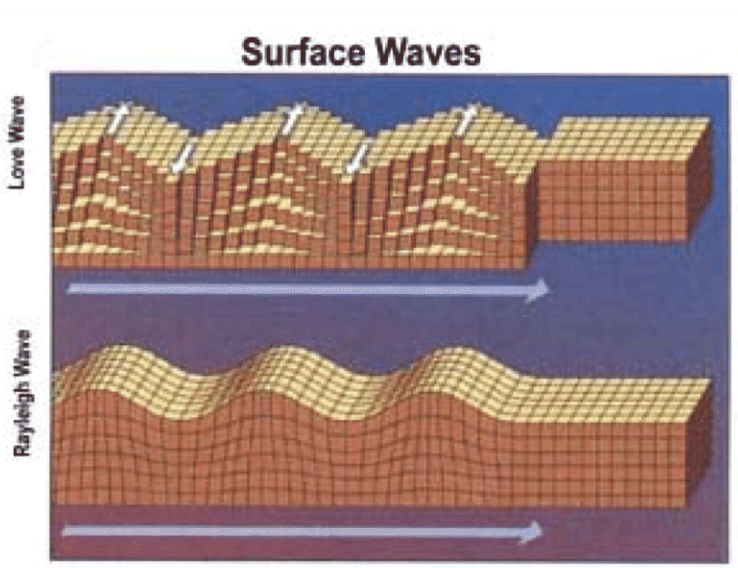


FIGURE 13.29
Love waves and Rayleigh waves are the two types of surface waves.

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** 13.29). 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** 13.30). 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 13.30
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** 13.31).

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

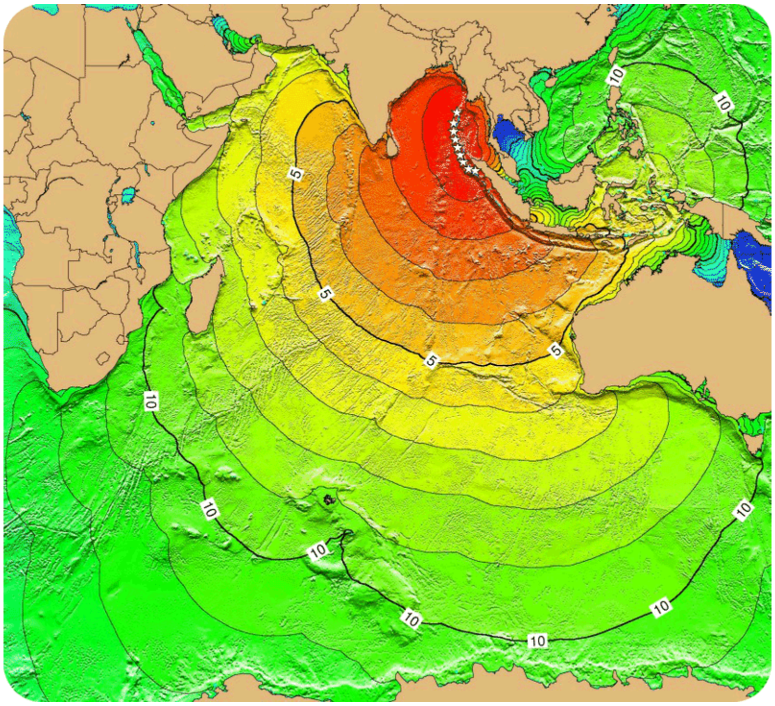


FIGURE 13.31
Travel time map for the Boxing Day Tsunami (in hours). Countries near red, orange, and yellow areas were affected the most.

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** 13.32). 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 13.32
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?

13.3 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** 13.33).

Modern seismographs record ground motions using electronic motion detectors. The data are recorded digitally on a computer.

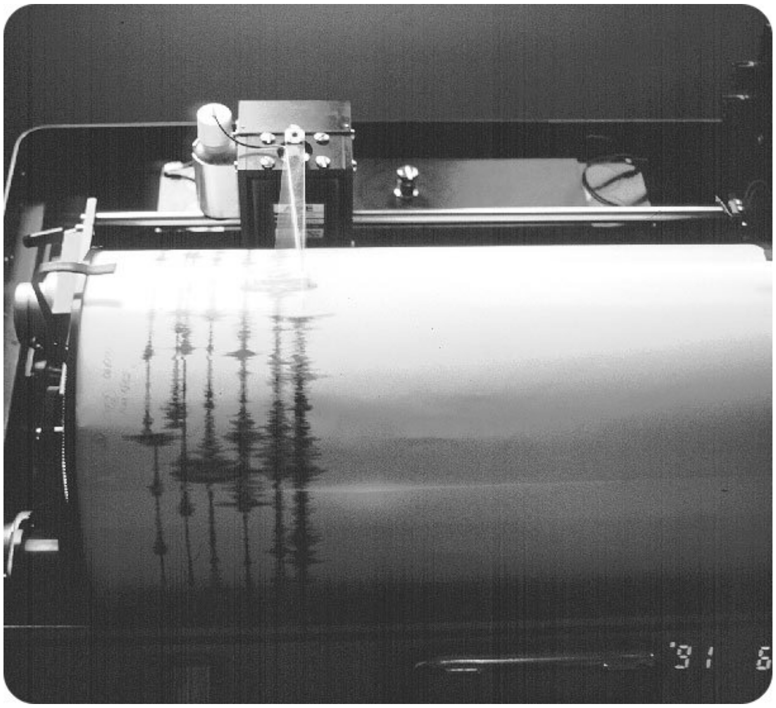


FIGURE 13.33
This seismograph records seismic waves.

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** 13.34). 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.

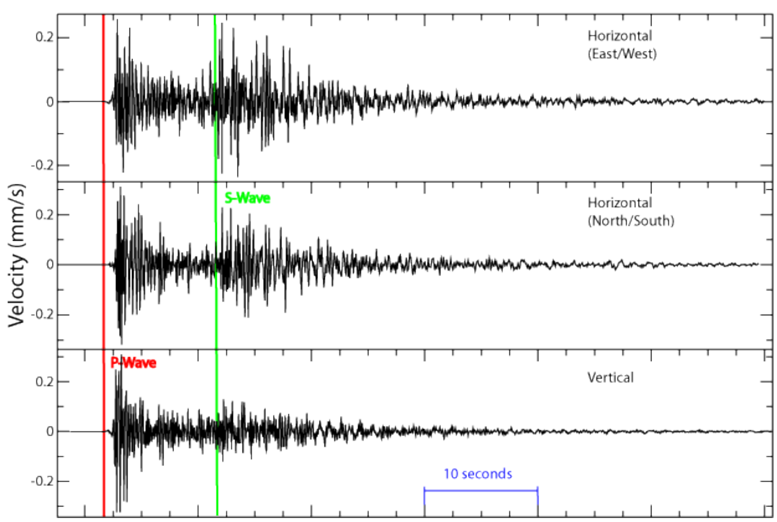


FIGURE 13.34
These seismograms show the arrival of P-waves and S-waves.

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** 13.35).

FIGURE 13.35
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** 13.36). 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** 13.37). 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 13.36
Earthquake and tsunami damage in Japan, 2011. The Tōhoku earthquake had a magnitude of 9.0.

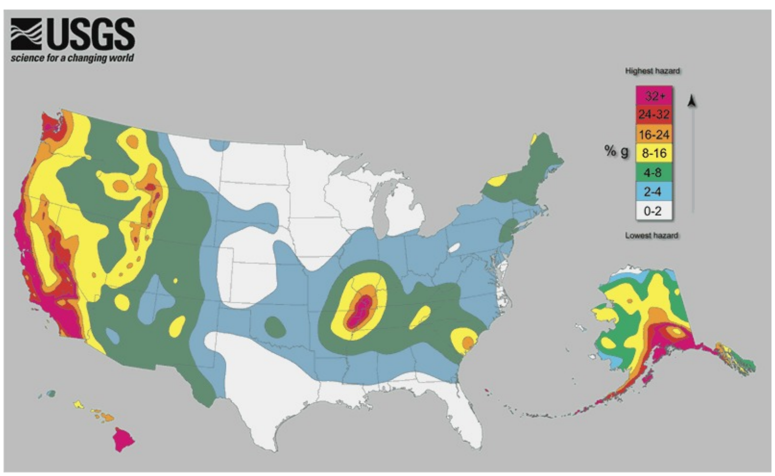


FIGURE 13.37
This map shows earthquake probability regions in the United States.

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?

13.4 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** 13.38). 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.

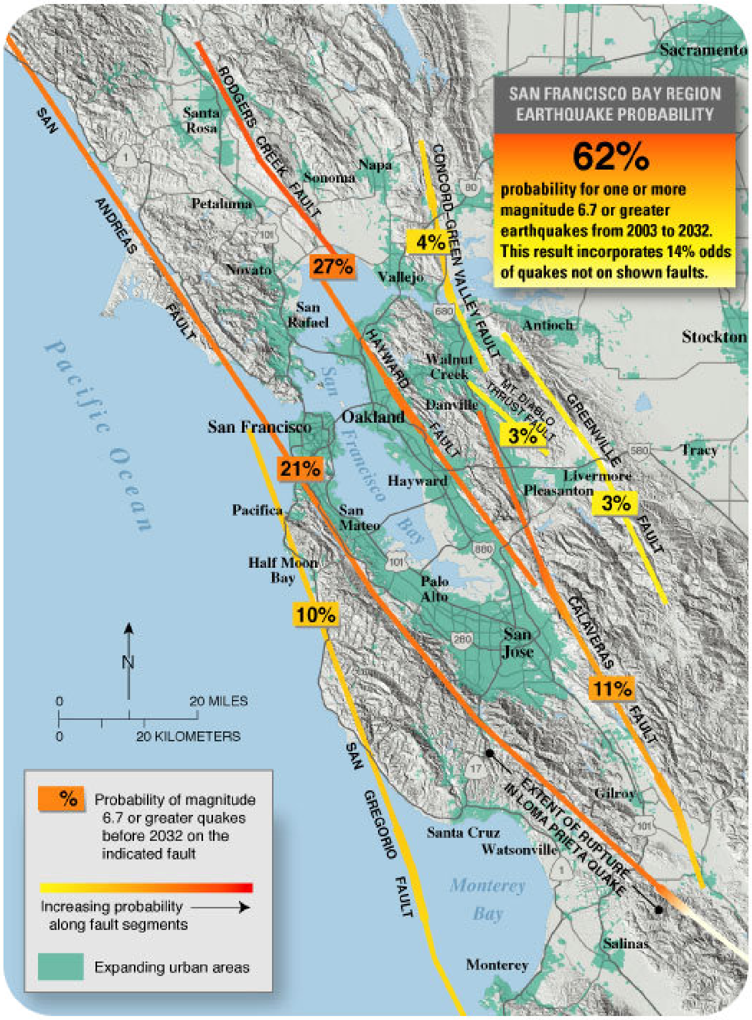


FIGURE 13.38

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** 13.39).

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** 13.40). 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 13.39
Mexico City suffers tremendously in earthquakes because it is built on an old lake bed. In 1985 many buildings collapsed.

FIGURE 13.40
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** 13.41).

FIGURE 13.41
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** 13.42). 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 13.42
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?

13.5 References

1. Ryan Dickey (Flickr:Wallula Junction). http://www.flickr.com/photos/meesterdickey/2075201884/ . CC BY 2.0
2. Roland Gotthard. http://commons.wikimedia.org/wiki/File:Asymmetric_shear.jpg . Public Domain
3. Jodi So. CK-12 Foundation . CC BY-NC 3.0
4. Wolfgang Staudt. http://commons.wikimedia.org/wiki/File:Grand_Staircase-Escalante_National_Monument_-%282279640905%29.jpg . CC BY 2.0
5. Image copyright Zack Frank, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
6. Courtesy of National Park Service. http://commons.wikimedia.org/wiki/File:Grand_Staircase-big.jpg . Public Domain
7. User:Jstuby/Wikipedia. http://commons.wikimedia.org/wiki/File:Grandview-Phantom_Monocline.jpg . Public Domain
8. (A) Pearson Scott Foresman; (B) Flickr:woosh2007. (A) http://commons.wikimedia.org/wiki/File:Anticline_(PSF).png; (B) http://www.flickr.com/photos/manea/2995252828/ . (A) Public Domain; (B) CC BY 2.0
9. (A) User:Jonathan3784/Wikipedia; (B) Mark A. Wilson (Department of Geology, The College of Wooster). (A) http://commons.wikimedia.org/wiki/File:Syncline.gif; (B) http://commons.wikimedia.org/wiki/File:SynclineCalico.JPG . Public Domain
10. Image copyright Paul Matthew Photography, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
11. (A) Roy Luck; (B) Mark A. Wilson (Department of Geology, The College of Wooster). (A) http://www.flickr.com/photos/royluck/6206254956/; (B) http://commons.wikimedia.org/wiki/File:RamonFault1.JPG . (A) CC BY 2.0; (B) Public Domain
12. John Sullivan, PD Photo. http://commons.wikimedia.org/wiki/File:Barns_grand_tetons.jpg . Public Domain
13. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
14. Jodi So. CK-12 Foundation . CC BY-NC 3.0
15. Courtesy of Robert E. Wallace, USGS. http://pubs.usgs.gov/gip/dynamic/San_Andreas.html . Public Domain
16. Pierre Dèzes 1999, "Tectonic and metamorphic Evolution of the Central Himalayan Domain in Southeast Zanskar (Kashmir, India)". http://commons.wikimedia.org/wiki/File:India_71-0_Ma.gif . Author allows use for any purpose, provide reference is made to http://comp1.geol.unibas.ch/zanskar/
17. Flickr:ilkerender. http://www.flickr.com/photos/ilker/2493909927/ . CC BY 2.0
18. Rinaldo Wurglitsch (Flickr:Rinaldo W.). http://www.flickr.com/photos/wurglitsch/2128894200/ . CC BY 2.0
19. Courtesy of the US Geological Survey, User:Gregors/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Fault-Horst-Graben.svg . Public Domain
20. Image copyright kavram, 2013. http://www.shutterstock.com . Used under license from Shutterstock.com
21. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
22. Jodi So. CK-12 Foundation . CC BY-NC 3.0
23. Courtesy of C.E. Meyer, United States Geological Survey. http://commons.wikimedia.org/wiki/File:LomaPrieta-PacificGardenMall.jpeg . Public Domain
24. Courtesy of Association of Bay Area Governments, User:Leonard G./Wikipedia. http://commons.wikimedia.org/wiki/File:Flat_eq_map_anotated.png . Public Domain
25. Courtesy of Lance Cpl. Ethan Johnson, U.S. Marine Corps,. http://www.flickr.com/photos/usnavy/5567678289/ . CC BY 2.0
26. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:NMSZ_Vergleich.jpg . Public Domain
27. Raymond Chou. CK-12 Foundation . CC BY-NC 3.0
28. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Pswaves.jpg . Public Domain

29. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Pswaves.jpg . Public Domain
30. David Rydevik. http://commons.wikimedia.org/wiki/File:2004-tsunami.jpg . Public Domain
31. Courtesy of NOAA, NGDC. http://www.ngdc.noaa.gov/hazard/tsu_travel_time_events.shtml . Public Domain
32. Flickr:youngthousands. http://www.flickr.com/photos/theyoungthousands/2609041263/ . CC BY 2.0
33. Courtesy of R. P. Hoblitt, US Geological Survey. http://commons.wikimedia.org/wiki/File:Seismograph_Pinatubo.jpg . Public Domain
34. User:Crickett/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Seismogram.gif . The copyright holder of this work allows anyone to use it for any purpose including unrestricted redistribution, commercial use, and modification
35. CK-12 Foundation. . CC BY-NC 3.0
36. Courtesy of the US Navy. http://commons.wikimedia.org/wiki/File:Tsunami_damage_north_of_Sendai_1x1_resized.jpg . Public Domain
37. Courtesy of the US Geological Survey. http://earthquake.usgs.gov/hazards/about/basics.php . Public Domain
38. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Eq-prob.jpg . Public Domain
39. Courtesy of the US Geological Survey. http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Celebi,%20M.%2040ct&SIZE=medium . Public Domain
40. Courtesy of the National Oceanic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:Good_Friday_Earthquake_at_Turnagain_Arm.jpg . Public Domain
41. User:Leonard G./Wikimedia Commons. http://commons.wikimedia.org/wiki/File:TransamericaPyramidFromTI.jpg . Public Domain
42. Matthew Lew. CK-12 Foundation . CC BY-NC 3.0

CHAPTER 14 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.

14.1 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** 14.1 shows where volcanoes are located.

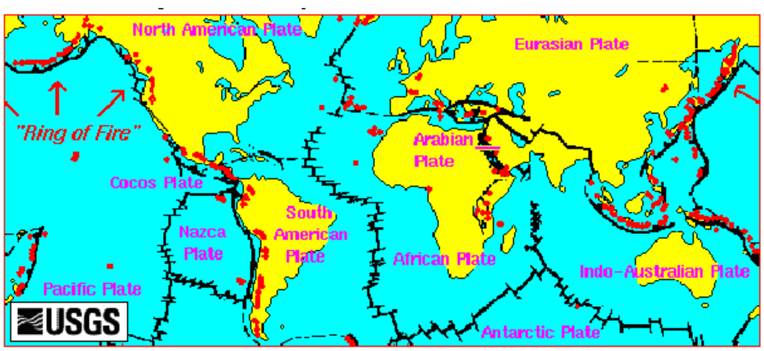


FIGURE 14.1
This map shows where volcanoes are located.

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** 14.2). 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.

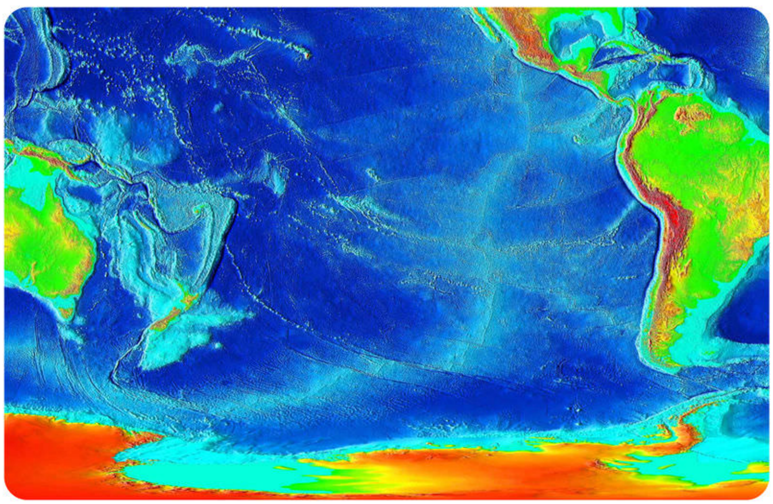


FIGURE 14.2
The Pacific Ocean basin is a good place to look for volcanoes. The light blue wavy line that goes up the right-center of the diagram is the East Pacific Rise. Trenches due to subduction are on the west and east sides of the plate. Hawaii trends southeast-northwest near the center-top of the 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** 14.3).

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** 14.4).

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.

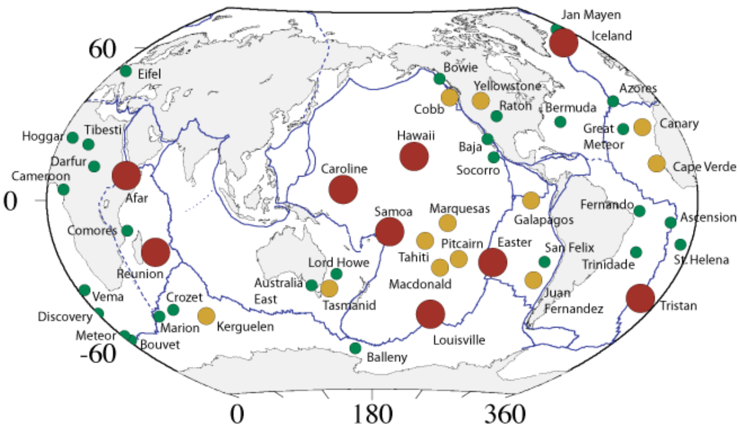


FIGURE 14.3

Mantle plumes are found all over the world, especially in the ocean basins. The size of the eruptions is different at different plumes.

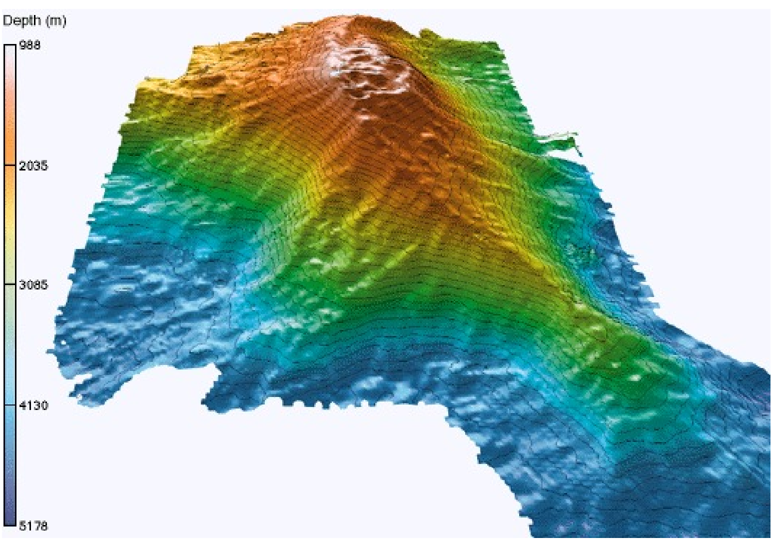


FIGURE 14.4

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** 14.1), 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?

14.2 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** 14.5). 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?

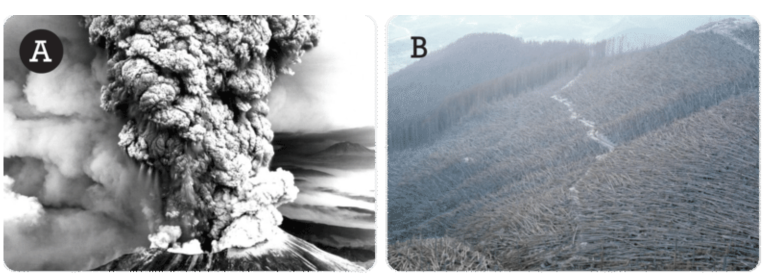


FIGURE 14.5
(A) Mount St. Helens eruption on May 18, 1980. Mt. Adams is in the background on the right. (B) The eruption of Mt. St. Helens blew down acres of trees like they were toothpicks.

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** 14.6). 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.

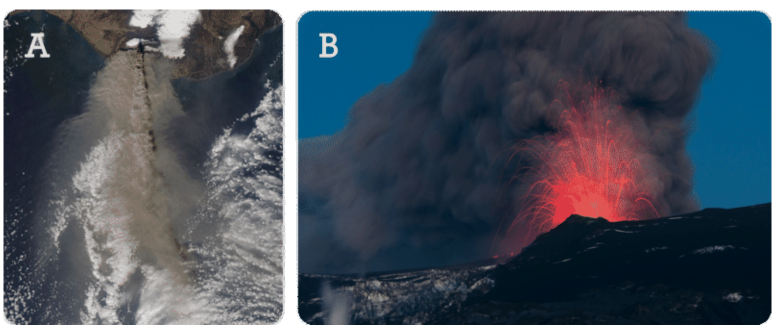


FIGURE 14.6
(A) Eyjafjallajökull volcano in Iceland spewed ash into the atmosphere in 2010. This was a fairly small eruption, but it disrupted air travel across Europe for six days. (B) The eruption seen from nearby.

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** 14.18).

Non-explosive Eruptions

Some volcanic eruptions are non-explosive (**Figure** 14.7). 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 14.7
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^{o}C and 1300^{o}C (**Figure** 14.8).

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.

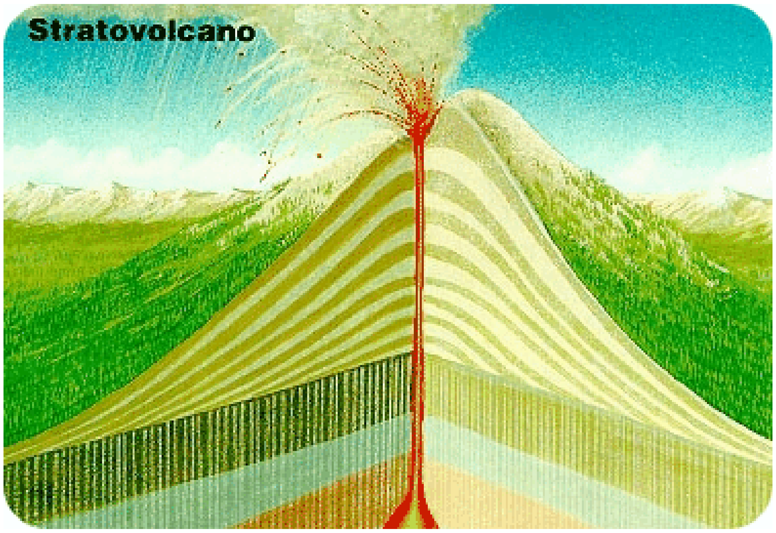


FIGURE 14.8
Magma beneath a volcano erupts onto the volcano's surface. Layer upon layer of lava creates a volcano.

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** 14.9). 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** 14.10).

FIGURE 14.9
Ropy pahoehoe flows are common on Kilauea Volcano in Hawaii.

FIGURE 14.10
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** 14.11). 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.

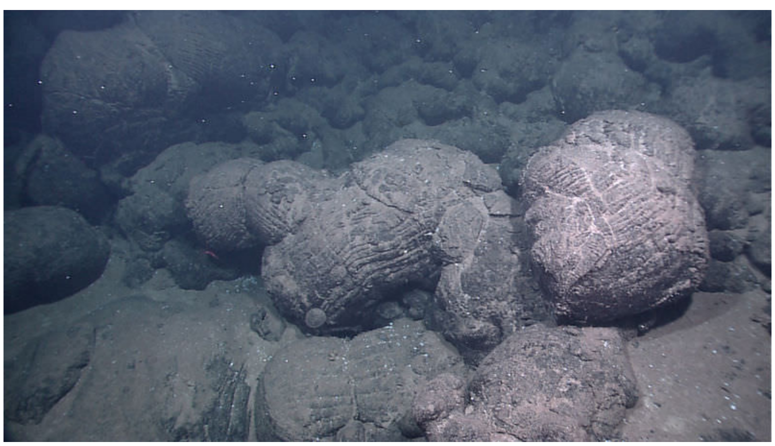


FIGURE 14.11
These underwater rocks in the Galapagos formed from pillow lava.

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** 14.12). 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 14.12

(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** 14.13). Satellites can look for high temperature spots or areas where the volcano surface is changing. This allows scientists to detect changes accurately and safely.

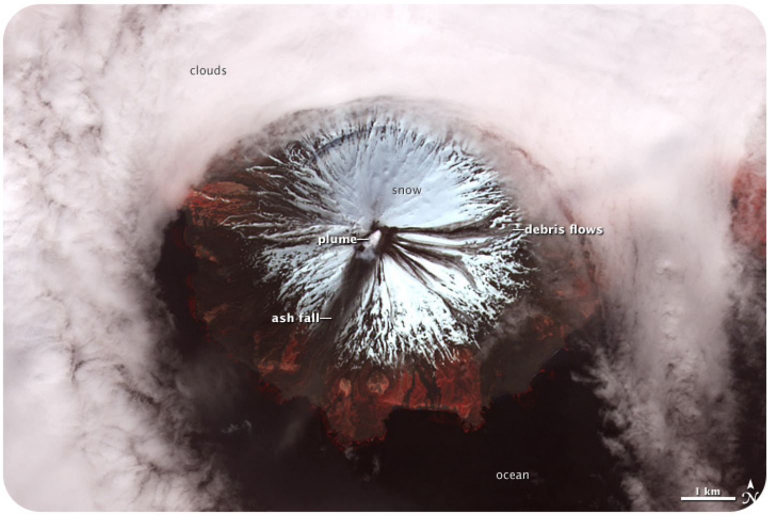


FIGURE 14.13
Mount Cleveland, in Alaska, is monitored by satellite.

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?

14.3 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 14.14 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** 14.15). 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 14.14
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.

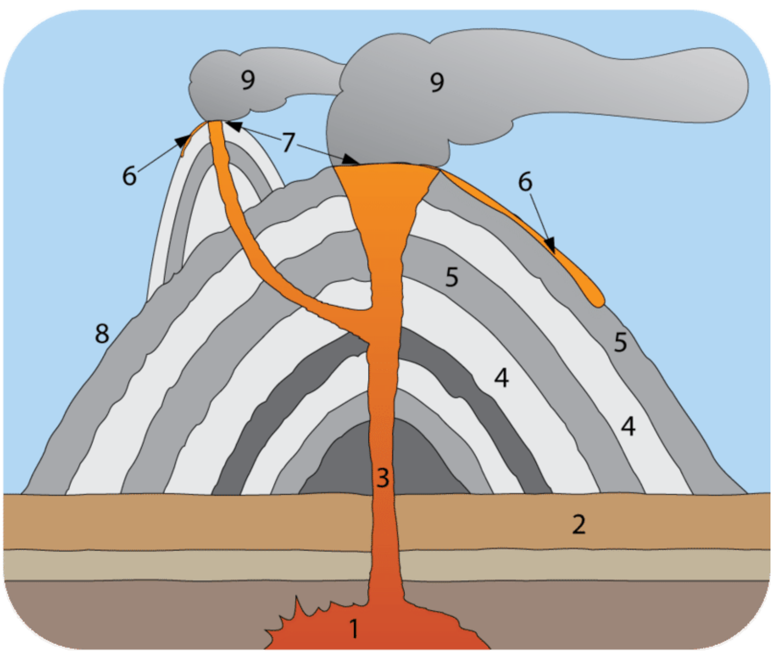


FIGURE 14.15
A cross section of a composite volcano reveals alternating layers of rock and ash: (1) magma chamber, (2) bedrock, (3) pipe, (4) ash layers, (5) lava layers, (6) lava flow, (7) vent, (8) lava, (9) ash cloud. Frequently there is a large crater at the top from the last eruption.

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** 14.16 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 14.16
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** 14.17).

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** 14.18.

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 14.17
A cinder cone volcano in Lassen National Park.

FIGURE 14.18
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** 14.19). 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.

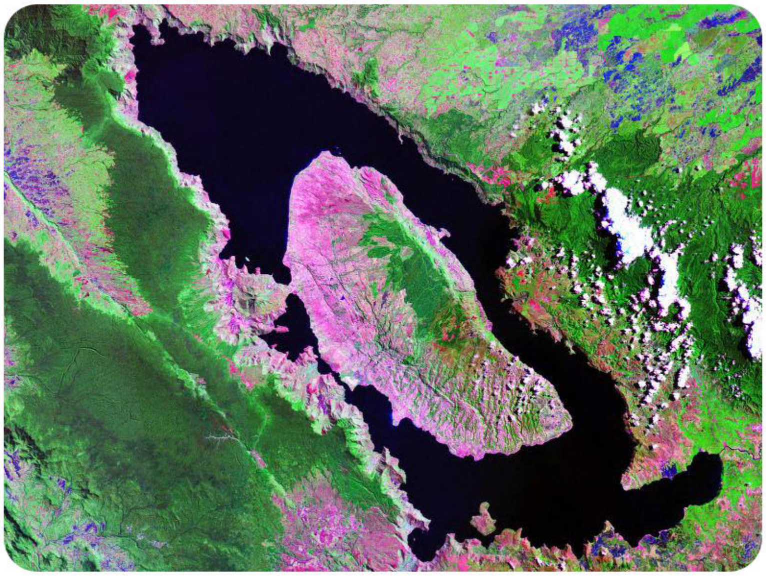


FIGURE 14.19
Lake Toba is now a caldera. It was the site of an enormous super eruption about 25 million years ago.

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?

14.4 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** 14.20).

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 14.20
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** 14.21). 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 14.21
Lava erupts into the Pacific Ocean in Hawaii, creating new land.

Landforms from Magma

Magma that cools underground forms **intrusions** (**Figure** 14.22). Intrusions become land formations if they are exposed at the surface by erosion.

FIGURE 14.22
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** 14.23). 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 14.23
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?

14.5 References

1. Courtesy of the US Geological Survey. http://commons.wikimedia.org/wiki/File:Volcano_Map.png . Public Domain
2. Courtesy of National Oceanographic and Atmospheric Administration. http://commons.wikimedia.org/wiki/File:East_Pacific_Rise.jpg . Public Domain
3. User:Foulger/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:CourtHotspots.png . Public Domain
4. Courtesy of John Smith and Brooks Bays, NOAA. http://commons.wikimedia.org/wiki/File:Loihi_3d.gif . Public Domain
5. Courtesy of (A) Robert Krimmel, USGS; (B) Lyn Topinka, USGS. (A) http://vulcan.wr.usgs.gov/Imgs/Jpg/MSH/Images/MSH80_eruption_plume_with_adams_05-18-80_bw_med.jpg; (B) http://vulcan.wr.usgs.gov/Imgs/Jpg/MSH/Images/MSH80_blowdown_singe_08-22-80_med.jpg . Public Domain
6. (A) Courtesy of NASA; (B) David Karnå. (A) http://commons.wikimedia.org/wiki/File:Eruption_of_Eyjafjallaj%C3%B6kull_Volcano,_Iceland_April_17_Detail.jpg; (B) http://commons.wikimedia.org/wiki/File:Eyjafjallaj%C3%B6kull_major_eruption_20100510.jpg . (A) Public Domain; (B) CC BY 1.0
7. Courtesy of Michael Ryan, US Geological Survey. http://commons.wikimedia.org/wiki/File:Lava_flow_at_Krafla,_1984.jpg . Public Domain
8. Courtesy of US Geological Survey. http://commons.wikimedia.org/wiki/File:Stratovolcano.jpg . Public Domain
9. Makuahine Pa'i Ki'i. http://www.flickr.com/photos/hawaii-mcgraths/4280082817/ . CC BY 2.0
10. Courtesy of the Hawaiian Volcano Observatory, USGS. http://commons.wikimedia.org/wiki/File:Close-up_of_a_skylight_on_coastal_plain,_with_lava_stalactites_forming_on_the_roof_of_the_tube.jpg . Public Domain
11. Courtesy of NOAA Okeanos Explorer Program, Galapagos Rift Expedition 2011. http://www.flickr.com/photos/noaaphotolib/9784030245/ . CC BY 2.0
12. (A) Flickr:gnuckx; (B) Ralph Arvesen (Flickr:rarvesen); (C) Ben Townsend. (A) http://commons.wikimedia.org/wiki/File:Etna_Volcano_Paroxysmal_Eruption_July_30_2011_-_Creative_Commons_by_gnuckx_%289%29.jpg; (B) http://www.flickr.com/photos/rarvesen/9429614139/; (C) http://www.flickr.com/photos/bwtownsend/496917076/ . CC BY 2.0
13. Courtesy of Jesse Allen Robert Simmon, NASA. http://commons.wikimedia.org/wiki/File:Mount_Cleveland_2010-06-01.jpg . Public Domain
14. Flickr:skyseeker. http://commons.wikimedia.org/wiki/File:Mt._Fuji.jpg . CC BY 2.0
15. Zachary Wilson. CK-12 Foundation . CC BY-NC 3.0
16. Graeme Churchard (Flickr:GOC53). http://www.flickr.com/photos/graeme/5587431742/ . CC BY 2.0
17. Courtesy of LassenNPS. http://www.flickr.com/photos/lassennps/8368094653/ . CC BY 2.0
18. Flavia (Flickr:Flavia_ff). http://www.flickr.com/photos/mistressf/788501243/ . CC BY 2.0
19. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Toba_zoom.jpg . Public Domain
20. Flickr:Scrubhiker (USCdyer). http://www.flickr.com/photos/scrubhiker/8546578554/ . CC BY 2.0
21. Ewen Roberts. http://www.flickr.com/photos/donabelandewen/4319096623/ . CC BY 2.0
22. Jon Apon (Flickr:MDRIV3R). http://www.flickr.com/photos/mdriv3r/439521623/ . CC BY 2.0
23. John Sullivan, PD Photo. http://commons.wikimedia.org/wiki/File:Old_Faithfull-pdPhoto.jpg . Public Domain

CHAPTER 15 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.

15.1 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** 15.1. Preserved traces can include footprints, burrows, or even wastes. Examples of trace fossils are also shown in **Figure** 15.1.

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** 15.2.

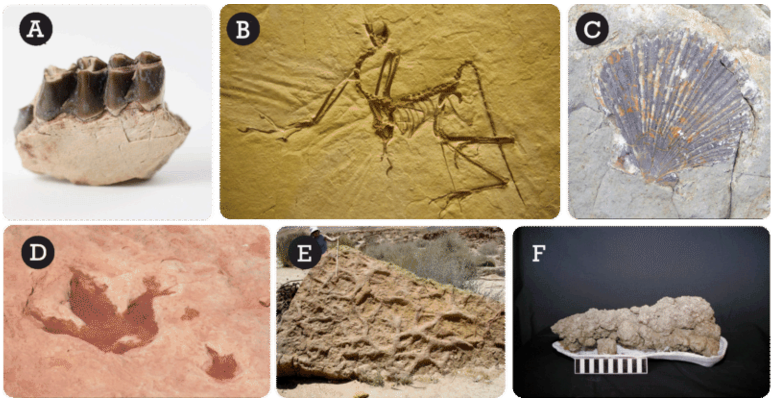


FIGURE 15.1

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.

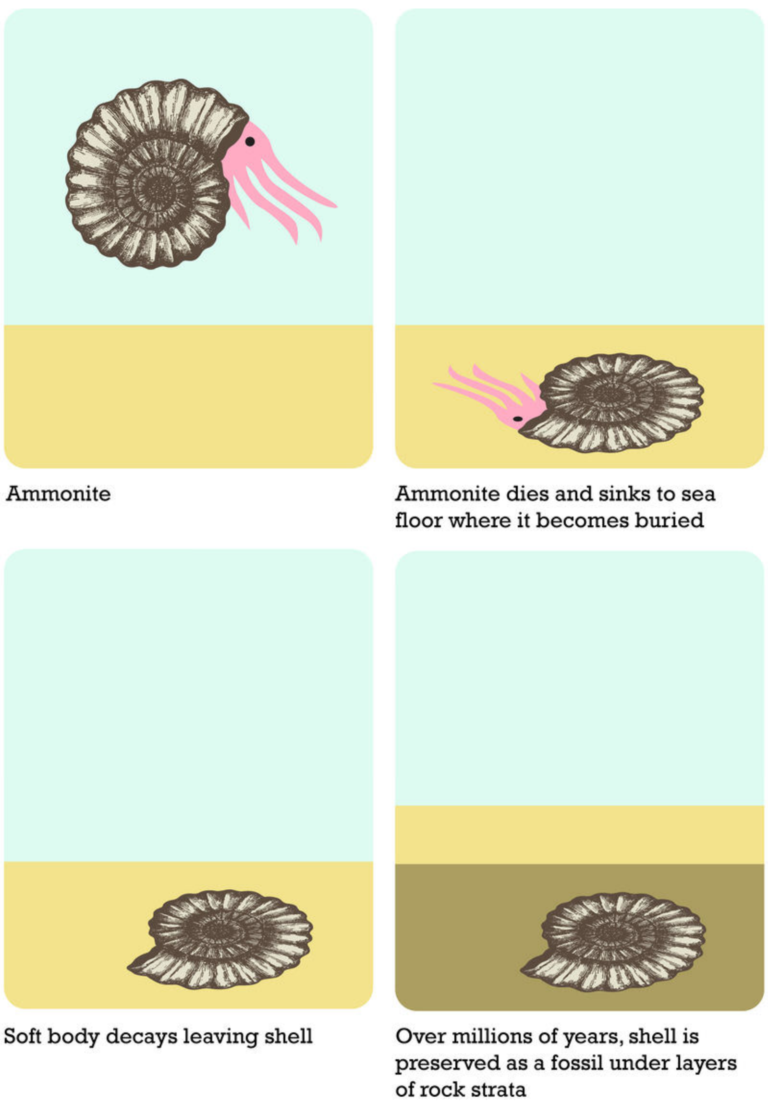


FIGURE 15.2

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** 15.3.

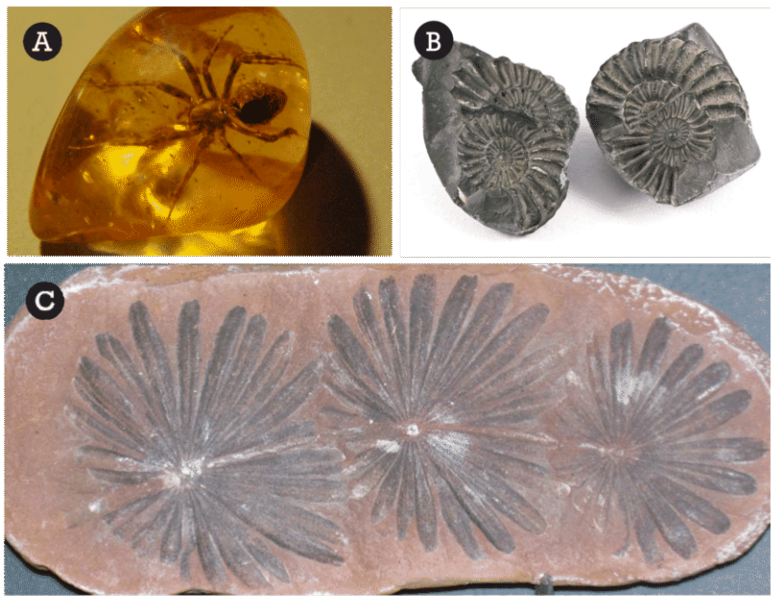


FIGURE 15.3
Ways Fossils Form. (A) Complete Preservation. This spider looks the same as it did the day it died millions of years ago! (B) Molds and Casts. A mold is a hole left in rock after an organism's remains break. A cast forms from the minerals that fill that hole and solidify. (C) Compression. 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** 15.4.
- 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 15.4
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** 15.5, 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 15.5
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** 15.3 and the fossil dinosaur tracks in **Figure** 15.1. 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?

15.2 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** 15.6. 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.

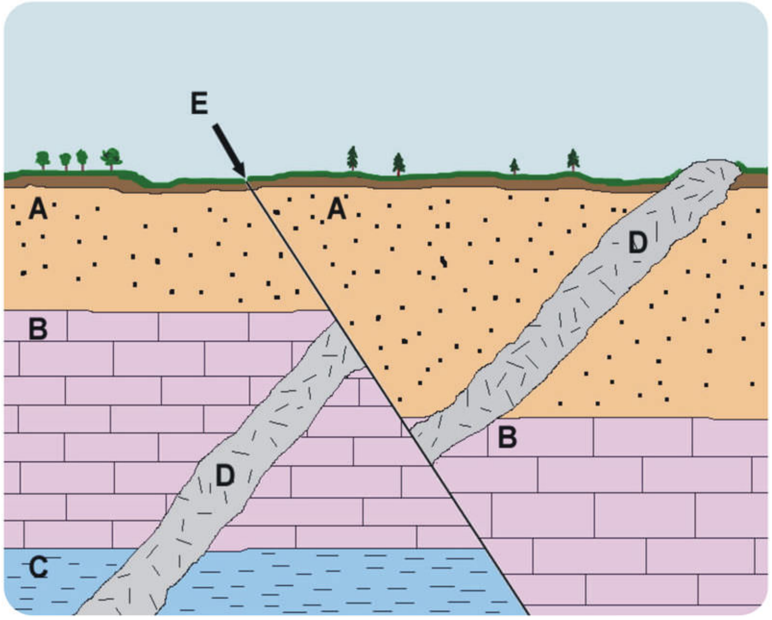


FIGURE 15.6
Laws of Stratigraphy. This diagram illustrates the laws of stratigraphy. A = Law of Superposition, B = Law of Lateral Continuity, C = Law of Original Horizontality, D = Law of Cross-Cutting Relationships

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** 15.7.

FIGURE 15.7
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** 15.8. 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 15.8
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** 15.9. 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** 15.10. 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.

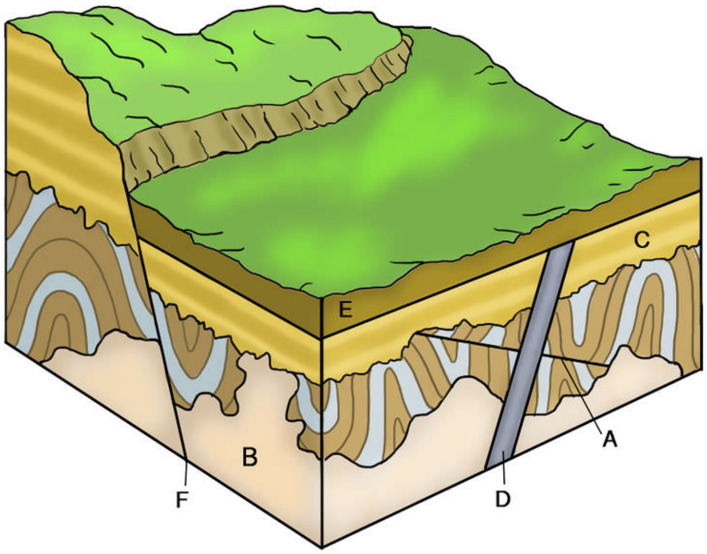


FIGURE 15.9
Cross-cutting relationships in rock layers. Rock D is a dike that cuts across all the other rocks. Is it older or younger than the other rocks?

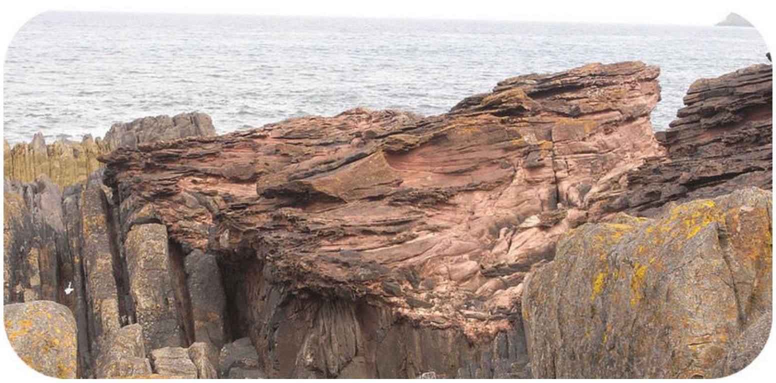


FIGURE 15.10
Hutton's unconformity, in Scotland.

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** 15.11). 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!

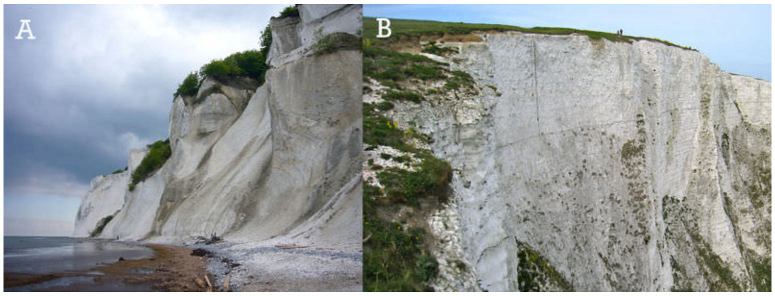


FIGURE 15.11
Chalk Cliffs. (A) Matching chalk cliffs in Denmark and (B) in Dover, U.K.

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** 15.12. If two rock layers have the same index fossils, then they're probably about the same age.

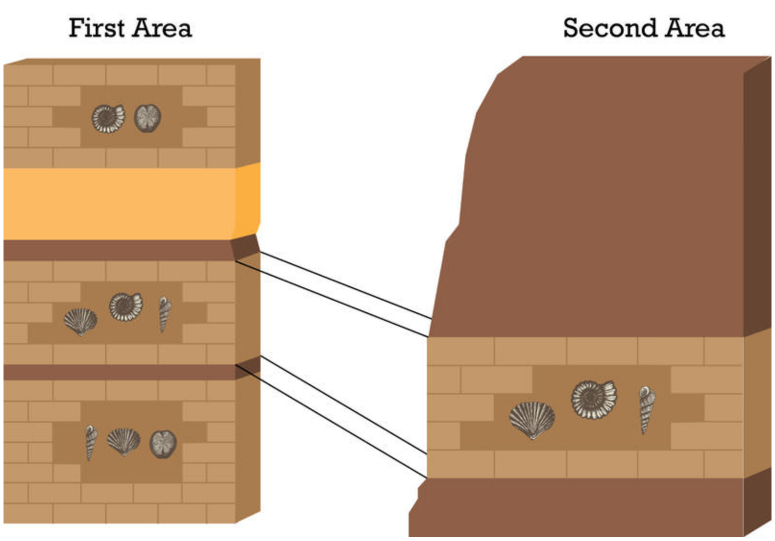


FIGURE 15.12
Using Index Fossils to Match Rock Layers. Rock layers with the same index fossils must have formed at about the same time. The presence of more than one type of index fossil provides stronger evidence that rock layers are the same age.

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** 15.13 shows you what the geologic time scale looks like.

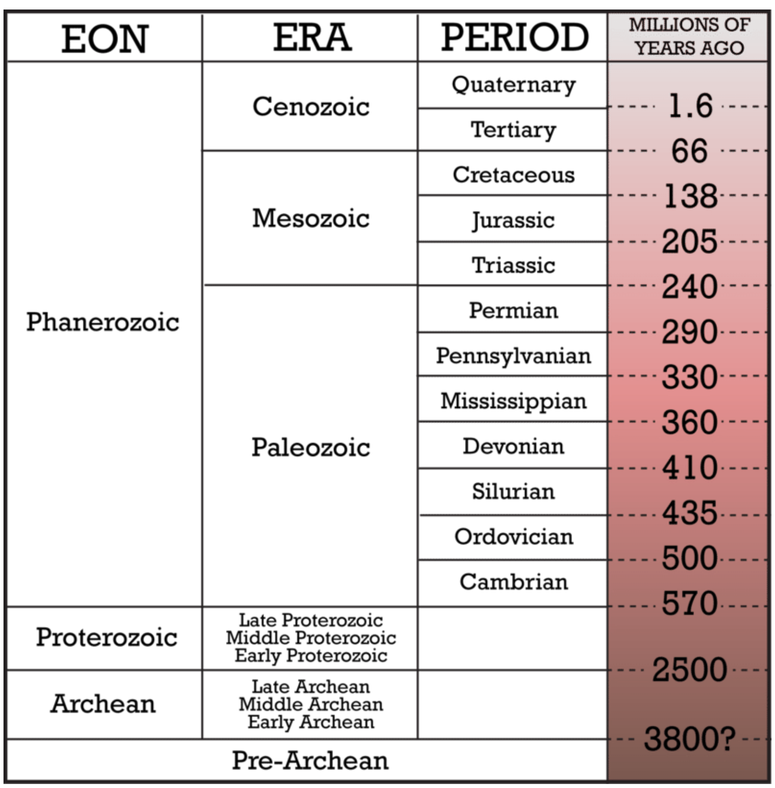


FIGURE 15.13
The Geologic Time Scale.

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** 15.14 is a different kind of the geologic time scale. It shows how Earth's environment and life forms have changed.

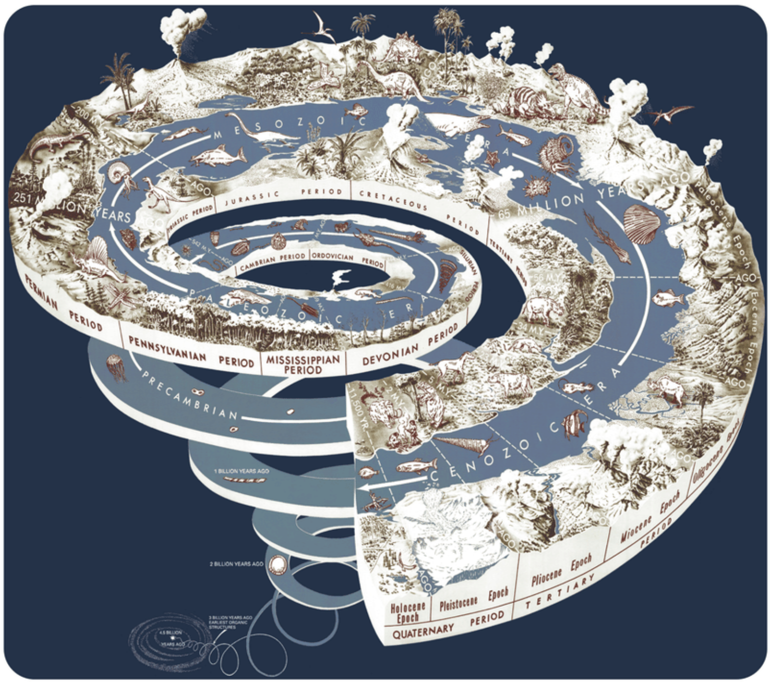


FIGURE 15.14
The evolution of life is shown on this spiral.

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

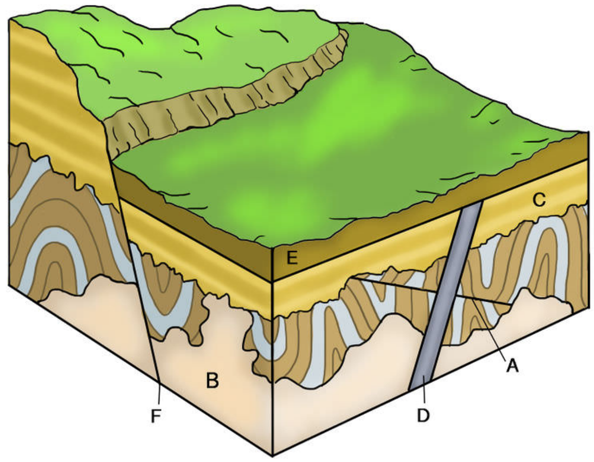
Recall

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?

15.3 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** 15.15. 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** 15.16 shows carbon dioxide, which forms in the atmosphere from

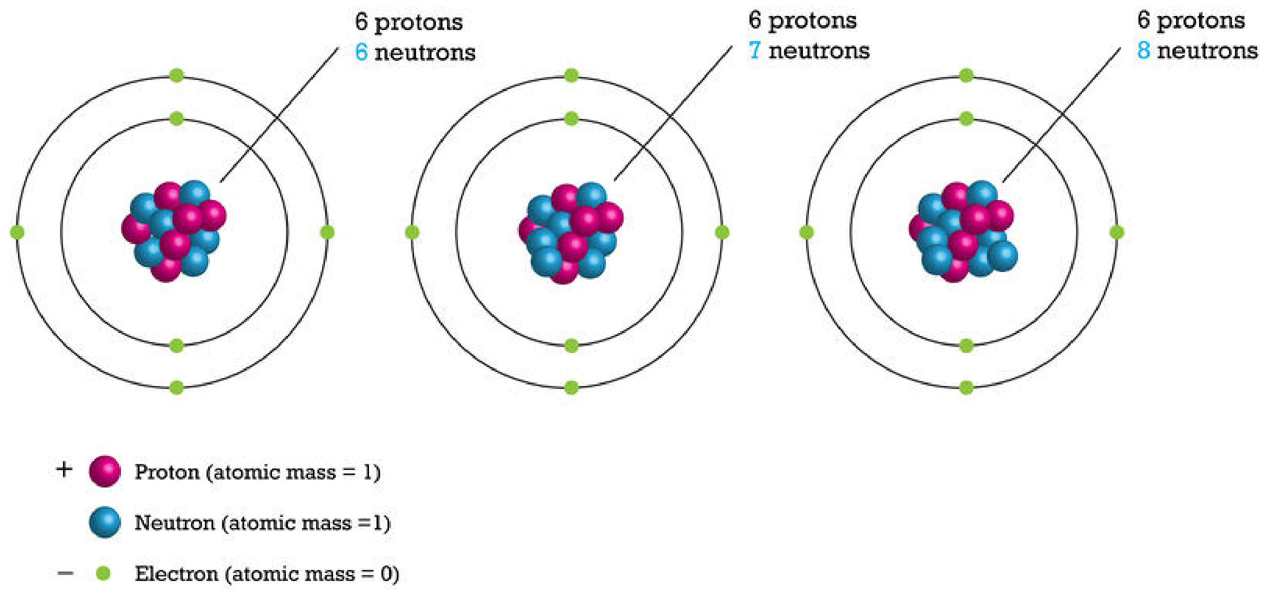


FIGURE 15.15
Isotopes are named for their number of protons plus neutrons. If a carbon atom had 7 neutrons, what would it be named?

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.

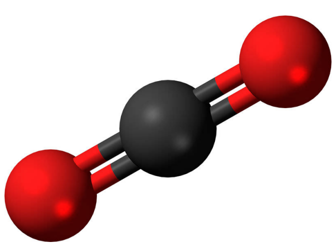


FIGURE 15.16
Carbon-14 forms in the atmosphere. It combines with oxygen and forms carbon dioxide. How does carbon-14 end up in fossils?

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** 15.17.

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** 15.18 graphs the rate of decay of carbon-14.

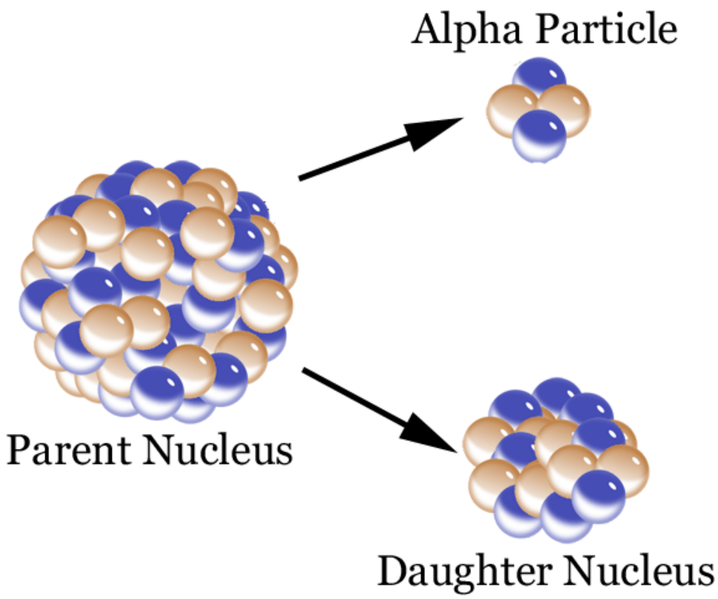


FIGURE 15.17
Unstable isotopes, such as carbon-14, decay by losing atomic particles. They form different, stable elements when they decay. In this case, the daughter is nitrogen-14.

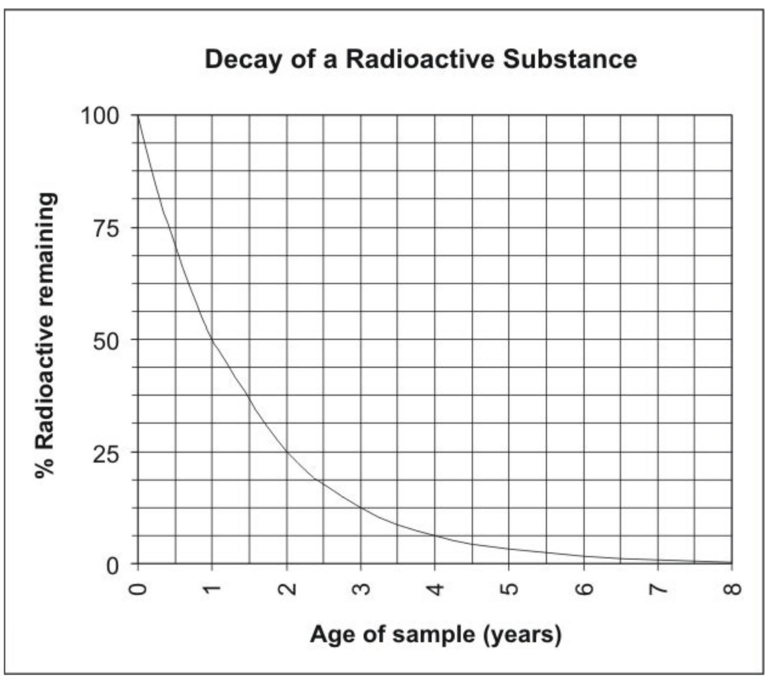


FIGURE 15.18
The rate of decay of carbon-14 is stable over time.

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 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** 15.1 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 15.1: 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.

Lesson Review Questions

Recall

1. Define absolute age. How does it differ from relative age?

2. What is radioactive decay?

3. How do different isotopes of the same element differ? How are they the same?

4. Describe how carbon-14 forms and decays.

5. What is radiometric dating?

Apply Concepts

6. Carbon has a third isotope, named carbon-13. Apply lesson concepts to infer how many protons and neutrons are found in each atom of carbon-13. Carbon-13 is a stable isotope, like carbon-12. How useful would carbon-13 be for radiometric dating?

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?

15.4 References

1. Image copyright Geoff Hardy, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
2. (A) Flickr:furtwangl; (B) Hannes Grobe/AWI; (C) Ben Salter (Flickr:Capt' Gorgeous); (D) edmondo gnerre; (E) Mark A. Wilson (Department of Geology, The College of Wooster); (F) Courtesy of the U.S. Geological Survey. (A) http://www.flickr.com/photos/furtwangl/3283595757/; (B) http://commons.wikimedia.org/wiki/File:Archaeopteryx-8-senkenberg_hg.jpg; (C) http://www.flickr.com/photos/ben_salter/2103829606/; (D) http://www.flickr.com/photos/edgnerre/2891672667/; (E) http://commons.wikimedia.org/wiki/File:ThalassinoidesIsrael.JPG; (F) http://commons.wikimedia.org/wiki/File:Coprolite.jpg . (A) CC BY 2.0; (B) CC BY 3.0; (C) CC BY 2.0; (D) CC BY 2.0; (E) Public Domain; (F) Public Domain
3. Christopher Auyueng. CK-12 Foundation . CC BY-NC 3.0
4. (A) Elisabeth; (B) Image copyright ribeiroantonio, 2013; (C) James St. John (Flickr:jsj1771). (A) http://commons.wikimedia.org/wiki/File:Spider_in_amber_%281%29.jpg; (B) http://www.shutterstock.com; (C) http://www.flickr.com/photos/jsjgeology/8281567838/ . (A) CC BY 3.0; (B) Used under license from Shutterstock.com; (C) CC BY 2.0
5. Courtesy of the National Park Service. http://www.nps.gov/imr/photosmultimedia/photogallery.htm?id=F17B1C64-155D-451F-6765341D9B8E553F . Public Domain
6. Daderot. http://wikimedia.commons.org/wiki/File:Asaphellus_species,_intact_Trilobite_fossils,_Early_Ordovician_Period,_Dra_Valley,_Morocco_-_Royal_Ontario_Museum_-_DSC09851.JPG . Public Domain
7. Kurt Rosenkrantz. CK-12 Foundation . CC BY-NC 3.0
8. Ron Sanderson. http://www.publicdomainpictures.net/view-image.php?image=26142&picture=coastal-scene-tasmania&large=1 . Public Domain
9. Courtesy of Michael Quinn/Grand Canyon National Park. http://www.flickr.com/photos/grand_canyon_nps/7556098142/ . CC BY 2.0
10. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
11. User:Lysippos/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Hutton%27s_unconformity_siccar_point.JPG . CC BY 3.0
12. (A) Chad K; (B) Kyle Taylor. (A) http://www.flickr.com/photos/chad_k/248461570/; (B) http://www.flickr.com/photos/kyletaylor/3540955820/ . CC BY 2.0
13. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
14. Christopher Auyeung, based on information from US Geological Survey. CK-12 Foundation . CC BY-NC 3.0
15. Courtesy of Joseph Graham, William Newman, and John Stacy, USGS. http://commons.wikimedia.org/wiki/File:Geological_time_spiral.png . Public Domain
16. Image copyright branislavpudar, 2014. http://www.shutterstock.com . Used under license from Shutterstock.com
17. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
18. User:Jynto/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Carbon_dioxide_3D_ball.png .
19. Kurt Rosenkrantz and Sam McCabe. CK-12 Foundation . CC BY-NC 3.0
20. Kurt Rosenkrantz. CK-12 Foundation . CC BY-NC 3.0

CHAPTER 16 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.

Miles Orchinik – CK–12 Foundation. miles–home.smugmug.com/Nature/Yellowstone–journal/9367656_bN4r9#626957014_UdT2X. CC BY–NC 3.0.

16.1 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** 16.1). 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** 16.2). Dwarf plants, comets, and asteroids formed too (**Figure** 16.3).

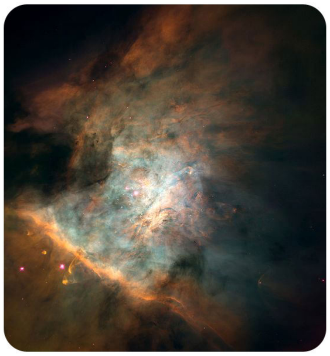


FIGURE 16.1
The Orion Nebula is the birthplace of new stars.

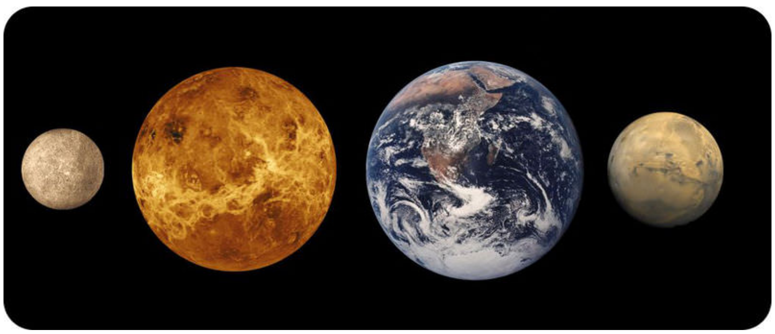


FIGURE 16.2
The Inner Planets.

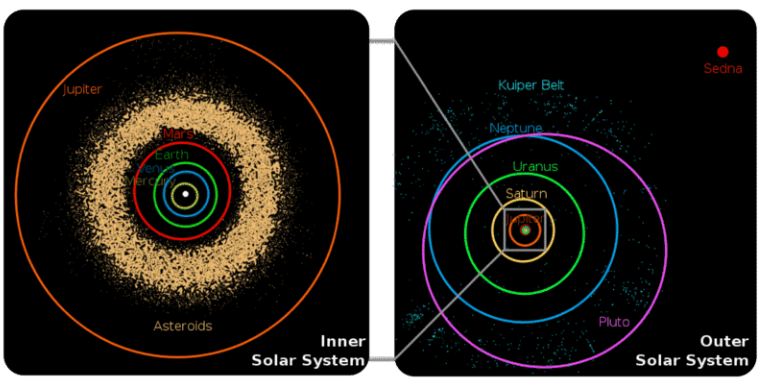


FIGURE 16.3
The Kuiper Belt, a ring of icy debris in our solar system just beyond Neptune, contains many solar system bodies.

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** 16.4). 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.

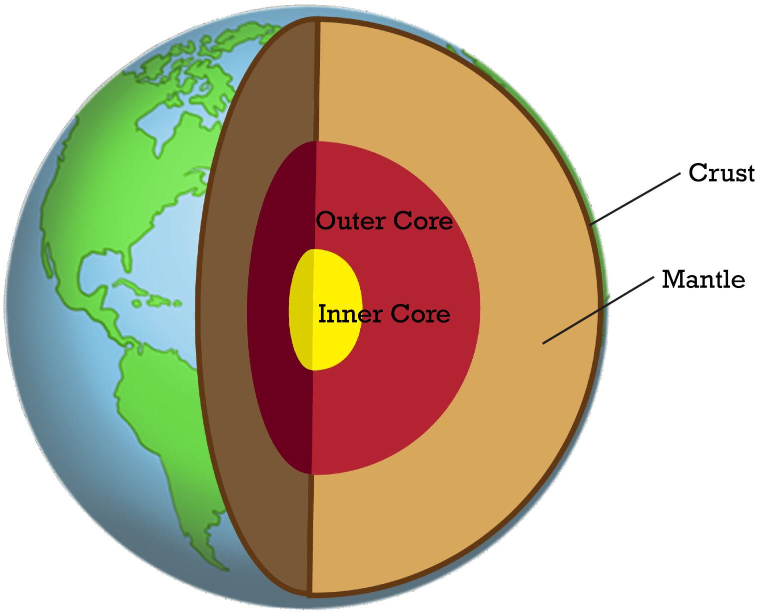


FIGURE 16.4
Earth's layers.

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** 16.5). Take a look at the list of gases. What's missing? The early atmosphere had almost no oxygen.

FIGURE 16.5
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?

16.2 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** 16.6). 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.

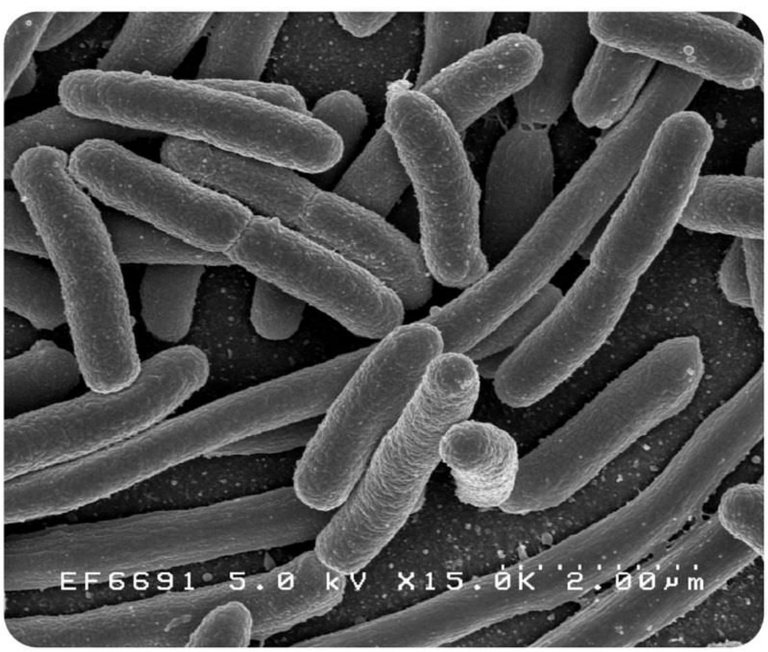


FIGURE 16.6
E. coli (Escherichia coli) is a primitive prokaryote that may resemble the earliest cells.

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** 16.7). Now they are called blue-green algae. They are common in lakes and seas and account for 20% to 30% of photosynthesis today.

FIGURE 16.7

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** 16.8). 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.

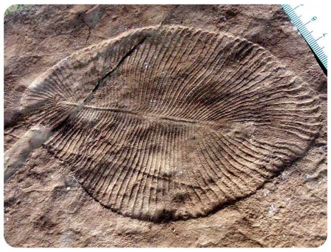


FIGURE 16.8
This fossil is from the Ediacara Fauna. Nothing alive today seems to have evolved from the Ediacara organisms.

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?

16.3 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** 16.9) 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 16.9

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** 16.10).

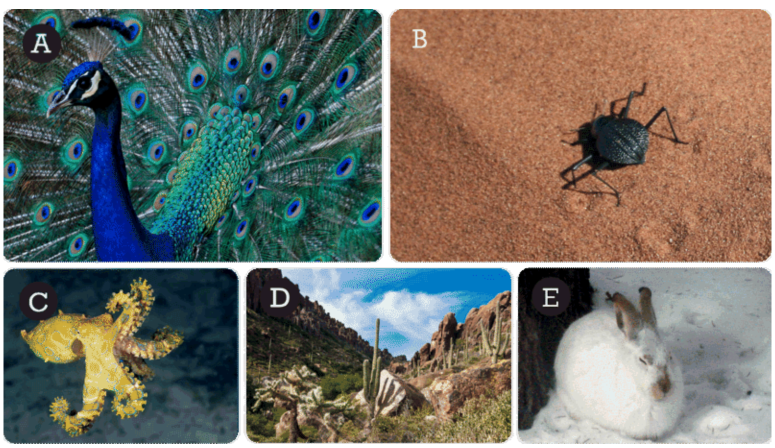


FIGURE 16.10

(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.

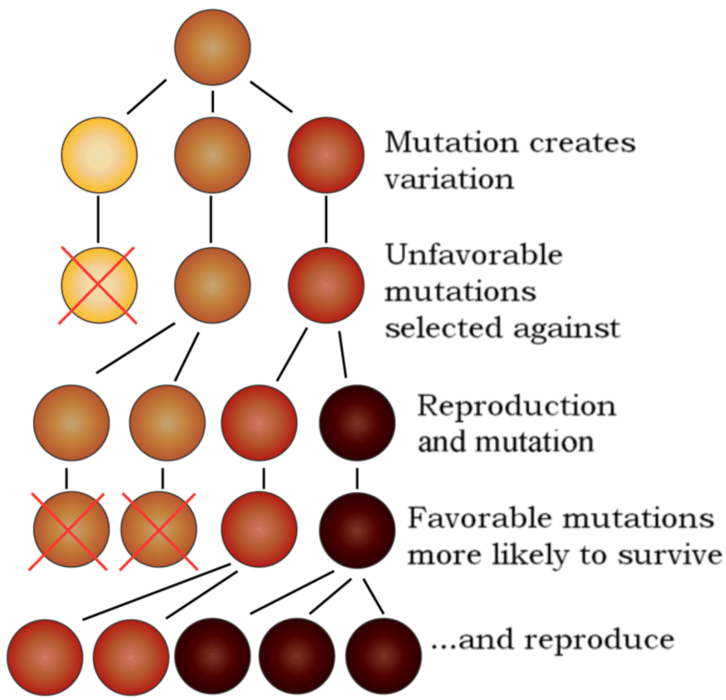


FIGURE 16.11
Genetic mutation is central to the creation of biological diversity.

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** 16.12). 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** 16.1). 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** 16.14). 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.

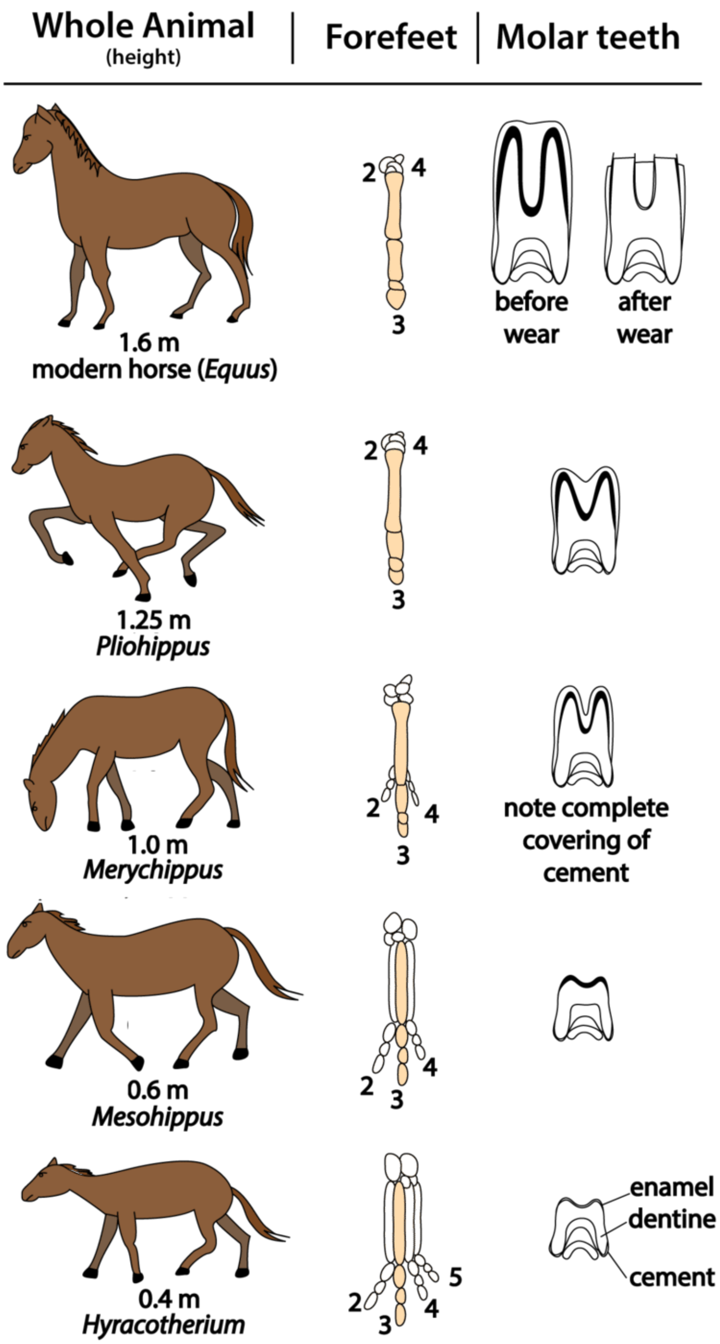


FIGURE 16.12

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** 16.13 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 16.13
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.

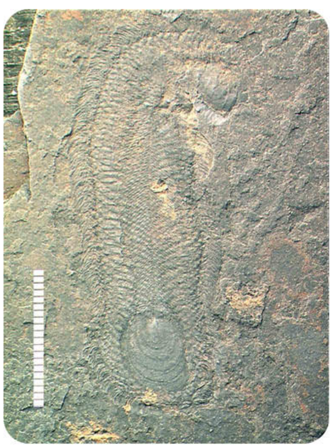


FIGURE 16.14
Halkieria, or scale worms, are an example of a fossil life from the Cambrian.

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** 16.15). Feathered dinosaurs gave rise to birds.

FIGURE 16.15
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** 16.16).

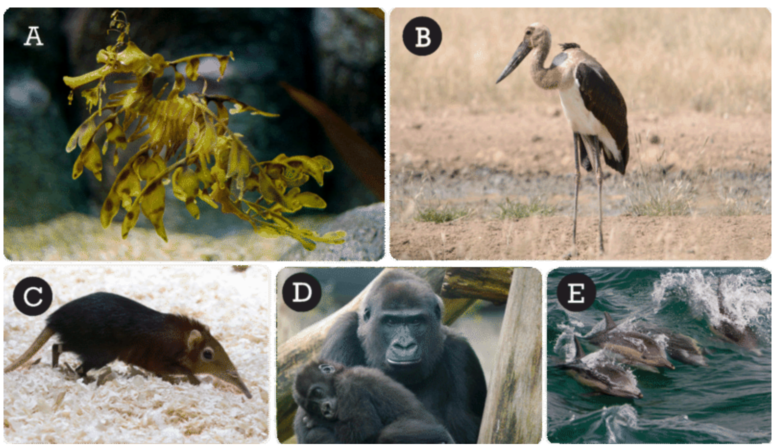


FIGURE 16.16
(A) A sea dragon is a type of fish. (B) African maribou. (C) Elephant shrew. (D) A mountain gorilla mother holding her baby. (E) A dolphin pod.

Table 16.1 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 16.1: 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 16.1: (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** 16.1, from top to bottom:

- Mariana Ruiz Villarreal (Wikimedia:LadyofHats). http://commons.wikimedia.org/wiki/File:Abrictosaurus_-dinosaur.png . Public Domain.

16.4 References

1. Courtesy of C.R. O'Dell and S.K. Wong, NASA. http://commons.wikimedia.org/wiki/File:Orion.nebula.arp.750pix.jpg . Public Domain
2. Courtesy of NASA, User:Koppelo/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Terrestrial_planet_size_comparisons-2.jpg . Public Domain
3. Courtesy of NASA. http://commons.wikimedia.org/wiki/File:Oort_cloud_Sedna_orbit.svg . Public Domain
4. Christopher Auyeung and Laura Guerin. CK-12 Foundation . CC BY-NC 3.0
5. John Loo. http://www.flickr.com/photos/johnloo/627528082/ . CC BY 2.0
6. Courtesy of Rocky Mountain Laboratories, NIAID, NIH. http://commons.wikimedia.org/wiki/File:EscherichiaColi_NIAID.jpg . Public Domain
7. Courtesy of P. Carrara, National Park Service. http://commons.wikimedia.org/wiki/File:Stromatolites.jpg . Public Domain
8. User:Verisimilus/Wikipedia. http://commons.wikimedia.org/wiki/File:DickinsoniaCostata.jpg . CC BY 2.5
9. Courtesy of the U.S. Geological Survey. http://commons.wikimedia.org/wiki/File:A03_Charles_Dolittle_-Walcott_USGS.jpg . Public Domain
10. (A) Madison Berndt; (B) Lawrence Murray; (C) Angell Williams; (D) Miles Orchinik - CK-12 Foundation; (E) Steven Taschuk (Flickr:stebulus). (A) http://www.flickr.com/photos/madisonberndt/5830411257/; (B) http://www.flickr.com/photos/lawmurray/3074135645/; (C) http://www.flickr.com/photos/53357045@N02/4973031491/; (D) http://miles-home.smugmug.com/Landscapes/Southwest-in-snow/15567127_KvkM7#1166214084_MxgQR; (E) http://www.flickr.com/photos/stebulus/5062541709/ . (A, B, C, E) CC BY 2.0; (D) CC BY-NC 3.0
11. Hana Zavadska. CK-12 Foundation . CC BY-NC 3.0
12. Zachary Wilson. CK-12 Foundation . CC BY-NC 3.0
13. Thomas H Brown. http://www.flickr.com/photos/63048706@N06/6747999869/ . CC BY 2.0
14. Jakob Vinther. http://commons.wikimedia.org/wiki/File:Halkieria_%281%29.jpg . Public Domain
15. Ryan Somma, National Museum of Natural History. http://commons.wikimedia.org/wiki/File:Dolichorhynchops.jpg . Public Domain
16. (A) Jesse Richmond; (B) Brian Ralphs; (C) Jim, the Photographer; (D) Marieke IJsendoorn-Kuijpers (Flickr:mape_s); (E) John Liu (Flickr:LifeSupercharger). (A) http://www.flickr.com/photos/gerbache/8826694382/; (B) http://www.flickr.com/photos/birdbrian/3564357872/; (C) http://www.flickr.com/photos/jcapaldi/7481952688/; (D) http://www.flickr.com/photos/mape_s/333862026/; (E) http://www.flickr.com/photos/8047705@N02/5563610502/ . CC BY 2.0